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Progress Energy

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United States Nuclear Regulatory Commission
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H. B. ROBINSON STEAM ELECTRIC PLANT, UNIT NO. 2
DOCKET NO. 50-261/LICENSE NO. DPR-23

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION PERTAINING TO NRC GENERIC LETTER 2004-02, "POTENTIAL IMPACT OF DEBRIS BLOCKAGE ON EMERGENCY RECIRCULATION DURING DESIGN BASIS ACCIDENTS AT PRESSURIZED-WATER REACTORS"

Ladies and Gentlemen:

By letter dated July 25, 2008, a request for additional information (RAI) regarding the H. B. Robinson Steam Electric Plant (HBRSEP), Unit No. 2, response to NRC Generic Letter (GL) 2004-02, "Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized-Water Reactors," was provided by the NRC.

Attachment I to this letter provides an Affirmation in accordance with the provisions of Section 182a of the Atomic Energy Act of 1954, as amended, and 10 CFR 50.54(f).

Attachment II to this letter provides the response to the RAI.

A commitment is being made, in response to Request Number 25, pertaining to verification that plant conditions are bounded by the final WCAP-16793-NP and the final NRC Safety Evaluation when it is issued. If you have any questions concerning this matter, please contact Mr. Curtis A. Castell, Supervisor –Licensing/Regulatory Programs, at (843) 857-1626.

Sincerely,

C. T. Baucom
Manager – Support Services – Nuclear

Progress Energy Carolinas, Inc.
Robinson Nuclear Plant
3581 West Entrance Road
Hartsville, SC 29550

A116
NRR

CTB/cac

Attachments:

I. Affirmation

II. Response to Request for Additional Information on the Supplemental Response to NRC Generic Letter 2004-02, "Potential Impact of Debris Blockage on Emergency Recirculation during Design Basis Accidents at Pressurized-Water Reactors"

c: L. A. Reyes, NRC, Region II
M. G. Vaaler, NRC, NRR
NRC Resident Inspector

AFFIRMATION

The information contained in letter RNP-RA/08-0124 is true and correct to the best of my information, knowledge, and belief; and the sources of my information are officers, employees, contractors, and agents of Carolina Power and Light Company, also known as Progress Energy Carolinas, Inc. I declare under penalty of perjury that the foregoing is true and correct.

Executed On: 12/17/08

E. A. McCartney
E. A. McCartney
Site Vice President, HBRSEP, Unit No. 2

H. B. ROBINSON STEAM ELECTRIC PLANT, UNIT NO. 2

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATON ON THE SUPPLEMENTAL RESPONSE TO NRC GENERIC LETTER 2004-02, "POTENTIAL IMPACT OF DEBRIS BLOCKAGE ON EMERGENCY RECIRCULATION DURING DESIGN BASIS ACCIDENTS AT PRESSURIZED-WATER REACTORS"

By letter dated July 25, 2008, a request for additional information (RAI) regarding the H. B. Robinson Steam Electric Plant (HBRSEP), Unit No. 2, response to NRC Generic Letter (GL) 2004-02, "Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized-Water Reactors," was provided by the NRC. The following information is provided in response to this RAI.

NRC Request 1:

Please provide justification for the assumption that 50 percent of small fines of fiber and 50 percent of fine particulate will be retained in the upper containment rather than being washed down into the containment pool.

The licensee's position that 50 percent of fine fibrous and particulate debris is retained in upper containment is a deviation from the baseline guidance in the Nuclear Energy Institute's (NEI) Guidance Report 04-07, "Pressurized Water Reactor Sump Performance Evaluation Methodology." The staff further considers this position non-conservative because it is contrary to existing conclusions based on testing evidence. For instance, regarding fibrous debris, a reference discussed in the licensee's submittal (NUREG/CR-6369, V2, "Drywell Debris Transport Study: Experimental Work") to support its position actually concludes that "all finer debris that are smaller than the grating, but are captured on the grating as a result of inertial capture, would be washed down when subjected to break and/or containment sprays. A transport factor of 1.0 should be assigned for such fragments." This conclusion seemingly applies equally for fine particulate.

Response:

The non-conservative nature of this assumption as it relates to the NEI Baseline Methodology is largely offset by utilizing a blowdown transport factor of only 10% for debris that is blown into the upper containment. The remaining 90% is assumed to fall to the floor where it is subject to pool fill and recirculation transport. The NEI Baseline Methodology recommends a 25% transport factor for debris blown into the upper containment with only 75% assumed to fall to the floor. Therefore, there is less debris assumed to be transported to the upper containment where it could potentially be retained.

This refinement differs from the NEI baseline washdown transport factor of 100% for small fibrous debris due to the fact that plant specific attributes enhance holdup in upper regions. The NUREG/CR-6762 assessment was based on more refined geometrical assessments and BWR spray with gratings. For a simplified approach, the NEI Sump Evaluation Methodology assumes 100% of the fines to be transported to the containment floor, not taking into account debris blown into areas shielded from containment spray by equipment and structures, or debris lodged into trapped areas. The 100% assumption by the NEI methodology was developed as part of the "Baseline Methodology" and by design is very conservative, as indicated in the Safety Evaluation Report (SER) for the NEI methodology.

This 50% washdown assumption is reasonable based on the following:

1. NUREG/CR-6762, Volume 4, Section 5.2, concluded that washdown of up to three-fourths of the debris deposited on containment surfaces cannot be ruled out and therefore established a 75% transport fraction considering spray flow rates exceeding 8,000 gallons per minute (gpm). The volunteer plant assessments documented in the SER (Appendices IV and VI) show that the calculated washdown to the pool was on the order of 71% (Table IV-1). The containment spray flow estimated for the volunteer plant assessment was 15,220 gpm (Table 1, page VI-63). The maximum HBRSEP, Unit No. 2, containment spray flow rate is 2,470 gpm, which is significantly lower than the 8,000 gpm assumed in NUREG/CR-6762 and the 15,220 gpm estimated for the volunteer plant assessment.

2. The results of the drywell debris transport study (DDTS) testing documented in NUREG/CR-6369, Volume 2, Table 4-3, showed that approximately 40-50% of small fiberglass debris landing on grating would be washed through the grating due to spray flows. This testing was performed at spray flow rates between 1 and 12 gpm/square feet. Analysis performed determined that the maximum spray flow rate for HBRSEP, Unit No. 2, is 0.19 gpm/square foot. Therefore, the results of the DDTS testing were able to be conservatively applied for HBRSEP, Unit No. 2. Any debris that lands in the annulus area would have to pass through grating at both the 275 feet elevation and the 251 feet elevation.

3. The models used in NUREG/CR-6762, Volume 4, were designed to identify spaces and surfaces where insulation debris would not likely be washed away by sprays or drainage flow (e.g., an area that is not affected by sprays or that has too little drainage flow to transport debris). The NUREG/CR-6369, Volume 2, Table 4-3, transport factors (1.0 for fines, 38-47% for small pieces, and 2-33% for medium pieces) were derived from testing where essentially all debris was exposed to water flow (break or spray). In other words, the transport factors were based on the underlying assumption that debris blown to the upper containment was exposed to water flow (break or spray). This is a fundamental difference between NUREG/CR-6762, Volume 4, and NUREG/CR-6369, Volume 2, in the approach used to derive the two washdown transport fractions. It is reasonable to credit sheltering and therefore the NUREG/CR-6762 transport fraction of 75% is more representative than the NUREG/CR-6369, Volume 2, transport fraction of 1.0 for fines.

4. Per NEI 04-07, Section 3.4.3.3.1, "small fines" are comparable to what is classified as small and medium in Table 3.7 of NUREG/CR-6369, Volume 2. Based on NUREG/CR-6369,

Volume 2, Table 4-3, fines washdown is 100%, small pieces washdown is 38-47% and medium pieces washdown is 2-33%. The average of these is 53%, which closely approximates the 50% used in the HBRSEP, Unit No. 2, debris transport calculation.

5. As discussed on pages 23 and 25 of the supplemental response, analysis determined that the total washdown fraction of the small fibrous debris through two layers of grating at HBRSEP, Unit No. 2, is 38.8%. This was based on 45% of the debris ejected to the upper containment passing through two layers of grating with a 50% transport fraction each, and 55% of the debris passing through a single layer of grating. The overall debris transported to the grating was conservatively accounted for by applying the assumed 50% washdown transport fraction to debris that is blown into the upper containment.

6. Fine debris ejected from the pump bays into the upper containment will fall to the operating floor level. This floor can be divided into three areas; 1) inside the polar crane rail, 2) outside the polar crane rail, and 3) refueling canal. The openings from the pump bays to the upper containment are closer to the center of containment than the polar crane rail. The refueling canal and floor area inside the rail amount to approximately 48% of the total area on the operating level. The rail is set in a gutter approximately 18 inches wide and 9 inches deep. The floor inside the crane rail slopes toward the rail gutter. The sloped floor area represents 39% of the total floor area. The gutter has drains that discharge to the reactor sump. Initially the debris within the polar crane rail gutter will be directed to the reactor sump, which is considered an inactive pool. Some of the debris may be directed to floor drains on lower levels if the line becomes blocked by debris, but these drains are covered with gratings that will tend to filter debris and become blocked. If the drains become blocked, remaining debris will be carried with the water over the polar crane rail that will function as a curb and trash rack to further limit transport of debris to the floor gratings. The quantity of debris retained due to these design features has not been quantified. This information is presented to further demonstrate that 100% washdown is not realistic for HBRSEP, Unit No. 2.

7. Blowdown is considered to be omni-directional within the pump bay. Part of the jet will be directed upward in a chimney effect within the pump bay, whereas expansion will also propagate downward to the RCP foundation and the main floor elevation. The limiting break location for HBRSEP, Unit No. 2, determined in the debris generation calculation, is near the bottom of the pump bay and there are multiple levels of gratings between the break location and the upper containment. The flow area available for debris to pass to the upper level of containment from the pump bays, such as areas where there are openings in the overhead concrete floor, is approximately 391 square feet as opposed to the total area of the pump bay ceilings of 4,960 square feet. The flow passage to upper containment therefore represents less than 8% of the total ceiling area above the break. Also, approximately two-thirds of the open ceiling area will be in the two pump bays remote from the break site. The annular clearance where the steam generators penetrate the operating floor is minimal (7 inches, excluding insulation, which would close the clearance to approximately 3 inches). Except for the small annulus around the steam generators and pressurizer, the openings to the upper levels of containment are covered with grating. During the blowdown phase, because of the multiple levels of gratings above the break location, the small flow area allowing access to

the upper level of containment, and the tortuous path necessary to reach the upper level of containment through the ceiling openings in the distant pump bays, 10% of the small debris was estimated to be ejected from the top of the pump bay and be available for spray washdown.

The remaining 90% of the debris generated by the break in the pump bays is assumed to fall to the floors of the pump bays. Conservatively, no credit is taken for any small fibrous debris holdup by grating in the pump bay at the 251 feet elevation. No credit is taken for fines to adhere to any structures in the containment pump bays. In reality, a portion of the small fines would be blown into tight or sheltered non-transportable areas within the pump bays. Based on NUREG/CR-6369, Volume 2, approximately 10% of debris passing through 20 feet of typical piping and structural steel will be retained on the equipment and approximately 24% is retained in a 90° turn. Given the path required to exit the distant pump bays to the upper containment, it is reasonable that the debris will pass through at least one 90° turn and 34% of the debris will be retained on equipment before exiting the pump bays to the upper containment. This quantity is neglected and provides a level of conservatism in the transport fractions, because approximately 8% of the pump bay ceiling is open to containment spray.

Due to the relatively low HBRSEP, Unit No. 2, containment spray flow rate and taking into account areas in containment where debris is trapped or shielded from containment spray washdown, the washdown of small debris (fiber and particulate) has been qualitatively estimated to be lower than that recommended in the NEI Baseline Methodology.

The combined increase in overall transport fractions between the baseline methodology and the HBRSEP, Unit No. 2, calculation methodology, including both the washdown differences and blowdown differences (NRC Request 4), is 3.4% for fibrous insulation and 4% for particulate insulation. These small differences are more than offset by limiting the inactive sump volume to 15%, in lieu of the calculated value of 35%. The overall HBRSEP, Unit No. 2, debris transport fraction for fibrous insulation small fines is 10% to 20% greater than that calculated using the baseline methodology when the inactive pool fraction is set equal to 0.35. The overall debris transport fraction for particulate insulation fines is 20% greater than that calculated using the baseline methodology when the inactive pool fraction is set equal to 0.35.

A parametric study was performed as part of the design head loss calculation. Based on the parametric results, the expected change in head loss due to the above-described increases in debris would be an increase of 0.08 feet. This difference in head loss and NPSH margin is not significant in comparison to the conservatisms in the NPSH margin calculation methodology. These conservatisms were determined to provide at least 1.7 feet by not assuming the instantaneous formation of chemical precipitates at the start of recirculation (delayed precipitation) and up to an additional 26 feet by crediting the minimum pre-accident partial pressure of dry air in containment.

<u>NRC Request 2:</u>

Please provide justification to support the assumptions of zero percent erosion of large fibrous debris pieces and zero percent transportability for large fibrous debris pieces.

The supplemental response did not explicitly address the transportability and erosion of larger pieces of fibrous debris (although erosion was addressed in an NRC staff RAI for the licensee's September 2005 GL 2004-02 response (ADAMS Accession No. ML052490343)). However, based upon other information in the submittal, it may be deduced that zero percent erosion was considered for large pieces, and that zero percent transport was considered for large pieces. The staff's safety evaluation (SE) on NEI 04-07 specifically noted that licensees should consider erosion of large pieces and transport of large pieces when using the baseline guidance.

Response:

Erosion was incorporated in the analysis because it is inherent in the methodology. The debris size fractions for the destruction of specific debris, which are dictated in the SER, include the erosion of large pieces to small fines.

The logic tree for Nukon and Temp-Mat fibrous insulation debris incorporates the fiber debris size distribution of 60% small debris and 40% large debris, which is from the NEI Baseline Methodology as approved by the SER. The 60% fraction for small fines includes consideration for fibrous erosion as discussed in NEI 04-07, Section 3.4.3.2, an excerpt of which follows:

> "Some material in the post-DBA environment will be eroded by the water flows. Additionally, some debris material may be disintegrated by the water flow. The classification for fibrous material in the ZOI adopted by this guidance assumes that all fibrous materials classified as small fines are essentially reduced to the individual fibers. As such, the debris classification implicitly considers the erosion and disintegration of the debris by conservatively assuming that they are already of a characteristic size that cannot be further decreased by erosion or disintegration. For fibrous insulation material, the large pieces are assumed to be jacketed or canvassed. According to NUREG/CR-6369, jacketed pieces are not subjected to further erosion."

The section of the SER on NEI 04-07 titled, "Staff Evaluation of [Guidance Report] GR Section 3.4.3.2," states, "The baseline approach contains the assumption that all large pieces of fibrous insulation material would be jacketed or canvassed and therefore would not be subject to further erosion resulting from water flows. Although this assumption is inconsistent with debris generation data acquired through NRC-sponsored tests, the staff position is that the overall impact of this non-conservatism on the results of the analysis is relatively minor in terms of the acceptance of the baseline guidance, and therefore acceptable. This is based on GR assumptions which include a large fraction of small debris (60 percent), all of which is assumed to be small fines. These are unrealistically conservative assumptions which substantiate the minor importance of addressing degradation of large debris."

The SER (page 83) identifies a specific concern with erosion of large pieces, i.e., "...if large portions of the large piece debris are located directly below large flows of falling water.". It is not expected that large portions of large piece debris will be physically located directly below large flows of falling water. Given the low density of insulation relative to water, large flows of falling water are expected to relocate large pieces of debris to more quiescent areas. Some of the large debris could be subject to this erosion. As noted in the SER, erosion of these large pieces is not expected to result in large quantities of additional fine debris. Additional erosion of large pieces beyond that included in the baseline methodology was not included in the debris volume. This small volume is expected to be largely offset by the conservative assumption that certain fibrous insulations are destroyed as 100% fines. Kaowool, unibestos, and unspecified fiberglass insulations are all conservatively assumed to be destroyed as 100% fines with no further potential for erosion. This assumption was made because there is no specific destruction test data for these particular materials. Debris from these sources makes up approximately 25%-30% of the total volume of fine fibrous debris. The assumption results in approximately 10%-12% increase in the volume of fines over a more typical 60% distribution of fines.

A qualitative assessment was performed, which indicates that the characteristic transport velocities will not transport large debris (fibrous or reflective metal insulation [RMI]) to the strainers. Due to the HBRSEP, Unit No. 2, configuration, very little debris, large or small, can be ejected upwards into the containment dome or outside the bioshield area. Debris that could be blown out and land either in the annulus area or underneath the refueling canal would not transport onto the strainer during the recirculation phase. This is due to the fact that the strainers are 4,000 square feet in surface area, and as such, the bulk strainer approach velocity during recirculation phases will be extremely low. During recirculation the strainer uniform approach velocity would only be 0.002 feet/second for the 4,000 square feet strainer. Velocity in the annulus area will be on the order of 0.167 feet/second at 3,820 gpm. The uniform approach velocities projected are too low for movement of large pieces of fibrous or RMI debris in a pool. Large is defined as pieces of insulation larger than 4 inches by 4 inches. The terminal settling velocity for large pieces of RMI debris is 0.48 feet/second (2 inch square pieces or larger, NUREG/CR-6772, Table 3.5). The flow velocity associated with incipient tumbling of large RMI debris is 0.28 feet/second (2 inch square pieces or larger, NUREG/CR-6772, Table 3.5). Hence, the uniform approach velocity during recirculation would not be sufficient to suspend or move large pieces of RMI debris towards the strainers. The terminal velocity for large pieces of fibrous debris is noted as 0.41 feet/second (6 inch pieces or larger, NUREG/CR-6772, Table 3.1). The flow velocity associated with incipient tumbling of large fibrous debris is 0.37 feet/second (NUREG/CR-6880, Table 5-3). Hence, the approach velocity during recirculation would not be sufficient to suspend or move large pieces of fibrous debris towards the strainers.

<u>NRC Request 3:</u>

Please provide justification to support the assumption that 15 percent of the debris in the containment pool during pool fill up will be trapped in inactive pool volumes.

The licensee assumed that 15 percent of the debris in the containment pool during pool fill up would be trapped in inactive containment pool volumes. The staff's SE on NEI 04-07 considers 15 percent to be the recommended maximum limit that licensees should assume for debris trapped in inactive volumes, but the staff intended that this reduction in debris reaching the strainer should only be taken if an adequate technical basis exists to support it. No such basis was provided in the supplemental response.

Response:

Debris transport in the containment bottom floor pool during filling will transport the small fines to the recirculation pool. Some of the small fines will be transported to the inactive volumes of the pool that do not participate in the recirculation flow, e.g., the reactor vessel head storage stand and reactor sump. The transport factor to the inactive pools was determined by calculating the ratio of the volumes of the inactive pool to the total pool volume.

The debris transport calculation specifically analyzes inactive volumes. The reactor sump is the largest inactive volume available to retain debris. Relief panels are provided on the reactor sump such that the water and debris can flow into the reactor sump from outside of the reactor cavity. Once the reactor sump is full, the volume will remain stagnant and retain the debris that is within this volume because this volume is below the ECCS sump elevation and there will not be water flowing through the reactor sump. The volume of the reactor sump is 8,393 cubic feet.

The volume determined as the total inactive volume was 8,555 cubic feet. For conservatism, only the reactor sump inactive volume of 8,393 cubic feet is considered further.

The maximum total pool volume is 23,752 cubic feet. The retained debris fraction for the large break LOCA is therefore: 8,393 cubic feet / 23,752 cubic feet = 0.35 or 35%.

The SER states that the inactive pool transport fraction should be limited 15%. Therefore, the inactive/active volume fraction utilized was set to 15%.

NRC Request 4:

Please provide justification to support the position that only 10 percent of fine particulate debris will be blown into the upper containment.

The licensee assumed that only 10 percent of fine particulate debris would be blown into the upper containment based on "multiple levels of grating above the break location and the small flow area around the steam generator at Elevation 275 feet." Underestimate of this scenario would result in an unrealistic amount of fine particulate debris being considered captured in inactive containment pool volumes. It appears counterintuitive that grating and a small flow area around a steam generator would be sufficient to cause 90 percent of fine particulate debris to blow down to the containment pool.

Response:

See the response to NRC Request 1 for a combined assessment of the percentage of debris blown into the upper containment and an assumed washdown less than 100%.

NRC Request 5:

Please provide the size distribution of fibrous debris used in head loss testing. Please compare this distribution with the sizes of fibrous debris predicted to reach the strainer by the plant debris transport evaluation.

The submittal states that 60 percent of the fibrous material was considered small fines and 40 percent large pieces. In the debris characteristics section, a table states that 60 percent of the fibrous insulation types are fines. It is unclear what percentage of the fibrous debris added to the testing was actually fines. In general, the licensee's strainer test vendor has tested with a generic fiber mix that consists of fibrous debris that is shredded and mixed with water prior to addition. This may result in the size distribution of fibrous debris reaching the strainer not matching the assumptions made in the transport and debris characteristics evaluations. The amount of truly fine fiber added to a test can have a significant impact on how the debris bed forms and the resulting head loss. In addition, the use of a fiber size mixture that is coarser than that predicted by the other evaluations can result in the lack of a thin bed forming during testing when one may actually occur in the plant.

Response:

Dry fibrous insulation was cut into 12 inch pieces, then shredded and inspected to verify debris produced fell in the size Class 1 through 4 of NUREG/CR-6808, Table 3-2. The size classes reported in NUREG/CR-6224, Table B-3, are identical to those reported in NUREG/CR-6808. It is noted that neither of these NUREG reports specify the percent of debris included in each class. NEI 04-07, Section 3.4.3.3.1, defines "small fines" as debris comprised of Classes 1 through 6 of NUREG/CR-6224. Classes 5 and 6 are larger than Classes 1 through 4. Therefore, the HBRSEP, Unit No. 2, fiber was verified to be generally finer than required by NEI 04-07. Fibers were observed to exist in a range of sizes from single individual fibers to small (approximately <1 inch) tufts of fibers before additional processing. Fiber was observed to be substantially smaller than the category defined in NEI 04-07 as "large pieces." The category of "small fines" as described in NEI 04-07 could be applied to the fiber used in the HBRSEP, Unit No. 2, testing based solely on the observed condition of the fiber at the end of the dry processing steps. As discussed below, additional mixing of the fiber with electric paint mixers, combined with the method used to introduce the debris into the test tank, breaks the fiber down further.

After these initial characteristics were met, the shredded fiber was weighed in the desired quantities. The debris was then boiled for at least 30 minutes to remove the binder and ensure the fiber would not float. After boiling, the debris was vigorously mixed with water in a confined volume with an electric paint mixer to further break up fiber clumps. The paint mixer was typically applied again immediately before each batch of debris was added to the test tank. After mixing, the debris was poured into the test tank adjacent to the water return flow. As noted in testing documented in NUREG/CR-6808, Section 5.2.6, insulation debris undergoes additional fragmentation producing additional fine debris that remained suspended even at low levels of pool turbulence when it was subjected to flow agitation associated with the inlet flow into the pool. The resulting fines were deemed to be readily transportable and appropriate for testing. The resulting fiber mixture is consistent with the baseline methodology employed.

The as-shredded debris, before further disintegration from boiling, mechanical stirring, and agitation from turbulence in the pool, has an expected terminal settling velocity of 0.13 feet/second or less. The average pool velocity is 0.17 feet/second, indicating the debris used in head loss testing is readily transportable to the sump and typical of what would be expected to transport to the screens.

From the baseline methodology that was employed, two size distributions were used – small fines and large pieces. The size distribution of insulation debris created in the ZOI is classified into two primary categories: (1) Fines and small pieces that readily transport; and (2) Large pieces, which do not readily transport. This approach is suggested by NUREG/CR-6808 and NUREG/CR-6762, Volume 3. Fines and small pieces are considered transportable by fluid forces and are defined as any material that could potentially be transported by blowdown, containment sprays, or post-accident pool flows. The fines and small pieces group includes debris created by erosion of the large pieces. The large pieces are not considered transportable by fluid forces and generally do not pass through gratings, trash racks, and radiological protection fences.

The HBRSEP, Unit No. 2, fiber debris was prepared to satisfy the "small fines" size distribution from NEI 04-07. Therefore, the as-tested fibrous debris is expected to provide the appropriate proportion of the various fiber size classes (including individual fibers) comprising the definition of "small fines."

<u>NRC Request 6:</u>

Please provide justification that testing was conducted with a debris mix and flow conditions that resulted in prototypical or conservative head loss values.

In general, NRC guidance expects that in some cases (especially for thin bed testing) only fine fibrous debris will transport to the strainer unless a plant specific evaluation shows transport of larger debris to be prototypical. Transport of coarser fiber would likely be delayed (or not occur at all) due to its lower transportability. Non-prototypical stirring can drive larger fibrous debris onto the strainer, resulting in non-prototypical non-homogeneities in the debris bed and thereby causing lower head loss.

<u>Response:</u>

Fibrous debris used in head loss testing was prepared in a manner that produced readily transportable debris as discussed in the response to NRC Request 5. Both fibrous and particulate debris are generated simultaneously by a pipe break. The average water velocity of the fluid flowing toward the screens exceeds the settling velocities of both 10 micron particulates and the fiberglass fibers used in testing. Therefore, it would be prototypical for both fiber fines and particulates to reach the screens simultaneously. No debris larger than Class 4, as defined in NUREG/CR-6808, Table 3-2, was used; as discussed in the response to NRC Request 5, the NEI 04-07 definition of "small fines" includes larger size debris, up to Class 6.

The debris introduction location was selected to maximize the transport of the debris to the strainers, thus ensuring that the results obtained were conservative. Without manual stirring, the debris tended to settle next to the screens due to the low average approach velocity of 0.002 feet/second, and therefore head loss through the screens was minimal. Following debris additions, head loss was allowed to increase to a relatively stable value prior to manual stirring. Manual stirs were repeated until they became ineffective in increasing head loss. The manual stirs were considered to be non-prototypical and conservative. With the manual stirring, and the variations in debris addition methodologies, it was determined that a thin debris bed (equivalent fiber bed thickness of 1/8 inch to 3/8 inch) did not exhibit the high "thin-bed" head loss characteristic of a flat plate strainer. Thick debris beds were found to have substantially higher head losses and were considered limiting and conservative.

Three thin bed tests were conducted for the purpose of determining the thin bed threshold debris quantity to load the strainer. The fiber and particulate were mixed in separate buckets and were not combined prior to addition to the test tank. In Test 1B, the total particulate load was added to the tank. The flow rate was maintained until the head loss stabilized and more than five pool turnovers occurred. Then, the fiber debris, equivalent to a bed thickness of 1/8 inch, was added to the tank. In Tests 1C and 1D, the particulate and fiber debris were added to the tank at the same time. Test 1C fiber debris quantity was equivalent to 3/8 inch. Test 1D fiber debris quantity was equivalent to 1/8 inch. Varying the method of debris addition ensured that both stratified and homogeneous debris beds were assessed.

For the thick bed test (Test 2), the fiber and particulate were initially mixed in separate buckets. The separate buckets were then mixed together prior to adding to the tank.

NRC Request 7:

Please provide details on the debris introduction techniques used during testing (e.g., where was debris added, what was the concentration of debris when added). Justify that the debris introduction did not result in non-prototypical agglomeration of debris or non-prototypical deposition of debris on the strainer.

Response:

As discussed in the response to NRC Request 6, prepared debris was combined with water in five gallon buckets and mixed thoroughly with a paint mixer attached to an electric drill until a homogeneous slurry was formed prior to introduction to the test tank. The mixture was then poured into the test tank down the tank wall behind a sparger (reference Figure 2). The sparger then mixed the debris with the water in the tank. The sparger at the front of the tank and the mechanical mixers at the back of the tank, combined with manual stirring of debris that settled behind the sparger, kept the debris suspended until it settled on or adjacent to the screens. The debris concentration in the five gallon buckets was not controlled.

The sparger was designed to disperse tank return flow and debris, reduce localized turbulence on the strainer modules, and minimize direct impact on the strainer modules while entraining material by increasing turbulence away from the strainers. Sparger holes were selectively directed towards the walls and floor of the test tank, and were sized to limit the velocity of the flow exiting any particular sparger hole.

Two mechanical mixers at the back of the tank were positioned to direct flow to the side walls of the test tank and the back of the strainer plenum. This created a flow path that transported debris upward so that it could then redeposit randomly.

Introduction of the debris behind the sparger, the sparger dispersing flow, and the mechanical mixers ensured the debris reaching the screens was thoroughly mixed, well dispersed, and capable of being transported to the screens by the low screen approach velocity. This test method effectively prevented large agglomerations of debris. Manual stirring of debris that settled behind the sparger and mechanical mixing at the rear of the tank ensured debris did not remain settled on the tank floor more than a few inches from the screens and ensured that debris had multiple opportunities to settle on the screens. The manual stirring was considered non-prototypical but conservative.

NRC Request 8:

Please provide documentation of how much debris, and to the extent possible, what types of debris, settled during testing.

Response:

The 1 by 4 screen array prototype nearly filled the bottom of the test tank (reference Figure 1). The spacing between the screen and the tank side walls was approximately 6 and 5/8 inches, which approximates the edge-to-edge distance between adjacent strainer groups as installed in the plant. The spacing between the screen end and the sparger was approximately 12 inches. The vast majority of debris that did not settle on the screens settled within approximately 12 inches of the screen. The sparger and manual stirs kept very little debris from settling between the sparger and the tank wall. Mechanical mixers installed behind the plenum allowed only minimal debris to settle between the plenum and the tank wall. The test reports did not record the volume of debris that settled remote from the screens (i.e., behind the sparger and plenum). As seen in Figures 3 and 4, the amount of debris that settled in these remote areas was not significant when compared to the overall quantity of debris added to the test tank. Visual observations confirmed there was no significant accumulation of debris more than a few inches from the screens.

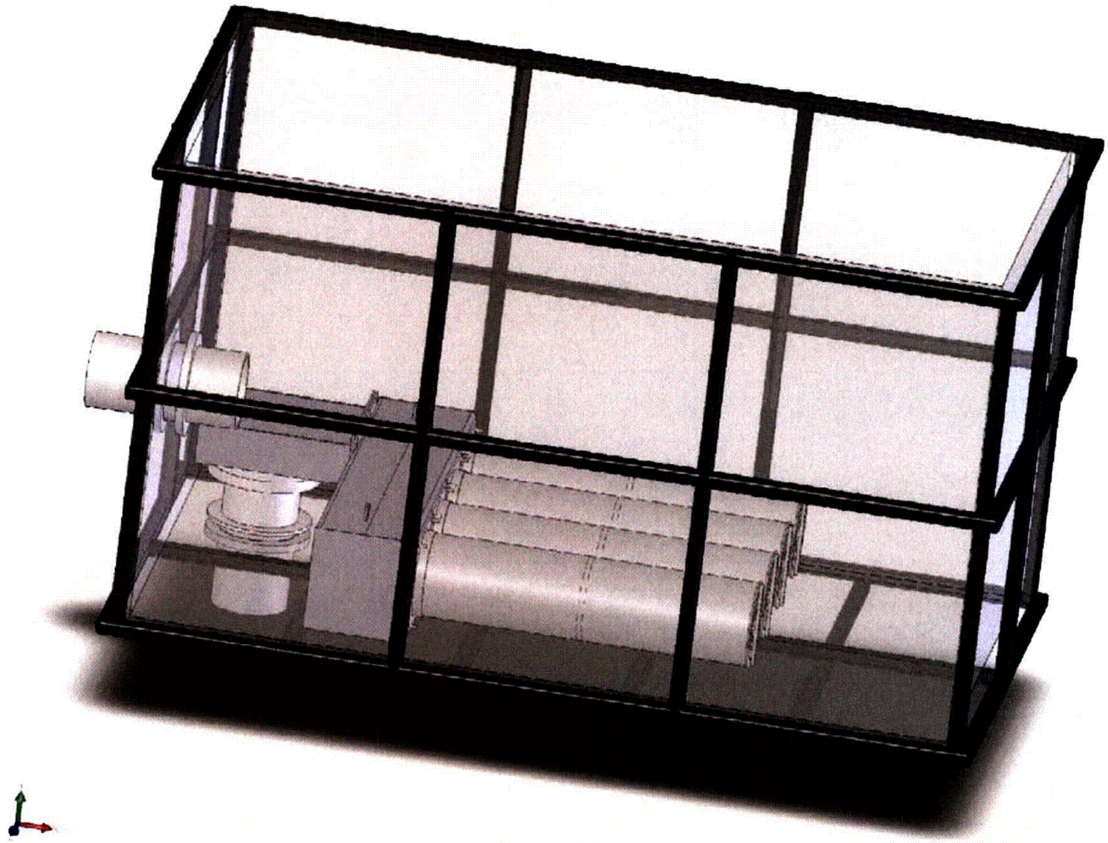


Figure 1
Arrangement of the 1 by 4 Strainer Array in the Test Tank

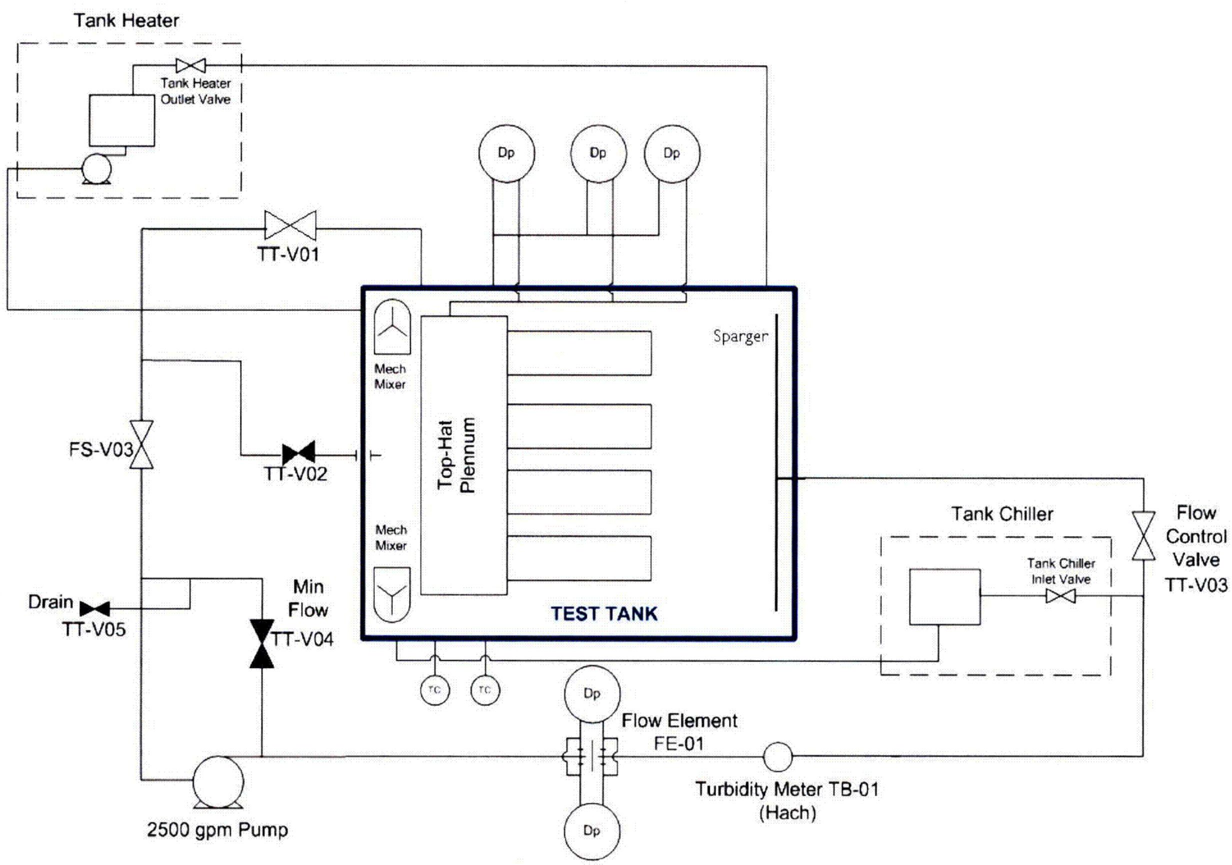


Figure 2
Test Loop Schematic

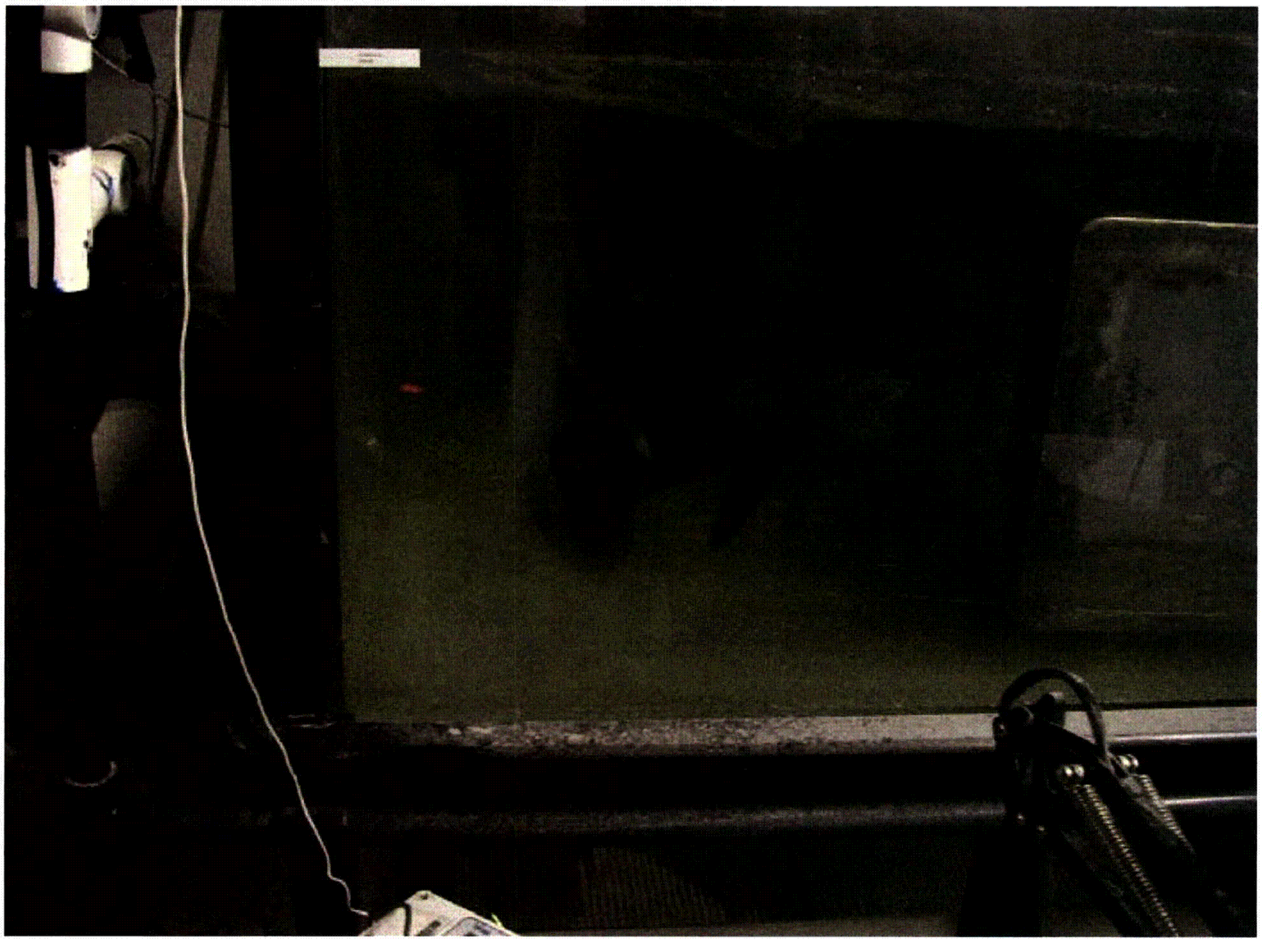


Figure 3
Rear of Tank Mechanical Mixer

Figure 4
Debris Accumulation Between Sparger and Tank Front Wall
Test 2 (Maximum Bed and Chemicals, Chemical Effects Test) Side of Tank View of Sparger [debris bed during testing after first two chemical additions]

NRC Request 9:

Please provide details on any extrapolations that were conducted using the NUREG-6224, "Head Loss Correlation," correlation. In addition, for any extrapolation, except to higher temperatures, please provide justification for why the extrapolation is prototypical or conservative. Please provide details on any vertical loop testing that was performed to support or inform these extrapolations.

Response:

The only extrapolation made using the NUREG/CR-6224 correlation was for increased temperature. The screens were added to the NPSH calculation and adjusted for flow rate changes. The head loss to flow rate correlation was based on measured data that showed a linear relationship and is considered prototypical. For the design basis case, including the loaded strainers in the NPSH calculation changed the system flow rate by less than 0.7%, which represents a head loss change of approximately 0.02 feet.

NRC Request 10:

Please provide details on the vortex testing that was completed to show where vortex suppressors needed to be installed (e.g., approach velocity, submergence, strainer size, and orientation). Please provide the criteria that were used (e.g., margin to vortexing) to determine which strainer modules required a vortex suppressor.

The submittal states that HBRSEP installed vortex suppressors over strainer sections where vortexing was predicted. The submittal does not state which strainer modules had vortex suppressors installed and what margin to vortexing was achieved for the modules that do not require vortex suppressors.

Response:

Vortex testing was conducted on horizontal, single top hat modules, 36 inches in length with perforated plate diameters of 8 inches and 6 inches, a perforated plate surface area of 9.2 square feet and a cross-sectional flow area through the strainer base plate of 0.132 square feet. The water level was set to 3 inches above the top of the perforated plate of the strainers. The average approach velocity was increased in this testing from 0.01 feet/second to 0.03 feet/second with no air-entraining vortices detected. Testing was also conducted from 0.04 feet/second to 0.09 feet/second showing that air-entraining vortices could occur at these velocities and were completely eliminated by standard 1.5 inches-thick floor grating installed flush with the surface of the water.

Based on testing described above, a correlation was derived for flow velocity through the top hat base plates and the onset of vortexing. The derived correlation was used to calculate the maximum approach velocity that can be sustained without vortexing. The limiting maximum approach velocity was determined to be 0.0115 feet/second.

The maximum normalized approach velocity with the strainer fully loaded is 0.002 feet/second. This is well below the limiting maximum approach velocity of 0.0115 feet/second. Therefore, air entrainment due to vortexing is not expected once the strainer is fully loaded and approach velocities move toward normalized approach velocities.

The screens are arranged on a horizontal plenum mounted on the floor with top hat strainers arranged in sets of two (one on either side of the plenum). In addition, there are two plenums, one located inside the crane wall and one located outside the crane wall. The maximum expected approach velocity with clean screens was calculated as 0.017 feet/second at the first set of top hats nearest the sump (i.e., nearest the pump suction) located inside the crane wall. However, the approach velocities drop off very quickly and the third set of top hats has an approach velocity of 0.009 feet/second, which is approximately 21% below the limiting approach velocity. The maximum expected approach velocity for the first set of top hats outside the crane wall is below the limiting approach velocity by approximately 10%. The remaining top hats inside and outside the crane wall are well below the limiting value.

To eliminate the concern over air core vortices, vortex suppressors were initially installed over the first eight sets of top hats inside the crane wall and over the first eight sets of top hats outside the crane wall in Refueling Outage (RO)-24. In RO-25, in the fall of 2008, the balance of walkway and vortex suppressors were installed over the top hats outside the crane wall. Due to congestion in the area inside the crane wall created by the now-installed plenums and top hats, the balance of vortex suppressors inside the crane wall were not installed. Inside the crane wall, the eighth set of top hats have a maximum expected approach velocity of 0.004 feet/second, and outside the crane wall, the eighth set of top hats have a maximum expected approach velocity of 0.002 feet/second, both providing a margin to vortexing of more than a factor of 2.8.

NRC Request 11:

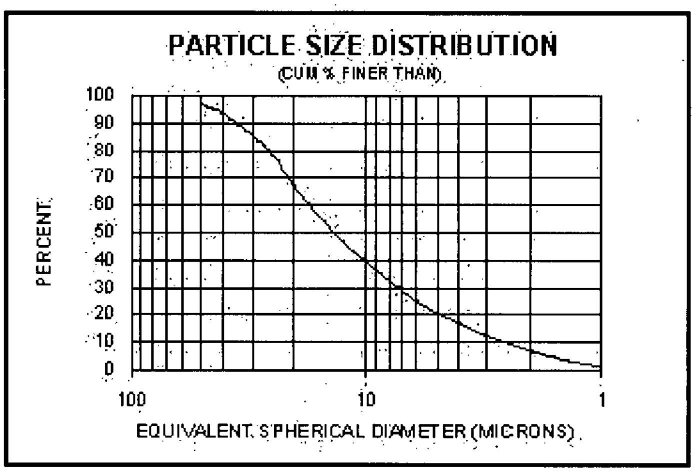
Please provide the size distributions for the particulate debris used during testing. Discuss how these size distributions compare with the guidance in NEI 04-07 and justify any differences with that guidance.

Response:

Coatings

Guidance in NEI 04-07 is to assume all coatings within the ZOI and unqualified coatings outside the ZOI fail as 10 micron particulate.

HBRSEP, Unit No. 2, used Si-Co-Sil 53 as a coating surrogate with a size distribution as shown below.



Based on the Si-Co-Sil 53 typical particle size distribution shown above and the approach discussed on Page 3-61 of NEI 04-07 to determine a composite specific surface area (Sv) for a mixture of different particle sizes, the aggregate Sv for the Si-Co-Sil 53 was estimated to be approximately 246,000 feet^{-1} which is greater than the Sv for 10 micron particulate (180,000 feet^{-1}). The Sv for each size range was determined based on the maximum particle size from the range. By using the maximum particle size, the calculated Sv is conservatively minimized, which is appropriate for the purpose of comparing to the Sv for a 10 micron particle, since a higher Sv is expected to yield a higher head loss. Therefore, use of the Si-Co-Sil 53 surrogate is conservative.

Size (microns)	% Finer Than	Fraction (v)	Sv (1/feet)	$Sv_n^2 * v_n$	Aggregate Sv (1/feet)
100	100	0.05	18000	16200000	
75	95	0.1	24000	57600000	
30	85	0.45	60000	1620000000	
10	40	0.1	180000	3240000000	
7	30	0.1	257143	6612244898	
5	20	0.1	360000	12960000000	
3	10	0.1	600000	36000000000	
	Total:	1		60506044898	245980

Latent Debris

Silica sand prepared by Performance Contracting, Inc., was used as a surrogate material for latent dirt and dust debris. The size distribution of the silica sand was prepared to be consistent with the latent dirt/dust size distribution provided in the SER. The table below presents this size distribution.

Blended Silica Sands Size Distribution	Size Class	Allocation Basis	Actual	NRC Target
< 75 microns	Fine	37.04%	37%	37%
> 75 microns < 500 microns > 500 microns < 2000 microns	Medium	0.56% 20.80% 12.60% 0.95%	35%	35%
> 2000 microns	Coarse	28.05%	28%	28%
		100%	100%	100%

NRC Request 12:

Please provide a revised response to NRC RAI No. 41 contained in an NRC letter dated February 8, 2006 (ADAMS Accession No. ML060370460).

Specifically, on page 4 of the licensee's September 1, 2005, GL 2004-02 response (ADAMS Accession No. ML052490343) it was stated that "the result of the water level calculation shows that the most limiting case, which is the small break LOCA [loss of coolant accident] of the pressurizer spray line, results in a depth of at least 1.2 feet above the containment floor, and the applicable emergency operating procedures ensure that at least 1.5 feet is available at the start of containment sump recirculation. The ECCS [emergency core cooling system] sump design will be such that the water level will completely submerge the screens."

Information on pages 29 and 39 of the March 7, 2008, supplemental response, taken together, show that at a level of 229.5 feet (18 inches or 1.5 feet above the containment building floor) there are 3.5 inches of water above the strainers. However, it is unclear how a level of 1.5 feet above the containment floor is assured by operating procedures. Please clarify this point.

Response:

The sump minimum water level calculation conservatively concludes that during a small break LOCA the sump water elevation may only reach 229.3 feet when the Refueling Water Storage Tank (RWST) reaches 27% level. The procedure controlling transition to recirculation, EPP-9, is entered when the RWST level reaches 27% and initiates transition to recirculation when the RWST reaches 27% provided the containment sump water level is at least 229.5 feet. If the sump water level has not reached 229.5 feet, injection from the RWST would continue after the RWST reaches 27% until the minimum containment water level is reached and before recirculation begins. There is sufficient water in the RWST to support increasing the sump water level from 229.3 feet to 229.5 feet. Using the same conservative assumptions, when the RWST reaches 9% the sump water level will be at least 230.1 feet. It should be noted that the water level calculation was developed to determine minimum sump water levels and is conservatively biased. For the small break LOCA case, it assumes the Reactor Coolant System (RCS) remains pressurized, the Safety Injection (SI) accumulators don't inject into the RCS, and there is no initial loss of water from the RCS to the sump.

NRC Request 13:

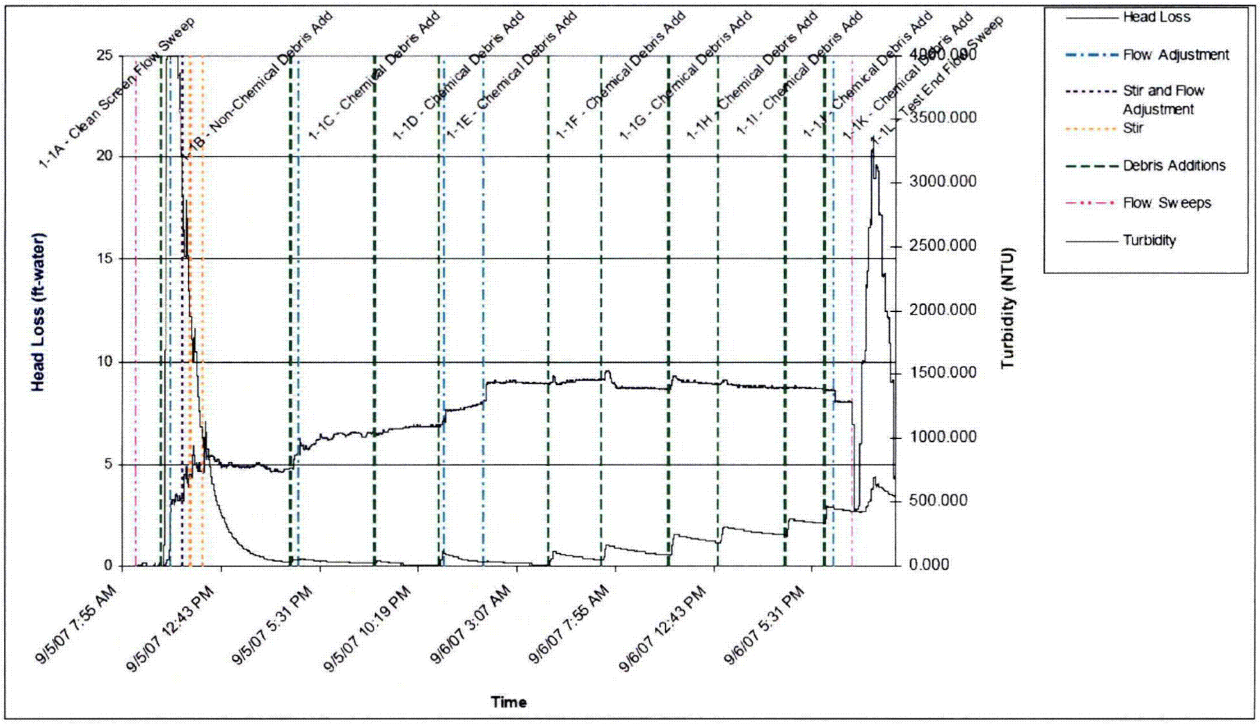
The head loss plot on Page 79 of the March 7, 2008, supplemental response shows little or no effect from the last few chemical precipitate additions to the test loop. There appears to be a debris bed redistribution after chemical addition number 2H, possibly due to calcium silicate dissolution.

Given the small remaining net positive suction head (NPSH) margin for HBRSEP, please indicate whether the head loss plot shown on page 79 of the March 7, 2008, supplemental response provides the maximum integrated head loss test result or only the integrated head loss test data for a specific break scenario. Please provide the other head loss plots if additional head loss tests were performed.

Response:

Two tests were completed, identified as Test 1-1 and 2. Test 1-1 added chemicals to a maximum load of 600 pounds compared to 1,500 pounds in Test 2. The plot shown on Page 79 of the submittal is from Test 2 and provides the maximum integrated head loss test result of two tests that were completed for chemical effects head loss determination. The first part of Test 2 was a confirmatory test of Test 1-1 and had slightly higher non-chemical debris head loss and slightly higher peak chemical head loss over Test 1-1.

The results of Test 1-1 are plotted below:



NRC Request 14:

Based on the gradual increase in turbidity associated with the addition of chemical precipitate surrogate depicted by the figure on page 79 of the March 7, 2008, supplemental response, the staff considers it possible that boreholes or other openings may have been present in the debris bed. Specifically, the turbidity at the end of the test apparently exceeded the turbidity just prior to thin-bed formation. The relative flatness of the head loss trace over the majority of the chemical addition sequence is also indicative of bed disruptions driven by the differential pressure across the debris bed.

Please provide the basis for using temperature scaling in light of these indications that bed disturbances caused by differential pressure may have occurred (since the bed disruptions may not have occurred at higher temperatures).

Response:

Two head loss tests were conducted. The first part of the second test (Test 2) was a confirmatory test of Test 1-1, which closely matched the non-chemical debris head loss results of the initial test and had slightly higher peak chemical head loss. The second test resulted in the head loss shown on Page 79 of the supplemental response. The plot shown on Page 79 provides the maximum integrated head loss test result from the two tests.

The turbidity data for both Test 1-1 and 2 show the decrease in suspended particulates over time, thus indicating that the fibrous debris bed is filtering the water as it passes through the debris bed and strainer. For each additional chemical precipitate batch that is added, a slight increase in turbidity is seen. However, the turbidity shows a decrease in suspended particulates over time indicating that the debris bed is filtering the water.

The increasing head loss value per test or batch and the low turbidity levels during the test indicate that there is sufficient fibrous debris to cover the strainer and capture the chemical precipitate and particulate debris. Initially, for each batch of chemical precipitate, the head loss increased with the addition of more precipitate. However, after sub-Test 1-1E, additional batches of chemical precipitates did not result in an increase in head loss.

The data from both Test 1-1 and 2 show that a "steady state" head loss is achieved at approximately 8.5 feet to 9 feet where upon additional chemical additions had no further impact. The exact determination of the mechanism(s) behind this phenomenon would require testing and analysis beyond the scope of the prototype head loss tests. With respect to this investigation, confirmatory testing in Test 2 verified this behavior on a macroscopic level and thus was utilized in the strainer performance evaluation.

NRC Request 15:

Please provide a description of the system configuration and assumptions that provide the basis for the flow rate (3820 gallons per minute (gpm)) used to compute the "minimum NPSH margin" in the limiting NPSH margins calculation, including an explanation of which pumps are running and their flow rates.

Response:

The flow rate of 3,820 gpm occurs at the initiation of recirculation in accordance with procedure EPP-9. A single RHR pump is aligned for recirculation as the RWST reaches 27% level. SI and containment spray (CS) pumps continue to take suction from the RWST. Under this alignment the RHR pump and sump flow rate is 3,820 gpm assuming no head loss across the sump screens. Flow will be slightly less when accounting for the screen head loss.

NRC Request 16:

A single-train sump design flow rate of 3820 gpm was used in the NPSH and head loss calculations as the flow rate that would result in the most limiting NPSH margin. Although the use of this value for computing NPSH margin with a clean strainer may be conservative (based on the discussion in the March 7, 2008, supplemental response), there is no basis provided to conclude that this single-train flow rate is conservative when debris bed head loss is factored in. In fact, based on the significant increase in head loss during the flow sweep in the head loss plot on page 79 of the March 7, 2008, submittal, it appears that increased flow due to dual-train operation could result in a significant increase in debris bed head loss, which could potentially overwhelm any benefit from a higher flow rate that is associated with the other terms in the clean strainer NPSH margin.

Please identify the maximum sump flow rate for dual-train operation and provide a basis that 3820 gpm is the bounding flow rate when both NPSH and debris bed head loss are considered. The basis should include a description of the results of any head loss testing performed at flow rates above 3820 gpm.

Response:

By procedure, only one RHR pump is run during recirculation (Case 1 in table below), except when in "piggyback" alignment. In that case total flow is limited by the capacity of the SI pumps and CS pumps (Case 2 below) and, if aligned for simultaneous cold leg injection from the RHR pumps and hot leg injection through the SI pumps, the cold leg injection flow is limited by closing down the RHR heat exchanger outlet valves (Case 3 below). The ECCS screen head loss test information has been incorporated into the NPSH head loss calculation. The most limiting case including the screen head loss continues to be the single pump operation. Analysis results for the limiting case and the maximum dual pump operation case are tabulated below. Note that the minimum NPSH margin increased from 0.1 feet to 0.3 feet due to the inclusion of the screens and debris in the flow path. The increased system resistance reduced system flow and NPSH required (NPSHR).

Case	Screen Flow (gpm)	Pump Flow (gpm)	Screen Debris and Plenum Head Loss (feet)	Pump NPSHR (feet)	NPSH Margin (feet)
1 (1 RHR pump for cold leg injection per procedure EPP-9)	3,794	3,794	5.2	14.5	0.3
2 (1 RHR pump aligned to 2 SI pumps and 1 CS pump for hot leg injection per procedure EPP-9)	2,463	2,463	3.0	9.8	4.5
3 (2 RHR pumps aligned to 2 SI pumps for simultaneous hot and cold leg injection per procedure EPP-10)	3,142	A: 1,560 B: 1,582	4.1	A: 9.2 B: 9.2	A: 8.8 B: 8.9

NRC Request 17:

Please provide a summary of structural qualification results and design margins for the various components of the sump strainer structural assembly. This summary should include interaction ratios and/or design margins for structural members, welds, concrete anchorages, and connection bolts as applicable.

Response:

The structural qualification of the sump strainer structure is in accordance with HBRSEP, Unit No. 2, design criteria documents. The sump strainer is designed primarily to the requirements of the American Institute of Steel Construction (AISC) code, supplemented by other codes and standards, as appropriate. The structural design codes specify allowable stress limits, which include required design margins (safety factors) to ensure that structural stresses do not approach material ultimate capacity. Consequently, design margins are inherent to the design philosophy used by the code methodology. Compliance with the code-specified stress limits provides sufficient assurance of design adequacy/margins. The implicit design margins/safety factors for various structural components are listed below:

Component	Allowable Stress Limit	Design Margin/ Safety Factor
Structural Steel	0.9Sy / 0.31Su	69 % / 3.2
Threaded Stud and Bolt	0.34 Su	66 % / 3.0
Concrete Anchor Bolts	Vendor Specified	NA / 4.0

NRC Request 18:

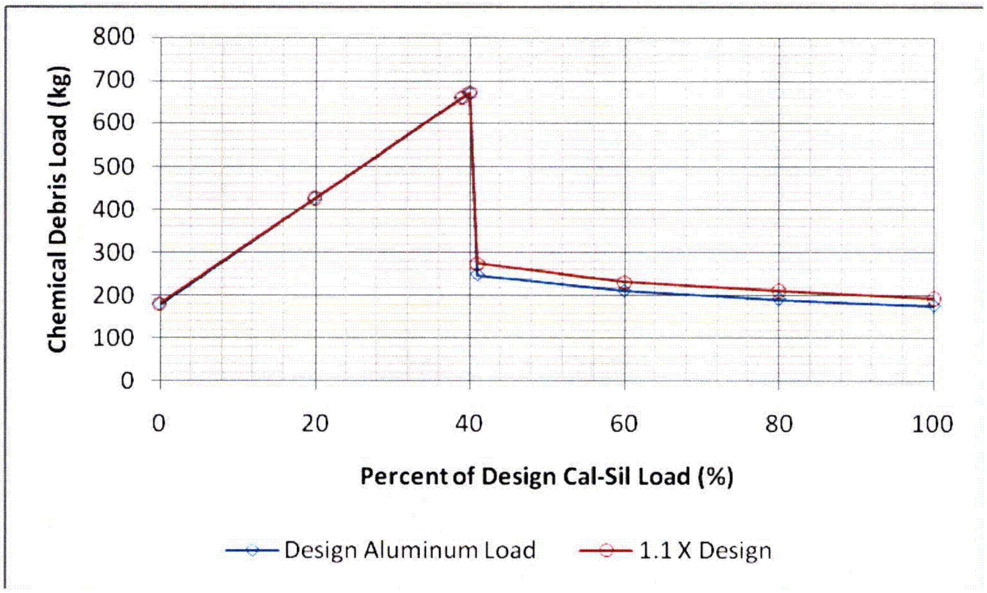
HBRSEP has taken credit for silica inhibition of aluminum corrosion. On page 77 of the March 7, 2008, submittal, the licensee stated that when credit is taken for silica inhibition, chemical precipitate load is maximized when calcium silicate debris input is reduced to 40 percent of that predicted to reach the screen.

Please state whether there are plausible break locations containing less than 40 percent calcium silicate debris that would result in a greater chemical precipitate load than tested due to insufficient silica to reach the threshold silica concentration for inhibition. If so, please discuss why the actual debris tested resulted in a more conservative head loss test compared to an alternate test.

Response:

Break locations and associated debris loads were selected and evaluated to determine the greatest debris loads that could be generated. Any given break location (or an alternate break location that may not have been evaluated since it was not a bounding debris load) could plausibly produce a lesser amount of any particular type of debris, including Cal-Sil. To capture this effect, breaks with calcium silicate between 0% and 100% of the full debris load were considered based on the WCAP-16530-NP and WCAP-16785-NP methodologies, as seen in the figure provided below. The precipitous drop between 40% and 41% is an artifact of the analysis methodology and the peak would be lower than shown due to non-zero inhibition at silicate levels at or below the model threshold, but it is conservative to use the maximum prediction which occurs at 40%.

A break resulting in 40% of the predicted maximum chemical debris was used as the basis for the maximum quantity of chemical precipitant used in testing. Below 40% there is reduced silica available to form chemical precipitates, which results in less chemical debris generation. Above 40% the increased silicate inhibits aluminum corrosion, which results in less chemical debris generation. The debris load tested included the maximum chemical precipitant (based on 40% of the predicted Cal-Sil) and the equivalent of the full debris load that would be transported to the strainer including 100% of the transportable Cal-Sil debris, and was, therefore, the most conservative head loss test. Further, the stepped nature of the introduction of the chemical precipitant debris allows evaluation of all predicted chemical precipitation quantities from 0% to 100% of the predicted Cal-Sil chemical debris load.



NRC Request 19:

Please provide the amounts of time needed for sufficient calcium silicate insulation dissolution to reach the 50 parts per million (ppm) silica and 100 ppm silica concentration in the containment pool and the basis for these calculated times.

Response:

The chemical debris generation analysis indicates that for the worst case chemical debris generation of 40% of the design silica load (results in the maximum mass of chemical debris generated), silica concentrations in the containment pool reach 50 ppm in less than 48 hours and plateau at 99 ppm in under 240 hours.

The chemical debris generation analysis indicates that for the 100% of the design silica load condition, silica concentrations in the containment pool reach 50 ppm in approximately 11 hours and 100 ppm in approximately 48 hours.

The chemical debris generation analysis is based on the chemical generation model of WCAP-16530-NP and WCAP-16785-NP including conservative modifications to the model as described in response to NRC Request 21.

NRC Request 20:

Please provide details concerning how aluminum oxyhydroxide (AlOOH) solubility was credited during the chemical effects evaluation. Please explain whether the approximately 13 percent reduction in chemical debris load was based on temperatures above 140°F. Also, please explain whether additional precipitate was added to the test loop at a point representing when the pool temperature reaches 140°F.

Response:

The solubility of aluminum oxyhydroxide was assumed to be 40 ppm aluminum between temperatures of 140°F and 200°F. At temperatures greater than 200°F, the solubility was assumed to be 98 ppm aluminum. The supplemental response stated that not crediting solubility of AlOOH would increase the debris load over the tested chemical debris load by approximately 13%. This 13% estimate mentioned in the submittal was based on containment aluminum quantities that have since been revised to correct a transposition error between mass and surface area for one submerged aluminum component. While the spreadsheet model used allowed credit for the solubility of aluminum oxyhydroxide, comparison using a spreadsheet evaluation with that enhancement removed, and with the corrected aluminum quantities, shows that only a small amount aluminum oxyhydroxide was predicted to form; that is, the majority of the aluminum was predicted to precipitate as sodium aluminum silicate, and therefore the solubility of aluminum oxyhydroxide was inconsequential to that analysis. Solubility of aluminum oxyhydroxide has an impact of less than 2% on the total mass of chemical debris for the bounding case of 40% Cal-Sil in the sump, and no impact on cases with 45% or more Cal-Sil in the sump. The total mass of precipitates without crediting AlOOH solubility is only 3 pounds, or 0.2% above the 1500 pound test load.

No additional precipitate was added to the test loop to represent the pool temperature dropping below 140°F. As discussed above, the as-tested chemical debris mass was essentially the same as that predicted to form when AlOOH solubility is not credited. Furthermore, at the minimum pre-accident containment pressure of -0.8 psig, water less than 209°F is subcooled. The improvement in NPSH margin due to subcooling is slightly offset by the increased head loss through the screens due to the viscosity change in the water with temperature. However, the net improvement is over 24 feet when the sump cools to 140°F. Improvement in NPSH margin due to lower water temperature will more than offset a small increase in debris loading and head loss due to precipitation of AlOOH at temperatures below 140°F.

NRC Request 21:

Please provide the basis for why the chemical effects evaluation remains conservative when crediting aluminum inhibition by silica and AlOOH solubility.

Response:

WCAP-16785-NP, Section 2.0, states, "In order to estimate the degree of conservatism in the generic model, the test conditions used during the individual Integrated Chemical Effects Tests (ICET) program runs (Reference 2.3-4) were used as inputs to the WCAP-16530-NP chemical model, and a comparison of the model predictions to the ICET results was performed. This evaluation demonstrated that under some test conditions the chemical model provides a high degree of conservatism for aluminum corrosion. The results indicate that the high degree of conservatism may be a result of the inhibition of aluminum corrosion by the presence of silicates...

"...Currently the WCAP-16530-NP model assumes that 100% of the available aluminum forms precipitates and 100% of the available calcium forms precipitates if phosphate is present. In reality, solubility limits dictate the quantity of species remaining in solution. Consequently, some fraction of the dissolved species may not actually form precipitates as conservatively assumed, but may remain in solution."

Aluminum inhibition by the presence of silicates is a documented phenomenon that will reduce the quantity of dissolved aluminum in the post-LOCA pool, as noted above. Crediting this is reasonable when implemented in a conservative manner.

To add conservatism to the WCAP-16785-NP proposed methodology, the suggested aluminum release reduction factor of two was assumed to occur between 75 and 100 ppm Si instead of between 50 and 75 ppm as suggested in the WCAP. This reduction factor is only applied in the pH range of 7 to 9 and below 200°F. Outside of this range, the original aluminum release rate equation (from WCAP-16530-NP) was used.

Rather than implement the silicate inhibition limit with the revised aluminum release rate equation from WCAP-16785-NP at 75 ppm, the silicate inhibition limit on submerged aluminum was conservatively raised to 100 ppm. The refined aluminum release rate equation is only applied in the pH range of 6.5 to 11 and below 200°F. Outside of this range, the original aluminum release rate equation (from WCAP-16530-NP) was used.

Both of these refinements (aluminum release reduction factor of 2 between 75-100 ppm Si and revised release equation above 100 ppm Si) were applied to submerged aluminum only. No credit was taken for silicate inhibition of un-submerged aluminum. The silica released from fiberglass was assumed not to contribute to the corrosion inhibition of aluminum; instead, only silicates from Cal-Sil were used to inhibit aluminum corrosion. This restricted the quantity of inhibition that could occur by further reducing the silica concentration. Therefore, conservatism was added to the WCAP-16785-NP silica inhibition refinements through the following: Increased concentration threshold value for crediting silicate inhibition, reduction of the scope of aluminum applied to only those amounts determined to be submerged, and reduction in the scope of silica, which was used to trigger the implementation.

The estimation of chemical precipitate amount remains conservative because of assumptions remaining in the WCAP-16530-NP model, such as the assumption that aluminum that goes into solution forms a precipitate. In addition, conservatism was added back to the WCAP-16785-NP revisions in the form of increasing the recommended concentration threshold value for crediting silicate inhibition, and no credit was taken for silicate inhibition on un-submerged surfaces. The HBRSEP, Unit No. 2, prediction assumes that the silica derived from fiberglass is available for the formation of precipitates, but not available to inhibit corrosion of aluminum.

The spreadsheet model allowed for crediting solubility of aluminum oxyhydroxide. A comparison using a spreadsheet evaluation with that enhancement removed shows that 26 pounds of aluminum oxyhydroxide was predicted to form. This represents 1.7% of the total of 1,503 pounds predicted and only 0.2% above the tested debris load of 1,500 pounds. Testing showed the head loss was relatively insensitive to changes in the chemical debris load at elevated loads. The last three chemical debris adds did not increase the overall head loss. Therefore, the overall chemical effects evaluation remains conservative.

NRC Request 22:

Please provide additional information regarding the likelihood of blockage at the refueling canal drain and the potential adverse consequences of blockage at this drain.

The supplemental response states that a trash rack will not be installed around the refueling canal drain because (1) sufficient water would reach the containment floor during a large-break LOCA to initiate recirculation, and (2) blockage was considered by the licensee to be unlikely. However, the staff generally does not consider blockage of a 3-inch drain to be unlikely, since a very small quantity of debris (e.g., a single piece) could be sufficient to result in blockage.

An adequate technical basis was not provided in the supplemental response to support the conclusion that blockage of the refueling canal drain is unlikely at HBRSEP. The staff considers blockage at this drain to be of potential concern because (1) for a large-break LOCA, if the sprays are run in recirculation mode, a large quantity of water may eventually be held up in the refueling canal if the drain is blocked, and (2) for a small-break LOCA, the drain may be credited as passing flow during the injection phase of the LOCA.

Response:

Although blockage is considered to be unlikely, no credit was taken for the refueling canal drain for a large break LOCA, because there is no trash rack at that location. Containment water level used in the evaluation assumed blockage at the refueling canal drain. With this blockage, sufficient water would reach the containment floor during a large break LOCA to initiate recirculation.

For a small break LOCA, no blockage of the drain was assumed based on the minimal debris generated during a small break LOCA and the restricted access from the pump bays to the upper level of containment as discussed in the response to NRC Request 1. The water level for a small break LOCA results from a break in the pressurizer spray line, a break in the RCS loop piping, or a break in the attached RCS piping. The quantity of debris generated for these breaks is so small that is not practical to expect that the refueling canal drain would become blocked. The minimum water level calculation does evaluate holdup in the canal due to the head required to drive flow from the refueling canal at a rate to match containment spray flow.

NRC Request 23:

The supplemental response states that the licensee did not consider trash racks necessary for floor drains at the depressions below the steam generator platforms, and it notes that 2 of the 3 drains are credited with passing flow post-LOCA. Given the proximity of these drains to the reactor coolant system and the apparent potential for debris to accumulate at these drains via blowdown and/or washdown, the basis for crediting flow through these drains is unclear.

To support the conclusion that the drains would not become blocked following a LOCA, please provide the following information: (1) the diameter of the floor drains, (2) a description of any cover grating installed over the drains, (3) the basis for considering blockage at 2 of the 3 drains unlikely, and (4) a description of any potential adverse consequences that would occur if all 3 drains became blocked following a LOCA.

Response:

1. The floor drains are 3 inches in diameter.

2. The drain openings have typical commercial floor drain grates over them.

3. The RCP bays are compartmentalized and remote from each other. The other two cavities are far removed from the LOCA site and isolated from the surrounding water by surrounding floor mat elevation which is higher than the minimum flood elevation by 1.5 feet.

4. If the three drains were to clog, an additional 200 cubic feet of water could be retained. Water level and volume have the following correlation: 8,698.8 cubic feet/feet. The additional retention would therefore lower the minimum water level by 0.02 feet. The lower water level may delay initiation of recirculation by 24 seconds as an additional 200 cubic feet is injected into containment. Even if recirculation were to start with the water level 0.02 feet lower, the difference is less than the minimum pump NPSH margin, so there would be no adverse affects on the pumps.

NRC Request 24:

The supplemental response states that debris blockage would not occur at the 2 feet wide openings in the crane wall where steel bars have been installed in place of the previous coarse mesh screens.

Please provide the following information in support of this conclusion: (1) the number of openings, (2) the height of the openings and their elevation above the containment floor, (3) the size of the openings between the steel bars, and (4) the basis for considering blockage at these openings to be unlikely.

Response:

1. There are 17 openings.

2. The openings are 2 feet high. The bottom of the openings are at floor level. The tops are at 2 feet above the floor.

3. The openings between the bars are nominally 6 and 3/8 inches.

4. Blockage of the openings is considered unlikely because the openings are large at 24 inches by 6 and 3/8 inches, and there are a relatively large number of them.

NRC Request 25:

The NRC staff considers in-vessel downstream effects to be not fully addressed at HBRSEP as well as at other PWRs. HBRSEP's March 7, 2008, GL 2004-02 submittal refers to draft WCAP-16793-NP. The NRC staff has not issued a final SE for WCAP-16793-NP, nor is the staff aware that satisfactory testing for a problem bed of debris at the core inlet has been performed for HBRSEP plant conditions and fuel type.

The licensee may demonstrate that in-vessel downstream effects issues are resolved for HBRSEP by verifying that the plant conditions are bounded by the final WCAP-16793-NP and the corresponding final NRC staff SE (not yet issued), and by addressing the conditions and limitations in the final SE. The licensee may also resolve this item by demonstrating, without reference to WCAP-16793 or the NRC staff SE, that in-vessel downstream effects have been appropriately addressed at HBRSEP.

Response:

It will be verified that HBRSEP, Unit No. 2, plant conditions are bounded by the final WCAP-16793-NP and the corresponding final NRC staff SE, and by addressing the conditions and limitations in the final SE.

Additional Information Pertaining to NPSH Margins:

Subsequent to the supplemental response submittal, the NPSH calculation was revised to incorporate the strainer and debris head loss including chemical effects. As a result, the residual NPSH margin increased from 0.1 feet, (based on subtracting the clean screen plus chemical/debris head loss from the NPSH margin without screens) to 0.3 feet. This was due to the screen resistance in the system flow path causing a small reduction in flow (3,794 gpm vs. 3,820 gpm) with a corresponding reduction in NPSH required.

Benchtop Testing Results

Subsequent to the supplemental response submittal, benchtop testing was performed to determine the time line for chemical precipitate formation in the HBRSEP, Unit No. 2, sump. The testing simulated the debris mix, temperature, chemistry, pH, and exposed materials, e.g., aluminum (aluminum was conservatively increased in one of the tests above the design value by 20%), of the HBRSEP, Unit No. 2, sump over a period of 72 hours. Inspection of the water and debris utilized Inductively Coupled Plasma-Atomic Emission Spectrometry and Scanning Electron Microscopy analysis and indicated that chemical precipitates will not form in the HBRSEP, Unit No. 2, sump in less than 72 hours. Existing analyses assume that chemical precipitates completely form at time zero.

Excluding the head loss attributable to chemical precipitates decreases the debris-laden screen head loss at design conditions by 1.7 feet (that is, 3.51 feet with chemical precipitates as compared to 1.80 feet without chemical precipitates) and increases residual NPSH margin 1.7 feet from 0.3 feet to 2.0 feet. The margin will be maintained as long as the sump water vapor pressure decreases by more than 0.7 psi (1.7 feet) below the minimum allowable pre-accident containment pressure before the chemical debris forms. The water temperature corresponding to a 0.7 psi drop in vapor pressure below the minimum allowable pre-accident containment pressure (-0.8 psig) is 206°F at 13.2 psia.

Based on the containment analysis, which is biased to maximize containment pressure and temperature, the sump water will cool to below 200°F after approximately 8.3 hours. As stated, testing shows that chemical precipitates will not form in less than 72 hours. Based on the substantial margin between chemical formation in more than 72 hours and pool cooling in 8 hours, it is reasonable to conclude a minimum residual NPSH margin of 2.0 feet will be maintained assuming chemical precipitates form at time zero.

The NPSH margin calculation was based on head loss measured during prototype testing and adjusted for temperature. To address concerns raised in NRC Request 14 regarding debris bed shifting as a result of the higher test differential head and the validity of temperature adjustments to the measured head loss, the effect of not crediting temperature adjustment was also considered.

Prototype maximum measured head loss was 10.1 feet, or 6.59 feet (2.7 psi) more than the design, temperature-adjusted head loss (3.51 feet). The adverse effect of increased head loss due to chemical debris on NPSH margin will be ameliorated by a decrease in the sump water vapor pressure of at least 2.7 psi below the minimum pre-accident containment pressure of 13.9 psia, or 11.2 psia. The saturation temperature at 11.2 psia is 199°F. The sump is predicted to cool to 189°F in 11.1 hours based on containment analysis and to less than 183°F after 72 hours. At 189°F, the vapor pressure is 9.2 psia, which offsets with margin the uncompensated peak prototype measured head loss by 2.0 psi (4.8 feet). At 183°F, the vapor pressure is 8.0 psia, which will more than offset the uncompensated peak prototype measured head loss by 3.2 psi (7.6 feet).

Based on the above, the minimum expected residual NPSH margin is 2 feet. Residual NPSH margin will be greater than 4.8 feet after 11 hours and greater than 7.6 feet after 72 hours, even if the chemical effects head loss reaches the prototype measured peak head loss without temperature adjustment (10.1 feet) when chemical precipitates form. Chemical precipitates are not expected to form in less than 72 hours.

Dry Air Partial Pressure

Inherent in the calculation methodology used to determine NPSH is conservatism from not crediting the presence of air in containment prior to the accident. The standard methodology assumes the sump water is at saturation temperature corresponding to the minimum pre-accident containment pressure. A more realistic but still conservative approach is identified in NEI 04-07, Section 6.4.7.1, based on the law of partial pressures. Section 6.4.7.1 states it is reasonable to assume that the total pressure in containment is the sum of the partial pressure of water vapor corresponding to the sump saturation pressure, and the dry air partial pressure which remains constant at the pre-accident value. The dry air pressure prior to the event is to be calculated assuming 100% relative humidity at a containment temperature corresponding to the maximum normal operational temperature experienced at the plant. The recognition of the pre-event air pressure acknowledges the thermal-hydraulic condition of containment prior to the event without crediting containment overpressure based on the accident scenarios.

Based on an assumed initial containment temperature of 130°F (120°F is the maximum allowed by the Technical Specifications) and a pressure of -1.0 psig (-0.8 psig is the minimum allowed), the minimum dry air partial pressure prior to the event is 11.5 psia. Following the accident, as the containment atmosphere increases in temperature, the air partial pressure will also increase. The air volume is also compressed as it is displaced by the water spilled and injected into containment following the accident. The resulting increase in air partial pressure due to the temperature increase and volume decrease is conservatively discounted.

Another conservative assessment of air pressure can be made by assuming the minimum containment pressure of -3.0 psig (11.7 psia) based on inadvertent containment spray actuation at a temperature of 45°F and no heat input from a LOCA. At 45°F, the vapor pressure of water is 0.14 psia. The minimum partial pressure of dry air in containment is therefore 11.5 psia (11.7 – 0.15 psia).

Conservatively assuming a sump water temperature of 32°F, sump water density would be 62.4 pounds/cubic feet or 0.43 psi/foot, and the minimum partial pressure of air represents a minimum hydrostatic head of 26.7 feet. An additional margin of 26 feet obtained by crediting the minimum partial pressure of air provides substantial additional margin to the design residual NPSH margin of 0.3 feet.

The conservatism in the calculation methodology, as demonstrated here, shows that the maximum measured screen head loss without temperature adjustment provides a margin of more than a factor of two. Actual margin is expected to be greater because the additional head loss from the screens will reduce system flow, thereby decreasing NPSH required.