NRC Request

1. *Entergy Nuclear Operations, Inc. (the licensee) stated in its submittal dated June 30, 2009, that the break selection process was re-performed after fibrous debris zones of influence (ZOI) were reduced. However, the licensee further stated that after a significantly large fiberglass component was identified, deference was given to evaluating breaks for other debris sources. The Nuclear Regulatory Commission (NRC) staff cannot determine from this information whether the break selection was conservative. Please verify and justify that the break selection process identified the break that results in the maximum potential fibrous debris load and that this debris load was considered in the remaining portions of the head loss evaluation.*

Entergy Nuclear Operations Response:

The break selection process identified Break S5 as the maximum fibrous debris load which was used in subsequent head loss evaluations and strainer testing. Use of Break S5 as the limiting break for fiber is detailed in several locations within Palisades 6/30/2009 submittal. The break selection process utilized the guidance of NEI 04-07 in deriving the maximum fibrous debris load. The following is an excerpt from Reference 1.1, Section 4.2 Break Locations:

> Identifying the break locations is the first step in determining the LOCA generated debris. The break selection process is described in the NEI Methodology in Section 3.3.4 (Reference 6.1.1). Per Section 1.3.2.3 of Reg. Guide 1.82 (Reference 6.1.6) at minimum, the following postulated break locations were considered:
>
> - Breaks in the reactor coolant system (e.g., hot leg, crossover leg, cold leg, pressurizer surge line) and, depending on the plant licensing basis, main steam and main feedwater lines with the largest amount of potential debris within the postulated ZOI,

<u>References</u>

1.1 EA-MOD-2005-04-06 Revision 3 dated 2/9/2009, “Acceptance of Debris Generation Calculation 2005-01340 Rev 2”

NRC Request

Note: Questions 2 through 9 below are being addressed in whole or in part by the Pressurized Water Reactor Owners Group. The NRC staff expects the degree to which the Owners Group is able to generically resolve these issues to be clear by the time the licensee's responses to these requests for additional information (RAIs) are due. As appropriate, the licensee may respond to these RAIs with reference to NRC staff official correspondence on resolution of the staff's questions of the Owners Group. In any event, some of the questions will need a plant-specific response.

2. *The supplemental response dated June 30, 2009, credited a reduced ZOI for low-density fiberglass. Please describe the jacketing/insulation systems used in the plant for which the testing was conducted and compare those systems to the jacketing/insulation systems tested. Demonstrate that the tested jacketing/insulation system adequately represented the plant jacketing/insulation system. The description should include differences in the jacketing and banding systems used for piping and other components for which the test results are applied, potentially including steam generators, pressurizers, reactor coolant pumps, etc. At a minimum, the following areas should be addressed:*

    a. *How did the characteristic failure dimensions of the tested jacketing/insulation compare with the effective diameter of the jet at the axial placement of the target? The characteristic failure dimensions are based on the primary failure mechanisms of the jacketing system, e.g., for a stainless steel jacket held in place by three latches where all three latches must fail for the jacket to fail, then all three latches must be effectively impacted by the pressure for which the ZOI is calculated. Applying test results to a ZOI based on a centerline pressure for relatively low L/D nozzle to target spacing would be non-conservative with respect to impacting the entire target with the calculated pressure.*

    b. *Was the insulation and jacketing system used in the testing of the same general manufacture and manufacturing process as the insulation used in the plant? If not, what steps were taken to ensure that the general strength of the insulation system tested was conservative with respect to the plant insulation? For example, it is known that there were generally two very different processes used to manufacture calcium silicate whereby one type readily dissolved in water but the other type dissolves much more slowly. Such manufacturing differences could also become apparent in debris generation testing, as well.*

    c. *The information provided should also include an evaluation of scaling the strength of the jacketing or encapsulation systems to the tests. For example, a latching system on a 30 inch pipe within a ZOI could be* *stressed much more than a latching system on a 10 inch pipe in a scaled ZOI test. If the latches used in the testing and the plants are the same, the latches in the testing could be significantly under-stressed. If a prototypically sized target were impacted by an undersized jet it would similarly be under-stressed. Evaluations of banding, jacketing, rivets, screws, etc., should be made. For example, scaling the strength of the jacketing was discussed in the Ontario Power Generation (OPG) report on calcium silicate debris generation testing.*

3. *There are relatively large uncertainties associated with calculating jet stagnation pressures and ZOIs for both the test and the plant conditions based on the models used in the Westinghouse Commercial Atomic Power (WCAP) reports the licensee used to justify reduced ZOIs. What steps were taken to ensure that the calculations resulted in conservative estimates of these values? Please provide the inputs for these calculations and the sources of the inputs.*

4. *Describe the procedure and assumptions for using the ANSI/ANS-58-2-1988 standard to calculate the test jet stagnation pressures at specific locations downrange from the test nozzle.*

   a. *Was the analysis based on initial conditions (temperature) that matched the initial test temperature? If not, please provide an evaluation of the effects of any differences in the assumptions.*

   b. *Was the water subcooling used in the analysis that of the initial tank temperature or was it the temperature of the water in the pipe next to the rupture disk? Test data indicated that the water in the piping had cooled below that of the test tank.*

   c. *The break mass flow rate is a key input to the ANSI/ANS-58-2-1988 standard. How was the associated debris generation test mass flow rate determined? If the experimental volumetric flow was used, then explain how the mass flow was calculated from the volumetric flow given the considerations of potential two-phase flow and temperature dependent water and vapor densities? If the mass flow was analytically determined, then describe the analytical method used to calculate the mass flow rate.*

   d. *Noting the extremely rapid decrease in nozzle pressure and flow rate illustrated in the test plots in the first tenths of a second, how was the transient behavior considered in the application of the ANSI/ANS-58-2-1988 standard? Specifically, did the inputs to the standard represent the initial conditions or the conditions after the first extremely rapid transient, e.g., say at one tenth of a second?*

e. Given the extreme initial transient behavior of the jet, justify the use of the steady state ANSI/ANS-58-2-1988 standard jet expansion model to determine the jet centerline stagnation pressures rather than experimentally measuring the pressures.

5. Describe the procedure used to calculate the isobar volumes used in determining the equivalent spherical ZOI radii using the ANSI/ANS-58-2-1988 standard.

a. What were the assumed plant-specific reactor coolant system (RCS) temperatures and pressures and break sizes used in the calculation? Note that the isobar volumes would be different for a hot leg break than for a cold leg break since the degrees of subcooling is a direct input to the ANSI/ANS-58-2-1988 standard and which affects the diameter of the jet. Note that an under calculated isobar volume would result in an under calculated ZOI radius.

b. What was the calculational method used to estimate the plant-specific and break-specific mass flow rate for the postulated plant loss-of-coolant accident (LOCA), which was used as input to the standard for calculating isobar volumes?

c. Given that the degree of subcooling is an input parameter to the ANSI/ANS-58-2-1988 standard and that this parameter affects the pressure isobar volumes, what steps were taken to ensure that the isobar volumes conservatively match the plant-specific postulated LOCA degree of subcooling for the plant debris generation break selections? Were multiple break conditions calculated to ensure a conservative specification of the ZOI radii?

6. Provide a detailed description of the test apparatus specifically including the piping from the pressurized test tank to the exit nozzle including the rupture disk system.

a. Based on the temperature traces in the test reports it is apparent that the fluid near the nozzle was colder than the bulk test temperature. How was the fact that the fluid near the nozzle was colder than the bulk fluid accounted for in the evaluations?

b. How was the hydraulic resistance of the test piping which affected the test flow characteristics evaluated with respect to a postulated plant specific LOCA break flow where such piping flow resistance would not be present?

c. *What was the specified rupture differential pressure of the rupture disks?*

7. *If the application of the reduced ZOI is applied to components other than piping, please respond to this question. Please provide the basis for concluding that a jet impact on piping insulation with a 45° seam orientation is a limiting condition for the destruction of insulation installed on steam generators, pressurizers, reactor coolant pumps, and other non-piping components in the containment. For instance, considering a break near the steam generator nozzle, once insulation panels on the steam generator directly adjacent to the break are destroyed, the LOCA jet could impact additional insulation panels on the generator from an exposed end, potentially causing damage at significantly larger distances than for the insulation configuration on piping that was tested. Furthermore, it is not clear that the banding and latching mechanisms of the insulation panels on a steam generator or other RCS components provide the same measure of protection against a LOCA jet as those of the piping insulation that was tested. One WCAP reviewed asserts that a jet cannot directly impact the steam generator, but will flow parallel to it. It seems that some damage to the SG insulation could occur near the break, with the parallel flow then jetting under the surviving insulation, perhaps to a much greater extent than predicted by the testing. Similar damage could occur to other component insulation. Please provide a technical basis to demonstrate that the test results for piping insulation are prototypical or conservative of the degree of damage that would occur to insulation on steam generators and other non-piping components in the containment.*

8. *Some piping oriented axially with respect to the break location (including the ruptured pipe itself) could have insulation stripped off near the break. Once this insulation is stripped away, succeeding segments of insulation will have one open end exposed directly to the LOCA jet, which appears to be a more vulnerable configuration than the configuration tested by Westinghouse. As a result, damage would seemingly be capable of propagating along an axially oriented pipe significantly beyond the distances calculated by Westinghouse. Please provide a technical basis to demonstrate that the reduced ZOIs calculated for the piping configuration tested are prototypical or conservative of the degree of damage that would occur to insulation on piping lines oriented axially with respect to the break location.*

9. *At least one WCAP noted damage to the cloth blankets that cover the fiberglass insulation in some cases resulting in the release of fiberglass. The tears in the cloth covering were attributed to the steel jacket or the test fixture and not the steam jet. It seems that any damage that occurs to the target during the test would be likely to occur in the plant. Was the potential for damage to plant insulation from similar conditions considered?*

For example, the test fixture could represent a piping component or support, or other nearby structural member. The insulation jacketing is obviously representative of itself. What provides the basis that damage similar to that which occurred to the end pieces is not expected to occur in the plant? It is likely that a break in the plant will result in a much more chaotic condition than that which occurred in testing. Therefore, it would be more likely for the insulation to be damaged by either the jacketing or other objects nearby.

Entergy Nuclear Operations Response, RAI's 2-9:

The PWR Owners Group (PWROG) provided a response to generic RAIs associated with reduced ZOI testing on March 5, 2010, (Reference 2.1). The open RAI issues and responses in Reference 2.1 were grouped and worded differently than Palisades RAIs 2 through 9, but a direct comparison is not required due to discussion that follows. The PWROG has not adequately resolved all open issues at this time. Additionally, smaller upstream dimensions in the test rig than the nozzle diameter were identified during the process of addressing the generic RAIs. The NRC staff has provided their conclusions in NRC letter dated 3/31/2010, (Reference 2.2), regarding the current status of crediting reduced ZOI WCAP test reports. In summary, the NRC staff concluded that the small diameter locations upstream of the test nozzle constitute significant test design errors, and, absent substantial additional information, render all recommended ZOIs in similar test reports invalid.

As Palisades was explicitly crediting reduced ZOI test reports WCAP-16836-P and WCAP-16710-P cited in Reference 2.2, Palisades will need to re-evaluate the amount of debris generation without crediting the currently assumed reduced ZOI for Nukon and Thermal Wrap. Use of associated ZOIs provided by NEI 04-07 SER is planned along with evaluating the possible exclusion of pressurizer insulation above the support skirt for a break below the support skirt provided the support skirt would physically block any jet associated with the break, which is an allowance provided by References 2.1 and 2.2.

<u>References</u>

2.1 PWROG Letter OG-10-84, "PWROG Response to Request for Additional Information Regarding Pressurized Water Reactor Owners Group Bases for Licensee Debris Generation Assumptions for GSI-191, (PA-SEE-0639 Revision 1)," March 5, 2010.

2.2 NRC Letter, Jonathan Rowley of NRR to Anthony Nowinowski of the PWR Owners Group Program Management Office, "Nuclear Regulatory Commission Conclusions Regarding Pressurized Water Reactor Owners Group Response To Request For Additional Information Dated January

25, 2010 Regarding Licensee Debris Generation Assumptions For GSI-191," March 31, 2010. (ADAMS Accession Number: ML100570364)

NRC Request

10. *In* *RAI 2* *from the NRC's letter dated December 24, 2008 (ADAMS Accession No. ML083450689), the NRC staff requested information concerning debris characteristics for several debris sources listed in the February 27, 2008, supplemental response to GL 2004-02. The licensee responded in the June 30, 2009, supplemental response. However, the staff has the following questions remaining on this response.*

    a. *Please provide the basis for concluding that exposure of unjacketed fibrous material to containment spray will not result in the generation of debris.*

    b. *Please provide the basis for concluding that pieces of Marinite debris will not transport to the strainers or erode in the post-LOCA containment pool. Although Section 4.2.2.2.5 of NEI 04-07 states that Marinite can be assumed to be broken into large chunks, the staff could not determine that NEI 04-07 or the accompanying safety evaluation provides a basis for concluding that this Marinite is not susceptible to transport or erosion. The staff has seen results from testing demonstrating that Marinite does erode when submerged and exposed to flow.*

Entergy Nuclear Operations Response to 10a:

The NRC SER for NEI 04-07 Appendix VI at ml043280016 provides the below example material which appear to have been meant as tutorial material.

Appendix VI, Detailed Blowdown/Washdown Transport Analysis for Pressurized-Water Reactor Volunteer Plant, on page VI-29

> Table VI-4 summarizes the assumed fractions of fibrous debris that were eroded. It was assumed that condensate drainage would not cause further erosion of debris and that intact or covered debris would not erode further. Erosion does not apply to fine debris because that debris is already fine. About 1 percent of the small- and large-piece debris that the sprays directly impacted was considered to have eroded. This amount of erosion was considered to be conservative because the DDTS concluded that the erosion was less than 1 percent. No erosion of the intact debris was assumed because the canvas cover likely would protect the insulation.

Table VI-4. Total Erosion Fractions for Fibrous Debris

Exposure	Fines	Small	Large	Intact
Condensate	N/A	0	0	0
Sprays	N/A	1%	1%	0

From context the above table applies to material outside its jacket and exposed and shredded by break blowdown effects. Both smalls and larges are assigned 1% erosion due to sprays.

From the original submittal of June 30, 2009 in Table 3a2, “Summary of Debris Generated” it can be seen in the rows for unjacketed Nukon that a 17D ZOI was assumed and for breaks S1 through S6 the amount of such insulation is 0.8, 0.89, 0.8, 0, 0.8 and 1.79 cubic feet. From the repeated numbers it is assumed that breaks were recounting the same insulation.

The row for low density fiberglass unjacketed also used a ZOI of 17D and shows for the same break set 0.59, 0.59, 0.59, 0.59, and 0.59 cubic feet. Again the repeat numbers are indicative of each break counting the same insulation.

Since this set of breaks with a 17D ZOI specified encompasses very nearly the entire volume of containment containing insulated pipes, it is concluded that the volume of unjacketed insulation is extremely small and approaches 2 cubic feet. It is further noted that during plant walkdowns for GSI-191 in 2004 attempts were made to photograph all insulated piping. Unjacketed fiberglass would have been considered anomalous and would have been specially photographed for that reason. Review of the walkdown photographs agrees with the ZOI debris generation calculation that such instances are rare and the associated volume is minimal. In most cases it was “stuffed” into pipe support gaps or was the result of missing or pulled open jacketing.

If the 2 cubic foot estimate is accepted, then 1% erosion is an insignificant (0.02 cubic feet) contribution to the total fiber in the sump and is well within the error margins of the debris generation calculation.

The unjacketed quantity estimate is necessary because only piping within the ZOI of the breaks was cataloged for GSI-191 and no specific record was made of “all insulation within containment”. It is also noted that loose fiberglass without a convection blocking cover is ineffective piping insulation and not sanctioned by plant insulation specifications.

Entergy Nuclear Operations Response to 10b:

Large chunks of Marinite are unlikely to transport due to their large size and density. This tendency not to transport is exacerbated by the fact that the majority of the “Marinite” insulation is in fact Transite insulation. Transite insulation is a similar material but has a significantly higher density (100 lb/ft^3 [Ref. 10.2]) than Marinite-I and Marinite-M (46 lb/ft^3 for both [Refs. 10.3, 10.7]). Based on best available information, it appears that the “Marinite” at Palisades is 19.6% Marinite I, 13.7% Marinite M, and 66.7% Transite [Ref. 10.1].

NUREG/CR-6772 presented experimental data which showed the incipient tumbling velocity of Marinite to be 0.77 ft/s, with large pieces (4x4 in. flat pieces) experiencing no movement up to the test maximum of 0.99 ft/s flow velocity [Ref. 10.6]. Therefore it is reasonable to assume that the large pieces of Marinite debris in the pool will not transport.

NUREG/CR-6772 states that, “Considering the amount of plastic deformation needed to pull these small rubbery pieces apart, the disintegration of Marinite into smaller fragments as a result of turbulence was judged to be highly unlikely.” [Ref. 10.6] This is restated as well in NUREG/CR-6808, where it is noted that, “…it was conjectured that the levels of agitation that might develop in a containment pool would not cause Marinite material to disintegrate.” [Ref. 10.5]

Erosion testing of Marinite showed that when exposed to flow velocity of 0.4 ft/s for 32 hours, the Marinite samples experienced a maximum weight loss of 1.22% [Ref. 10.5]. However, this quantity was determined to be primarily the wearing away of the rough edges initially found on the broken Marinite sample pieces. This erosion pattern was very similar to that observed on Cal-Sil samples tested concurrently with the Marinite. Images of the Cal-Sil before and after erosion testing are shown in Figure 10.1 and Figure 10.2, respectively.

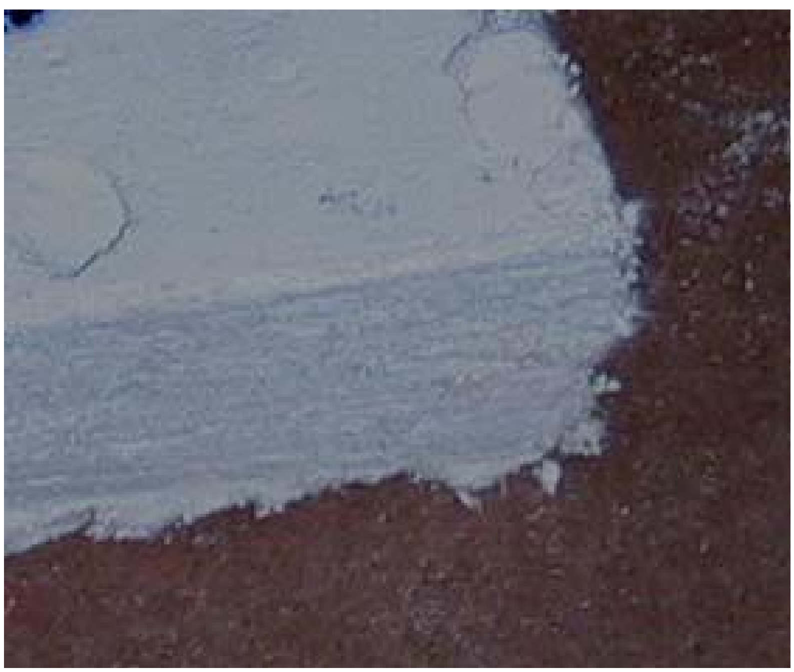


Figure 10.1: Cal-Sil Sample Before Erosion Testing

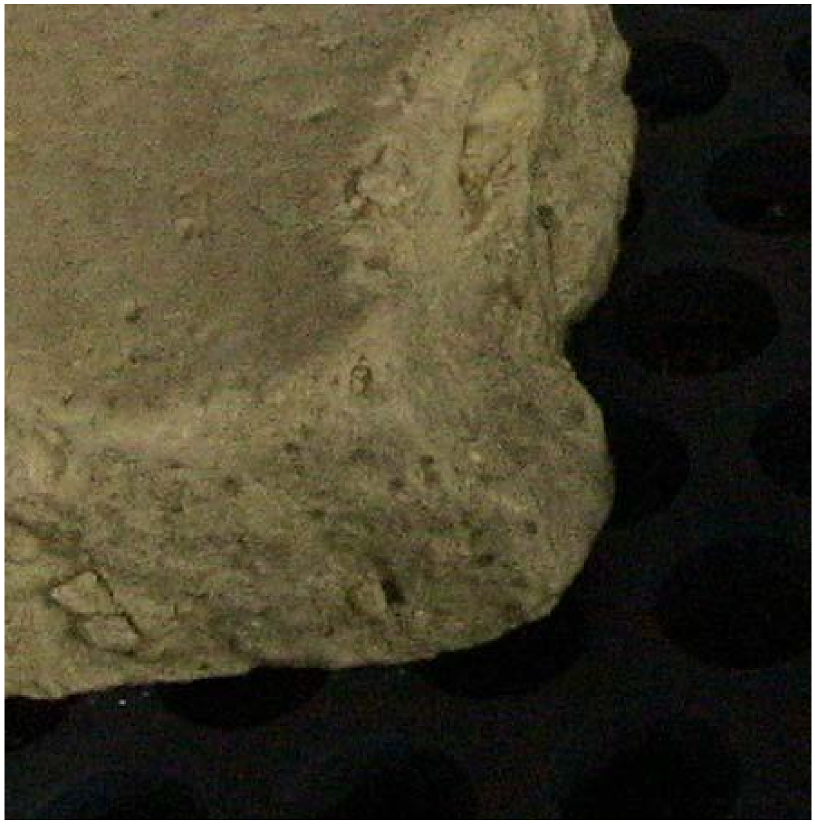


Figure 10.2: Cal-Sil Sample After Erosion Testing

Thus, although there was a 1.22% erosion of sample weight over 32 hours, it is expected by the erosion pattern that this would represent the majority of the erosion of the sample expected to take place over the 30 day mission time.

Further, it should again be taken into account that the flow erosion testing was performed on Marinite 1 insulation material, where as the majority of the insulation material designated as Marinite for the Palisades plant is actually Transite [Ref. 10.1], which in addition to being more dense is also significantly harder. Marinite-I insulation has Brinell hardness number of 1.2 (45.5 kg load, 19.05 mm [Ref. 10.3]) while the Transite insulation has a Brinell hardness number of 17 (500 kg load, 6 mm diameter [Ref. 10.2]. Thus it is reasonable to assume that quantity of debris which erodes off the "Marinite"-type insulation debris pieces in the pool is insignificant.

Therefore it is appropriate to assume that the "Marinite" insulation debris in the Palisades plant will neither transport to the strainers nor erode in the pool.

References

10.1 EA-MOD-2003-0021-01.

10.2 BNZ Transite Specification Sheet.

10.3 BNZ Marinite I Specification Sheet.

10.4 ALION-REP-LAB-2352-218, “Marinite 1 Flow Erosion Testing Report”, Rev. 0.

10.5 UREG/CR-6808, “Knowledge Base for the Effect of Debris on Pressurized Water Reactor Emergency Core Cooling Sump Performance”.

10.6 NUREG/CR-6772, LA-UR-01-6882, “GSI-191: Separate Effects Characterization of Debris Transport in Water”.

10.7 BNZ Marinite M Specification Sheet.

NRC Request

11. *In RAI 3 from the NRC's letter dated December 24, 2008, the NRC staff requested that the licensee discuss any changes that have been made to the licensee's analysis that are associated with debris characterization at a level of detail consistent with the NRC supplemental response content guide. The licensee responded in the June 30, 2009, supplemental response by providing tables of debris quantities for each break. Although knowing the debris quantities is helpful, it is unwieldy to compute the percentages of debris in each size category for each ZOI subregion for each break. Since the percentages are the most important aspect of determining the adequacy of treatment of debris characterization, please provide the percentages of debris assumed in each category within the ZOI or ZOI subregion, as applicable.*

Entergy Nuclear Operations Response:

Provided below are the supporting Size Distribution Tables for those giving Cubic Feet and Pounds included original June 30, 2009 supplement. They appear to have the information the NRC is seeking. These tables are provided by Reference 11.1. Also see RAI 13 response which is associated with Table 3.1.

Table 3.1: Size Distribution for Jacketed Nukon and Thermal Wrap [Refs. 6.8]

Size	ZOI (5.0 D)	ZOI (7.0 - 5.0 D)
Fines	18%	0%
Small Pieces	42%	0%
Large Pieces	40%	0%
Intact Pieces	0%	100%

Table 3.2: Size Distribution for Unjacketed Nukon, Unjacketed Low Density Fiberglass and Jacketed Low Density Fiberglass Insulation [Ref. 6.1]

Size	ZOI (7.0 D)	ZOI (11.9 - 7.0 D)	ZOI (17.0 - 11.9 D)
Fines (Individual Fibers)	20%	13%	8%
Small Pieces (< 6" on a side)	80%	54%	7%
Large Pieces (>6" on a side)	0%	16%	41%
Intact (covered) Blankets	0%	17%	44%

Table 3.4.3: Size Distribution for Calcium Silicate

	Jacketed		Cloth Covered	
Size	ZOI (0 - 2.7D)	ZOI (5.45 - 2.7D)	ZOI (0 - 2.7D)	ZOI (2.7 - 28.6D)
Fines	50%	25%	50%	25%
Small Pieces	50%	16%	50%	16%
Large Pieces	0%	0%	0%	59%
Remains on Target	0%	59%	0%	0%

Table 3.4.4: Size Distribution for Reflective Metal Insulation

Size	ZOI (2D)
Fines	75%
Small Pieces	
Large Pieces	25%
Intact	0%

References

11.1 ENERCON Report ENTP-003-PR-02, Revision 0, “GSI-191 Debris Size Distribution and Debris Erosion Report for Palisades Nuclear Station”

- Reference 11.1, Table 3.1 Reference 6.8 is Design Input Record for EC 7833, “Enercon Size Distribution and Erosion Report”
- Reference 11.1, Table 3.2 Reference 6.1 is ALION-REP-ALION-2806-01, Rev. 3, “Insulation Debris Size Distribution for use in GSI-191 Resolution”

NRC Request

12. *In* <u>*RAI 4*</u> *from the NRC's letter dated December 24, 2008, the NRC staff requested that the licensee provide debris characteristics information for Alpha Maritex insulation. The licensee responded that characterization information for this debris was obtained from WCAP-16727. The licensee summarized WCAP-16727 as stating that from 10-25 percent of the material would be characterized as small pieces and fines, and further stated that the debris would readily settle and would not transport in the containment pool based in part on a comparison to paint chip transport test data and an experiment in the head loss test flume at Alden Research Laboratory. The NRC staff did not consider this response to be adequate for the following reasons: (1) it was not clear that the debris generation testing discussed in WCAP-16727 was adequately scaled to collect debris characterization information, (2) it was not clear that comparison of Alpha Maritex (a fibrous material) to paint chips is valid with respect to debris transport properties, (3) it was not clear that the transportability of Alpha Maritex fines was addressed by the licensee, and (4) as discussed in a subsequent RAI, it is not clear that the "averaged" flow conditions simulated in the head loss testing for Palisades were prototypical or conservative with respect to the plant condition. Please address the above issues regarding the Alpha Maritex insulation.*

Entergy Nuclear Operations Response:

Palisades utilized the WCAP-16727 stated Westinghouse opinion that the debris from lead blankets would not transport. Squares pieces of Alpha Maritex of 1 inch size were tested at Palisades's containment velocities as modeled in the Alden flume and did not transport which confirmed the Westinghouse statement.

We understand that one or more other plants shredded whole sections of lead blankets and in those flumes some of the string like material from the shredder action on Alpha Maritex cloth may have transported to the strainer at the velocities utilized in the testing for those plants. It is noted that for the one test we are aware which was also done at Alden, the velocity in the test flume was significantly higher than what Palisades used.

If additional testing is done for Palisades a scaled amount of shredded cloth will be included depending upon the state of knowledge as to the ZOI for lead blankets that exists at the time of the test.

The blankets are constructed in long strips and are hung, as a general rule, from one end. This facilitates the blankets blowing out and away from the break flow and to there by escape destruction. With the exception of 2 installations on the Pressurizer Spray lines, all the blankets at Palisades are hung in this manner. The 2 spray line installations are draped across an open frame surrounding 3 sides of the pipe. They are bolted at mid blanket to avoid falling off the pipe frame during plant operation due to vibration from the Primary Coolant Pumps and unsteady flow in the Pressurized Spray lines. This would represent a small amount of debris of a type not viewed as a strong participant in strainer pressure drop.

Those blankets which are not within the ultimately acceptable ZOI can, if required, be removed during plant operation and reinstalled during outages as they had previously been. If they can ultimately be re-qualified for Post LOCA survival or by acceptable testing, then they can be left on during operation and that will reduce the dose required to remove and reinstall them. This would be a negligible amount in proportion to that incurred for other GSI-191 activities such as modification or removal of insulation. The blankets have no credited function during plant operation; they are only an outage ALARA issue.

NRC Request

13. *The assumed debris size distribution of 60 percent small fines and 40 percent large pieces for jacketed Nukon and Thermal Wrap within a 5D ZOI is inconsistent with Figure II-2 of the NRC staff's SE dated December 6, 2004 (Agencywide Documents Access and Management System (ADMAS) Accession No. ML0432800007), on NEI 04-07, which considers past air jet testing and indicates that the fraction of small fines should be assumed to reach 100 percent at jet pressures in the vicinity of 18–19 pounds per square inch (psi). At 5D (5 times the pipe diameter), the jet pressure is close to 30 psi, which significantly exceeds this threshold. Furthermore, the licensee's assumption that the size distribution for debris in a range of 5D to 7D is 100 percent intact blankets also appears to be inconsistent with existing destruction testing data. These assumptions for the jacketed Nukon and Thermal Wrap debris size distributions appear to be based on the recent Westinghouse/Wyle ZOI testing discussed in WCAP-16710-P. However, that testing was not designed to provide size distribution information, and much of the target material was exposed to jet pressures much lower than would be expected for a prototypically sized break. Furthermore, given the assumption that insulation between 5D and 7D is 100 percent intact pieces that do not transport or erode, the licensee has effectively assumed a 5D ZOI rather than a 7D ZOI for jacketed Nukon and Thermal Wrap. In light of this information concerning previous testing experience, please provide a basis for considering the assumed debris size distribution of 60 percent small fines and 40 percent large pieces within a 5D ZOI to be conservative or prototypical, as well as the distribution of 100 percent intact pieces in a 5D to 7D ZOI subregion.*

Entergy Nuclear Operations Response:

The assumed size distribution for jacketed Nukon and Thermal Wrap was based on Reference 13.1. Based on response to RAI's 2 through 9, attempting to support a size distribution for 5D and 7D is no longer necessary. For future calculations, Palisades will either evaluate use of the fibrous-debris size distribution provided in NEI 04-07 SER Appendix VI, Table VI-2 or will utilize the size distribution approach noted in RAI 11 Response, Table 3.2.

References

13.1 Westinghouse Letter Report CPAL-09-3 dated January 30, 2009, "Fibrous Debris Size Distribution for Palisades Nuclear Plant Based on Jet Impingement Testing of Jacketed NUKON® Insulation Pillows Reported in WCAP-16710-P"

NRC Request

14. *The June 30, 2009, supplemental response appeared to indicate that only 50% of the calcium silicate within a 5.45D ZOI was assumed to be destroyed into small fines. The other 50% of the calcium silicate within this ZOI was assumed to remain intact following the impact of the LOCA jet. The assumed size distribution appeared to be based on OPG testing for which less than 50% of the target calcium silicate was damaged by jet impingement. Please address the following items concerning the assumed calcium silicate debris distribution:*

    a. *Significant portions of the target insulation in the OPG tests were not exposed to jet forces representative of the calculated ZOI. In other words, the insulation targets used for testing were so long (48 inches) that, due to the small size of the jet nozzle (2.86 inches), a significant portion of the insulation targets was not subjected to destruction pressures prototypical of a complete rupture of RCS piping. In addition, some OPG tests demonstrated the occurrence of insulation damage at distances in excess of that corresponding to a spherical 5.45D. Although a 5.45D ZOI was accepted for calcium silicate based on the OPG testing, the NRC staff's safety evaluation on NEI 04-07 conservatively recommended that 100% of the calcium silicate within a spherical 5.45D ZOI be assumed to be destroyed into small fines, which compensated for these test setup issues. Thus, please justify assuming a 5.45D ZOI with 50% intact pieces in light of the information presented herein.*

Entergy Nuclear Operations Response to 14a:

Based on the photographic evidence from the OPG tests used in determining the size distribution of destroyed Cal-Sil debris (5D, 7D, 9D, 11D, 13D, and 20D tests presented in Figures 14.1 through 14.6) it is apparent that most significant destruction of the target insulation was not directly in front of the jet nozzle but was instead located almost randomly along the length of the target [Ref. 5]. The 9D and 7D tests (OPG tests 8 and 12) show a very uniform destruction pattern along nearly the entire length of the target, with the far side of the target insulation removed and the nearside remaining intact under intact jacketing. The 13D and 20D tests (OPG tests 14 and 15) show a destruction pattern centered at one end of the target, with the centerline of the target directly in front of the nozzle relatively intact.

It is important to note that the nozzle diameters (i.e. 5D, 7D, etc.) used in the nomenclature of the OPG tests are not representative of the spherical ZOI's which are used in debris generation calculations. These spherical ZOI are generated based on the jet impingement pressure experienced by the insulation target. An approximation† of the spherical ZOI's equivalent to each of the OPG tests pictured above can be determined by interpolation from the methodology for determining spherical ZOI from impingement pressures outlined in the SER. These approximate ZOI are shown in Table 14.1.

Table 14.1 – Approximate Equivalent Spherical ZOI's

OPG Nomenclature	Approximate Equivalent ZOI
5D	2.92D
7D	3.36D
9D	3.65D
11D	3.90D
13D	4.32D
20D	5.45D

Figure 14.1 - OPG 5D Test Target Post-Destruction (Jacketing Removed) (Figure D4 in Ref. 5)

†The approximations given were determined by identification of the jet impingement pressure experienced by the target for each test from Figure II-12 of the SER [Ref. 22]. These jet impingement pressures were then converted to approximate equivalent ZOI's by interpolation of the values in Table 3-1 of the SER [Ref. 22].

Figure 14.2 - OPG 7D Test Target Post-Destruction (Figure D5 in Ref. 5)

Figure 14.3 - OPG 9D Test Target Post-Destruction (Rear View) (Figure D7 in Ref. 5)

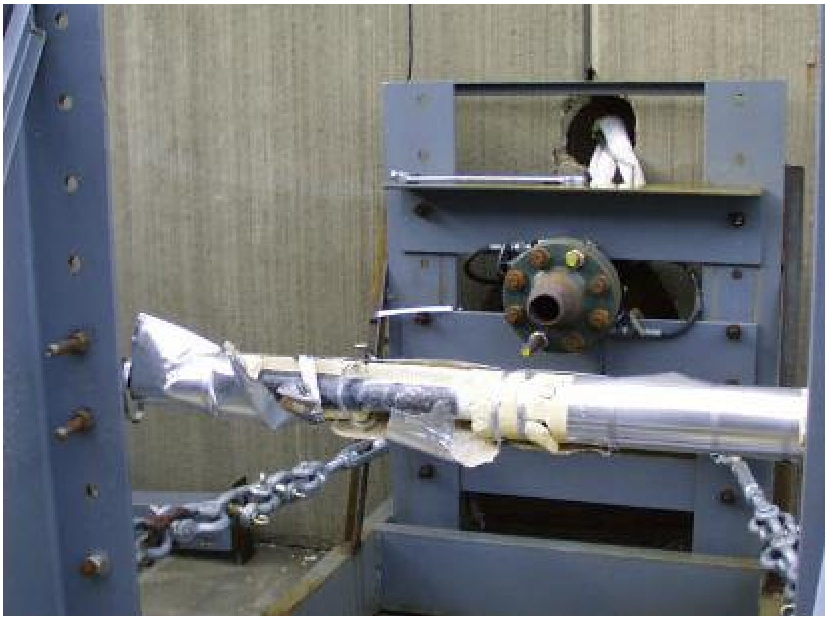


Figure 14.4 - OPG 11D Test Target Post-Destruction (Rear View) (Figure D9 in Ref. 5)

Figure 14.5 - OPG 13D Test Target Post-Destruction (Rear View) (Figure D11 in Ref. 5)

Figure 14.6 - OPG 20D Test Target Post-Destruction (Rear View) (Figure D14 in Ref. 5)

In addition to visual observation of the results of the tests, it is stated explicitly in the test report that “For tests with target distances from 7 to 13 D, presented in Table 2, it was found that the zone of damage extended to one or both ends of the target [Ref. 5].”

The OPG report also includes a discussion of the pressure profile on the target, based on correlations for pressure distribution detailed by Kastner [Ref. 20]. This discussion notes that assuming the jet is centered between two bands spaced 8.25” apart, the maximum pressure between the bands at 3D would be 0.65 MPa, while the average pressure would be 0.60 MPa. The discussion further notes that at a 5D distance the maximum pressure is 0.28 MPa and the average pressure is 0.27 MPa. Finally at 10D the difference between the maximum pressure and the average pressure is negligible. These pressure profiles are displayed in Figure 14.7 [Refs. 5, 20].

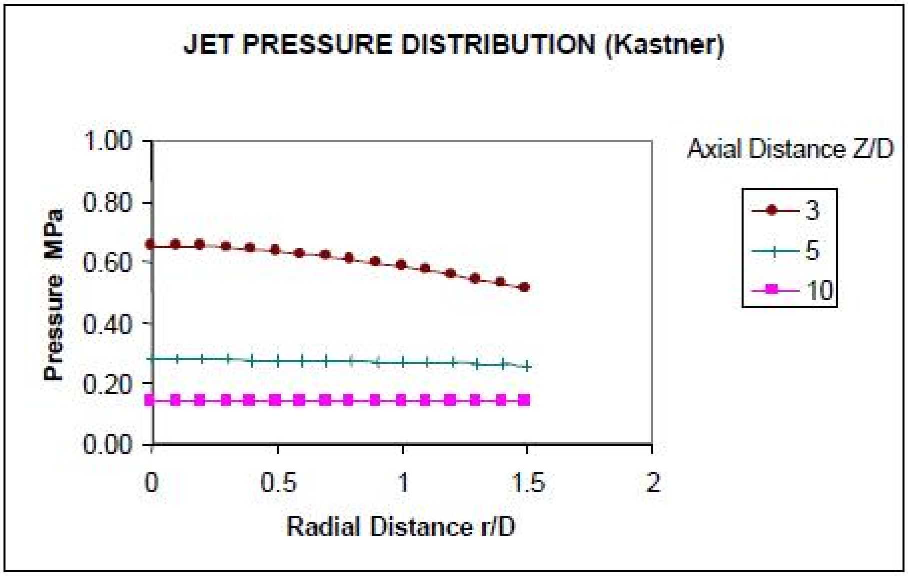


Figure 14.7 – Pressure Difference Between Bands as Given by Kastner (Figure 6 in Ref. 5)

Comparison to Alternate Testing – General Electric Nuclear Energy (GE) conducted air jet destruction testing on aluminum-jacketed Calcium Silicate insulation at the Colorado Engineering Experiment Station, Inc. (CEESI), as documented in NUREG/CR-6808 [Ref. 15]. The results of the CEESI air jet destruction testing recommended a destruction pressure of 160 psig for aluminum-jacketed Calcium Silicate insulation. The SER recommends (Section 3.4.2.2) reducing the destruction pressures determined in air jet destruction tests by 40% to account for two phase jet effects. Thus the adjusted destruction pressure determined in the CEESI testing is 96 psig. By comparison the OPG results are conservative, documenting destruction of similar Aluminum-jacketed Calcium Silicate insulation at pressures as low as 24 psig, for an approximate equivalent ZOI of 5.45D. The adjusted destruction pressure of 96 psig recommended by the CEESI air jet destruction testing would convert to an approximate equivalent ZOI of 2.6D.

Conservatisms –There are a number of conservatisms to be considered which were used in the process of converting the OPG test results into a destroyed debris size distribution.

First, the destroyed debris size distribution determined from the OPG tests utilized only those tests in which the longitudinal seam was placed at 45° from the jet. The 45° tests where shown overwhelmingly to have the greatest destruction impact on the target. The tests performed with the longitudinal seam placed at 0° from the jet produced destroyed debris out to a maximum of 7D, and for the tests performed with the longitudinal seam placed at 180° no damage was observed even at a distance of 3D. This is in stark contrast to the damage observed out to the 20D range for the 45° tests. As it is extremely unlikely that the jet expanding from a pipe break would hit all possible insulation at 45° with respect to their longitudinal seams, the use of only 45° tests in the determination of the debris size distribution and ZOI represents a significant conservatism [Ref. 5].

Further, the OPG tests were conducted solely for freely expanding jets. As noted in the report, it is reasonable to assume that within the congested areas common to plant containments, blockage may occur and dissipate some of the energy of the jet [Ref. 5].

Inherent conservatisms are also present in the size distribution used by Palisades in comparison to the results of the OPG 45° testing, as shown in Table 14.2.

Table 14.2 - Cal-Sil Debris Size Distribution Compared to Average OPG Size Distribution

Size	Palisades Size Distribution 0-2.7D ZOI	Palisades Size Distribution 2.7D-5.45D ZOI	Average Size Distribution of OPG Destroyed Debris
Fines (Particulate)	50%	25%	20%
Small Pieces (Under 1” to Over 3”)	50%	16%	13%
Remains on Target	0%	59%	67%

For the reasons stated, Palisades believes that the 5.45D ZOI paired with the size distribution displayed in Table 14.2 is sufficiently conservative. However, based on the NRC’s concerns voiced during the teleconference held April 26, 2010, Palisades will utilize a 6.4D ZOI paired with the size distribution shown in Table 14.3. This ZOI and size distribution combination is consistent with ZOI and size distribution outline for Cal-Sil in the ALION size distribution document [Ref. 25]. The ZOI and size distribution outlined for Cal-Sil in the ALION size distribution document has been used for the debris generation of Cal-Sil in the Indian Point plant. In the Section 3.2 of the Indian Point Audit Report [Ref. 26] the size distribution outlined in the ALION size distribution document is accepted as sufficiently conservative in part due to the conservative extension of the ZOI to 6.4D (equivalent to a destruction pressure of 20 psig, reduced from the SE-accepted recommendation of 24 psig) and the conservative extension of the cloth covered Cal-Sil insulation ZOI to 28.6D. Palisades will utilize the same conservative extension of the ZOI of jacketed Cal-Sil to 6.4D, and will continue to extend the cloth covered Cal-Sil to 28.6D.

Table 14.3 - Cal-Sil Debris Size Distribution Compared to Average OPG Size Distribution

Size	Palisades Size Distribution 0-2.7D ZOI	Palisades Size Distribution 2.7D-6.4D ZOI	Average Size Distribution of OPG Destroyed Debris
Fines (Particulate)	50%	23%	20%
Small Pieces (Under 1" to Over 3")	50%	15%	13%
Remains on Target	0%	62%	67%

NRC Request

b. *Please identify the jacketing and banding, latching, etc., of the calcium silicate insulation at Palisades and compare this insulation material to the material that was tested by OPG to support the assumed debris characterization of 50% intact pieces based on the application of the OPG test results. Please also compare the manufacturing process for the calcium silicate at Palisades with that used for the OPG testing (i.e., hydraulically pressed or molded – see Section 3.3.3 of Indian Point Audit Report).*

Entergy Nuclear Operations Response to 14b:

There are at least 2 kinds of Cal-Sil in Palisades Plant [Ref. 23]. The original plant specified asbestos binder and aluminum "jacketing". By 1980 it was illegal to reinstall this material if it was removed from the piping. Also after 1975 it was known that there was a possible post LOCA hydrogen generation problem with aluminum so plant procedures were amended to require installation of Stainless jacketing if the existing aluminum had to be replaced. Thus the majority of the Cal-Sil insulation in the Palisades plant is assumed to be either asbestos-reinforced material jacketed with aluminum (referred to as Palisades Type 1) or asbestos-free Thermo-12™ Gold Cal-Sil material jacketed with stainless steel (referred to as Palisades Type 2) [Ref. 23, 24].

The relevant characteristics of the insulation material used in the OPG testing are compared to those of the Cal-Sil insulation materials installed in the Palisades plant in Table 14.4 [Ref. 23, 24].

Table 14.4 - Cal-Sil Insulation Characteristic Comparison

Characteristic	OPG [Ref. 5]	Palisades Type 1	Palisades Type 2*
Jacketing Material	Aluminum-	Aluminum	Stainless Steel

	1100		
Jacketing Thickness	0.016 in.	0.016 in. minimum	0.016 in. minimum
Band Material	Stainless Steel	Stainless Steel**	Stainless Steel**
Band Thickness	0.02 in.	0.016-0.025 in.	0.016-0.025 in.
Band Width	0.5 in.	0.5 in.	0.5 in.
Band Spacing (Centerline)	8 in.	12” maximum	12” maximum
12” maximum Cal-Sil Manufacturing Process	Not provided	Asbestos reinforced; post-autoclave process	Asbestos-free Thermo-12™ Gold Cal-Sil; Pabco Process

*Palisades Type 2 Cal-Sil is allowed by specification at the Palisades plant, but is believed to be installed in minimal quantities.
**All bands are observed to be SS but specification does allow aluminum or galvanized metal. [Ref. 23].

Jacketing Material and Thickness - The thickness of both aluminum and stainless steel jacketing types is a minimum of 0.016 in [Ref. 7]. Thus it is reasonable to conclude that the aluminum jacketing is of equivalent or greater strength, as it is of equivalent or larger thickness to that used in the OPG tests. Further, the aluminum cladding used at the Palisades plant is ASTM B 209, Alloy: 5005 (Temper: H-14, Finish: mill). This aluminum is known to have a material tensile strength of 23 ksi [Ref. 21]. The aluminum jacketing used in the OPG testing was Aluminum 1100 [Ref. 5]. The tensile strength of Aluminum 1100 is 13 ksi [Ref. 8]. As the aluminum jacket used in the Palisades plant is known to have greater material tensile strength (23 ksi) than the aluminum jacketing used in the OPG testing (13 ksi) it is reasonable to conclude that the jacketing in use at the Palisades plant is of equivalent or greater strength to that used in the OPG testing. This is especially important as the failure mode observed in the OPG testing was shearing of the cladding [Ref. 5].

The stainless steel jacketing allowed by specification at the Palisades plant is believed to be present only in minimal quantities. The majority of the cladding is believed to be aluminum [Ref. 23].

Banding Style and Spacing – The specification for the bands used to fasten the jacketing characterizes the bands as 0.016-0.02 in. thick for pipes of outer diameter up to 12 in. and 0.02-0.025 in. thick for pipes of outer diameter greater than 12 in. The specification allows for aluminum bands as opposed to stainless steel bands for use with aluminum jacketing, however all bands are observed to be stainless steel. Similarly galvanized metal straps are allowed by the specification in place of stainless steel bands, but galvanized metal straps were not found in the plant during walkdowns [Ref.23].

It is thus concluded that the banding used to fasten the jacketing to the insulation in the Palisades plant is equivalent to that used in the OPG testing, comprised primarily of stainless steel bands of 0.02 in. thickness.

The bands used in the Palisades plant to fasten the jacketing are spaced a maximum of 12 in. apart [Ref. 23]. This is marginally further apart than the 8in. spacing used in the OPG tests [Ref. 5]. However, the failure mode observed in the testing was not band failure, but rather shearing of the cladding.

Cal-Sil Manufacturing Process – In his document, *Summary of Calcium Silicate Insulation Types Used inside Containment at US Nuclear Plants,* [Ref. 6] Gordon H. Hart, P.E., describes that over the past 50 years or so of nuclear power plant construction and operation, several different types of Cal-Sil pipe and block insulation have been used. The summary prepared by Hart was based upon information provided by Tom Whitaker of Technical Support at Industrial Insulation Group, LLC, (11G), currently the only North American manufacturer of Cal-Sil.

Hart categorizes Cal-Sil with asbestos fiber as Type I Cal-Sil created with a post-autoclave process that was discontinued in the early 1970's due to asbestos' carcinogenic attributes. Type II is free of asbestos fibers and is made by a filter press pre-autoclave. Type III is also free of asbestos fiber and is made in a pour and mold process known as the Pabco Process, also a Post Autoclave process.

Further, according to IIG, Type III Cal-Sil is more friable than Type II Cal-Sil. Type III Cal-Sil is softer and will most likely erode faster in a moving fluid than Type II Cal-Sil. Further according to IIG**,** "To my (Whitaker's) knowledge, there is no published information related to erosion rates of any of these products. The comparison of the erosion rates is based on personal experience in the Calcium Silicate business since 1972."

Also according to IIG**,** Whitaker indicates that, "My opinion is that the asbestos-based Cal-Sil would have less erosion due to moving fluids than the non-asbestos based insulation products."

In summary, based upon the above information,

- Type 1, asbestos fiber-reinforced, Post Autoclave process, Cal-Sil is the least susceptible to erosion of the three Cal-Sil types described by Hart,

- Type II, non-asbestos, Johns-Manville Process Cal-Sil is less susceptible to erosion than the Type III Cal-Sil, and

- Type III, Pabco/Post Autoclave Process Cal-Sil is the most susceptible Cal-Sil to erosion of the three Cal-Sil types described by Hart.

As stated above the first type of Cal-Sil insulation installed in the Palisades plant is asbestos containing (Palisades Type 1) and is assumed to be equivalent to Hart Type I. The second type of Cal-Sil insulation installed in the Palisades plant is asbestos-free (Palisades Type 2) formed using the Pabco process and is assumed to be equivalent to the Hart Type III. The Hart Type II Cal-Sil is not believed to be in use at Palisades because the Owens-Corning plant was in the east coast area and also most of the new Cal-Sil was installed by PCI personnel from Kansas (PCI was the installation arm of Owens-Corning through the 1990's) who likely used one of the western (Colorado) Cal-Sil Plants some of which were built by Pabco.

The asbestos reinforced Palisades Type I Cal-Sil insulation, as equivalent to the least friable of all Hart-type Cal-Sil insulations, is assumed to be equal to or superior in destruction resistance to that used in the OPG tests.

The asbestos free Palisades Type 2 Cal-Sil insulation is equivalent to the most friable of all Hart-type Cal-Sil insulations. However, this type of Cal-Sil insulation is present in much lower quantities within the plant than the more robust Type 1 Cal-Sil insulation (equivalent to Hart-Type I). Further, dissolution testing was performed on Thermo-12™ Gold Cal-Sil type Cal-Sil insulation (equivalent to Palisades Type 2 Cal-Sil insulation) at Alion test facilities. These tests showed that large scale dissolution did not occur [Ref. 9]. As documented in Section 5.2.5 of NUREG/CR-6808 [Ref. 15], at least one type of Cal-Sil has been shown to undergo as much as 76% weight loss under hot water and occasional stirring. Therefore, it has been shown that the Palisades Type 2 Cal-Sil insulation is not the most friable of available Cal-Sil insulation.

Based on discussion with the Staff during a 4/26/2010 Technical Call, it is understood that further support for the Palisades banding spacing differences from that used in the OPG testing is needed. This may be in the form of a calculation to determine whether the additional strength of Palisades jacketing offsets the added banding spacing. Installing additional banding could also be a solution. Additionally, Palisades needs to better address whether all banding installed is in fact stainless steel. Both these items will be evaluated further.

NRC Request

c. *The 50% of the calcium silicate considered to be undamaged was not considered for potential erosion and transport to the strainer. However, for a number of the OPG tests, the insulation jacketing was removed, even when the base insulation material was not completely removed from the pipe. In light of the removal of the jacketing in a number of tests, please justify that erosion of the calcium silicate remaining on pipes need not be considered.*

Entergy Nuclear Operations Response to 14c:

While a sizable portion of jacketing was removed in a number of the OPG tests, the jacketing removed was overwhelmingly from areas in which the base insulation was removed (see Figures 14.8 through 14.10). For the insulation material which remains on the target, the overwhelming majority of the surface area of the Calcium Silicate material remains protected by jacketing material. Only approximately 20% of the material remaining on the target is unprotected by jacketing material. The potential for erosion of the intact calcium silicate insulation from the containment spray flow and the impact on the overall quantity of calcium silicate material reaching the containment sump strainer is considered negligible for the following reasons:

- A significant portion of the Calcium Silicate material that is unprotected by the jacketing material, but remains on the piping, would not be coincidentally in the path of the containment spray flow.

- The safety evaluation (SE) for NEI 04-07 [Ref. 22] concludes that the containment spray erosion rate for low density fiberglass insulation is less than one (1) percent. Although the SE does not provide a containment spray erosion rate for calcium silicate insulation, the containment spray erosion rate for calcium silicate insulation is expected to be extremely low, similar to low density fiberglass insulation. The recirculation pool erosion rate of 17% was measured for calcium silicate insulation, whereas a recirculation pool erosion rate of 10% was measured for low density fiberglass insulation. The relationship between the Calcium Silicate and low density fiberglass recirculation pool erosion rates is expected to be similar to the relationship between the Calcium Silicate and low density fiberglass containment spray erosion rates.

- Due to uncertainties in the Zone of Influence for unjacketed Calcium Silicate insulation, an extremely conservative ZOI of 28.6D (largest ZOI for all insulation provided in NEI 04-07) is used for unjacketed calcium silicate insulation. Further, none of the unjacketed Calcium Silicate insulation within the ZOI is assumed to remain on the piping. All the calcium silicate insulation reaches the containment recirculation pool. Therefore, the large pieces of calcium silicate insulation that are generated as part of the break are subjected to erosion within the recirculation pool.

- As provided in Table 14.3, the size distribution to be used for Palisades debris generation calculation is extremely conservative when compared to the size distribution observed in the OPG testing.

Therefore, it is concluded that the erosion of the Calcium Silicate pieces that remain on the piping after the break is negligible when compared to the other conservatisms included in determination of the quantity of calcium silicate insulation that reaches the Palisades containment sump strainer.

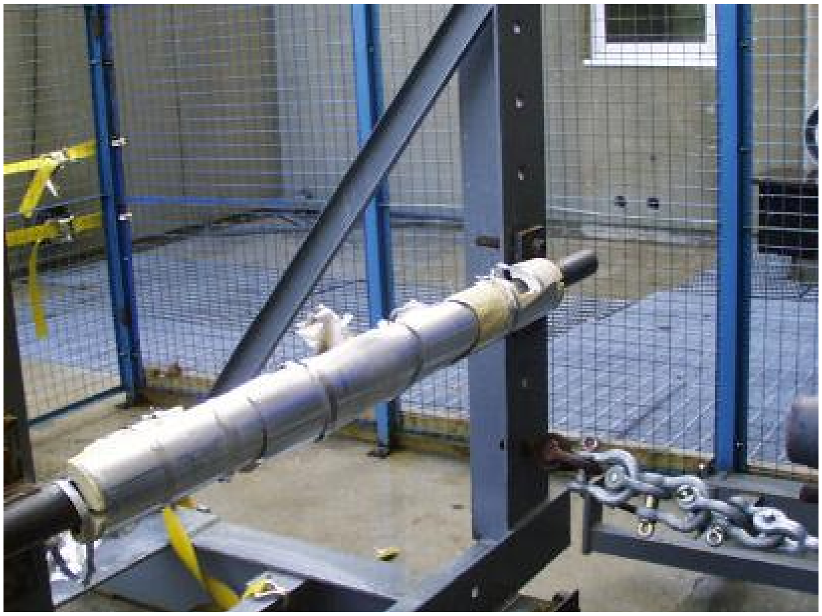


Figure 14.8 - OPG 9D Test Target Post-Destruction (Front View) (Figure D8 in Ref. 5)

Figure 14.9 OPG 11D Test Target Post-Destruction (Front View) (Figure D10 in Ref. 5)

Figure 14.10 OPG 20D Test Target Post-Destruction (Front View) (Figure D13 in Ref. 5)

References

1. EA-MOD-2003-0021-01.
2. BNZ Transite Specification Sheet.
3. BNZ Marinite I Specification Sheet.
4. ALION-REP-LAB-2352-218, “Marinite 1 Flow Erosion Testing Report”, Rev. 0.
5. Ontario Power Generation, “Jet Impact Tests—Preliminary Results and Their Applications,” N-REP-34320-10000-R00. April 2001.
6. Gordon H. Hart, P.E, “Summary of Calcium Silicate Insulation Types Used inside Containment at US Nuclear Plant”, December 31, 2007.
7. CS85-P-HT1.
8. Avallone, Eugene A. et. al.,“Marks’ Standard Handbook for Mechanical Engineers”, Ninth Edition.
9. ALION-REP-PAL-7199-22, “Palisades Cal-Sil Flow Erosion and Dissolution Testing Report”, Rev. 0.
10. ALION-REP-ENT-7199-21, “Palisades Fiberglass Debris Flow Erosion Testing Report”, Rev. 0.
11. ALION-PLN-I006-02, “Erosion Testing of Small Low Density Fiberglass Debris: Test Plan”, Rev. 1.
12. ALION-REP-LAB-2352-99, “Test Report: Erosion Testing of Mineral Wool Insulation”, Rev. 0.
13. ALION-REP-LAB-2352-77, “Test Report: Erosion Testing of Low Density Fiberglass Insulation”, Rev. 3.
14. ALION-REP-ENT-7637-02, “Palisades Erosion Assessment – Average Velocity and Turbulence for Non-Transporting Debris”, Rev. DRAFT.
15. NUREG/CR-6808, “Knowledge Base for the Effect of Debris on Pressurized Water Reactor Emergency Core Cooling Sump Performance”.
16. NUREG/CR-6772, LA-UR-01-6882, “GSI-191: Separate Effects Characterization of Debris Transport in Water”.
17. BNZ Marinite M Specification Sheet.
18. NUREG/CR-6224, “Parametric Study of the Potential for BWR ECCS Strainer Blockage Due to LOCA Generated Debris”.
19. ALION-REP-ALION-I006-04, “Erosion Testing of Small Pieces of Low Density Fiberglass Debris - Test Report”, Rev. 0.
20. Kastner, W. and Rippel, R., Jet Impingement Forces on Structures-Experiments andEmpirical Calculation Methods, Nuclear Science and Engineering, 105, pp269-284 (1988).
21. Aluminum 5005-H14 Physical Data based upon Metals Handbook, Vol.2 – Properties and Selection: Nonferrous Alloys and Special-Purpose Materials, ASM International 10th Ed. 1990; Metals Handbook, Howard E. Boyer and Timothy L. Gall, Eds. American Society for Metals, Materials Park, OH, 1985; Structural Alloys Handbook, 1996 edition, John M. (Tim) Holt, Technical Ed; C. Y. Ho, Ed., CINDAS/PurdueUniversity, West Lafayette, IN, 1996; and Aluminum Standards. (http://www.matweb.com)

22. NEI 04-07, Volume 2, “Safety Evaluation by the Office of Nuclear Reactor Regulation Related to NRC Generic Letter 2004-02,” Rev. 0, December 6, 2004.
23. Palisades Design Input for RAI Responses, DRAFT.
24. Palisades Specification M-136.
25. ALION-REP-ALION-2806-01, “Insulation Size Distribution for use inGSI-191 Resolution”, Rev. 3.
26. Indian Point Audit Report.

NRC Request

15. *The licensee's June 30, 2009, supplemental response stated that large pieces of debris were assumed to be retained on the 608'6" elevation (EL) rather than transporting to the 590' EL. The licensee's response added that it was ultimately inconsequential whether the large pieces were retained on the 608'6" EL or washed down to the 590' EL, since direct transport to the strainer would not occur in either case, and an equivalent degree of erosion would occur regardless of the elevation on which the debris was assumed to settle. It was not clear to the NRC staff that it was inconsequential whether large pieces remained on the 608'6" EL or transported to and settled on the 590' EL. In particular, the NRC staff expected that the flow conditions (e.g., velocity and turbulence) on these two elevations could be significantly different, thereby leading to different percentages of eroded debris. In particular, the NRC staff expected that erosion would be more severe on the 608'6" EL because (1) shallow pools exist, (2) there is significant potential for break and/or spray drainage to create high-velocity and high-turbulence flow conditions, and (3) the potential exists for direct exposure to break and/or spray drainage flows. It is not clear to the NRC staff that flow conditions of this sort are bounded by industry erosion testing conducted with significant submergence, no direct exposure to drainage flow, and relatively low velocity and turbulence values, and how this potential discrepancy has been addressed in the licensee's strainer performance evaluation. Therefore, please identify the range of water velocity and turbulence levels expected on the 608'6" EL, the expected water depth, as well as the basis for concluding that an equivalent degree of erosion would occur for debris retained on the 608'6" EL as would occur on the 590' EL considering the industry erosion test conditions and results. As applicable, please also provide similar discussion for any other locations where significant debris holdup was credited for which erosion may occur under similar conditions to that applicable to the 608'6" EL (e.g., the stairwells leading from the 608'6" EL to the 590' EL).*

Entergy Nuclear Operations Response:

For Palisades containment the limiting break from a debris generation and also a debris transport perspective occurs in the A-loop. The A loop geometry is shown in Figure 3 with run-off paths identified by letter code. Overall, 83 ft of 6" high curbing surround the area marked in yellow. Only one trench-like opening exists in the curbing. This run-off path is marked K. Approximately half of the area is protected from direct spray from above by the steam generator and other concrete closures in the upper elevations of containment. Given the spray and break-flow inputs that exist during an A-loop break, the floor of the area marked in yellow will flood to over-flow the curbing. To support the run-off of water, the water level will rise to 7". Given the length of the curbing, an approach velocity to the curb of 0.09 ft /sec can be calculated. This velocity is insufficient to allow the larges to transport out of the curbed area since the lift-over-curb velocity for larges is 0.34 ft/sec [Ref. 15.2 and 15.3]. While the areas of direct break flow impact may be subjected to high velocities it is expected that a) the duration of exposure of a large amount of insulation to such high velocities is very short as the insulation is pushed away by sheeting water after the initial blast and blow-down b) the amount of insulation exposed to high velocities for an extended period of time is very small. Even though a large amount of debris will be pushed to areas where break flow no longer provides significant velocity and spray flow does not exist (half of the area is covered by concrete slab or protected by the upper geometry of the steam generator) large debris is eroded to fines at a value of 10%. Furthermore, note that the velocities approaching the curb will drop off dramatically to the point where larges will stop transporting and not block the curbing.

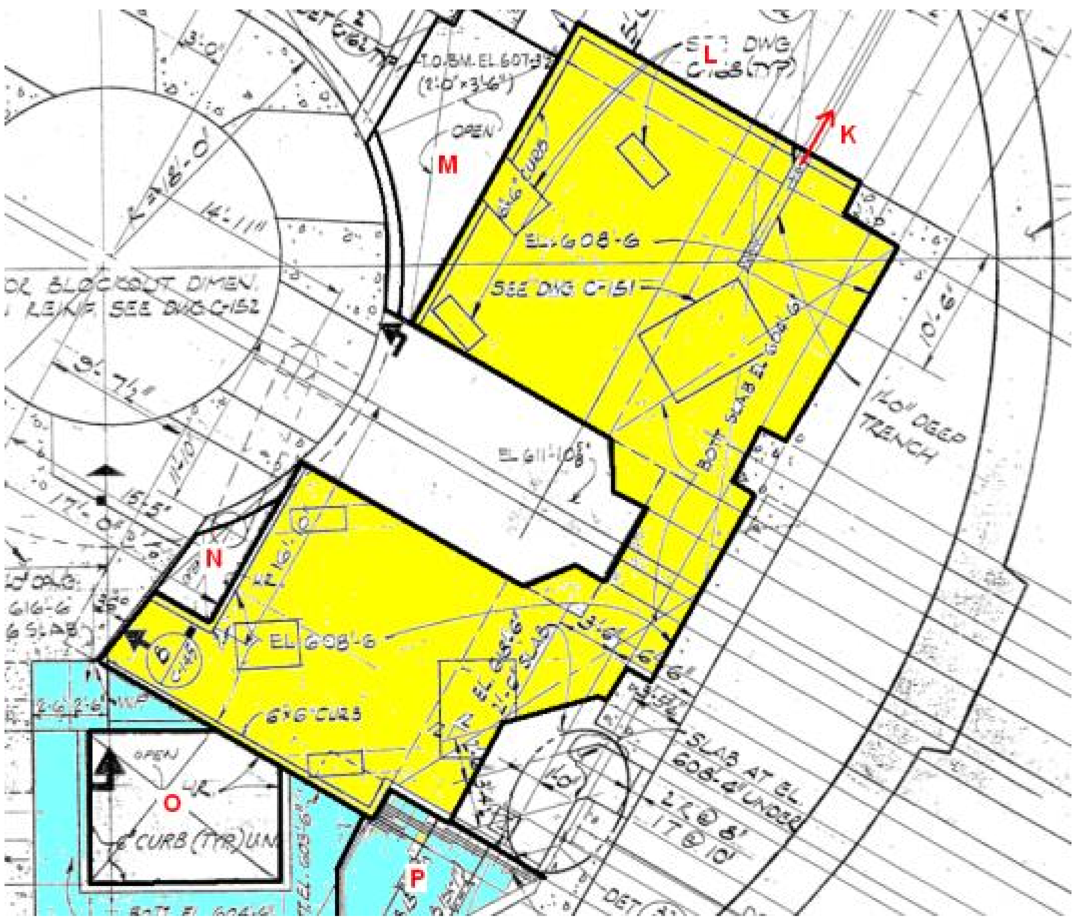


Figure 3. Immediate area of A-Loop SG compartment [Ref. 15.1]

Another significant conservatism is provided by the treatment of smalls in the approach to debris transport on the 608'6" EL. While the above calculations show that the approach velocity to the curbing is limited to 0.09 ft/sec and a 6" curb exists for all but 9" (trench marked K) of the perimeter of the area, all smalls are transported to the sump from the 608'6" EL. A significant portion of the smalls transported to the sump (37%) were calculated to be transportable to the strainer based on a very conservative 0.06 ft/sec incipient tumbling velocity [Ref. 15.1]. This fraction is consistent with ignored areas of possible smalls transport (see RAI 18). In addition, the fraction of smalls not considered transportable to the strainers was eroded at 10%. Therefore significant additional conservatism exists in the overall treatment of debris generated on the 608'6" EL which should be taken into account in evaluating the treatment of large fiber transport on 608'6" EL.

Debris transport treatment of larges for B-loop breaks was similar. The geometry for the B-loop is somewhat different from the A-loop due in part to the fact that the A-loop compartment includes the pressurizer. While less of the perimeter on the B-loop is bounded by curbing, significantly less debris is generated in the compartment. Significantly greater overall debris erosion of larges can be supported on B-Loop breaks before fines generation for these breaks begin to exceed A-Loop breaks fines generation. The erosion percentage necessary before B-loop breaks fines generation eclipses that of A-loop breaks is 33%. It is therefore clear that A-loop debris transport represents the limiting case for the Palisades nuclear plant.

References

15.1 AREVA Calculation 32-9099369-000 dated February 2009, Palisades Nuclear Power Station - Debris Transport

15.2 NEI Guideline, “Pressurized Water Sump Performance Evaluation Methodology,” December 2004.

15.3 SER-GSI-191 SE, Revision 0, "Safety Evaluation of NEI Guidance on PWR Sump Performances", Office of Nuclear Reactor Regulation, December 2004

NRC Request

16. *Although the licensee's June 30, 2009, supplemental response quoted a statement in NUREG/CR-2982 indicating that mineral wool can remain afloat for extended periods of time, it did not appear that the licensee had accounted for the potential for floatation adequately in the following two respects:*

a. No basis was presented to justify the assumption that no large pieces of mineral wool would be capable of transporting over the 6-inch curb, in part due to floatation by virtue of trapped air.

b. No basis was presented to justify that no large and small pieces of mineral wool would be capable of transporting to the strainers, in part due to floatation by virtue of trapped air. Although strainer testing was performed with mineral wool debris, based on the PCI test procedure, this material was thoroughly soaked with water, and thus the potential for transport by floatation was not examined.

Please provide additional information to justify the assumption regarding flotation of mineral wool, considering the above.

Entergy Nuclear Operations Response:

The previous submittal to the NRC detailed the equipment contributing mineral wool debris ([Ref. 16.2], Table 3a1, p.17) in the considered LOCA debris generation scenarios. Mineral wool debris is obtained from the pressurizer shell. The pressurizer is located in a corner of the A-loop steam generator compartment. The postulated breaks in the A-loop compartment would tend to keep debris in the immediate equipment corner where the pressurizer is located. Note that the pressurizer is located greater than 7D away from the limiting debris break ([Ref. 16.2], Table 5.2-6, p.35). Furthermore, the pressurizer floor elevation is below the main steam generator compartment and grating [Ref. 16.1] covers the pressurizer floor area. The remainder of the steam generator compartment does not exhibit grating except for in very small areas. The pressurizer area is not open to any spray flow from above. Figure 16.46.1 is provided to illustrate the layout of the area of the steam generator compartment under consideration here. Based on this information the following is expected with respect to the behavior of mineral wool debris:

- The mineral wool debris originating from the pressurizer will largely remain near the pressurizer.
- Transport of debris off the grating is not expected since water flow in the area is small and no standing water exists to support floatation.
- Debris deposited onto the grating on the pressurizer grating will not be subject to increased erosion since spill flow in this area is very low (0.35 ft^3/sec)0 and the area does not see any spray flow.

- While it is possible that some very small fraction of mineral wool smalls from the pressurizer could end up on the main steam generator floor, this debris will mix with Nukon fiber debris.
- Small mineral wool debris that remains afloat in the main steam generator compartment could flow over the existing curb and down into the containment pool. The test basis was developed by neglecting this possible transport (floating), instead eroding all mineral wool debris, including the vast majority which is not subject to spray flow or other transport mechanisms.

Based on the above discussion debris transport of mineral wool larges by floatation is not credible and only possible for small fractions of mineral wool smalls. Although the bulk of the mineral wool debris will be located on largely dry grating, all mineral wool debris smalls and larges were eroded at 10% to fines leading to a very conservative testing basis for mineral wool debris.

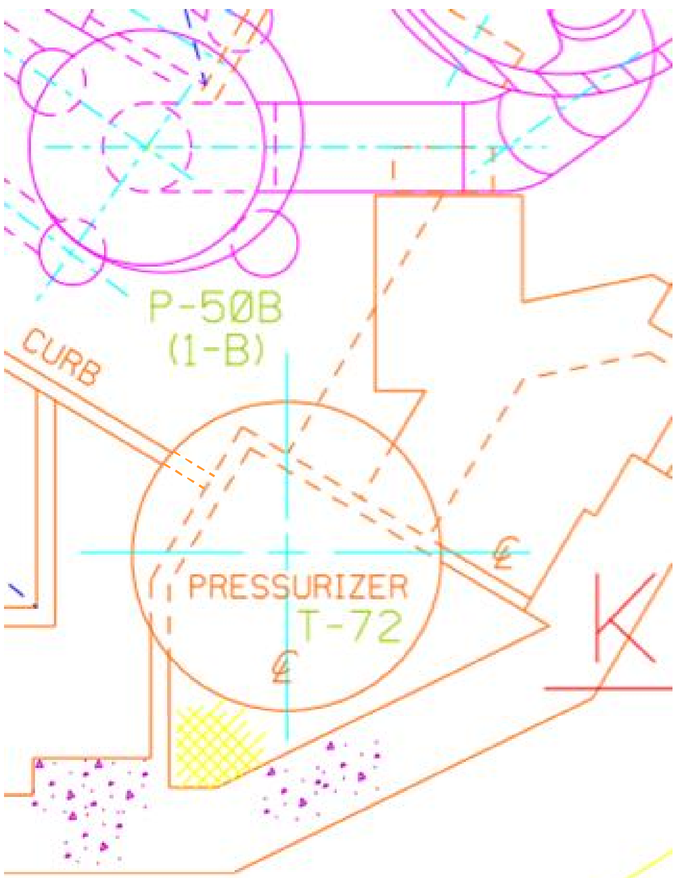


Figure 16.4. View of SG-A compartment near pressurizer

References

16.1 32-9099369-000 AREVA Calculation dated February 2009, Palisades Nuclear Power Station - Debris Transport

16.2 Palisades June 30, 2009 Submittal to NRC, Follow-up Supplemental Response to NRC Generic Letter 2004-02

16.3 NEI Guideline, “Pressurized Water Sump Performance Evaluation Methodology,” December 2004.

16.4 SER-GSI-191 SE, Revision 0, "Safety Evaluation of NEI Guidance on PWR Sump Performances", Office of Nuclear Reactor Regulation, December 2004.

NRC Request

17. *The June 30, 2009, supplemental response provided cumulative erosion percentages for frangible debris in Table 3e4. Several values in this table in the copy of the document available to the NRC staff in ADAMS Accession No. ML091820275 were illegible. Please provide another copy of Table 3e4 that can be clearly read. Please also provide a description of any testing performed to support the assumed erosion percentages for debris pieces in the containment pool or other areas of containment where erosion was assumed to occur (e.g., 608'6" EL, stairwells, etc.). Please specifically include the following information:*

Entergy Nuclear Operations Response:

Below Table 17.1 provides the information that was in Table 3e4 of the 6/30/09 supplemental response. Balance of RAI 17 response is provided below after each specific NRC request.

Table 17.1 Tumbling velocities and erodible fractions

Debris Type	Erosion Factor	Incipient Tumbling Velocity (ft/s)
Nukon/Thermal Wrap Jacketed	10%	0.06
Calcium Silicate Metal Jacketed	17%	0.25
Transco RMI	N/A	0.20
Low Density Fiberglass Jacketed	10%	0.06
Calcium Silicate Cloth Covered	17%	0.25
Low Density Fiberglass Unjacketed	10%	0.06
Nukon Unjacketed	10%	0.06
Mineral Wool Jacketed	10%	0.30
Qualified Coatings	N/A	100% transport assumed
Unqualified Coatings	N/A	100% transport assumed
Latent Debris	N/A	100% transport assumed

NRC Request

a. *Please describe the test facility used for any erosion testing and 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 locations where erosion could occur.*

Entergy Nuclear Operations Response to 17a:

The original erosion tests were performed at the ALION Science & Technology's Hydraulics Laboratory in Warrenville, IL. Transport tests were performed to determine tumbling velocities and were performed in the Transport Flume. Erosion tests were performed in the Transport Flume as well as in the enclosed Vertical Test Loop [Refs.12, 13].

New erosion tests were recently performed at ALION Science & Technology's Hydraulics Laboratory in Warrenville, IL to conservatively determine erosion factors for Low Density Fiberglass insulation materials (LDFG) and to address the NRC's concerns with the original testing. The results of the new tests designed to address the concerns with the original testing have given results that support the 10% erosion factor developed in the original tests [Ref. 19].

Table 17.2 – Incipient Tumbling Velocities and Test Velocities

Debris Type	Erosion Factor	Incipient Tumbling Velocity (ft/s)	Erosion Testing Velocity (ft/s)
Nukon/Thermal Wrap Jacketed	10%	0.06	0.12
Calcium Silicate Metal Jacketed	17%	0.25	0.40
Transco RMI	N/A	0.20	N/A
Low Density Fiberglass Jacketed	10%	0.06	0.12
Calcium Silicate Cloth Covered	17%	0.25	0.40
Low Density Fiberglass Unjacketed	10%	0.06	0.12
Nukon Unjacketed	10%	0.06	0.12
Mineral Wool Jacketed	10%	0.30	0.12
Qualified Coatings	N/A	100% transport assumed	N/A
Unqualified Coatings	N/A	100% transport assumed	N/A
Latent Debris	N/A	100% transport assumed	N/A

Table References 8, 10, 11, 19.

LDFG – Flow Velocity and Kinetic Energy: After the bulk transport of the debris, a total of 64.2% of the small fiberglass debris generated would be on the containment pool floor where it could be exposed to erosion. The average flow velocity and turbulent kinetic energy (TKE) was calculated in six different zones within the containment [Ref. 14]

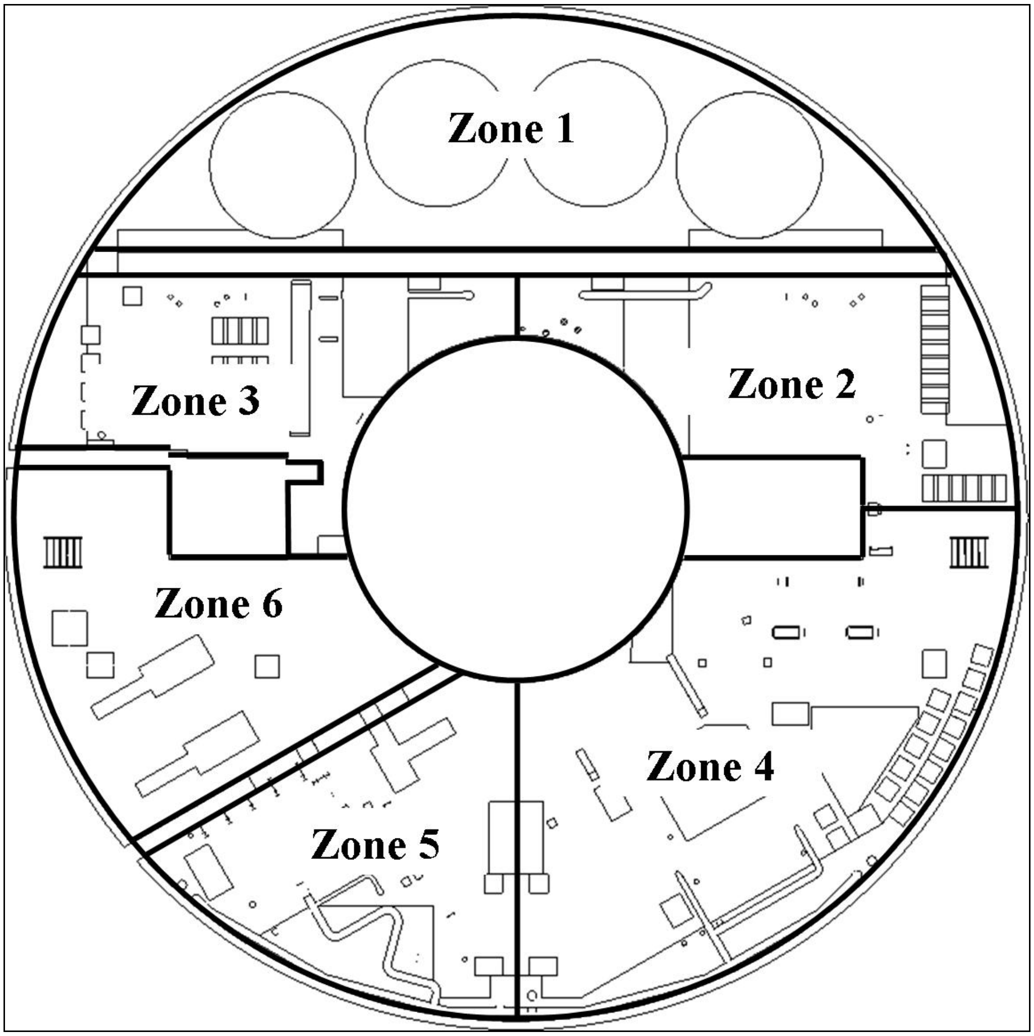


Figure17.1 – Containment Erosion Zones

Table 17.3 – Summary of Settled Fibrous Insulation Debris

Location	Percent of small pieces settled	Average Velocity (ft/s)	Average TKE (ft^2/s^2)
Zone 1	20.4%	0.0080	0.00010
Zone 2	8.9%	0.0081	0.000078
Zone 3	0.4%	0.020	0.00039
Zone 4	25.2%	0.013	0.000044
Zone 5	2.6%	0.0071	0.000028
Zone 6	6.7%	0.0059	0.000030
Total/Weighted Average	**64.2%**	**0.0098**	**0.000067**

As presented in Table 17.3, the average velocity, weighted by quantity of settled fiber experiencing the flow in each location, is 0.0098 ft/s, with an average TKE, weighted similarly, of 0.000067 (ft^2/s^2) [Ref. 14].

The new erosion tests were conducted utilizing a flow velocity of 0.12 ft/s, bounding not only the weighted average velocity, but the maximum average flow velocity in any zone (zone 3) by a factor of 6.

While it is not possible to determine the exact quantity of turbulent kinetic energy in the testing flume apparatus, it is possible to determine the total kinetic energy of 0.0072 ft^2/s^2 which compares favorably to the total kinetic energy of the highest average velocity zone (zone 3), which has a turbulent kinetic energy of 0.00039 ft^2/s^2. Thus the water in the test flume is significantly more energetic and bounds the energy present within containment.

LDFG – Target Size: The erosion fraction of 10% determined in the original tests and confirmed in the new tests is applied to both small and large fiber pieces in the pool. The erosion fraction determined is assumed to be applicable to all affected sizes of LDFG due to the results of the original testing which determined that proportional erosion of small pieces conservatively bounds the proportional erosion of larger pieces.

During the original testing, small pieces (1"x1"x1") were tested under an approach velocity of 0.12 ft/s, while large pieces (6"x3"x1") were tested under a higher approach velocity of 0.37 ft/s [Ref. 13]. Even with the higher approach velocity the erosion experienced by the large pieces was significantly less (1% to 6%) than the erosion experienced by the small pieces (2% to 18%) [Refs.13, 19]. The results clearly showed how the proportional erosion of small pieces bounds the proportional erosion of larger pieces.

LDFG – Chemical Conditions: NUKON and Mineral Wool "erosion" are essentially the departure of individual fibers from a piece of NUKON/Mineral Wool, not the wearing down of the fibers themselves, i.e., "erosion" is not a result of fibers being "worn/eroded" down to a finer diameter by removal of small amounts of the basic material. While insulation made of NUKON or Mineral Wool material is a compressible, porous material without a solid binder holding it together, prior to the start to each erosion test, ALION boiled the NUKON samples in tap water for over 10 minutes and used pre-baked Mineral Wool in order to remove any oils that could be considered to act as a binder [Ref. 10].

ALION is not aware of any experimental evidence that suggests that the departure of individual fibers from a piece of NUKON or Mineral Wool would be different for either chemically non-neutral and/or elevated temperature solution versus flow of equal velocity of tap water. In the absence of any experimental evidence to the contrary, and the absence of a "binder" that could react to chemistry or temperature, there is no reason to believe that the "erosion" results (departure of individual fibers) for an elevated-temperature, chemically non-neutral solution would be significantly different from that obtained with room-temperature tap water.

Both the Cal-Sil erosion tests (completed) and the LDFG erosion tests (ongoing) are conducted at room temperature, and this temperature is recorded with each data point. The increased post-LOCA water temperature at Palisades would have little effect on the flow erosion of fiberglass and Cal-Sil with respect to water density and viscosity differences. The lack of containment recirculation chemicals and neutral pH of the tap water would also have little effect on the flow erosion mechanism. Testing was mainly measuring the mechanical affect of circulating tap water around stationary insulation samples to observe the amount of fiberglass that is released into the flowing water [Refs. 8, 10].

Cal-Sil: The Cal-Sil erosion tests were performed under a flow velocity of 0.40 ft/s, which significantly bounds both the tumbling velocity of the Cal-Sil pieces involved (0.25 ft/s) as well as the flow velocity conditions predicted to be experienced in the containment (see Table 17.1). Like the on-going LDFG erosion testing, this significant margin in flow velocity also causes the Cal-Sil erosion tests to be bounding from a kinetic energy standpoint, with a total kinetic energy of 0.08 ft2/s2 in the tests compared to a maximum turbulent kinetic energy of 0.00039 ft/s predicted to be experienced in the containment.

Additional dissolution tests were conducted for the Cal-Sil debris at 190±5° F with 3000 ppm boron (as the limiting boron concentration) under different chemistries. The pH range of dissolution testing was 4.8 to 8.75 which bounds the final minimum and maximum pH at Palisades plant, 7.0 to 8.0. These dissolution tests found that large scale dissolution of Cal-Sil did not occur due to chemical differences in the water and are the basis for the application of the neutral pH tap water erosion tests to the Palisades plant [Ref. 8].

Mineral Wool: The mechanism for mineral wool and fiberglass was examined in a series of tests conducted by ALION Science & Technology [Ref. 10]. The same erosion mechanism (attrition) that affected the NUKON LDFG testing [Ref. 10] was observed during the erosion of mineral wool. The mineral wool samples would release smaller fibers or loosely bound pieces of fiber; the sample did not actually erode into fines. This mechanism gives reason to an upper bound of erosion once the lose fibers detach from the sample. After such a washing, the mineral wool sample would rest in the flowing water and cease to “erode” further.

Table 17.4 - NUKON and Mineral Wool Characteristics [Ref. 10]

	Density (lbs/ft)	Fiber Diameter (microns)	Constitution (% substance)
NUKON	2.4	7	Fiber glass wool: 85-96 Phenolic Formaldehyde Binder: 4-15
Mineral Wool	8	5-7	Mineral Fiber: 94-99 Phenolic Formaldehyde Binder: 1-6

Mineral wool has less binder and a higher density than NUKON. Mineral wool also has a component called "shot" which is a particulate type matter that is fabricated into the mineral wool fibers. This shot increases the density of the mineral wool, but the shot did not appear to erode during the flow erosion testing beyond the initial washing of the outer most layers. If a great deal of the shot did indeed wash out during erosion, then a more substantial weight loss would be observed for the mineral wool. The fact that the mineral wool behaves similarly to the shot-free NUKON conveys the impression that the mineral wool shot is not significantly affected by the flow erosion. Although NUKON LDFG and mineral wool insulation are not the exact same material, the erosion properties of both insulations compare readily. It was observed during testing that both materials erode through the release of constituent fibers and not through the wearing away of fibers or binder. Both material samples rested in the testing environment similarly: neither material dissolved or disintegrated when placed into the flowing water, and both materials retained their shapes when taken out of the water after testing. The test results for each duration of mineral wool test were also similar, specifically the pattern of decreasing erosion per hour over time. Table 17.5 [Refs.12, 13] presents the results of the original mineral wool and NUKON erosion tests performed by ALION in 2007. The weight loss percentage presented for NUKON after 2 hours is the average over the two data points available, the percentage presented after 16 hours represents the sole data point determined in testing [Ref. 13]. Both mineral wool percentages represent the sole data points determined at the respective time during testing [Ref. 12].

Table 17.5 – Fibrous Debris Material Erosion Results

	Percentage Weight Lost after 2 hours	**Percentage Weight Lost after 16 hours**
NUKON	4.56%	7.54%
Mineral Wool	2.44%	6.55%

Due to the similarities between LDFG and Mineral Wool in regards to the method of erosion, the results of the LDFG erosion testing will be applied to Mineral Wool as well.

NRC Request

b. *Please identify the duration of the erosion tests and how the results were extrapolated to the sump mission time.*

Entergy Nuclear Operations Response to 17b:

Cal-Sil: Tests were conducted with a range of durations from 1 hour to 101 hours. The data was then conservatively extrapolated to the 720 hour sump mission time by the application of a linear fit curve to the entire set of data points (inclusive of all tests, regardless of duration). This extrapolation is conservative due to the assumption of a constant rate of erosion, where it is more realistic to assume a reduction in the rate of erosion over time.

LDFG: The new testing completed to address the concerns of the NRC dealt with extrapolation by performing a 30 day test, matching the 720 hour sump mission time and removing the necessity of any form of extrapolation.

NRC Request

c. Please provide a basis for adding debris attributed to erosion processes after the addition of small debris pieces. The addition of fines after small pieces is not consistent with previous debris sequencing discussions for the Performance Contracting, Inc. (PCI) test protocol or the NRC staff's March 2008 head loss review guidance. In addition, some industry test results have suggested that erosion occurs to a significant extent relatively soon after debris pieces are exposed to flow.

Although the June 30, 2009, supplemental response provided discussion intending to demonstrate that sufficient margins existed in the licensee's strainer performance analysis to bound the quantity of fibrous fines that would be associated with explicitly analyzing the erosion of small pieces of fibrous debris settling in the test flume, the NRC staff did not consider the margins discussed to be sufficient based on the following reasons:

Although the analytical transport calculation did not credit the settlement and holdup of fine debris, the NRC staff considers that the head loss testing permitted substantial credit for fine settlement.

Based on the flume velocities used for the licensee's head loss testing, the NRC staff expected that a significant majority of the small pieces of fiber added to the test would not have reached the strainers.

Based on the test scaling leading to denser debris piles in the test flume than expected for prototypical plant conditions and the fact that the small pieces of debris added to the test had been mechanically shaken to release loosely attached fibers, the NRC staff expected that the actual erosion in the test flume would be very small and would not be representative of erosion under plant conditions.

It was not clear to the NRC staff that significant credit could be taken for the capture of fines in inactive volumes based on the accepted guidance positions that a significant fraction of the fines would tend to be distributed to upper containment during blowdown, and that inactive volumes would be filled early in the event, prior to the completion of the bulk of debris washdown.

It was not clear to the NRC staff that significant retention credit could be taken for small pieces in upper containment, since small pieces of debris are considered to be of a size small enough to pass through gratings. Based on NRC-sponsored washdown tests, it was recommended that retention credit on gratings not be taken on debris smaller than the size of the grating opening. It is not clear to the NRC staff that sufficient retention credit is appropriate for other locations in upper containment.

Entergy Nuclear Operations Response for 17c:

With respect to the main 17c RAI, ENO believes that the sequencing of eroded fines after the introduction of smalls was appropriate and prototypical, reference further discussion provided in the response to RAI 26a. Timing for most erosion to reach the strainers would exceed the time for smalls to transport based on erosion trend data seen in Reference 19 versus tumbling velocities of the smalls. However, based on discussions to date with the NRC, certain elements of the existing testing protocol will not be accepted by the NRC without refinements. For any future testing using a refined PCI flume test protocol, ENO would plan to add the eroded fiber fines with the initial fiber fines to eliminate this potential NRC concern.

The several paragraphs in RAI 17 that follow 17c seem to deal with a separate issue, namely fiber smalls added to the flume that did not transport should have been accounted for in the amount of eroded fines added. This issue is a generic PCI test protocol open item that may be discussed at a June 2, 2010 meeting between the PCI strainer testing team and the NRC. Palisades will follow the outcome from the June 2, 2010 meeting in this area if covered. If the June 2, 2010 meeting does not specifically cover this topic, then for any future testing using a refined PCI flume test protocol, Palisades will add the appropriate amount of eroded fines to cover the amount of smalls entered into the flume, conservatively assuming none will transport.

References

1. EA-MOD-2003-0021-01.
2. BNZ Transite Specification Sheet.
3. BNZ Marinite I Specification Sheet.
4. ALION-REP-LAB-2352-218, “Marinite 1 Flow Erosion Testing Report”, Rev. 0.
5. Ontario Power Generation, “Jet Impact Tests—Preliminary Results and Their Applications,” N-REP-34320-10000-R00. April 2001.
6. Gordon H. Hart, P.E*, “*Summary of Calcium Silicate Insulation Types Used inside Containment at US Nuclear Plant”.
7. CS85-P-HT1.
8. Avallone, Eugene A. et. al.,“Marks’ Standard Handbook for Mechanical Engineers”, Ninth Edition.
9. ALION-REP-PAL-7199-22, “Palisades Cal-Sil Flow Erosion and Dissolution Testing Report”, Rev. 0.
10. ALION-REP-ENT-7199-21, “Palisades Fiberglass Debris Flow Erosion Testing Report”, Rev. 0.
11. ALION-PLN-I006-02, “Erosion Testing of Small Low Density Fiberglass Debris: Test Plan”, Rev. 1.
12. ALION-REP-LAB-2352-99, “Test Report: Erosion Testing of Mineral Wool Insulation”, Rev. 0.
13. ALION-REP-LAB-2352-77, “Test Report: Erosion Testing of Low Density Fiberglass Insulation”, Rev. 0.
14. ALION-REP-ENT-7199-21, “Palisades Erosion Assessment – Average Velocity and Turbulence for Non-Transporting Debris”, Rev. 0. **NOT CURRENTLY ISSUED.**
15. NUREG/CR-6808, “Knowledge Base for the Effect of Debris on Pressurized Water Reactor Emergency Core Cooling Sump Performance”.
16. NUREG/CR-6772, LA-UR-01-6882, “GSI-191: Separate Effects Characterization of Debris Transport in Water”.
17. BNZ Marinite M Specification Sheet.
18. NUREG/CR-6224, “Parametric Study of the Potential for BWR ECCS Strainer Blockage Due to LOCA Generated Debris”.
19. ALION-REP-ALION-I006-04, “Erosion Testing of Small Pieces of Low Density Fiberglass Debris - Test Report”, Rev. 0. **NOT CURRENTLY ISSUED.**

NRC Request

18. *The June 30, 2009, supplemental response states that flow pathlines and velocity isocontours were used to identify isolated eddies that had velocities higher than the incipient tumbling velocity but did not contribute to debris transport from the zone. A plot that appears to show minimal trapping in eddies enclosed by or connected to transporting isocontours for a sample case was included in the supplemental response, but it was not clear whether this behavior is also characteristic of the limiting design case. Therefore, for the limiting design basis conditions, please either demonstrate that minimal credit for hold-up in such eddies was taken, or else identify the types and quantities of debris assumed to be trapped in eddies of this sort, and provide the basis for not considering debris assumed to be present in these areas at the switchover to recirculation as transporting to the strainers considering the following points:*

    a. *Even in steady-state flow problems, chaotic perturbations result in variance in the solution that will alter the flow pattern in isolated eddies and allow fluid and debris elements in these eddies to escape as time progresses (or the number of computational iterations increases).*

    b. *Sophisticated turbulence models are expected to be necessary to accurately predict the behavior of eddies if they are credited with the retention of debris. Please discuss the fidelity of the turbulence model used in the computational fluid dynamics code and discuss whether the converged solution was run further and checked at various intervals after convergence was reached to demonstrate evidence of the stability of any eddies credit debris hold up.*

    c. *Suspended phases and floor-transporting debris do not precisely follow streamlines of fluid flow. Phase slip can be particularly significant when the streamlines exhibit significant curvature, such as in an eddy.*

    d. *There are significant uncertainties associated with modeling blowdown, washdown, and pool fill transport mechanisms. The initial debris distribution at switchover can vary significantly.*

Entergy Nuclear Operations Response:

The debris transport quantity is determined by examining the iso-contour area of the tumbling velocity of the debris under consideration. Some iso-contour areas were neglected in determining the transportable debris quantity. However this procedure was only applied to smalls debris. These iso-contour islands were neglected because the iso-contour was not contiguous with the strainer. In general a significant distance exists between the accounted for iso-contour and the neglected iso-contour islands. The minimum distance between any neglected iso-contour island and the closest accounted for iso-contour area in Zone 1 (CWST) is greater than 5 ft. There is a very small neglected iso-contour island in Zone 4 where the distance to the next connected contour is only 2 ft but the neglected area is only 2% of total iso-contour area in that zone and an even smaller fraction of the overall iso-contour area.

If the analysis would have accounted for all the neglected iso-contour islands, an increase of 15% in the amount of small fiber would result. Coupled with this, a decrease of 1.5% in the fiber fines is also caused since the increased transport of smalls leaves less fiber behind that must be eroded. The neglect of 15% of the fiber smalls put an additional 1.5% of fiber fines into the test debris load. There is therefore a balance between conservatism in the amount of fines and conservatism in the amount of smalls when considering the neglected smalls transport. In addition, the isolated contours neglected are indeed unlikely to transport across the low velocity area that disconnects them from a transportable iso-contour.

Furthermore, isolated iso-contour islands for the Palisades conditions do not consist of turbulent eddies exhibiting enclosed recirculation. The isolated islands ignored are due to one of two conditions. The first condition (type 1) is due to an isolated drainage source that locally generates velocities in excess of the tumbling velocity but diffuses before getting close to a transporting iso-contour area. The second condition occurs where a portion of the flow passes through a restriction which speeds up the flow locally but does not result in connection to a transporting iso-contour. Figure 5 shows the neglected iso-contour portions colored in red. Adjacent to the iso-contour plot within Figure 5 is a pathline plot which illustrates the general flow field within the containment sump. Single arrows in the iso-contour portion of the figure identify type 1 isolated contour areas (due to flow sources). Double arrows linking the two portions of the figure identify type 2 isolated contour areas. The pathline plot underlines that none of the isolated contour areas correspond to recirculating eddies whose stability was questioned in the request for addition information.

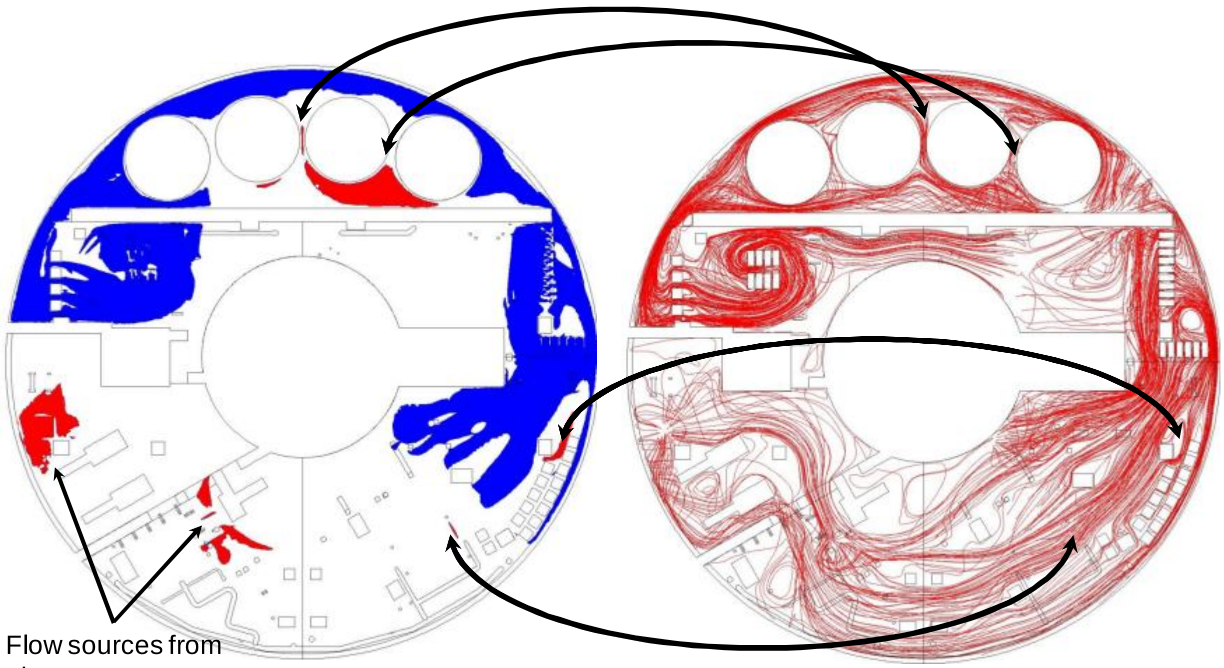


Figure 5. Origin of isolated iso-contour islands [Ref. 18.1]

References

18.1 AREVA Calculation 32-9099369-000 dated February 2009, Palisades Nuclear Power Station - Debris Transport

NRC Request

19. Please provide cumulative transport percentages for each type of debris that are integrated over all regions of the containment pool for the limiting design basis case. Please specify for which break the results are applicable.

Entergy Nuclear Operations Response:

Below is a copy of Table D-1 from the Palisades Transport analysis, [Ref. 19.1] done for the November 2008 Flume test that gives percent of debris transported. It should be used with Table 3e7 on page 81 of the June 30, 2009 submittal for limiting break S5. It can be used with Table 3e8 for break S6 which was used for enveloping the CalSil insulation.

		Contour Areas						Transport Fractions					
Break	Velocity (ft/s)	Zone 1 (ft^2)	Zone 2 (ft^2)	Zone 3 (ft^2)	Zone 4 (ft^2)	Zone 5 (ft^2)	Zone 6 (ft^2)	Zone 1 (%)	Zone 2 (%)	Zone 3 (%)	Zone 4 (%)	Zone 5 (%)	Zone 6 (%)
A (S5)	0.06	479.78	290.62	491.01	493.49	0.00	0.00	51.90%	33.21%	59.04%	25.67%	0.00%	0.00%
	0.20	0.00	2.38	2.02	0.00	0.00	0.00	0.00%	0.27%	0.24%	0.00%	0.00%	0.00%
	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
B (S6)	0.06	0.00	545.34	215.16	1344.19	521.28	615.71	0.00%	62.32%	25.87%	69.93%	57.59%	62.74%
	0.20	0.00	91.46	0.00	21.03	0.00	0.00	0.00%	10.45%	0.00%	1.09%	0.00%	0.00%
	0.25	0.00	33.76	0.00	0.00	0.00	0.00	0.00%	3.86%	0.00%	0.00%	0.00%	0.00%
	0.30	0.00	0.13	0.00	0.00	0.00	0.00	0.00%	0.01%	0.00%	0.00%	0.00%	0.00%
B	0.06	49.73	253.09	584.81	530.35	307.99	613.74	5.38%	28.92%	70.32%	27.59%	34.03%	62.54%
(S6)	0.20	0.00	8.70	3.31	0.00	0.00	0.00	0.00%	0.99%	0.40%	0.00%	0.00%	0.00%
Door	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
OPEN	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

Table D-1: Contour Areas of Incipient Tumbling Velocity and Transport Fractions, Base Case Simulations

<u>References</u>

19.1 AREVA Calculation 32-9099369-000 dated February 2009, Palisades Nuclear Power Station - Debris Transport

NRC Request

20. *The June 30, 2009, and February 27, 2008, supplemental responses indicate that a blowout panel has been installed to impede air flow into the air room while simultaneously preventing water hold up. The NRC staff noted that the transport analyses for Palisades appeared to have been performed with the air room door closed (NRC staff could not determine whether this referred to the blowout panel or another door). Please clarify whether this assumption refers to the blowout panel or another door, and additionally confirm that the assumption of the air room door being closed either results in conservative debris transport results or is a valid assumption.*

Entergy Nuclear Operations Response:

The Air room doors and the Air Room Blowout Panels are separate and differently designed items. The assumption applies to a door, the blowout panel is always assumed to be open. The below provides the details reasons why.

The air room extends from 590' Elevation upwards to approximately 625' Elevation and encompasses the containment personnel lock and the portion of the North Stairwell from the lock to the 590' Elevation floor which encompasses a part of the ECCS sump. Its function was initially to allow more rapid purging of that space with outside air and shorten the time for personnel to gain access to containment. Much of the Primary Coolant System instrumentation is mounted on the walls of this space and quick access was judged to be desirable. After TMI the ability to purge containment was severely restricted and this function was no longer very useful. However, the air flow restriction was utilized in the plant fire analysis to help restrict the progress of a fire so the air room is being maintained for that purpose.

On 590' Elevation there are 2 doors which swing inward so that water pressure of accumulating Post LOCA water will tend to force them into their jams (load not on the latches) and hence would require that the doors buckle in order to open. The doors are standard 3 by 7 foot industrial strength steel doors set in steel frames which are anchored to reinforced concrete. One of the doors faces West and this path is a long way from the strainers. The other faces East and separates the water sources falling inside the air room from the AB bank of strainers therefore having a potential impact on the path of the water flow on 590' Elevation. and on the path of the debris which is assumed to be falling with the water. Each of these doors is equipped with an anti-shine L shaped radiation barrier on the outside of the air room. This tends to affect the flow streams and tends to reduce the effect of opening the door in the analysis.

Directly to the north of the West Door are 2 Blowout Panels. [Ref. 20.1] These panels are each 6 by 10 feet thus being about 3 times the size of a door (60 sq ft vice 21 sq ft) and are set in the 2 foot thick concrete north shield wall and begin 6 inches off the 590' Elevation floor. The blowout panels are only 2 feet apart and the first one is only 1.5 feet north of the West Door [Ref. 20.2]. The blowout panels are half inch thick Marinite and the panels are cut and suspended to facilitate easy blow out due to air pressure or breakage due to water pressure low on the panel [Ref. 20.3]. The blowout panels have no radiation shine baffles. The blowout panels are assumed to be open in the analysis since they are engineered to be in that condition following a large LOCA due to break pressure effects and due to water differential pressure for a small LOCA.

Palisades has run numerous CFD cases while preparing for a "Test for Success" strategy during the November 2008 flume testing campaign. In general the air room doors were assumed closed since that was known by past CFD analysis to usually be the worst case. It has been shown that the position of the West Door has almost no effect due to the 2 blowout panels being open and having open space 4 times the door.

The position of the East Door has relatively little effect on breaks on the "A" Steam Generator side (Pressurizer side) because the break flow and hence most of the debris falls a long ways away. For "B" Steam Generator Side breaks it has a major effect and for this reason was explicitly run in the transport analysis for each situation, [Ref. 20.4]. Thus there was a three break set of "limiting breaks" always run. They were Hot leg A side, Hot leg B side, and Hot leg B with East door open. Thus actual amounts of debris on the screen were calculated for all three cases and the output was used to judge the worst case for flume testing.

For the November 2008 Tests the S5 Hot Leg A (East air room door closed) break was chosen as the worst break, however, the S6 Hot Leg B (East air room door closed) had more CalSil so the CalSil from that break was used to "envelope" the situation and avoid having to make a judgment on the trade off quantity of fine fiber for fine particulate.

References

20.1 Palisades Plant Drawing C-73

20.2 Palisades Plant Drawing C-144

20.3 Palisades Modification EAR-2003-0176, MOD-2003-0021

20.4 AREVA Calculation 32-9099369-000 dated February 2009, Palisades Nuclear Power Station - Debris Transport

NRC Request

21. *The NRC staff understood that the head loss testing conducted by PCI modeled flow conditions during the recirculation phase of a LOCA and modeled all debris (other than a fraction of the latent debris added with the recirculation pump stopped) as entering the containment pool one flume-length (nominally 30 feet) away from the containment sump strainers. Flow conditions during the pool-fill phase of the LOCA were not modeled in the testing, nor was the potential for debris to enter the containment pool closer than one flume-length from the strainer due to the effects of blowdown, washdown, and pool fill transport. The lack of modeling of these two transport aspects of the head loss testing appeared to result in a non-prototypical reduction in the quantity of debris reaching the test strainer and, ultimately, non-conservative measured head loss values. This is a significant issue because of the large settlement credit allowed during the head loss test. Please provide the technical basis for not explicitly modeling transport modes other than recirculation transport, considering the following points:*

a. *As shown in Appendix III of he NRC staff's SE on NEI 04-07, containment pool velocity and turbulence values during fill up may exceed those during recirculation, due to the shallowness of the pool. Some debris that would not transport during recirculation may transport during the pool-fill phase. In addition, latent debris on the containment pool floor could be stirred into suspension by these high-velocity, turbulent flows, unlike the latent debris added to the quiescent PCI flume.*
b. *The pool fill phase will tend to move debris away from the locations where it washes down to the 590' EL, and a fraction of this debris would be moved nearer to the recirculation sump strainers.*
c. *Representatively modeling the washdown of some fraction of the debris nearer the strainer than one flume-length away would be expected to increase the quantity of debris transported to the strainer and the measured head loss, since a shorter flume would offer less opportunity for debris to settle. This statement applies both to debris that tends to settle in the head loss test flume, as well as debris considered to settle analytically.*

Entergy Nuclear Operations Response:

Figure 21.1 shows the modeled inlets for the Palisades containment sump [Ref. 21.1]. Figure 21.1 shows that in the compartmentalized containment of Palisades spray and break-flow run-offs combine and split into many different locations. Debris allocation to the sump is by proximity zone where the amount of debris put into each proximity zone is proportional to the flow into it. The procedure employed in the debris transport calculation follows recommended guidelines in NEI-04/07 [Ref. 21.3, 21.4]. There is also is a dependence on where the flow originates and how much debris is at that location from debris generation. The proximity zones are shown in Figure 21.2. Although pool fill-up is not explicitly accounted for by analysis, debris is distributed evenly in the proximity zones even though the debris enters the zones from particular areas. As an example, the area marked K&L on Figure 21.1 receives 30% of the overall recirculation flow. Conversely inlet Q receives only 1% of the flow. The pool fill phase is accounted for by distributing the debris evenly in proximity zone 1 which largely moves the debris closer to A & B strainer trains. As discussed further below, the opening between the containment wall and the CWST room wall near C & D strainer trains only carries 19% of the total CWST outflow and therefore does not represent a major path for debris to the C & D strainer trains. The distribution of debris evenly in proximity zone 1 therefore conservatively accounts for pool-fill transport of the debris.

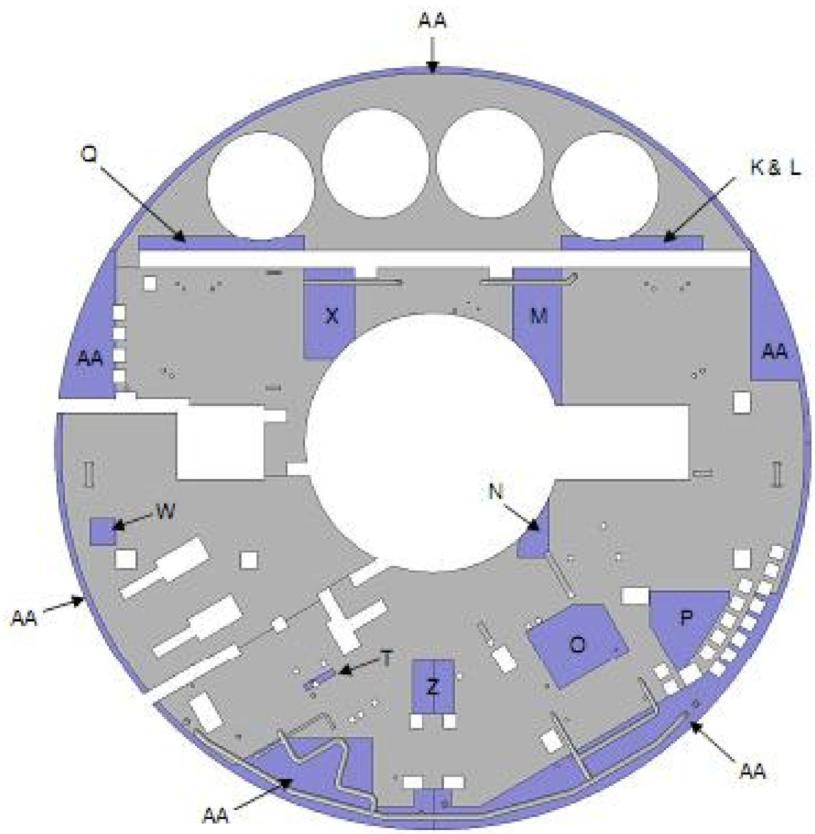


Figure 21.1 CFD domain flow inlets [Ref. 21.1]

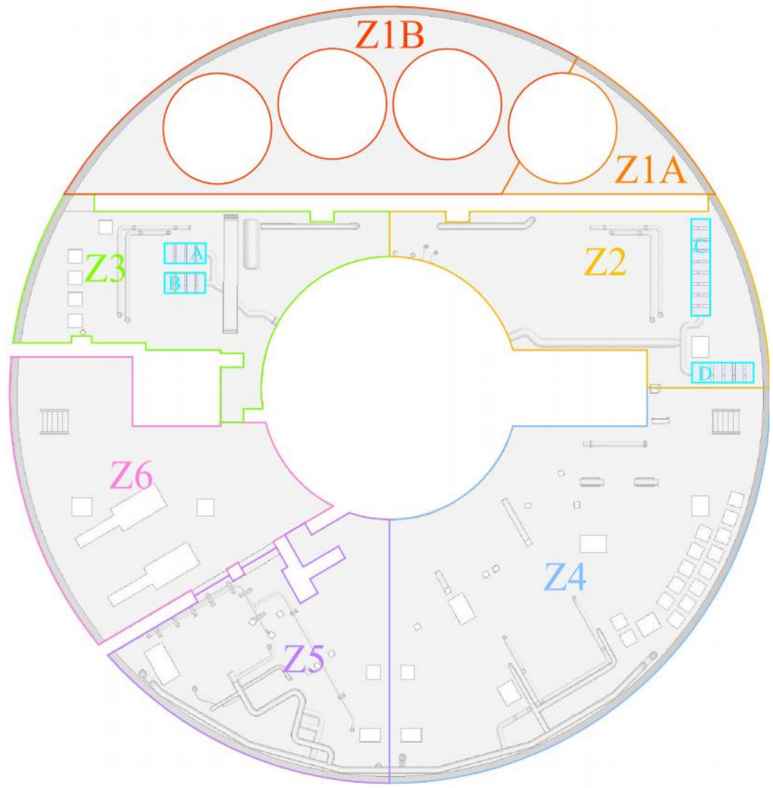


Figure 21.2. Proximity zones for Palisades containment sump [Ref. 21.1]

Note that similar arguments and conservatisms are implied in assuming debris is distributed evenly in the remainder of the proximity zones. Finally if the total flow into Zones 4-6 is compared to the surface area of Zones 4-6, it is seen that Zones 4-6 receive 54% of the flow while occupying 60% of the total surface area. This implies that the general flow direction upon pool fill will be out of Zones 2 and 3 which contain all four strainer trains towards Zones 4-6. The debris transport calculation conservatively does not account for this preferential movement of debris away from the strainers. Neglecting cross-zone debris transport during pool fill, as done for the debris transport calculation, is conservative relative to the plant condition.

To further quantify the conservatism contained in adding debris at 30 ft from the strainer, an analysis was conducted to conservatively estimate the distance debris has to travel to reach each of the strainer trains. To arrive at representative averages for the distance traveled, the overall flow paths and flow splits were respected while drawing linear segments following these paths to conservatively estimate the total distance traveled by debris.

The general flow-splits among the proximity zones is shown in Figure 21.. The arrows indicate the flow direction across each of the boundaries. Based on comparison of the calculated debris transport quantities, the bounding scenario for debris transport is obtained when considering the east air room door closed and therefore, there is no flow from zone 6 directly to zone 3. Note however also that only 25% of the flow comes from the intersection of zones 2 and 3.

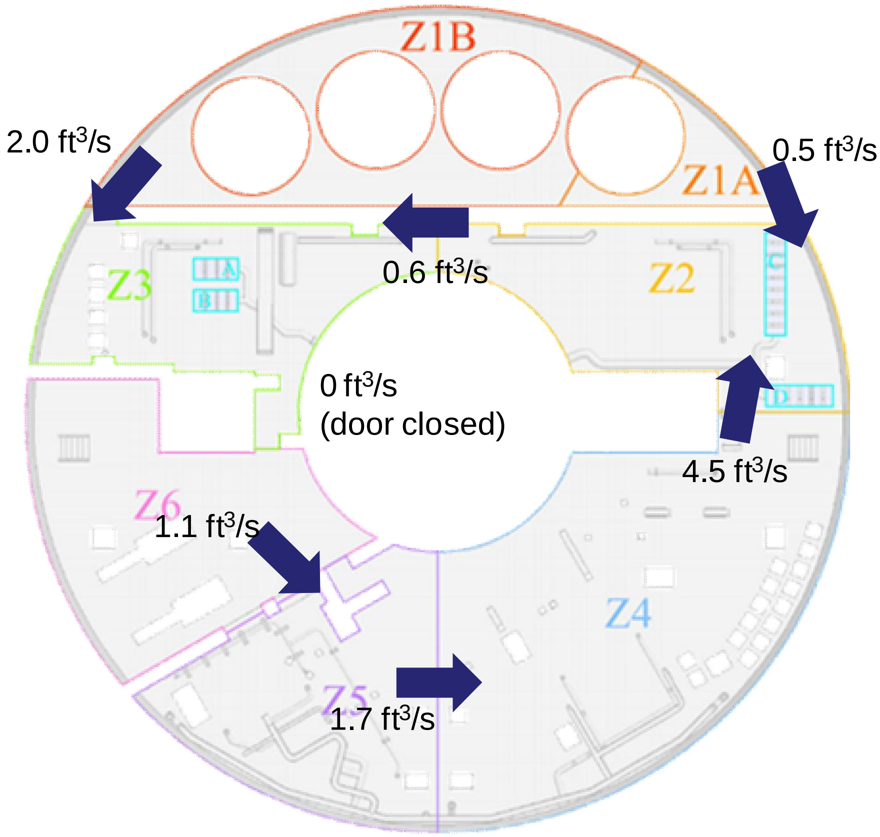


Figure 21.3 Proximity zone flow split

Note that the only Zone exhibiting two exit flows is Zone 1. Zone 1 is therefore subdivided by the relative flow fractions exiting from each side. Figure 21. therefore shows a dividing line which apportions 81% of the Zone 1 area to the exit near strainer banks A & B and 19% to the exit near strainer banks C & D. Pathlines indicate that none of the flow from the CWST room exit near strainer banks C & D actually goes to strainer banks A & B which is expected based on the overall layout of the strainers. Furthermore, the flow-source indicated as letter M in Figure 21.1 (located within proximity Zone 2) contains ample flow volume to make up the cross-flow from Zone 2 to Zone 3. No flow from Zone 4-6 therefore is considered to be required to make up the strainer train flow demand in Zone 3. With this information the distances traveled from each of the proximity zones to the strainer banks can be appropriately weighted.

To define the average origination point for the debris, the centroid of the relevant area is employed. Fine debris is assumed to be uniformly distributed within each proximity zone and so the centroid of the complete proximity zone is employed for Zones 2-6 to define the fine material origination point. For Zone 1, multiple exit flow points exist and the zone is subdivided to apportion the zone by the CFD predicted flow split (81%/19%) as discussed above. Fine debris from Zone

1 is therefore considered to originate from the centroid of each of the two sub zones comprising Zone 1. For small debris, the velocity iso-contour centroids within each zone are employed to describe the origination point of the debris. For Zone 1, the iso-contours are split along the overall sub-zone boundary and then analyzed for centroids. The two separate iso-contour centroids for Zone 1 are then used to describe the origination point for the debris within each of the sub-zones of Zone 1. The destination point for the strainer train is the centroid of the strainer module train. In some cases the centroid corresponding to the origination point lies in a non-fluid zone (e.g. inside a CWST tank). In this case, the origination point is moved on an arc to the nearest intersection between the boundary of the fluid zone and the arc. The center point of the arc is the previous distance point drawn from the strainer origin. This method needed to be applied only to Zone 1A, both for smalls and fines. The best graphical example is shown in Figure 21.4 for the treatment of the centroid of all of Zone 1A (since fines are 100% transportable in each zone and uniformly distributed upon generation).

Debris quantities are derived from the debris transport calculation [Ref 21.1]. Flow rates through each zone are derived from those indicated in Figure 21.3, which stem from the CFD calculation employed to perform the transport calculation [Ref. 21.1]. Within each zone the debris and flow is divided among the modules according to the module flow rate. For example, in Zone 3, 0.6 ft^3/s of flow originates from Zone 2 going to Zone 3. Since both strainer trains A & B draw the same flow, half of this flow is apportioned to strainer train A and half to strainer train B. For Zone 2, the situation is slightly different as strainer train C has a higher flow capacity than strainer train D. But the debris and flow are again apportioned according to the relative flow between the two strainer trains.

The following equation (1) calculates the average distance a given type of debris travels to a strainer train i.

$$\overline{d_i} = \left(\sum_{Z=1}^{Z=6} Q_{i_Z} \cdot V_{i_Z} \cdot d_{i_Z}\right) \Big/ \left(\sum_{Z=1}^{Z=6} Q_{i_Z} \cdot V_{i_Z}\right) \qquad (1)$$

In the above equation Q_{i_Z} is the flow mapped to strainer train i from Zone Z. V_{i_Z} is the debris quantity mapped to strainer train i from Zone Z. d_{i_Z} is the distance debris has to travel from Zone Z to strainer train i. The summation uses Zone 1A for strainer trains C & D and Zone 1B for strainer trains A &B. Following equation (1), an average distance can be calculated for all strainer trains. An overall average distance is then derived from these four distance measurements by averaging all four distances weighting each of the distances by the flow to each strainer train. Should a given combination of transport and strainer train not be possible due to the viable flow paths available, the entry is marked "NA" in the tables below. For example, since no flow from Zone 4 goes to strainer trains A & B, the table entries for transport from Zone 4 to strainer trains A&B are marked "NA".

Further explanation is necessary with respect to the flow weighting employed in Equation (1). The flows used in the weighting are the flows transporting debris to the strainer train in a given area. This means that for strainer train C, for example, the flow rate weighting for debris in Zone 2 (the location of strainer train C) is equal to the full strainer train flow rate since all of the flow going to the strainer could transport debris. Conservatively, this approach weights the debris distances for debris located within the same zone as the strainer train quite heavily. Note also for example that the flow weighting for debris originating from Zone 4 is relatively high since the flows from Zone 5 and Zone 6 run through Zone 4 and could therefore transport debris from Zone 4.

The calculation also respects the applied limitation for small debris that this debris cannot bridge a separation between iso-contours of its tumbling velocity. This means that although strainer trains A and B receive flow from Zone 2, the distance from the transportable iso-contour in Zone 2 to strainer trains A and B is not used. The iso-contour within Zone 2 is not connected via a viable flow path to the iso-contour in Zone 3. This treatment is only required for non-fine debris and for this debris transport calculation and analysis only applied to fiberglass smalls.

Figure 21.4 shows the drawing used to calculate the distances for fine fiberglass debris from the various zones to each of the strainer trains. Table 21.1 shows the results of the calculations using Equation (1) and then performing an overall flow weighted average to obtain a final representative measure of the distance that debris has to travel to the strainer. The table indicates that fine fiberglass debris is required to move an average of 45 ft to reach the strainer trains. The calculation shown was repeated for the distribution of fine mineral wool debris and a distance of 45 ft was again calculated. Results for the mineral wool fine debris are not summarized in a table. Considering the conservatism used in distributing debris for the pool fill phase, the distance clearly underlines the conservative test approach of adding debris at 28-30 ft from the strainer.

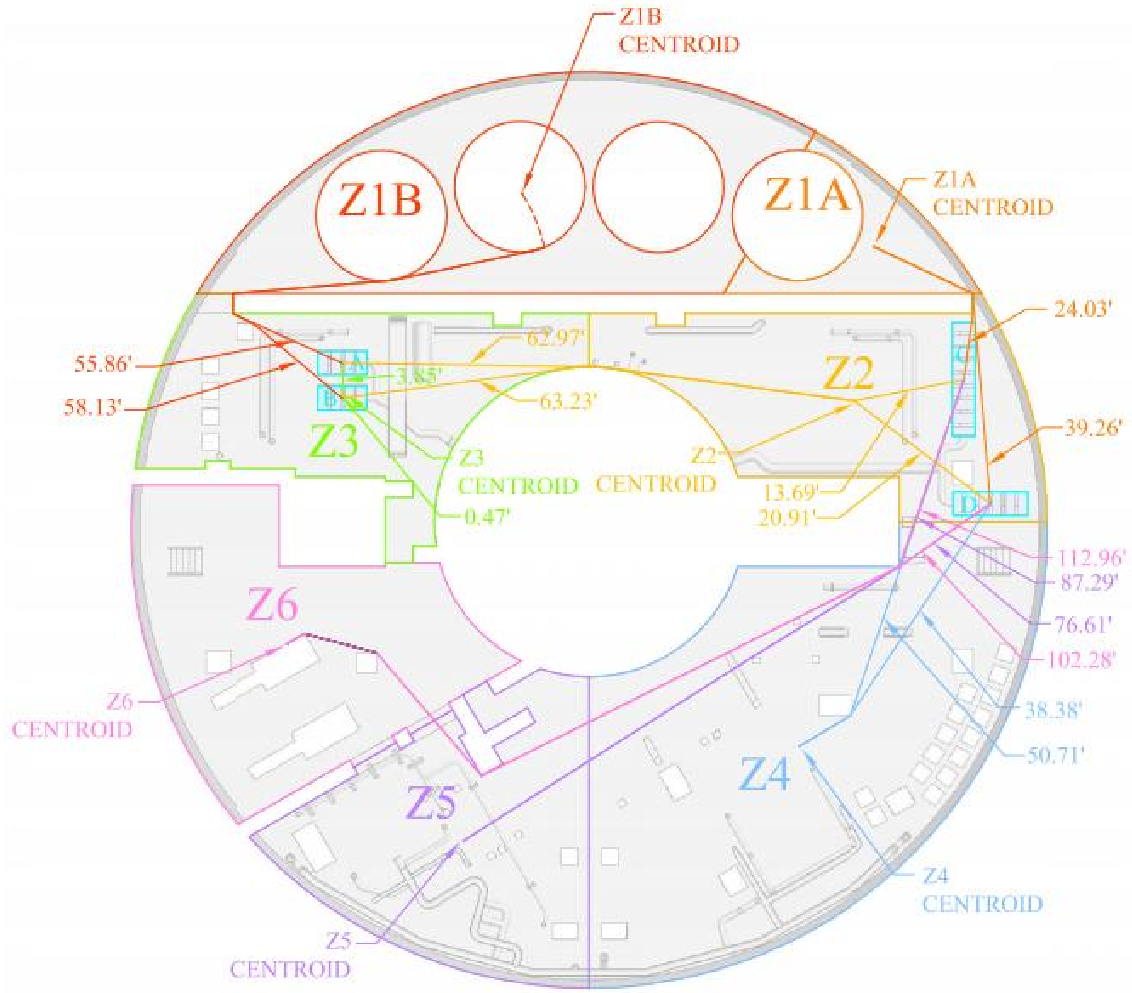


Figure 21.4 Fines debris distances

Table 21.1 Averaging summary for fiberglass fines debris

Strainer Group	Number of Modules	Zone 1A Debris ft³	1A Flow ft³/s	1A Distance ft	Zone 1B Debris ft³	1B Flow ft³/s	1B Distance ft	Zone 2 Debris ft³	2 Flow ft³/s	2 Distance ft	Zone 3 Debris ft³	3 Flow ft³/s	3 Distance ft
A	4	NA			39.675	1.005	56	15.629	0.301	63	0.965	1.346	4
B	4				39.675	1.005	58	15.629	0.301	63	0.965	1.346	0.5
C	9	9.306	0.280	24	NA			15.629	3.029	14	NA		
D	6	9.306	0.187	39				15.629	2.019	21			

Strainer Group	Number of Modules	Zone 4 Debris ft³	4 Flow ft³/s	4 Distance ft	Zone 5 Debris ft³	5 Flow ft³/s	5 Distance ft	Zone 6 Debris ft³	6 Flow ft³/s	6 Distance ft	Strainer Train Average Distance ft	Representative Average Debris TravelDistance ft
A	4	NA			NA			NA			55	45
B	4										57	
C	9	39.465	2.647	51	2.715	1.031	87.29	6.942	0.678	113	42	
D	6	39.465	1.833	38	2.715	0.687	76.61	6.942	0.452	102	36	

Figure 21.5 shows the drawing used to calculate the distances for small fibrous debris from the various zones to each of the strainer trains. Table 21.2 shows the results of the calculations using Equation (1) and then performing an overall flow

weighted average to obtain a final representative measure of the distance that debris has to travel to the strainer. The table indicates that small fibrous debris is required to move an average of 31 ft to reach the strainer trains. This distance exceeds the debris addition distance used of 30 ft. It should be noted that pool-fill transport processes will largely result with small debris on the floor and transport along the containment floor by tumbling is significantly more difficult than transport in the top of the water column where the fibrous debris is inserted during testing. Adding debris at 30 ft is therefore a justifiable approach to use in testing.

Following additional discussions with NRC staff (i.e., 4/26/2010 Technical Call and 4/28/2010 Meeting with PCI on Large Flume test Protocol), the above approach employed to determine the average distance traveled by debris was deemed insufficient to justify adding debris at 30 ft from the strainer. In order to accept the above analysis, information would be required to show that the likely varying transport fraction for debris outside and inside of 30 ft from the strainers will result in a conservative amount of debris transported to the strainers. For any potential tests considered going forward, debris will not be added at the end of the flume only. The methodology for determining where debris would be added in possible future testing will be discussed with the staff in the framework of the meetings with PCI on the Large Flume Test Protocol, the next meeting which is scheduled to occur in June 2010.

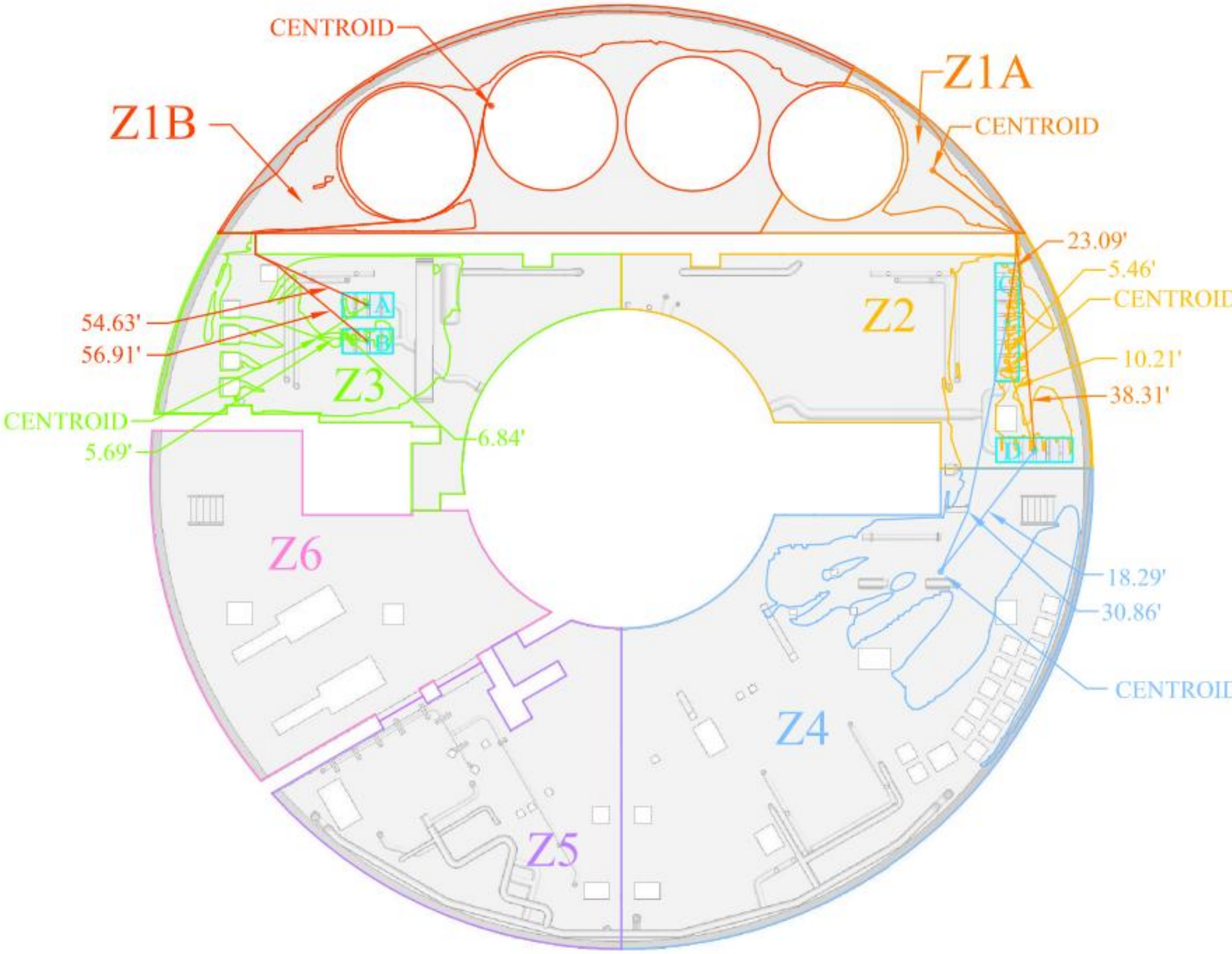


Figure 21.5 Fiber smalls debris distances

Table 21.2. Averaging summary for fiber small debris

		Zone											
		1A			1B			2			3		
Strainer Group	Number of Modules	Debris ft^3	Flow ft^3/s	Distance ft	Debris ft^3	Flow ft^3/s	Distance ft	Debris ft^3	Flow ft^3/s	Distance ft	Debris ft^3	Flow ft^3/s	Distance ft
A	4	NA			35.541	1.005	55	NA			1.233	1.346	7
B	4				35.541	1.005	57				1.233	1.346	6
C	9	8.337	0.280	23	NA			8.764	3.029	5	NA		
D	6	8.337	0.187	38				8.764	2.019	10			

		Zone									Strainer Train Average Distance	Representative Average Debris Travel Distance
		4			5			6				
Strainer Group	Number of Modules	Debris ft^3	Flow ft^3/s	Distance ft	Debris ft^3	Flow ft^3/s	Distance ft	Debris ft^3	Flow ft^3/s	Distance ft	ft	ft
A	4	NA			NA			NA			53	31
B	4										55	
C	9	17.283	2.647	31	0.000	1.031	0	0.000	0.678	0	22	
D	6	17.283	1.833	18	0.000	0.687	0	0.000	0.452	0	16	

References

21.1 Areva Calculation 32-9099369-000 dated February 2009, Palisades Nuclear Power Station - Debris Transport

21.2 June 30 Submittal to NRC Palisades June 30, 2009 Submittal to NRC, Follow-up Supplemental Response to NRC Generic Letter 2004-02

21.3 NEI 04-07, NEI Guideline, “Pressurized Water Sump Performance Evaluation Methodology,” December 2004.

21.4 SER-GSI-191 SE, Revision 0, "Safety Evaluation of NEI Guidance on PWR Sump Performances", Office of Nuclear Reactor Regulation, December 2004.

NRC Request

22. *Please discuss any sources of drainage that enter the containment pool near the containment sump strainers (i.e., within the range of distances modeled in the head loss test flume) and identify their locations and flow rates. Please identify whether the drainage would occur in a dispersed form (e.g., droplets) or a concentrated form (e.g., streams of water running off of surfaces). Based on the June 30, 2009, supplemental response, it appears that sources of drainage were not modeled in the head loss test flume. The NRC staff expects that the lack of modeling of these drainage sources led to non-prototypically low transport results in the test flume. Therefore, please provide contour plots of the calculated turbulence (which include a numerical scale with units) for the CFD calculation for the test flume and compare it to that for the full-containment plant CFD calculation. The NRC staff does not consider the licensee's theoretical arguments supporting a higher level of turbulence in the linear flume as compared to the plant to be convincing in light of CFD comparisons for other plant conditions to flume flows at corresponding velocities that have typically shown the plant condition to experience significantly higher turbulence.*

Entergy Nuclear Operations Response:

Figure 21.1 shows the spray and drainage sources into the containment sump. Note that the areas designated as AA represent direct containment spray and are therefore by definition inlets in the form of droplets whose near surface turbulence impact has negligible effect on debris transport. Three other areas with flow input, marked X, M and P have boundaries within 30 ft of the strainer trains A-D. Of these, X is extremely weak at less than 0.1 ft^3/s. P represents a minor run-off flow of about 0.35 ft^3/s, originating from grating under the pressurizer and is therefore justifiably modeled as dispersed input flow with limited turbulence generation potential [Ref. 21.5]. This leaves area M (flow at 0.76 ft^3/s) to be considered which represents flow from the steam generator compartment. More than half of area M is covered above with grating. Although some of the water could remain concentrated, this is improbable given the unstable nature of a water sheet and the near proximity of the broken up water droplets from the flow that has passed through the grating. Note also that the flow not affected by grating only amounts to 5% of the total recirculation flow further reducing the potential impact on debris transport. Finally, the edge of spray / drainage area M is more than 25 ft away from the nearest strainer bank and therefore barely within the modeled length of the flume. The compartmentalized nature of the Palisades containment distributes the break-flow energy effectively throughout containment and results in relatively quiescent conditions in the containment sump.

The quiescent conditions of the containment sump are illustrated by the turbulence contours shown in Figure 22.1, Figure 22.2 and Figure 22.4. The figures show turbulence at two different depths to illustrate the diminished role turbulence is expected to play in debris transport, as explained below. The lower limit of the scale in Figures 22.2 and 22.3 corresponds to the expected mid water-column turbulence level in the flume based on initial calculations. This turbulence level is not corrected for the difference between containment and flume temperatures. Note that the maximum turbulence level outside of the strainers themselves is approximately 0.01 ft^2/sec^2 which is quite low from an absolute standpoint. A contour plot illustrating the full range of turbulence in containment is shown in Figure 22.1. Note that the 0.01 ft^2/sec^2 level is only attained in a very small area of containment. A more focused range in the contour plot is shown in Figure 22.2, illustrating that the bulk of Palisades containment is at turbulence levels far below even 0.001 ft^2/sec^2. The previous supplemental response [Ref. 21.2] indicated that the turbulence levels between flume and containment would be expected to be similar, if not higher in the flume because of the presence of shear producing walls. This statement is correct for cases where there is no significant source of turbulence near the strainers that would allow turbulence to be transported to the near field of the strainers. Due to the compartmentalized nature of the Palisades containment, there are no strong sources of turbulence due to break or spray flow in containment. For the A&B strainer trains, the strongest source of turbulence occurs due the 90 degree turn that the flow has to execute to leave the CWST room and make it past the containment NaTB baskets to the strainers. For the C&D strainer trains, the strongest source of turbulence is from the restriction of flow originating from the west side of containment and then turning toward the strainers.

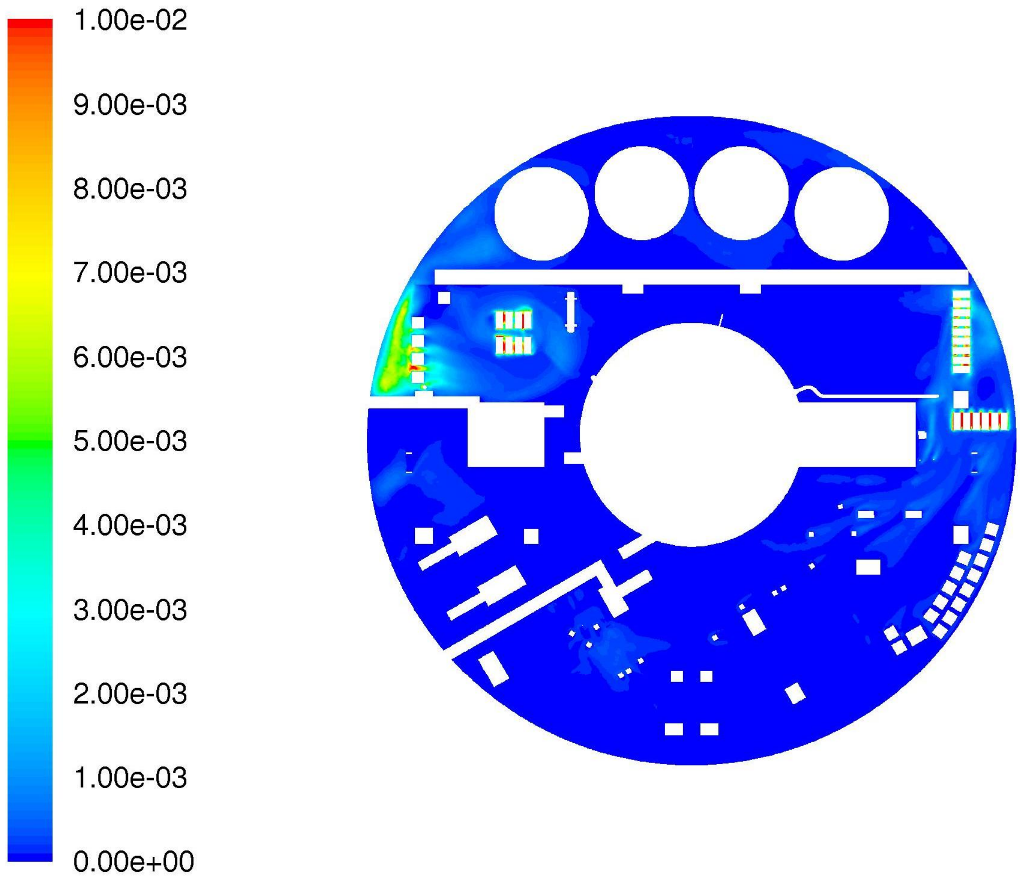


Figure 22.1 Turbulent kinetic energy contours (ft^2/sec^2) at half-foot water depth

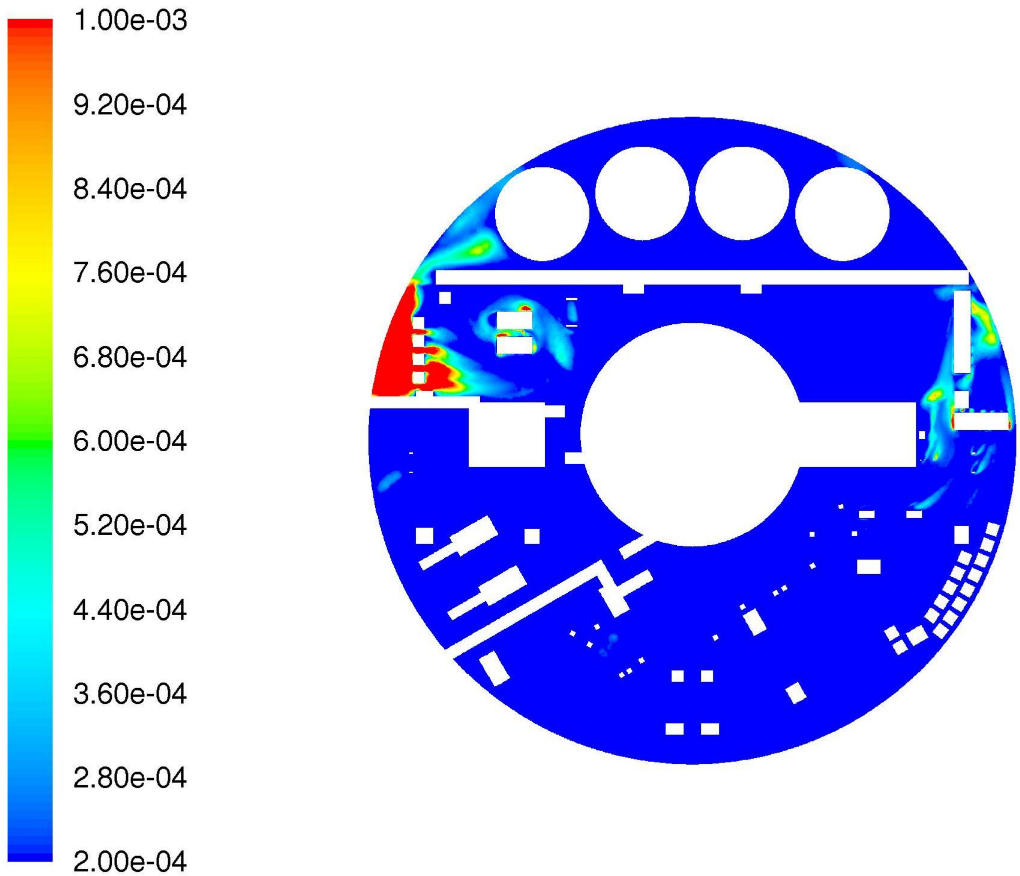


Figure 22.2 Turbulent kinetic energy contours (ft^2/sec^2) at 1in water depth

The dominant turbulence producing features are thus bluff bodies located (e.g. NaTB baskets, columns etc) that lie within a concentration of flow. The turbulence is not associated with concentrated sources of water entering the containment sump or break flow energy. The fact that the source of turbulence can be traced back to bluff-body type separations is important since it implies the existence of an associated low velocity region behind the bluff body. The unsteadiness in the flow moving around the bluff bodies would tend to over time accumulate debris in the low velocity region. This drop-out and low velocity region is ignored in the conducted transport analysis and associated testing. Once the turbulence is generated, it is carried toward the strainer. However, in contrast to the test flume, as Figure 22.2 and Figure 22.3 imply, the turbulence near the floor becomes significantly lower than further up in the water column. In the test flume the flow-guiding walls and floor provide a concentration of turbulence near the floor likely reaching to approximately 5e-4 ft^2/sec^2 (green in Figure 22.2 and Figure 22.3). Since debris transport is predominately expected to occur in the lower parts of the water column, it is turbulent kinetic energy in these regions that is expected to be the best measure of the likelihood that debris settling will be prevented (or debris suspension enabled) by turbulent kinetic energy. Flume turbulence levels are higher near the floor relative to the mid water column in the flume whereas containment turbulence levels near the floor are lower near the floor relative to the mid water column.

Furthermore, areas of relatively high turbulence are small on a recirculation flow basis when considering that a large portion of the overall recirculation flow is drawn in by strainer banks C & D (65%). Areas bounded by the expected flume turbulence level are even larger for these two strainer trains.

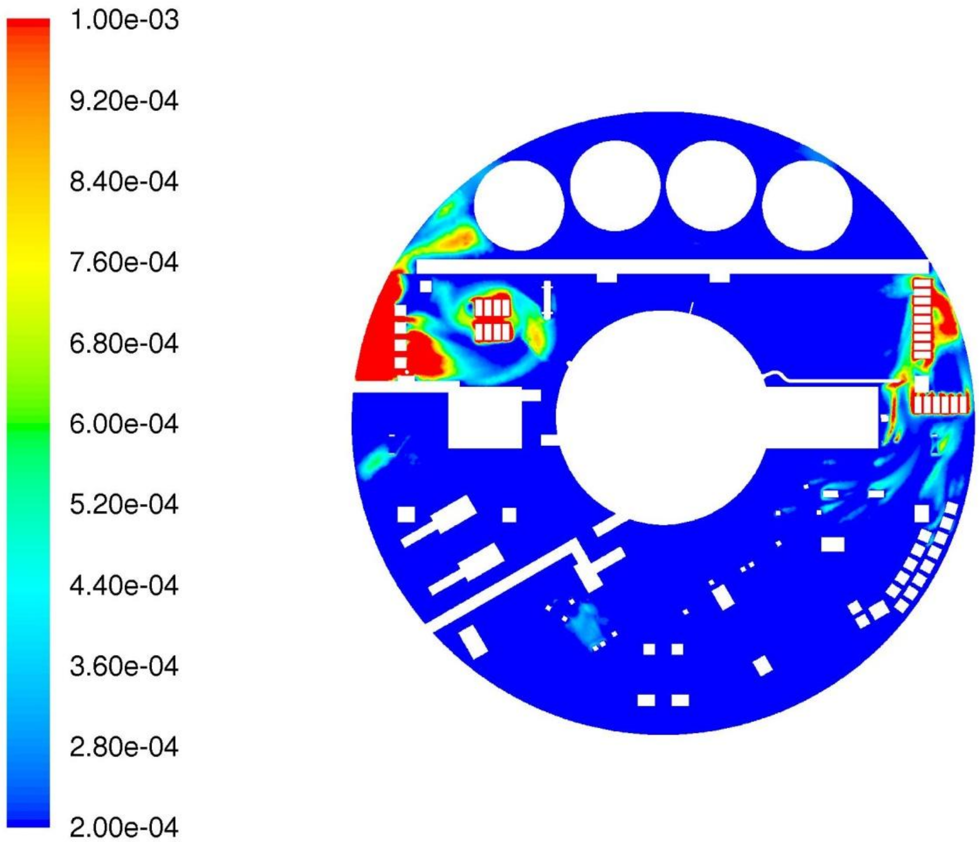


Figure 22.3 Turbulent kinetic energy contours (ft^2/sec^2) at half-foot water depth

In summary therefore, it can be expected that effective turbulence levels (accounting for the difference in temperature and associated material settling rates between conducted testing and expected containment conditions) of near 1e-3 ft^2/sec^2 will be seen in a comparison between flume turbulence levels and containment turbulence levels. The 1e-3 ft^2/sec^2 turbulence level bounds a dominant portion of the approach areas employed by the flow on its way to the strainers. While somewhat larger turbulence levels exist in small areas of containment on selected approaches, the 1e-3 ft^2/sec^2 turbulence level is a prototypical turbulence level for flow approaching the Palisades strainers. In view of this, Palisades proposes to do a CFD of the Palisades flume test setup which can be compared with the above plots. It is anticipated that such an analysis will show the flume and the containment are comparable.

Transport conditions for several breaks were considered before determining that break S5 with East Air Room Door closed was limiting. Based on discussions with NRC staff (i.e., 4/26/2010 Technical Call and 4/28/2010 Meeting with PCI on Large Flume test Protocol), additional justification must be provided for the diffuse flow boundary conditions employed in the near field of the strainers. It is anticipated that a) additional information with respect to containment geometry and b) considerations of water sheet atomization regardless of structure impact will allow justification of the boundary conditions employed and/or provide clear prototypical treatment of all run-off flows. Considerations of b) will be discussed with the staff going forward in the framework of the meetings with PCI on the Large Flume Test Protocol, the next meeting which is scheduled to occur in June 2010.

References

22.1 AREVA Calculation 32-9099369-000 dated February 2009, Palisades Nuclear Power Station - Debris Transport

22.1 Palisades June 30, 2009 Submittal to NRC, Follow-up Supplemental Response to NRC Generic Letter 2004-02

22.3 NEI Guideline, “Pressurized Water Sump Performance Evaluation Methodology,” December 2004.

22.4 SER-GSI-191 SE, Revision 0, "Safety Evaluation of NEI Guidance on PWR Sump Performances", Office of Nuclear Reactor Regulation, December 2004.

22.5 Hur, Hong B., "Modeling a rain-induced mixed layer", Thesis, Naval Postgraduate School, Monterey, CA, June 1990.

NRC Request

23. *The June 30, 2009, supplemental response described the licensee's methodology of averaging velocities along different approaches to the strainer modules in order to determine the flow conditions for the head loss test flume for the Palisades strainer testing. During the chemical effects audit for Palisades, the NRC staff also considered this methodology based on the more detailed descriptions and results from the CFD modeling report. Based on this information, the NRC staff considered the licensee's methodology for determining the head loss test flume flow conditions as lacking adequate justification and appearing non-conservative. In particular, the average velocities calculated for a number of the cases and configurations included approaches to the strainer that experienced relatively little flow of water and debris. The velocities associated with these relatively stagnant approaches that appeared to have little impact on debris transport to the strainer were arbitrarily weighted equally with higher velocity pathways by which the majority of the water flow and generated debris appeared to reach the strainers. This practice appeared to result in non-prototypically low flume velocities for strainer testing, leading to increased debris settling and lower head losses than expected for the plant condition. Therefore, please provide the following information to justify the velocities chosen for the head loss test flume:*

   a. *Velocity contour plots for the containment pool, including close-up plots in the vicinity of the strainers, as well as a table of the velocities used in the head loss test flume for comparison.*

   b. *Justification for weighting stagnant approaches to the strainers, along which little debris transport occurs, equally with high-velocity approaches by which the majority of debris transports to the strainers.*

Entergy Nuclear Operations Response:

The requested flume approach velocity profile as a function of distance from the test strainer is given in Table 23.1. The velocities given in the table are a result of applying the methodology described previously [23.1]. Additional details and justification for the approach definitions employed is illustrated and explained below. The approach to applying the methodology to the parallel strainer trains A, B, C and D was to consider A and B strainer trains as one ensemble and C and D, each separately. The discussion below will detail how an approach velocity profile was derived for each of these cases. To obtain the overall average approach velocity given in Table 23.1, a strainer module flow based average was employed where the weighting of a given ensemble's (A&B, C or D) average approach velocity was equal to the number of modules contained in the ensemble. Since each module draws the same amount of flow, the resulting average is a flow-weighted average.

Table 23.1 Flume approach velocity

Distance from Strainer (ft)	Module Weigted Velocity (ft/s)
1	0.0825
3	0.0825
5	0.072
7	0.106
9	0.115
13	0.112
18	0.0818
30	0.116

Figure 23.1 shows a velocity contour plot near strainer trains A & B. The contour plot is taken at an elevation of 591 ft, 1 ft off the containment sump floor. The four approaches are indicated by sets of arrows on the figure. The arrows show that Approach 1 and Approach 3 are relatively short approaches whereas the major approaches are Approach 2 and Approach 4. For areas where only two approaches exist (beyond 7 ft from the strainer) the higher velocity approach (Approach 4) is weighted double. Note that Approach 2, although exhibiting a low velocity contains more than a quarter of the amount of flow relative to the overall flow going to strainers A & B. By double weighting Approach 4, the fastest approach is appropriately emphasized relative to Approach 2. Note also that the approaches for strainers A & B only make up 35% of the overall recirculation flow. Approach 2 shows arrows running across a cylindrical tank. Some of the velocity stream does divert under the tank to approach the strainers and this path is represented by the area weighted average velocity of this approach.

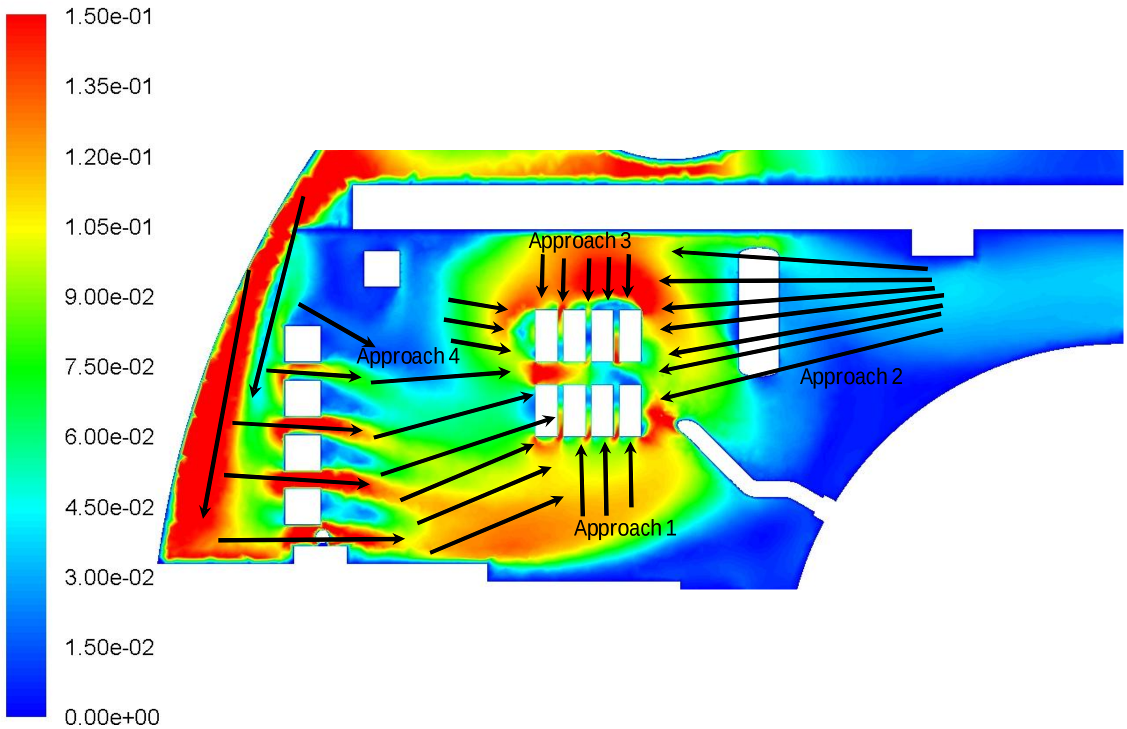


Figure 23.1 Strainer trains A&B approaches (Velocity - ft/s)

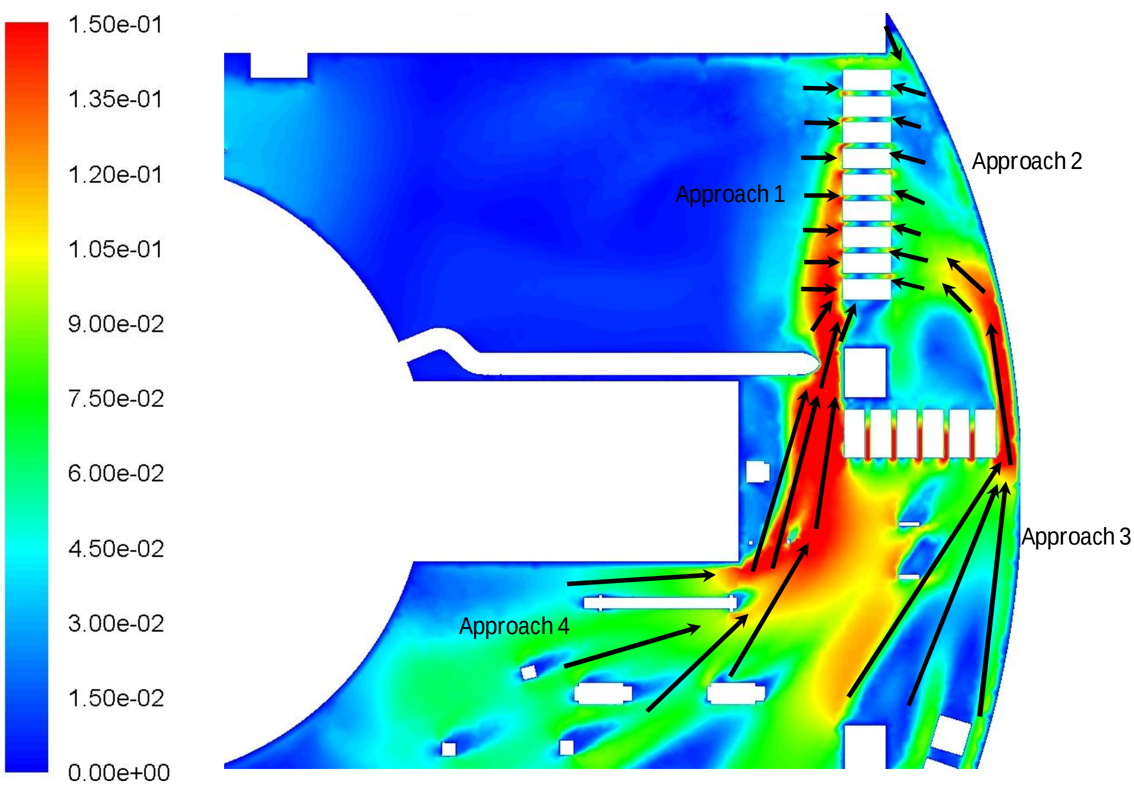


Figure 23.2 Approach descriptions for strainer bank C (Velocity - ft/s)

Figure 23.2 shows the approaches used to describe the approach velocity to strainer train C. Note that Approach 1 and Approach 2 are short and the approach velocity is dominated by Approach 3 and Approach 4. The fastest of these (Approach 4, generally) was weighted double in the determination of the average approach velocity for strainer train C.

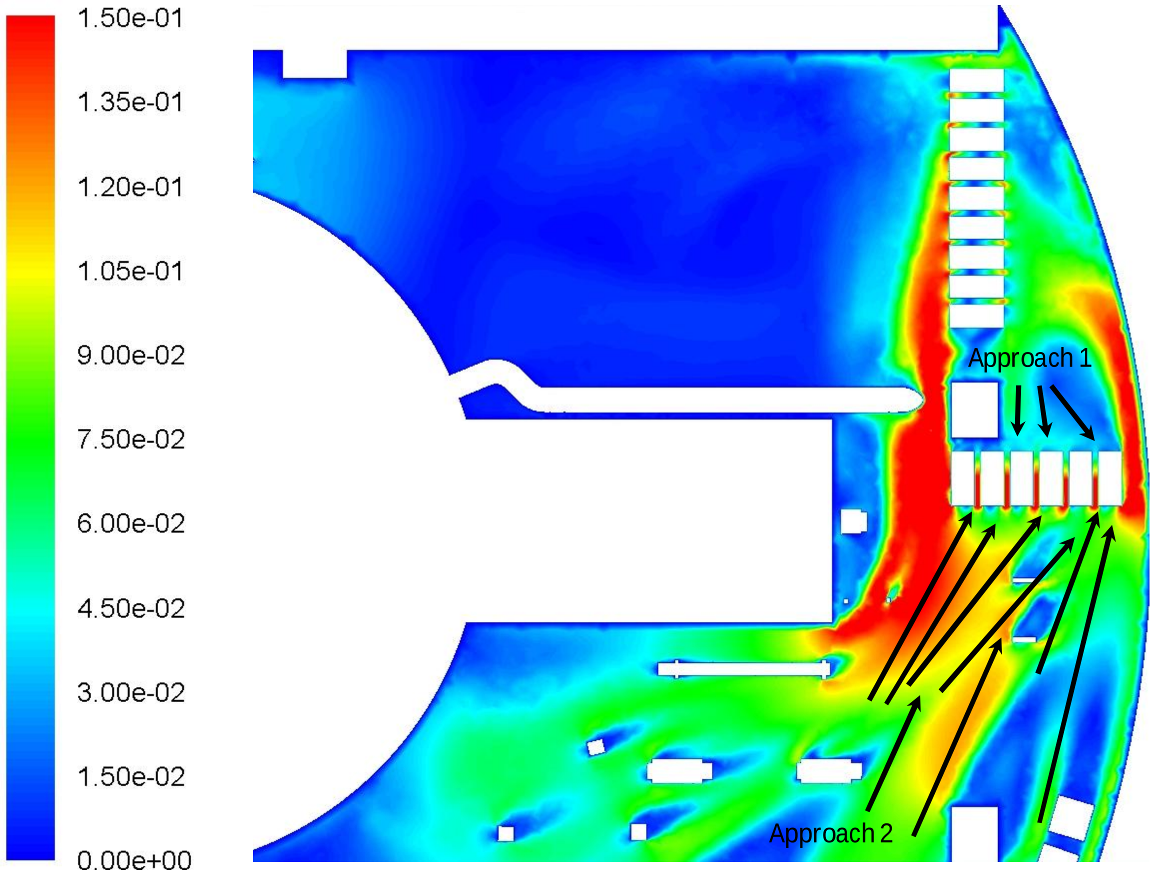


Figure 23.3 Approach descriptions for strainer bank D (Velocity - ft/s)

Figure 23.3 shows the approaches used to describe the approach velocity to strainer train D. Note that Approach 1 is fairly short and the approach velocity is dominated by Approach 2. Approach 2 is also the faster approach and is therefore double-weighted for the cases where two approaches are observed.

Reviewing Figure 23.1 to Figure 23.3, the contour plots show that while some areas exist with velocities greater than those tested in the flume, these areas are relatively small and the flume velocities employed are prototypical of those in containment approaching the strainers.

<u>References</u>

23.1 Palisades June 30, 2009 Submittal to NRC, Follow-up Supplemental Response to NRC Generic Letter 2004-02.

NRC Request

24. *In RAI 13 from the NRC's letter dated December 24, 2008, the NRC staff requested information regarding the postulated single failure of a low-pressure safety injection (LPSI) pump to automatically trip following receipt of a recirculation actuation signal. After reviewing the licensee's response in the June 30, 2009, supplemental response, the NRC staff did not consider the issue fully addressed with respect to debris transport for the following reasons: (1) modeling the failure of a LPSI pump to trip automatically would likely lead to additional debris transport in the head loss test flume, as well as in the analysis, (2) the NRC staff expects that the transport of additional fines and/or small pieces would have increased the head loss for the Palisades design basis test, and (3) it is not likely that the LPSI pump flow would be terminated in time such that the transport effects from this flow can be completely neglected. The supplemental response argues that 15 minutes is an appropriate time for crediting remote operator actions to ensure that the LPSI pump flow is terminated. However, because the failure mechanism and necessary recovery action (e.g., tripping the pump breaker or remotely tripping the pump) would not be known ahead of time, based on the information provided by the licensee, it was not clear to the NRC staff that the remote operator actions could reasonably be accomplished in 15 minutes. It is not clear, for example, that the first remote operator action would be successful for all potential failure modes, or that applicable procedures include sufficiently detailed guidance for the operators. Please provide additional information to address the NRC staff's concerns and state how much time is required for one turnover of the containment pool volume in the case of a LPSI pump failure to trip.*

Entergy Nuclear Operations Response:

Palisades approach for addressing the LPSI failure to trip scenario was analytical (Reference 24.1) with consideration of strainer test results based on design maximum flow with no LPSI pumps running. Main reason for this approach is there was no way to adequately model such a scenario using the existing test protocol that requires introduction of all fine particulate before fine fiber addition followed by the small debris. Use of the LPSI failure to trip flow rate would require introduction of all non-chemical debris before the flow rate could be reduced, simulating the subsequent termination of the LPSI pump running, before the chemical debris is added. Such a test would not be representative of what would occur in the plant with respect to debris transport and would be extremely conservative. Given the low probability for a LPSI failure to trip to occur (estimated ~ 0.001), Palisades performed strainer testing using flow rates and velocities that were representative of the maximum design flow rate assuming with no LPSI flow.

The strainers have a 2.6 ft water head loss allocated to address both clean strainer head loss and debris head loss. The clean strainer head loss, (1.026 ft head loss at 212 ^{o}F), can be readily calculated for the increased flow for a LPSI failure to trip scenario. The assumed debris head loss for the LPSI took into consideration the measured head loss from the design basis strainer test to estimate what the corresponding head loss might be for the starting point of the LPSI failure to trip evaluation.

The November 2008 tests for the design basis debris loading resulted in 0.44 feet of head loss with all but the chemical precipitate debris in the flume (Reference 24.2). The design basis debris load used in the November 2008 testing is the full 30 day loading.

The EOP's direct the operators to manually trip the LPSI pumps if they continue to operate post RAS. The trip verification happens very soon after RAS and simulator experience shows that a running LPSI pump could be tripped or its supply bus could be tripped within 15 minutes of RAS. Note that this 15 minute time frame is not a defined time critical operator action and specific time validation has not yet occurred. The current EOP direction is detailed for each action to be taken and the component the action is to be taken on. Verifying that the LPSI pumps have tripped post RAS is the first step in EOP Supplement 42. The first attempt for tripping the operating LPSI pump is using the control switch in the control room. This would be performed and if successful, the LPSI pump would be expected to be running less than 5 minutes post-RAS. If the control room control switch is unsuccessful, the next step in the procedure would dispatch an operator to trip the pump at the LPSI pump bus breaker. If the second effort is also unsuccessful, then the associated safety bus is tripped in the control room. This last step is also relatively quick. If Palisades were to go directly to tripping the safety bus in the control room if the pump control switch failed, the entire effort is then estimated at less than 10 minutes. This could eliminate any uncertainty in timing associated with tripping the pump at the LPSI pump bus breaker. Palisades proposes to time validate the current EOP actions and if difficulties exist in completing actions within 15 minutes, then consideration will be given to going directly to tripping the safety bus in the control room if the pump control switch failed.

The sump contains approximately 30,000 cu ft of water equal to approximately 225,000 gallons. At approximately 7,000 gpm flow with the LPSI pump running, one turnover is approximately 30 minutes. Therefore 15 minutes is approximately one half turnover.

It is known that the following portions would not be on the strainer at 15 minutes even with the additional flow:

1. Chemical Precipitates

2. Eroded fibers (approximately 1/3 or more of the total fine fibers, Reference RAI Response 26, Table26a-1)
3. Failed paint particulate and chips (do not fail instantly as shown by test & most of the volume is unqualified paint not in the ZOI of the break)
4. A significant fraction of the Calcium Silicate particulate (fines form by erosion)

The combination of less than 2/3 of the sensitive fiber, less than half of the paint related particulate and significantly reduced Cal-Sil fine particulate, when combined with one half turnover of the sump volume suggests that assuming only half of the measured 30 day sump debris pressure drop would be conservative. Therefore a debris related head loss of 0.22 ft at 3591 gpm was justified as an appropriate starting point of the LPSI failure to trip evaluation. However, a higher value of 0.4 ft head loss was assumed for the staring point at 3591 gpm. When clean strainer head loss and debris head loss was corrected to the LPSI failure to trip flow conditions, the results was 4.82 ft head loss, (reference Table 3g1 on page 135 of the 6/30/2009 submittal) which was acceptable.

The CFD and Debris Transport analysis supporting the November 2008 strainer test used the lower non-LPSI failure flow and that output was used to compute dropout fractions. However the fine fiber component was assumed to transport 100% independent of CFD velocity and increased velocity would not have increased the quantity of fines used in the test flume. The amount of fiber fines that may have transported in test flume in November 2008 would have been greater if the test was run at the higher LPSI failure to trip flow conditions for the 30 day debris load. However, for the arguments offered in the preceding paragraphs, the starting point for the LPSI failure to trip evaluation used a conservative value to address added transport. With respect to fiber smalls, the amount of smalls used in the November 2008 strainer test was conservatively high as demonstrated by the fact that much did not transport due to the conservatively low 0.06 ft/s tumbling velocity assumed in the CFD and debris transport evaluation. If a more representative tumbling velocity of 0.12 ft/s had been used, it would have provided at least some offset for any increase in transport of smalls under LPSI failure to trip flow conditions. With respect to a higher flow in the test flume under LPSI failure to trip flow conditions, additional fiber smalls might have transported but those have smaller effect on pressure drop and a case can be made for additional smalls reducing head loss by interfering with development of a thin bed.

The above discussion provides justification for the analytically derived head loss for the short period of time that the LPSI pump is running. Once the running LPSI pump is terminated, the amount of debris transported to the strainers could then be higher once the remaining 30 day design basis debris amount transports. The November 2008 strainer test results (<0.75 ft with chemical) did have margin to the 1.568 ft head loss available for debris (i.e., 2.6 ft available for design minus clean strainer and associated piping head loss). Given the LPSI failure to trip is a low probability event combined with the worse case debris case based on a large break double guillotine being a very low probability event, the combination of these two events probably could be supported as not required to be analyzed, if necessary, through an appropriate License Amendment Request.

<u>References</u>

24.1 EA-MOD-2005-004-03 Rev 3 dated 4/6/2010, “ESS Flow Rates and NPSH during Recirc Mode with CSS Thottling”

24.2 AREVA Document 66-9097941-000, “Palisades Test Report for ECCS Strainer Performance November 2008 Testing”, 2/16/2009.

NRC Request

25. In RAI 13 from the NRC's letter dated December 24, 2008, the staff asked for information regarding the single failure of a LPSI pump to trip at the time of switchover to recirculation, or to be restarted during the event. This issue was not fully addressed in the supplemental response with respect to the affect on head loss and vortexing. The licensee stated that the emergency operating procedures have been revised to remove the steps that directed restarting the LPSI pump, and the licensee evaluated the overall head loss associated with a running LPSI pump. The evaluation was acceptable except that it did not address the potential for additional transport to the strainer (as discussed above) if head loss testing had been conducted with the higher flow rate.

    Please provide the assumptions of the analytical evaluation and its results, with adequate bases for the assumptions, and verify that the results do not affect the head loss evaluated both for the short-term LPSI pump run duration and for the mission time of the strainer. In addition, please verify that the higher LPSI flow rates would not result in air entrainment (vortexing or deaeration) either at the strainer or the ECCS pump suction pipe in the sump due to the potentially higher head losses if the level behind the strainer were drawn down into the sump. Also, please verify that the strainer testing conservatively represented the flow velocities near the strainer under the LPSI failure-to-trip scenario or provide information that shows that testing contained adequate representation of the flows under this condition.

Entergy Nuclear Operations Response:

The first identified item, assumptions of the analytical evaluation and its results, is addressed in RAI 24 response. The last identified item, strainer testing flow velocities, is addressed in RAI 24. The response to the balance of the RAI 25 request follows.

Vortex testing was performed on the Palisades strainer design at a submergence of 2" over the top of strainer consistent with the minimum containment water elevation of 593'-4" (Reference EC12249, Rev. 0) and flow rates associated with a large break LOCA (LBLOCA). Testing performed on the strainer determined that the strainer did not exhibit any characteristics associated with a vortex or vortex formation. Based on these test results, Entergy concluded that an air core vortex that could draw air into the Palisades strainer modules is not expected for the LBLOCA conditions.

The low pressure safety injection (LPSI) failure to trip flow rate of 7,148 gpm (Reference EA-MOD-2005-004-03, Rev. 3) is approximately 2 times the 3,591 gpm LBLOCA flow rate (Reference EC12249, Rev. 0). Although the strainer vortex testing was not performed at the higher LPSI failure to trip flow rate, it is not expected that air would be drawn into the ECCS pump suction lines at these higher flow rates for the following reasons:

i. Air core vortices were not observed during the testing at the minimum LBLOCA water level that fully submerges the strainer modules, 593'-4" (Reference EC12249, Rev. 0), consistent with the minimum water level during a LPSI failure to trip event. The strainer perforated plate provides some flow straightening that minimizes the potential for air core vortices. Air core vortices were not observed in the testing until the water level water was decreased to the small break LOCA (SBLOCA) elevation of 592.34 feet (Reference EA-SDW-97-003, Rev. 3). For a SBLOCA, the water level is below the top of the strainer modules (strainer is partially submerged). The LPSI failure to trip condition would not occur when the strainer is partially submerged at the SBLOCA water level since the LPSI pumps could not inject into the Primary Coolant System for breaks that generate the SBLOCA water level.

ii. If an air core vortex was drawn into the strainer during a LPSI failure to trip event at the LBLOCA minimum water level of 593'-4" (Reference EC12249, Rev. 0), any air that could be ingested into the containment sump would be released through the containment sump vents since the strainer is vented. This would eliminate the possibility of any potential air ingestion into the Emergency Core Cooling System (ECCS) pump suction lines.

iii. The containment water level would submerge the containment sump vents if the containment water level reached the 595 feet elevation (Reference Drawings M-74, Sheet 1, Rev. 13 and VEN-M802, Sheet 1, Rev. 0). At this water level, the strainer is submerged over 20 inches (10 times the submergence at the tested minimum LBLOCA water level). Using the Froude number as defined in Appendix A of the NRC Regulatory Guide 1.82, Revision 3, dated November 2003; the following can be concluded:

    The Froude number (Fr) is a non-dimensional parameter used to describe a fluid flow field and consequently evaluate hydraulic performance. The Froude Number (Fr) is the ratio of inertial forces to gravitational forces that has been used to evaluate the susceptibility to air core vortices. The Froude number as defined in Appendix A of the NRC Regulatory Guide 1.82 is:

$$FroudeNumber = \frac{U}{\sqrt{gs}}$$

Where: g = acceleration due to gravity
s = minimum submergence
U = velocity

Since vortices were not evident at the tested LBLOCA flow rate and the minimum strainer submergence condition, the Froude number for the tested condition can be compared to the Froude Number for the LPSI failure to trip condition to determine the susceptibility to air core vortices. The Froude Number for the tested condition can be defined as:

$$FroudeNumber_1 = \frac{U_1}{\sqrt{gs}_1},$$

and the Froude Number for the LPSI fail to trip condition will be defined as:

$$FroudeNumber_2 = \frac{U_2}{\sqrt{gs}_2}.$$

Equating the Froude Numbers for both flow conditions yields the following equation:

$$\frac{U_1}{\sqrt{gs_1}} = \frac{U_2}{\sqrt{gs}_2}$$

Solving the equations for the ratio of s_2/s_1, a comparison can be made to the ratio of the velocities using the following equation:

$$\frac{S_2}{S_1} = \left(\frac{U_2}{U_1}\right)^2$$

The strainer surface area is constant for the strainer tested condition at 3,591 gpm and the LPSI failure to trip condition (7,148 gpm). Although the flow distribution between the strainer modules will be slightly different for the LPSI failure to trip condition due to the strainer internal losses, an assessment of the susceptibility of the strainer modules to an air core vortex can be performed by assuming that the strainer approach velocity is proportional to the strainer flow rate. Solving the above equation with a flow ratio of 2 (ratio of flow rate for the LPSI failure to trip condition to the tested condition) gives a required submergence ratio of 4 for the higher flow rate for the LPSI failure to trip condition.

In summary, the LPSI failure to trip condition with an associated water level of 595 feet results in a required submergence of approximately 4 times the submergence for the tested conditions. Since the strainer submergence at the water elevation of 595 feet is 10 times greater than the tested condition; ingestion of air core vortices is not expected at containment water levels that submerge the containment vents.

NRC Request

26. *Some subparts of the licensee's response to RAI 14 from the NRC's letter dated December 24, 2008, were not responded to satisfactorily, as follows.*

   a. 14.e: Debris preparation and introduction methods.

   The licensee provided the debris preparation and introduction methods. The staff observed issues with the debris preparation and introduction during the review of test video. The Palisades supplemental response stated that some of the fines were removed from the small fibrous debris prior to addition to the test flume. The PCI method of removing these fines from the smalls is to shake the smalls on a shaker table. The NRC staff does not believe that this is conservative or prototypical of plant debris as some fines are likely contained in small fibrous pieces. The removal of the fines from small pieces for testing may be non-conservative when compared to the plant condition. The licensee should provide justification that the removal of the fines from the small fibrous debris prior to the introduction of smalls into the flume is prototypical or conservative with respect to debris that would be generated in the plant. Additionally, the licensee should provide information that justifies that debris used in the testing was prototypically sized. Please provide information that justifies that the debris introduction sequence did not non-conservatively affect transport during testing.

Entergy Nuclear Operations Response 26a:

Utilizing the information provided in Table 26a-1 (below), each of the Staff's three (3) specific concerns/issues for RAI 26a can be addressed. The three (3) Staff concerns/issues are as follows:

1. *The Palisades supplemental response stated that some of the fines were removed from the small fibrous debris prior to addition to the test flume. The PCI method of removing these fines from the smalls is to shake the smalls on a shaker table. The staff does not believe that this is conservative or prototypical of plant debris as some fines are likely contained in small fibrous pieces. The removal of the fines from small pieces for testing may be non-conservative when compared to the plant condition. The licensee should provide justification that the removal of the fines from the small fibrous debris prior to the introduction of smalls into the flume is prototypical or conservative with respect to debris that would be generated in the plant.*

2. *Additionally, the licensee should provide information that justifies that debris used in the testing was prototypically sized.*

3. *Please provide information that justifies that the debris introduction sequence did not non-conservatively affect transport during testing.*

Even though the three (3) Staff concerns/issues are related, they are individually addressed.

The following chronological and historical summary of issues directly related to the three (3) Staff concerns/issues is provided in order to obtain a better perspective of the background associated with the Staff's issues: separation of fines from small fines, prototypically sized debris, and debris sequencing.

- NEI 04-07 (May 2004) does not provide specific guidance regarding an integrated head loss test protocol.
- SE (December 2004) for NEI 04-07 also does not provide specific guidance regarding an integrated head loss test protocol.
- PCI/AREVA/Alden and Licensees (i.e., the Team) utilized available and relevant NUREG/CRs such as 2982 (December 1983) and 6773 (November 2002) to develop the Large Flume Test Protocol since guidance was not available in either NEI 04-07 or the SE for same.
- PCI/AREVA/Alden and Licensees (i.e., the Team) met with and discussed the Large Flume Test Protocol on more than nine (9) occasions (February 2007 (ML072530885) – February 2008 (ML080370262)).
- The Staff in various public meetings with the NEI/PWROG/Licensees and Public praised the fact that the Team had engaged the Staff regarding the proposed test protocol when other strainer vendors had not including some that had actually completed testing without ever discussing the protocol with the Staff in advance of testing.
- The 'draft' of the *NRC Staff Review Guidance Regarding Generic Letter 2004-02 Closure in the Area of Strainer Head Loss and Vortexing* (ML072600348) (i.e., so-called March Guidance Document) issued for comment in approximately October 2007 did not provide any guidance/objections/clarifications to integrated head loss testing as well as the preparation and classification of fine fibrous debris. In addition the terms prototypical and conservative were not defined individually or what was meant by the term 'prototypical or conservative'.
- During the October 24, 2007 public meeting between the Staff and representatives from NEI, the PWORG, Licensees, and the public, the Staff responded to a specific question regarding wording in the 'draft' March Guidance Document that 'fine fibrous debris is individually or readily suspendable fibers'. The Staff response at the direction and questioning of the director was ***'fines' were <u>not</u> single fibers, but could be 'clumps' or 'bunches' of fibers.***

- The Team and Licensees initiated Large Flume Test activities in January 2008. Members of the Staff and a Staff outside contractor witnessed the first test. The Staff provided feedback to the Team which the Team incorporated as well as 'lessons learned' into a revision to the Large Flume Test Protocol.
- The Staff documented the positive observations of the initial Licensee test (ML081840095).
- In the 'final' issued version of the so-called March Guidance Document, there is much discussion by the Staff that 'fine' fibrous debris ***be individually or readily suspendable fibers*** (Page 4 as well as others). The discussion in the subject document is in direct contradiction with the Staff SER for NEI 04-07 and the Staff response to a specific question from NEI, the PWROG representative, and licensees made in the October 24, 2007 public meeting, that *'fines' were <u>not</u> single fibers, but could be 'clumps' or 'bunches' of fibers*. The terms prototypical and conservative were still not defined individually or what was meant by the term 'prototypical or conservative' even though they are utilized extensively in the document.
- Subsequent Licensee tests were performed and successfully completed utilizing the revised Large Flume Test Protocol. The Staff on a number of occasions observed and witnessed the subject tests. The Staff documented their observations (ML083590250). There is no mention that the revised Large Test Flume Protocol that was utilized was deficient or that there were any issues regarding debris preparation, debris settlement, or agglomeration of fibrous debris.
- The Staff was fully aware of the fact that fine fibrous debris had been removed from small fines for a Licensee test, since the Staff had been present at the Licensee test and had also received a copy of the debris allocation sheets which specifically indicated that fines were removed from small fines (ML083590250).
- All Licensee Large Flume Tests utilizing the revised Large Flume Test Protocol were completed on November 11, 2008.
- The Staff stated in a Licensee's July 9, 2009 public meeting regarding open RAIs that fiber fines are expected to conform to Classifications 1, 2 & 3 of NUREG/CR-6808 as shown in Table 3-2 *Size Classification Scheme for Fibrous Debris*. This is a new (i.e., July 2009) 'definition' for fine fibrous debris as stated by the Staff to the industry which is different from that provided in the SE for NEI 04-07 and the March 2008 Staff issued, NRC Staff Review Guidance Regarding Generic Letter 2004-02 Closure in the Area of Strainer Head Loss and Vortexing which also occurred after all of the Licensee Large Flume Testing was completed in November 2008.
- Staff issues, (DRAFT) NRC Staff Synopsis of Issues and Status Regarding Credit for Debris Settlement on February 25, 2010 – more than sixteen (16) months after all Licensee testing had been completed.

Response to RAI26a Issue 1, Removal of fines from smalls:

PCI separated the fines from smalls in order to test the fibrous debris form know as small fines in a more conservative manner. The reason to remove fines from small fines was in response to the staff's concerns regarding debris introduction sequence for the Large Flume Test Protocol. It was agreed by the staff that the Protocol would adhere to the basic criterion of introducing debris from the most transportable to the least transportable. This is not prototypical, but it is very conservative. Since fine fibrous debris based on the staff's opinion will more readily transport than small fibrous debris, the fines were separated from the small fines.

Regarding the staff statement, …*The staff does not believe that this is conservative or prototypical of plant debris as some fines are likely contained in small fibrous piece.* PCI agrees this is not prototypical; however, it is very conservative to separate and segregate the fines from the classification of small fines, and introduce the separated fines before the remaining small fibrous debris in our test protocol. The Large Flume Test Protocol was specifically developed to be more conservative than the prototypical plant condition.

By removing the fines from the small fines, and introducing them to the test flume before the remaining small fibrous debris, a greater percentage of separated fine fibrous debris was introduced for the PNP test. This is clearly more conservative than introducing fines as a sub-set of small fines.

If the staff is suggesting that by removing fines from the debris classification small fines is not conservative, there is no basis for the staff's suggestion. The PNP Design Basis debris types and quantities were fully met during the PNP head loss test at ARL. It would have been overly conservative since the fines within the small fines are either contained within the quantity of small fines or they are separated from the small fines as fine fibrous debris. Fine fibrous debris cannot exist in both fibrous debris classifications, that is small fines and fines. In addition, there is no regulatory requirement or guidance document that supports such a staff suggestion.

Table 26a-1 provides a summary of the fibrous debris types, quantities, and classifications utilized for the PNP Design Basis Test performed in November 2008.

Table 26a-1 PNP Fibrous Debris Types, Quantities & Classifications				
Fibrous Debris Type[3]	**Unit**	**Debris Allocation Scaled Quantity[1]**	**Debris Rounded Allocation Quantity[1]**	**Measured Quantity – Used in PNP Test[2]**

NUKON Fines	lbm	8.991	9.0	9.05
NUKON Smalls (W/Fines Removed)	lbm	7.642	7.7	7.75
NUKON Larges – Eroded (Treated as Fines)	lbm	3.327	3.4	3.45
Mineral Wool Fines	lbm	6.909	7.0	7.05
Mineral Wool Larges – Eroded (Treated as Fines)	lbm	3.720	3.8	3.85
Latent Fiber (Fines)	lbm	1.342	1.4	1.45
Total Fibrous Debris Quantity	**lbm**	**31.931**	**32.3**	**32.6**
% Increase from Scaled Qty	**%**	**NA**	**1.2**	**2.1**
% Fines including Latent	**%**	**76.1**	**76.2**	**76.2**
% Smalls	**%**	**23.9**	**23.8**	**23.8**
Fines & Small Fines Debris Summary for Testing				
% Fines including Latent	%	76.1	76.2	76.2
% Smalls W/Fines Removed	%	23.9	23.8	23.8
% Additional Fines Contained (i.e., 16%) in Smalls W/Fines Removed[4]	%	3.82 (16.0% x 23.9%)	3.81 (16.0% x 23.8%)	3.81 (16.0% x 23.8%)
% Total Smalls - Tested	**%**	**20.08**	**19.99**	**19.99**
% Total Fines - Tested	**%**	**79.92**	**80.01**	**80.01**

NOTE:(1) Values based on PCI calculation TDI-6031-02

(2) Values based on AREVA Test Plan 63-9095797-001 and Test Report 66-9097941-000

(3) Debris descriptions and quantities from Areva Calculation 32-9099369-000

(4) Initial percentage of fines contained in small fines smalls after initial fines removed (i.e., 25%) is an additional 16% fines based on PCI document Performance Contracting, Inc., SSFS-TD-2007-004, Supplement 1, Rev. 1, *Sure-Flow Suction Strainer – Testing Debris Preparation & Surrogates* (ML092430056 & ML092580203)

As can be seen from the results of the subject table, PNP classified more than 80% of their entire debris quantity as fine fibrous debris which was also utilized in the PNP head lost test (Test 4: Design Basis Test).

Finally, it should be noted that the staff was fully aware of the fact that fine fibrous debris had been removed from small fines for a previous licensee test, since the staff had been present at the licensee test and had also received a copy of the debris allocation sheets which specifically indicated that fines were removed from small fines.

In addition, the staff observed and documented as part of the same licensee test (ADAMS ML083590250), the following: *The PCI/Areva debris preparation methodology has been revised to remove any fine fibrous debris from the small debris category by subjecting "smalls" processed through a wood chipper to a shaker table with coarse screen. The old methodology left any fine debris that was created in the process of making the small debris in the mixture; whereas the new process allows loose "fines" to be removed from the "smalls". This reduces the total fine debris available for transport to the strainer to be more representative of the design basis specified by the client.*

It is evident that the staff was fully aware of the change in debris preparation to remove fines from small fines for licensee testing. It should be further noted that the total quantity of fine fibrous debris utilized in both the PNP and licensee tests were specified by the licensee and representative of the expected quantities for the licensee's plant. Simply stated the removal of fines from small fines fibrous debris did not have any affect on nor reduced the total specified Design Basis quantity of fine fibrous debris utilized for a licensee's test, and in all cases the 'recommended' percentage of fine fibrous debris as discussed in the SE for NEI 04-07 was significantly exceeded.

Response to RAI26a Issue 2, testing *debris prototypically sized*:

The design input for strainer testing defined the debris size distribution for PNP strainer test in terms of fines and smalls (no larges were determined to transport to the strainers). The debris types, scaled quantities, and classifications used for the PNP strainer qualification test were documented in the AREVA NP Test Plan (Test 4: Design Basis Test). Please refer to Table 26a-1 for additional information regarding the various fibrous debris classifications and quantities. The fibrous debris utilized for the PNP test was prototypically sized.

The Staff has raised a number of issues and questions regarding fibrous debris sizing with respect to the fibrous debris classifications of both fine and small fines fibrous debris. The following discussion provides a historical perspective of the issue of fibrous debris sizing and fibrous debris size distribution as it relates to the Large Flume Test Protocol as utilized for the PNP test. The discussion perspective also provides clarification of the various NUREG/CRs and their definition of and classification of fibrous debris sizing. The subject referenced NUREGs and other documents were used to develop the subject Protocol.

Generally speaking, there is no regulatory and/or industry definition of fine fibrous debris generated as the result of a Design Basis LOCA. This conclusion is based on an extensive review of regulatory and industry documents. Therefore, the term '*prototypically sized debris*' is subjective and has no known objective criteria with respect to size and/or classification. However, PCI has processed and prepared dry fibrous debris into classifications that are prototypical of post-LOCA conditions based on various NUREG/CRs related to the issue.

That being said, in Section VI.3 *Methodology* of the Safety Evaluation (SE) for NEI 04-07, the BWR drywell debris transport study (DDTS) is discussed. The study is documented in NUREG/CR-6369-1, -6369-2, and -6369-3. It should be noted that the configuration of a BWR Mark I drywell (containment) on which the subject DDTS evaluations were performed is very small, very different, more confined, and has considerably more platforms, gratings, walkways, and other structures that would significantly 'shred' fibrous debris during the initial post-LOCA blow down period than would be reasonably expected for a typical, large PWR containment. Therefore use of the DDTS results, conclusions, and their application to a large, dry PWR containment and the associated post-LOCA generated fibrous debris would be extremely conservative, but not prototypical. The DDTS (page VI-9) concluded that based on CEESI air blast tests of fibrous insulation, that when an LDFG blanket was completely destroyed, 15 to 25 percent of the insulation was in the form of very fine debris (i.e., debris too fine to collect readily by hand). It should be noted that very fine debris as defined in the subject NUREG/CR does not mean nor infer individual fibers of fibrous insulation.

On page VI-14 of the SE for NEI 04-07, it states in part … *The analysis of the AJIT testing performed at CEESI to support the DDTS determined that whenever entire blankets were completely destroyed, 15 to 25 percent of the insulation was too fine to collect by hand. In this case, complete destruction means nearly all of the insulation was either fine or small pieces. In any case, 15 to 25 percent of the blanket (an average of 20 percent) can be considered fine debris for the purposes of this analysis.* It can be concluded that *complete destruction* means *either fine or small pieces* (of fibrous debris), and <u>*not*</u> individual fibers. It is recognized that individual fibers constitute an unknown portion of the fine or small fibrous debris pieces, and most likely not the majority of the debris pieces.

It should be further noted that, NUREG/CR-6369 Volume 1, specifically Section 2.2 *Debris Size Methodology* states in part … *the fact that debris size distribution that is universally applicable to plant conditions and accident scenarios is not available. On the other hand, there is consensus that the debris can be broadly divided into three size classes: small[9], large, and large-canvassed, according to their relative size and pathways available for their transport.*

Footnote 9 identified with the class of smalls from the previous paragraph states as follows, [9]*It should be noted that, initially, efforts were made to further classify small debris into sub-groups fines, smalls, and medium consistent with NUREG/CR-6224 study [Ref. 2.1]. However, a decision was made to collapse them into a single group called small because: a) fines, smalls and medium pieces have very similar transport pathways and b) existing debris size distribution data does not differentiate these three size groups [Ref. 2.3].*

Even though NUREG/CR-6369 states that … *the debris can be broadly divided into three size classes*, NUREG/CR-6369 is actually based on NUREG/CR-6224 which classified fibrous debris not *by size, but actually by shape* (refer to subsequent discussion below).

Finally, Table 2-5 *Debris classification* from NUREG/CR-6369 Volume 1 provides the following information.

Table 2-5. Debris classification.

Debris Type	Dimensions	NUREG/CR-6224 Terminology	Transport Characteristics
Small (Figure 2-5)	<6″ x 4″	Classes 2-6	• Smaller than (≈equal to) grating clearance. Will be forced through gratings • Gravitation settling negligible • Vent capture unlikely • Pool turbulence can keep them in suspension • Washdown by sprays and break flow
Large (Figure 2-6)	> 6″x4″	6+	• Unlikely to be forced through grating even at flow velocities >200 ft/s. • No washdown by sprays • Erosion by break flow • Capture at vents
Large-Canvassed (Figure 2-7)	>6″x4″ covered with canvas	"Non-transportable"	• Transport unlikely • No pathway for transport identified
Canvas Fragment (Figure 2-8)	1″x1″ to 3″x3″	Not considered	• Same as small

In addition to the information provided in Table 2-5, NUREG/CR-6369 Volume 1 also provides photographs of the various fibrous debris classifications including smalls. Figure 2-5 depicting the fibrous debris classification smalls is shown below. Note the physical size of the small classification fibrous debris.

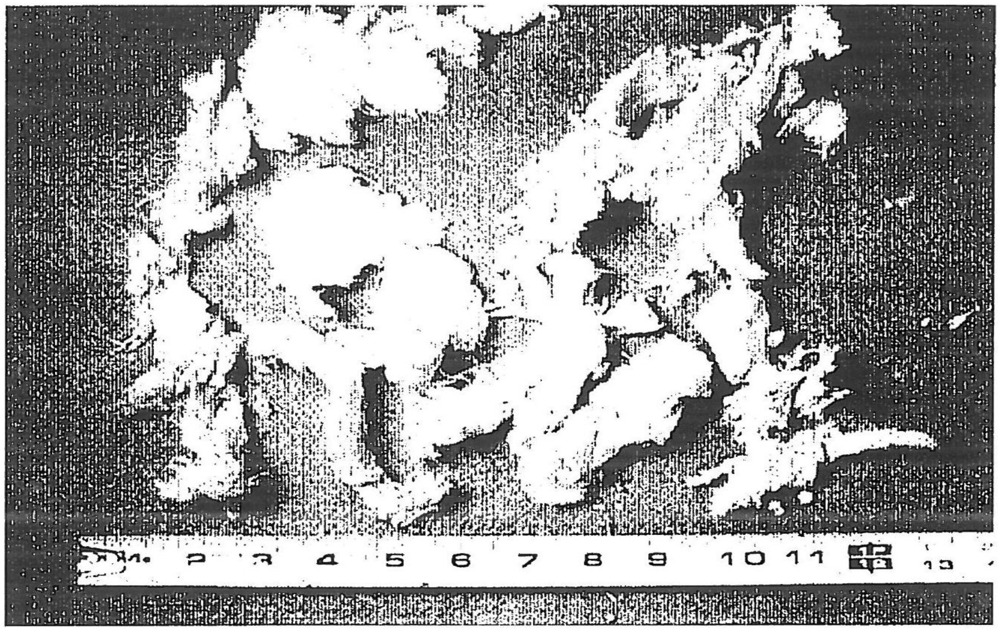


Figure 2-5. A photograph of small size insulation debris produced in air-jet tests.

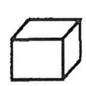
As stated in Table 2-5 from NUREG/CR-6369 Volume 1, smalls are classified as fibrous debris passing through a standard floor grating of less than *6" x 4"*. NEI 04-07 specified that fibrous debris classified as small fines was fibrous debris that would pass through a standard *4" x 4"* floor grating. PCI document, *Sure-Flow® Suction Strainer – Testing Debris Preparation & Surrogates*, Technical Document No. SFSS-TD-2007-004 very conservatively defines the small fines classification as fibrous debris that would pass through a standard *4" x 1"* floor grating. Therefore, the PCI classification of small fines which was used for all licensee testing including PNP is significantly more conservative than that stated in either NUREG/CR-6369 Volume 1 or NEI 04-07.

Table 2-5 also discusses the transport characteristics of the fibrous debris classified as smalls. In part, the subject Table states that: *Gravitation settling is negligible* and *Pool turbulence can keep them in suspension*. These statements in the subject NUREG/CR are in relation to the stated definition for small, which is any fibrous debris that will pass through a 6" x 4" grating. This would include fine fibrous debris, but it also would include significantly larger pieces of fibrous debris. It could therefore be concluded that NUREG/CR-6369 Volume 1 supports the fact that fibrous debris passing through a 6" x 4" grating will not be affected by gravitational settling and that fluid turbulence will keep the subject fibrous debris in suspension.

As part of Table 2-5, reference is made to NUREG/CR-6224 terminology with regard to fibrous debris classification. Section B.4.1 *Classification of Fibers* and

Table B-3 *Fibrous Debris Classification by Shape* found in NUREG/CR-6224 discuss fibrous debris classification. Table B-3 is provided below.

Table B-3 Fibrous Debris Classification by Shape

Class No.		Description	Settling Characteristics	Settling Velocity in Calm Pools	Strainer Filtration Efficiency
1		Very small pieces of fiberglass material, "microscopic" fines which appear to be cylinders of varying L/D.	Drag equations for cylinders are well known, should be able to calculate fall velocity of a tumbling cylinder in still water.	1-3.5 mm/s Based on Cal. for 0.5 - 2.54 cm long fibers	Unknown
2		Single flexible strand of fiberglass, essentially acts as a suspended strand.	Difficult to calculate drag forces due to changing orientation of flexible strand.	Same as above	Nearly 1.0
3		Multiple attached or interwoven strands that exhibit considerable flexibility and which due to random orientations induced by turbulence drag could result in low fall velocities.	This category is suggested since this class of fibrous debris would likely be most susceptible to re-entrainment in the recirculation phase if turbulence and/or wave velocity interaction becomes significant.	0.04 ft/s - 0.06 ft/s (measured)	1.0 (measured)
4		Formation of fibers into clusters which have more rigidity and which react to drag forces more as a semi-rigid body.	This category might be represented by the smallest debris size characterized by PCIs air blast experiments.	0.08 - 0.13 ft/s (measured)	1.0 (measured)
5		Clumps of fibrous debris which have been noted to sink. Generated by different methods by various experimenters.	This category was characterized by the PCI air test experiments as comprising the largest two sizes in a three size distribution.	0.13 - 0.18 ft/s (measured)	1.0 (measured)
6		Larger clumps of fibers. Forms an intermediate between Classes 5 and 7.	Few of the pieces generated in PCI air blast tests consisted of these debris types.	0.16 - 0.19 ft/s (measured)	1.0 (measured)
7		Precut pieces (i.e. .25" by .25") to simulate small debris. Other manual/mechanical methods to produce test debris.	Dry form geometry known, will ingest water, should be able to scope fall velocities in still water assuming various geometries.	0.25 ft/s (calculated)	1.0 (estimated)

Section B.4.1 *Classification of Fibers* discusses the methodology that was utilized in classifying fibrous debris and that is presented in Table B-3. Section B.4.1 states in part … *The debris classes of Table B-3 can best be described as shape classes since their classification is based solely on their shape. Implicitly, however, each shape is associated with a narrow range of sizes and thus a narrow range of settling velocities.* The Section further states … *However, owing to their ill-defined shapes, it is difficult to further classify these debris by their shape classes and to develop appropriate size distribution curves (i.e., it is difficult to determine what fraction of the residual debris belongs to each shape class).* Finally the Section states … *Usage of settling groups instead of the shape classes described above provides for finer classification of debris. Section*

B.5 presents further discussion on the settling groups used for classifying the NUKON material and their relationship to shape classes in Table B-3.

It should be noted that Section B.4.1 *Classification of Fibers* and Table B-3 *Fibrous Debris Classification by Shape* found in NUREG/CR-6224 does not provide any specific information with regard to fibrous debris size and/or if a screening method such as a 4” x 4” or a 6” x 4” standard floor grating opening was utilized. Therefore the relative sizes of the subject fibrous debris classifications found in Table B-3 are unknown and could be significantly large as long as the classification shape of the fibrous debris was such that it settled at a certain rate.

This is a very important distinction since NUREG/CR-6224 concluded that size is not really important with regard to fibrous debris transport and settling, but in fact the shape of the fibrous debris controls the transport and settling. Therefore it can be inferred that the actual size of fibrous debris per NUREG/CR-6224 is not important.

In addition, the NUREG/CR-6224 settling rates provided in Table B-3 are not stated in relation to a water temperature or temperature range. It should be noted that water temperature has a significant effect on fibrous debris settlement rates even more so than the shape and/or configuration of the fibrous debris. This conclusion is documented in both NUREG/CR-2982, *Buoyancy, Transport, and Head Loss of Fibrous Reactor Insulation* and NUREG/CR-6772, *GSI-191: Separate-Effects Characterization of Debris Transport in Water*, and to a lesser extent in NUREG/CR-6773, *GSI-191: Integrated Debris-Transport Tests in Water Using Simulated Containment Floor Geometries* (Please refer to following discussion).

Following the first Licensee Large Flume Test, the Staff in March 2008 issued the document, *NRC Staff Review Guidance Regarding Generic Letter 2004-02 Closure in the Area of Strainer Head Loss and Vortexing* (also known as the March Guidance Document). It should be noted that no reference is made to NUREG/CR-6224, - 6369, or -6808 (discussed below) in the March Guidance Document with regard to the specific subject of fibrous debris sizing classifications or Table 2-5, Table B-3, or Table 3-2. However, the various terms such as fines, fine fiber, finer fiber, etc. are utilized in the subject document, but are never objectively defined within the document and/or reference made to any NUREG/CR or other guidance documents.

In the March Guidance Document, there is much discussion by the Staff that ‘fine’ fibrous debris ***be individually or readily suspendable fibers*** (Page 4 as well as others). The discussion in the subject document is in direct contradiction with the Staff SER for NEI 04-07 and the Staff response to a specific question from NEI, the PWROG representative, and licensees made in the October 24, 2007 public meeting, that ***'fines' were not single fibers, but could be 'clumps' or 'bunches' of fibers***.

In the March Guidance Document, there is also much discussion by the Staff that fine fibrous debris should be mixed so that agglomeration does not occur that would not be prototypical. However, no guidance or description is provided by the Staff of what is meant by agglomeration as has been previously discussed. It would appear that 'clumps' and 'bunches' based on previous Staff discussion (i.e., October 24, 2007 public meting) would be prototypical and conservative with regard to defining agglomeration. It appears that the Staff's primary concern with regard to fine fibrous debris agglomeration is that the subject debris will settle and not transport as readily as individual fibers. However, there is no basis provided by the Staff as to why they believe that fine fibrous debris would not agglomerate in the post-LOCA containment environment.

As a matter of fact it would seem that it would be more prototypical and likely that the fine fibrous debris would actually agglomerate, would not readily transport and would readily sink as individual fibers in the quiescent post-LOCA containment 212 ^{o}F plus fluid prior to the initiation of ECCS/CSS recirculation. A review of various regulatory documents such as NUREG/CRs provides no support that fine fibrous debris will exist as individual fibers and not agglomerate in the post-LOCA containment. However, on the other hand there are regulatory documents that support the opposite position, that is, fine fibrous debris including individual fibers will settle and not readily transport.

NUREG/CR-2982 *Buoyancy, Transport, and Head Loss of Fibrous Reactor Insulation* on Page 19, Section 3.1 Buoyancy Tests, specifically paragraphs a), c), and e) state in part:

a) In general, the time needed for insulation to sink was ***found to be less at higher water temperatures.*** (emphasis added)

c) The fiberglass (Filomat) readily absorbs water, ***particularly hot water, and sinks rapidly (from 20 to 30 seconds in 120 ^{o}F water)***. ***This is also true for individual fibers***. (emphasis added)

e) … Damaged fiberglass insulation pillows ***will sink before activation of the recirculation system*** … (emphasis added)

Since the initial post-LOCA water temperature in all cases for all Licensees will easily exceed 120 ^{o}F, it can be concluded based on the subject NUREG/CR report that fiberglass insulation and more importantly individual fiberglass fibers will sink before the initiation (i.e., approximately 15 – 40 minutes post-LOCA) of the ECCS/CSS in the recirculation mode. It is interesting to note that NUREG/CR-6808, -6224, or -6369 nor the March Guidance Document makes any mention of NUREG/CR-2982, NUREG/CR-6772, or NUREG/CR-6773, and specifically that fiberglass individual fibers will sink in 20 to 30 seconds in 120 ^{o}F water. It should be noted that NUREG/CR-2982 predates all of the subject NUREG/CRs by more than 13 years and NUREG/CR-6772 and NUREG/CR-6773 were specifically funded to investigate GSI-191 issues. In addition during Licensee fiber by-pass testing at the Alden Research Laboratory it was also noted that significant quantities of fibrous debris including fine fibrous debris settled, and did not reach the strainer in the Licensee prototypical flow streams and at water temperatures of approximately 120 ^{o}F. It should be noted that the subject fibrous debris in accordance with the Large Flume Test Protocol was not allowed to 'sit' in a quiescent flume, but was instead added to a moving flume flow stream, and still significant settling of the fibrous debris occurred. The recent Licensee fiber by-pass testing supports the conclusion reached in NUREG/CR-2982 and NUREG/CR-6772 that individual fibers will rapidly sink in water greater than 120 ^{o}F.

The extremely important conclusion supported by testing associated with and documented in NUREG/CR-2982, that is … fiberglass (Filomat) readily absorbs water, *particularly hot water, and sinks rapidly (from 20 to 30 seconds in 120 ^{o}F water)*. *This is also true for individual fibers*. … has some bearing on the information contained in Table B-3 of NUREG/CR-6224. Note that as was previously discussed NUREG/CR-6224 is the 'basis' for NUREG/CR-6808 and -6369 regarding debris size classifications.

The buoyancy test facility at ARL which served as the primary research facility for NUREG/CR-2982 was 5.0' in depth. The subject NUREG/CR documents that individual fiberglass fibers will sink in 20 to 30 seconds results in settlement rates of 0.167 fps to 0.25 fps. It could therefore be concluded that the settling tests performed and documented in NUREG/CR-6224 were performed at a much colder water temperature (i.e., < 120 ^{o}F) which is both conservative and non-prototypical of post-LOCA conditions. This conclusion is reached based on the stated settlement rates for fibrous debris classes 1 – 3 summarized in Table B-3 of NUREG/CR-6224. The subject table lists settlement rates of 0.003 – 0.011 ft/s for class 1 and 0.04 – 0.06 ft/s for class 3. These settling rates are significantly different than those stated in NUREG/CR-2982 as well as recent testing performed at ARL.

In addition to the conclusions reached in NUREG/CR-2982 regarding rapid sinking of fibrous debris in heated water prototypical of containment post-LOCA fluid conditions, NUREG/CR-6772, *GSI-191: Separate-Effects Characterization of Debris Transport in Water,* provides further evidence and support that fibrous debris will rapidly sink in heated water. Section 2.2.1.1 *Effect of Temperature* states in part … *Post-LOCA water temperature is approximately 80 ^{o}C, which is significantly different for the ambient temperature proposed for use in the test program. It can be postulated that water temperature could affect debris settling characteristics because density and viscosity are temperature-dependent. Further the saturation rates of debris may be temperature-dependent because* *surface tension varies with temperature. This set of experiments provided data to quantify these effects, as described below.*

<u>Saturation of Debris in Hot Water.</u> *When fibrous debris was introduced to water at ambient temperature, it was observed to float on the surface for more than 24 h. Even when shredded fiber fragments were forcibly immersed in ambient-temperature water for 24 h, they subsequently would rise up to the surface when released. However, if the fiber shreds were immersed in hot water (80 ^{o}C) for as little as 2 min, they readily sank and remained submerged. In the aftermath of a LOCA, the temperature of water in a PWR recirculation sump is likely to be closer to 80 ^{o}C than to (~ 20 ^{o}C).*

It should be noted that 80 ^{o}C is 176 ^{o}F, and 20 ^{o}C is 68 ^{o}F. Therefore debris settlement and transport tests in ambient (i.e., cold) water are very conservative but are significantly non-prototypical of the post-LOCA containment fluid conditions.

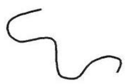
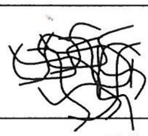
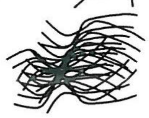
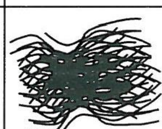
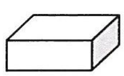
The difference in settlement rates between NUREG/CR-6224 and NUREG/CRs -2982 and -6772 can be easily explained. Simply stated, NUREG/CR-6224 testing was performed at non-prototypical relatively cold water temperatures, while NUREG/CR-2982 and -6772 utilized prototypical relatively hot water temperatures. This conclusion is supported by Section 4.1 *Buoyancy Tests* of NUREG/CR-2982 which indicates that fiberglass in 50 ^{o}F water took 20 to 60 minutes to sink and only took 20 – 30 seconds to sink in 120 ^{o}F water, and Section 2.2.1.1 *Effect of Temperature* of NUREG/CR-6772 which indicates that fibrous debris introduced to water at ambient temperature (i.e., 68 ^{o}F) was observed to float on the surface for more than 24 hours. Even when shredded fiber fragments were forcibly immersed in ambient-temperature water for 24 hours, they subsequently would rise up to the surface when released. However, if the fiber shreds were immersed in hot water (i.e., 176 ^{o}F) for as little as 2 min, they readily sank and remained submerged. In the aftermath of a LOCA, the temperature of water in a PWR recirculation sump is likely to be closer to 176 ^{o}F than to 68 ^{o}F . Accordingly, the settling rates established in NUREG/CR-6224 and which subsequently were utilized to establish fibrous debris shapes/sizes/configurations in Table 2-5 of NUREG/CR-6369, and eventually Table 3-2 of NUREG/CR-6808, and all of which form the basis for the March Guidance Document appear to be based on potentially erroneous data based on non-prototypical test water temperatures that resulted in unsupported staff positions regarding non-prototypical fibrous debris size classifications, fibrous debris settling, and fibrous debris transport.

The Staff stated in a Licensee's July 9, 2009 public meeting regarding open RAIs that fiber fines are expected to conform to Classifications 1, 2 & 3 of NUREG/CR-6808 as shown in Table 3-2 *Size Classification Scheme for Fibrous Debris* (see table below). *This is a new (i.e., August 2009) 'definition' for fine fibrous debris as stated by the Staff to the industry which is different from that provided in the*

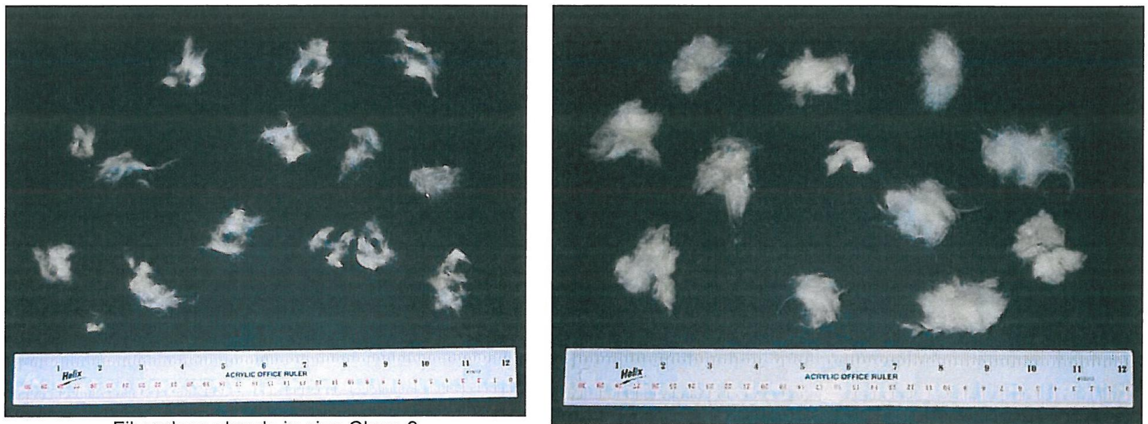
SE for NEI 04-07. It should also be noted that Class 3 fibrous debris is defined and pictured as ’clumps’ measuring up to ~ 1” in accordance with NUREG/CR-6808, Figure 3-3 (see photo (Figure 3-3) following Table 3-2 below).

It should be noted that the subject ‘new’ fibrous debris classification criteria based on NUREG/CR-6808, as well as similar classification schemes are all based on *dry* fibrous debris. There are no known available objective criteria or guidance to assess or evaluate processed **wet** fibrous debris with regard to size classification criteria, the mixing/preparation of same in support of integrated testing, the addition of same to a test flume for integrated testing, and finally the ability to assess, evaluate, and/or determine prototypical agglomeration and concentration of same.

Table 3-2 Size Classification Scheme for Fibrous Debris[3-2]

No.	Description	
1		Very small pieces of fiberglass material; “microscopic” fines that appear to be cylinders of varying L/D.
2		Single, flexible strands of fiberglass; essentially acts as a suspending strand.
3		Multiple attached or interwoven strands that exhibit considerable flexibility and that, because of random orientations induced by turbulent drag, can exhibit low settling velocities.
4		Fiber clusters that have more rigidity than Class 3 debris and that react to drag forces as a semi-rigid body.
5		Clumps of fibrous debris that have been noted to sink when saturated with water. Generated by different methods by various researchers but easily created by manual shredding of fiber matting.
6		Larger clumps of fibers lying between Classes 5 and 7.
7		Fragments of fiber that retain some aspects of the original rectangular construction of the fiber matting. Typically precut pieces of a large blanket to simulate moderate-size segments of original blanket.

It is also noted that the ‘sketches’ (Table 3-2 from NUREG/CR-6808) of the debris classifications do not agree with the actual photographs of debris classifications (refer to the photographs (Figure 3-3) below for debris classes 3 and 5). It should be further noted, that NUREG/CR-6808 does not contain any photographs of the very important debris 1 and 2 classes which the staff is stating is their basis for acceptable small fine debris. Furthermore, there are no ‘hard’ physical descriptions of the debris classifications with respect to size/dimensions, volume, weight, ‘screening’ characterization (i.e., passing through a grating opening), etc. This makes it extremely difficult to objectively assess the exact nature of each debris classification as discussed in NUREG/CR-6808.



Fiberglass shreds in size Class 3

Fiberglass shreds in size Class 5

Figure 3-3. Fiberglass Insulation Debris of Two Example Size Classes

Finally, the most important aspect of the subject debris classifications as the issue relates to NUREG/CR – 6224, - 6369, and -6808, and the SE for NEI 04-07 is the fact that all of the subject NUREG/CRs and the supporting tables, sketches, and descriptions contradict each other. *Simply stated there is no definitive mechanism to classify fibrous debris in an objective manner, nor is there an objective mechanism to distribute the fibrous debris by classification.*

NUREG/CR-6369 concluded that small (not fines) classified fibrous debris was not affected by gravitational settling and that pool turbulence would keep the debris in suspension. Contrary to the statements made in the SE for NEI 04-07 regarding debris sizing and classifications, the Staff stated during a Licensee’s meeting to discuss RAIs that they considered the fibrous debris classifications 1 – 3 found in NUREG/CR-6808 as meeting their definition of fine fibrous debris. It should be noted that the ‘screening’ criteria utilized to ‘define’ small fines for the subject SE for NEI 04-07 and the subject NUREG/CRs (-6369 & -6808) was a 4” x 4” and a 6” x 4” standard floor grating opening, respectively. However, PCI utilized a 4” x 1” standard floor grating opening which is therefore very conservative when compared to either the SE or NUREG/CR screening criterion. Simply stated, PCI’s processing methods result in a significant order of magnitude smaller fibrous debris classified as small fines than if the guidance found in the SE for NEI 04-07 or the subject NUREG/CRs were utilized. The use of PCI’s classification of fibrous debris resulted in much smaller fibrous debris that would also be more readily transportable during Licensee Large Flume Testing than if SE or NUREG/CR screening criterion were utilized for the fibrous debris. The subject PCI processed small fines fibrous debris was utilized in the subsequent Large Test Flume for Licensees.

Based on the discussion provided, it can be concluded that the processing of dry fibrous debris used for PNP testing resulted in very conservative and prototypical fibrous debris size classifications that are readily transportable.

In summary,

- PNP fibrous debris has been processed and prepared in accordance with the PCI 'white paper' SSFS-TD-2007-004 *Sure-Flow Suction Strainer - Testing Debris Preparation & Surrogates*, the PCI 'white paper' SSFS-TD-2007-004, Supplement 1, Rev. 1, *Sure-Flow Suction Strainer – Testing Debris Preparation & Surrogates* (ML092430056 & ML092580203), and the Large Flume Test Protocol which have been provided to and discussed with the Staff.

- PCI has processed raw fibrous debris materials into 'fines' representative of both eroded or latent fibrous debris and 'fines/smalls' by recognized mechanical process devices (i.e., chipper (smalls) & Munson machine (fines)). (ML092580203)

- The PCI definition of small fines has resulted in even more conservative and significantly smaller fibrous debris for ARL testing than if either the NUREG/CR-6369 Volume 1 or NEI 04-07 definition of small debris were utilized. PCI utilizes a 4” x 1” standard grating opening for ‘sizing’ processed fibrous debris as opposed to the 6’ x 4” or 4” x 4’ standard grating opening found to be acceptable by both the Staff’s SE for NEI 04-07 and NUREG/CR-6369 Volume 1.

- All of PCI’s processed small fines fibrous debris meets and/or exceeds the ***dry*** fibrous debris classes of 1, 2 & 3 as defined by NUREG/CR-6808, the smalls classification as defined by NUREG/CR-6369 Volume 1, and classes 2 – 6, inclusive for NUREG/CR-6224.

- The SE for NEI 04-07 found no issue with the NEI 04-07 definition of small fines which are both larger in size classification and less conservative with respect to fibrous debris transport issues than the PCI definition of small fines.

- Samples of dry latent, fines/smalls, and larges' were provided to the Staff before any Large Flume Testing was initiated and were found to be *'representative of what the Staff had expected*'.

- ***Dry*** fibrous debris meeting the aforementioned fibrous debris classifications has been deemed to readily transport based on the testing performed in support of the subject NUREG/CRs.

- The percentage of fine fibrous debris 'contained' in the PCI classification of smalls was 16% that required additional processing to free the fine fibrous debris.

- Observations and comments by the Staff and lessons learned by PCI/AREVA/Alden during the initial Large Flume Test for a Licensee were incorporated into all subsequent tests and the Large Flume Test Protocol.

- Actual preparation (i.e., mixing of debris) of fibrous debris and introduction of same for Licensee Large Flume Tests has consistently been performed by many of the same Alden personnel

As previously discussed, the Large Flume Test fibrous debris preparation, sequencing, concentration, and potential agglomeration of debris following a post-LOCA event is both prototypical and conservative for PNP.

In addition, the following should be noted.

- There is no objective regulatory and/or industry guidance or criteria that addresses the issues of ***wet fibrous debris size classification***, debris sequencing, concentration of debris slurries prepared for testing, the potential for debris to agglomerate during preparation and addition of same to the test flume in support of a prototypical integrated test.

- The fibrous debris preparation and introduction of same to the Large Test Flume does represent a very conservative quantity of small fines including fines and small fiber clumps which are transported in the representative Licensee flow streams. Since the fibrous debris is transportable, it will collect on the Licensee test strainer based on the expected Licensee post-LOCA conditions.

To re-state - the debris preparation, sequencing of debris, concentration of debris slurries prepared for testing, the potential for debris to agglomerate during preparation and addition of same was prototypical of the expected Licensee post-LOCA conditions, and very conservatively represented the actual and expected Licensee post-LOCA conditions within the containment.

In conclusion, the preparation, concentration, and introduction sequencing of fibrous debris did not promote the agglomeration of the debris and did not inhibit the transport of same other than what would have naturally occurred in an open, free flowing water stream such as what would occur in a Licensee's post-LOCA containment following initiation of ECCS/CSS recirculation. Therefore, the subject fibrous debris was properly prepared and did not agglomerate or adversely affect the debris transport to the strainer. The PNP Large Flume Test was conservative and prototypical of the actual Licensee post-LOCA containment conditions and LOCA scenario.

Response to RAI26a Issue 2, *debris introduction sequence not non-conservatively affect transport*:

The PNP Design Basis test (Test 4) debris addition sequence was conservative and prototypical for an integrated debris transport and head loss test. Accordingly, the PNP ARL Large Flume Test debris addition sequence did not adversely affect the ability of transportable debris to reach the test strainer. The sequencing and concentration of debris slurries prepared for testing, the potential for debris to agglomerate during preparation and addition of same was prototypical and also very conservatively, since the actual and expected PNP post-LOCA conditions within the containment were represented. Please refer to the responses to RAI 17e and 28 for additional information and discussion. The subject RAI response addresses and provides additional and related information for RAI 26a.

Debris Introduction & Sequencing

The PNP bounding debris head loss tests performed in November 2008 as documented in the test report met the intent of the discussions between the Staff and PNP/PCI/AREVA/ARL (ADAMS Accession No. ML080310263), and utilized the following sequence in order of debris addition:

- **Batch 1** (25% of latent fiber debris quantity)
- **Batch 2** (Cal-Sil)
- **Batch 3** (acrylic powder – coating surrogate)
- **Batch 4** (dirt & dust)
- **Batch 5 (**Sil-Col-Sil)
- **Batch 6** (tin powder – IOZ surrogate)
- **Batch 7 - 11** (NUKON & mineral wool – fine fibrous debris)
- **Batch 12** (1/32" acrylic paint chips – coating surrogate)
- **Batch 13** (NUKON – small fibrous debris)
- **Batch 14** (Cal-Sil – eroded)
- **Batch 15 & 16** (NUKON & mineral wool – eroded)
- **Batch 17 - 55** (aluminum oxyhydroxide – PNP design basis chemicals)
- **Batch 56 - 117** (aluminum oxyhydroxide – PNP beyond design basis chemicals)

Each debris type in a 'batch' was mixed in an individual container and separately added to the test flume. In addition, a minimum of two (2) pool turnovers took place between the additions of subsequent debris types.

Also, the debris types were sequenced from the most transportable to the least transportable with the exception of batch 15 and 16. These batches represented the potentially eroded NUKON and mineral wool fibrous debris that was determined not to transport. The sequencing was based on the prototypical post-LOCA conditions that fibrous debris erosion would not immediately occur, but would take place at some later time post-LOCA when the combination of wash-down, spray, and recirculation were present.

Therefore, it can be concluded that the sequencing of fibrous, particulate, and chemical precipitate debris did not affect the transport of the subsequent debris being added to the test flume nor the PNP bounding debris head loss test results. This conclusion is supported based on the following facts:

- There were two (2) or more flume turnovers before the addition of the next debris type to ensure that the debris type had adequate time to transport within the flume. The delay in the addition of subsequent debris would ensure that the previous debris was not prohibited from potential transport by the subsequent debris.

- One (1) flume turnover for PNP takes approximately 14.15 minutes based on the PNP Design Basis scaled ECCS/CSS flow rates and ARL CFD model. At the slowest PNP scaled flume flow velocity of 0.0682 ft/s, debris added to the test flume could travel a distance of approximately 58 ft during the approximately 14.15 minute duration required for one (1) flume turnover. The PNP test flume length from the point of debris introduction to the PNP strainer module is approximately 30 ft. Therefore, the added debris could travel a potential distance of *almost 4 times* the length of the PNP test flume before the subsequent addition of debris takes place based on the *lowest* PNP scaled flume flow velocity and two (2) flume turnovers. Subsequent added debris would not be prohibited from being transported by previously added debris.

- Floating and/or settled debris would not preclude the transport of subsequent debris since it is located at the outside ‘extremes’ of the flume flow boundaries, away from the subject debris.

In conclusion, the introduction sequencing of PNP debris did not promote the agglomeration of the debris and did not inhibit the transport of same other than what would have naturally occurred in an open, free flowing water stream such as what would occur in the PNP post-LOCA containment following initiation of ECCS/CSS recirculation.

NRC Request

b. *14.q: The February 27, 2008, supplemental response states that containment accident pressure was not credited in evaluating flashing across the strainer. However, the submergence of the strainer is small when compared to the strainer head loss. In the supplemental response the licensee’s discussion of air ingestion into the strainer is* *not well supported. The licensee stated on Page 41 that the NUREG/CR-6224 correlation indicates 0.0% void fraction downstream of the screen. This statement does not appear correct, particularly in light of the statement on Page 46 of the supplemental response that no containment accident pressure was credited in the flashing calculation. The bases for the conclusion that flashing will not occur should be provided.*

The licensee provided updated information on the potential for flashing across the debris bed. Upon further review of the strainer design, the NRC staff believes that, since the strainer is vented to the atmosphere, flashing will not occur across the debris bed. The exception to this is if the water height in containment exceeds the elevation of the strainer vents. This could occur because the vents are relatively low in elevation. The vents are about 2.2 ft above the top of the strainer. Therefore if debris head loss is maintained less than 2.2 ft, flashing should not occur. The strainer design limits debris head loss to 1.57 ft. If this design parameter is not changed flashing will not occur. Please provide the maximum LOCA flood level and verify that the vent is not covered or evaluate the potential effects on deaeration and flashing.

Entergy Nuclear Operations Response 26b:

The staff inquired about whether flashing would occur across the strainer debris bed. The updated submittal provided in June 2009 summarized the conditions that impact flashing across the PLP strainer debris bed. The updated submittal concluded that there is only marginal strainer submergence for a large break LOCA to preclude flashing and the containment sump strainer is partially uncovered for a small break LOCA. ENO evaluated the containment overpressure for the short time period after the switchover to recirculation mode and before there is significant subcooling in the sump. The updated submittal provided in June 2009 concluded that the available containment overpressure is more than adequate to preclude the sump inventory from flashing when passing through the debris bed.

Under the conservative assumption of zero containment overpressure which was shown to be overly conservative based on the June 2009 submittal, there is a potential concern with flashing for the LBLOCA scenario with the flow passing through the strainer debris bed. Flashing will occur across the debris bed if the static head of water above the strainer module is less than the maximum strainer debris head loss limit of 1.57 feet (Reference EC12249, Rev. 0). Therefore, the potential exists for flashing across the strainer debris bed with the conservative assumptions that (a) the containment pressure equals the vapor pressure at the containment sump inventory temperature and (b) the head loss across the strainer debris bed is at its maximum design limit. However, the following should be noted:

i. Flashing across the debris bed is not considered a significant concern since the flow must descend to the level of the core tube, and below, to reach the sump; providing additional static head to collapse any voids created associated with flashing.

ii. Long term in the event, when the containment sump inventory cools, the containment pressure will be greater than the vapor pressure of the sump inventory providing significant pressure margin to prevent flashing. The minimum containment pressure long term in the event is bounded by the minimum containment pressure prior to the accident.

iii. At containment water levels that do not submerge the containment sump vents, where the submergence above the strainer modules is less than 1.82 feet (595' – 593.18') (Reference Drawing M-74, Sheet 1, Rev. 13; VEN-M802, Sheet 1, Rev. 0 and VEN-M802, Sheet 2, Rev. 1), the containment sump vents will be remain open to atmosphere allowing the escape of any possible entrained vapor.

Under the conservative assumption of zero containment over-pressure for the SBLOCA condition, the sump inventory may experience flashing when passing through the debris bed. The condition does not represent a concern since the potential for vapor phase transport through the strainer is minimal, given the interior of the strainer is in direct communication with the containment atmosphere.

This RAI inquires specifically about the impact of higher containment water levels that submerge the containment sump vents on flashing across the debris bed. At a containment water level of 595 feet, when the water level begins to exceed the containment sump vent elevation, there would be 1.82 feet (595' – 593.18') (Reference Drawing M-74, Sheet 1, Rev. 13; VEN-M802, Sheet 1, Rev. 0 and VEN-M802, Sheet 2, Rev. 1) of static head above the top of strainer modules. Since this static head exceeds the debris head loss design limit of 1.57 feet (Reference EC12249, Rev. 0), there is adequate static head of water above the strainer modules to prevent flashing assuming no containment overpressure. As described above, ENO concludes that the available containment overpressure is more than adequate to preclude the sump inventory from flashing when passing through the debris bed. Therefore, ENO concludes that the increased containment water level that submerges the containment sump vents will provide an increased static head of water above the strainer modules that will further suppress the potential for the sump inventory from flashing when passing through the strainer debris bed.

NRC Request

27. <u>*(Audit Open Item 6.1)*</u> *The licensee should provide a justification that Test 4 resulted in a realistic or conservative head loss for the strainer. Specifically, the licensee should provide additional information that justifies that a change in strainer hole size from 0.045 inches (Test 2, high head loss) to 0.095 inches (Test 4, low head loss) would result in a change in head loss of greater than an order of magnitude. The issues identified briefly below and discussed in detail in the NRC staff Chemical Audit Report of Palisades (ADAMS Accession No. ML091070664) should be considered in the development of the response to this open item. The audit report should be referenced and the issues discussed in the report should be fully addressed. The licensee provided some information regarding this issue and its sub-parts. However, additional information is required as described below.*

   a. *Please describe the testing methodology for the referenced PCI testing for foreign plants that shows that strainer hole size results in significant changes in head loss across the strainer. Provide information that validates that the testing was conducted similarly to the Palisades testing or that the results of the testing can be applied to the Palisades strainer.*

Entergy Nuclear Operations Response 27a:

The foreign utility strainer head loss testing and test results described in PCI proprietary document (ML090050043) as submitted by PNP to the Staff discusses the test methodology. Specifically, on Attachment 1, page 1 of 2 the subject document it states in part, … *All tests were in the Alden small flume to a testing protocol similar to that used by PCI for small flume testing in the U.S..* The Staff is very familiar with the Small Flume Test Protocol utilized for US Licensee head loss testing at ARL. The Staff has previously witnessed application of the Small Flume Test Protocol for US Licensee plants on a number of occasions, which were subsequently documented by the Staff (i.e., ML052230269 (03/17/05) and ML060750340 (01/18/06)).

As stated, the Small Flume Test Protocol was utilized for the foreign utility strainer head loss test program. On the other hand, PNP utilized the Large Flume Test Protocol which is similar, but is based on a number of different criteria and objectives. However in both cases, the PCI Sure-Flow® Strainer technology was utilized in the strainer design and therefore a comparison of the test results can be made, specifically the effect of strainer perforated plate hole size and head loss.

The document (ML090050043) previously provided to the Staff presented a comparative summary that concluded that a smaller strainer perforated plate hole size opening will result in an increased strainer head loss when the design basis parameters are essentially the same. This conclusion was true for both the foreign utility and PNP when the strainer head loss test was performed to the same test protocol and similar design basis parameters with the only variable being the strainer perforated plate hole size in both cases.

In addition to the conclusions reached in the document (ML090050043), there are other technical references that support the findings previously offered in the RAI response by PNP. Some of them are discussed as follows.

The technical paper, *An Investigation of Flow Through Screens* by W.D. Barnes and E.G. Peterson that was contributed by the Hydraulic Division and presented at the Annual Meeting of the American Society of Mechanical Engineers (November 26 – December 1, 1950) further supports the test results that concluded that a smaller perforated plate hole size will have a higher head loss than a larger hole size. The paper concluded that the greater the solidity ratio, that is the fractional degree to which the screen or perforated plate obstructs the flow, the greater the head loss. In other words, the smaller the hole size, the greater the head loss. The paper states in part, … *If a considerable dissipation of energy , i.e., reduction of pressure, is required, this may be obtained with a single screen of high solidity ratio – but at the expense of evenness in the velocity distribution*.

Another technical paper, *Discharge Coefficients Through Perforated Plates* by P.A. Kolodzie, Jr. and Matthew Van Winkle printed in the AIChE Journal, Volume 3, No. 3, 1957 further supports the test results and concluded that … *The variables which affect the orifice coefficients were found to be the hole diameter, hole pitch, plate thickness, fraction of the plate covered by the perforated plate area, and a Reynolds number based on the hole diameter.*

In the text, *Handbook of Hydraulic Resistance* (3rd Edition) by I.E. Idelchik, specifically Chapter 8, *Resistance to Flow through Barriers Uniformly Distributed Over the Channel Cross Section: Resistance Coefficients of Grids, Screens, Porous Layers, and Packings* there is additional supporting discussion that hole size affects the resistance coefficient as it relates to head loss.

It can therefore be reasonably concluded, that a smaller perforated plate hole size will have a higher head loss than a larger hole size.

NRC Request

b. *Please provide an evaluation of the information provided by PCI to the NRC staff in ADAMS Accession No. ML090050043 (proprietary) that states that hole size has not been observed to directly impact head loss performance and provide information as to why the Palisades strainer would not behave similarly to the description in that document.*

Entergy Nuclear Operations Response 27b:

As discussed in detail for the RAI 27a response, it was concluded that a smaller perforated plate hole size will have a higher head loss than a larger hole size. Therefore, it does not appear that the Staff's RAI statement, *Please provide an evaluation of the information provided by PCI to the staff in ML090050043 (proprietary)* ***that states that hole size has not been observed to directly impact head loss performance*** *and provide information as to why the Palisades strainer would not behave similarly to the description in that document.*, **is correct, since there is no supporting basis for the subject Staff statement.**

As a matter of fact, the PCI document (ML090050043) supports, states, and concluded that perforated plate hole size does make a difference. Specifically, a smaller perforated plate hole size based on the same design basis parameters will have a higher head loss than a larger perforated plate hole size.

It appears that the Staff's statement may be incorrect. If the Staff can provide further clarification regarding RAI 27b, PNP will respond accordingly. However, based on the statements and information provide by the Staff, PNP cannot provide further expalantion at this time.

NRC Request

c. *Please provide an evaluation of why the addition of eroded fines resulted in a significant head loss increase indicating that additional fibrous debris transport affected the ability of the bed to create head loss. This evaluation should concentrate on justification that fibrous debris transport issues during the test did not result in the large difference in head loss between the two tests.*

Entergy Nuclear Operations Response 27c:

The AREVA Test Plan (63-9095797-001) and the Test Report (66-9097941-000) were reviewed with regard to both Tests 2 and 4, respectively. This was done since the Staff did not state which test was the basis for their first statement regarding the addition of eroded fibers and increased head loss. The review of the both AREVA documents could not support the Staff's statement regarding the addition of eroded fines. PNP is not sure as to what documents the Staff has reviewed that supports their statement.

Furthermore, in the case of Test 2, eroded fines were never added to the test flume due to the documented high head loss. Test 2 was terminated before the eroded fines were added to the flume. A further review of Test 4 also did not support the Staff's statement.

It appears that the Staff's statement may be incorrect or based on other information that PNP has not seen. If the Staff can provide further clarification regarding RAI 27c, PNP will respond accordingly. However, based on the statements and information provide by the Staff, PNP cannot respond at this time.

NRC Request

d. *Please provide an evaluation of the information supplied by PCI that speculates that the effect of hole size diminishes above 0.045 inches and the how this relates to the smaller Palisades hole size of 0.045 inches.*

Entergy Nuclear Operations Response 27d:

As discussed in detail for the RAI 27a response, it was concluded that a smaller perforated plate hole size results in a larger head loss. As stated in the PCI document (ML090050043), PCI's response and statements are based on the limited test data from foreign utility strainer testing and that of PNP. Therefore, based on the limited test data, PCI speculated that the difference in head loss values was due to the hole size differences. The foreign utility strainer head loss testing and test results described in PCI proprietary document (ML090050043) as submitted by PNP to the Staff discusses and compares the head loss testing for that of the foreign utility and PNP. Specifically, on Attachment 1, page 2 of 2 the subject document it states in part, … *PCI speculates the affect of hole size diminishes above the 0.045" size hole; and becomes increasingly detrimental to head losses below 0.045" since PCI has had some success in testing with 0.045 "holes*…

PCI's statements were based on the limited testing data available. In addition, the response to RAI 27a provides further support for the conclusion that smaller perforated plate hole sizes will have a higher head loss than a larger perforated plate hole size.

NRC Request

e. *Please provide an evaluation of the physical phenomenon caused by the difference in strainer hole size that resulted in a debris bed morphology difference significant enough to result in the large difference in head loss values between the two tests.*

Entergy Nuclear Operations Response 27e:

As discussed as part of the response to RAI 27a and to a lesser extent in RAI 27d, it was concluded that a smaller perforated plate hole size will have a higher head loss than a larger perforated plate hole size. PNP did not make any statements nor reach conclusions with regard to small or large perforated plate hole size and their potential to initiate physical phenomenon and resultant debris bed morphology changes as they relate to head loss.

Any analysis and/or evaluation would be purely speculative regarding perorated plate hole size and debris bed morphology as the result of physical phenomena. As far as PNP knows there is no know publicly available test reports that address the issue of perforated plate hole size and post-LOCA debris bed head loss. In light of the unavailability of public test reports, the PCI test data for a foreign utility and that for PNP with regard to perforated plate hole size as it relates to strainer debris laden head loss may be the only test data available. The reference documents discussed in RAI response 27a do support the effect of perforated plate hole size and head loss, but they are all based on tests performed with clean fluids and no debris of any kind.

NRC Request

f. *Please provide an evaluation of how the debris addition sequence differences between the two tests affected the results. Specifically, address why the separate addition of Nukon and mineral wool in Test 2 provided similar transport of the fiber when compared to transport when the fiber addition consisted of a mixture of Nukon and mineral wool. Provide justification that excessive interaction of the fiber types did not occur and that transport was not affected non-conservatively. Consider that the concentration of the fibrous debris in the test flume is likely much higher than would be expected in the plant. Provide information from the testing that validates the evaluation. Alternately provide information that shows that the two fibrous debris types would both be generated by all break scenarios and arrive at the strainer near field simultaneously, and that the concentration in the test flume had no significant effect.*

Entergy Nuclear Operations Response 27f:

The June 30, 2009 submittal provided information related to RAI 27f. In general, the mixing was discussed as prototypical and similar transport was expected. Based on discussions to date with the NRC, certain elements of the existing testing protocol will not be accepted by the NRC without refinements. Therefore, to eliminate any concern over whether the mixing of Nukon and mineral wool had any unjustified advantageous effect, for any future testing using a refined PCI flume test protocol, ENO would plan to add the Nukon and mineral wool separately to eliminate this potential NRC concern.

NRC Request

28. *(Audit Open Item 6.2, related to 14.e above) The licensee should provide information that the test methodology resulted in realistic or conservative strainer head loss testing results. In particular, debris preparation and introduction methods used during testing should be justified as prototypical or conservative. The issues identified briefly below and discussed in detail in the NRC staff Chemical Audit Report of Palisades (ADAMS Accession No. ML091070664) should be considered in the development of the response to this open item. Items 1, 2, and 3 discussed in Section 5.4.2 of the audit report should be considered when developing the response to this open item. The licensee provided responses to the issues listed below, but additional information is required as described below:*

   a. *Observation of test video documenting the addition of fibrous debris indicated that the debris may not have been prepared as finely as NRC staff guidance would suggest or may have agglomerated during the debris introduction process. There are several examples on the video that indicate that fiber preparation and/or introduction may not have been controlled to the degree prescribed in NRC staff guidance. The licensee stated that the debris distribution used during the testing was representative of the post-LOCA debris distribution expected for the plant. The licensee further stated that the protocol implemented was consistent with other tests run by PCI that the NRC staff had observed. In addition, it was noted that some variation in debris form is expected depending on the debris preparation and introduction methods. The NRC staff's position is that these processes should be controlled such that consistent debris characteristics are maintained. The NRC staff's observations of previous testing for various plants resulted in trip reports that documented that fibrous debris preparation and introduction needed to be more closely controlled to ensure that fine fibers were properly prepared and introduced into the test flume. The NRC staff has noted inconsistency with these processes during PCI test observations as documented in trip reports. The agglomeration noted on the video of the Palisades test was excessive for fine fibers. The licensee further noted that any clumped fibrous debris would break up as it entered the flume and that the video alone is not a valid basis for judging the final form of the fiber once it enters the flow stream. The NRC staff agrees that some break down of clumps will likely occur when the fiber enters the flow stream. However, the degree of this effect is unknown. In addition, the NRC staff could not determine that the debris added to the flume was actually fine debris and may have been larger pieces. In the past, when the NRC staff noted excessive agglomeration, PCI has adjusted its practices to ensure that the debris was separated adequately that it could be seen that the debris was fine* *and not agglomerated. The licensee's response does not adequately address this issue. Please provide information that justifies that debris introduction and preparation provided prototypical or conservative test results.*

Entergy Nuclear Operations Response 28a:

The PNP Design Basis test (Test 4) debris preparation and addition was conservative and prototypical for an integrated debris transport and head loss test. Accordingly, the PNP ARL Large Flume Test debris addition did not adversely affect the ability of transportable debris to reach the test strainer. The concentration of debris slurries prepared for testing, the potential for debris to agglomerate during preparation and addition of same was prototypical and also very conservatively, since the actual and expected PNP post-LOCA conditions within the containment were represented. Please refer to the responses to RAI 17c and 26a for additional information and discussion. The subject RAI responses address and provide additional and related information for RAI #28a.

The concentration of debris slurries prepared for testing, the potential for debris to agglomerate during preparation and addition of same was prototypical of the expected PNP post-LOCA conditions, and very conservatively represented the actual and expected PNP post-LOCA conditions within the containment.

The agglomeration of debris did not occur due to prototypical debris concentrations during the preparation, during the addition of same, or within the ARL test flume for PNP. During debris addition slurries prepared for testing, the potential for debris to agglomerate during preparation and addition of same was prototypical of the expected PNP post-LOCA conditions, and very conservatively represented the actual and expected PNP post-LOCA conditions within the containment.

It should be noted that there are no guidance documents, such as NUREG/CRs or similar type documents that define excessive agglomeration, prototypical debris concentrations as they relate to agglomeration during debris preparation or addition, or higher than expected debris concentrations during debris addition as related to testing. Simply put, there is absolutely no available definitive or subjective documents and/or information that discuss the term prototypical agglomeration, the aforementioned issues or their potential impact on head loss testing.

Since there are no definitive or subjective criteria and/or guidance available with regard to the subject issues, the agglomeration of fibrous debris and more importantly, the homogeneous 'mixing' of both fibrous and particulate debris in the period prior to and after ECC/SCSS pump recirculation initiation would be realistically expected and prototypical. Numerous NUREG/CRs including 6773 as well as others support the agglomeration of debris, the settlement of same, the concentration of same, as well as the homogeneous ‘mixing’ of fibrous and particulate debris prior to and after the initiation of ECCS/CSS pump recirculation. Accordingly, the PNP test at ARL utilized the limited guidance found in NUREG/CR-6773.

PCI also utilized the guidance provided in NEI 04-07 and the Staff’s SER for NEI 04-07 for the initial preparation of the Large Flume Test Protocol. The subject Protocol was discussed face-to-face and in numerous telephone conversations (ML072530885 & ML080370262) with the Staff prior to the first Licensee test in early 2008. Based on observation by and comments from the Staff (ML081830645) during the first Licensee test as well as ‘lessons learned’ from the subject test, the Large Flume Test Protocol was further revised to address both the Staff’s comments and the ‘lessons learned’.

The Staff stated in a Licensee’s July 9, 2009 public meeting to discuss applicable RAIs, that the fiber classes 1 – 3 per NUREG/CR-6808, Table 3-2 are acceptable with regard to ‘defining’ fine fiber. It should be noted that the subject NUREG/CR and Table are specifically associated with *Section 3.1.2.1 Size Classification of Fibrous Debris* of the subject NUREG/CR. The subject Section is based on air-blast testing experiments of fibrous debris. In other words, the debris sizing classification in Table 3-2 is based on ***dry*** simulated post-LOCA destroyed fibrous debris. The subject NUREG/CR does not address the aspects of testing with the subject dry fibrous debris, the sizing of same, agglomeration of same, or the affects of agglomeration on testing. It should be noted that no reference is made to NUREG/CR-6808 in either NEI 04-07 or the Staff’s SER with regard to the specific subject of fibrous debris sizing classifications or Table 3-2. Most importantly, it should be noted that the Staff’s ‘new’ position with regard to fibrous debris classification for testing was made public approximately eight (8) months after the PNP testing was completed in November 2008.

Prior to the initiation of any Licensee testing in early 2008 and the completion of the Large Flume Test Protocol, PCI presented various samples of processed dry fibrous debris to the Staff in late 2007 during a GSI-191 public meeting (the Staff was given the samples and is believed to still have the subject samples in their possession). The samples were presented to the Staff in order to solicit comments or recommendations regarding the processing and size classification of the processed dry fibrous debris with regard to the proposed Large Flume Test Protocol. The subject samples consisted of the three (3) classifications of fibrous debris: latent/fines, small fines, and larges as defined in NEI 04-07 and the subsequent Staff SER.

The Staff indicated that the subject samples were representative of what they expected for each of the three (3) subject classifications of dry fibrous debris. It should be noted that PCI and the Licensees utilize a more conservative definition of small fines than that of the guidance documents (i.e., NEI 04-07 and the Staff’s SER for NEI 04-07). PCI utilizes a 1” x 4” grating in lieu of the recommended 4” x 4" grating to separate fines/smalls from larges. Therefore, the PCI definition of small fines results in significantly smaller-sized fibrous debris than, if the guidance recommendation were followed. Again, it should be noted that NEI 04-07, the Staff's SER for same, or the March Guidance Document specifically addressed, provided guidance, or discussed the size classification of small fines and larges.

Following the first Licensee Large Flume Test in February 2008, the Staff in March 2008 issued the document, *NRC Staff Review Guidance Regarding Generic Letter 2004-02 Closure in the Area of Strainer Head Loss and Vortexing* (also known as the March Guidance Document) (ML072600348). It should be noted that no reference is made to NUREG/CR-6808 in the March Guidance Document with regard to the specific subject of fibrous debris sizing classifications or Table 3-2. However, the various terms fines, fine fiber, finer fiber, etc. are utilized in the subject document, but are never defined within the document and/or reference made to NUREG/CR-6808, specifically Table 3-2.

During the public GSI-191 meeting of October 24, 2007, held prior to the initial Licensee Large Flume Test, the issue of fibrous debris 'fines' was specifically discussed and questions were raised by the Licensee, PWROG, and NEI representatives. In this meeting, the Staff agreed and stated in the meeting that ***'fines' were <u>not</u> single fibers, but could be 'clumps' or 'bunches' of fibers***. No further description or definition of what the Staff meant with regard to 'clumps' or 'bunches' was provided, in no case was NUREG/CR-6808 discussed in this regard, and most importantly, the term prototypical agglomeration was never discussed. Attendees at the subject meeting left with the understanding that fibrous debris 'fines' were ***not*** individual fibers.

In the final version of the March Guidance Document (ML072600348), there is much discussion by the Staff that 'fine' fibrous debris ***be individually or readily suspendable fibers*** (Page 4 as well as others). The discussion in the subject document is in direct contradiction with the Staff SER for NEI 04-07 and the Staff statements made in the October 24, 2007 public meeting, that ***'fines' were <u>not</u> single fibers, but could be 'clumps' or 'bunches' of fibers***.

In the March Guidance Document, there is also much discussion by the Staff that fine fibrous debris should be mixed so that agglomeration does not occur that would not be prototypical. However, no guidance or description is provided by the Staff of what is meant by agglomeration or 'agglomeration does not occur that would not be prototypical' as has been previously discussed. It would appear that 'clumps' and 'bunches' based on previous Staff discussion (i.e., October 24, 2007 GSI-191 public meeting) would be appropriate with regard to defining agglomeration.

It appears that the Staff's primary concern with regard to fine fibrous debris agglomeration is that the subject debris will settle and not transport as readily as individual fibers. However, there is no basis provided by the Staff as to why they believe that fine fibrous debris would not agglomerate in the post-LOCA containment environment. As a matter of fact it would seem that it would be more likely that the fine fibrous debris would actually agglomerate, would not readily transport, and instead would readily sink as individual fibers in the quiescent post-LOCA containment 212 ^oF plus fluid prior to the initiation of ECCS recirculation. A review of various regulatory documents such as NUREG/CRs provides no support that fine fibrous debris will exist as individual fibers and not agglomerate in the post-LOCA containment. However, on the other hand there are regulatory documents that support the opposite position, that is, fine fibrous debris including individual fibers will settle and not readily transport.

NUREG/CR-2982 *Buoyancy, Transport, and Head Loss of Fibrous Reactor Insulation* on Page 19, Section 3.1 Buoyancy Tests, specifically paragraphs a), c), and e) state in part:

b) In general, the time needed for insulation to sink was ***found to be less at higher water temperatures.*** (emphasis added)

c) The fiberglass (Filomat) readily absorbs water, ***particularly hot water, and sinks rapidly (from 20 to 30 seconds in 120 ^oF water)***. ***This is also true for individual fibers***. (emphasis added)

e) … Damaged fiberglass insulation pillows ***will sink before activation of the recirculation system*** … (emphasis added)

In addition to the conclusions reached in NUREG/CR-2982 regarding rapid sinking of fibrous debris in heated water prototypical of containment post-LOCA fluid conditions, NUREG/CR-6772, *GSI-191: Separate-Effects Characterization of Debris Transport in Water,* provides further evidence and support that fibrous debris will rapidly sink in heated water. Section 2.2.1.1 *Effect of Temperature* states in part … *Post-LOCA water temperature is approximately 80 ^oC, which is significantly different for the ambient temperature proposed for use in the test program. It can be postulated that water temperature could affect debris settling characteristics because density and viscosity are temperature-dependent. Further the saturation rates of debris may be temperature-dependent because surface tension varies with temperature. This set of experiments provided data to quantify these effects, as described below.*

<u>Saturation of Debris in Hot Water.</u> *When fibrous debris was introduced to water at ambient temperature, it was observed to float on the surface for more than 24 h. Even when shredded fiber fragments were forcibly immersed in ambient-temperature water for 24 h, they subsequently would rise up to the surface when released. However, if the fiber shreds were immersed in hot water (80 ^oC) for as little as 2 min, they readily sank and remained submerged. In the aftermath of a*

LOCA, the temperature of water in a PWR recirculation sump is likely to be closer to 80 ^{o}C than to (~ 20 ^{o}C).

It should be noted that 80 ^{o}C is 176 ^{o}F, and 20 ^{o}C is 68 ^{o}F. Therefore debris settlement and transport tests in ambient (i.e., cold) water are very conservative but are significantly non-prototypical of the post-LOCA containment fluid conditions. In addition, the tests and subsequent results would provide non-prototypical guidance with regard to fibrous debris transport and settlement issues and the evaluation of same. Simply stated, the fibrous debris including individual fibers would settle at a much greater rate and would not transport as readily.

Since the post-LOCA water in all cases for all Licensees will initially easily exceed 120 ^{o}F, it can be concluded based on the subject NUREG/CR report that fiberglass insulation and more importantly individual fiberglass fibers will sink before the initiation (i.e., approximately 15 – 40 minutes post-LOCA) of the ECCS in the recirculation mode. It is interesting to note that neither NUREG/CR-6808 nor the March Guidance Document (ML072600348) makes any mention of NUREG/CR-2982 or NUREG/CR-6772, and specifically that fiberglass individual fibers will sink in 20 to 30 seconds in 120 ^{o}F water. In addition during Licensee fiber by-pass testing at the Alden Research Laboratory it was also noted that significant quantities of fibrous debris including fine fibrous debris settled and did not reach the strainer in the prototypical flow streams and at water temperatures of approximately 120 ^{o}F. It should be noted that the subject fibrous debris was not allowed to ‘sit’ in a quiescent flume, but was instead very conservatively added to a moving flume flow stream, and still significant settling of the fibrous debris occurred.

NUREG/CR-6224 may be the only document that indirectly discusses non-agglomeration of debris (i.e., fibrous and particulate). However, this NUREG/CR is neither prototypical nor realistic of post-LOCA containment conditions with regard to debris size, configuration, agglomeration, mixing, etc. Instead, the subject NUREG/CR discusses closed vertical pipe loop (CVPL) testing of various debris types under theoretical extremely conservative, non-prototypical, and non-realistic conditions (i.e., addition of debris types in non-prototypical configurations and quantities, non-prototypical sequencing of debris types and sizes/configurations, non-prototypical flow velocities, non-prototypical application of gravity, non-prototypical post-LOCA conditions, etc.). The subject NUREG/CR also applies pipe flow parameters and conditions to the post-LOCA containment, when in reality the post-LOCA containment is open-channel flow. In addition, the analysis of the two (2) flow types is considerably different and not related. The PNP Large Flume Test performed at ARL is an integrated test that incorporates both debris transport and debris head loss testing. Therefore, most if not all of the content of NUREG/CR-6224 does not apply to the subject PNP test. However, it appears that the Staff is applying portions of NUREG/CR-6224 to the

PNP Large Flume Test, specifically debris sequencing, fibrous debris classification, and fibrous debris transport/settlement (i.e., agglomeration).

The application of NUREG/CR-6224 test conditions and criteria with regard to the review of the PNP Large Flume Test at ARL which is an integrated test (i.e., debris transport and head loss) is therefore neither appropriate nor relevant with respect to the realistic and prototypical post-LOCA conditions expected in the PNP containment, and which were utilized to the extent possible in the PNP Large Flume Test at ARL.

As previously discussed, the PNP concentration and potential agglomeration of fibrous debris following a post-LOCA event ***is*** prototypical and do not reflect the non-prototypical but extremely conservative positions of NUREG/CR-6224. The Staff's real concern is therefore interpreted to mean - did the fibrous debris utilized in the PNP test have adequate separation (fibers) to facilitate fibrous debris transport and allow collection on the test strainer in a representative or bounding manner based on the PNP expected post-LOCA conditions? The affect on head loss caused by fibrous debris agglomerating in the test flume is not relevant so long as the fibrous debris transports in the test flume and the collection of fibrous debris on the test strainer is representative and bounding to the specific PNP plant conditions.

The responses to RAIs 17e and 26a, inclusive form a comprehensive answer to this question. To re-state the response to this RAI - The concentration of fibrous debris slurries prepared for testing, the potential for fibrous debris to agglomerate during preparation, and addition of same was prototypical of the expected PNP post-LOCA conditions, and very conservatively represented the actual and expected PNP post-LOCA conditions within the containment.

In addition, the following should be noted.

- The fibrous debris preparation and introduction of same to the ARL test flume does represent a very conservative quantity of small fines including fines and small fiber clumps which are transported in the representative PNP flow streams. Since the fibrous debris is transportable, it will collect on the PNP test strainer based on the expected PNP post-LOCA fluid flow conditions.

- PCI has processed raw fibrous debris materials into fine fibrous debris representative of either eroded or latent fibrous debris and small fines by recognized mechanical process devices (i.e., chipper (smalls) & Munson machine (fines)).

- PCI has separated (i.e., size distribution) the processed fibrous debris utilizing a 1' x 4" grating opening which is ***more conservative*** than the 4" x 4" grating opening identified in NEI 04-07 and the Staff's SER for the same.

- Samples of latent, fines, small fines, and larges were provided to the Staff before any Large Flume Testing was initiated and were found to be *representative of what the Staff had expected*.

- Fibrous debris is processed and prepared in accordance with the PCI 'white paper' SSFS-TD-2007-004 *Sure-Flow Suction Strainer - Testing Debris Preparation & Surrogates*, the PCI 'white paper' SSFS-TD-2007-004, Supplement 1, Rev. 1, *Sure-Flow Suction Strainer – Testing Debris Preparation & Surrogates* (ML092430056 & ML092580203), and the Large Flume Test Protocol which have been provided to and discussed with the Staff.

- Documented positive observations and comments by the Staff (ML081840095) and lessons learned by PCI/AREVA/Alden during the initial Large Flume Test for a Licensee were incorporated into all subsequent tests.

- Actual processing, preparation (i.e., mixing of debris for testing), and introduction of fibrous debris for ARL Large Flume Testing has consistently been performed by the same PCI and Alden personnel, respectively.

To summarize, all of the fibrous debris (i.e., latent, fines, small fines, and smalls) for PNP as well as that for all of the other Licensees has been processed, prepared, and introduced to the test flume in accordance with the PCI 'white paper' *Sure-Flow Suction Strainer - Testing Debris Preparation & Surrogates*, the PCI/AREVA/Alden Large Flume Test Protocol, and most importantly by the same PCI and Alden personnel (in most cases). Observations and comments by the Staff and lessons learned by PCI/AREVA/Alden during the initial Large Flume Test for a Licensee were incorporated into all subsequent tests. Simply put there has been a significant level of consistency in the processing, preparation, and introduction of latent, fines/smalls, and large fibrous debris into the Large Test Flume. It should be further noted that samples of processed fibrous debris (dry material) as latent, fines/smalls, and larges were provided to the Staff and the determination was made that 'the samples were representative of what the Staff had expected.'

In conclusion, the preparation, concentration, and introduction of fibrous debris did not promote the agglomeration of the debris and did not inhibit the transport of same other than what would have naturally occurred in an open, free flowing water stream such as what would occur in the PNP post-LOCA containment following initiation of ECCS recirculation.

NRC Request

b. *The debris introduction sequence for the testing did not appear to be performed consistent with the procedure previously discussed between PCI/AREVA and the NRC staff. Some more easily transportable* *debris was added after less transportable debris. For example, debris added as eroded fibrous material was added after larger fibrous pieces. This is a potential non-conservative practice because in the test a large debris pile may form in the test flume. This pile may act as an impediment to the transport of debris that may otherwise transport if the pile was not present. In the plant such a debris pile is less likely to form because the concentration of debris is much lower than in the test. The debris captured in the flume overflow filters was also added at the original drop zone which is behind the debris pile. A portion of the latent fiber was added to the test flume prior to starting the recirculation pump. This may be non-conservative from a transport perspective because washdown and pool fill up transport is not modeled. It has been noted that the velocity of the flume is increased if a debris pile is present. While the debris pile will increase flume velocity to some extent, a porous debris pile on the flume bottom could capture debris such that the affect of higher flume velocity is negated. There are many variables that affect debris transport. The NRC staff could not determine that an adequate evaluation of these variables and their uncertainties was attained prior to the determination of debris introduction sequencing. The licensee stated that the addition of the eroded debris near the end of the non-chemical debris introduction is representative of the expected plant response. With the exception of the debris pile in the flume that would not be present in the plant, this is true. However, there are competing effects such that the debris pile in the flume may adversely affect the transport of the eroded fines. The NRC staff expects that the transport of fibrous debris in the flume over the debris pile may be dependent on the flume flow velocity with transport being more likely in higher flow streams. Because fine fibrous debris is known to be problematic for head loss, the licensee should employ test practices that ensure that the fibrous debris has an opportunity to transport similarly to expected plant transport. Alternately, the licensee could provide information that shows that the fine debris transports. During observations of a different test that added eroded fibers to the flume after other debris, the NRC staff was able to verify that the debris transported (based on changes in the head loss trend). A review of the head loss trend supplied in the licensee's supplemental response did not provide definitive information for this issue. Please provide justification that the debris introduction sequence did not affect head loss test results non-conservatively.*

Entergy Nuclear Operations Response 28b:

It should be noted that RAI 28b is almost identical in content to both RAI 17c and Staff Concern/Issue 3 from RAI 26a with regard to the issue of fibrous debris sequencing. Please refer to both RAI 17c and Staff Concern/Issue 3 from RAI 26a for additional discussion and explanation with regard to this issue.

The specific issue of eroded fibrous debris being added after other less transportable fibrous debris is in the test flume is addressed by the response to RAI 17c.

The new issue identified in RAI 28b, ***A portion of the latent fiber was added to the test flume prior to starting the recirculation pump.,*** was not addressed by the responses to RAIs 17c and Staff Concern/Issue 3 from 26a.

Based on the AREVA NP Test Plan for PNP, 25% of the latent fibrous debris was introduced along the length of the test flume prior to starting the recirculation pump. NUKON fine fiber was used as the debris constituent for latent fibers. A total of 0.40 lbm of NUKON fine fiber was weighed and introduced along the length of the test flume.

The location of post-LOCA debris before ECCS pump recirculation initiation is based on prototypical post-LOCA containment conditions indicating that the debris including latent fibrous debris would be scattered to varying degrees throughout the containment floor areas with heavier debris concentration immediately adjacent to the actual LOCA pipe break location. This prototypical condition is consistent with and based on the methodology and objectives documented in NUREG/CR–6773 regarding debris-transport tests for PWRs. Therefore, it is certainly reasonable to expect some latent fiber to be located near the strainer and on the containment floor prior to the initiation of ECCS recirculation. Please note the following:

1. Numerous NUREG/CRs including 2982, 6772, and 6773 confirm that fine fibrous debris settles quickly (i.e., one (1) minute or less) in water temperatures as low as 120 ºF which is considerably less than the actual initial post-LOCA expected water temperature of greater than 212 ºF.

2. There is approximately 15 - 45 minutes following the post-LOCA event prior to the initiation of ECCS recirculation. This would allow any fibrous debris including latent fiber to be subjected to both a significant time period and the greater than 212 ºF temperature water which would result in ideal conditions for settlement of the fibrous debris in the post-LOCA containment fluid as well as in the near field of the strainers. It should also be noted that the strainer/sump location is considered to be in a quiet zone when post-LOCA containment fill is complete. Regardless, 'some' fibrous debris is expected to be on the containment floor at the time of ECCS pump recirculation.

Therefore, it can be reasonably concluded that it is prototypical and representative that 'some' fibrous debris is located on the containment floor near the strainer/sump location when recirculation begins. The absence of 'some' fibrous debris during an initial Licensee's qualification test at ARL near the test strainer was, in fact, observed to be a weakness in the test protocol by the Staff who witnessed the test. In response to the comment, PCI revised the Test Plan and Protocol to begin introduction of either 0.5 lbs or 25% of the design basis latent fibrous quantity into the ARL test flume between the debris introduction drop zone and test strainer five (5) minutes prior to pump start to address this concern. All subsequent tests have followed this refinement to the Test Protocol which was discussed with the Staff approximately six (6) months prior to the PNP test.

To further address the Staff's concern, PCI/ARL implemented a number of special tests (August – September 2009) to observe in clean water (i.e., no particulate or chemical debris) the transportability of latent fibrous debris introduced five (5) minutes prior to pump start-up (i.e., simulated initiation of post-LOCA ECCS/CSS recirculation). The use of clean water without particulate debris is very conservative, since the particulate debris would have 'mixed' with the fibrous debris and resulted in significant trapping' or settlement of the 'mixed' fibrous and particulate debris. Implementation of the test without particulate debris is not prototypical of the expected Licensee post-LOCA conditions, but is very conservative with regard to the Test Protocol and test results. The test utilized various flow velocities that were bounding for various Licensee facilities and as were implemented in the ARL large flume test. ARL observed that the latent debris placed on the small flume floor with the pump off resulted in the subject fibrous debris being transported at various Licensee flow velocities, but very little of the debris reached the strainer. The flow velocity required to initiate the fibrous debris movement was usually greater than the actual Licensee flow rates and associated velocities. However, not much of the fibrous debris was transported to the strainer. In order to actually transport the fibrous debris to the strainer, flow velocities of more than 300% of the actual Licensee flow velocities were required.

Since the fibrous debris was observed to transport from its initial resting position in the subject small flume special tests, the introduction of 'some' latent fibrous debris prior to pump start was concluded to be realistic, representative, and prototypical of the actual PNP post-LOCA containment conditions and LOCA scenario.

NRC Request

c. *In some photos (especially the fiber only test photos), some fine fibrous debris appeared to be clumped into balls. The NRC staff has observed other tests during which shredded fiber has clumped into balls if not properly blended. The observed fibrous debris did not appear to exhibit properties that would be expected to result from jet impingement. The licensee stated that the debris was prepared prototypically. However, this question was specifically related to the pea-sized balls of fiber observed in the fiber-only test. The licensee* *should provide additional information that justifies that the fine fiber in the plant would exist, at least partially, in the form of small tight spheres, or provide an alternate explanation of the appearance of the finely prepared fiber.*

Entergy Nuclear Operations Response 28c:

A review of the videos was performed that documented the PNP Large Flume Test performed in November 2008. Specifically chapters 8, 9, 11, 13, 19, and 21 of the subject video were reviewed since they dealt with the issues regarding fibrous debris mixing and addition of the mixed fibrous debris to the test flume.

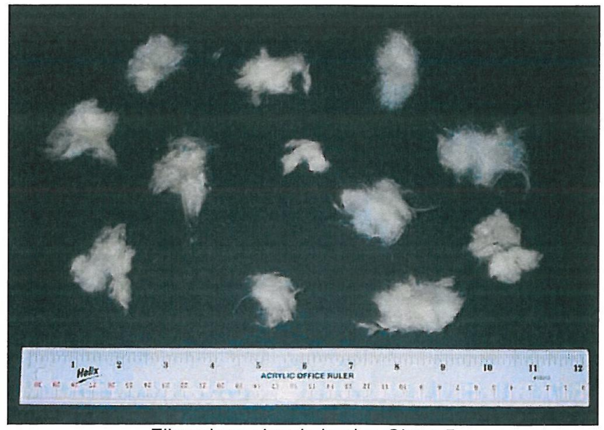
The review of the subject video chapters did not produce specific observation and/or recognition of the Staff's stated *pea-sized balls of fiber* or *in the form of small tight spheres*. It was observed that some of the fibrous debris within the containers as it was added to the test flume was somewhat 'lumpy' indicating that some of the fibrous debris was loosely connected, but was also indicative of Class 1, 2 & 3 fibrous debris as documented in NUREG/CR-6808, Table 3-2, that the Staff has previously indicated was an acceptable fibrous debris form for fine fibrous debris. However, there was as previously stated no specific observation that the subject fibrous debris was in the form of either *pea-sized balls* or *in the form of small tight spheres*.

The addition of the mixed fibrous debris to the test flume utilized 5-gallon buckets. As the fibrous debris is added to the test flume, the liquid portion of the mixed fibrous debris will 'separate' from the heavier fibrous debris, leaving the fibrous debris in a somewhat 'lumpy' state, but not in the form of either *pea-sized balls* or *in the form of small tight spheres*. As the remaining portions of mixed fibrous debris are introduced to the test flume, small quantities of fibrous debris may remain either in the bucket and/or on the test flume addition chute. As shown in the subject PNP videos a significant quantity of water is utilized to wash-down and 'mix' the remaining fibrous debris to ensure that it all enters the test flume in a diluted manner.

The effect of utilizing the buckets and the test flume chute result in the appearance of the 'lumpy' mixed fibrous debris. However, the observed 'lumpy' mixed fibrous debris is but a small quantity of the total fibrous debris introduced to the test flume.

It should also be noted that Class 3 fibrous debris is defined and pictured as 'clumps' measuring up to ~ 2" in accordance with NUREG/CR-6808, Figure 3-3 (see photo (Figure 3-3).

Fiberglass shreds in size Class 3



Fiberglass shreds in size Class 5

Figure 3-3. Fiberglass Insulation Debris of Two Example Size Classes

In addition, the observed ‘lumpy’ fibrous debris form is in agreement with the Staff’s response to a specific question from NEI, the PWROG representative, and licensees made in the October 24, 2007 public meeting, that ***<u>‘fines’ were not single fibers, but could be ‘clumps’ or ‘bunches’ of fibers</u>***.

Recently (August 2009 – September 2009), Licensees implemented a number of tests to observe in clean water (i.e., no particulate or chemical debris) the transportability and potential release/separation of fine fibrous debris and fine fibrous debris from NUKON small fibrous debris. The use of clean water without particulate debris was utilized for the subject tests, since it is very conservative, as the particulate debris would have ‘mixed’ with the fibrous debris and resulted in significant trapping and/or settlement of the ‘mixed’ fibrous and particulate debris. Implementation of the test without particulate debris is not prototypical of the expected Licensee post-LOCA conditions, but is very conservative with regard to the Test Protocol and test results. The test utilized Licensee specific flow velocities that were bounding and as were implemented in the ARL Large Flume Test.

ARL observed and documented, that … *The Nukon small fiber is added in the same manner as the fiber was added in the large flume testing. … A debris cloud of lighter debris can be observed breaking away during the introduction. … The lighter smaller fiber is transporting to the strainer at this time, while the heavier fiber material is starting to accumulate on the floor. The fiber on the floor is transporting across the floor however.* ARL further documents, that … *The fiber that has been introduced into the flume has all either settled or transported across the bed of fiber on the flume floor. The fiber is eroding from the leading edge of the debris pile. … The erosion of the fiber pile has slowed. Some small fiber pieces continue to break away at this time, but the pile is negligibly affected.*

ARL goes on to further document, that … *shows a picture of the strainer near the end of testing. It is clear from this picture that a significant amount of fines* *were released from the smalls and traveled to the strainer. … shows the picture of 0.25 lb of latent fine fiber on the screen, it is possible to conservatively conclude that at least twice this amount separated from the introduced small fiber (2.24 lb) and made it to the strainer here ….*

The responses to RAI #28 as well as RAI #13, and others all form a comprehensive answer to this RAI. To re-state the response to this RAI - The preparation of fibrous debris slurries, concentration of debris slurries prepared for testing, the potential for debris to agglomerate during preparation and addition of same was prototypical of the expected PNP post-LOCA conditions, and very conservatively represented the actual and expected PNP post-LOCA conditions within the containment.

In addition, the following should be noted.

- There is no regulatory and/or industry guidance or criteria that addresses the issues of fibrous debris preparation, concentration of debris slurries prepared for testing, the potential for debris to agglomerate during preparation and addition of same to the test flume in support of an integrated test.

- The fibrous debris preparation and introduction of same to the ARL test flume does represent a very conservative quantity of small fines including fines and small fiber clumps which are transported in the representative PNP flow streams. Since the fibrous debris is transportable, it will collect on the PNP test strainer based on the expected PNP post-LOCA conditions.

- PCI has processed raw fibrous debris materials into 'fines' representative of either eroded or latent fibrous debris and small fines by recognized mechanical process devices (i.e., chipper (smalls) & Munson machine (fines)).

- The SE for NEI 04-07 found no issue with the NEI 04-07 definition of small fines.

- PCI has separated (i.e., size distribution) the processed fibrous debris utilizing a 1' x 4" grating opening to establish the category of small fines. The PCI definition of small fines resulted in even more conservative and significantly smaller fibrous debris for ARL testing than if either the NUREG/CR-6369 Volume 1 or NEI 04-07 definition of small debris were utilized – PCI utilizes a 1" x 4" standard grating opening for fibrous debris separation as opposed to the 6' x 4" or 4" x 4' standard grating opening found to be acceptable by both the SE for NEI 04-07 and NUREG/CR-6369.

- Samples of ***dry*** latent, fines/smalls, and larges were provided to the Staff before any Large Flume Testing was initiated and were found to be 'representative of what the Staff had expected'.

- Fibrous debris has been processed, prepared, and introduced in accordance with the PCI document, *Sure-Flow® Suction Strainer – Testing Debris Preparation & Surrogates*, Technical Document No. SFSS-TD-2007-004 and the PCI/AREVA/Alden Large Flume Test Protocol which have both been provided to and discussed with the Staff.

- Observations and comments by the Staff and lessons learned by PCI/AREVA/Alden during the initial Large Flume Test were incorporated into all subsequent tests.

- Actual preparation (i.e., mixing of debris) of fibrous debris and introduction of same for the ARL Large Flume Testing has consistently been performed by the same Alden personnel

- During various Licensee tests at ARL (August 2009 – September 2009) latent fibrous debris introduced upstream of the test strainer and with the test pump operating at a range of scaled Licensee Design Basis flow rates and flow velocities, resulted in a 'cloud' of fine fiber (i.e., latent fibrous debris) that transported to the strainer which was observed and documented by ARL. In addition, the pump scaled flow rate required to start movement of the latent fibrous debris was in all cases greater than the various Licensee Design Basis flow rates. A flow rate and associated velocity greater than the various Licensee Design Basis conditions is required to transport latent fibrous debris.

To summarize, all of the fibrous debris (i.e., latent, fines, small fines, smalls, and larges), particulate, chemical, and miscellaneous debris for PNP as well as all of the other Licensees has been processed, prepared, and introduced to the test flume in accordance with the PCI 'white paper' *Sure-Flow Suction Strainer - Testing Debris Preparation & Surrogates*, PCI Debris Preparation SSFS-TD-2007-004 Supplement 1, the PCI/AREVA/Alden Large Flume Test Protocol, and most importantly by the same Alden personnel (in most cases). Observations and comments by the Staff and lessons learned by PCI/AREVA/Alden during the initial Large Flume Test for a Licensee were incorporated into all subsequent tests. Simply put there has been a significant level of consistency in the processing, preparation, and introduction of latent, fines/smalls, and large fibrous debris into the Large Test Flume. It should be further noted that samples of processed fibrous debris (dry material) as latent, fines, small fines, smalls, and larges were provided to the Staff and the determination was made that *the dry fibrous debris samples were representative of what the Staff had expected*.

In conclusion, the debris preparation, debris classification (sizing), amount of each debris classification (size) for each debris classification (size) category, and the basis for the debris classification (size) distribution chosen for the debris and debris surrogates including debris concentration and introduction sequencing of fibrous debris did not promote the agglomeration of the debris and did not inhibit the transport of same other than what would have naturally occurred in an open, free flowing water stream such as that which would occur in the PNP post-LOCA containment following initiation of ECCS/CSS recirculation.

NRC Request

d. Some debris may enter the containment pool closer than 30-40 ft from strainers during the blowdown, washdown, and pool fill-up phases of the LOCA. This debris would be more likely to transport to the strainer and less likely to contribute to the debris pile in the test flume. The test procedure did not attempt to model this aspect of the postulated event. This potential issue would likely have more influence as flume flow velocities decrease because settling would tend to occur over a shorter distance in a low velocity flow stream. Palisades' velocities are relatively low. The licensee provided information regarding the probable distribution of debris in the containment at the start of recirculation. The information appears to be reasonable. However, the test input parameters were based on debris amounts predicted by the transport evaluation to be at the strainer, not 30 ft away. It is apparent that not all of the debris reached the strainer during the test. The NRC staff believes that some debris would be closer than 30 ft and some further at the onset of recirculation. Due to variables in post accident debris distribution and transport phenomenon, the NRC staff cannot conclude whether the practice of placing most of the debris 30 ft from the strainer is conservative or prototypical. The level of confidence with this practice resulting in a realistic or conservative head loss is dependent upon individual plant parameters and test implementation. Because of the level of uncertainty in some aspects of the head loss evaluation, the licensee should ensure that sufficient conservatism is included in the testing to assure an overall conservative or prototypical result. In this area conservatism has not been demonstrated. Please discuss the acceptability of testing procedures given the above.

Entergy Nuclear Operations Response 28d:

See detailed discussion provided in response to RAI 21.

NRC Request

e. *The relatively low flume volume has an effect on the concentration of particulate and fine debris suspended in the flume. The volume of the flume affects the scaling between the strainer surface and the pool volume. Having a flume with a larger volume could avoid some of the concerns with over-concentration of debris in the flume and may reduce agglomeration. Flume debris concentration is significantly higher than the plant condition. The licensee did not provide a separate response to this issue, but referenced the response to the issues discussed above. Please provide justification that the concentration of debris in the test flume did not affect transport during head loss testing.*

Entergy Nuclear Operations Response 28e:

The staff's understanding of the test flume scaling methodology is not correct. There are actually two (2) scaling methodologies that are employed, but they are separate and mutually exclusive of each other. Neither scaling methodology determines the scaling factor between the strainer module surface area and the post-LOCA containment fluid volume. This has not been a requirement and/or issue for any Licensee to date, nor are there any requirements and/or guidance to make such a scaling determination. Simply put, it has not been required of any Licensee, strainer vendor, or test facility to make this scaling determination, and apply it to an actual strainer head loss test.

The first scaling methodology is associated with and is utilized to determine the debris quantities that will be used for the PNP test. PNP has twenty-three (23) strainer modules. One (1) strainer module was used for the PNP Design Basis Test (Test 4). Therefore, the ratio (i.e., 1/23) is multiplied times the PNP total strainer surface area represented by the entire twenty-three (23) modules minus 100 ft^2 of sacrificial area (PNP value) to address miscellaneous tags, labels, stickers, etc. that could potentially cover and block some of the strainer total surface area. The result is the scaling factor, which for PNP was 4.475%.

The PNP scaling factor, 4.475% is used to determine all debris type (i.e., fibrous, particulate, miscellaneous, and chemical precipitate) quantities and the test flume flow rate (i.e., gpm). The scaling factor is multiplied by each debris type total quantity to establish the debris quantity of each debris type that will be utilized for the PNP test. Likewise, the total PNP ECCS/CSS flow rate is multiplied by the scaling factor to establish the test flume flow rate (gpm).

The second scaling methodology is associated with the PNP test flume. Alden performs a CFD analysis and generates a fluid flow model of the PNP strainer arrangement and configuration within the PNP containment. The PNP CFD model is then utilized to develop the PNP test flume configuration based on the scaled fluid flow rate that was previously discussed. The result is a PNP specific scaled test flume that is prototypical and representative of the PNP post-LOCA fluid flow within containment. The basis for utilizing CFD modeling and the methodology utilized in developing the CFD PNP plant and test flume models is addressed in NEI 04-07, the SE for NEI 04-07, NUREG/CR-6773, *GSI-191: Integrated Debris-Transport Tests in Water Using Simulated Containment Floor Geometries, NRC Staff Review Guidance Regarding Generic Letter 2004-02 Closure in the Area of Strainer Head Loss and Vortexing* (ML072600348) (i.e., so-called March Guidance Document), and PCI/AREVA/Alden/Licensee meetings and telephone discussions that discussed the Large Flume Test Protocol including CFD application and methodology (i.e., More than nine (9) occasions (February 2007 (ML072530885) – February 2008 (ML080370262)).

It should be noted, that at no time did the Staff bring up or discuss the issue of the scaling factor between the strainer module surface area and the post-LOCA containment fluid volume with regard to the test flume. As previously stated this issue as can best be determined has not been brought up by the Staff, been a Staff concern, or has been documented in a Licensee RAI for any Licensee, strainer vendor, or test facility activities.

The test flume size (i.e., water volume) is directly related to and is a function of the first scaling methodology (i.e., scaling factor) and the second scaling methodology (i.e., CFD model). The test flume cannot be changed for any reason since it is an accurate representation of the flow velocities along the fluid flow path to the strainer module. Any changes such as making the test flume larger based on the scaling factor between the strainer module surface area and the post-LOCA containment fluid volume would have a negative and direct affect on the approach velocity within the test flume. Simply put, the test flume flow velocity would not be prototypical, conservative, or representative of the PNP post-LOCA containment fluid flow velocities associated with the strainer module configuration. Any such changes would also be in direct conflict with the Large Flume Test Protocol that was discussed with the Staff (ML072530885 & ML080370262), as well as the other previously identified reference documents that address the use and application of CFD methodology.

Please refer to the responses for RAIs 17c, 26a, and portions of the responses to 28a-d for additional information and discussion. The subject RAI responses address and provide additional and related information for RAI 28e.

Based on the discussion provided in the subject responses, it can be concluded that the quantity of fine fibrous debris and the fibrous debris classification size of same utilized for the PNP Large Flume Test was realistic, representative, and prototypical of the actual PNP post-LOCA containment conditions and LOCA scenario.

The PNP Large Flume Test debris addition activities did not adversely affect the ability of transportable debris to reach the strainer module. The sequencing and concentration of debris slurries prepared for testing, the potential for debris to agglomerate during preparation and addition of same was prototypical of the expected PNP post-LOCA conditions, and very conservatively represented the actual and expected PNP post-LOCA conditions within the containment.

The Staff has used the all encompassing term ‘agglomeration’ to describe the sequencing of debris and the related issue of debris concentration as it affects debris transport, settling, and strainer head loss testing. For PNP, the agglomeration of debris did not occur due to prototypical debris sequencing, concentrations during the preparation, during the addition of same to the test flume, or within the ARL test flume for PNP.

It should be noted that there are no documents, such as NUREG/CRs or similar type documents that provide guidance and/or define excessive agglomeration, prototypical debris concentrations as they relate to agglomeration during debris preparation or addition, or higher than expected debris concentrations during debris addition as related to integrated (i.e., transport, settling, and head loss) strainer testing. Simply put, there are absolutely no available definitive or subjective documents and/or information that discuss the term prototypical agglomeration, addresses the aforementioned issues, or their potential impact on integrated strainer testing.

Since there are no definitive or subjective criteria and/or guidance available with regard to the subject issues, the agglomeration of fibrous debris and more importantly, the homogeneous ‘mixing’ of both fibrous and particulate debris in the period prior to and after ECCS/CSS pump recirculation initiation would be realistically expected and prototypical. Numerous NUREG/CRs including 6772 and 6773 as well as others support the agglomeration of debris during the post-LOCA period, the settlement of same, the concentration of same, as well as the homogeneous ‘mixing’ of fibrous and particulate debris prior to and after the initiation of ECCS/CSS pump recirculation. Accordingly, the PNP test at ARL utilized the limited guidance found in NUREG/CR-6773. It should be noted that none of the NUREG/CRs or other documents discuss, address, or support the idea of debris sequencing for transport and/or integrated testing (i.e., debris transport, settling, and head loss).

NUREG/CR-6224 may be the only document that indirectly discusses sequencing and non-agglomeration of debris (i.e., fibrous and particulate). However, this NUREG/CR had a very different objective than integrated testing, which was to determine the most conservative sequencing that would achieve the highest possible head loss. In other words, the subject NUREG/CR had the primary objective of determining the worse-case head loss regardless if the test protocol was prototypical and realistic of the post-LOCA conditions within containment. Accordingly, this NUREG/CR is neither prototypical nor realistic of post-LOCA conditions with regard to debris transport, settling, size, sequencing, configuration, agglomeration, mixing, etc. Instead, the subject NUREG/CR utilizes a closed vertical pipe loop (CVPL) test apparatus to ‘matrix’ test various debris types under theoretical extremely conservative, non-prototypical, and non-realistic conditions (i.e., addition of debris types in non-prototypical sequences, sizes, configurations and quantities, non-prototypical flow velocities, non-prototypical application of gravity, non-prototypical post-LOCA conditions, etc.).

The subject NUREG/CR also applies pipe flow parameters and conditions to the post-LOCA containment and debris, when in reality the post-LOCA containment is open-channel flow which would result in transported debris being directly affected by gravity. In addition, the analysis of the two (2) flow types is very different and not related. The PNP Large Flume Test performed at ARL is an integrated test that incorporates debris transport, debris settling, and debris head loss testing. Therefore, most if not all of the content and conclusions of NUREG/CR-6224 does not apply to the subject PNP test.

The application of NUREG/CR-6224 test methodology, protocol, conditions and criteria, specifically the sequencing of debris by size and/or transportability with regard to the review of the PNP Large Flume Test at ARL is therefore neither appropriate nor relevant with respect to the realistic and prototypical post-LOCA conditions expected in the PNP containment, and which were utilized in the PNP Large Flume Test at ARL.

As previously discussed, the PNP ARL Large Flume Test sequencing, concentration, and potential agglomeration of debris following a post-LOCA event ***is*** prototypical. The Staff’s real concern is therefore interpreted to mean - did the fibrous debris utilized in the PNP test have adequate separation (fibers) to facilitate fibrous debris transport and allow collection on the test strainer in a representative or bounding manner based on the PNP expected post-LOCA conditions? The affect on head loss caused by fibrous debris agglomerating in the test flume is not relevant so long as the fibrous debris transports in the test flume and the collection of fibrous debris on the test strainer is representative and bounding to the specific PNP plant conditions.

The responses to RAIs 17c, 26a, as well as portions of 28a-d, and others all form a comprehensive answer to this question. To re-state the response to this RAI - The sequencing of debris, concentration of debris slurries prepared for testing, the potential for debris to agglomerate during preparation and addition of same was prototypical of the expected PNP post-LOCA conditions, and very conservatively represented the actual and expected PNP post-LOCA conditions within the containment. Most importantly, the PNP test protocol utilized the guidance (i.e., NEI 04-07; the SE for NEI 04-07; NUREG/CRs – 2982, -6772 & -6773; and the March Guidance Document (ML072600348)) available at the time of the test.

In addition, the following should be noted.

- There is no regulatory and/or industry guidance or criteria that addresses the issues of debris sequencing, concentration of debris slurries prepared for testing, the potential for debris to agglomerate during preparation and addition of same to the test flume in a detailed manner that would support an integrated test.

- The fibrous debris preparation and introduction of same to the ARL test flume does represent a very conservative quantity of small fines including fines and small fiber clumps which are transported in the representative PNPP flow streams. Since the fibrous debris is transportable, it will collect on the PNP test strainer based on the expected PNP post-LOCA fluid flow conditions.

- PCI has processed raw fibrous debris materials into 'fines' representative of either eroded or latent fibrous debris and small fines by recognized mechanical process devices (i.e., chipper (smalls) & Munson machine (fines)).

- PCI has separated (i.e., size distribution) the processed fibrous debris utilizing a 1' x 4" grating opening which is significantly more conservative than the 4" x 4" standard grating opening identified in NEI 04-07 and the Staff's SER for the same.

- Samples of latent, fines/smalls, and larges were provided to the Staff before any Large Flume Testing was initiated and were found to be 'representative of what the Staff had expected'.

- Fibrous debris has been processed, prepared, and introduced in accordance with the PCI document, *Sure-Flow® Suction Strainer – Testing Debris Preparation & Surrogates*, Technical Document No. SFSS-TD-2007-004 and the PCI/AREVA/Alden Large Flume Test Protocol which have both been provided to and discussed with the Staff.

- Observations and comments by the Staff and lessons learned by PCI/AREVA/Alden during the initial Large Flume Test were incorporated into all subsequent tests.

- Actual preparation (i.e., mixing of debris) of fibrous debris and introduction of same for the ARL Large Flume Testing has consistently been performed by the same Alden personnel

- During various Licensee tests at ARL (August 2009 – September 2009) latent fibrous debris introduced upstream of the test strainer and with the test pump operating at a range of scaled Licensee Design Basis flow rates and flow velocities, resulted in a ‘cloud’ of fine fiber (i.e., latent fibrous debris) that transported to the strainer which was observed and documented by ARL. In addition, the pump scaled flow rate required to start movement of the latent fibrous debris was in all cases greater than the various Licensee Design Basis flow rates. A flow rate and associated velocity greater than the various Licensee Design Basis conditions is required to transport latent fibrous debris.

To summarize, all of the fibrous debris (i.e., latent, fines/smalls, and larges), particulate, chemical, and miscellaneous debris for PNP as well as all of the other Licensees has been processed, prepared, and introduced to the test flume in accordance with the PCI 'white paper' *Sure-Flow Suction Strainer - Testing Debris Preparation & Surrogates*, PCI Debris Preparation SSFS-TD-2007-004 Supplement 1, the PCI/AREVA/Alden Large Flume Test Protocol, and most importantly by the same Alden personnel (in most cases). Observations and comments by the Staff and lessons learned by PCI/AREVA/Alden during the initial Large Flume Test for a Licensee were incorporated into all subsequent tests. Simply put there has been a significant level of consistency in the processing, preparation, and introduction of latent, fines/smalls, and large fibrous debris into the Large Test Flume. It should be further noted that samples of processed fibrous debris (dry material) as latent, fines, small fines, smalls, and larges were provided to the Staff and the determination was made that *the dry fibrous debris samples were representative of what the Staff had expected*.

In conclusion, the debris preparation, debris classification (sizing), amount of each debris classification (size) for each debris classification (size) category, and the basis for the debris classification (size) distribution chosen for the debris and debris surrogates including debris concentration and introduction sequencing of fibrous debris did not promote the agglomeration of the debris and did not inhibit the transport of same other than what would have naturally occurred in an open, free flowing water stream such as that which would occur in the PNP post-LOCA containment following initiation of ECCS/CSS recirculation.

NRC Request

29. *The June 30, 2009, supplemental response indicates that throttling the containment spray flow is credited to ensure adequate NPSH margin. Please provide the basis for determining the reduced spray flow required during recirculation mode.*

Entergy Nuclear Operations Response:

Modification EC8350 “Replace Containment Spray Isolation Valves per GSI-191 Resolution” [Ref. 29.1] was performed in order to maintain NPSH margin for the Containment Spray Pumps and allow installation of the new PCI designed sump strainers. An analysis EA-MOD-2005-005-003 Rev 1 was performed to determine the maximum flow under strainer design conditions in EC496 [Ref. 29.2] that would provide adequate NPSH to the pumps.

The 819 gpm valve throttled flow rate requirement (Ref. Specification M0255 and EA-MOD-2005-004-03 R1, ESS Flow Rates & Pump NPSH during Recirculation Mode with CSS Throttling (Case 1AAA D)) is to provide adequate NPSH available to the Containment Spray pumps during a design basis event where a Left Channel Power Failure (Loss of the Emergency Diesel Generator 1-1) occurs resulting in the loss of two of the three Containment Spray Pumps.

In this limiting case the amount of flow which passes through the containment spray header valve CV-3002 valve must be limited to the 819 gpm. However, as the LOCA event progresses the NPSH available increases due to containment sump temperature continuing to decrease below saturation to where throttling the Containment Spray flow would, though not credited, no longer be critical.

The design specification for the Strainers in EC496 was taken from Specification M0802 which was 2.6 foot water head loss due to debris at 1849 gpm flow through the strainers. This value reserved some capability for uncertainty and margins in the pump flows and NPSH calculations.

With this value established, a calculation EA-Gothic-04-08 Rev 2 of post LOCA containment conditions was done with the un-throttled flow in the injection mode time frame and the throttled flow in the Post RAS time frame. The results showed that the FSAR maximum temperature and pressure conditions were maintained.

EA-MOD-2005-004-03 determined minimum and maximum system flow rates, pump flow rates, and the minimum pump NPSH margins. The bounding case used for establishing the analytical limiting replacement valve throttling flow of 803 gpm (valve min throttling flow is 819 gpm (Ref. DIT CCI03)) in case 1AAA where after RAS initiates a Left Channel Failure, the failure of EDG 1-1 occurs. This alignment involves the CSS Pump P-54A supplying the HPSI Pump P-66A, CSS Header A, and the four PCS cold legs following the isolation of CSS Header B. This alignment would continue from shortly after RAS initiation until HPSI throttling or hot leg injection is initiated. This alignment can also occur following a failure of Sump Suction Valve CV-3030 to open.

References

29.1 Modification EC8350 “Replace Containment Spray Isolation Valves per GSI-191 Resolution”

29.2 Modification EC496, “Replace Containment Sump Screens Per GSI-191 Resolution (Passive Strainer)”

NRC Request

30. The June 30, 2009, supplemental response described components for which friction losses were considered. As requested in the content guide for GL 2004-02 responses, please also describe the methodology and/or references used to derive the formulas for calculating flow losses for these components in the NPSH margin calculation.

Entergy Nuclear Operations Response:

The analysis to evaluate containment spray pump NPSH post-RAS was performed using the Palisades ESS integrated hydraulic model developed with Pipe-Flo version 4.11 software. The software allows the user to specify a loss coefficient (K), enter a head loss vs. flow rate curve, or use standard industry formulas to calculate the loss coefficient for a piping system component. With respect to the strainer piping components, debris head loss, and clean strainer head loss, these values were all manually entered as either a function of head loss or a specific loss coefficient.

The clean strainer head loss was modeled in the software by first calculating the clean strainer head loss at flow rates of 1405 gpm and 3521 gpm as described in section 6.2.1 of EA-MOD-2005-004-03 Rev. 3. The regression function for calculating clean strainer head loss, as well as the additional head loss due to core tube length, was based on PCI Technical Document SFSS-TD-2007-002 submitted to the NRC March 25, 2009. The clean strainer and core tube head losses were combined to develop a total head loss data point for each strainer assembly at each of the two flow rates.

Using this approach, three data points were developed for each of the strainer assemblies to create four functions of head loss vs. flow rate which were entered into the hydraulic model (the first data point being 0 head loss at 0 flow rate) as system components. Pipe-Flo then uses this data to calculate an exponential equation of the form:

$$dP_{comp} = CW^n$$

dP_{comp} = pressure drop across the component
W = Flow Rate
C and n = Values determined using geometric regression

The approach to modeling head loss for the piping and components downstream of the strainer assemblies is described in section 6.2.2 of EA-MOD-2005-004-03 Rev. 3. Values for piping bends, orifices, enlargements, and exit losses from the downcomers to the sump were manually developed and entered into the model as specified loss coefficients (K) on a given pipeline. Friction loss for the piping is calculated by the Pipe-Flo software as a function of piping length, material and diameter, as well as water properties which were entered into the model.

The software uses the Darcy-Weisbach method for calculating piping friction losses. From the Pipe-Flo User's Guide:

The Darcy-Weisbach method takes into account fluid viscosity and pipe roughness, providing valid results for incompressible Newtonian fluids flowing in any round fully charged pipe. This formula can also be extended to compressible fluids with some restrictions.

The Darcy-Weisbach equation is as follows:

$$dP = \rho f(L/D)v^2/2g$$

dP = pressure drop
ρ = fluid density
f = Darcy friction factor
L = length of pipe
D = pipe diameter
v = mean fluid velocity
g = gravitational constant

Often, the Darcy-Weisbach is expressed in the following way:

$$dP = K\rho v^2/2g \qquad \text{where } K = f(L/D)$$

The K in the above equation is the total resistance coefficient for the pipeline. This "total K" is a combination of the K value for the pipe and the K value for the valves and fittings in the pipeline. Therefore, the pipeline pressure drop calculated is a combination of the pressure drop due to the pipe and valves.

Separate components to model head loss through the debris bed on the strainer were developed for the model using a function of head loss vs. flow rate, as was done for the clean strainer head loss. The head loss across the clean strainers, core tubes, and piping to the containment sump, was calculated for each strainer assembly at the maximum design total flow rate (3591 gpm). These head losses were subtracted from the maximum design fouled strainer head loss of 2.6 ft thus generating values of maximum additional head loss due to strainer fouling vs. flow rate. This data was extrapolated to a higher flow rate to provide a third data point (the first being 0 flow at 0 head) and entered into the Pipe-Flo model as debris components for each strainer module. When modeling scenarios that consider fouled strainers, the components were inserted into the model upstream of the clean strainer components. Further details may be found section 6.2.4 of EA-MOD-2005-004-03 Rev. 3.

References

30.1 EA-MOD-2005-004-03 Rev. 3 dated 4/6/2009, “ESS Flow Rates and NPSH During Recirc Mode with CSS Throttling”

30.2 PCI Technical Document SFSS-TD-2007-002, Rev 1 dated December 11, 2008, “Sure-Flow® Suction Strainer – Suction Flow Control Device (SFCD) Principles abd Clean Stariner Head Loss Design Procedures”

30.3 Pipe-Flo User’s Guide

NRC Request

31. A number of objects were cited as displacing water in the post-LOCA containment sump pool, including the reactor vessel insulation, pressurizer heater transformers (both of which objects appeared to be potentially non-leak tight and to have some hollow internal volume) and the containment buffer, which would presumably dissolve in the containment pool water. Please clarify whether other dissolvable or hollow and non-Ieaktight objects are credited with displacing volume in the post-LOCA containment pool, estimate the total displaced volume credited, and provide justification for crediting such objects with displacing water.

Response:

The minimum post-LOCA containment water level is determined in calculation EA-SDW-97-003, Revision 3. EA-SDW-97-003 utilizes an equation that relates containment water volume (V [ft^3]) to containment water level (h [ft]), referred to below as V(h). EA-SDW-97-003 determines the level corresponding to a given water volume by iteratively solving V(h), which is tantamount to finding the inverse of the equation.

The V(h) equation is developed from a similar equation derived in calculation EA-C-PAL-94-0016A-01, Revision 1. The equation in EA-C-PAL-94-0016A-01 is used to determine the maximum containment water level. Therefore, adjustments to this equation are made to develop an appropriate equation for determining the minimum containment water level.

The V(h)equation in EA-C-PAL-94-0016A-01 (the maximum containment water level calculation) treats the following objects as displacing water:

- Reactor Vessel
- Reactor Vessel Insulation
- Bioshield
- Clean Waste Receiver Tanks
- Concrete Structures
- Pressurizer Heater Transformers
- Miscellaneous Equipment
- Containment Buffer

The displacement volume calculations in EA-C-PAL-94-0016A-01 are assessed for conservatism and biases that are not applicable to a minimum water level calculation as follows.

<u>Reactor Vessel</u>
No biases towards maximum containment water level are noted in the development of the reactor vessel displacement volume calculation. Therefore,

no adjustments are made to the V(h) equation for this displacement volume in the minimum water level calculation.

Reactor Vessel (Cavity) Insulation
No significant biases towards maximum containment water level are noted in the development of the reactor vessel insulation displacement volume calculation. Note that insulation referred to in the calculation as reactor vessel insulation is actually reactor vessel cavity insulation. Reactor vessel insulation located on the reactor vessel itself is not included. Reactor vessel cavity insulation (present on the reactor cavity wall and floor) is not assumed to be water tight. Reactor vessel cavity insulation is assumed to displace 1/3 of the equivalent water volume for the displacement volume calculation. Prior to the reduction described below, the total volume ranges from 102 ft^3 to 117 ft^3, for the range of calculated minimum water levels (7.563·h + 84.474; h = 2.34 ft, 4.26 ft) out of total water volumes of 18,772 ft^3 and 34,385 ft^3, respectively. The range of minimum water level heights and volumes correspond to a 4-inch small break LOCA with left channel failure, SIRWT level at the technical specification minimum, adjusted to 212°F sump temperature; and a 42-inch hot leg large break LOCA with left channel failure, SIRWT level at the Admin limit, adjusted to 212°F sump temperature, respectively. For conservatism, the V(h) equation was adjusted by reducing the displacement volume for reactor vessel cavity insulation by an additional 25% in the minimum water level calculation.

Bioshield
No significant biases towards maximum containment water level are noted in the development of the bioshield displacement volume calculation. The two 1" drain lines from the reactor cavity to the containment sump are considered insignificant and are not removed from the displacement volume calculation. The total volume of these lines is less than 0.02 ft^3 (2·1.5'·π·(0.5/12)^2, M-74, Sheet 2); however, the lines are filled with corium plugs and the actual non-displacement volume is considerably less. Therefore, no adjustments are made to the V(h) equation for this displacement volume in the minimum water level calculation.

Clean Waste Receiver Tanks
The bottom hemisphere of the clean waste receiver tanks (596' elevation) is above the calculated minimum flood levels. The clean waste receiver tanks do not displace any water for the minimum water level calculation. Therefore, the V(h) equation was adjusted by removing the displacement of the clean waste receiver tanks in the minimum water level calculation.

Concrete Structures
No biases towards maximum containment water level are noted in the development of the concrete structures displacement volume calculation. Therefore, no adjustments are made to the V(h) equation for this displacement volume in the minimum water level calculation.

Pressurizer Heater Transformers

No significant net biases towards maximum containment water level are noted in the development of the pressurizer heater transformers displacement volume calculation. Transformer cabinets are assumed to displace 100% of the equivalent water and the switchgear cabinets are assumed to displace 25% of the equivalent water volume. The total volume of these components ranges from 146 ft^3 to 266 ft^3, for the range of calculated minimum water levels ($62.326 \cdot h$, h = 2.34 ft, 4.26 ft) out of total water volumes of 18,772 ft^3 and 34,385 ft^3, respectively. The assumed displaced volume amounts to less than 0.8% of the water volume. In addition, the switchgear are assumed to be 75% free space. Therefore, no adjustments are made to the V(h) equation for this displacement volume in the minimum water level calculation.

Miscellaneous Equipment

The development of the miscellaneous equipment displacement volume calculation is biased towards maximum containment water level. An additional 15% was added to the displacement volume equation to account for miscellaneous small equipment that may not have been identified explicitly in the walkdown. Prior to the reduction described below, the total volume of the additional miscellaneous small equipment ranges from 260 ft^3 to 265 ft^3, for the range of calculated minimum water levels ($16.910 \cdot h + 1692.128$ = 2.34 ft, 4.26 ft) out of total water volumes of 18,772 ft^3 and 34,385 ft^3, respectively. Therefore, the V(h) equation was adjusted by reducing the displacement volume for additional miscellaneous small equipment by 25% in the minimum water level calculation.

Containment Buffer

No significant biases towards maximum containment water level are noted in the development of the containment buffer displacement volume calculation. The total displacement volume assumed for the containment buffer is 200 ft^3. The “displacement” of water by the dissolved buffer depends on the partial molar volumes of the solvent (water) and the solute (buffer) in the solution and on the number of moles of each in the solution. Partial molar volumes are difficult to predict and may be larger or smaller than the pure molar volumes. That is, the volume of the solution may be different than the sum of the volumes of the solvent and solute, depending on the specific solvent and solute under consideration.

However, the mass of the solution is preserved such that the important quantity for NPSH calculations (static head) of the solution increases in proportion to the fractional mass increase. The buffer “displacement’ calculation resulted in 200 ft^3 of displacement volume, resulting in an absolute increase in static head (water level) of 0.3”, which represents a fractional static head increased of about 0.1% for the range of calculated minimum water levels (2.34 ft to 4.26 ft, with pump suction at the 573’ elevation). The mass of buffer in solution is required to be greater than 8,186 lbm of sodium tetraborate decahydrate equivalent (LCO

3.5.5), which represents a fractional mass increase and corresponding fractional static head increase of 0.4% to 0.7%. The additional water level predicted is therefore not significant and is compensated for by the minimum required buffer mass. Therefore, no adjustments are made to the V(h) equation for this displacement volume in the minimum water level calculation.

In addition, the following items were noted with respect to the development of the V(h) equation for the maximum water level calculation. An approximation is used to determine the free space in the tapered containment wall. The calculation of the additional volume of the sloped floor region of containment is biased low. Several short 4" diameter drains are ignored.

Tapered Wall Volume Approximation

The containment cylinder wall tapers to a smaller diameter as the 590' elevation is approached. No biases towards maximum containment water level are noted in the development of the tapered wall volume calculation. The approximation for the tapered wall volume is slightly conservative for the minimum water level calculation. Therefore, no adjustments are made to the V(h) equation for this volume.

Sloped Floor Volume

There is a bias towards maximum containment water level noted in the development of the sloped floor volume calculation. The development of the sloped floor volume contains conservatisms that lead to a smaller sloped floor volume. The total sloped floor volume calculated for the maximum water level calculation is 391.107 ft^3. Therefore, the V(h) equation was adjusted by increasing the volume for the sloped floor by 25% in the minimum water level calculation.

590' Floor Drains

Seven 4" diameter floor drains were conservatively ignored in the development of the sump volume calculation. The total drain volume is estimated to be less than 10 ft^3. Therefore, no adjustments are made to the V(h) equation for this volume.

Summary:

The credit taken for displacement volumes has been addressed. If no credit is taken for any displacement volume for the reactor vessel cavity insulation, pressurizer heater transformers, containment buffer, or miscellaneous additional equipment, the minimum water level is reduced by 0.08 ft to 0.09 ft for the range of minimum water levels calculated (the range 2.34 ft to 4.26 ft changes to 2.26 ft – 4.17 ft).

While justification for crediting displacement volumes has been discussed above, the cumulative impact of not crediting these volumes is on the order of a 1" reduction in minimum containment water level. Given the limited margin, the minimum water level calculation will be revised to provide a more rigorous accounting of both free space and displacement volume and biased consistently for minimum water level determinations.

References

31.1 EA-C-PAL-94-0016A-01, Revision 1, Containment Flood Analysis, December 1994.

31.2 EA-SDW-97-003, Revision 3, Minimum Post-LOCA Containment Water Level Determination, February 2009.

31.3 M-74, Sheet 2, Revision 0, Reactor Cavity Drain Plug, February 1997.

NRC Request

32. *Please clarify the assumption concerning the pump curves applied in the design analysis including a 7 percent allowance for flow degradation in the containment spray pumps, and an 8 percent allowance for flow degradation in the high-pressure safety injection pumps as it relates determination of conservative pump flow rates for the I\IPSH analysis. While not fully understanding the licensee's methodology, the NRC staff generally believes that assuming pump degradation when determining minimum NPSH margins for pumps could be non-conservative, since the required NPSH would seemingly be lower for a degraded pump with reduced flow. Please clarify whether the pumps are assumed to operate above or below their certified head-flow performance curves in determining NPSH margin and provide a basis for considering the calculated NPSH margins to be limiting in light of this flow assumption.*

Entergy Nuclear Operations Response:

The HPSI and containment spray degraded pump curves were developed by applying a uniform percentage flow reduction at all pump heads. As pump internal leakage is proportional to the square root of the pump head, this approach is conservative because no credit was taken for the smaller flow reduction that would occur at lower pumping head. The percentage of flow reduction was determined graphically by uniformly reducing the flow at all pump heads until the curve intersected with lower limit for inservice testing acceptance criteria. For the containment spray pumps this value was 7% and for the HPSI pumps 8%. The degraded pump curves also accounted for the minimum allowed diesel generator frequency by application of pump affinity laws to determine the flow rate and pump head at reduced pump rotation speed. Finally, instrument uncertainty was applied to further reduce pump flow rate and discharge head at each data point.

To develop the strong pump curves, pump affinity laws were used to calculate the pump head and flow rate at each data point due to the increased rotation speed at the maximum diesel generator frequency, then instrument uncertainty was applied in a positive fashion to increase further increase flow rate and pump head. Using this approach, the degraded pumps operate below their nominal performance and the strong pumps operate above their nominal performance curve.

The methodology for applying strong or degraded pumps in the hydraulic model is briefly described in section 3.g of the June 30, 2009 GL 2004-02 supplemental response on pages 138 – 140. However, it should be clarified that when degraded pump curves were used for purposes of calculating containment spray pump NPSHa, the degraded curves were applied on the opposite train of the pump being evaluated (e.g. a degraded HPSI and containment spray pump tandem on the first diesel train and a strong pump tandem on the second train). As the pumps are operating in parallel, the stronger pump train overpowers the degraded pump train increasing its flow rate and NPSHr. Therefore, the approach used was conservative.

NRC Request

33. *In RAI 18 from the NRC's letter dated December 24, 2008, the NRC staff asked about the typical amounts of algae and/or slime that are removed from the sump and why this amount of biological material does not need to be considered as an additional debris source after a postulated LOCA. The licensee provided the requested information which identified an amount of oil sludge, estimated at 27.5 gallons, which is contained in a cavity which connects, by means of a pipe, to the sump area downstream of the strainer. The licensee stated that due to the large amount (250,000 gallons) of what it considered "hot soapy sump water," the 27.5 gallons of either oily emulsion or algae created biological material would be dissolved. In addition, the licensee stated that the extreme agitation as it transits through the sump area will ensure good mixing takes place and will enhance the process of dissolution of solubles or suspension of small particles. The NRC staff believes that it is unlikely that the oil-based slime identified by the licensee will dilute in the sump pool as stated in the response, and that there is a potential for this material to be transported to the reactor core and spray nozzles. The bases for the NRC staff's concern is that the sludge has been proven difficult to remove, as indicated in page 168 of the June 30, 2009 RAI response, which states, "...the high viscosity of the material made a bubble form in the small screen squares and it resisted removal by a stiff wire brush that rode over the high points on the screens. Adding soapy cleaning solution did nothing to help this phenomenon." The physical and chemical properties of the oil sludge may not allow it to be easily diluted. Please provide further information on your plans to address the oil sludge during future plant operation. If it were to transport downstream of the strainer, has the amount of sludge been evaluated as part of the downstream effects analysis? Were any other approaches (e.g. hard piping the sump where the sludge is located from the strainer) considered?*

Response:

In RAI 18 of December 24, 2008, the NRC staff asked about the typical amounts of algae and/or slime that are removed from the sump. Details of the amount of material removed in days gone by during cleaning are usually not kept in any formally retrievable manner. It was known that some informal records were available from past System Engineers notes and also from Radiation Work Permit records but none of these were subject to independent validation and some of the descriptions were authored by cleaning crews who had very little system knowledge and were phrased in casual worker jargon.

To answer the request for information what records existed were used regardless of the pedigree. The original draft of the response to RAI 18 of 2/27/08 attempted to retain as much as possible of the original wording from several sources with several authors.

The present RAI appears to be based on a miss-understanding of the answer to the original RAI 18 from the NRC's letter dated December 24, 2008.

In the statement “The licensee provided the requested information which identified an amount of oil sludge, estimated at 27.5 gallons, which is contained in a cavity which connects, by means of a pipe, to the sump area downstream of the strainer” the 27.5 gallons was in a waste drum which was a part of the sump cleaning equipment that contained the results of vacuuming out the fluid that was left in the bottom of the sump. It is not a part of plant equipment and it is removed from containment after the cleaning work order is completed and before plant startup. The drum contents gravity separate in time and the 27.5 gallons is the result of the record having stated that the disposal drum contained about half water and half “slime”. This item was quoted in the RAI response to fulfill the requirement of “typical amounts” requested by the RAI. It was one of the few records that were in any way quantified. Most estimated it by talking about fractional inches of water slime mix observed in the 22 foot diameter sump “tank”. Because the bottom of the “tank” is uneven, the depth depends upon where the measurement is made. Furthermore the typical record made no attempt to state the how much of the residual fluid was water.

In the statement “*The licensee stated that due to the large amount (250,000 gallons) of what it considered "hot soapy sump water," the 27.5 gallons of either oily emulsion or algae created biological material would be dissolved. In addition, the licensee stated that the extreme agitation as it transits through the sump area will ensure good mixing takes place and will enhance the process of dissolution of solubles or suspension of small particles*.” there are several miss-statements resulting from removal from the original context. First it must be recognized that the area under discussion is a part of the plant that is before the ECCS pumps and is behind the current sump strainers. Thus the water from the “sump tank” must be taken into the pump suction pipes which are about 4 inches above the sump floor, transit down approximately 75 feet of 24” piping, enter the pump and be violently agitated by its impeller, exit the pump and transport through a heat exchanger, be returned to containment via either the HPSI injection valves which severely throttle flow or via containment spray which involves a throttled (multi-passage Drag Valve Style) valve and a spray nozzle. From there it must traverse the PCS and come out the break or fall as spray on to the floor. The runoff from both of these processes must transit containment and get into the 590 elevation “basement” floor and move in the 3 foot deep water containing Sodium Tetra-borate (aka the soapy component) where the ECCS suction strainers are located. This is the first contact that the “slime” could have with the strainers and would be the first opportunity to participate in the filter formation/blocking process. At this point it would be one part in 10,000 parts of water there having been multiple intense mixing steps prior to the contact point. Note that Sodium

Tetra-Borate is sold commercially as 20 Mule Team Borax specifically for the purpose of breaking down the surface tension of oily material embedded in clothing to facilitate dissolution in a washing machine and also to be a bactericide.

In the statement "The bases for the NRC staff's concern is that the sludge has been proven difficult to remove, as indicated in page 168 of the June 30, 2009 RAI response, which states, "...the high viscosity of the material made a bubble form in the small screen squares and it resisted removal by a stiff wire brush that rode over the high points on the screens. Adding soapy cleaning solution did nothing to help this phenomenon" again the problem is removal of the statement from context. This was a part of a 2 page discussion which was given for the sake of satisfying the "typical" part of the RAI and was a short discussion of cleaning efforts that had been employed in the past which were not continued due to poor results. The cleaning under discussion is done by hand under very trying circumstances.

To quote a corrective action document CR-PLP-2007-05055:
The sump cleaning and inspections were performed under the following conditions:

- *1" to ¼" of mud on sump bottom*
- *Dark - Poor lighting*
- *Wearing face shields and multiple layers of protective clothing and rubber gloves*
- *3.5' tall ceiling*
- *Warm and humid*
- *High contamination potential*

The sump screen is welded in place so that only the outside can be accessed. To further complicate the cleaning the screens are very close to the open mouth of the 24" recirculation suction pipes and extraneous fluids and possibly removed material easily enters the pipe and can not be easily removed. For containment isolation reasons these pipes are encased into a secondary isolation boundary from the containment wall to the Recirculation isolation valve. Thus there are no flush points or piping drain lines to remove material so it must be flushed through the ECCS System.

Cleaning tools typically used were stiff wire brushes, spray bottles, and mopping rags or absorbent paper materials supplied by Radioactive Material Control (RMC) personnel who are professional decontaminators and who actually do the majority of the cleaning with the help and direction of the System Engineer.

In the 2003 to 2006 time frame the methods had progressed to use of pressurized sprayers (like lawn hand pumped sprayers) using hot water and RMC supplied detergent. The heated spray when delivered to the screens in a fine spray would allow the material to run down the screens and be removed by wiping. It was this process which was meant to be referenced as evidence that hot soapy water worked to break up the slime. It was the prior to that cold spray, wire brush, vacuum suction hoses and hand towels that did not work well and caused severe ALARA concerns during some refueling outages if fuel failures had occurred.

The strainers in the immediately above discussion were cut out of the sump in 2007 when the 3,500 sq. ft. of PCI strainers were installed to meet GSI-191 criteria. Since the area is behind these strainers the procedure of clean the sump tank every Refueling Outage was retained.

The final NRC concern was driven by the miss-interpretation of the previous RAI and is resolved by the above discussion. In essence what is hard for a single RMC employee crawling around on his hands and knees in radioactive water with a small vacuum hose, a spray bottle, cold water and a brush being careful not to put foreign material into the ECCS/Shut Down Cooling system is not comparable to 400 horsepower of pumps moving essentially boiling water and intensely mixing it under pressure up to 1200 psi.

Furthermore more recent experience has been that less slime is seen than the above noted 27.5 gallons. This is believed to be due to better control of Primary Coolant Pump oil control, far less Containment Air cooler leakage due to coil replacement, finer screens installed in the 16" downcomer openings and close fitting 590 Elevation floor drain screens installed for GSI-191.

It is suggested that this material is similar to "sludge" seen in Boiling Water Reactor suppression pools. This is handled in PWR by the 200# of Latent Debris mocked up in testing as fine fiber and sand like material. Palisades has enough margin between the measured amount and the default 200# used to cover the dried "solid" portion of the slime.

An order of magnitude estimate would be 1000 sq ft of 3 mil thick paint or 0.25 cuft. This assumes the surface of the sump top, bottom, and sides were painted with an opaque layer of dried slime conservatively assumed to be 3 mils thick (in fact the pictures indicate that it is semi-transparent). [(2 x 22 x 22 x pi / 4 + 22 x 3.5 x pi) x 0.003 /12 = 0.2505 cu ft]

To consider it liquid slime, in Palisades testing the amount of extra chemical precipitate material was also more than adequate to cover the material in the sump. Chemical precipitate used in testing is slime like material and could be considered a surrogate approximately representative of the variable and unknown constituents of the extraneous dump material. Sufficient material beyond the design calculated amount was used to cover the 27 gallon approximation to sump condition (27/23 ~1 gallon when scaled to the test).

CR-PLP-2007-5055 Photo of 1 of 2 Sump Exits with Old Screen Removed
White material is dried Boric Acid