UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

April 7, 2010

LICENSEE: PSEG Nuclear LLC

FACILITY: Salem Nuclear Generating Station, Unit Nos. 1 and 2

SUBJECT: SUMMARY OF MARCH 16, 2010, MEETING WITH PSEG NUCLEAR LLC, REGARDING RESPONSE TO GENERIC LETTER 2004-02 FOR SALEM NUCLEAR GENERATING STATION, UNIT NOS. 1 AND 2 (TAC NOS. MC4712 AND MC4713)

On March 16, 2010, a Category 1 public meeting was held between the U.S. Nuclear Regulatory Commission (NRC) and representatives of PSEG Nuclear LLC (PSEG or the licensee) at NRC Headquarters, One White Flint North, 11555 Rockville Pike, Rockville, Maryland. The purpose of the meeting was to discuss PSEG's planned approach to address the NRC's request for additional information (RAI) dated February 4, 2010 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML100220520). The RAI pertains to information submitted by PSEG in response to Generic Letter 2004-02, "Potential Impact of Debris Blockage on Emergency Recirculation during Design Basis Accidents at Pressurized-Water Reactors," for Salem Nuclear Generating Station, Unit Nos. 1 and 2. A list of attendees is provided as Enclosure 1.

The licensee provided the following handouts during the meeting: (1) draft RAI responses (Enclosures 2 through 6); (2) slide presentation titled "Response to Generic Letter 2004-02" (Enclosure 7); (3) slide presentation titled "Assessment of 17D ZOI [zone of influence] for Jacketed Nukon" (Enclosure 8); and a tree diagram showing Salem Unit No. 1 debris transport (Enclosure 9).

The following summarizes the discussion of each proposed RAI response:

Previous RAI 1 and New RAIs 1 - 10

The licensee did not provide a draft response to these RAIs since PSEG no longer plans to rely on topical report WCAP-16710-P, "Jet Impingement Testing to Determine the Zone of Influence (ZOI) of Min-K and NUKON® Insulation for Wolf Creek and Callaway Nuclear Operating Plants," to justify a reduced ZOI. The licensee plans to use ZOI assumptions consistent with the NRC staff's safety evaluation (SE) dated December 6, 2004, for Nuclear Energy Institute (NEI) document NEI 04-07, "Pressurized Water Reactor Sump Performance Evaluation Methodology" (ADAMS Accession No. ML043280641). The NRC staff stated that these plans will satisfactorily resolve these RAIs.

New RAI 11

The NRC staff stated that the proposed response is acceptable. However, the licensee should include further information in the final response to help clarify the physical arrangement of the target blankets with respect to the break location (i.e., that blankets are far from the break location). A sketch or drawing would be one method to provide this information.

New RAI 12, New RAI 13, Previous RAI 14

The NRC staff stated that PSEG's draft responses are acceptable as presented. Note, during a subsequent discussion, the NRC staff raised additional questions on New RAI 12, which will be discussed at a future interaction.

New RAI 14

In PSEG's draft response, the fourth paragraph under the heading "Response to RAI 14a" states, in part, that "the Salem ECCS [emergency core cooling system] is designed to tolerate a single active failure during the short-term immediately following an accident..." The NRC staff stated that the final response should clarify whether "short-term" is equivalent to the injection phase. The NRC staff also stated that the final response should clarify whether failure of redundant containment sump level instrumentation is beyond the design-basis.

New RAI 15

The NRC staff stated that the final response should clarify whether it is beyond design-basis for the refueling water storage tank to reach low-low level before containment minimum sump level is reached.

Other Issues

In addition to discussion of the RAIs, the following issues were discussed.

1) The NRC staff stated that, in the near future, letters would likely be issued to licensee's that are currently relying on topical report WCAP-16710-P to justify reduced ZOIs. The licensees' will be asked to justify the ZOIs without crediting the topical report. The staff stated that an acceptable response would be that the licensee plans to use ZOI assumptions consistent with the NRC staff's SE for NEI 04-07. The NRC staff said a letter on this issue would not be issued to PSEG if the licensee submits a revised draft RAI response, in the next few weeks, consistent with the discussion above for previous RAI 1 and new RAIs 1 - 10. The licensee will coordinate with the NRC Project Manager regarding the schedule for the planned response.

2) In response to a question from the NRC staff, the licensee stated that Salem Units 1 and 2 do not utilize untopcoated inorganic zinc insulation. The NRC staff requested the licensee to validate if this information has previously been docketed. If not, the licensee should include this information in its RAI response.

3) The licensee discussed their revised debris generation and transport analysis. With respect to chemical effects, the revised analysis results in precipitate amounts greater than that previously tested during the Salem Unit 1 strainer head loss tests at Control Components Incorporated. However, the licensee believes that there is sufficient net positive suction head margin to accommodate the increased precipitate load. It was agreed that further discussion was needed on this subject.

4) With respect to debris transport, the NRC staff stated that it was important for the licensee to cite the documents that form the basis for the assumptions regarding transport of debris through gratings.

5) It was decided that a followup public meeting or phone conference would be held after the revised draft RAI response is submitted. A schedule for the final RAI response will be established following that meeting.

Members of the public were in attendance. Public Meeting Feedback forms were not received.

Please direct any inquiries to me at 301-415-1420 or Rick.Ennis@nrc.gov.

Richard B. Ennis, Senior Project Manager
Plant Licensing Branch I-2
Division of Operating Reactor Licensing
Office of Nuclear Reactor Regulation

Docket Nos. 50-272 and 50-311

Enclosures:
1. List of Attendees
2. Licensee Handout - RAI 11 - Draft for discussion (2 pages)
3. Licensee Handout - RAI 12 - Draft for discussion (13 pages)
4. Licensee Handout - RAI 13 - Draft for discussion (2 pages)
5. Licensee Handout - Previous RAI 14 - Draft for discussion (7 pages)
6. Licensee Handout - RAIs 14 & 15 - Draft for discussion (7 pages)
7. Licensee Handout - Response to Generic Letter 2004-02 (4 pages)
8. Licensee Handout - Assessment of 17D ZOI for Jacketed Nukon (55 pages)
9. Licensee Handout - Tree Diagram - Salem Unit 1 Debris Transport (1 page)

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LIST OF ATTENDEES

MARCH 16, 2010, MEETING WITH PSEG

RESPONSE TO GENERIC LETTER 2004-02

FOR SALEM NUCLEAR GENERATING STATION, UNIT NOS. 1 AND 2

Name	Title	Organization
Rick Ennis	Sr. Project Manager	NRC/NRR/DORL
Jeff Keenan	Manager Licensing	PSEG Nuclear LLC
Bob Peterson	Senior Manager	Sargent & Lundy
Helmut Kopke	Project Associate	Sargent & Lundy
Kiran Mathur	Senior Engineer	PSEG Nuclear LLC
Greg Sosson	Engineering Services Director	PSEG Nucleear LLC
Alan Johnson	Design Engineering Manager	PSEG Nuclear LLC
Paul Duke	Licensing Engineer	PSEG Nuclear LLC
Mike Scott	Branch Chief	NRC/NRR/DSS/SSIB
Mike Testa	Consultant	First Energy/Beaver Valley
Steve Smith	Reactor Systems Engineer	NRC/NRR/DSS/SSIB
Nageswara Karipineni	Reactor Systems Engineer	NRC/NRR/DSS/SSIB
Larry Doerflein*	Branch Chief	NRC/Region I/DRS/EB2
Elliott Rosenfeld*	Nuclear Engineer	New Jersey DEP
Kirk Troxler*		First Energy/Beaver Valley

* Participated via teleconference

Enclosure 1

RAI 11

The response noted that lead blankets were credited for shielding Min-K® microporous insulation on two of the intermediate RCS legs. The response did not justify this position. The licensee should justify that the lead blankets would provide adequate protection such that the Min-K would not become debris or show that the amount of Min-K added to the testing bounds the potential for Min-K debris generation.

The updated supplemental response showed that the debris generation evaluation contained some conservatism. For example, the Min-K amounts have a 40% margin for both units, although this conservatism did not specifically address the issue with the lead blanket providing protection for the Min-K described above. The licensee may be able to balance the issue identified above with this conservatism.

Response to RAI 11

At Salem Unit 2 the cross over piping (between steam generator and reactor coolant pump) has Min K insulation. The similar piping at Salem Unit 1 has metallic reflective insulation. Per engineering calculation S-C-RHR-MDC-2039, 8.75 cu ft of Min K insulation debris will be generated from each cross over piping loop.

The cross over piping is covered an all sides with lead blankets hung on grommets with an open back configuration. WCAP-16727-NP investigated debris generation by lead shielding blankets.

At Salem Unit 2, the two cross over loop piping are located on either side of the reactor wall. For jet impingement to impact third loop, it would have to pass through a treacherous path. Also, the third cross over loop piping is approximately 18D from the postulated break.

The current revision of the WCAP-16727 shows that at a distance of 1.25D "open-back" lead blankets (blankets hung by grommets such as at Salem) simply break free of their restraints and fly away. Based on the revised ZOI information, the 1.25D is increased to 2.5D (Reference 1). The blankets will get damaged. Because sufficient momentum transfer also occurs due to direct jet impingement, blankets secured in this orientation can be expected to separate from their mounting. The test showed that, within this ZOI, the blanket is torn from its metal grommets and the outer cover, although torn, remains attached to the body of the blanket itself.

Since the third cross over loop piping is located approximately 18D from the break, the jet impingement could impact the lead blankets in either of the following two ways.

- The blankets could remain in place and not get impacted by the jet impingement. This condition will protect the cross over piping insulation.
- The grommets could fail first as they are weakest link in the lead blanket configuration and the blankets would fall. This would dissipate the remaining energy of the break jet; thereby protecting the crossover leg insulation.

Additionally, the insulation jacketing would provide further resistance to damage. Also, the debris generation calculation provided an additional margin of 7 cu ft to the amount of Min K insulation debris generated.

Based on the above information, it is concluded that the third cross over piping loop insulation will not get damaged such as to cause debris generation.

Reference

1. E-mail from Timothy Croyle to Kiran Mathur dated 2/26/10 providing revised ZOI, pending issuance of the WCAP 16727 revision.

RAI 12

During the staff's audit of strainer performance calculations in October 2007, cumulative 30-day erosion percentages of 40% for Nukon and 15% for Kaowool© refractory fiber insulation were assumed to address NRC staff concerns associated with the erosion test results for Nukon and Kaowool. However, the March 31, 2009, supplemental response indicates that the currently assumed 30-day erosion percentages are 30% for Nukon and 10% for Kaowool. A basis was not provided in the supplemental response to justify the reduced erosion percentages that are currently assumed. Please provide a technical basis for the currently assumed 30-day erosion percentages for Nukon and Kaowool to address the concerns identified with the testing in the audit report and demonstrate that the percentages are prototypical or conservative for the plant condition.

Response to RAI 12

PSEG performed testing at Fauske and Associates Incorporated (FAI) to estimate the extent of the erosion of large and small pieces of Nukon and Kaowool fibrous debris in a 30-day period in the Salem containment pool. The NRC staff reviewed the erosion testing method, results, data analysis and conclusions during the detailed audit of the Salem Unit 1 and Unit 2 sump strainer design (Reference 10). A short description of the erosion testing performed is provided below followed by a discussion of the data analysis.

Test Description

The erosion testing was performed for the two primary types of fiber insulation present at Salem: Nukon and Kaowool. For each test, samples of each type of insulation were placed in stacked wire mesh baskets in a flume. The insulation samples were scissor cut rectangular pieces between 1/4 inch and 4 inches in size and were baked prior to the erosion tests to simulate exposure to hot surfaces in containment.

The baskets extended across the entire width of the flume and were installed downstream of the flow straightener. Two stacked baskets were used simultaneously to restrain the debris samples during the erosion testing. The Nukon fiber samples and Kaowool fiber samples were distributed between the two baskets such that the samples only occupied a fraction of the total basket volume and each piece of fiber was directly exposed to the flowing water. Initially, when all the fiber samples were placed in the two baskets the volume occupied by the fiber samples was between approximately 9 and 13 per cent of the total basket volume. As fiber samples were removed to be dried and weighed, the volume occupied by the debris in the two baskets continually decreased. A turbulence suppressor and flow straightener were located upstream of the fiber samples.

Erosion data was obtained for various erosion intervals. After each erosion interval, the wet fiber erosion samples were placed on trays, weighed and placed in a drying oven. The oven temperature was maintained at approximately 45 to 50°C while the erosion samples were dried. The samples were periodically removed from the oven and the samples and tray were re-weighed. The erosion samples and tray were then returned to the drying oven for additional drying. This process was continued until the weight of the erosion samples and tray did not change. To determine the long term erosion rates, the same fiber samples were used throughout the tests (i.e. long term erosion rates were obtained using pre-eroded pieces). Thus, the total exposure time of any given fiber sample was equal to the sum of all of the erosion intervals which were used to determine the erosion rate at different times for that fiber sample.

Figures showing the flume and wire mesh baskets are provided below. Note, the capture screen shown in Figures 1 and 2 was not used. These figures also do not show the wire mesh baskets which were used.

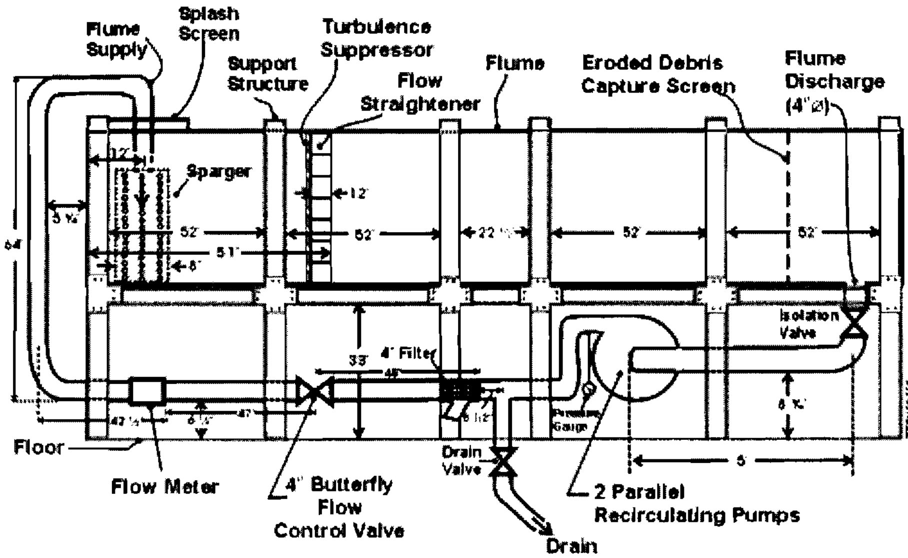


Figure 1: Side View of Flume

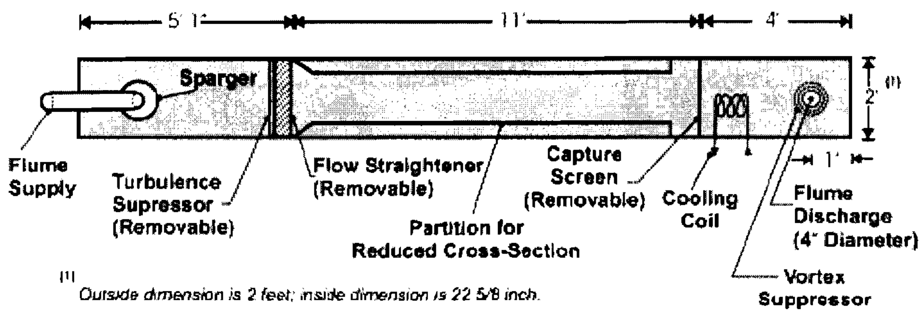


Figure 2: Top View of Flume

Figure 3: Photo Test Apparatus

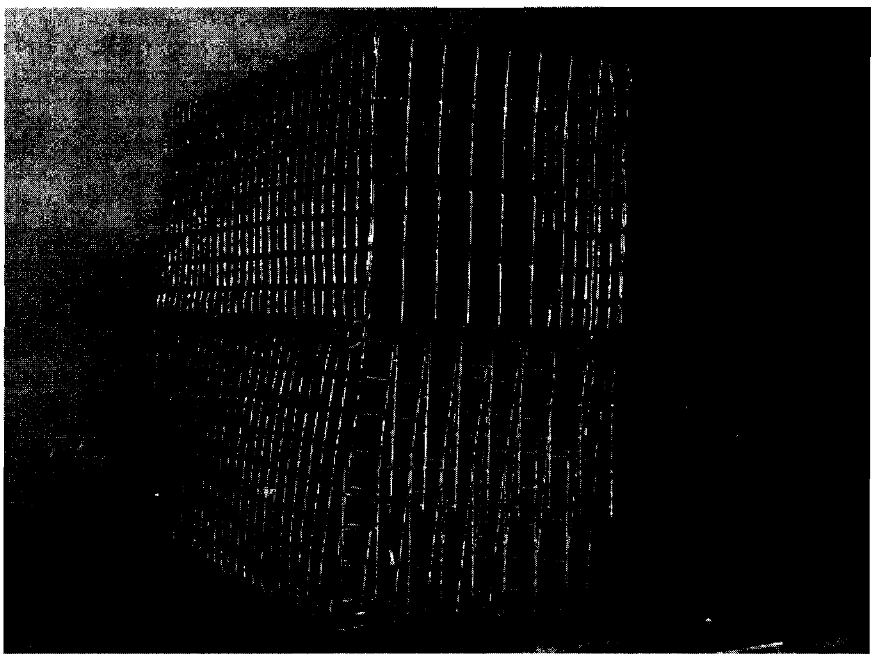


Figure 4: Fiber Samples in Baskets in the Flume during a Test

The velocity in the flume was nominally 0.72 ft/s which is greater than approximately 98% of the velocities found in the post-LOCA containment sump pool with two pumps operating based on CFD analysis (see Figure 5 below).

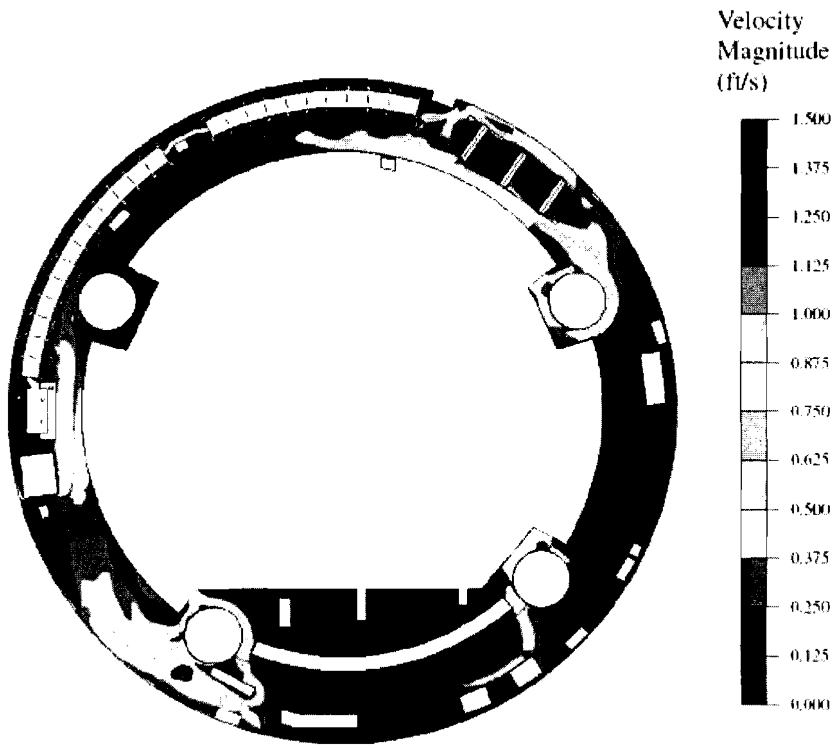


Figure 5: Velocity Magnitude 3 inches Above Floor for 9000 gpm Total Flow

The velocity around most of the debris interceptor and upstream of the debris interceptor in the annulus is significantly lower than 0.72 ft/s. In front of the debris interceptor, the approach velocities are generally less than 0.27 ft/s near the floor. Less than two percent of the total containment sump pool area near the floor has a velocity greater than 0.70 ft/s. In addition, most (~80%) of the areas of the pool where debris would be stalled have velocities of 0.41 ft/s or less near the floor.

The CFD analysis used to determine the flow velocity used in the erosion tests is based on the minimum water level. In reality, the minimum water level will occur at a single point at the start of the post-LOCA recirculation transient. As the water level rises, the flow velocities in the sump pool will be reduced proportionally. Thus, the fiber which is stalled in the pool or at the trash rack will be exposed to lower flow velocities, and is expected to erode at a slower rate. The highest minimum water level elevation for Salem is ~81'-7", which is 29 inches higher than the minimum water level elevation of 80'-10". The maximum water level at Salem is at elevation 83'-5", which is 2'-7" higher (more than twice) than the minimum water level elevation of 80'-10".

Furthermore, the freeboard above the fiber samples in the erosion tests was much less than that which would exist in the plant during recirculation. The tests utilized a flume water depth of 11.5 to 12.5" (~12"). In the plant, the minimum water level is 80'-10" during recirculation, the maximum floor height is 78'-4" in the annulus, and the debris interceptor height is approximately 9"; thus, there will be a minimum freeboard of 21" above the debris interceptor (total water depth of 30").

Since the fiber samples act as porous obstructions to flow in the flume, the velocity around the edges of the fiber samples in the test is much greater than the bulk velocity of 0.72 ft/s tested. For example, the velocity around a 2 inch fiber piece would be 120% [=12/(12-2)] of the nominal flume velocity in the test but only 107% [=30/(30-2)] of the nominal pool velocity in the plant (assuming no flow through the fiber pieces). As the mechanism for fiber erosion is most likely shear on the outer faces of the fiber debris pieces, testing of greater flow velocities around the fiber samples in the erosion tests than will exist in the plant is extremely conservative.

Data Analysis

The details regarding the data reduction and statistical analysis used to compute the 30-day erosion percentages are provided below.

The data from the erosion tests performed by FAI was first inspected to ensure that it was appropriate for use. As a result of this inspection, data from several tests was discarded. The reasons for discarding data were as follows: 1) inaccurate debris collection method and 2) fiber sample delamination during testing. In addition, some data indicated that no erosion had occurred over a given time period. Although plausible, especially in the long term, these data points were conservatively not included in the statistical analysis, thus resulting in higher average erosion rates.

For Nukon, a total of 40 data points are used which includes 29 short term data points and 11 long term data points. Of the short term data points, 23 are based on a nominal flow rate of 0.72 ft/s and 6 are based on a nominal flow rate of 0.40 ft/s. This is considered acceptable since the majority of the pool experiences velocities less than 0.41 ft/s, as described above. The inclusion of the lower velocity data results in a slightly lower, although more realistic, short term erosion rate than would result from the use of the high velocity data exclusively. For Kaowool, a total of 24 data points are used which includes 15 short term data points and 9 long term data points. The long vs. short term data points are described below.

The data from the erosion tests is analyzed using the Student's t-distribution. This distribution is appropriate for use in experimental scenarios where there is no knowledge of the population average (μ) or variance (σ), which is often the case when working with small sample sets (such as the erosion data). For large sample sizes ($n \geq 30$), the t-distribution does not differ significantly from the standard normal distribution.

Inspection of the data from the erosion tests reveals that the long-term results (those tests lasting longer than approximately 24 hours) for both Nukon and Kaowool can be characterized as normally distributed. This is based on a comparison of the data to the Normal distribution. The short-term results (those tests lasting approximately 24 hours or less) exhibit a more random distribution. This is possibly a result of the sample preparation which causes small fibers to be generated, but which remain on the sample pieces. These small fibers are then washed off the pieces relatively soon after being placed in the test flume, causing a "puff" of fibers to be "eroded." While this phenomenon is not erosion in the strictest sense, it is nonetheless a real phenomenon that would likely occur for jet damaged insulation during and/or shortly after a LOCA; therefore, it is not discounted in this evaluation.

After the "puff" subsides, the erosion mechanism is expected to be constant, i.e. the method of erosion is not expected to change between the short-term tests and the long-term tests. Therefore, it is reasoned that the non-normality of the short-term sample distribution is a matter of the sample size not being sufficiently large to capture the normality of the larger population, rather than a fundamental difference between short and long-term erosion. Thus, it is assumed, based on the normality of the long-term data and the expected similarities between short and long-term erosion, that the short-term test data can also be characterized as normally distributed. Furthermore, given the randomness of the short-term data, a precise means of analysis is not readily available. However, this approach is considered acceptable given the conservatisms integral to this analysis. Thus, the use of the t-distribution for analysis of the short and long-term erosion data is appropriate based on the inspection of the data in comparison to the normal distribution.

Separate analyses are conducted for the data from the short-term tests (t < 27 hours for Nukon and t < 25 hours for Kaowool) and those from the long-term tests (t > 27 hours for Nukon and t > 25 hours for Kaowool). This data may be utilized in a time dependent debris generation analysis, but the results are also combined to give an indication of the total erosion over the course of the entire 30-day recirculation period. The analyses of the short-term and long-term data are conducted similarly and the method of combining them is discussed below.

The analyses are begun by determining the sample mean (x) and sample standard deviation (s) using basic statistical equations, given below, where x_i is a data point and n is the number of data points. The data is given in percent per hour.

$$x\ (\%/hr) = \frac{\sum x_i}{n}$$

$$s\ (\%/hr) = \sqrt{\frac{\sum (x_i - x)^2}{n-1}}$$

For the long-term data, each data point is then evaluated for statistical validity using the Grubbs test which is outlined in *"Procedures for Detecting Outlying Observations in Samples"* by Frank Grubbs (Technometrics, Vol. 11, No. 1, February 1969). This step is skipped for the short-term data due to the non-normality of that data, as discussed above. The article by Grubbs provides Critical T values (re-named Critical Z values herein) which, based on the sample size under investigation, provide a means of determining if a data point is an "outlier" or invalid point. If the Z value of a given point (Z_i), calculated using the equation below, is greater than the Critical Z value, that point is likely an outlier and is therefore excluded from the analysis.

$$Z_i = \frac{|x - x_i|}{s}$$

The Critical Z values chosen for the analysis of the erosion data are for a 5% Significance Level, which is analogous to a 5% chance of erroneously discarding a valid data point. Essentially, a 5% Significance Level equates to a 95% confidence that all invalid data points are identified correctly.

A single outlier was found in the Kaowool long-term data and no outliers were found in the Nukon long-term data. Since the outlier was determined to be higher than expected, rather than lower, it was left in the analysis of the population mean and confidence level for conservatism; however, it was excluded from the calculation of the tolerance limit. Since the calculated tolerance limit is not used for anything other than development of Figures 1 and 2 below, the result of including the outlier in this portion of the analysis only highlights the disparity between the outlier data point and the valid data points. Because no outliers were excluded from the calculation of the population mean and confidence interval, the sample mean and standard deviation calculated using all data points are used throughout the analysis. These values of the mean and standard deviation are then used in the determination of the population mean confidence interval and the upper and lower tolerance limits.

Since the exact population mean is unknown, a confidence interval is used to determine the probable population mean. A 90% confidence level is used, meaning that the population mean is expected to be within the determined interval 90% of the time. The confidence interval is determined using the equation below where CL represents the limits of the confidence interval. The t-distribution value ($t_{\alpha/2}$) is determined based on α =0.10 (α/2=0.05) where α is 1 minus the confidence level.

$$\text{CL } (\%/\text{hr}) = x \pm \frac{t_{\alpha/2}}{\sqrt{n}} \times s$$

The expected/average (A = x), minimum (A = minimum CL), and maximum (A = maximum CL) average erosion fraction over a time period is calculated using the equations below. The expected values as well as the upper and lower bounds are computed. Two equations are used since the short and long-term erosion data are evaluated separately. These equations are based on Section III.3.3.3 of Appendix III of the NRC SE for NEI 04-07.

For short term erosion (up to time t in hours): $ER_{0-t}\ (\%) = 1 - \left(1 - \frac{A}{100}\right)^{t}$

For long term erosion (from time t to 720 hours): $ER_{t-720}\ (\%) = 1 - \left(1 - \frac{A}{100}\right)^{720-t}$

These values are then combined using the following equation to determine the expected, minimum, and maximum total erosion fraction over a 30-day period.

$$ER_{0-720}\ (\%) = ER_{0-t} + (1 - ER_{0-t}) \times ER_{t-720}$$

To further evaluate the quality of the data, a tolerance limit is determined and the sample data is compared to it. Similar to a confidence interval, a tolerance limit provides boundaries within which a value is expected to fall a certain amount of the time. For this analysis, a 95% tolerance limit is calculated with a 95% confidence level; thus, there is a 95% confidence that the tolerance limits bound 95% of the data. The upper tolerance limit (TL) is determined using the following equation, where k is based on the confidence level and the proportion of measurements bound by the limits. The lower tolerance limit is not computed since analytically it is less than 0 which is not physically possible; thus the lower tolerance limit is not included in Figures 6 and 7.

$$\text{TL } (\%/\text{hr}) = x + k \times s$$

Unlike a confidence interval, which bounds the population mean, a tolerance limit is intended to bound a percentage of all the data (in this case, 95%). Hence, the fact that the vast majority of the data falls within the tolerance limit boundaries (see Figures 6 and 7) lends further support to the validity of the data.

In Figures 6 and 7 below for Nukon and Kaowool, respectively, the sample data points are plotted based on their erosion rate in percent per hour (logarithmic scale) versus their time spent in the flume. The confidence interval is then overlaid on top of this plot, as are the tolerance limits. Outlier data points are identified as such on the plots. These graphs show good correlation to the numbers computed. The data used to generate these plots is presented in Tables 1 and 2 at the end of this RAI response.

Figure 6: Nukon Erosion Rate as a Function of Time in Flume

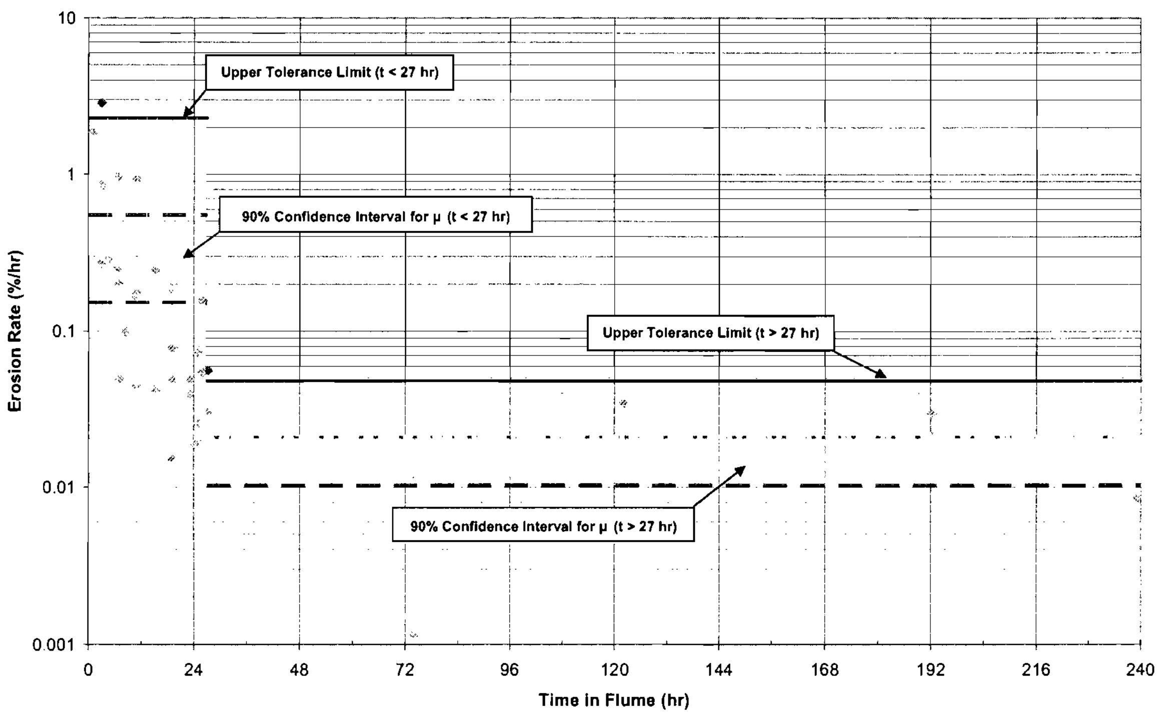
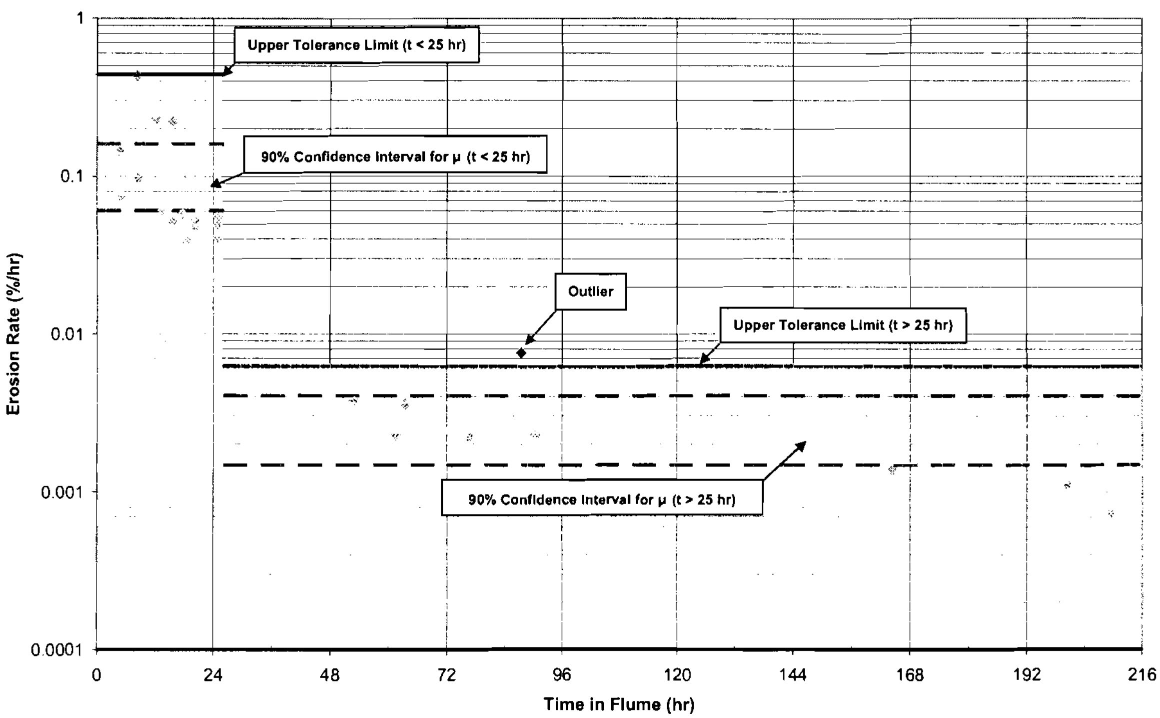


Figure 7: Kaowool Erosion Rate as a Function of Time in Flume



Based on the statistical analysis, the average erosion rate for Nukon debris is 0.35 ± 0.20 %/hr during the first 27 hours that the Nukon is exposed to flowing water. After 27 hours, the average erosion rate decreases to 0.016 ± 0.005 %/hr. Using this data, it is determined that the average 30-day erosion fraction for small and large piece Nukon debris is 18.4 +7.1/-7.8%. To be conservative, a 30-day erosion fraction of 20%, which is the average 30-day erosion fraction plus 9% margin, is used for Nukon debris. This value is different than that presented in the March 2009 Supplemental Response, partially due to the inclusion of the 6 aforementioned low velocity erosion data points.

Similarly, based on the statistical analysis, the average erosion rate for Kaowool debris is 0.11 ± 0.049 %/hr during the first 25 hours that the Kaowool is exposed to flowing water. After 25 hours, the average erosion rate decreases to 0.0028 ± 0.0013 %/hr. Using this data, it is determined that the average 30-day erosion fraction for small and large piece Kaowool debris is 4.6 +2.0/-2.1%. To be conservative, a 30-day erosion fraction of 5%, which is the average 30-day erosion fraction plus 10% margin, is used for Kaowool debris. This value is different than that presented in the March 2009 Supplemental Response.

The use of 30-day erosion fractions of 20% and 5% for Nukon and Kaowool, respectively, is different than the 30-day erosion fractions of 30% for Nukon and 10% for Kaowool which were previously used and presented in the March 2009 Supplemental Response. As stated in Section 3.5.3.3 of the Salem GL 2004-02 NRC Audit Report (ADAMS Accession No. ML082170506) from the October 2007 on-site audit, the 30% and 10% values were independently verified by the NRC as conservatively high. Thus, use of the average values with ~10% margin is considered acceptable given the conservatisms discussed below.

The 30-day erosion fractions of 30% and 10% for Nukon and Kaowool, respectively, were further increased to 40% and 15% for conservatism as recognized in the Salem GL 2004-02 NRC Audit Report. However, during the post-Audit effort to "test for success" in 2008, unnecessary conservatisms were removed from the design debris load. One of the most significant conservatisms removed was the arbitrary margin added to the 30-day erosion fractions. Removal of this conservatism resulted in the use of 30-day erosion fractions of 30% and 10% for Nukon and Kaowool, respectively, to "test for success" as stated in the March 2009 Supplemental Response.

Given the recent NRC concerns with WCAP-16710 for reduced Zones of Influence (ZOIs) for jacketed Nukon, Salem currently plans to use a ZOI of 17D for both jacketed and unjacketed Nukon based on the SE for NEI 04-07. The increased jacketed Nukon ZOI is only applicable to the jacketed Nukon installed in Unit 1. Unit 2 only contains a small amount of unjacketed Nukon and therefore never utilized the reduced jacketed Nukon ZOI in WCAP-16710. In order to cope with the increased quantity of Nukon insulation due to this ZOI increase relative to the design, further conservatism has been removed from the 30-day erosion fraction in that the average value with margin will be used (i.e. 20% for Nukon, 5% for Kaowool) instead of the upper bound with margin.

Use of the average erosion value (with ~10% margin) rather than the upper bound erosion is judged to be appropriate and reasonable. This approach is consistent with the Drywell Debris Transport Study (NUREG/CR-6369), which states that central estimates (averages) are realistic representations while upper bound values are those which will most likely never be exceeded. Furthermore, this approach is consistent with the overall holistic resolution approach endorsed by the Commission in its Staff Requirements Memorandum dated November 16, 2006 (ADAMS Accession No. ML063200471), which states that licensees may use a combination of measures which provide reasonable assurance that long term core cooling is maintained.

In addition to being computed in a conservative manner, the use of 30-day erosion fractions of 20% and 5% for Nukon and Kaowool is considered conservative due to the following conservatisms implicit in the testing and overall sump performance analysis.

- All debris in the tests is eroded at a nominal flow velocity of 0.72 ft/s which is greater than approximately 98% of the velocities in the post-LOCA sump based on CFD analysis.
    - The flow velocity in front of the debris interceptor in the plant is generally less than 0.27 ft/s near the floor based on CFD analysis.
    - Most areas of the post-LOCA sump pool where debris would stall have a flow velocity of 0.41 ft/s or less based on CFD analysis.
    - Data taken at a flow velocity of 0.4 ft/s indicated less erosion than data at a flow velocity of 0.72 ft/s.
- The erosion test velocity of 0.72 ft/s is much greater than the Nukon and Kaowool incipient and bulk tumbling velocities (0.12-0.16 ft/s) applicable to the Salem sump configuration (see NUREG/CR-6772).
- The fiber samples in the erosion tests had a freeboard less than the minimum freeboard above the debris interceptor of 21 inches in the plant. Thus, the velocity over the top of the fiber pieces in the plant is expected to be much less than over the fiber pieces in the erosion test.

- All debris in the pool is conservatively modeled as transporting to the debris interceptor in the transport analysis as opposed to stalling in the pool in low-flow areas of the pool or being retained on structures.
- The 30-day erosion quantity was modeled as arriving at the sump at the onset of recirculation rather than over a 30-day period in the vendor strainer testing. This is conservative since the debris load would be transient and since erosion would most likely be inhibited once chemical precipitates formed and deposited on stalled fiber pieces in the pool.
- The design sump flow is maintained for 30-days post-accident.

Therefore, the use of 30-day erosion fractions of 20% and 5% for Nukon and Kaowool is considered conservative and appropriate.

Nukon Test Data from ER05, ER07, ER08, ER10 & ER11

Point	Test Number	Debris Type	Piece Number	Erosion Interval (hr)	Total Erosion Time (hr)	Initial Mass (g)	Final Mass (g)	Eroded Mass (g)	Erosion Rate (%/hr)
6	ER05	NUKON-1 IN	I	1.00	1.00	2.7	2.65	0.05	1.852
7	ER05	NUKON-1 IN	II	2.83	2.83	2.63	2.61	0.02	0.269
33	ER07	NUKON-1 IN	I	2.07	3.07	2.54	2.39	0.15	2.858
38	ER07	NUKON-2 IN	I	2.07	3.07	7.32	7.19	0.13	0.859
8	ER05	NUKON-1 IN	III	4.83	4.83	2.16	2.13	0.03	0.288
34	ER07	NUKON-1 IN	II	3.82	6.65	2.44	2.35	0.09	0.966
39	ER07	NUKON-2 IN	II	3.82	6.65	6.22	6.16	0.06	0.253
9	ER05	NUKON-1 IN	IIII	6.80	6.80	2.2	2.17	0.03	0.201
10	ER05	NUKON-1 IN	V	8.58	8.58	2.35	2.33	0.02	0.099
11	ER05	NUKON-1 IN	VI	10.58	10.58	2.21	2.17	0.04	0.171
35	ER07	NUKON-1 IN	III	6.08	10.91	1.94	1.83	0.11	0.932
40	ER07	NUKON-2 IN	III	6.08	10.91	6.53	6.46	0.07	0.176
36	ER07	NUKON-1 IN	IIII	8.47	15.26	1.92	1.88	0.04	0.246
41	ER07	NUKON-2 IN	IIII	8.47	15.26	5.59	5.57	0.02	0.042
37	ER07	NUKON-1 IN	V	10.47	19.05	2.06	2.02	0.04	0.186
42	ER07	NUKON-2 IN	V	10.47	19.05	6.26	6.25	0.01	0.015
43	ER08	NUKON-1 IN	III	12.10	23.01	2.08	2.07	0.01	0.0397
47	ER08	NUKON-2 IN	III	12.10	23.01	6.72	6.68	0.04	0.0492
48	ER08	NUKON-2 IN	IIII	9.03	24.30	5.82	5.81	0.01	0.0190
45	ER08	NUKON-1 IN	V	6.00	25.05	2.29	2.28	0.01	0.0728
49	ER08	NUKON-2 IN	V	6.00	25.05	6.5	6.49	0.01	0.0256
46	ER08	NUKON-1 IN	VI	3.00	26.05	2.13	2.12	0.01	0.1565
50	ER08	NUKON-2 IN	VI	3.00	26.05	6.13	6.12	0.01	0.0544
63	ER10 (0.4 fps)	NUKON-2 IN	I	4.1	7.1	4.95	4.94	0.01	0.0493
64	ER10 (0.4 fps)	NUKON-2 IN	II	8.1	11.1	5.48	5.46	0.02	0.0451
65	ER10 (0.4 fps)	NUKON-2 IN	III	16.26	19.26	5.52	5.45	0.07	0.0780
66	ER10 (0.4 fps)	NUKON-2 IN	IIII	16.26	19.26	5.08	5.04	0.04	0.0484
66	ER10 (0.4 fps)	NUKON-2 IN	V	24.26	27.26	5.48	5.44	0.04	0.0301
67	ER10 (0.4 fps)	NUKON-2 IN	VI	24.26	27.26	6.6	6.51	0.09	0.0562
75	ER11	NUKON-1IN	V	48	73.05	2.287	2.2743	0.0127	0.0116
76	ER11	NUKON-2IN	V	48	73.05	6.5019	6.4828	0.0191	0.0061
69	ER11	NUKON-2IN	VI	48	74.05	6.1172	6.1138	0.0034	0.0012
74	ER11	NUKON-1IN	VI	24	98.05	2.1358	2.1281	0.0077	0.0150
75	ER11	NUKON-2IN	VI	24	98.05	6.1138	6.097	0.0168	0.0114
76	ER11	NUKON-1IN	VI	24	122.05	2.1271	2.1094	0.0177	0.0347
77	ER11	NUKON-2IN	VI	24	122.05	6.0973	6.0688	0.0285	0.0195
78	ER11	NUKON-1IN	IIII	24	192.30	2.1357	2.1207	0.015	0.0293
79	ER11	NUKON-2IN	IIII	24	192.30	5.7636	5.7338	0.0298	0.0215
79	ER11	NUKON-1IN	III	24	239.01	2.0582	2.054	0.0042	0.0085
80	ER11	NUKON-2IN	III	24	239.01	6.654	6.6316	0.0224	0.0140

Kaowool Test Data from ER09 & ER12

Point	Test Number	Debris Type	Piece Number	Erosion Interval (hr)	Total Erosion Time (hr)	Initial Mass (g)	Final Mass (g)	Eroded Mass (g)	Erosion Rate (%/hr)
51	ER09	KAOWOOL-1 IN	I	3.82	4.82	3.47	3.46	0.01	0.0754
55	ER09	KAOWOOL-2 IN	I	3.82	4.82	9.23	9.18	0.05	0.1418
54	ER09	KAOWOOL-1 IN	V	3.32	8.38	2.81	2.77	0.04	0.4288
58	ER09	KAOWOOL-2 IN	V	3.32	8.38	9.32	9.29	0.03	0.0970
53	ER09	KAOWOOL-1 IN	III	7.2	12.27	2.41	2.37	0.04	0.2305
59	ER09	KAOWOOL-3 IN	I	12.47	13.47	21.38	21.22	0.16	0.0600
52	ER09	KAOWOOL-1 IN	II	12.47	15.54	2.91	2.83	0.08	0.2205
56	ER09	KAOWOOL-2 IN	II	12.47	15.54	9.26	9.2	0.06	0.0520
62	ER09	KAOWOOL-3 IN	V	12.47	17.53	21.03	20.88	0.15	0.0572
60	ER09	KAOWOOL-3 IN	II	15.42	18.48	21.9	21.77	0.13	0.0385
57	ER09	KAOWOOL-2 IN	III	10.33	20.38	11.26	11.2	0.06	0.0516
61	ER09	KAOWOOL-3 IN	III	15.42	20.38	21.92	21.76	0.16	0.0473
54	ER09	KAOWOOL-1 IN	IIII	19.85	24.92	2.75	2.72	0.03	0.0550
58	ER09	KAOWOOL-2 IN	IIII	19.85	24.92	9.26	9.17	0.09	0.0490
62	ER09	KAOWOOL-3 IN	IIII	19.85	24.92	19.99	19.83	0.16	0.0403
81	ER12	KAOWOOL-1 IN	I	48	52.82	3.4376	3.4314	0.0062	0.0038
89	ER12	KAOWOOL-3 IN	I	48	61.47	21.2156	21.1926	0.023	0.0023
86	ER12	KAOWOOL-2 IN	II	48	63.54	9.1909	9.1752	0.0157	0.0036
85	ER12	KAOWOOL-2 IN	I	72	76.82	9.1724	9.158	0.0144	0.0022
82	ER12	KAOWOOL-1 IN	II	72	87.54	2.8279	2.8125	0.0154	0.0076
90	ER12	KAOWOOL-3 IN	II	72	90.48	21.743	21.7073	0.0357	0.0023
91	ER12	KAOWOOL-3 IN	III	144	164.38	21.7263	21.6837	0.0426	0.0014
88	ER12	KAOWOOL-2 IN	V	192	200.38	9.2785	9.2586	0.0199	0.0011
92	ER12	KAOWOOL-3 IN	V	192	209.53	20.862	20.8327	0.0293	0.0007

RAI 13

The Salem Unit 1 chemical effects head loss test was conducted utilizing the full debris load. However, the Unit 1 thin bed test had a significantly higher head loss (78 mbar) than the non-chemical full load head loss (30 mbar). Please provide information that justifies that the chemical effects testing conducted with the full debris load bounds the head loss that could occur on a chemically laden thin bed. Alternately, a thin bed test can be conducted with chemicals to ensure that the head loss included in the evaluation is bounding for potential plant conditions.

Response to RAI 13

The Unit 1 thin bed test used a debris load and flow rate that were greater than those used for the Unit 1 full load test. Furthermore, the Unit 1 thin bed test utilized room temperature water, while the Unit 1 full load test utilized a heated test loop. The impact of each of these factors is discussed below. The Unit 1 thin bed test was Test 3-repeat and the Unit 1 full load test was Test 5 in the 2-Sided MFTL Head Loss Tests. Both tests were performed using the "2-Sided" MFTL configuration.

The total debris loads for the Unit 1 thin bed (TB) and full load (FL) tests are provided in Tables 3f.4.1.5.6-2/3/6/7 of the March 2009 Supplemental Response. These are the debris loads at which the maximum head loss values cited in the RAI were recorded. The main differences are shown below. The % difference is based on the full load test.

Debris Type	Thin Bed Test Volume ft^3	Full Load Test Volume ft^3	% Difference %
Nukon	310	236	31%
Kaowool	39	33	18%
Qualified Coatings	12.6	11.5	9.6%

The Unit 1 thin bed test included more debris than the final design debris load which was used for the full load test. This is acceptable, though, since the thin bed test was used to demonstrate a trend (i.e. that the thin bed effect was not experienced on a complex strainer).

A more appropriate comparison of head losses is the full load head loss to the head loss after the addition of Portion 12 in the 1 thin bed test (see Figure 3f.4.2.3.3-1 of the March 2009 Supplemental Response). The full load theoretical bed thickness was 0.90 inches, and theoretical bed thickness after Portion 12 was 0.86 inches. The thin bed head loss after the addition of Portion 12 was ~58 mbar (see Figure 3f.4.2.3.3-1 of the March 2009 Supplemental Response). The thin bed head loss after the addition of Portion 14, which corresponded to a theoretical bed thickness of 1.12 inches, was 78.5 mbar.

In addition, the maximum full load head loss was measured at 106°F, while the thin bed test was performed with 74°F water. The ratio of water viscosities at 74°F to 106°F is 1.45; thus, the thin bed head loss of 58 mbar at 74°F is equivalent to 40 mbar at 106°F. Furthermore, the thin bed test utilized a flow rate of 9000 gpm, not the design two pump flow rate of 8850 gpm. This reduces the equivalent thin bed head loss of 40 mbar to 39 mbar.

Although 39 mbar is greater than 32.5 mbar (the peak full load head loss per §3f.4.2.3.4 of Attachment 1 to the March 2009 Supplemental Response), it also does not account for the ~10% more qualified coatings (~5% more coatings overall) in the thin bed test. The impact of the additional coatings in the thin bed test is considered to offset the addition of 75 g more Min-K to the full load test than specified (see Table 3f.4.1.5.6-7 of the March 2009 Supplemental Response). The additional coatings in the thin bed test result in 1.1 kg more stone flour being added to the test loop than in the full load test, which is significantly more than 75 g.

Thus, the head losses measured for the Unit 1 thin bed and full load tests were very comparable. In addition, previous Unit 1 testing which used the "1-Sided" MFTL configuration (see §3f.4.1.4 of Attachment 1 to the March 2009 Supplemental Response) indicated that the thin bed effect was not observed. Furthermore, the Unit 2 thin bed and full load tests which used the "2-Sided" MFTL configuration (described in §3f.4.2.3 of Attachment 1 to the March 2009 Supplemental Response) also indicated that the thin bed effect was not observed. Based on the equivalence of the thin bed and full load head losses, along with CCI's experience of their strainer not exhibiting the thin bed effect, the Unit 1 full load test was the appropriate test to use as the basis for the chemical effects test. Therefore, the chemical effects head loss test was performed using the full load test for Unit 1.

Previous RAI 14

In its March 31, 2009, submittal, the licensee provided a calculation of void fraction due to vortexing and degasification of the fluid as it passes through the debris bed. Staff evaluation of the response is split into two sections. Further information is required for both the vortex formation and degasification areas.

Previous RAI 14 - Vortex Formation
The supplemental response stated that there is a potential for intermittent vortex formations during two pump operation at the minimum submergence level with little or no debris on the strainer. The March 31, 2009, submittal stated that video analysis of the test showed that the maximum air ingestion rate during the test was 0.05% by volume. The response further calculated that the total air entrainment would be 0.00356% if the entire strainer train was included in the calculation. The staff needs more information regarding the video analysis and the calculation to determine whether the methodology used to derive the estimate is realistic. It is not clear how video could be used to estimate the amount of entrained air.

Previous RAI 14 Response - Vortexing

The vortex analysis is based on the following video which has been provided. The video was taken during the CCI Generic Vortex Tests conducted in January 2008.

CCI_vort_test_45mm_45m3h.MOV

The video was used to determine the size of potential vortices which could occur for the clean screen condition. The size of the vortex relative to the pocket was estimated based on the image below. Figure 1 below is an image that was taken from a video of a clean screen vortex test whose Froude number (0.218) and submergence (1.8 in) bound the worst case Froude number and submergence (3.8 inches) at modules nearest the sump pit at Salem. The minimum submergence at Salem is based on the minimum water level at switchover of 80'-10", which includes 0.25 inches of margin. The water level then increases from the minimum to over 81'-6" for the conservative case of a LOCA with full RCS reflood. The water level following switchover is computed using the conservative assumptions outlined in §3g.8 of Attachment 1 to the March 2009 Supplemental Response.

The CCI Generic Vortex Tests were used to develop Figure 3f.3.1.1-2 in the March 2009 Supplemental Response, repeated as Figure 2 below. Figure 2 shows strainer operating regions with respect to vortex formation based on strainer submergence level and Froude number. The data point selected for the vortex analysis (explained below) is marked as a black 'X' on the red "Limit_C" line used to delineate the unsafe operating region from the operating region with limited air intake. Salem operates in the safe region with limited air intake, as shown by the U1_2pump, U2_1pump, and U2_2pump data points in Figure 2. Vortices such as the one shown occurred less than 20% of the time, but are conservatively assumed to occur 100% of the time in the vortex analysis.

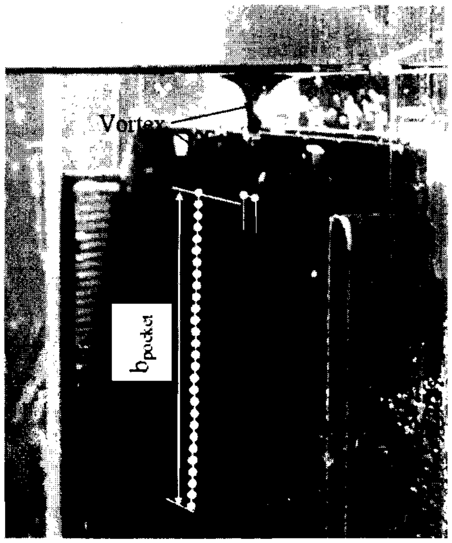


Figure 1: Screen Shot from Vortex Test Video

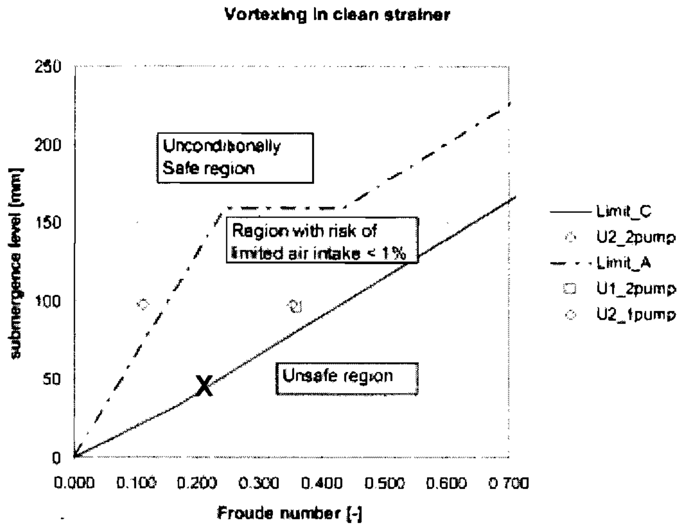


Figure 2: Clean Strainer Vortex Test Results

Based on scaling of the screen shot in Figure 1, the vortex diameter is approximately 1/27th of the height of the pocket. Since the pocket opening is 120 mm tall, the diameter of the vortex is 4.44 mm [=120 mm/27], and the cross sectional area of the vortex is 1.55×10^{-5} m^2 [=$\pi d^2/4$].

The air from the vortex is modeled as reaching the velocity of water once it is inside the pocket. Thus, the proportion of air ingested (α_p) is the ratio of the cross section of the vortex to the cross section of the 4 pockets which were used during the tests. The inside of the pocket is 70 mm wide and 109 mm tall. Thus, the 0.05% [=1.55×10^{-5} m^2 / (4*0.070 m*0.109 m)] air ingestion by volume is computed.

In addition, water will flow through all rows of the strainer, not just the top row (only the top row of pockets of the test strainer was open during the vortex tests). At Salem, each strainer module is 7 rows tall. Thus, the effective air ingestion over the entire height of the strainer is 0.00726% [=0.05%/7].

At Salem, a train of strainer modules is connected to the sump pit. For the clean strainer scenario at Salem, 49% of the water to the sump flows through the nearest 1/3 of the strainer module nearest the sump pit (e.g. through the first ~3 columns of pockets nearest the sump pit). The remaining water (51%) flows through the furthest 2/3 of the module nearest the sump pit and two modules further from the sump pit. The strainer trains have a total of 24 and 23 modules, respectively, for Units 1 and 2; thus, almost no water flows through the modules furthest from the sump pit for the clean strainer condition. The flow split is determined using the methodology provided in §3f.9 of Attachment 1 to the March 2009 Supplemental Response. Thus, the potential volumetric fraction of air entering the sump pit is 0.00356% [=0.00726%*0.49].

Previous RAI 14 - Degasification
The licensee determined that degasification of the fluid could occur as it passes through the debris bed. The licensee postulated that any evolved gasses would be reabsorbed by the liquid prior to reaching the pump suction due to the static head of water above the pump. It was not clear to the staff that any gasses that evolved from the sump fluid would be reabsorbed into the fluid prior to flowing into the pump suction. It was not clear that the dynamics of reabsorption were fully addressed or that all possibilities for evolved gasses were considered. For example, could the gasses collect within the strainer and be entrained in the flow as larger bubbles later in the event? This issue could be mitigated if it were shown that higher submergence would result for the large break LOCA such that degasification were reduced or eliminated and that the head loss across the strainer for a small break LOCA would be significantly lower. Please provide justification for the conclusion in the submittal that all gasses would be reabsorbed prior to the fluid entering the pump, or provide an alternative evaluation of degasification and its effects on the pump.

Previous RAI 14 Response - Degasification

The response to this RAI consists of two parts. First, an assessment is performed to determine the quantity of air evolved as well as its impact on NPSH. Second, an assessment is performed to determine the ability of the evolved air to form air bubbles at the top of the suction box.

Air Evolution
In order to assess the impact of degasification, an alternate analysis was performed in lieu of demonstrating that evolved air bubbles would dissolve back into solution. The alternate analysis determined the quantity of air which would come out of solution as the water passed through the debris bed and then determined the void fraction at the pump inlet. The quantity of air which is dissolved in solution and which evolves from solution is computed using Henry's Law. The methodology used is consistent with that employed in the NUREG/CR-6224 Correlation and Deaeration Software Package issued in 2005 (ADAMS Accession No. ML051590366).

The analysis was performed using both the DEPS Minimum Safeguards and the DEPS Maximum Safeguards post-LOCA pressure/temperature profiles in order to determine the worst case void fraction. The sump pool is assumed to be saturated with air. The relative humidity above the sump pool (which impacts the amount of air in solution) was modeled as 100% as would be expected in a post-accident environment at switchover. A transient water level was used wherein the minimum strainer submergence was modeled at the time of switchover, and the water level increased thereafter (as determined in the minimum flood level analysis). In addition, the amount of air evolved was computed separately for each row of pockets (7 rows total) since less air comes out of solution in the lower pockets due to the greater air solubility at higher pressures. The air evolved was tracked separately for each pocket row up to the pump inlet. At the pump inlet, the total void fraction was computed as the average of the void fraction computed based on the air evolved in each individual row. Averaging the individual void fractions is appropriate since the flow from the individual rows will be mixed in the suction piping. For sump temperatures less than 160°F (at which chemical precipitates could be present), the void fraction was conservatively computed based on the top row only due to the potential presence of bore holes.

The analysis conservatively ignored any re-dissolution of the air en route to the pump inlet. However, compression was credited for the evolved air bubbles at the pump inlet due to the greater pressure at the pump inlet relative to the pressure immediately downstream of the strainer. The compression is modeled as isothermal since it is gradual, the evolved air bubbles are relatively small (see Section below for size of bubbles), and the surrounding water is at a constant temperature as the fluid flows from the strainer to the pump inlet.

The void fraction (α_p) at the pump inlet was then used to compute a β multiplier for the NPSH required in accordance with Appendix A of Regulatory Guide 1.82, Revision 3 (e.g. $NPSH_{required}$ for α_p<2% = $NPSH_{required}$ x β where $\beta = 1+0.50*\alpha_p$). The maximum void fraction at the pump inlet was less than 0.25% by volume for all scenarios.

An example analysis for the limiting NPSH margin scenario (U2 – 1 pump) for DEPS Maximum Safeguards is provided for illustration. For single pump operation in hot leg recirculation for Unit 2, the flow rate is 4980 gpm and the NPSH required is 24 feet. The limiting margin occurs at a sump temperature 194.1°F, which is the temperature below which the initial partial pressure of air in containment is credited in the NPSH computation. This temperature occurs at approximately 1.7 hours post-LOCA for the Unit 2 DEPS Maximum Safeguards scenario. At this time, the containment pressure is 36.7 psia and the sump vapor pressure is 10.2 psia (resulting in a partial pressure of air of 26.6 psia). The water level elevation is 81.6 feet which results in a submergence of 1.2 ft (0.5 psi) for the top row of pockets and 2.9 ft (1.2 psi) for the bottom row of pockets (based on the elevation of the middle of the entrance to the pocket).

At 194.1°F, the strainer head loss of 3.7 ft (1.54 psi). Given this head loss, the partial pressure of air downstream of the debris bed at the elevation of the top pockets is 25.5 psia and at the bottom pockets is 26.2 psia. Based on the Henry's constant of $6.53x10^{-5}$ lbm-air/ft^3-water/psia at 194.1°F, the quantity of air which evolves across the debris bed is $7.0x10^{-5}$ lbm-air/ft^3-water in the top pockets and 2.3x10-5 lbm-air/ft^3-water in the bottom pockets. This air is isothermally compressed as it flows towards the pump inlet at elevation 46.8 ft, despite 5.7 ft (2.4 psi) in suction line losses. At the pump inlet, the total pressure is 47.4 psia and the partial pressure of air is 37.2 psia. Since the partial pressure of air at the pump inlet is greater than at the water surface, the solubility of air is greater at the pump inlet. However, as stated above, this is not credited. The void fraction at the pump inlet based on the water which flows through the top pockets is 0.045%, while the void fraction at the pump inlet based on the water which flows through the bottom pockets is 0.015%. Given uniform flow, the average void fraction at the pump inlet is 0.030% by volume.

The void fraction of 0.030% results in a β value of 1.015 (= 1 + 0.5*0.030). Applying this to the NPSH required of 24 feet results in an increase in NPSH required of 0.36 ft, which is equal to the reduction in the minimum available NPSH margin shown in the table below.

The results of this analysis for the scenarios with limiting NPSH margins are summarized below.

Scenario	Minimum NPSH Margin (α_p=0 at Pump Inlet) ft	Minimum NPSH Margin (α_p > 0 at Pump Inlet) ft	Delta ft
DEPS Minimum Safeguards			
U1 – 1 pump (Cold Leg Recirc)	1.6	1.6	0.01
U1 – 2 pump (Cont. Spray Recirc)	6.8	6.5	0.22
U2 – 1 pump (Hot Leg Recirc)	1.4	1.1	0.31
U2 – 2 pump (Cont. Spray Recirc)	2.3	1.4	0.92

Scenario	Minimum NPSH Margin (α_p=0 at Pump Inlet) ft	Minimum NPSH Margin (α_p > 0 at Pump Inlet) ft	Delta ft
DEPS Maximum Safeguards			
U1 – 1 pump (Cold Leg Recirc)	1.6	1.6	0.01
U1 – 2 pump (Cont. Spray Recirc)	6.8	6.5	0.26
U2 – 1 pump (Hot Leg Recirc)	1.4	1.1	0.36
U2 – 2 pump (Cont. Spray Recirc)	2.3	1.2	1.1

The above analysis is conservative since it neglects any dissolution of air downstream of the strainer. It also neglects the "salting-out" effect which states that the solubility of gases in water with electrolytes (e.g. boric acid) is less than in fresh water.

Therefore, sufficient NPSH available exists for the RHR pumps even when considering the impact of any potential air evolution as the sump fluid passes through the debris bed/strainer.

Air Accumulation in Suction Box
The ability of air bubbles to accumulate at the top of the suction box is addressed using streamlines produced as part of the CFD analysis of the suction box created for the strainer head loss computation. Based on the streamlines shown in Figure A-25 below, there is a clear movement of water entering the sump pit from the diffuser of the z-shaped duct to the ECCS pump suction pipes, with velocities in the top region of the pit of 1 m/s or more. The streamline plots show the primary flow of water from the diffuser moving towards the rear wall of the pit and then down towards the pump suction pipes.

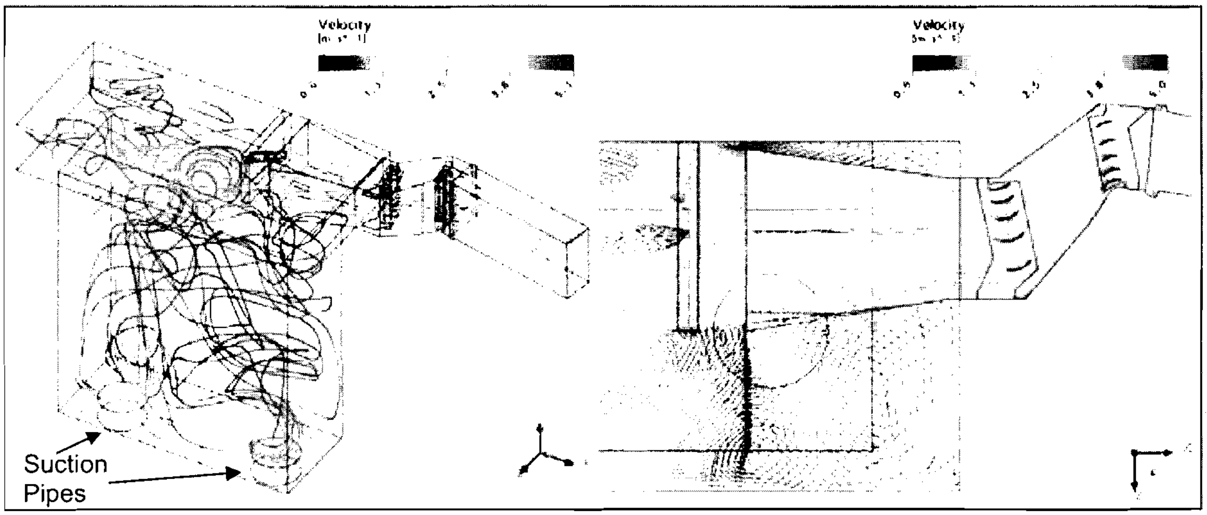


Figure A- 25 Streamlines and vector plot (9000 gpm transient)

The CFD analyses also determined that the average velocity across both a horizontal plane near the top of the sump (not in the suction box) and a horizontal plane near the bottom of the sump (near the outlet pipes) is ~0.3 m/s for a 5110 gpm flow and ~0.5 m/s for a 9000 gpm flow. These velocities are much greater than the maximum upward velocity for air bubbles evolved in the debris bed.

The maximum upward air bubble velocity is the terminal velocity. The terminal velocity is computed by performing a force balance on a spherical bubble where the buoyancy force is offset by the gravity force and drag force (which is velocity dependent). For air bubbles from 10-100 μm in diameter, the maximum terminal velocities in the post-LOCA sump are on the order of $2x10^{-4}$ to 0.02 m/s, respectively, and therefore, the air bubbles would remain entrained in the downward flow. The bubble size is based on the maximum expected size of the interstitial spaces in a debris bed. Based on Figures 3 and 4 below, the interstitial spaces between fibers in a debris bed are expected to be 10-100 μm.

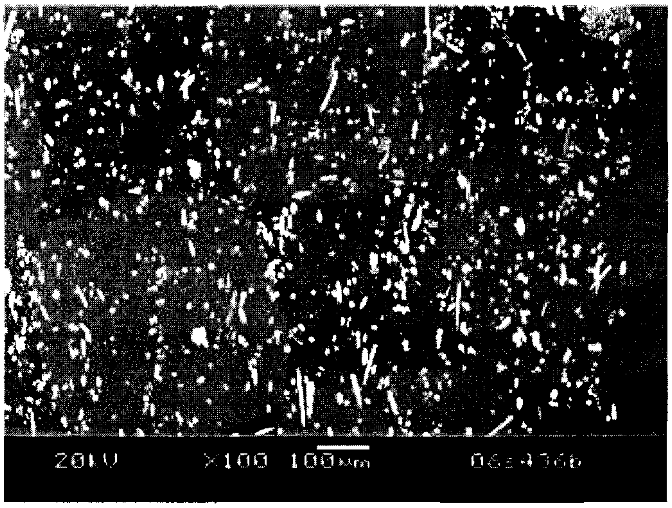


Figure 3: SEM of Nukon Fiber Region in a Debris Bed

Figure 4: SEM of Particulate Embedded in Fibrous Debris Bed

Figure 3 is Figure 6.30 of NUREG/CR-6917 and Figure 4 is Figure VIII-1 of Appendix VIII to the NRC SE for NEI 04-07. Figure 3 is based on a debris bed which contained 1015 g/m^2 (0.21 lbm/ft^2) of Nukon fiber and a total debris loading of 1522 g/m^2 (0.31 lbm/ft^2) per Section 6.4 of NUREG/CR-6917. Figure 4 is based on the tests documented in NUREG/CR-6874; however, multiple debris loadings were tested and it is not clear which test the picture is based on. Per Table 2.1 of NUREG/CR-6874, Nukon fiber loadings of 0.023 and 0.046 ft^3/ft^2 were tested. Thus, the debris bed shown in Figure 4 is either for 0.05 or 0.11 lbm/ft^2 of Nukon (based on an as-fabricated density of 2.4 lbm/ft^3).

The total fiber (Nukon, Kaowool, Fiberglas, and Latent) loading is 0.21 lbm/ft^2 for Unit 1 and 0.11 lbm/ft^2 for Unit 2 based on the total fiber debris masses presented in Tables 3f.4.1.5.6-3 and 3f.4.15.6-4 of Attachment 1 to the March 2009 Supplemental Response and the total strainer area in §2 of Attachment 1 to the March 2009 Supplemental Response. Including 12 ft^3 of coating debris (94 lbm/ft^3) and 1 ft^3 of latent particulate (169 lbm/ft^3) results in an additional 0.27 lbm/ft^2 of particulate debris for Unit 1 and 0.28 lbm/ft^2 of particulate debris for Unit 2, resulting in total debris loadings of 0.48 and 0.39 lbm/ft^2 for Units 1 and 2, respectively. Thus, the total debris loading on the Salem strainers is greater than the debris loadings in the tests upon which Figures 3 and 4 are based. Therefore, the interstitial spaces in the Salem debris beds will most likely be smaller than 10-100 μm, which provides support for the evolved air bubbles being on the order of 10-100 μm.

It is recognized that bore holes may occur at low sump temperatures (<160°F) at which chemicals are present. Fewer interstitial spaces will exist in a bore hole than in the debris bed. However, bore holes will not result in completely clean strainer area as is evidenced in Figure 3f.4.2.3.4-4 of the March 2009 Supplemental Response, shown below.

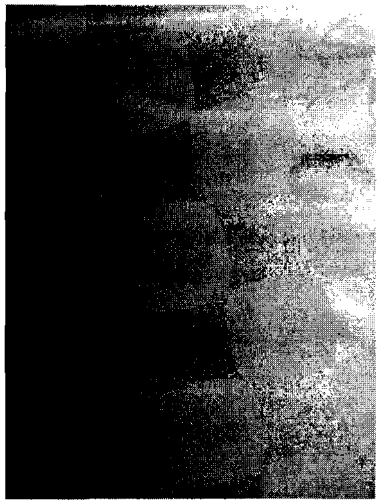


Figure 5: Unit 1 Full Load Test Debris Bed After Chemical Addition

Therefore, air bubbles evolved in flow through bore holes would have a size similar to those evolved in the debris bed. These air bubbles would remain entrained in the downward flow in the suction box. Thus, air bubbles would not accumulate at the top of the suction box.

NRC RAI #14a
Please discuss whether the operation of the residual heat removal pumps has been evaluated with respect to vortex formation at the RWST suction intake with the water level at the low-low-level setpoint to ensure adequate pump performance.

NRC RAI #14b
Please also discuss whether the minimum water level for Case 1 credits the injection of the accumulators. If credit is taken, please provide a basis to demonstrate that their injection would be expected and a basis for considering the Case 1 to be a limiting water level that bounds small-break LOCA cases for which the accumulators may not inject or may not fully inject. If a more limiting water level is possible for small-break LOCA conditions without accumulator injection, please identify this water level.

NRC RAI #15
Page 2 of Attachment 1 to the licensee's submittal of March 31, 2009, indicates that level switches used for indication of containment flood levels "alert the control room operator when sufficient sump level has been achieved to support initiation of cold leg recirculation". This statement suggests that two conditions must now be satisfied before recirculation switchover is initiated: RWST low water level AND containment sump level. Please describe what action the operator would take if both of these conditions are not met; in particular, a case where the RWST is exhausted, but indicated containment water level is too low to have activated the level switches.

Response Background

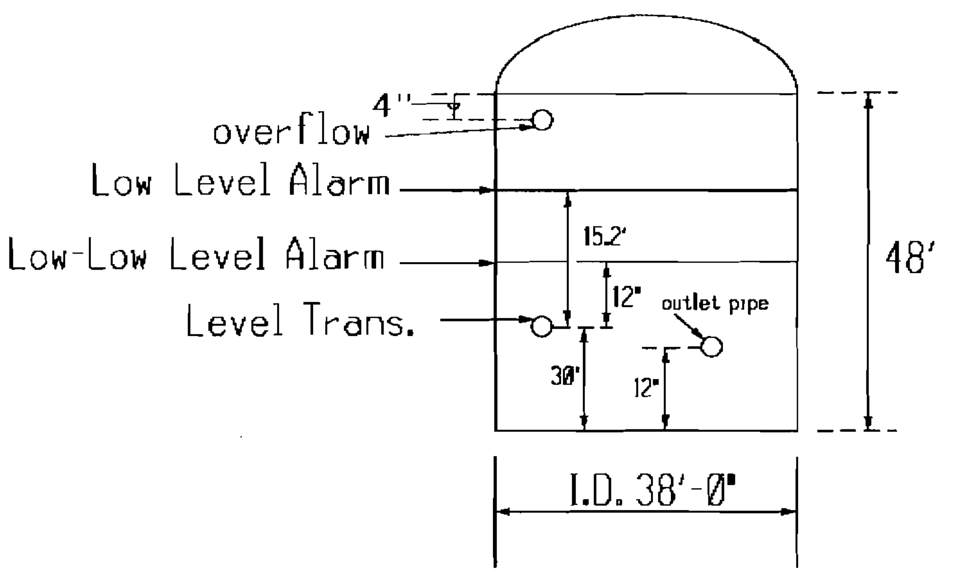
RWST Description
Refueling Water Storage Tank (RWST) provides borated water which is injected into the Reactor Coolant System (RCS) through the Emergency Core Cooling System (ECCS) pumps or sprayed into containment for containment heat removal and pressure control during the injection phase of Loss of Coolant Accident (LOCA).

The RWST level is monitored by two separate level transmitters. Additionally, the alarm is provided for "RWST High", "RWST low", and "RWST Low-Low" water level. The low-low setpoint is indication that the tank has reached the low-low level. The low level alarm setpoint is set high enough to ensure a sufficient volume is available to allow operators the time to switch from injection to recirculation phase before level decreases to the low-low level setpoint. The setpoints are established such that they account for instrument uncertainty.

Design Information

- Total Capacity = 400,000 gallons
- Technical Specification minimum volume = 364,500 gallons
- Level tap located 2.5 ft above the bottom for zero reference
- Total span of 48 ft
- Internal Diameter = 38 feet
- ECCS Outlet nozzle = 12 inches from bottom
- Low-Low level alarm = 1 foot above the level tap
- Low level alarm = 15.2 feet above the level tap

Refueling Water Storage Tank



System Response

When a LOCA occurs, an automatic Safety Injection (SI) signal is initiated via the Engineered Safety Features (ESF) System on Containment High Pressure (4 psig) or Low-Low Pressurizer Pressure (1765 psig), or manually via key switches in the control room.

The SI signal starts the Centrifugal Charging pumps, the Safety Injection Pumps, and the Residual Heat Removal (RHR) Pumps. These pumps inject to the RCS cold legs, taking suction from the RWST. The initial injection of borated water from the RWST to the RCS is referred to as the ECCS injection phase. The Containment Spray (CS) pumps start automatically when containment pressure reaches the initiation setpoint of 15 psig. The CS pumps also take suction from the RWST, through a separate line (different from the ECCS suction) and discharge to the containment ring header.

When RWST level reaches its low-level alarm at 15.2 feet, procedural guidance directs operators to initiate switchover to the recirculation phase. One of the first steps the operator needs to verify is that the adequate sump level exists (80' 11") for transfer to recirculation operation. Switchover to recirculation operation is initiated only if adequate water level exists.

Due to design differences between Salem Unit 1 and Salem Unit 2 there is a slightly different strategy for system swap over to recirculation operation.

For Unit 1, once adequate sump inventory has been verified for the swap over to the recirculation phase, the following actions are taken: The operators will stop the RHR pumps and manually reconfigure the pump suctions from the RWST to the recirculation sump. After the manual realignment of the pump suction is completed, the RHR pumps are restarted in accordance with the EOPs and recirculate the containment sump water to the RCS cold legs and provide suction to the Charging and SI pumps. One RHR pump also provides recirculation containment spray flow to one ring header. This alignment is referred to as cold leg recirculation.

The Unit 2 procedure is similar to Unit 1. Once RWST low level alarm is reached and the required containment flood level is verified, operators arm a semi-automatic swap over system. This semi-automatic swap over system realigns the RHR pump suctions from the RWST to the recirculation sump. The remainder of the transition process is similar to that of Salem Unit 1 and controlled by emergency operating procedures.

In case the RWST reaches the low level (15.2 feet level above the level tap) and the required containment flood level is not reached, then the operator continues to drawdown from the RWST until either required containment flood level (80' 11") is reached or RWST low-low water level alarm is reached. During this period, the control room operator uses various combinations of ECCS pumps in accordance with EOPs. However, all the operating ECCS and CS pumps are stopped when the RWST reaches low-low alarm level.

At Salem, the plant operators are trained to complete switchover from injection phase to recirculation phase within the minimum time available from RWST low level to low-low level. This condition is based on maximum flow of the ECCS pumps in a maximum safeguard scenario. The pump configuration, flow rates, and minimum time to low-low level are discussed in VTD 323585 for Unit 1 (Reference 7) and VTD 323001 for Unit 2 (Reference 8).

The drain down time for the RWST is extended for the small break LOCA since the RCS pressure remains above the RHR pump shutoff head. The charging pumps and safety injection pumps are aligned to take suction from the RHR pumps before the RWST reaches the low-low level alarm. This will ensure uninterrupted flow to the core. The small break LOCA with elevated RCS pressure is not the limiting in terms of RWST drain down times.

<u>Emergency Operating Procedures</u>

Salem Units 1 & 2 use Emergency Operating Procedures (EOPs) during various phase of LOCA.

- Per EOP-LOCA-1 (Reference 2) the injection phase continues until the RWST low level alarm is reached which corresponds to RWST level of 15.2 feet.
- When the RWST low level alarm is reached, EOP-LOCA-3 (Reference 3) is entered. One of the first steps in this EOP is to verify that the adequate sump level exists (80' 11") for

transfer to recirculation operation. If adequate water level exists then switchover to recirculation operation is initiated.

- If inadequate water level exists for recirculation operation, then EOP-LOCA-5 (Reference 4) is entered. Under this EOP the ECCS injection from the RWST continues until either required containment flood level (80' 11") is reached or RWST low-low water level alarm is reached.
- Under EOP-LOCA-5, if the RWST level reaches low-low level alarm setpoint and the required containment flood level is not reached, then all the operating ECCS and CS pumps that take suction from RWST are stopped.
- EOP-LOCA-5 provides various steps that would add makeup to the RWST to extend its time available as a viable suction source.
- EOP-LOCA-5 also provides steps if the RWST is depleted.

Response to RAI 14a

As stated above, the RHR pumps stop taking suction from the RWST once the RWST level is at 15.2 feet and the required containment level is reached. Anti-vortex suppression devices are installed in the RWST suction lines. Therefore, there is more than adequate submergence available to preclude vortex in the RHR pumps.

It should be noted that RHR pump operation at the RWST low-low level setpoint is a very unlikely scenario. During a LOCA, water from the RWST will be directed into the RCS through the ECCS pumps to provide core cooling or sprayed into containment for containment heat removal and pressure control. The water pumped from the RWST will collect on the containment floor and mix with that discharged from the postulated large break in the RCS piping raising the containment flood level.

The only way the RWST reaches the low-low alarm level and the containment sump level does not exceed the alarm set point level is, if a RWST pipe break occurs outside the Reactor Containment or containment flood level indication malfunctions.

The first possibility requires a break in the RCS pressure boundary and another break in the RWST piping outside the Reactor Containment during the injection phase. This is not a credible accident; assuming two breaks is outside the Salem design and licensing basis. As noted in UFSAR Section 6.3.1.4, the Salem ECCS is designed to tolerate a single active failure during the short-term immediately following an accident, or to tolerate a single active or passive failure during the long-term following an accident.

There are two redundant level switches installed inside the Reactor Containment. The possibility of both malfunctioning is extremely remote. Also, in addition to the level switches there are two separate level transmitters that provide the containment flood level.

In case the RWST reaches the low level alarm and the required containment flood level is not reached, the EOP-LOCA-5 provides guidance for operation of the ECCS pumps. It directs the operator to immediately initiate RWST makeup and to stop the operating ECCS and CS pumps. All the operating ECCS and CS pumps are stopped (if they are not already stopped) at low-low level alarm if the required containment flood level is not reached.

Based on the above information it is concluded that there is no concern associated with vortex formation for the RHR pumps.

Response to RAI 14b

Reference 1 was created to determine the minimum flood level inside the Reactor Containment following a design basis LOCA. During the recirculation phase of LOCA, the containment sump strainers need to be fully submerged to ensure the operability of the RHR pumps. The strainers have a minimum submergence of 3 inches during recirculation based on the minimum flood level and the height of the installed strainers.

The ECCS pumps take suction from the RWST during the injection phase of LOCA. When the RWST level reaches the low level set point, a control room alarm is generated indicating that the operator should begin to initiate the switchover to the recirculation phase. Also, the level switches installed inside the Reactor Containment provide an alarm to the control room when the containment flood level has reached 80' 11", the minimum flood level for the operator to initiate recirculation.

Reference 1 determined the most limiting case for minimum containment flood level. In this case a break on the Reactor Coolant Piping (RCS) is large enough to allow RCS blow down but not large enough to allow the total ECCS flow to drain from the break (i.e., the ECCS pumps are able to keep the entire RCS full).

The case with the minimum water level from Reference 1 will be used to provide a response to the RAI. This case assumed a break in the RCS piping that would cause the system pressure to drop low enough to actuate injection from the ECCS Accumulators. It will be modified such that injection from the ECCS Accumulators will not be credited.

The following evaluation determines the containment flood level without crediting the accumulators. This evaluation is for Salem Unit 1. Since the differences between the two Units are very small, this evaluation will also be applicable to Salem Unit 2. The information provided below is from Reference 1 unless otherwise noted.

RWST volume needed to reach Containment flood level of 80' 11" = 264,380 gallons
Volume in each accumulator = 6500 gallons (Reference 7)
Water in four accumulators = 26,000 gallons

Based on the minimum flood level calculation, containment volume at RWST low level alarm (with accumulator injection) = 207,800 gallons

Containment flood volume at RWST low level alarm (without accumulator injection) = 207,800 - 26,000 = 181,800 gallons

Additional water volume below RWST low level alarm to reach 80' 11" = 264,380 – 181,800 = 82,580 gallons

RWST low level alarm from the RWST level tap = 15.2 feet
RWST volume per level = 8483.2 gallons/feet
RWST low-low level alarm above level tap = 1 foot

Calculated water level in feet below low level alarm = 82,580/8483.2 = 9.8 feet
RWST level above level tap = 15.2 – 9.8 = 5.4 feet

Based on the above evaluation, the minimum containment flood level will be reached prior to reaching the RWST low-low level alarm with a margin of 4.4 feet of RWST level. Therefore, there is no concern with adequate submergence even if the accumulators are not credited.

Response to RAI 15

As discussed above, the EOPs are entered during a design basis LOCA. These EOPs provide adequate guidance.

When the RWST low level alarm is reached, EOP-LOCA-3 (Reference 3) is entered. One of the first steps in this EOP is to verify that the adequate sump level exists (80' 11") for transfer to recirculation operation. If adequate water level exists then switchover to recirculation operation is initiated.

If inadequate water level exists for recirculation operation, then EOP-LOCA-5 (Reference 4) is entered. Under this EOP, the ECCS injection from the RWST continues until either required containment flood level (80' 11") is reached or RWST low-low water level alarm is reached.

EOP-LOCA-5, requires all the ECCS pumps taking suction from RWST be stopped if the RWST low-low level alarm is reached and the containment flood level alarm setpoint is not reached. It also provides various steps that would add makeup to the RWST to extend its time available as a viable suction source and to minimize the RWST outflow, thereby extending the time core cooling can be provided by the RWST. One of the alternate suction sources would be providing borated water from the Reactor Makeup Water Control System by taking suction from the Boric Acid Storage Tank mixed with the water from Primary water Storage Tank and using the centrifugal charging pumps and normal charging lines to inject water into the RCS.

Based on the above information, the Salem EOPs provide adequate information to take necessary actions when the conditions to switchover to recirculation phase are not satisfied (RWST low water level and containment sump level).

References

1 S-C-CAN-MDC-2061 Minimum Containment Flood Level
2. 1(2)-EOP-LOCA-1 Loss of Reactor Coolant
3 1(2)-EOP-LOCA-3 Transfer to Cold Leg Recirculation
4. 1(2)-EOP-LOCA-5 Loss of Emergency Recirculation
5. S-C-RHR-MDC-1711 Available NPSH at RHR Pumps in Recirculation Mode
6 S-C-VAR-MDC-1429 Minimum Usable Volume for Various Safety Related and Important to Safety Tanks
7. S-C-A900-MDC-0082 Containment Volume Verses Flood Level Analysis
8. VTD 323585 Unit 1 RWST Draindown & Cold Leg Recirculation Engineering Report
9. VTD 323001 Unit 2 RWST Draindown & Cold Leg Recirculation Engineering Report
10. NRC letter to PSEG, "Salem Nuclear Generating Station Units 1 and 2: Report on Results of Staff Audit of Corrective Actions to Address Generic Letter 2004-02 (TAC Nos. MC4712 and MC4713)," dated August 12, 2008

Response to Generic Letter 2004-02

Salem Generating Station

March 16, 2010

Salem
GENERATING STATION

Enclosure 7

Agenda

Overview

Individual RAI discussions

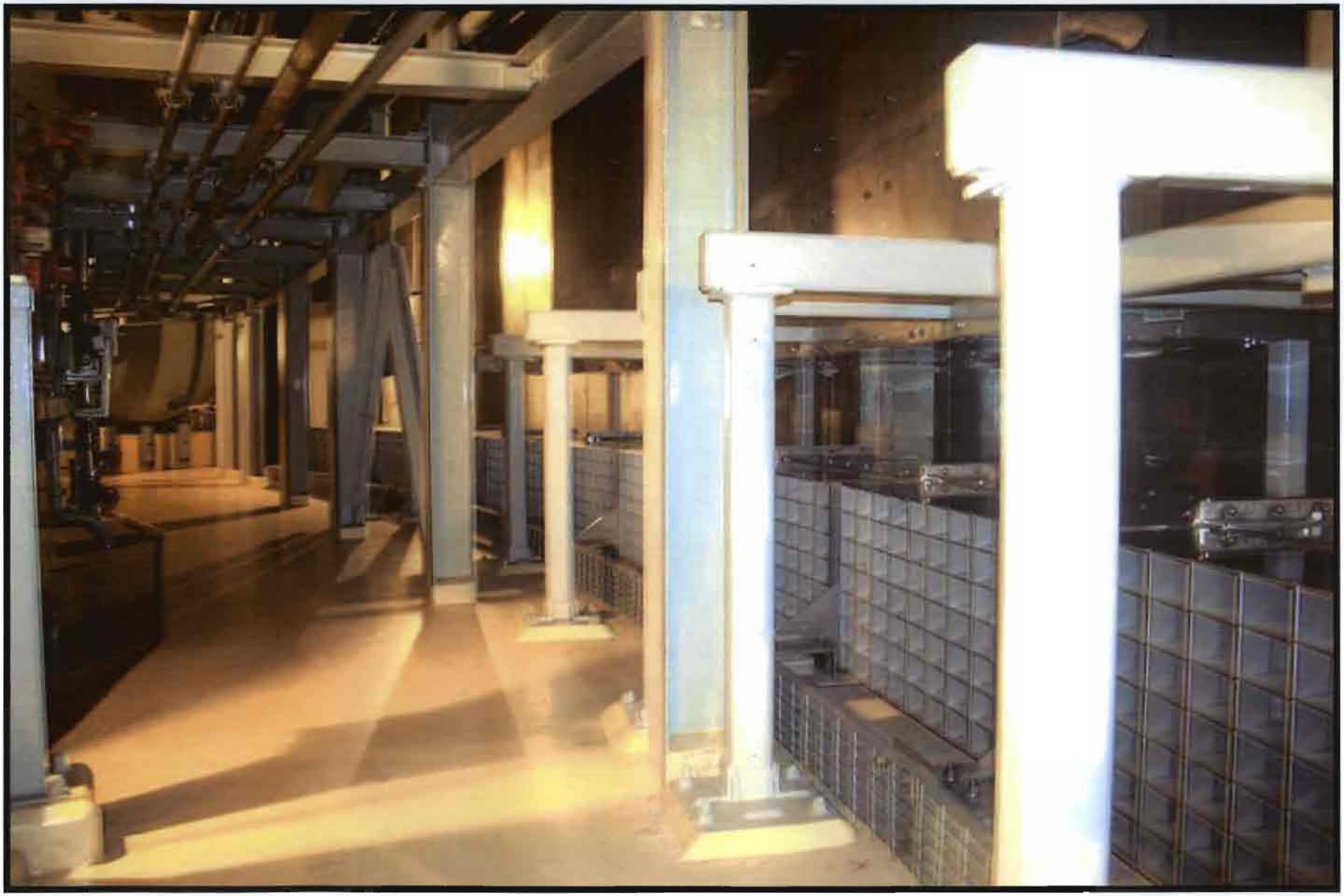
- Vortexing, degasification
  - Previous RAI 14
- Full load vs. thin bed head loss
  - RAI 13
- Net positive suction head (NPSH)
  - RAIs 14 & 15
- Erosion percentage
  - RAI 12
- Lead blanket shielding
  - RAI 11
- Debris generation / zone of influence
  - Previous RAI 1
  - RAIs 1 - 10

Discussion / caucus

Modifications

- Replacement strainers
  - Original sump strainers - 85 ft^2; 1/8 in nominal hole size
  - New strainers - 4,854 / 4,656 ft^2; 1/12 in nominal hole size
- Debris interceptor
  - 9 in tall; prevents large debris from reaching strainer pockets
- Containment sump level instrumentation
  - Additional level switches; higher accuracy
- Door / gate modifications
  - Prevent water hold-up
- Insulation replacement
  - Calcium silicate replaced with RMI
  - Min-K replaced where possible
- RMI on Unit 2 steam generators
- Administrative procedure changes
  - Ensure potential debris sources assessed for adverse effects

Overview - Installed CCI Strainers



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Assessment of 17D ZOI for Jacketed Nukon Salem 1

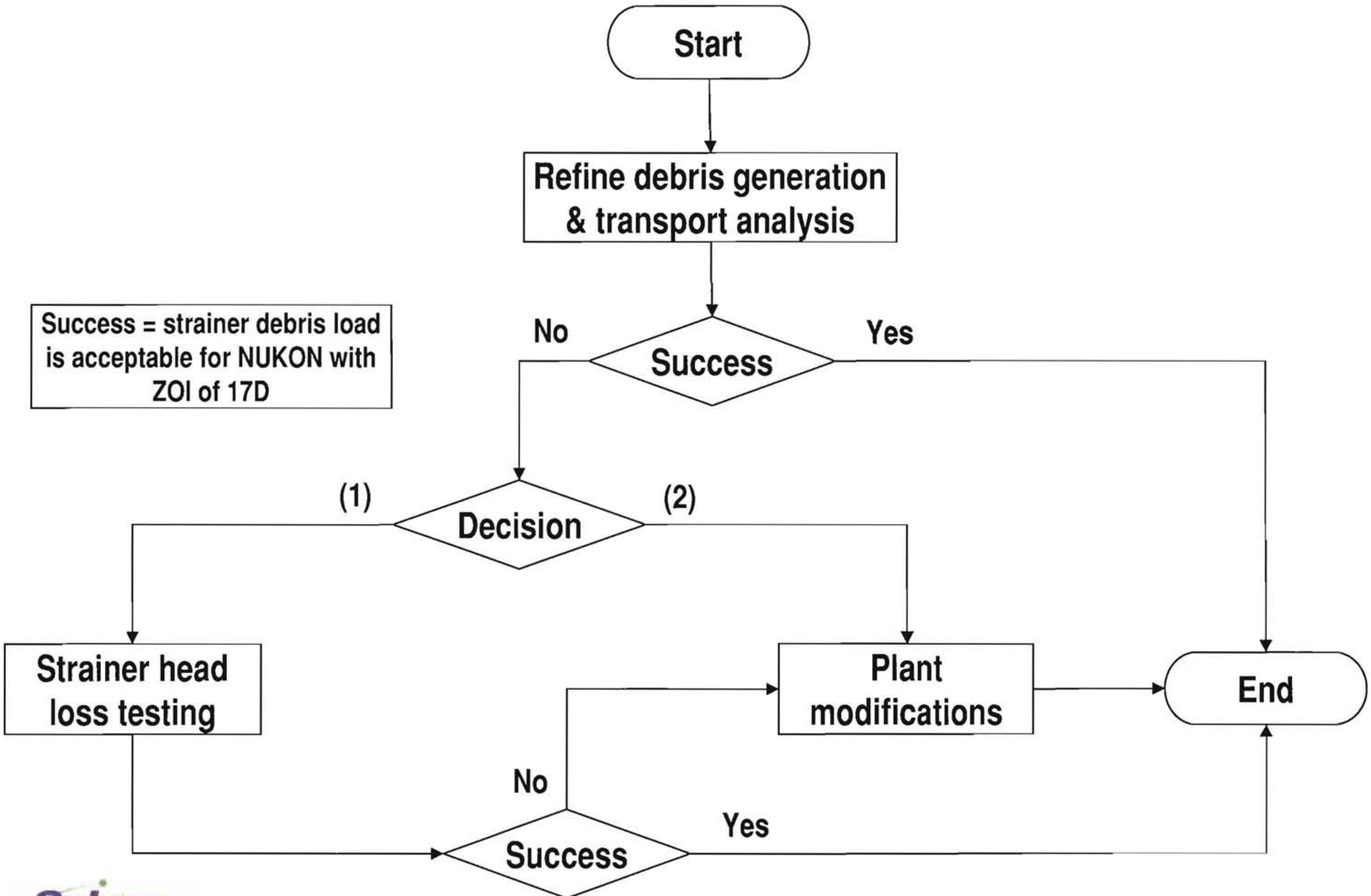
NRC/PSEG Meeting

March 16, 2010

Salem GENERATING STATION

Enclosure 8

Assessment Flow Chart



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Background

- Salem - Unit 1 utilized 7D ZOI for jacketed Nukon (SG & pressurizer shells)
- Salem - Unit 1 utilizes 17D ZOI for unjacketed Nukon (SG & pressurizer bottoms)
- Salem – Unit 2 does not have jacketed Nukon and utilizes 17D ZOI for unjacketed Nukon
- Debris generation & transport analysis refined for Unit 1 to remove conservatism to address NRC concerns regarding WCAP-16710-P

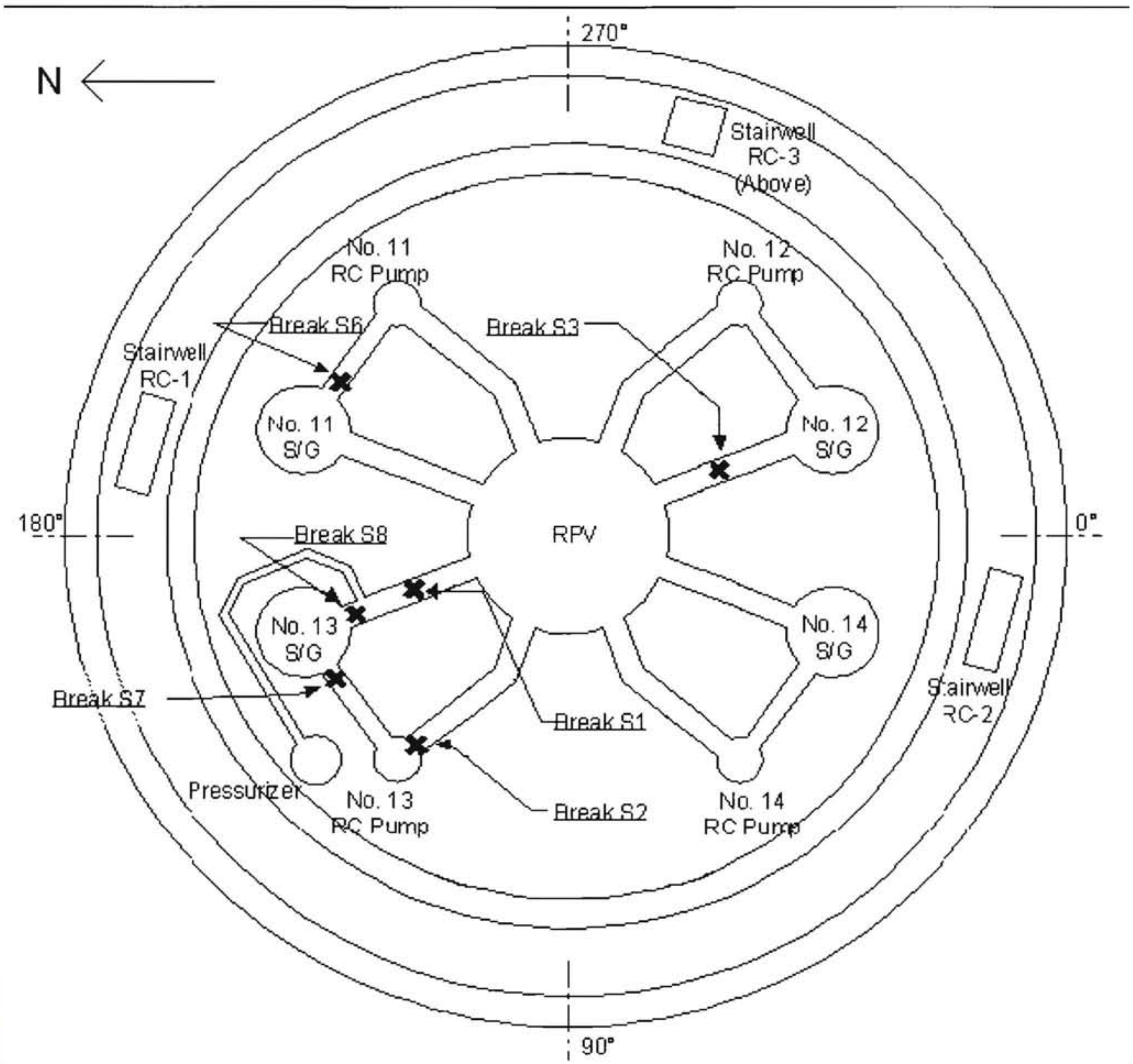
Outline

- **Review refinements/changes in approach**
- **Review impact on results**
  - Debris generation
  - Debris transport
  - Chemical effects
  - Impact on head loss
  - Fuel deposition

Debris Generation

- **Analysis revised to use 17D for all Nukon insulation**
- **Refined analysis utilizes concentric spherical shells at 1D intervals from 7D to 17D**
- **Limiting break is S7 on 31" diameter cross-over leg of SG 13 at El. 98'-7"**
  - Break S7 ZOI extends to El. 142'-5"
  - Break S8 is on 29" diameter hot leg of SG 13 at El. 97' (smaller ID + lower El. ∴ less debris)
- **SGs 11 & 13 & pressurizer within 17D ZOI**
- **SGs 12 & 14 are outside 17D ZOI**

Salem 1 Containment Layout



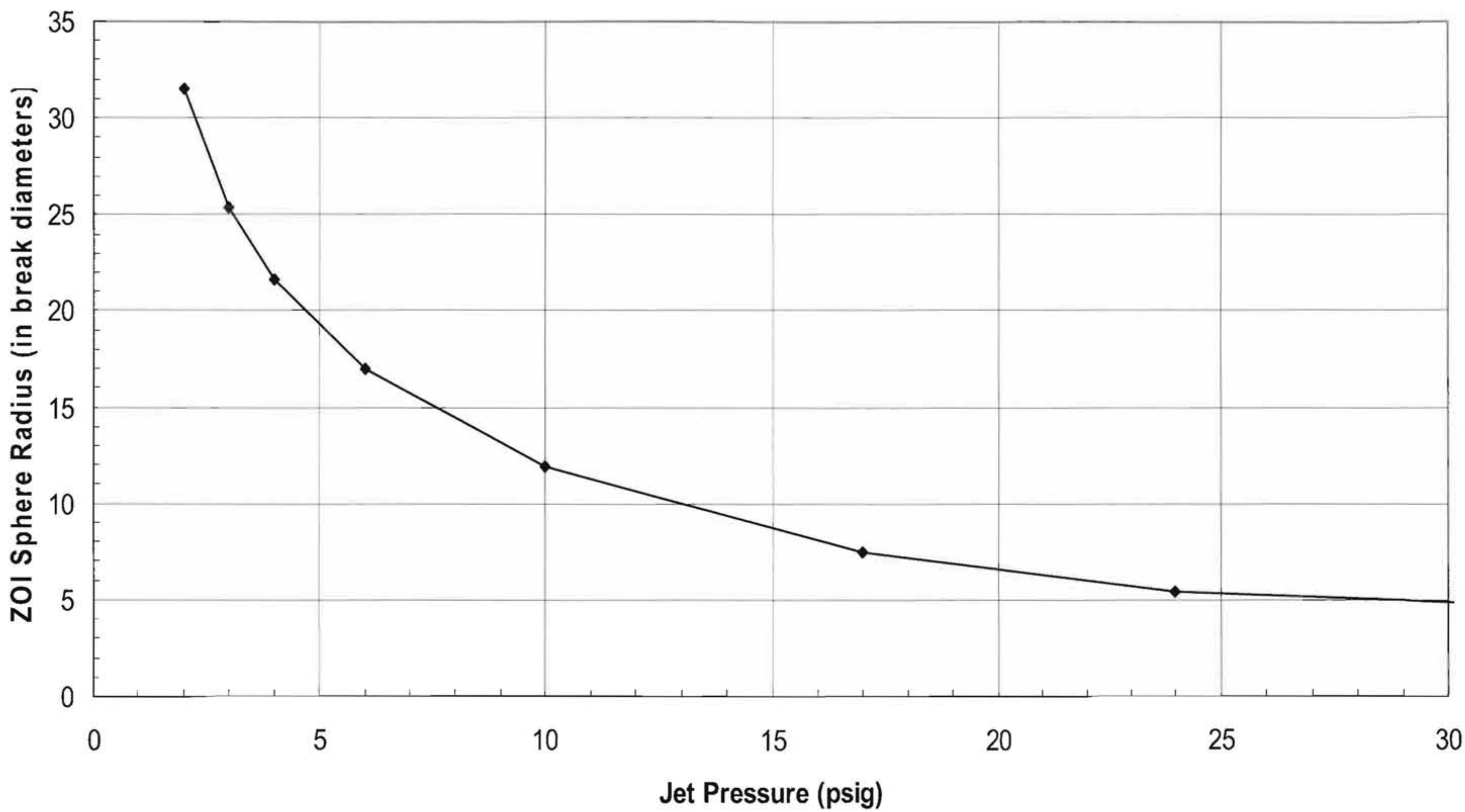
ZOI Sub-Shell Debris Distribution

ZOI Sub-Shell	SG 13			Pressurizer			SG 11			Sub-total
	Bottom (ft³)	Shell (<125') (ft³)	Shell (>125') (ft³)	Bottom (ft³)	Shell (<125') (ft³)	Shell (>125') (ft³)	Bottom (ft³)	Shell (<125') (ft³)	Shell (>125') (ft³)	(ft³)
0-7D	81.5	176.6	0.0	38.4	48.6	0.0	0.0	0.0	0.0	345.1
7-8D	0.0	39.1	0.0	0.0	30.7	0.0	0.0	0.0	0.0	69.8
8-9D	0.0	38.2	0.0	0.0	28.6	0.0	0.0	0.0	0.0	66.9
9-10D	0.0	37.7	0.0	0.0	27.5	0.0	24.2	17.0	0.0	106.5
10-11D	0.0	18.7	18.7	0.0	20.2	6.6	12.7	31.5	0.0	108.5
11-12D	0.0	2.0	35.2	0.0	7.2	19.2	11.8	39.2	0.0	114.6
12-13D	0.0	0.0	37.0	0.0	0.0	26.1	14.1	51.8	0.0	129.0
13-14D	0.0	0.0	40.2	0.0	0.0	23.8	18.6	92.2	10.0	184.9
14-15D	0.0	0.0	48.4	0.0	0.0	21.7	0.0	35.1	31.0	136.1
15-16D	0.0	0.0	38.6	0.0	0.0	19.7	0.0	25.0	21.9	105.2
16-17D	0.0	0.0	46.6	0.0	0.0	17.7	0.0	20.7	19.7	104.7
Sum:	81.5	312.4	264.7	38.4	162.9	134.8	81.5	312.4	82.5	**1471.1**

Nukon Size Distribution

- Different size distribution within each ZOI sub-shell based on jet pressure in shell
- Jet pressure at each sub-shell based on Table I-3 of Appendix I of SE to NEI 04-07
- Jet pressure at the centroid of each sub-shell used for size distribution
- Jet pressure used to determine "Small Fines" fraction based on Figure II-2 of Appendix II to SE for NEI 04-07
- AJIT data for LDFG (Nukon & Knauf) used to determine split between large & intact debris

ZOI as a Function of Jet Pressure



Based on Table I-3 of Appendix I of SE for NEI 04-07

Salem GENERATING STATION

Small Fines Fraction

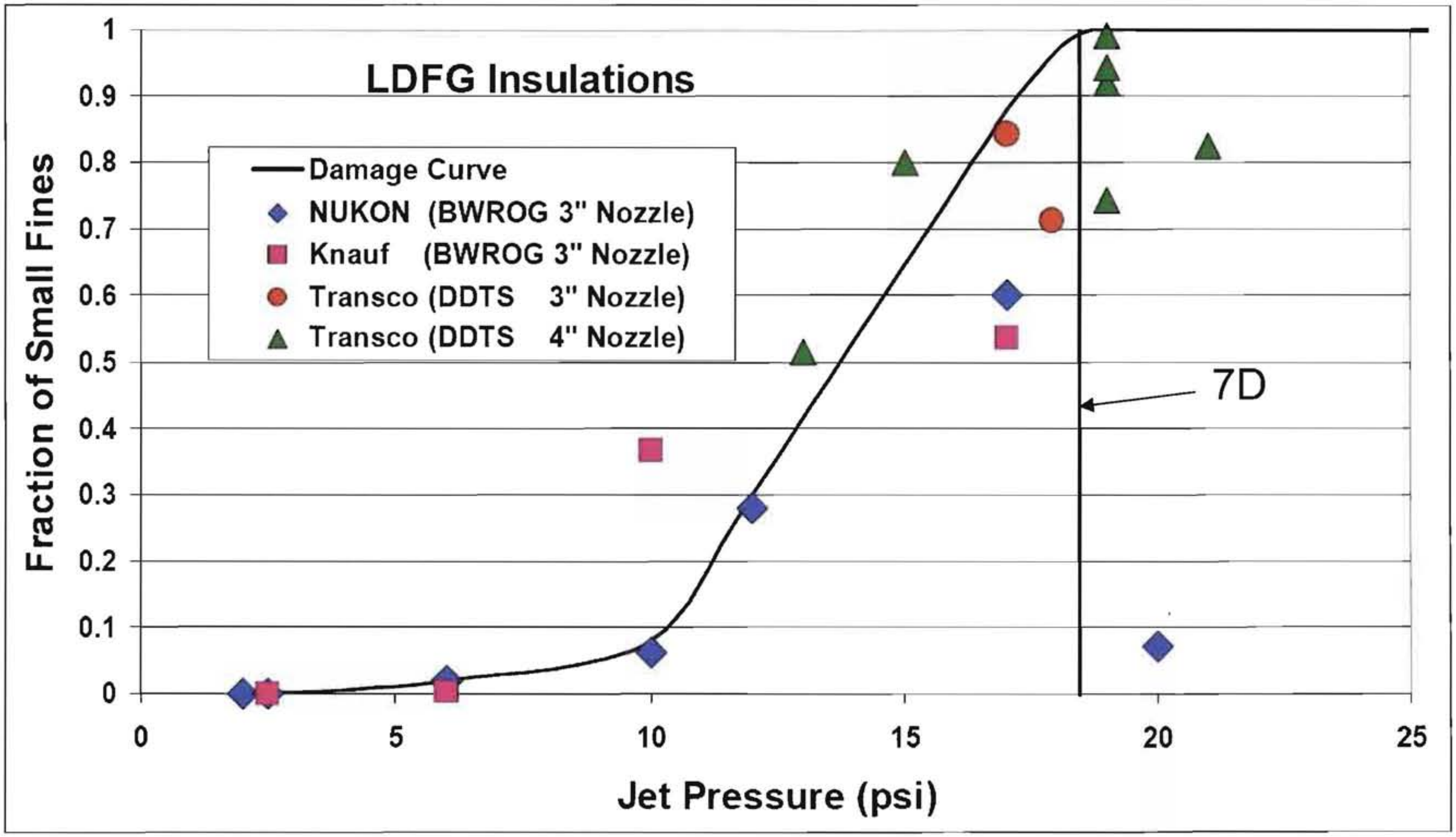
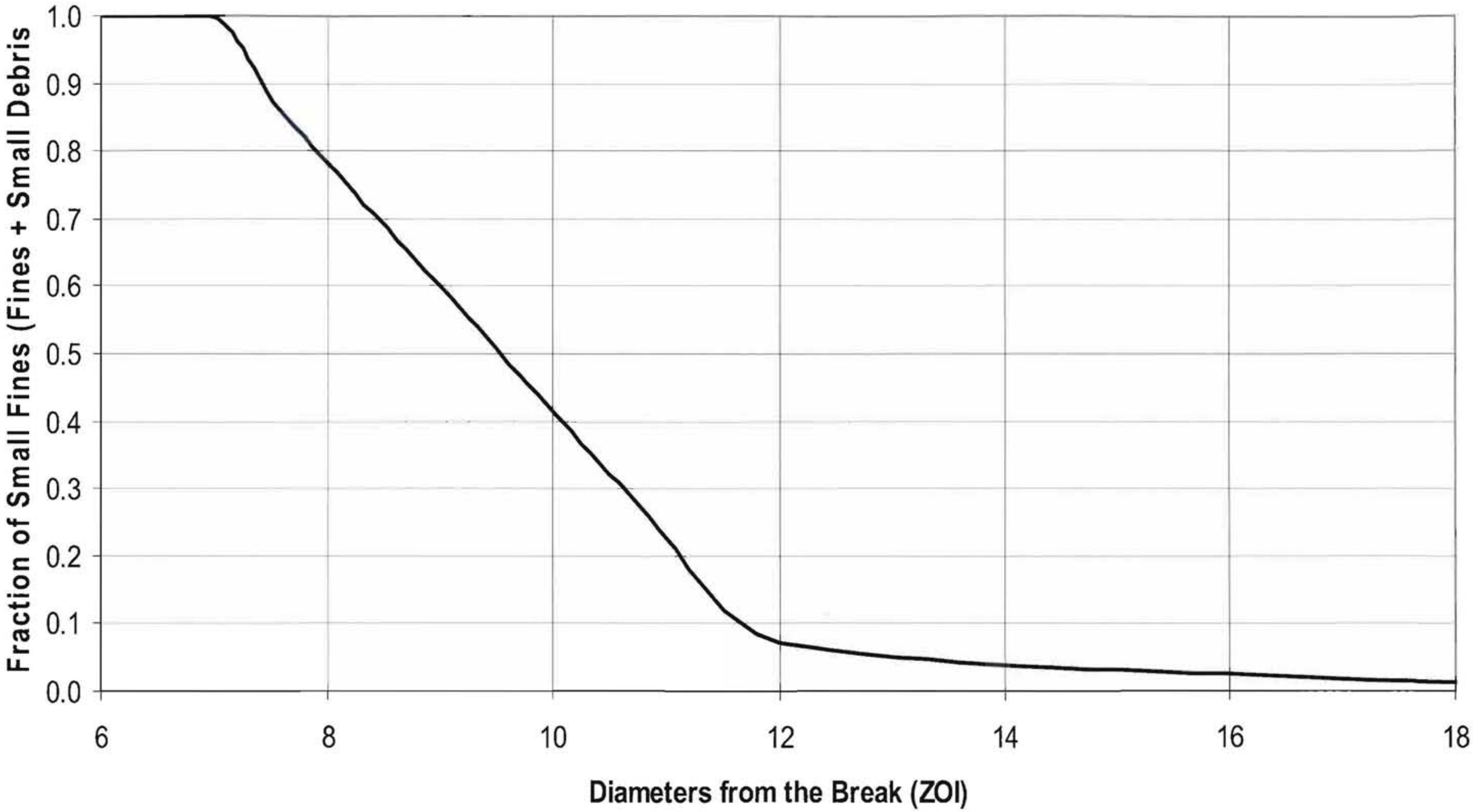


Figure II-2. LDFG Damage Curve for Small Fine Debris

From Appendix II of SE for NEI 04-07

Fraction of Small Fines as a Function of ZOI



Based on Table I-3 of App. I & Fig. II-2 of App. II of SE for NEI 04-07

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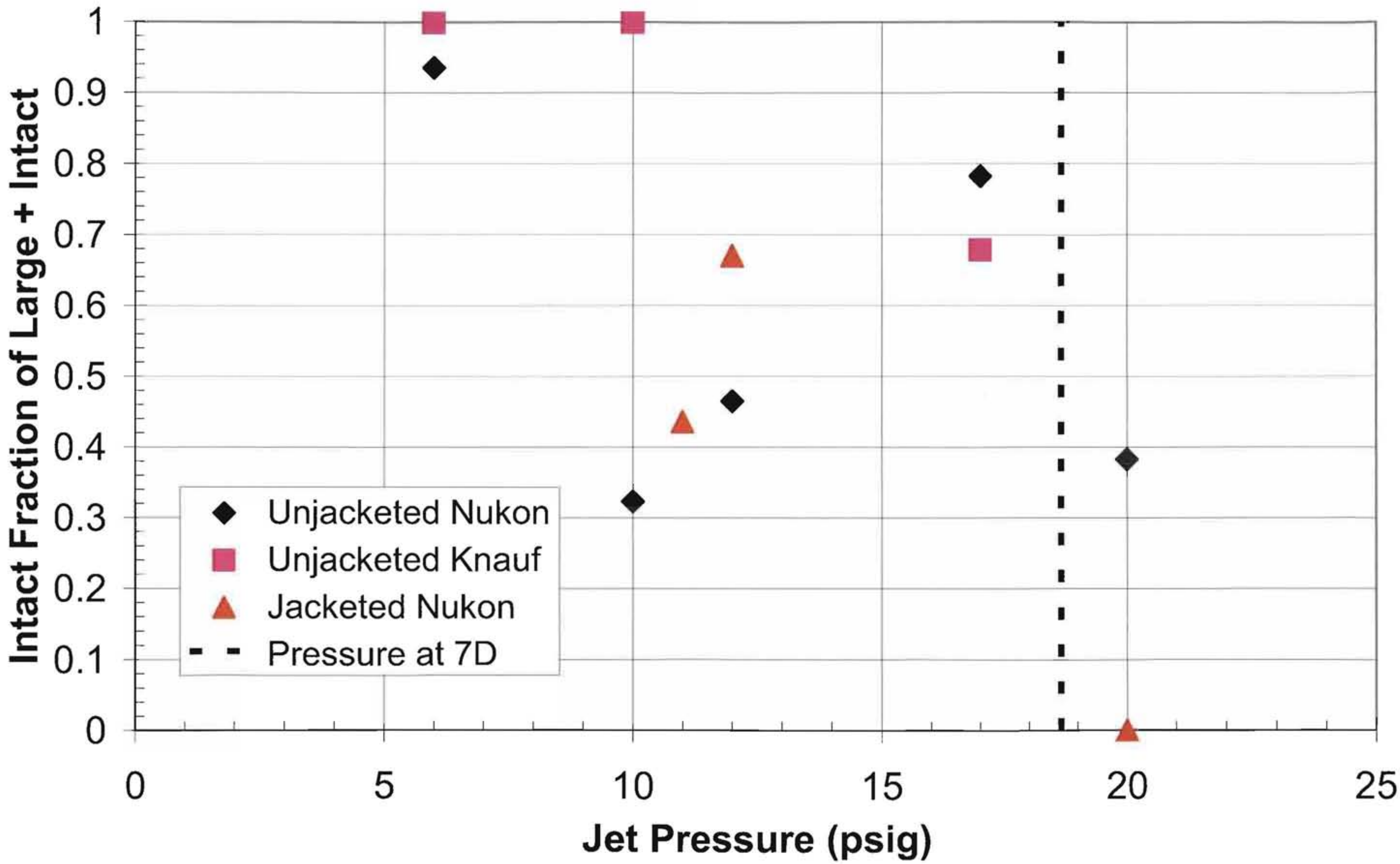
AJIT Data for Large & Intact Debris



Based on Air Jet Impact Tests (AJITs) for LDFG Insulation

4-Category Nukon Size Distribution

- **"Small Fines" consist of fines and small debris**
  - 20% of small fines are fines based on DDTS test results (consistent with volunteer plant analysis in Appendix VI of SE for NEI 04-07)
  - 80% of small fines are small piece debris
- **Large and intact debris constitute the non "small fines" portion of the debris**
- **50% of large and intact debris is intact based on AJIT test data**

Nukon Size Distribution

ZOI Sub-Shell	ZOI for P_{jet}	P_{jet} (psig)	2-Category Size Distribution		4-Category Size Distribution (fraction within Each ZOI Sub-Shell)			
			Small Fines	Large/ Intact	Fines	Small	Large	Intact
0-7D	-	-	1.00	0.00	0.200	0.800	0.000	0.000
7-8D	7.53	16.9	0.87	0.13	0.174	0.696	0.065	0.065
8-9D	8.53	15.4	0.69	0.31	0.138	0.552	0.155	0.155
9-10D	9.53	13.8	0.50	0.50	0.100	0.400	0.250	0.250
10-11D	10.52	12.2	0.32	0.68	0.064	0.256	0.340	0.340
11-12D	11.52	10.6	0.12	0.88	0.024	0.096	0.440	0.440
12-13D	12.52	9.5	0.06	0.94	0.012	0.048	0.470	0.470
13-14D	13.52	8.7	0.04	0.96	0.008	0.032	0.480	0.480
14-15D	14.52	7.9	0.03	0.97	0.006	0.024	0.485	0.485
15-16D	15.52	7.2	0.03	0.97	0.006	0.024	0.485	0.485
16-17D	16.52	6.4	0.02	0.98	0.004	0.016	0.490	0.490

Nukon Size Distribution Results

ZOI Sub-Shell	Debris Generated Below El. 125'-0" (ft^3)				Debris Generated Above El. 125'-0" (ft^3)			
	Fines	Small	Large	Intact	Fines	Small	Large	Intact
0-7D	69.0	276.1	0.0	0.0	0.0	0.0	0.0	0.0
7-8D	12.2	48.6	4.5	4.5	0.0	0.0	0.0	0.0
8-9D	9.2	36.9	10.4	10.4	0.0	0.0	0.0	0.0
9-10D	10.7	42.6	26.6	26.6	0.0	0.0	0.0	0.0
10-11D	5.3	21.3	28.3	28.3	1.6	6.5	8.6	8.6
11-12D	1.4	5.8	26.5	26.5	1.3	5.2	23.9	23.9
12-13D	0.8	3.2	31.0	31.0	0.8	3.0	29.6	29.6
13-14D	0.9	3.5	53.2	53.2	0.6	2.4	35.5	35.5
14-15D	0.2	0.8	17.0	17.0	0.6	2.4	49.0	49.0
15-16D	0.1	0.6	12.1	12.1	0.5	1.9	38.9	38.9
16-17D	0.1	0.3	10.1	10.1	0.3	1.3	41.2	41.2
Sub-tot:	109.9	439.7	219.7	219.7	5.7	22.8	226.7	226.7

Nukon Size Distribution Summary

Debris Size	Debris Quantity (ft^3)	Debris Fraction
Fines	115.6	7.9%
Small Pieces	462.5	31.4%
Large Pieces	446.5	30.4%
Intact Pieces	446.5	30.4%
Sum:	1471.1	100.0%

- 39% fines and small debris
- Fewer fines and small debris are expected due to a significant amount of large and intact debris being generated from a 2nd steam generator not near the break

Debris Transport

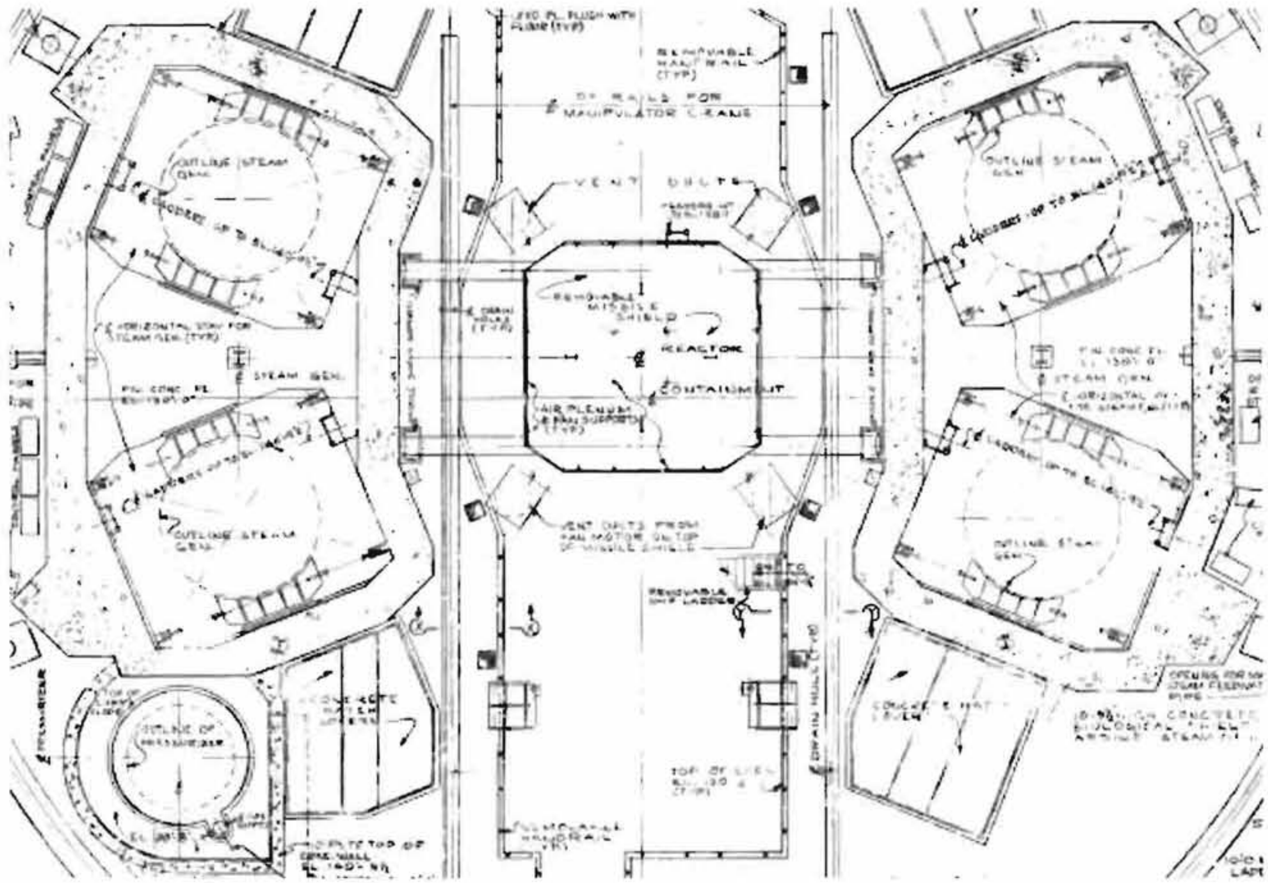
- **Changes relative to March 2009 Supplemental Response**
  - Revised size distribution for Nukon
  - Debris generation in upper containment
  - Retention of small, large & intact blowdown debris in upper containment
  - Inertial capture of fines and small debris in doorways
  - Inactive volumes
  - Erosion of retained small & large debris in upper containment from contain[redacted]

Debris Generation in Upper Containment

- **17D ZOI for Nukon extends above the operating floor for both SGs and PZR**
- **Debris on SG 13 (attached to the broken pipe) generated to the full extent of ZOI**
  - El. 125' is 10.2D from the break on SG near the break
- **Portion of debris on pressurizer and the far SG shielded by the bottom of the operating floor (El. 125')**

Layout of Upper Containment

- Grating surrounds SGs at El. 125'-1 1/2"
- Floor with 10" curb surrounds PZR at El. 130'
- Walls surround SGs and PZR at elevations > 125'



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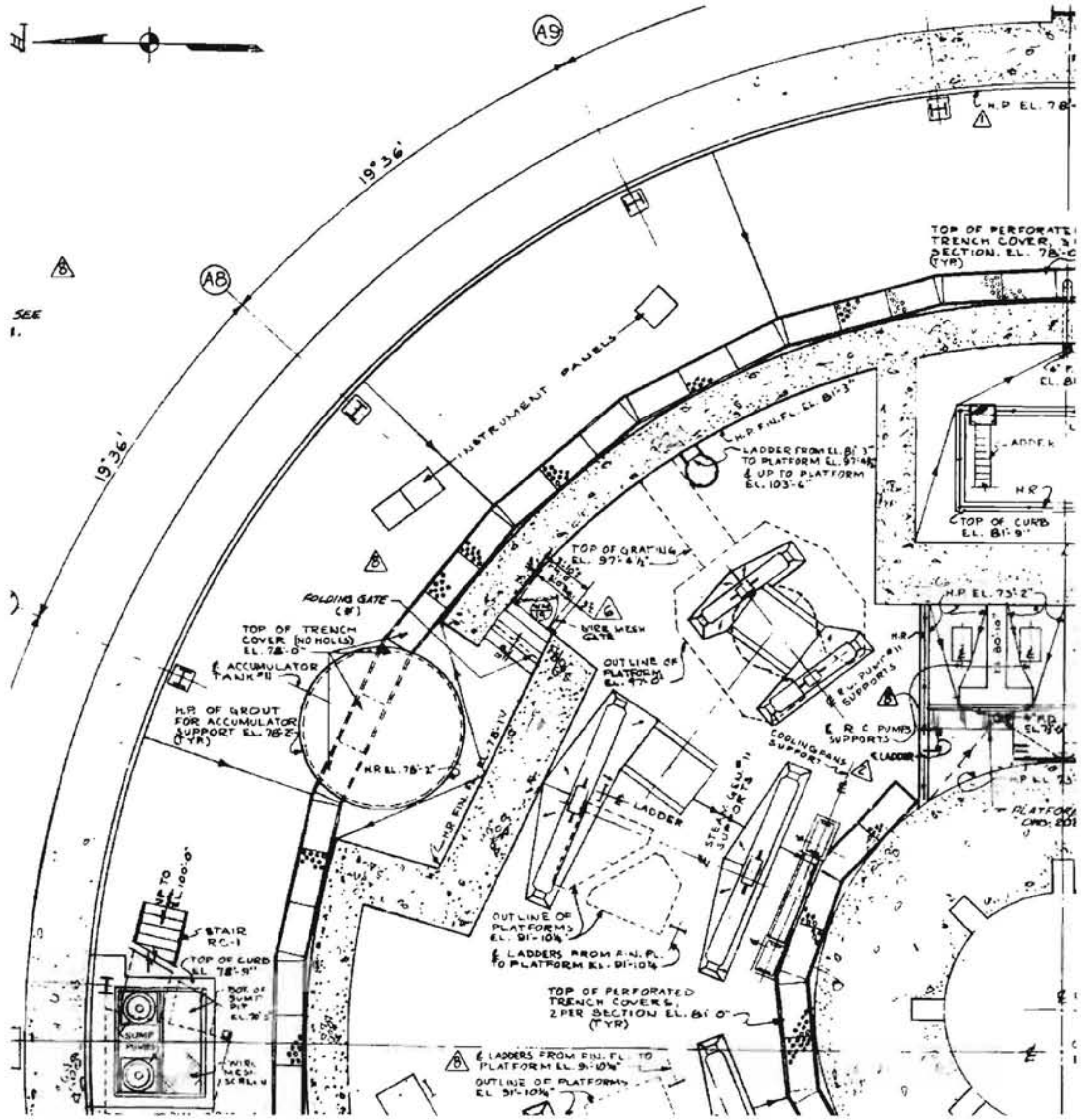
Retention of Debris in Upper Containment

- **All fines are transported to sump pool during washdown**
- **Each grating filters out 25% of small debris based on DDTS**
  - 2 sets of grating (El. 100' & 130') at ctmt liner
  - 1 set of grating (El. 125') around SG
- **All large and intact debris remains in upper containment as it does not pass through gratings or lift over curbs**

Inertial Debris Capture

- **Portion of fines and small debris generated below El. 125' subject to inertial debris capture in bioshield doorways (which are not sprayed)**
- **Break flow split between upper containment and bioshield doorways based on area ratio**
  - 20% of flow through the 4 bioshield doorways

Doorways in Bioshield



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Inertial Debris Capture (cont.)

- 17% capture as fines and small debris flow through doorways due to 90° bend & wire mesh gates
- Consistent with volunteer plant analysis in Appendix VI to SE for NEI 04-07
- 3.4% (0.20*0.17) capture of fines and small debris generated below El. 125'

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Inactive Volumes

- Trenches surrounding primary shield and bioshield
- Elevator pit
- Credited for trapping of fines and small debris not subject to inertial capture
- 7% of sump volume credited for sequestering fines at switchover
- 3% of sump volume credited for sequestering small debris due to perforated plate over trenches

Spray Erosion

- Small and large debris retained in upper containment is subject to erosion from containment spray
- 1% erosion for both small & large debris consistent with volunteer plant analysis in Appendix VI of SE for NEI 04-07

Pool Erosion

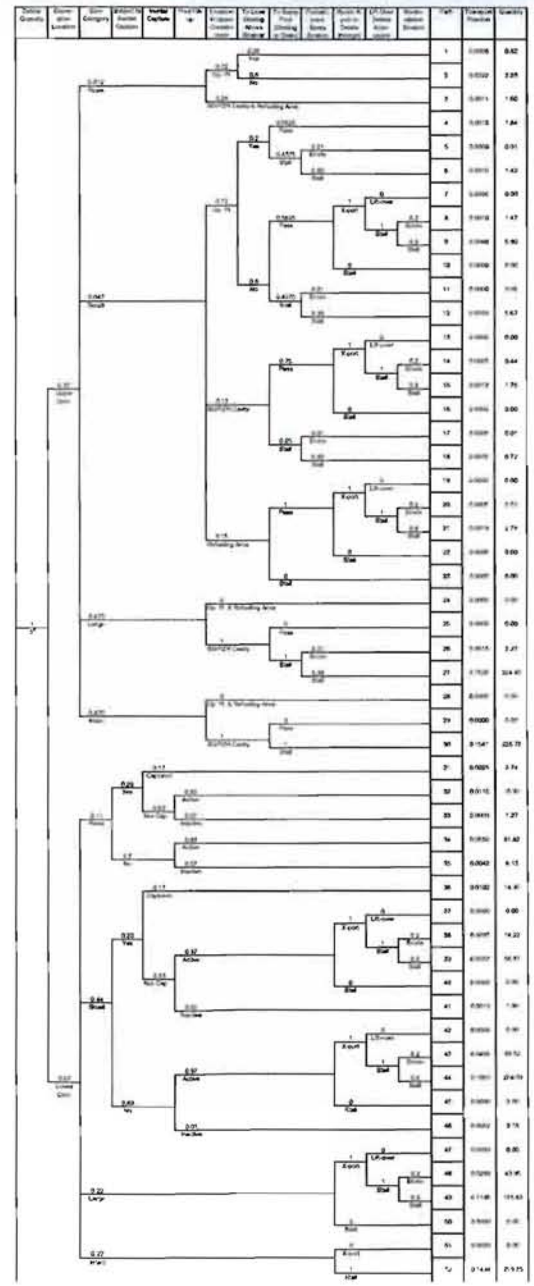
- March 2009 Supplemental Response used 30-day erosion fractions of 30% for Nukon & 10% for Kaowool
- Current RAI 12 response supports use of 30-day erosion fractions of 20% for Nukon & 5% for Kaowool

Unchanged Transport Methodology

- 100% transport of small & large debris in the sump pool to the debris interceptor in front of the strainers during recirculation
- No small or large debris lifts over the ~9" debris interceptors
- All debris transporting to strainer is fines except small pieces from upper containment that pass through gratings above the strainers

Debris Transport Tree

- **Detailed debris transport tree was developed**
  - Separate transport paths for debris generated in upper and lower containment
- **Shows all transport paths considered for Nukon**



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Results of Nukon Debris Transport

Debris Size	El. < 125'	El. > 125'
Fines (ft^3)	98.8 (as fines)	5.7 (as fines)
Small Pieces (ft^3)	82.7 (as fines)	4.5 (1.8 as small, 2.7 as fines)
Large Pieces (ft^3)	44.0 (as fines)	2.3 (as fines)
Sub-total (ft^3)	225.5	12.5
Total (ft^3)	238.0	

Owens-Corning Fiberglas (OCFG)

- Previously modeled as 100% fines
- Made with the same glass fibers (CAS 65997-17-3) and binder (CAS 25104-55-6) as Nukon based on MSDSs
- As-fabricated density of 3.7-3.9 lbm/ft^3 vs. 2.4 lbm/ft^3 for Nukon
- OCFG more robust than Nukon
- Apply baseline Nukon size distribution and 20% 30-day erosion data to OCFG

Owens-Corning Fiberglas (cont.)

- **43 ft^3 generated**
- **60% small fines**
  - 20% fines » 5.2 ft^3 fines
  - 80% small » 20.6 ft^3 small
- **40% large & intact debris**
  - 50% large » 8.6 ft^3 large
  - 50% intact » 8.6 ft^3 intact
- **Fines & small subject to inertial capture and inactive volumes**
- **Small & large erode 20% over 30 days**
- **10.2 ft^3 total OCFG fines at strainer**

Kaowool

- **30-day erosion fraction of 5% (RAI 12)**
- **Kaowool more robust than Nukon**
  - Apply baseline Nukon size distribution
  - Same as methodology previously used
- **Size distribution revised to utilize same split between fines and small pieces as Nukon**
- **Size distribution revised to utilize same split between large and intact pieces as Nukon**

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Kaowool (cont.)

- **122 ft^3 generated**
- **60% small fines**
  - 20% fines » 14.6 ft^3 fines
  - 80% small » 58.6 ft^3 small
- **40% large & intact debris**
  - 50% large » 24.4 ft^3 large
  - 50% intact » 24.4 ft^3 intact
- **Fines & small subject to inertial capture and inactive volumes**
- **Small & large erode 5% over 30 days**
- **17.1 ft^3 total Kaowool fines at strainer**

Comparison of Transported Debris to Tested Debris

Debris Type	Debris at Strainer (ft^3)	Debris Tested by CCI (ft^3)	Δ (ft^3)
Nukon	238.0	236.4	-1.6
Kaowool	17.1	33.1	16.0
Owens Corning Fiberglas	10.2	45.0	34.8
Min-K	0.0	5.3	5.3
Qualified Epoxy Coatings	9.5	11.5	2.0
Unqualified Coatings	0.5	0.5	0.0
Latent Fiber	12.5	12.5	0.0
Latent Particulate	1.0	1.0	0.0

- Minor additional Nukon debris offset by significantly reduced OCFG and Kaowool quantities
- Current approach ignores retention of small fines in upper containment
- Significant margin in qualified coating and Min-K quantities
- Existing head loss testing bounds revised transported debris quantities

Equivalent Nukon

- **Convert Kaowool and OCFG margin to equivalent Nukon margin via as-fabricated density ratio**
  - $V_{Equivlanent\ Nukon} = V_X * (\rho_X/\rho_{Nukon})$
  - $\rho_{Nukon} = 2.4\ lb/ft^3$, $\rho_{Kaowool} = 8\ lb/ft^3$, $\rho_{OCFG} = 3.7\ lb/ft^3$
- **16.0 ft^3 Kaowool margin » 53.3 ft^3 equivalent Nukon**
- **34.8 ft^3 OCFG margin » 53.7 ft^3 equivalent Nukon**
- **Total equivalent Nukon margin = 105.4 ft^3 (=53.3+53.7-1.6)**

Time Dependent Nukon at Strainer

	DEPS Min SG Sump Temperature				
	193.7°F	160°F	140°F	120°F	111°F
Time post-LOCA (hr)	9.1	21.3	36.3	192	720
Integrated Nukon Erosion Fraction	0.034	0.078	0.099	0.12	0.20
Nukon Debris at Strainer (ft^3)	**130.7**	**159.1**	**172.7**	**186.3**	**238.0**
Integrated Kaowool Erosion Fraction	0.011	0.025	0.030	0.035	0.05
Equivalent Nukon Debris at Strainer (ft^3)	**186.1**	**220.2**	**235.9**	**251.8**	**310.9**

- Nukon & Kaowool erosion fraction computed based on average erosion rates plus ~10% margin as described in the response to RAI 12
- Equivalent Nukon debris is sum of Kaowool & OCFG equivalent Nukon quantities and Nukon quantity
- Strainer head loss test performed with 236.4 ft^3 of Nukon debris (416 ft^3 of equivalent Nukon)

Chemical Effects

- Nukon ZOI increased from 7D to 17D
- Sprayed intact debris is not included

Dissolved Chemicals

	Salem Unit 1 - March '09 Supplemental Response	Salem Unit 1 17D ZOI for Nukon
Calcium (kg)	20.1	24.7
Silicon (kg)	69.4	111.8
Aluminum (kg)	41.9	43.5

Chemical Effects

Precipitate Amounts

	Salem Unit 1 - March '09 Supplemental Response	CCI Unit 1 Strainer Head Loss Test	Salem Unit 1 17D ZOI for Nukon
$NaAlSi_3O_8$ (kg)	215.9	216.0	347.8
AlOOH (kg)	43.6	43.7	17.2
$Ca_3(PO_4)_2$ (kg)	0.0	0.0	0.0
Total (kg)	259.5	259.7	365.0

- **The 17D precipitate total is 41% greater than that tested at CCI.**
  - Increase in precipitate total is 31% if intact debris in pool is not included.
- **The amount of AlOOH decreases with a 17D Nukon ZOI because the ratio of dissolved Al to dissolved Si decreases leaving less excess Al to form AlOOH.**

Impact of Chemical Effects on Strainer Head Loss

- **Chemical precipitates added in 4 portions during each head loss test**
  - 3 portions $NaAlSi_3O_8$, 1 portion AlOOH
- **Bore holes formed after 1st & 2nd portions for both Unit 1 and Unit 2 tests**
  - 1st & 2nd portions were each 28% of total chemical debris load for Unit 1
- **Bore holes establish a head loss limit for the debris bed**

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Debris Bed Bore Holes

Test 5 debris bed after 1st chemical portion (underwater photo of front of strainer)

Unit 1 Strainer Head Loss Test

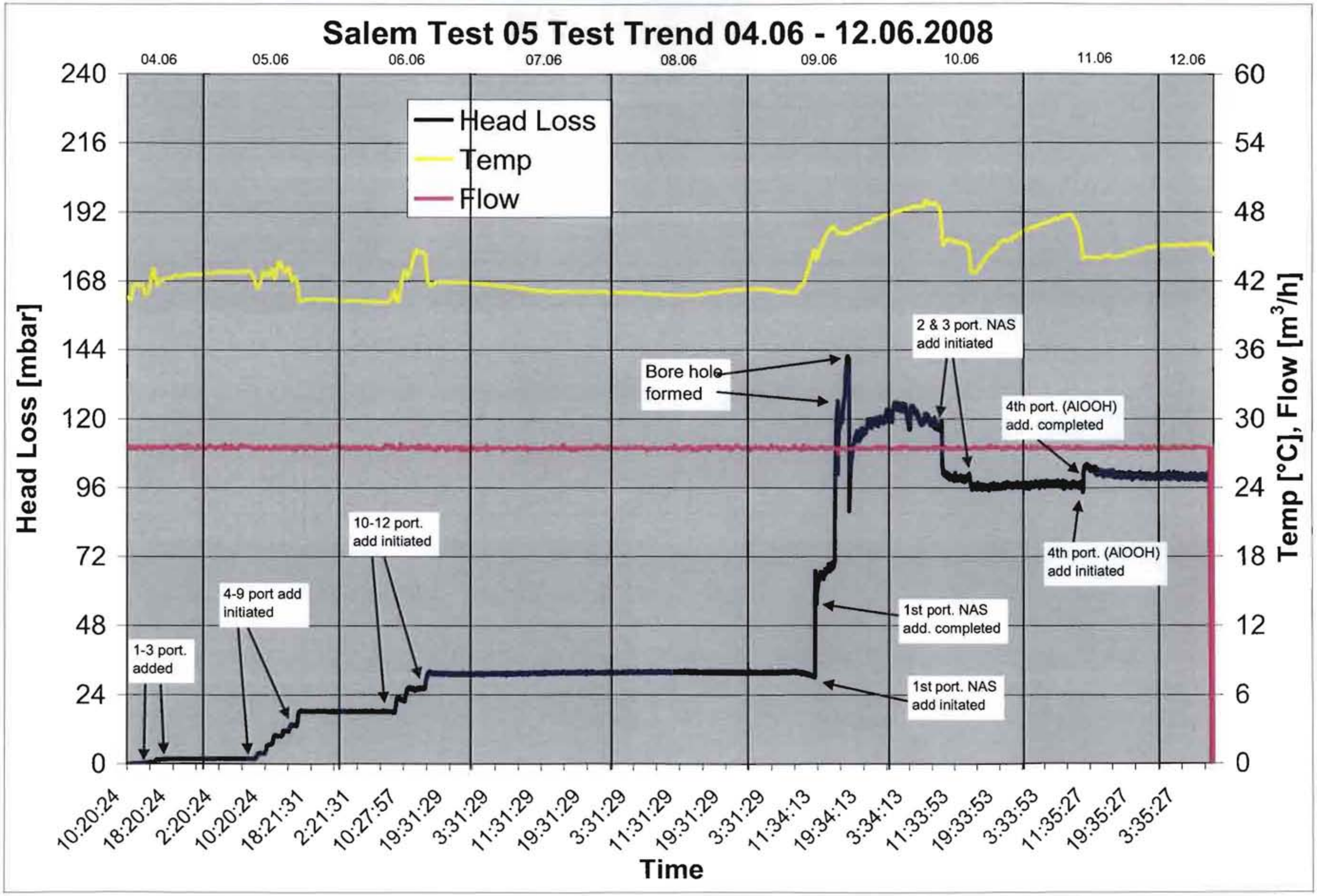


Fig. 3f.4.2.3.4-1 of Att. 1 to March 09 Supplemental Response

Unit 2 Strainer Head Loss Test

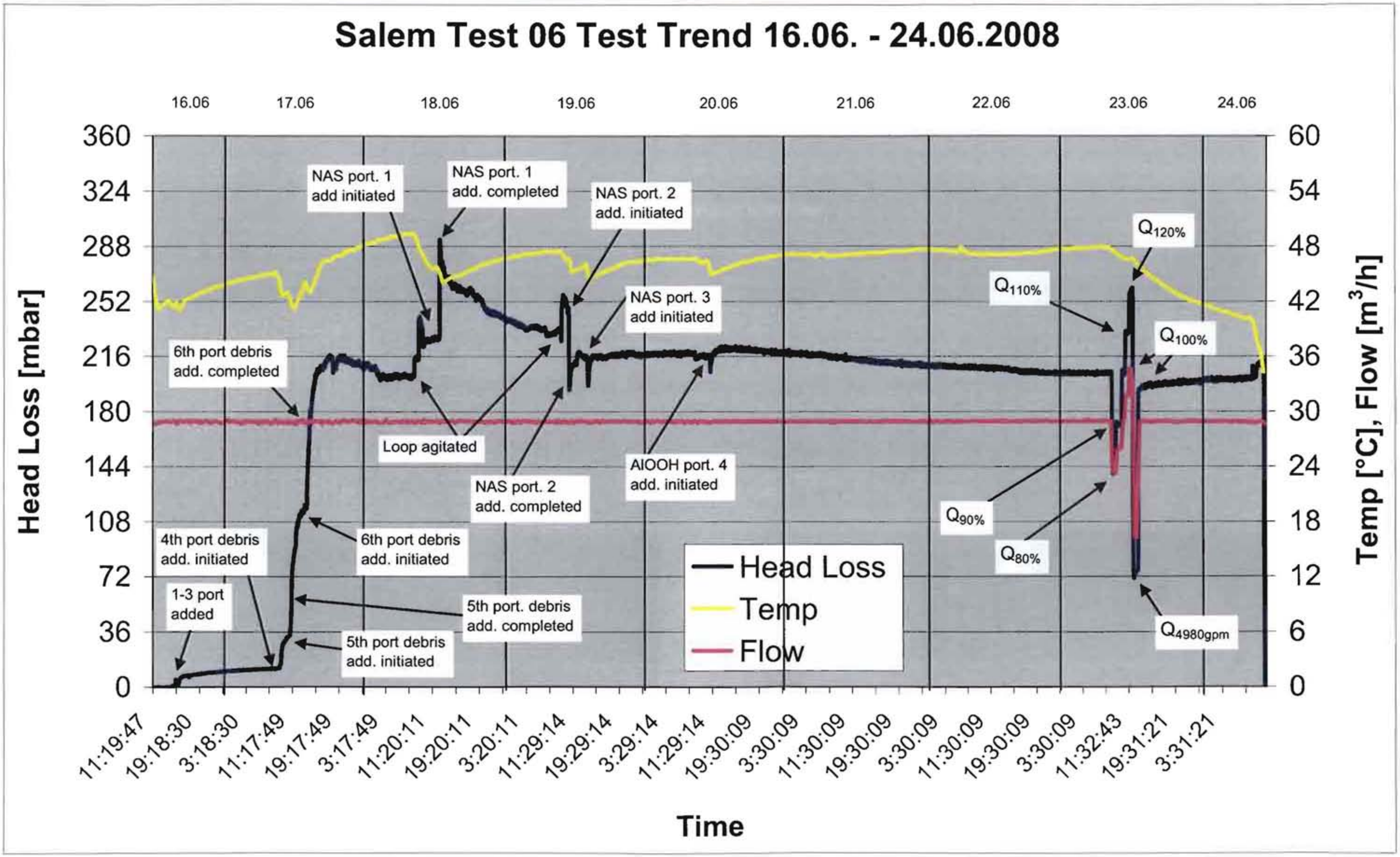


Fig. 3f.4.2.3.5-1 of Att. 1 to March '09 Supplemental Response

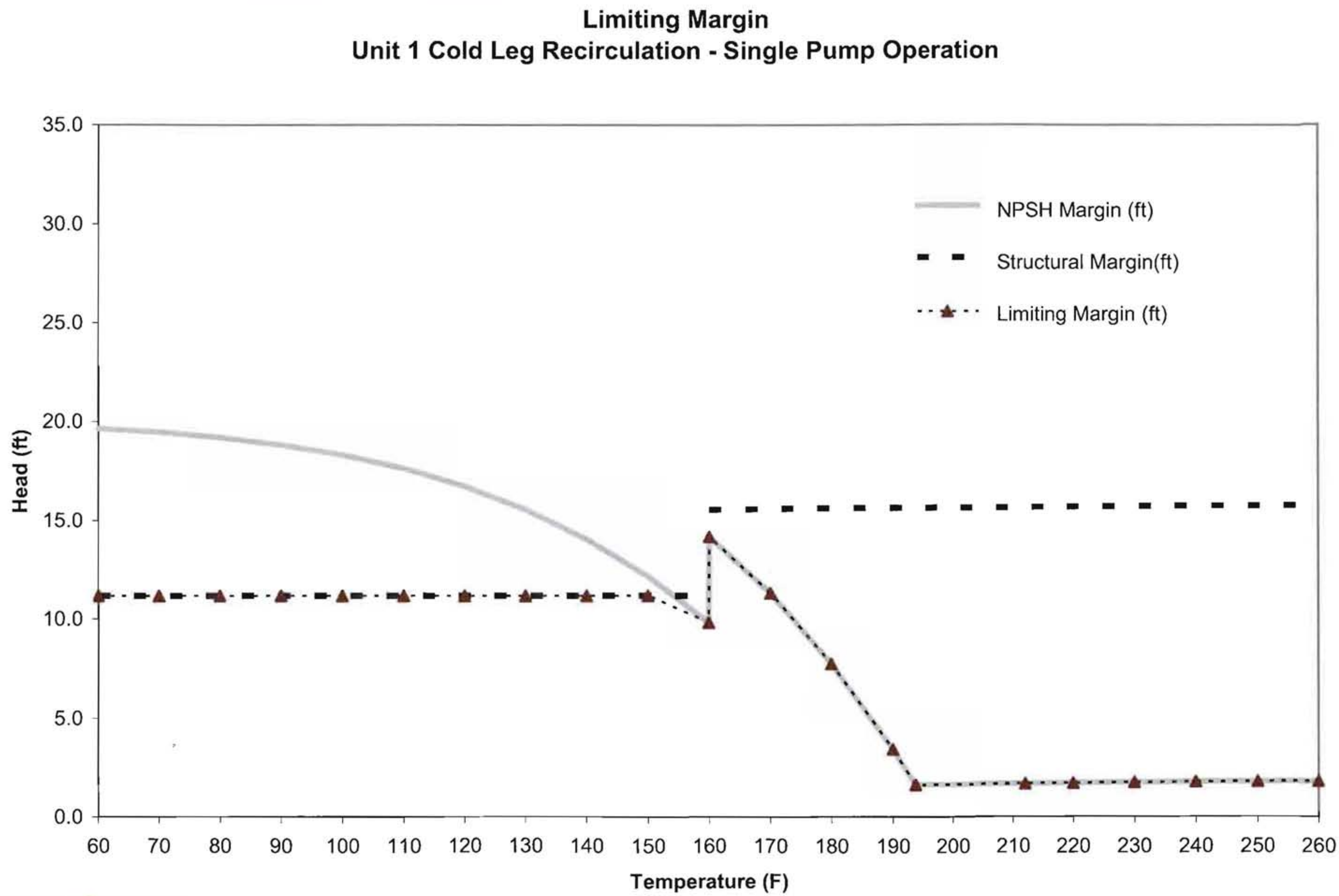
Impact of Chemical Effects on Strainer Head Loss

- **Precipitates added after 2nd portion had minimal impact on head loss**
- **Refined non-chemical debris load is less than tested debris load**
    - Significant fiber, coating, and Min-K margin
    - Theoretical bed thickness less than that tested
- **Increased precipitate load is not expected to adversely impact the tested head loss**

Margin

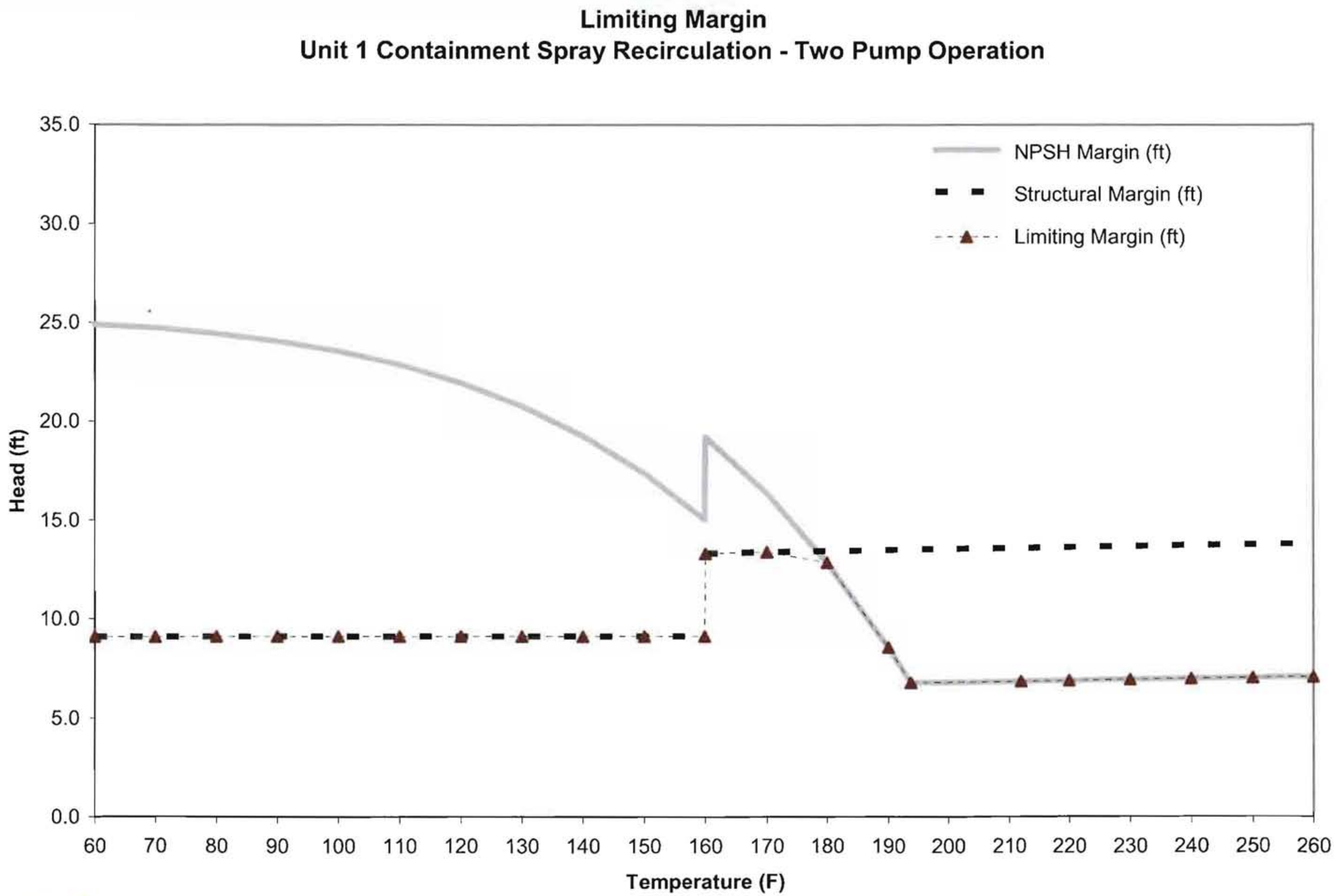
- NPSH margin is the difference between NPSH available & NPSH required
- Structural margin is the difference between the strainer structural limit and the strainer head loss
- Limiting margin is the lesser of NPSH and structural margin
- Significant margin exists at low sump temperatures

Limiting Margin – 1 Pump Operation



From §3g.16 of Att. 1 to March '09 Supplemental Response

Limiting Margin – 2 Pump Operation



From §3g.16 of Att. 1 to March '09 Supplemental Response

Available Margin

Parameter	1-Pump Operation Cold Leg Recirculation		2-Pump Operation Containment Spray Recirculation	
	T = 193.7°F (prior to chemical effects)	T ≤ 160°F (onset of chemical effects)	T = 193.7°F (prior to chemical effects)	T ≤ 160°F (onset of chemical effects)
Strainer Head Loss (ft)	1.3	5.8	3.4	7.8
Debris Bed Head Loss (ft)	0.3	4.8 (Bore Holes)	0.6	4.8 (Bore Holes)
Limiting Margin (ft) (NPSH or Structural)	1.6 (NPSH)	9.8 (NPSH)	6.8 (NPSH)	9.1 (Structural)

- Margins do not include reduction of 0.01 ft (1-pump) and 0.26 ft (2-pump) due to potential air evolution.

Margin Summary

- **Equivalent Nukon debris load is less than the tested debris load**
- **Chemical debris load is greater than the tested chemical debris load**
  - Bore holes limit the head loss increase
  - >9 feet of margin at temperatures at which precipitates may form
  - Margin available for an additional ~2x the debris head loss

Fuel Deposition

- **Nukon ZOI increased from 7D to 17D**

	Salem Unit 1 7D ZOI for Nukon	Salem Unit 1 17D ZOI for Nukon	Allowable Limits
Total Fuel Deposition Thickness (mils)	28.5	31.2	50
Maximum Cladding Temperature (°F)	390	390	800

Significant margin still exists relative to the allowable limits

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Summary

- 30-day Nukon debris load with 17D ZOI is approximately the same as tested debris load
- 30-day equivalent Nukon debris load with 17D ZOI is less than tested equivalent Nukon debris load
- Time dependent Nukon and equivalent Nukon debris loads are significantly less than the tested debris load at the onset of chemical effects

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Summary (cont.)

- **Additional generated Nukon increases chemical debris load above tested debris load**
  - Bore holes preclude significant increase in bed head loss
  - Head loss margin of 9.1 ft available to address additional chemical effects

Conclusions

- With the refinements/changes discussed Salem Unit 1 can accommodate an increase to 17D ZOI for Nukon
- Salem Unit 2 does not have jacketed Nukon and utilizes 17D ZOI for unjacketed Nukon

Fuel Assembly Blockage

NRC/PSEG Meeting

March 16, 2010

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Fuel Assembly Blockage

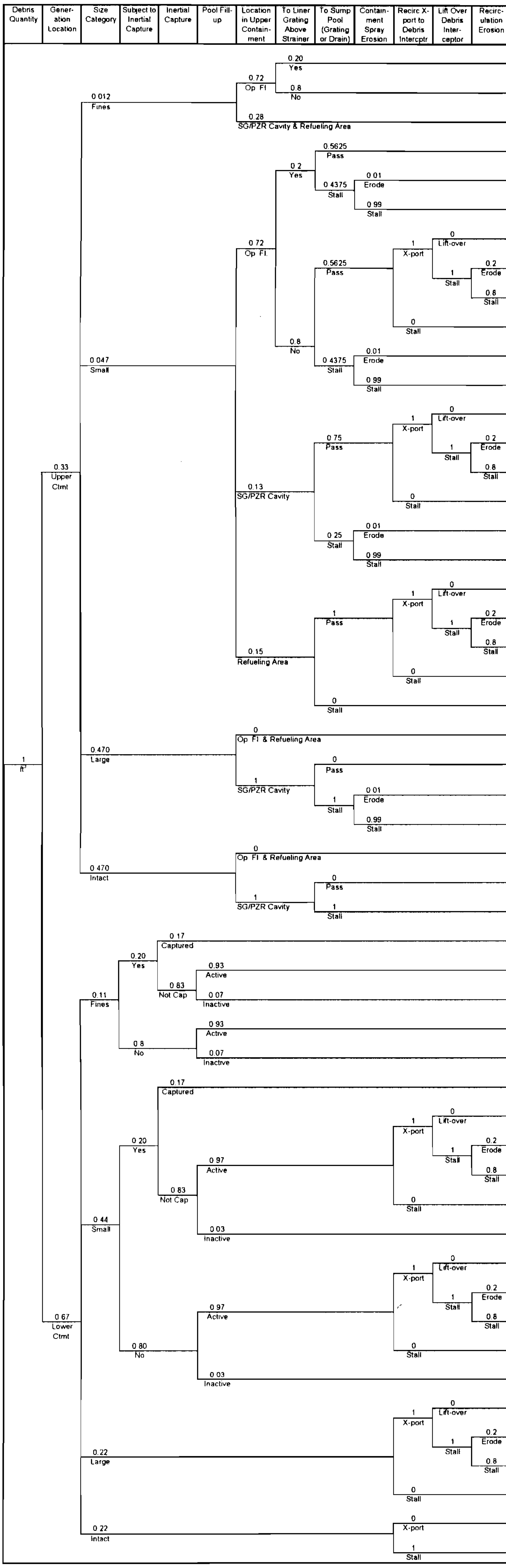
- Values not impacted by increased ZOI for Nukon as bypass amounts are based on debris transported to the strainer, not directly on generated debris
- Inputs for Draft Margin Calculator are being gathered
- Preliminary bypass results generated

Fuel Assembly Blockage Results

- Bypass debris amounts are compared to acceptance criteria found in WCAP-16793, Rev 1, in table below.

Debris	Bypass Debris Amount per Fuel Assembly (lbm)	Allowable Bypass Debris per Fuel Assembly (lbm)
Fiber	0.021	<0.33
Total Particulate	8.41	< 29
Chemicals	4.17	< 13
Calcium Silicate	-	< 6
Microporous (Min-K)	0.44 – Unit 1 2.03 – Unit 2	< 3.2

PSEG
Salem Unit 1



Path	Transport Fraction	Quantity	Debris Deposition Location
1	0.0006	0.82	Downstream Fines
2	0.0022	3.28	Upstream Fines
3	0.0011	1.60	Upstream Fines
4	0.0013	1.84	Downstream Small
5	0.0000	0.01	Downstream Fines
6	0.0010	1.42	Stalled Small
7	0.0000	0.00	Upstream Small
8	0.0010	1.47	Upstream Fines
9	0.0040	5.90	Stalled Small
10	0.0000	0.00	
11	0.0000	0.06	Upstream Fines
12	0.0039	5.67	Stalled Small
13	0.0000	0.00	Upstream Small
14	0.0003	0.44	Upstream Fines
15	0.0012	1.75	Stalled Small
16	0.0000	0.00	
17	0.0000	0.01	Upstream Fines
18	0.0005	0.72	Stalled Small
19	0.0000	0.00	Upstream Small
20	0.0005	0.70	Upstream Fines
21	0.0019	2.78	Stalled Small
22	0.0000	0.00	
23	0.0000	0.00	Stalled Small
24	0.0000	0.00	
25	0.0000	0.00	
26	0.0015	2.27	Upstream Fines
27	0.1526	224.46	Stalled Large
28	0.0000	0.00	
29	0.0000	0.00	Upstream Fines
30	0.1541	226.73	Stalled Intact
31	0.0025	3.74	Stalled Fines
32	0.0115	16.98	Upstream fines
33	0.0009	1.27	Stalled Fines
34	0.0556	81.82	Upstream fines
35	0.0042	6.13	Stalled Fines
36	0.0102	14.95	Stalled Small
37	0.0000	0.00	Upstream Small
38	0.0097	14.22	Upstream Fines
39	0.0387	56.87	Stalled Small
40	0.0000	0.00	
41	0.0013	1.90	Stalled Small
42	0.0000	0.00	Upstream Small
43	0.0466	68.52	Upstream Fines
44	0.1863	274.09	Stalled Small
45	0.0000	0.00	
46	0.0062	9.18	Stalled Small
47	0.0000	0.00	Upstream Large
48	0.0299	43.95	Upstream Fines
49	0.1195	175.80	Stalled Large
50	0.0000	0.00	
51	0.0000	0.00	Stalled Intact
52	0.1494	219.75	Stalled Intact

Fraction	Quantity	Debris Type
0.0006	0.8	Downstream Fines
0.0013	1.8	Downstream Small
0.0000	0.0	Downstream Large
0.1600	235.3	Upstream Fines
0.0000	0.0	Upstream Small
0.0000	0.0	Upstream Large
0.0076	11.1	Stalled Fines
0.2551	375.2	Stalled Small
0.2721	400.3	Stalled Large
0.3035	446.5	Stalled Intact
0.1618	**238.0**	**Total Transported**
0.8382	**1233.1**	**Total Stalled**
1.0000	**1471.1**	**Total**

ENCLOSURE 9

4) With respect to debris transport, the NRC staff stated that it was important for the licensee to cite the documents that form the basis for the assumptions regarding transport of debris through gratings.

5) It was decided that a followup public meeting or phone conference would be held after the revised draft RAI response is submitted. A schedule for the final RAI response will be established following that meeting.

Members of the public were in attendance. Public Meeting Feedback forms were not received.

Please direct any inquiries to me at 301-415-1420 or Rick.Ennis@nrc.gov.

/ra/
Richard B. Ennis, Senior Project Manager
Plant Licensing Branch I-2
Division of Operating Reactor Licensing
Office of Nuclear Reactor Regulation

Docket Nos. 50-272 and 50-311

Enclosures:
1. List of Attendees
2. Licensee Handout - RAI 11 - Draft for discussion (2 pages)
3. Licensee Handout - RAI 12 - Draft for discussion (13 pages)
4. Licensee Handout - RAI 13 - Draft for discussion (2 pages)
5. Licensee Handout - Previous RAI 14 - Draft for discussion (7 pages)
6. Licensee Handout - RAIs 14 & 15 - Draft for discussion (7 pages)
7. Licensee Handout - Response to Generic Letter 2004-02 (4 pages)
8. Licensee Handout - Assessment of 17D ZOI for Jacketed Nukon (55 pages)
9. Licensee Handout - Tree Diagram - Salem Unit 1 Debris Transport (1 page)

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