Progress Energy

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FEB 28 2008

Serial: HNP-08-015
10 CFR 50.54(f)

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

SHEARON HARRIS NUCLEAR POWER PLANT, UNIT NO. 1
DOCKET NO. 50-400/LICENSE NO. NPF-63

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

References:
1. Generic Letter 2004-02, "Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized-Water Reactors," dated September 13, 2004

2. Letter from J. Scarola, to the Nuclear Regulatory Commission (Serial: HNP-05-101), "Response to NRC Generic Letter 2004-02, 'Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized-Water Reactors,'" dated September 01, 2005

3. Letter from W. H. Ruland, Nuclear Regulatory Commission to A. Pietrangelo, Nuclear Energy Institute, "Revised Content Guide for Generic Letter 2004-02 Supplemental Responses," dated November 21, 2007

4. Letter from W. H. Ruland, Nuclear Regulatory Commission to A. Pietrangelo, Nuclear Energy Institute, "Supplemental Licensee Responses to Generic Letter 2004-02, 'Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized-Water Reactors,'" dated November 30, 2007

5. Letter from T. H. Boyce, Nuclear Regulatory Commission to R. J. Duncan II, "Shearon Harris Nuclear Power Plant, Unit 1 – Generic Letter 2004-02, 'Potential Impact of Debris Blockage on Emergency Recirculation During Design-Basis Accidents at Pressurized-Water Reactors,' Extension Request Evaluation (TAC NO. MC4688)" dated December 28, 2007

Ladies and Gentlemen:

NRC Generic Letter (GL) 2004-02 (Reference 1), issued September 13, 2004, requests that addressees perform an evaluation of the emergency core cooling system (ECCS) and containment

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spray system (CSS) recirculation functions in light of the information provided in the GL and, if appropriate, take additional actions to ensure system function. Carolina Power & Light Company (CP&L) doing business as Progress Energy Carolinas, Inc., provided Harris Nuclear Plant's (HNP) written response to the NRC in accordance with 10 CFR 50.54(f) on September 01, 2005 (Reference 2).

Harris Nuclear Plant has completed its modification to the containment sump. The new sump strainer is installed, debris generation and transport analyses performed, and strainer head loss and chemical testing completed. However, HNP's internal reviews have not been finalized to allow submission of the final results to the NRC by the February 29, 2008, due date as required per NRC's guidance dated November 30, 2007 (Reference 4). Therefore, HNP requested, and was granted by the NRC, an extension until March 31, 2008, for submittal of these remaining internal reviews (Reference 5).

Accordingly, the attached submittal is HNP's supplemental response to GL 2004-02, containing all information presently available to HNP. This response is being submitted in accordance with the NRC's approved content guide for supplemental responses (Reference 3). The remaining items (that is, those not available to support this current submission) will be provided by March 31, 2008, as previously authorized (Reference 5).

This document contains no new regulatory commitment.

Please refer any questions regarding this submittal to Mr. Dave Corlett at (919) 362-3137.

I declare, under penalty of perjury, that the foregoing is true and correct
Executed on [ FEB 2 8 2008.

Sincerely,

R. J. Duncan, II
Vice President
Harris Nuclear Plant

RJD/kms

Attachments: 1. Supplemental Response Technical Input
2. Associated Drawings

cc: Mr. P. B. O'Bryan, NRC Sr. Resident Inspector
Mr. V. M. McCree, NRC Acting Regional Administrator, Region II
Ms. M. G. Vaaler, NRC Project Manager

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**Executive Summary**

Harris Nuclear Plant (HNP) has confidence that it has fully addressed Generic Safety Issue 191 (GSI-191). The main focus of HNP's effort to address GSI-191 was the installation of new recirculation sump screens. Whereas the old screens were 398 $ft^2$ per train, the new screens are 3,001 $ft^2$/train. Additionally, the perforations of the new screens are more restrictive than those of the old screens (3/32" in diameter for the new screens vs. 1/8" diameter for the old screens). The new screens would be fully submerged under all Loss of Coolant Accident (LOCA) conditions.

The adequacy of the replacement sump screens with respect to head loss were validated through prototypical testing; this testing included chemical precipitates in the debris mix. The predicted quantities of chemical precipitates were determined using the methodology of WCAP-16530-NP, "Evaluation of Post-Accident Chemical Effects in Containment Sump Fluids to Support GSI-191," revision 0. No refinements were made to this model (e.g., no credit was taken for any inhibition of aluminum corrosion).

HNP also reduced the source term of Min-K insulation by reinforcing Min-K cassettes with banding. This banding was validated by testing to reduce the zone of influence (ZOI) for the cassettes.

HNP also implemented programmatic controls to restrict the quantities of fibrous insulation that could be added to the containment building as well as to eliminate the use of deficiency tags in the containment building.

Downstream-effects evaluations were based on the guidance of WCAP-16406-NP, "Evaluation of Downstream Sump Debris Effects in Support of GSI-191," revision 1.

The vessel internals and fuel were evaluated to assure that the evaluations in WCAP-16793-P, "Evaluation of Long-Term Cooling Considering Particulate, Fibrous and Chemical Debris in the Recirculating Fluid," revision 0, are representative of HNP. These evaluations, including use of the LOCADM model developed by Westinghouse, determined the peak fuel temperature during recirculation to be well below the long term core cooling acceptance criterion of 800°F.

There are several conservatisms in the effort to fully resolve GSI-191. Some of the more significant conservatisms include:

- No credit is taken for containment pressure, except for pressure necessary to maintain the fluid in its liquid phase (i.e., liquid vapor pressure) for meeting the net positive suction head (NPSH) requirements of the containment spray pumps and the residual heat removal (RHR) pumps.

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- Although two of the three limiting breaks at HNP are smaller than a design-basis large-break loss-of-coolant accident (LBLOCA), the RHR flowrate for a LBLOCA was conservatively used. One of these postulated breaks is at the reactor vessel nozzle, and the analyzed break area for this break is 150 square inches. The other postulated break is on a pressurizer safety valve line, which is six inches in diameter. The higher flowrate used in the evaluations results in a higher than expected head loss.
- HNP has procedural guidance to secure containment spray when containment pressure drops below 8 psig. The containment analysis shows that containment pressure will drop below 8 psig in approximately 24 hours. Once containment spray is secured, the flowrate through the recirculation sump screens will drop, thereby reducing the head loss across the debris bed. Also, the velocity of water in the sump pool will decrease, and the sump pool will not have spray impinging on the pool surface, thereby promoting the settling of debris in the sump pool. No credit was taken for reduced flowrates or velocities resulting from the securing of containment spray.
- Most of the procedural changes made in response to NRC Bulletin 2003-01 have been made permanent.

## 1. Overall Compliance

*Provide information requested in GL 2004-02 Requested Information Item 2(a) regarding compliance with regulations.*

> *GL 2004-02 Requested Information Item 2(a)*
> *Confirmation that the ECCS and CSS recirculation functions under debris loading conditions are or will be in compliance with the regulatory requirements listed in the Applicable Regulatory Requirements section of this GL. This submittal should address the configuration of the plant that will exist once all modifications required for regulatory compliance have been made and this licensing basis was updated to reflect the results of the analysis described above.*

HNP response:

Harris Nuclear Plant (HNP) is in compliance with the regulatory requirements listed in the Applicable Regulatory Requirements section of Generic Letter (GL) 2004-02. Compliance with the applicable regulatory requirements has been achieved through analysis, plant-specific testing, mechanistic evaluations, installation of new and larger containment recirculation sump screens, reinforcement of Min-K insulation cassettes, and programmatic and process changes to ensure continued compliance. The analysis methodology used for demonstrating compliance is that described in Nuclear Energy Institute (NEI) 04-07, Volume 1, "Pressurized Water Reactor Sump Performance Methodology," and NEI 04-07, Volume 2, "Safety Evaluation by the Office of

Nuclear Reactor Regulation Related to NRC Generic Letter 2004-02," revision 0, (SE) dated December 2004.

The configuration of the plant is discussed below. The licensing basis has been updated, consistent with 10 CFR 50.71(e), to reflect the actions taken in response to GL 2004-02.

## 2. General Description of and Schedule for Corrective Actions:

*Provide a general description of actions taken or planned, and dates for each. For actions planned beyond December 31, 2007, reference approved extension requests or explain how regulatory requirements will be met as per* <u>*Requested Information*</u> *Item 2(b).*

> <u>*GL 2004-02 Requested Information Item 2(b)*</u>
> *A general description of and implementation schedule for all corrective actions, including any plant modifications, that you identified while responding to this GL. Efforts to implement the identified actions should be initiated no later than the first refueling outage starting after April 1, 2006. All actions should be completed by December 31, 2007. Provide justification for not implementing the identified actions during the first refueling outage starting after April 1, 2006. If all corrective actions will not be completed by December 31, 2007, describe how the regulatory requirements discussed in the Applicable Regulatory Requirements section will be met until the corrective actions are completed.*

<u>HNP response</u>:

HNP has taken the following actions to address GSI-191.

- <u>Replacement of the recirculation sump screens</u>. During RFO14 (fall of 2007), HNP replaced the recirculation sump screens. The replacement sump screens provide approximately 3,000 square feet of straining area per sump and are of the "top-hat" design. The top hats sit vertically on a framework that is located near the bottom of the sump pit. The original design included vortex suppressors above the pump suctions in the sump pits; the new design includes vortex suppressors above the top hats. The existing trash racks were modified by cutting off the bottom foot so as to allow flow even if the smaller openings become blocked. The bottom foot is protected by an 18-inch tall curb. The framework, top hats, and vortex suppressor are all fabricated of austenitic stainless steel. This action was previously communicated to the NRC as a planned action in the September 01, 2005, submittal.
- <u>Installation of a trash rack in the refueling canal drain</u>. During RFO14 (fall of 2007), HNP installed a trash rack in the refueling canal drain. This trash rack is removable such

that it can be removed prior to refueling operations and reinstalled following completion of refueling operations. This trash rack is fabricated of austenitic stainless steel. This action was previously communicated to the NRC as a planned action in the September 01, 2005, submittal.

- Reinforcement of insulation cassettes containing Min-K. HNP had previously told the NRC in the September 01, 2005, submittal that it planned to remove the insulation cassettes from containment and replace them with a different type of insulation. All of these cassettes are on safety-relief valve (SRV) loop seals and power-operated valve (PORV) water seals in the pressurizer cubicle. HNP did not remove the Min-K from containment; instead, HNP reinforced the cassettes with stainless-steel banding such that a break in one of the SRV lines would not affect all of the Min-K insulation in the pressurizer cubicle.
- Removal of aluminum fire extinguishers from containment. In 2003, HNP discovered that the fire extinguishers in containment were made of aluminum. These fire extinguishers were subsequently removed from containment during power operations; this action was completed in RFO14 (fall of 2007).
- Removal of plastic signage from containment. During RFO14 (fall of 2007), HNP removed most of the plastic signage from containment. These signs and labels were operator aids for locating components. In some cases, the components had redundant stainless-steel tags that were left on the components. In some other cases, the plastic signs were replaced with porcelainized metal tags. In other cases, the plastic signs were replaced with stenciling.
- Revised the modification procedure. The corporate modification procedure, EGR-NGGC-0005, has been revised to add screening questions regarding insulation and aluminum-containing material in containment as well as regarding flow paths that water would take during the recirculation phase of an accident.
- Revised the deficiency tag procedure. The site deficiency tags are paper tags and represent a potential source of debris. The site deficiency tag procedure, AP-038, was revised to specifically prohibit the use of deficiency tags in containment.
- Revised the containment closeout procedure. The site containment closeout procedure, OST-1081, was revised to provide a definition of latent debris, acceptance criteria for latent debris, and specific steps to assure that any latent debris in containment is within the acceptance criteria. Although HNP has determined that the quantity of latent debris in containment is significantly less than that assumed in the debris generation calculation, HNP elected to place a control on the latent debris that may be generated inside containment.

No other corrective actions are planned by HNP.

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## 3. Specific Information Regarding Methodology for Demonstrating Compliance:

### a. Break Selection

*The objective of the break selection process is to identify the break size and location that present the greatest challenge to post-accident sump performance.*

- *Describe and provide the basis for the break selection criteria used in the evaluation.*
- *State whether secondary line breaks were considered in the evaluation (e.g., main steam and feedwater lines) and briefly explain why or why not.*
- *Discuss the basis for reaching the conclusion that the break size(s) and locations chosen present the greatest challenge to post-accident sump performance.*

HNP response:

HNP evaluated a number of break locations and piping systems and considered breaks that rely on recirculation to mitigate the event. The following break location criteria were considered:

Break Criterion No. 1 – Breaks in the reactor coolant system (RCS) with the largest potential for debris;
Break Criterion No. 2 – Large breaks with two or more different types of debris;
Break Criterion No. 3 – Breaks with the most direct path to the sump;
Break Criterion No. 4 – Large breaks with the largest potential particulate debris to insulation ratio by weight; and
Break Criterion No. 5 – Breaks that generate a "thin bed" – high particulate with a 1/8" thick fiber bed.

This spectrum of breaks is consistent with that recommended in the NRC Safety Evaluation (SE) and is also consistent with regulatory position 1.3.2.3 of Regulatory Guide 1.82, "Water Sources for Long-Term Recirculation Cooling Following a Loss-of-Coolant Accident", revision 3.

HNP considered breaks in the primary coolant system piping having the potential for reliance on Emergency Core Cooling System (ECCS) sump recirculation. The review determined that a primary coolant system piping large-break loss-of-coolant accident (LBLOCA) and certain primary coolant system piping small break LOCAs (SBLOCAs) would require ECCS sump recirculation. HNP considered other high-energy line breaks (e.g., secondary side breaks) and determined that sump recirculation was not required.

For small breaks, only piping that is two inches in diameter and larger was considered. This is consistent with section 3.3.4.1 of the SE, which states that breaks less than two inches in diameter need not be considered. Section 3.3.5 of the SE describes a systematic licensee approach to the break-selection process that includes beginning the evaluation at an initial location along a pipe and stepping along in equal increments (five-foot increments per the SE), considering breaks at each sequential location. However, because of the size of the ZOI applied in the analyses and the consequent volume of debris generated, HNP determined it was not necessary to evaluate five-foot increments.

The evaluation identified break locations that provided limiting conditions for each of the five break selection criteria above. For break criterion no. 1, six possible break locations were identified: at the crossover-leg nozzle at the steam generator and the mid-point of the crossover leg on each of the three loops of the RCS. The results of the evaluation of insulation debris generation for break criterion no. 1 determined that a break at the crossover-leg nozzle at the steam generator on RCS loop B would generate the largest quantity of insulation debris.

It was determined that the debris generated by the limiting case for break criterion no. 1 bounds the debris generated for break criterion no. 2, "large breaks with two or more different types of debris," as multiple types of insulation debris are generated by this break.

For break criterion no. 3, "breaks with the most direct path to the sump," the evaluation notes that the only piping subject to a LOCA outside of the secondary shield wall (where the ECCS sumps are located) is the piping to and from the letdown heat exchangers. The heat exchangers are surrounded by barriers that would prevent free expansion, and only RMI is installed on the piping in this area. Thus, the limiting break for break criterion no. 1 bounds the debris generated for break criterion no. 3.

For break criterion no. 4, "large breaks with the largest potential particulate debris to insulation ratio by weight," the evaluation concluded that two postulated break locations yield limiting values of the potential particulate debris to insulation ratio. The first break is a break at a reactor hot-leg nozzle. This break would involve RMI, Microtherm, and Temp-Mat. The second break is a break on one of the 6" lines upstream of a pressurizer safety relief valve. This break would involve RMI and Min-K.

For break criterion no. 5, "breaks that generate a thin bed," the evaluation did not identify a specific break location that would lead to a thin bed. Rather, the evaluation states that the thin-bed effect will be specifically postulated and addressed in the head-loss calculation. This calculation includes the head-loss test results for a thin-bed case.

In summary, HNP determined that a postulated LBLOCA on RCS loop B at the steam generator crossover-leg nozzle yields the limiting amount of debris. A break at the reactor vessel hot-leg nozzle generates a large amount of RMI, Microtherm, and Temp-Mat debris. A break on a pressurizer safety line generates a large amount of RMI and Min-K debris. The thin-bed break is specifically postulated and accounted for through testing. It was concluded that these reactor coolant system breaks generate the largest amount of debris, and also the worst combination of debris with the possibility of being transported to the ECCS sumps.

The FSAR description of the accident analysis for a Main Steam Line Break (MSLB) states, in part, that "[t]he removal of decay heat in the long term (following the initial cooldown) using the remaining intact Steam Generators (SG) requires only the auxiliary feedwater system as a water source and the secondary system safety valves to remove steam." Based on this description, it can be inferred that the intact SGs are available for heat removal, as both the aforementioned system, structure and components (SSCs) are safety-related and have redundant components. With decay heat removal controlled by steaming of the intact SGs, ECCS recirculation is not necessary to maintain long-term decay heat removal in this event.

Table 15.2.8-4 of the FSAR provides a sequence of events following a feed water line break (FWLB) that shows initiation of plant cooldown by use of the main steam safety valves on the intact SG. Although this scenario may lead to momentary opening of the pressurizer safety relief valves, they would reseat quickly, precluding any significant loss of RCS inventory. Thus, with decay heat removal controlled by steaming of the intact SG, ECCS recirculation is not necessary to maintain long-term decay heat removal in this event. The containment analysis shows that the energy release for a feedwater line break is bounded by the analyses for a MSLB. Therefore, containment spray recirculation is not necessary for containment heat removal in this event.

All phases of the plant-specific accident scenarios were evaluated to develop debris generation values for the breaks listed in the previous summary paragraph. These accident scenario cases are:

1. Case 1: RCS break on loop B crossover leg at the SG (limiting break for break criteria 1,2,3)
2. Case 2: RCS break near reactor vessel nozzle (limiting break for break criterion 4)
3. Case 3: Break on a 6" pressurizer safety line (limiting break for break criterion 4)

**b. Debris Generation/Zone of Influence (ZOI) (excluding coatings)**

*The objective of the debris generation/ZOI process is to determine, for each postulated break location: (1) the zone within which the break jet forces would be sufficient to damage materials and create debris; and (2) the amount of debris generated by the break jet forces.*

- *Describe the methodology used to determine the ZOIs for generating debris. Identify which debris analyses used approved methodology default values. For debris with ZOIs not defined in the guidance report/SE, or if using other than default values, discuss method(s) used to determine ZOI and the basis for each.*
- *Provide destruction ZOIs and the basis for the ZOIs for each applicable debris constituent.*

- *Identify if destruction testing was conducted to determine ZOIs. If such testing has not been previously submitted to the NRC for review or information, describe the test procedure and results with reference to the test report(s).*
- *Provide the quantity of each debris type generated for each break location evaluated. If more than four break locations were evaluated, provide data only for the most limiting locations.*
- *Provide total surface area of all signs, placards, tags, tape, and similar miscellaneous materials in containment.*

HNP response:

HNP applied the ZOI refinement discussed in section 4.2.2.1.1 of the SE, which allows the use of debris-specific spherical zones of influence (ZOIs). Using this approach, the amount of debris generated within each ZOI is calculated, and the individual contributions from each debris type are summed to arrive at a total debris source term.

The sources of debris at HNP include insulation debris, coatings debris, and latent debris. The evaluation concludes that there are six types of insulation inside the containment building that could potentially form debris following a LOCA. These insulation species are: 1) RMI, 2) Nukon, 3) Thermal-Wrap, 4) Microtherm, 5) Temp-Mat, and 6) Min-K. The ZOI of each species of insulation is discussed below.

RMI: Consistent with Table 3-2 of the NRC safety evaluation (SE) of NEI 04-07, a ZOI of 28.6D is used for Mirror RMI.

Nukon: Consistent with Table 3-2 of the NRC SE of NEI 04-07, a ZOI of 17D is used for Nukon.

Thermal-Wrap: Because Thermal-Wrap and Nukon are both low-density fiberglass insulation species and have similar material properties per table 3-2 of the NEI 04-07 Guidance Report (GR), Thermal-Wrap is assumed to have the same destruction pressure as Nukon. Thus, a ZOI of 17D is also used for Thermal-Wrap.

Microtherm: Because Microtherm and Min-K are both particulate-type insulation species and have similar material properties per Table 3-2 of the GR, Microtherm is assumed to have the same destruction pressure as Min-K from Table 3-2 of the NRC SE. Thus, a ZOI of 28.6D is used for Microtherm. HNP credits destruction of 50% of the Microtherm within this ZOI for the following reasons:

- Sections 6.2.1.2.1 and 6.2.1.2.3 of the FSAR state that the design and licensing basis break inside the reactor cavity is 150 square inches in area. This value does not consider Leak Before Break (LBB). Westinghouse assumed a 150 $in^2$ rupture area when analyzing for asymmetric loads in the reactor cavity. Using this area as the maximum allowable break area, Ebasco designed the reactor vessel hot and cold leg restraints. Using geometric parameters from the restraints, Westinghouse then calculated the actual rupture areas of approximately 32 $in^2$ for the hot leg and 90 $in^2$ for the cold leg. Thus, the actual break areas are even less than that assumed in the analyses.

- The restraints would limit separation of the piping, resulting in a disc-shaped jet instead of a conical or a spherical jet.
- The postulated break in the cavity would be where the RCS piping terminates at the RV nozzle. The plane of the disc-shaped jet is offset from the Microtherm cassettes, which are located adjacent to the outer diameter of the reactor vessel.
- The Microtherm in the cassettes is completely encapsulated by stainless-steel jacketing. These cassettes were fabricated by Transco, and the Transco fabrication specifications call for spot-welding. Table 3-2 of the SE shows that the ZOI for Transco RMI cassettes is 2D, whereas the ZOI for Mirror RMI cassettes is 28.6D. It can be inferred that Transco's cassettes are robust.

Temp-Mat: Consistent with Table 3-2 of the NRC SE of NEI 04-07, a ZOI of 11.7D is used for Temp-Mat. Because Temp-Mat is part of the cassettes containing Microtherm, 50% of the Temp-Mat within the ZOI is assumed to be destroyed using the same justification as for Microtherm.

Min-K: Table 3-1 of NEI 04-07 and the associated NRC SE use a ZOI of 28.6D for Min-K. HNP uses a ZOI of 4D for Min-K. The basis for this ZOI is air-jet testing documented in CDI Report Number 96-06, "Air Jet Impact Testing of Fibrous and Reflective Metallic Insulation," revision A, dated December 1996. This testing showed that the Diamond Power Mirror RMI cassettes with the same thickness of stainless-steel jacketing as the HNP Min-K cassettes (also fabricated by Diamond Power) were not punctured by the air jet at a jet impingement pressure of 105 psig.

Testing of Mirror RMI cassettes with banding performed at jet impingement pressures of 20 psig and 105 psig did not generate any RMI debris. The jet impingement pressure of 105 psig was conservatively reduced to 40 psig, corresponding to a ZOI of 4D per Table 3-1 of the SE. This reduction in jet impingement pressure bounds the 40% reduction in destruction pressure called for in section 3.4.2.2 of the SE when using air-jet testing. Thus, banding similar to that used in the testing was installed on the HNP Min-K cassettes to justify use of a ZOI of 4D.

The quantities of insulation destroyed in a break on the crossover leg at the SG nozzle are given in Table 3b.1.

Table 3b.1

| Insulation Species | Quantity Destroyed ($ft^3$) |
|---|---|
| Mirror RMI | 916.76 |
| Nukon | 51.71 |
| Thermal-Wrap | 553.48 |

The quantities of insulation destroyed in a break at a reactor vessel hot-leg nozzle are given in Table 3b.2.

Table 3b.2

| Insulation Species | Quantity Destroyed ($ft^3$) |
|---|---|
| Mirror RMI | 400.26 |
| Microtherm | 12.18 |
| Temp-Mat | 1.17 |

The quantities of insulation destroyed in a break on a pressurizer safety line are given in Table 3b.3.

Table 3b.3

| Insulation Species | Quantity Destroyed ($ft^3$) |
|---|---|
| Mirror RMI | 391.92 |
| Min-K | 12.32 |

Table 3b.4 gives the following surface areas for miscellaneous materials in containment; these materials have been evaluated as being credible debris sources.

Table 3b.4

| Material Species | Total Surface Area ($ft^2$) |
|---|---|
| Adhesive Labels on Insulation Cassettes | 343.8 |
| Adhesive Labels on HVAC Ductwork | 29.2 |
| Temporary Modification Tags | 0.62 |
| Tape | 2 |

**c. Debris Characteristics**

*The objective of the debris characteristics determination process is to establish a conservative debris characteristics profile for use in determining the transportability of debris and its contribution to head loss.*

- *Provide the assumed size distribution for each type of debris.*

- *Provide bulk densities (i.e., including voids between the fibers/particles) and material densities (i.e., the density of the microscopic fibers/particles themselves) for fibrous and particulate debris.*
- *Provide assumed specific surface areas for fibrous and particulate debris.*
- *Provide the technical basis for any debris characterization assumptions that deviate from NRC-approved guidance.*

HNP response:

The characteristics of each type of debris are as follows.
The size distribution for RMI is given in Table 3c.1. This size distribution is based on testing described in NUREG/CR-6808.

Table 3c.1

| Debris Size (in) | Percentage of Total Insulation |
|---|---|
| ¼ | 4.3% |
| ½ | 20.2% |
| 1 | 20.9% |
| 2 | 25.6% |
| 4 | 16.8% |
| 6 | 12.2% |

The size distribution for low-density fiberglass (LDFG) (i.e., Nukon and Thermal-Wrap) is given in Table 3c.2. This size distribution is based on Appendices II and VI of the SE. It was determined that within the overall ZOI, the size distribution would vary based on the distance of the insulation from the break (i.e., insulation debris generated near the break location would consist of more small pieces than insulation debris generated near the edge of the ZOI).

Table 3c.2

| Size | 18.6 psi ZOI (7.0 L/D) | 10.0-18.6 psi ZOI (11.9-7.0 L/D) | 6.0-10.0 psi ZOI (17.0-11.9 L/D) |
|---|---|---|---|
| Fines (individual fibers) | 20% | 13% | 8% |
| Small Pieces (<6" on a side) | 80% | 54% | 7% |
| Large Pieces (>6" on a side) | 0% | 16% | 41% |
| Intact Blankets | 0% | 17% | 44% |

The size distribution for high-density fiberglass (HDFG) (i.e., Temp-Mat) is given in Table 3c.3. The size distribution is based on Appendices II and VI of the SE. Because Temp-Mat has a higher destruction pressure than LDFG, it was assumed that the breakdown of the fines/small pieces and large pieces/intact blankets can be conservatively estimated in the same way as for

LDFG. This is consistent with section 3.4.3.3.1 of the GR, which assumed that Temp-Mat would have the same size distribution as LDFG.

Table 3c.3

| Size | 45.0 psi ZOI (3.7 L/D) | 10.2-45.0 psi ZOI (11.7-3.7 L/D) |
|---|---|---|
| Fines (individual fibers) | 20% | 7% |
| Small Pieces (<6" on a side) | 80% | 27% |
| Large Pieces (>6" on a side) | 0% | 32% |
| Intact Blankets | 0% | 34% |

For both Microtherm and Min-K, a particle size of 2.5 to 20 microns is used, based on vendor information.

Coatings within the ZOI are assumed to fail as 10-micron diameter particles, consistent with the GR and SE. Unqualified coatings outside the ZOI, except for unqualified epoxy coatings, are assumed to fail as 10-micron diameter particles per the SE.

HNP's September 1, 2005, submittal mentioned two exceptions from the NRC methodology. The first exception is that the Zone of Influence (ZOI) for qualified epoxy coatings has been established as a sphere with a radius of five times the pipe break diameter. The basis for this is the testing documented in WCAP-16568-P, "Jet Impingement Testing to Determine the Zone of Influence (ZOI) for DBA-Qualified/Acceptable Coatings", revision 0, which shows that a ZOI of 5D is conservative with respect to the test results. This WCAP was reviewed for applicability to HNP, and it was determined that WCAP-16568-P is applicable to HNP.

The second exception is that unqualified epoxy coatings outside the ZOI are assumed to fail as chips, with a characteristic size dependent on coating thickness. The basis for this assumption was included in our September 1, 2005, submittal.

HNP also assumes a ZOI for inorganic zinc coatings as a sphere with a radius of five times the pipe break diameter. The basis for this assumption is the same as that for the ZOI for qualified epoxy coatings. This is an exception to the SE, which recommends using a ZOI of ten times the pipe break diameter.

Densities, characteristic size, and other material-specific debris inputs are taken from NEI 04-07 and the associated SE, vendor-specific information, and plant-specific information. These values are summarized in Table 3c.4. Specific surfaces areas are not applicable because HNP determined head loss across the debris bed through prototypical testing and therefore did not use the NUREG-6224 correlation for head loss.

Table 3c.4

| Debris Material | Macroscopic Density (lb/ft$^3$) | Microscopic Density (lb/ft$^3$) | Characteristic Size (microns) |
|---|---|---|---|
| Nukon | 2.4 | 175 | 7 |
| Thermal-Wrap | 2.4 | 175 | 5.5 |
| Temp-Mat | 11.8 | 162 | 9 |
| Microtherm | 15.6 | 187 | 2.5-20 |
| Min-K | 16 | 162 | 2.5-20 |
| Qualified epoxy coatings | N/A | 112 | 10 |
| Qualified zinc primer | N/A | 457 | 10 |
| Unqualified epoxy coatings | N/A | 112 | 21-mil chips |
| Unqualified coatings | N/A | 80 | 10 |
| Carboline 4674 | N/A | 86 | 10 |
| Latent debris (dirt/dust) | N/A | 169 | 17.3 |
| Latent debris (fiber) | 2.4 | 175 | 7 |

**d. Latent Debris**

*The objective of the latent debris evaluation process is to provide a reasonable approximation of the amount and types of latent debris existing within the containment and its potential impact on sump screen head loss.*

- *Provide the methodology used to estimate quantity and composition of latent debris.*
- *Provide the basis for assumptions used in the evaluation.*
- *Provide results of the latent debris evaluation, including amounts of latent debris types and physical data for latent debris as requested for other debris under c. above.*
- *Provide amount of sacrificial strainer surface area allotted to miscellaneous debris.*

HNP response:

The quantity and composition of the latent debris in containment was evaluated by sampling for latent debris considering guidance in NEI 04-07 and the associated SE.

Samples were obtained to determine the mass distribution per unit area of latent debris, referred to as latent debris density (e.g., grams/ft$^2$) of representative surfaces throughout containment.

The highest measured debris density was then applied to all horizontal surface areas inside containment to calculate the total amount of latent debris inside containment.

The latent debris density was estimated by weighing sample bags before and after sampling and dividing the net weight increase by the sampled surface area.

A total of fourteen samples were obtained. The results of the latent-debris calculation conservatively determined the total debris loading on horizontal surfaces in the containment building to be 87.9 lb. Assuming thirty additional pounds of latent debris on vertical surfaces in accordance with section 3.5.2.2 of the SE yields a total of 117.9 lb of latent debris in containment. Therefore, it was elected to use a conservative bounding value of 200 lb for the latent-debris source term in containment.

Visual examination of the debris showed very low fiber content. In lieu of analysis of the samples, conservative values for debris-composition properties were assumed as recommended by NEI 04-07 Volume 2 (the NRC SE). This results in a very conservative estimate of fiber content. The particulate/fiber mix of the latent debris is thereby assumed to be 15% fiber. The latent fiber debris is assumed to have a mean microscopic density of 175 $lbm/ft^3$, and the latent particulate debris is assumed to have a nominal density of 169 $lbm/ft^3$. The latent debris fiber bulk density is assumed to be that of low-density fiberglass (LDFG), which is 2.4 $lbm/ft^3$. The characteristic size of the latent fibers is also assumed to be that of LDFG or approximately 7 microns.

The screen design assumes 100 $ft^2$ of screen area is covered by miscellaneous latent debris (e.g., labels, tags, etc.).

**e. Debris Transport**

*The objective of the debris transport evaluation process is to estimate the fraction of debris that would be transported from debris sources within containment to the sump suction strainers.*

- *Describe the methodology used to analyze debris transport during the blowdown, washdown, pool fill-up, and recirculation phases of an accident.*
- *Provide the technical basis for assumptions and methods used in the analysis that deviate from the approved guidance.*
- *Identify any computational fluid dynamics codes used to compute debris transport fractions during recirculation and summarize the methodology, modeling assumptions, and results.*
- *Provide a summary of, and supporting basis for, any credit taken for debris interceptors.*
- *State whether fine debris was assumed to settle and provide basis for any settling credited.*

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- *Provide the calculated debris transport fractions and the total quantities of each type of debris transported to the strainers.*

HNP response:

The methodology used in the HNP debris-transport analysis is based on the NEI 04-07 GR for refined analyses as modified by the NRC's SE, as well as the refined methodologies suggested by the SE in Appendices III, IV, and VI. The specific effect of each mode of transport was analyzed for each type of debris generated, and a logic tree was developed to determine the total transport to the sump screens. The logic tree used is somewhat different from the baseline logic tree provided in NEI 04-07. This departure was made to account for certain non-conservative assumptions identified by the SE including the transport of large pieces, the erosion of small and large pieces, the potential for washdown debris to enter the pool after inactive areas have been filled, and the direct transport of debris to the sump screens during pool fill-up.

Debris transport is the estimation of the fraction of debris that is transported from debris sources (break location) to the sump screens. The four major debris transport modes are discussed below:

**Blowdown transport**—the vertical and horizontal transport of debris to all areas of containment by the break jet.

A CAD model of containment was developed, and this CAD model was used to estimate the volume of upper containment (the volume above the refueling canal and operating deck) and the volume of lower containment (including the open area inside the steam generator enclosures and the annulus below the operating deck). This model determined that the volume of upper containment is 75% of the total containment volume. The evaluation assumes that fine and small-piece debris is transported by the blowdown flow, and the flow split is proportional to the volumes of upper and lower containment, so 75% of the fines are transported to upper containment. Some of the small-piece debris would be trapped by structures and grating; the evaluation determines that 48% of small fibrous debris is transported by the blowdown to upper containment, based on the results of a drywell debris transport study test. The BWR Utility Resolution Guide (BWR URG) indicates that grating would trap approximately 65% of the small RMI debris blown toward it, so that 26% of the small RMI debris is blown to upper containment.

**Washdown transport**—the vertical (downward) transport of debris by the containment spray and break flows.

The evaluation conservatively assumes that all of the debris (fines and small pieces) blown to upper containment would be washed back down to lower containment, with the exception of any small-piece debris held up on gratings as it is washed down. The evaluation determined the washdown transport fraction of small fibrous debris to the annulus to be 14% based on the percentage of spray flow that flows to the annulus and drywell debris transport study (DDTS) testing showing that floor grating would pass 40-50% of small fibrous debris that is washed down to the grating. Similarly, the washdown transport fraction of small fibrous debris to the steam generator compartments is 16%. The BWR URG indicates that the retention of small RMI debris on gratings is approximately 29%. The evaluation determines the washdown transport fractions for small RMI to the annulus and to the SG compartments to be 28% and 23%, respectively, based on the percentages of spray flow and the BWR URG results. The washdown transport fraction for the refueling canal of 13% is based on the percentage of spray flow landing in the refueling canal, as there is no grating to trap debris.

**Pool fill-up transport**—the transport of debris by break and containment spray flows from the refueling water storage tank (RWST) to regions that may be active or inactive during recirculation.

The evaluation conservatively neglects the potential inactive areas of miscellaneous piping and the area below the elevator shaft. The evaluation considers fine debris to be uniformly distributed in the pool water at the time a volume is filled, so the transport fractions developed in this section apply to fine debris. For breaks outside the reactor cavity, the evaluation determines that the transport fraction of debris carried directly to the sumps during pool fill-up to be 8% to each sump based on the ratio of the volumes of a sump and the pool volume at the level at which the sumps start to fill up. The evaluation uses a similar ratio to determine the transport fraction of debris to the reactor cavity (keyway sump) during fill-up to be 23%. However, in accordance with section 3.6.3 of the SE, this transport fraction is limited to 15%, which is the value used in the subsequent analysis. For breaks inside the reactor cavity (e.g., the hot-leg nozzle break), the keyway sump is considered an active volume instead of an inactive volume. The transport fraction of debris to each recirculation sump is thus 5% due to the larger active pool at the time of sump fill-up.

**Recirculation transport**—the horizontal transport of debris from the active portions of the recirculation pool to the sump screens by the flow through the ECCS and containment spray system.

Computational fluid dynamics (CFD) was used to determine the transport fractions of the debris during recirculation. The CFD code used was Flow-3D Version 9.0 Windows using an Alion-modified subroutine. Flow-3D is configuration-controlled under Alion's quality assurance (QA) program, and Version 9.0, with the modified subroutine, has been validated and verified under the Alion QA program.

All of the latent debris was assumed to be uniformly distributed on the containment floor at the start of recirculation. This is conservative because it does not take into account that some latent debris would be trapped on equipment and structures above the pool level. Unqualified coatings were assumed to be uniformly distributed in the recirculation pool at the start of recirculation. Fine debris in lower containment at the end of blowdown was assumed to be uniformly distributed in the pool at the beginning of recirculation. Fine debris washed down from upper containment was assumed to be in the vicinity of the locations where containment spray water reaches the pool in the annulus, in the steam generator compartments, and at the discharge location of the refueling canal drain. Small and large pieces of debris were assumed to be uniformly distributed between the locations where it would be destroyed and the sump screens, which is conservative because the blowdown and the majority of the pool fill-up phases are multidirectional flows that would tend to distribute debris around containment.

Because HNP has two separate recirculation sumps, three CFD cases were run to investigate the difference in recirculation transport for a break close to a sump, as well as the difference in transport given the maximum flow rates associated with a failure of an entire train versus failure of a RHR pump. The first case evaluated a break in the Loop A piping combined with a failure of the A train. The second case evaluated a break in the Loop B piping combined with a failure of the A train. The third case evaluated a break in the worst case location (determined from the results of the first two cases) combined with a failure of the A RHR pump (which places the B RHR pump into runout, while the A containment spray pump continues to operate).

A rectangular mesh was defined in the CFD model that was fine enough to resolve important features, but not so fine that the simulation would take prohibitively long to run. A six-inch cell length was chosen as the largest cell size that could reasonably resolve the concrete structures that compose the containment floor. For the cells right above the containment floor, the mesh was set to three inches tall in order to closely resolve the vicinity of settled debris. To further define specific objects, node planes were placed at the tops of key structures, including the scuppers in the personnel shield wall and the curbs around the sumps. The total cell count in the model was 627,200, a satisfactory compromise between model run time and model resolution.

The kinetic energy of the containment spray drainage was introduced to the CFD model just below the pool surface. The containment spray drainage was modeled as various regions populated with discrete mass source particles; the appropriate flow rate and velocity was set for the sprays in each of these regions. Because the flow through the reactor cavity drains to the keyway sump, and the associated kinetic energy would be dispersed before reaching the main pool, the kinetic energy of this flow was neglected, but a mass source was added at the floor level above the keyway sump. The flow and kinetic energy from the refueling canal drain was introduced below the drain line discharge. Condensation drainage down the walls was neglected. The break source was situated near the postulated break location, below the surface of the pool. The break stream momentum was accounted for by introducing the break flow to the pool at the velocity a freefalling object would have if it fell the vertical distance from the break to the surface of the pool. The break stream was modeled by defining a flow region populated with mass source particles and setting the flow rate and velocity in a similar manner as the containment spray sources. The sumps were modeled as mass sinks within the boundaries of the sump cavities.

Turbulence was modeled via the renormalized group theory (RNG) model, which was judged to be the most appropriate for this CFD analysis because of the large spectrum of length scales that would likely exist in the containment pool during recirculation. The RNG model applies statistical methods in a derivation of the averaged equations for turbulence quantities. RNG-based turbulence schemes rely less on empirical constants while setting a framework for the derivation of a range of models at different scales. Sensitivity calculation shows that the Flow-3D containment pool calculation utilizing the more sophisticated turbulence models (the RNG model included) gives results that differ significantly from calculations utilizing the less sophisticated models. Differences in results between calculations made with the more sophisticated models have been shown to be slight.

The CFD model was started from a stagnant state at a pool depth of 2.9 ft and run long enough for steady-state conditions to develop. The model was run for a total of five minutes of real time for the first and third cases and four minutes of real time for the second case.

The transport mechanisms for debris in the containment pool are the carrying of suspended debris by bulk flow in the pool, tumbling or sliding of sunken debris along the floor, and lifting of sunken debris over a curb. The metrics used to predict debris transport are the turbulent kinetic energy (TKE) needed to keep debris suspended and the flow velocity necessary to tumble sunken debris along a floor or to lift it over a curb.

Fine material is assumed to be spherical in shape and is assumed to settle per Stokes' Law. This is a reasonable assumption, as the particulate debris is sufficiently small in size that it may be approximated as being generally spherical and would settle slowly within the applicability of Stokes' Law. Settling is credited only where the TKE is insufficient to keep the particulates in suspension, and this generally occurs in regions distant from the recirculation sumps.

The velocity required to tumble epoxy paint chips was analytically determined to be 0.68 ft/s, which is less than the experimental data presented in NUREG/CR-6916, which reports the velocity required to tumble 19-mil thick epoxy paint chips ranges from 0.98 ft/s to 1.42 ft/s. The evaluation conservatively uses 0.68 ft/s.

Credit was taken for the 18" high concrete curbs surrounding the sump structures for stopping RMI debris from being transported to the sumps based on the velocities in the vicinity of the sumps being insufficient to lift the pieces of RMI debris over the curbs. In all cases, the volume of RMI debris that is transported to the curbs is less than the volume of debris that the curbs can conservatively stop. The curbs were conservatively not credited with stopping any other debris, including pieces of fiberglass debris and intact fiberglass blankets.

The following steps were taken to determine the percentage of a particular type of debris that could be expected to transport through the containment pool to the recirculation sump screens.

- Colored contour velocity and TKE maps indicating regions of the pool through which a particular type of debris could be expected to transport were generated from the Flow-3D results in the form of bitmap files.
- The bitmap files were overlaid on the initial debris distribution plots and imported into AutoCAD with the appropriate scaling factor to convert the length scale of the color maps to feet.
- For the uniformly-distributed debris, closed polylines were drawn around the contiguous areas where velocity or TKE was high enough that debris could be carried in suspension or tumbled along the floor to the sump screens.
- The areas within the closed polylines were determined using an AutoCAD querying feature.
- The combined area within the polylines was compared to the debris distribution area.
- The percentage of a particular debris type that would transport to the sump screens was estimated based on the above comparison.

Plots showing the TKE and the velocity magnitude in the pool were generated for each case to determine areas where specific types of debris could be transported. The limits on the plots were set according to the minimum TKE or velocity values necessary to move each type of debris. Overlying yellow areas represent regions where the debris would be tumbled along the floor. The yellow TKE portion of the plots is a three-dimensional representation of the TKE. The velocity portion of the plots represents the velocity magnitude just above the floor level (1.5 inches), where tumbling of sunken debris could occur. Directional flow vectors were also included in the plots to determine whether debris in certain areas would be transported to the sump screens or transported to quieter regions of the pool where it could settle to the floor.

Some types of debris could erode when subjected to the continuing forces of break or spray flows and pool turbulence. Microtherm and Min-K debris are assumed to be 100% fines with no further potential for erosion. Also, stainless-steel RMI is assumed not to break down into smaller pieces following the initial generation at the beginning of the LOCA. Thus, the only insulation debris types with the potential for erosion are the Nukon, Thermal-Wrap, and Temp-Mat fiberglass. The individual fibers would not be subject to further erosion, and by definition, intact blankets are still covered by the original jacketing and therefore would also not be subject to erosion. Appendix III of the SE recommends using a value of 90% debris-eroded value for both small- and large-piece debris to ensure conservatism in the overall transport results. The SE notes that this number can possibly be reduced once better erosion data are available. The HNP evaluation notes that the test data (described in the SE) showed in general that the erosion consisted primarily of small, loosely attached pieces of fiber breaking off from larger pieces. Therefore, it is considered reasonable to assume that erosion would taper off after 24 hours (when loosely-attached small pieces created during blowdown have been depleted). For conservatism, the erosion value at 24 hours is rounded up to 10%, and this erosion fraction was applied to both small and unjacketed large fiberglass pieces in the containment pool. This value of erosion fraction is further supported by the testing documented in ALION-REP-LAB-2352-77, "Erosion Testing of Low Density Fiberglass Insulation", revision 1. This testing shows that the erosion fraction for small-piece LDFG after thirty days with water moving over the fiberglass at 0.12 ft/s was 10%. This velocity is comparable to HNP's bulk pool velocity.

Debris transport fractions and quantities of debris transported to recirculation sump screens for a break on the RCS crossover leg at the SG nozzle:

| Debris Species | Transport Fraction | Quantity Transported to Sump |
|---|---|---|
| Mirror RMI | 11% | 0 $ft^2$ (captured by curb) |
| Nukon | 34% | 18 $ft^3$ |
| Thermal-Wrap | 29% | 160 $ft^3$ |
| Qualified epoxy coatings | 94% | 281 lb |
| Qualified zinc primer | 94% | 277 lb |
| Degraded/unqualified epoxy coatings | 0% | 0 lb |
| Unqualified coatings | 100% | 145 lb |
| Latent debris particles | 77% | 131 lb |
| Latent debris fibers | 73% | 22 lb |

Debris transport fractions and quantities of debris transported to recirculation sump screens for a break on the RV hot leg nozzle:

| Debris Species | Transport Fraction | Quantity Transported to Sump |
|---|---|---|
| Mirror RMI | 11% | 0 $ft^2$ (captured by curb) |
| Temp-Mat | 41% | 0.48 $ft^3$ |
| Microtherm | 99% | 12.1 $ft^3$ |
| Qualified epoxy coatings | 99% | 217 lb |
| Degraded/unqualified epoxy coatings | 0% | 0 lb |
| Unqualified coatings | 100% | 145 lb |
| Carboline 4674 | 99% | 24 lb |
| Latent debris particles | 95% | 162 lb |
| Latent debris fiber | 89% | 27 lb |

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Debris transport fractions and quantities of debris transported to recirculation sump screens for a break on the pressurizer safety line:

| Debris Species | Transport Fraction | Quantity Transported to Sump |
|---|---|---|
| Mirror RMI | 11% | 0 $ft^2$ (captured by curb) |
| Min-K | 94% | 11.6 $ft^3$ |
| Qualified epoxy | 94% | 24 lb |
| Carboline 4674 | 94% | 13 lb |
| Unqualified coatings | 100% | 145 lb |
| Latent debris particulates | 77% | 131 lb |
| Latent debris fiber | 73% | 22 lb |

**f. Head Loss and Vortexing**

*The objectives of the head loss and vortexing evaluations are to calculate head loss across the sump strainer and to evaluate the susceptibility of the strainer to vortex formation.*

- *Provide a schematic diagram of the emergency core cooling system (ECCS) and containment spray systems (CSS).*
- *Provide the minimum submergence of the strainer under small-break loss-of-coolant accident (SBLOCA) and large-break loss-of-coolant accident (LBLOCA) conditions.*
- *Provide a summary of the methodology, assumptions and results of the vortexing evaluation. Provide bases for key assumptions.*
- *Provide a summary of the methodology, assumptions, and results of prototypical head loss testing for the strainer, including chemical effects. Provide bases for key assumptions.*
- *Address the ability of the design to accommodate the maximum volume of debris that is predicted to arrive at the screen.*
- *Address the ability of the screen to resist the formation of a "thin bed" or to accommodate partial thin bed formation.*
- *Provide the basis for the strainer design maximum head loss.*
- *Describe significant margins and conservatisms used in the head loss and vortexing calculations.*
- *Provide a summary of the methodology, assumptions, bases for the assumptions, and results for the clean strainer head loss calculation.*
- *Provide a summary of the methodology, assumptions, bases for the assumptions, and results of the debris head loss analysis.*

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- *State whether the sump is partially submerged or vented (i.e., lacks a complete water seal over its entire surface) for any accident scenarios and describe what failure criteria in addition to loss of net positive suction head (NPSH) margin were applied to address potential inability to pass the required flow through the strainer.*
- *State whether near-field settling was credited for the head-loss testing and, if so, provide a description of the scaling analysis used to justify near-field credit.*
- *State whether temperature/viscosity was used to scale the results of the head loss tests to actual plant conditions. If scaling was used, provide the basis for concluding that boreholes or other differential-pressure induced effects did not affect the morphology of the test debris bed.*
- *State whether containment accident pressure was credited in evaluating whether flashing would occur across the strainer surface, and if so, summarize the methodology used to determine the available containment pressure.*

HNP response:

Schematic diagrams of the ECCS and containment spray system (CSS) are contained in Attachment 2 of this supplemental response.

The tops of the top hats are at elevation 223'-3" (223.25 ft). The minimum containment water level following a SBLOCA is 223.6 ft, and the minimum containment water level following a LBLOCA is 223.9 ft. Thus, the minimum submergence of the strainer under SBLOCA conditions is 0.35 ft, and the minimum submergence of the strainer under LBLOCA conditions is 0.65 ft.

The vortexing evaluation used three different vortexing evaluation methodologies. The first methodology used is that in Regulatory Guide 1.82, revision 3 and NUREG-0897. Using the minimum containment water level of 223.6 ft and the maximum RHR flow of 4,500 gpm, the Froude number for the flow through the RHR suction lines is 0.19, the pipe velocity is 2.88 ft/s, and the minimum submergence of the RHR suction line is 6.91 ft. The RHR lines, which are more limiting than the CSS lines, meet the RG 1.82/NUREG-0897 criteria for Froude number and intake velocity but not submergence. Therefore, zero air ingestion cannot be ensured using these criteria.

The second methodology is also based on RG 1.82/NUREG-0897, but models the top hat assembly as one suction pipe within another and assumes the total flow through a top hat to be split into two flows in direct portion to the total screen area of each flowpath. The "outer pipe" is defined as the flow area between the 10" diameter tube and the 7" diameter tube, and the "inner pipe" is defined as the flow area inside the 5" diameter tube. The submergence of the top hat is defined as the distance from the minimum water level to the top of the top hat, or a distance of 0.35 ft. The RHR flow is again assumed to be 4,500 gpm, and the maximum flow through one top hat is assumed to be 258 gpm (about twice the uniform flow rate of 129 gpm through each of the thirty-five top hats) to account for a top hat over the suction line having a higher flow than a top hat some distance from the suction line. The maximum Froude number thus estimated is 0.307, the maximum pipe velocity is 1.03 ft/s, and the minimum submergence is 0.35 ft. This methodology fails two of the three RG 1.82/NUREG-0897 criteria for ensuring zero air entrainment. Therefore, zero air ingestion cannot be ensured.

The third methodology is that of Knauss in "Swirling Flow Problems at Intakes," dated 1987. Knauss' methodology uses the intake diameter as the characteristic length in the relationship for the Froude number and provides a critical submergence required to avoid vortex formation at the intake. Using this methodology considering suction through the pump suction intake at the bottom of the sump, the RHR suction pipe satisfies the criterion for critical submergence. However, using this methodology considering the top hats as the suction point (similar in manner to the second methodology described above), the submergence of the "inner pipe" does not meet the stated criteria; thus, zero air ingestion through the inner portion of the top hats cannot be ensured.

Because it was not conclusively shown that vortexing would not occur, the design of the replacement sump screens includes a vortex suppressor, fabricated of floor grating, over the top hats. The vortex suppressor is completely submerged under all recirculation conditions. The vortexing evaluation notes that the strainer assembly, in conjunction with the vortex suppressor, will provide superior vortex suppression than will the floor grating alone. Additionally, the total RHR suction line flow is distributed among the thirty-five top hats in the sump pit, reducing the forces that cause swirl. The PWR hydraulic guidelines in table A-2 in Appendix A to RG 1.82 show that having dual intakes results in less stringent criteria to preclude vortex formation. This adds further basis to the argument that having multiple suction points reduces the susceptibility to vortexing.

Sump strainer head losses were determined through a combination of testing and analysis. HNP conducted prototypical head-loss testing to determine the head losses through the screens and the associated debris bed. This testing was conducted at the Alion Science and Technology Hydraulics Laboratory in Warrenville, Illinois. The clean strainer head loss was established using analytical methods.

The head-loss testing was conducted in the fall of 2006 and in the spring of 2007. The testing in the fall of 2006 did not include chemical precipitates as part of the debris mix, whereas the testing in the spring of 2007 included chemical precipitates. All of the tests were conducted using tap water at a test temperature of 80°F to 90°F. Also, the approach velocity in all of the tests was maintained to obtain steady-state head-loss data at the specified flow rates. This is conservative with respect to the approach velocity of a strainer subjected to debris. As the debris bed builds on the strainer and NPSH decreases, the flow rate through the associated pumps will decrease. Maintaining constant flow rate and approach velocity in the test forces the head loss to increase to the point of steady state whereas in the plant the flow rate would continue to decrease until equilibrium is reached. This results in conservative head-loss data obtained in the testing.

Both series of tests routed flow from the tank inlet through the strainer/plenum assembly, and out through the test tank side connection. For the non-chemical effects testing, the tank inlet had a diffuser. For the chemical-effects testing, the tank inlet had a sparger assembly that directed the incoming water horizontally across the tank bottom, precluding the settling of debris on the tank bottom. The plenum to which the top hats were mounted had walls installed on three sides to simulate the hydraulic effects of the sump pit walls and adjacent top hats next to the array. The front of the array was located in close proximity to the tank wall, which is representative of a fourth wall.

For the non-chemical effects testing, a three-by-three array of 42"-long double top hats was used. Each top hat has an effective screen area of 26.1 $ft^2$, for a total effective screen area of 235 $ft^2$. The design screen size used at this time was 2,967 $ft^2$ (per train), which is slightly smaller than the 3,001 $ft^2$ (per train) of the final design. The screen area used to scale debris quantities was reduced by 100 $ft^2$ from the 2,967 $ft^2$ value to account for blockage from tags and labels. Four tests were conducted: a thin-bed threshold test at an equivalent fibrous bed thickness of 1/8", a full fibrous debris load test using the quantity of fiber postulated to be transported to the recirculation strainers for the limiting LOCA location, a Microtherm test for a RCS hot-leg break in the reactor cavity, and a confirmatory test of whichever of the first three tests had the highest head loss. As the Microtherm case yielded the highest head loss, this confirmatory test used Microtherm.

The quantity (mass) of fibrous debris used in the thin-bed test was determined by multiplying the bed thickness of 1/8" by the prototype screen area and the density of Thermal-Wrap and Nukon. For the full fibrous debris load test, the mass of fibrous debris used in the testing was determined by multiplying the volume of fiber by the density of Thermal-Wrap and Nukon. The scaled mass is determined by multiplying this mass by the scaling factor (the ratio of the surface areas of the prototype array to the full-scale strainer assembly).

The mass of Microtherm used in the testing was determined by multiplying the volume of Microtherm by the density of Microtherm and then multiplying this mass by the scaling factor. The mass of Temp-Mat used in the testing was determined by multiplying the volume of fiber by the density of Temp-Mat. The scaled mass is determined by multiplying this mass by the scaling factor.

For coating debris, the scaled mass is determined as follows: First, the actual coating volume is determined by dividing the mass of each coating debris by the actual coating density. Then, the scaled volume of the coating surrogate is determined by multiplying the sum of all of the actual coating volumes by the scaling factor. Finally, the coating surrogate (ground silica) scaled mass is determined by multiplying the scaled volume by the surrogate density of 165 $lb/ft^3$. This allows the quantity of the surrogate used in the test to occupy the same volume as that of the actual scaled debris.

For materials where the test material or surrogate is the same density as the actual material in the plant (dirt/dust), the scaled mass is determined by simply multiplying the mass by the scaling factor.

The shredded fiber was inspected to ensure that it met the size distribution requirements that are defined in NUREG/CR-6808. Once the shredded fiber had been inspected, it was weighed out and boiled in water to remove the binder. The boiled fiber was then placed in a bucket of water at a temperature within ±10°F of the water used for testing. The particulate debris was weighed out and also placed in a bucket of water at a temperature within ±10°F of the water used for testing. The fiber and particulate were then thoroughly mixed together with a paint mixer attached to an electric drill until a homogeneous slurry was formed. The complete contents of the buckets were added to the test tank to ensure no loss of fine debris. The debris was added to the tank in the corner near the return line. This location was selected to maximize the transport of debris to the strainers.

For the thin-bed test, a clean flow sweep was first performed. This flow sweep was performed at flow rates of 420 gpm to 793 gpm. The flow rate was then reduced to 472 gpm, then particulate and fiber debris were added to the tank. Manual agitation of the tank with a paddle along with a mechanical mixer kept the particulate and fibrous debris suspended. The flow rate was maintained until head loss stabilized. The acceptance criteria for stabilization were a less than 1% increase in head loss over a one-hour period and at least five pool turnovers occurred. Flow sweeps were performed once a stabilized head loss was achieved. The head loss monotonically increased over the duration of the test and was 0.14 ft (at 83°F) when the stabilization criteria were met. This low head loss implies that there was insufficient fibrous debris available to form a uniform thin bed over the complex geometry of the double top hats.

The full fibrous debris and the Microtherm tests were conducted in a similar manner. Because this first series of tests did not include chemical debris and thus are not limiting with respect to head loss, the results of these three tests will not be discussed here.

For the chemical effects testing, a three-by-three array of double top hats was used, except for the full fibrous load test, which used a two-by-two array of the double top hats. The design screen size used was 3,001 $ft^2$ (per train), which is the finalized design screen size. The screen area used to scale debris quantities was reduced by 100 $ft^2$ from the 3,001 $ft^2$ value to account for blockage from tags and labels. Four tests were conducted: a full fibrous debris load test, a full debris load bed using Microtherm, a full debris load bed using Min-K, and a full debris load bed using Min-K, but without bypass-eliminator mesh installed in the top hats. All previous testing, both non-chemical effects and chemical-effects, had the bypass-eliminator mesh installed in the top hats.

For the chemical-effects tests, the fibrous and particulate debris was prepared as for the non-chemical effects tests. The chemical precipitates were prepared in accordance with the methodology in WCAP-16530-NP, "Evaluation of Post-Accident Chemical Effects in Containment Sump Fluids to Support GSI-191," revision 0. The chemical precipitate loads generated for each test were based on the thirty-day result of the spreadsheet developed with WCAP-16530-NP. For each chemical-effects prototype test, a time-dependent analysis was developed that determined the amount and type of chemical precipitates generated based on the amount and types of debris destroyed. For each test, five total precipitate batches were introduced to mimic the time-variant nature of precipitate formation. The fifth and final batch added brought the precipitate loading in the tank to the thirty-day value predicted by the spreadsheet.

For each of the chemical-effects tests, a clean-strainer flow sweep was performed, then the flow was reduced to the flow for the debris-head loss portions of the test. The fibrous and particulate debris were first added to the tank, then the batches of precipitates were added. Debris and precipitates were added in the front corner nearest the return line; as with the non-chemical effects testing, this location was selected to maximize the transport of debris to the strainers. After each batch of precipitates was added, head loss was allowed to stabilize in accordance with the test plan before adding the next batch. After the fifth and final batches were added, head loss was allowed to stabilize such that head loss increased less than 1% over a one-hour period and at least five pool turnovers had occurred. A flow sweep was then performed. The results of this testing, at test temperatures, are given in Table 3f.1:

Table 3f.1

| Test | Head Loss (ft) |
|---|---|
| 1 (full fiber loading) | 2.6 |
| 2 (Microtherm) | 3.42 |
| 3 (Min-K with bypass-eliminator mesh) | 9.31 |
| 4 (Min-K without bypass-eliminator mesh) | 3.57 |

The results of test 3, when adjusted to accident condition temperature, are unacceptably high. As this test used the bypass-eliminator mesh, which was not installed in the plant, this test is not representative of plant configuration and was not used in the subsequent evaluation. Of the other three tests, test 4 has the highest head loss. This measured head loss is conservatively corrected for increases in temperature or flow using a 50% laminar term and a 50% turbulent term (i.e. $R_L = 0.5$ and $R_T = 0.5$) and decreases in temperature or flow using a 100% laminar term and a 0% turbulent term (i.e., $R_L = 1.0$ and $R_T = 0$) in the following equation:

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$$\Delta H_2 = \Delta H_1[R_L(\mu_2/\mu_1)(U_2/U_1) + R_T(\rho_2/\rho_1)(U_2^2/U_1^2)]$$

where $R_L$ = ratio of laminar flow
$\mu$ = dynamic viscosity at temperature (lbm/ft/sec)
U = approach velocity (ft/s)
$R_T$ = ratio of turbulent flow
P = density at temperature (lbm/ft$^3$)
$\Delta H$ = head loss (ft)

These correction factors were derived from the chemical-effects test data. The head loss is adjusted to 212°F to be consistent with the NPSH calculations. The head loss thus determined for the limiting break is 2.34 ft.

Boreholes and changes in debris-bed morphology would be observed by the head-loss curve flattening out and becoming ragged as the differential pressure exceeds the shear strength of the debris bed and the boreholes form and collapse. Chemical effects tests 1, 2, and 4 did not exhibit this behavior (as discussed above, test 3 was not used in the subsequent evaluation). Also, as flow was increased during the flow sweeps after the debris beds had formed, the flow remained primarily laminar. Thus, boreholes or shifts in the debris bed are not evident.

HNP calculated the additional head loss associated with flow on the underside of the strainer assembly, including flow through the 4" x 18" hole in the divider wall that separates the RHR half of the sump from the containment-spray half. This head loss was calculated using information from Crane Technical Paper No. 410, "Flow of Fluids Through Valves, Fittings, and Pipe," Fried and Idelchik, "Flow Resistance: A Design Guide for Engineers," and Churchill, "Friction-Factor Equation Spans All Fluid-Flow Regimes". This head loss assumes a clean-screen head loss for a top hat of 0.12 ft based on testing performed by Enercon. The lowest sump water temperature is assumed constant at 50°F, as lower temperatures yield higher viscosities, resulting in lower Reynolds numbers and higher friction factors. The flow across the strainer is assumed to be uniform and normalized over the total strainer area, which is conservative because the flow will balance with the path of least resistance, i.e., more flow will be experienced by the top hats that are closer to the recirculation lines for the initial, clean condition. In addition, intake flow through the perforated plate is assumed to be uniform, which is reasonable given that the entire strainer is submerged. The head loss thus calculated is 0.80 feet, including 0.12 ft for the head loss through a top hat.

The sum of the experimentally-derived head loss of the top hats and the associated debris bed and the analytically-determined head loss of the underside of the strainer assembly is 2.34 ft + 0.80 ft – 0.12 ft (top hat head loss is included in both of these terms) = 3.02 ft. This value of head loss is less than the limiting NPSH margin of 3.14 ft.

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The HNP strainer is designed to a maximum differential pressure of 7 psid. This design differential pressure was determined by multiplying the limiting NPSH margin of 3.14 ft by the ratio of the viscosities of water at 212°F and 50°F, yielding a differential pressure of 6.3 psid at 50°F. This differential pressure was then bounded by the design value of 7 psid for conservatism.

The strainer interstitial volume is calculated to be 374 $ft^3$. The maximum volume of debris that is transported to the recirculation sump screens is 187 $ft^3$, which is substantially less than the interstitial volume. Thus, the strainer can accommodate the maximum volume of debris that is predicted to arrive at the strainer without the formation of a circumscribed debris bed.

The sump screens are fully submerged under all recirculation conditions. As such, no failure criteria in addition to loss of NPSH margin were considered.

Near-field settling was not credited during testing. The test tank had a sparger to keep the bottom free of settled debris. Additionally, manual agitation of the tank was performed to ensure debris was transported to the prototypical strainer assembly and not settle out.

The maximum calculated void fraction as a result of vapor formation due to the pressure drop across the recirculation sump screens is 2.36%, which is less than the value of 3% from Attachment V-1 of the SER. Containment overpressure was credited in this analysis; an assumed pressure of 40 psia was used to maximize the concentration of air in the saturated water at containment conditions.

## g. Net Positive Suction Head

*The objective of the NPSH section is to calculate the NPSH margin for the ECCS and CSS pumps that would exist during a loss-of-coolant accident (LOCA) considering a spectrum of break sizes.*

- *Provide applicable pump flow rates, the total recirculation sump flow rate, sump temperature(s), and minimum containment water level.*
- *Describe the assumptions used in the calculations for the above parameters and the sources/bases of the assumptions.*
- *Provide the basis for the required NPSH values, e.g., three percent head drop or other criterion.*
- *Describe how friction and other flow losses are accounted for.*
- *Describe the system response scenarios for LBLOCAs and SBLOCAs.*
- *Describe the operational status for each ECCS and CSS pump before and after the initiation of recirculation.*

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- *Describe the single failure assumptions relevant to pump operation and sump performance.*
- *Describe how the containment sump water level is determined.*
- *Provide assumptions that are included in the analysis to ensure a minimum (conservative) water level is used in determining NPSH margin.*
- *Describe whether and how the following volumes have been accounted for in pool level calculations: empty spray pipe, water droplets, condensation and holdup on horizontal and vertical surfaces. If any are not accounted for, explain why.*
- *Provide assumptions (and their bases) as to what equipment will displace water resulting in higher pool level.*
- *Provide assumptions (and their bases) as to what water sources provide pool volume and how much volume is from each source.*
- *If credit is taken for containment accident pressure in determining available NPSH, provide description of the calculation of containment accident pressure used in determining the available NPSH.*
- *Provide assumptions which minimize the containment accident pressure and maximize the sump water temperature.*
- *Specify whether the containment accident pressure is set at the vapor pressure corresponding to the sump liquid temperature.*
- *Provide the NPSH margin results for pumps taking suction from the sump in recirculation mode.*

HNP response:

The Safety Injection System (SIS) is composed of three subsystems, which enable it to perform its function over a wide range of reactor coolant system (RCS) accident conditions. The first subsystem, high head safety injection (HHSI) functions when the RCS leak rate is relatively small (or nonexistent in a main steam or feedwater line break) and the pressure is high. Low head safety injection (LHSI) is the subsystem that provides reactor core protection when the RCS leak rate is large (LOCA) and the pressure has become low. Finally, passive safety injection (PSI) is the subsystem that functions at the intermediate RCS pressure where HHSI is not entirely effective, because of the high leak rate involved, and LHSI is not yet operable.

The SIS has two operational phases, injection and recirculation. The injection phase operates as a once-through loop, in which water from sources independent of the RCS are introduced into the reactor core. These sources are the refueling water storage tank (RWST) and the PSI cold leg accumulators (CLAs). All three SIS subsystems are capable of this phase of operation. The recirculation phase operates as a recycle loop in which spilled reactor coolant and injection-phase water is recirculated back into the reactor core. This spilled water accumulates in the two containment sumps. The recirculation phase of operation is further divided into a cold-leg recirculation mode and a hot-leg recirculation mode. Only the HHSI and LHSI subsystems are functional in this phase of operation.

The SIS merges with several safety-related systems to create flow paths that carry borated water to the reactor core. The LHSI subsystem receives support from the Residual Heat Removal (RHR) system pumps and heat exchangers, while the HHSI subsystem is aided by the chemical volume and control system (CVCS) charging and safety injection pumps (CSIPs). All three subsystems are reliant upon the containment spray system (CSS) for the delivery of borated water from the RWST (also under the scope of the CSS). In the case of PSI, the RWST provides suction to the hydrostatic test pump, which provides makeup to the accumulators.

There are two RHR pumps. There are three CSIPs; one pump is powered from the "A" train safety bus, another is powered from the "B" train safety bus, and the third is configured to receive power from either bus 1A-SA or 1B-SB by way of a manual transfer switch.

SIS operation is triggered by the safety injection actuation or "S" signal. The "S" signal automatically places the SIS in the injection phase of operation via automatic pump starts and valve realignments. The "S" signal is generated by the engineered safety features actuation system for any of the following conditions:

- Low pressurizer pressure (1,850 psig)
- High containment pressure (3.0 psig)
- Low steam line pressure (601 psig)
- Manual SIS initiation

In the event of a large LOCA such as a double-ended RCS cold leg pipe rupture, a rapid depressurization of the RCS occurs. The operating CSIP continues to run, and a second pump starts through the sequencer. The CSIPs will come up to speed and will be injecting borated water into the RCS cold legs within approximately ten to fifteen seconds after receipt of the "S" signal. When the RCS pressure decreases below the normal operating pressure of the CLAs (approximately 585-665 psig), borated water will be forced into the RCS cold legs. As the RCS pressure decreases below the shutoff head of the RHR pumps (approximately 140 psig), these pumps begin injecting borated water from the RWST into the RCS cold legs. The SIS requires no immediate operator actions during the injection phase following a large LOCA, other than to monitor the operation of the pumps, the increasing water level in the containment sump, and the decreasing water level in the RWST.

The switchover from the injection mode to the recirculation mode is initiated automatically and completed manually by operator action from the main control room. Protection logic is provided to automatically open the four SIS recirculation sump isolation valves when two of four RWST level channels indicate a RWST low-low level in conjunction with the "S" signal already received.

This automatic action aligns the two RHR pumps to take suction from the containment sump. It should be noted that the RHR pumps provide continuous flow to the RCS cold legs during this automatic realignment. This flow is assured because the CSIPs and RHR pumps will continue to take suction from the RWST following the automatic action until the operator manually, from the main control board (MCB), isolates the RWST from the RHR pumps and aligns them to deliver flow to the CSIP suction header along with continued flow to the RCS cold legs. Thus, the CSIPs are supplied by the discharge of the RHR pumps during recirculation.

At approximately 6.5 hours after the accident, hot-leg recirculation flow shall be initiated to prevent boron precipitation at the top of the core where reactor coolant may be boiling. Valve realignments are performed manually from the MCB that direct flow from the HHSI and LHSI subsystems to the RCS hot legs. Thereafter, hot and cold leg recirculation will be alternated every 6.5 hours.

The Containment Spray System (CSS) has two containment spray pumps. The Containment Spray Actuation Signal (CSAS) is the actuating signal for the CSS. This signal can be initiated manually or automatically on a containment pressure signal of 10 psig.

Upon receipt of the CSAS, the injection mode begins. The CSS pumps automatically start and the containment spray header isolation valves and the containment spray chemical additive valves automatically open on receipt of the CSAS.

The switchover from injection to recirculation is an automatic action that transfers the suctions of the CSS pumps from the RWST to the recirculation sumps. This automatic action, which is triggered by a low-low level in the RWST, coincident with a CSS pump running, involves the opening of the containment sump recirculation valves and the closing of the injection line isolation valves. A time delay is present between the opening of the recirculation line valves and the closing of the injection line valves to allow sufficient time for the recirculation line to fill. This assures that there will be adequate net positive suction head (NPSH) for the CSS pumps at all times.

The maximum sump water temperature is 244°F. The maximum sump flowrate, assuming a single failure of a train, would be 5,754 gpm, and the maximum sump flowrate, assuming a single failure of an RHR pump, would be 6,363 gpm. The difference in flowrates is due to the failure of the RHR pump results in two CSIPs being supplied by the running RHR pump, resulting in a higher flowrate than would occur if a single train failed, and the running RHR pump supplied only one CSIP.

The equation used for determining available NPSH for the RHR pump is

$NPSH_{available} = h_{ambient\ pressure} + h_{static\ head} - h_{line\ losses} - h_{vapor\ pressure}$

When the RHR pump is taking suction from the containment sump, no credit is taken for subcooling of the sump fluid. In other words,

$h_{ambient\ pressure} = h_{vapor\ pressure}$

The equation then becomes

$NPSH_{available} = h_{static\ head} - h_{line\ losses}$

The available NPSH calculation uses an RHR pump flowrate of 4,500 gpm, which is the maximum flowrate of the RHR pump. The required NPSH of the RHR pump at this flowrate is 19 ft, and the available NPSH is 22.14 ft, resulting in a NPSH margin of 3.14 ft. The RHR pump NPSH margin was used to determine the acceptability of the head loss across the debris-laden screens during the recirculation mode of emergency core cooling following a postulated LOCA.

The NPSH requirements of the CSS pumps have been evaluated for both the injection and recirculation phase following a loss of coolant accident. For recirculation, the available NPSH calculation uses a CSS pump flowrate of 2,110 gpm, which is the maximum expected flow of the CSS pump during recirculation. No reliance is placed on the containment pressure for meeting the NPSH requirements for the CSS pumps. The equation used for determining available NPSH for the CSS pump is

$NPSH_{available} = h_{containment} + h_{static\ head} - h_{line\ losses} - h_{vapor\ pressure}$

where

$h_{containment} = h_{vapor\ pressure}$

The minimum NPSH required during recirculation is 12 ft, and the available NPSH is 27.17 ft, resulting in a NPSH margin of 15.17 ft.

None of the SIS and CSS pumps are stopped as part of the transition to recirculation; thus shutdown of pumps is not credited for reducing flowrates and head loss to increase NPSH margins. The flowrate of 4,500 gpm used in determining the NPSH margin of the RHR pumps is based on one RHR pump failing, leaving one RHR pump feeding two CSIPs, which results in the maximum flow rate for a single RHR pump.

The RHR pump net positive suction head available (NPSHA) calculation uses Equation 3-14 of Crane Technical Paper No. 410, "Flow of Fluids Through Valves, Fittings, and Pipes" to determine the head loss due to frictional resistance in the piping and line losses due to other components. Resistance values for piping and components were also taken from Crane Technical Paper No. 410. Similarly, the CT pump NPSH calculation uses resistance values for piping, valves, and fittings from the Hydraulic Institute's "Engineering Data Book," first edition.

ECCS pump specifications include a specified maximum required NPSH which the pump is required to meet. Pump vendors have verified that the required NPSH for the ECCS pumps is less than the maximum required NPSH through testing in accordance with the criteria established by the Hydraulic Institute Standards. NPSH requirements for the CSS pumps were required to be verified by a suction suppression test for each pump. The test procedures for the CSS pumps were required to be in accordance with the standards of the Hydraulic Institute and the ASME Power Test Code for Centrifugal Pumps (PTC) 8.2.

The minimum water level in containment at the start of transition to recirculation was calculated to be 223.6 ft elevation for a small-break LOCA and 223.9 ft for a large-break LOCA. The floor of containment is at elevation 221'; thus, the minimum pool depth is 2.6 ft for a small-break LOCA and 2.9 ft for a large-break LOCA. The LBLOCA minimum water level is assumed for all cases, as the limiting break locations in terms of debris generation are all LBLOCAs.

The calculation uses the RWST, the accumulators, and the containment spray addition tank (CSAT) as water sources. The total volume of water injected from the RWST is 37,322 cubic feet. This volume does not credit any water injected from the RWST during the transition to recirculation and assumes the level of the RWST is initially at the low alarm setpoint. Each of the three accumulators is assumed to be at the Technical Specification minimum level, and the total volume of water added to the sump pool from the accumulators is 2,982 cubic feet. For a small-break LOCA, the accumulators are assumed to not discharge. In determining the minimum water level in containment, a maximum of 64 cubic feet of water is assumed to be educted from the CSAT at the time the containment atmosphere reaches its peak temperature, thereby maximizing the quantity of water vapor in the containment atmosphere and thus minimizing the water level.

The RCS is considered a source of water for the sumps only for the case in which the LOCA is on the pressurizer surge line. For the design-basis LBLOCA cases, no water from the RCS is credited for the water level in containment.

The water-level calculation determines the quantity of water added to containment and the quantity of water diverted from the sumps. The net mass of water added to the containment floor is calculated using a correlation for the relationship between the containment water level and the water volume. Determination of the minimum water level accounts for water holdup in the following locations:

- Water vapor held up in the containment building atmosphere following a LOCA.
- Normally dry containment spray ring headers and risers. Similarly, the calculation assumes that the suction piping leading from the sumps to the RHR and CT pumps is initially empty.
- Shrinkage of the water in the RCS as the RCS cools down.
- Condensation on containment surfaces. This includes a non-flowing layer of condensation on the containment heat-sink surfaces, except for the containment wall, dome, and floor, of 0.03 inches in thickness as well as a flowing layer of condensation on the containment wall and dome.
- Filling of the pressurizer steam space.
- Water flow in transit from the pipe break. This includes two trains of CSS flow falling from the upper ring of the containment spray nozzles and assumes all of the RHR flow falling from the top of the pressurizer surge line to the containment floor.
- ECCS leakage, including equipment leakage and backleakage into the RWST.
- Holdup in the refueling cavity to develop the hydraulic head to push the containment spray flow that falls into the cavity through the cavity drain line.
- Holdup in the containment building elevator.
- Holdup in the Steam Generator and RCP pedestals.
- Holdup on the operating floor.
- Holdup in the manipulator crane rails.
- Holdup in the RCP oil collection system.
- The calculation also assumes 300 cubic feet of miscellaneous holdup.

The water-level calculation assumes that structural components will displace water, resulting in a higher pool level. These structural components include the twenty-two steel columns adjacent to the containment liner, the recirculation sump structures, the walls around the reactor coolant drain tank pumps and heat exchanger, the primary shield wall, the secondary shield wall, the ribs between the secondary shield and the personnel shield walls, the personnel shield wall, the refueling cavity walls, the air plenums, and the reactor coolant pump and steam generator pedestals. The curbs around the recirculation sumps, the reactor vessel cavity (the incore sump), the refueling cavity leakage enclosure, and the elevator, as well as the elevator platform, ramp, and the elevator are also credited with displacing water. The pads for the airborne radiation removal units, the nonsafety containment fan coolers, and the primary shield cooling fans are credited with displacing water. Each of the two frames and housings of the airborne radiation removal units is credited with displacing three cubic feet of water, each of the three frames and housings of the nonsafety containment fan coolers are credited with displacing three cubic feet of water, and the housing for the primary shield cooling fans is credited with displacing one cubic foot of water.

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Subsequent to the development of the water-level calculation, some additional equipment was credited as displacing water as available inventory for a 50-gpm seal leak of an RHR pump for four hours. The equipment credited as displacing water are the lead storage boxes on the floor of containment, the RCP oil-leakoff tanks, the recirculation sump screens and associated framework, the recirculation sump trash racks, the lead shielding around the incore sump, and miscellaneous equipment on the 221' elevation of containment. Also, the RHR and CSS suction lines from the sumps were credited as being half full of water instead of empty as there are procedural controls that maintain water in these lines.

**h. Coatings Evaluation**

*The objective of the coatings evaluation section is to determine the plant-specific ZOI and debris characteristics for coatings for use in determining the eventual contribution of coatings to overall head loss at the sump screen.*

- *Provide a summary of type(s) of coating systems used in containment, e.g., Carboline CZ 11 Inorganic Zinc primer, Ameron 90 epoxy finish coat.*
- *Describe and provide bases for assumptions made in post-LOCA paint debris transport analysis.*
- *Discuss suction strainer head loss testing performed as it relates to both qualified and unqualified coatings and what surrogate material was used to simulate coatings debris.*
- *Provide bases for the choice of surrogates.*
- *Describe and provide bases for coatings debris generation assumptions. For example, describe how the quantity of paint debris was determined based on ZOI size for qualified and unqualified coatings.*
- *Describe what debris characteristics were assumed, i.e., chips, particulate, size distribution and provide bases for the assumptions.*
- *Describe any ongoing containment coating condition assessment program.*

HNP response:

HNP uses the following coating systems in the containment building:
- Keeler & Long 7107 epoxy primer and Keeler & Long 7475 epoxy topcoat (steel coating)
- Nutec 6 epoxy primer and Nutec 1201 epoxy topcoat (steel coating)
- Carboline 890 epoxy (steel and concrete coating)
- Starglaze 2011S epoxy surfacer, Nutec 11 touch-up epoxy surfacer, and Nutec 1201 epoxy topcoat (concrete coating)

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For qualified coatings, the size of the zone of influence (ZOI) is based on testing performed on representative coating systems. A spherical ZOI of 5D for DBA-qualified epoxy and for inorganic zinc (IOZ) primer was selected based on WCAP-16568-P, "Jet Impingement Testing to Determine the Zone of Influence (ZOI) for DBA-Qualified/Acceptable Coatings," revision 0, dated June 2006. This documents states that no jet-impingement damage was observed for epoxy topcoats, regardless of the undercoat or substrate, at a minimum $L/D_{break} = 1.37$ and that an $L/D_{break} = 4.28$ is an appropriate and defensible estimate of the ZOI for untopcoated zinc based on conservative extrapolation of the test data.

The debris-generation calculation assumes that the reactor vessel and pressurizer are coated with Carboline 4674 based on the Westinghouse vendor manuals for these components. Additionally, the debris-generation calculation assumes approximately 2,580 $ft^2$ of inorganic zinc (IOZ) primer in each steam generator compartment based on Table 6.2.5-6 of the FSAR listing 7,739 $ft^2$ of zinc-based paint on "other NSSS equipment." This is conservative, as the coatings program does not list any zinc-based paint in containment.

For the debris-generation analysis, all qualified coatings within the 5D ZOI were assumed to fail as 10-micron particles, which is consistent with the GR and the SE.

The total surface area of qualified coatings within the ZOI was estimated using a plant-specific AutoCAD model of containment developed in support of the debris-transport analysis. This model is based on drawings of the containment building and extends from the floor of the containment building to the operating deck.

Degraded qualified epoxy coatings outside the ZOI are assumed to fail as 21-mil chips. Section 3.4.3.6 of the NEI methodology recommends that unqualified epoxy coatings outside the ZOI fail as particulate with a diameter of 10 microns. However, the 10-micron size is associated with erosion of coatings due to high-pressure jet impingement inside the ZOI. Coatings outside the ZOI will not be exposed to jet impingement and, therefore, the predominant failure mechanism will not be erosion. Section 3.7.2 of the Crystal River 3 (CR3) pilot plant audit report states that "[t]he NRC staff agrees that degraded qualified coatings outside the ZOI failing as chips as a reasonable assumption."

HNP assumes that all other unqualified coatings (i.e., OEM coatings), regardless of their location in containment, fail as particles with a diameter of 10 microns. This assumption is consistent with the SE.

The debris-transport analysis shows that coatings chips do not transport to the recirculation sumps. Thus, the only coatings that are transported to the recirculation sumps are in the form of particulates.

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HNP conducted head-loss testing to ensure the head loss across the replacement sump screens was acceptable. This testing was conducted by Alion at their facility in Warrenville, Illinois. This testing is more fully described in section 3f of this supplemental response. This testing used SIL-CO-SIL 53 Ground Silica manufactured by U.S. Silica Company as a surrogate material for the coatings. The ground silica is a spherical particulate ranging in size from just under 1 μm to approximately 100 μm. The specific gravity of this material is 2.65, corresponding to a density of 165 lb/ft$^3$. The coating densities at HNP range from 80 lb/ft$^3$ to 457 lb/ft$^3$. An adjustment was made to compensate for the difference in the volume of the material such that an equivalent volume of the surrogate material was used. The majority of the failed HNP coatings are assumed to be on the order of 10 μm or greater. Because a significant portion of the ground silica material is less than 10 μm, the ground silica would tend to produce a debris bed with a lower porosity and higher surface-to-volume ratio than a debris bed comprised of coating material. Thus, the use of ground silica as a surrogate for coating material is conservative.

Coatings in containment are safety-related and applied as Service Level I unless specifically exempted otherwise. Some protective coatings in containment have been classified as unqualified coatings as described in procedure MNT-NGGC-0009. These unqualified coatings are documented in plant calculation HNP-C/CONT-1012, "Containment Unqualified Coatings Log," periodically monitored, and assessed using the guidance contained in procedure EGR-NGGC-0023, "Primary Containment Coatings Condition Assessment" to assure that these coatings do not adversely affect the safety-related performance of the ECCS during post-LOCA recirculation.

EGR-NGGC-0023 specifies a 100% walk-through of containment to visually assess the condition of the protective coatings. This procedure states that coatings are considered to be acceptable, provided none of the following conditions are observed:

- Blistering greater than size No. 6 (Medium) as specified in ASTM D714
- Cracking greater than standard No. 6 as specified in ASTM D661 (checking of any grade specified in ASTM D660 is acceptable)
- Flaking greater than standard No. 6 as specified in ASTM D772
- Rusting equal to or greater than Grade 7 as specified in ASTM D610
- Insufficient adhesion, as determined by the Coating Program Manager
- Unqualified coatings.

Unqualified coatings have at least one of the following attributes:

- Cannot be attested to having passed the required laboratory testing, including irradiation and simulated Design Basis Accident
- On vendor-supplied items which are not procured with a qualified coatings system or it is not practical to be recoated in accordance with Service Level I requirements
- Does not meet the manufacturer's approved quality assurance program

- Coating was improperly applied or applied by an unqualified applicator
- Exhibits unacceptable defects at any time after installation
- Certifications are not available on material or applicator
- Coatings Application Reports are not available
- Inspections were performed by an unqualified person
- Inaccessible to repair, coat, or inspect
- Existing coatings degraded while in service and has not or cannot be removed, repaired, replaced, or evaluated to an acceptable status
- Cannot be evaluated as acceptable to plant licensing basis requirements.

**i. Debris Source Term**

*The objective of the debris source term section is to identify any significant design and operational measures taken to control or reduce the plant debris source term to prevent potential adverse effects on the ECCS and CSS recirculation functions.*

- *Provide the information requested in GL 04-02 Requested Information Item 2.(f) regarding programmatic controls taken to limit debris sources in containment.*

  *GL 2004-02 Requested Information Item 2(f)*
  *A description of the existing or planned programmatic controls that will ensure that potential sources of debris introduced into containment (e.g., insulations, signs, coatings, and foreign materials) will be assessed for potential adverse effects on the ECCS and CSS recirculation functions. Addressees may reference their responses to GL 98-04, "Potential for Degradation of the Emergency Core Cooling System and the Containment Spray System after a Loss-of-Coolant Accident Because of Construction and Protective Coatings Deficiencies and Foreign Material in Containment," to the extent that their responses address these specific foreign material control issues.*

*In responding to GL 2004 requested Information Item 2(f), provide the following:*

- *A summary of the containment housekeeping programmatic controls in place to control or reduce the latent debris burden. Specifically for RMI/low-fiber plants, provide a description of programmatic controls to maintain the latent debris fiber source term into the future to ensure assumptions and conclusions regarding inability to form a thin bed of fibrous debris remain valid.*
- *A summary of the foreign material exclusion programmatic controls in place to control the introduction of foreign material into containment.*

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- *A description of how permanent plant changes inside containment are programmatically controlled so as to not change the analytical assumptions and numerical inputs of the licensee analyses supporting the conclusion that the reactor plant remains in compliance with 10 CFR 50.46 and related regulatory requirements.*
- *A description of how maintenance activities including associated temporary changes are assessed and managed in accordance with the Maintenance Rule, 10 CFR 50.65.*

*If any of the following suggested design and operational refinements given in the guidance report (guidance report, Section 5) and SE (SE, Section 5.1) were used, summarize the application of the refinements.*

- *Recent or planned insulation change-outs in the containment which will reduce the debris burden at the sump strainers*
- *Any actions taken to modify existing insulation (e.g., jacketing or banding) to reduce the debris burden at the sump strainers*
- *Modifications to equipment or systems conducted to reduce the debris burden at the sump strainers*
- *Actions taken to modify or improve the containment coatings program*

<u>HNP response</u>:

Section 5 of NEI 04-07 and section 5.1 of the associated SE list five design and operational refinements that could lower the plant debris source term. The following is a list of those five refinements and HNP's actions to lower the plant debris source term.

<u>Housekeeping and FME programs</u>:
Plant procedure OST-1081, "Containment Visual Inspection When Containment Integrity Is Required Mode 5" is performed prior to setting containment integrity. One purpose of this procedure is to perform a visual inspection to verify that no loose debris is present in containment that could be transported to the containment sump. HNP revised OST-1081 to add the following definition of latent debris:

> "Latent debris is defined as unintended dirt, dust, (including miscellaneous particles), paint chips, fibers, pieces of paper (shredded or intact), plastic, tape, adhesive labels, fines or shards of thermal insulation, fireproof barrier, or other materials that are already present in the containment prior to a postulated break in a high-energy line inside containment. Potential origins for this material include activities performed during outages and foreign particulates brought into containment during outages."

HNP also included an acceptance criterion for latent debris in OST-1081.

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The interim compensatory measure taken in response to Bulletin 2003-01 to revise the containment close-out procedure to provide more specific guidance on containment cleanliness and to implement the plant's more stringent criteria for containment cleanliness have been left in place.

Plant procedure AP-545, "Containment Entries," establishes controls for maintenance and inspection entries into the containment building during Modes 1 through 4, during Mode 5 after the completion of OST-1081 in preparation for entering Mode 4, and for the initial entry preceding a scheduled outage. This procedure restricts the loose, buoyant items that could be taken into containment during such an entry and could be transported to the sumps during a LOCA to 40 square feet of material. Such material consists of plastic bags, Tygon tubing, cloths and towels, plastic radiation signs, and radiation rope. Items that are not buoyant or will stay attached to or be worn by an entrant such that it would reasonably accompany the individual out of containment are not included. A visual inspection of the areas of the containment building affected by the containment entry verifies that no loose debris, including welding slag, grinding debris, and insulation debris, is present in containment. AP-545 also controls and limits the amount of aluminum and zinc in the containment building.

Additionally, the deficiency tag procedure (AP-038) was revised to prohibit the use of deficiency tags in containment.

Change-out of insulation:
HNP has not replaced any insulation.

Modify existing insulation:
HNP made one plant modification to existing insulation. HNP reinforced the cassettes containing Min-K insulation. This modification is supported by the test data presented in CDI Report Number 96-06, "Air Jet Impact Testing of Fibrous and Reflective Metallic Insulation," revision A. These data show that a Diamond RMI cassette with 0.032 inch thick stainless-steel jacketing can withstand an air-jet blast at a destruction pressure of 105 psi. This destruction pressure was conservatively lowered to 40 psi. This reduction in destruction pressure bounds the 40% reduction in destruction pressure required by section 3.4.2.2 of the NRC SE when using air-jet testing. This reduced destruction pressure corresponds to a ZOI of 4D, thus HNP has credited reducing the ZOI from 28.6D to 4D.

There were some sections of Min-K insulation on each line that could not be banded or sufficiently reinforced to achieve a ZOI of 4L/D. The amount of Min-K in these portions of piping has been estimated by measuring the actual amount in one of each type of line. Initially, the density of Min-K was conservatively assumed to be 16 lb/ft$^3$, but the actual density is 10 lb/ft$^3$. After adding in the additional Min-K and changing the assumed density from 16 lb/ft$^3$ to 10 lb/ft$^3$, the total Min-K that can be generated from a pipe break above the pressurizer is less than the amount included in the chemical-effects testing. Therefore, it is acceptable to allow the above discussed insulation to remain in its originally fabricated condition without reinforcing.

Modify Other Equipment or Systems:
HNP has made two changes to other equipment or systems.

The first change is that HNP originally allowed lead shielding blankets to be stored in the containment building in stacks. HNP has since designed and installed carbon-steel boxes to store these lead blankets such that they would be isolated from potential design basis accident (DBA) conditions inside the containment building. These boxes are externally coated with Service Level I coatings and are equipped with safety hasps and clips to secure the box lid from movement and to prevent any water or spray intrusion into the boxes. Plant procedure PLP-401 was revised to ensure that these boxes are secured shut prior to containment close-out.

The second change is that HNP removed most of the plastic signs, tags, and labels from containment. This was accomplished during RFO14 (fall 2007).

Modify or Improve Coatings Program:
HNP has not made any changes to its coatings program.

To maintain the required configuration of the containment recirculation function that supports the inputs and assumptions utilized to perform the mechanistic evaluation of this function, HNP has implemented programmatic and process controls as described below.

Plant procedures, programs, and design requirements were reviewed to determine those that could impact the analyzed containment or recirculation function configuration. These reviews resulted in the identification of those documents that required revision to ensure maintenance of the inputs and assumptions into the future.

The Engineering related documents that were revised or developed to support and maintain the required configuration control for maintenance of the inputs and assumptions that support the resolution of GSI-191 are:

- Corporate procedure EGR-NGGC-0005, "Engineering Change" (the modification procedure) was revised to provide screening criteria regarding the creation or alteration of potential sources of debris that could interfere with ECCS suction from the recirculation sump or with operation of the associated pumps; addition or reduction in materials in containment that could affect post-accident hydrogen generation and/or chemical precipitate formation, including most piping/component insulation materials; and the creation or modification of openings in the crane wall, bioshield wall, secondary shield wall or D-ring wall (including any associated screens or similar barriers installed over the

openings), or modify containment floors, which could alter water flow to the ECCS recirculation sump.
- Specification CPL-HNP1-M-009, "Blanket-Type Thermal Insulation for Use in Containment" has a change posted against it to remove interchangeability of RMI with fibrous insulation.
- The inputs and assumptions for debris generation, debris transport, head-loss determination (including chemical-effects considerations), upstream effects (included in water-level calc), and downstream effects analyses and associated testing have been documented in approved engineering documents to facilitate evaluation of conditions that may be contrary to analysis and modification input assumptions and to ensure that future changes to the plant may be readily evaluated against these design and licensing basis criteria.

The plant documents, not already mentioned above, that were revised to support and maintain the required configuration control for maintenance of the inputs and assumptions that support the resolution of GSI-191 are:
- Maintenance procedures were revised to ensure proper installation of the reinforced Min-K cassettes.
- The refueling cavity procedure was revised to ensure the trash rack on the refueling cavity drain is installed following cavity draindown and decontamination in preparation for startup.

HNP is not an all-RMI/low-fiber plant, so no programmatic controls were implemented to maintain the latent debris fiber source term into the future to ensure assumptions and conclusions regarding the inability to form a thin bed of debris remain valid. However, based on the margin available between the measured quantity of latent debris and the assumed quantity of latent debris, combined with consistent housekeeping practices going forward, it is expected that the actual quantity of latent debris will remain bounded by the quantity included in the head-loss testing.

Plant procedure WCM-001, "On-Line Maintenance Risk Management," provides guidance for managing the risk of maintenance performed during Modes 1, 2, and 3 (on-line maintenance). On-line maintenance includes routine preventive maintenance tasks, surveillance tests, planned system outages, and corrective maintenance while the plant is in Operations Modes 1, 2, or 3. On-line maintenance is performed to enhance the reliability and availability of systems and components in a manner that is commensurate with safety pursuant to 10 CFR 50.65, as implemented in the corporate procedure for the Maintenance Rule Program. The on-line risk assessment is a methodology that incorporates risk assessment into the work planning process to establish the requirements for managing the conduct of maintenance during power operation. The results of this evaluation are documented to identify high-risk jobs scheduled during the week and to describe the requirements for safely and reliably accomplishing these activities.

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HNP uses EOOS (an acronym for Equipment Out of Service, which is an EPRI software product that uses plant-specific probabilistic safety analysis models to estimate risk). Because EOOS does not consider the containment response to severe accidents and does not include risk of internal fires and external events, the analyst should consider whether risk is adversely impacted from:

- Unavailability of containment systems
- Unavailability of fire detection or suppression systems
- Activities that could increase the probability of a fire
- Activities that impact Maintenance Rule high safety significant systems, structures, or components not modeled in EOOS
- Activities that could initiate a plant transient due to the nature of the system involved and the intrusiveness of the maintenance

Corporate procedural guidance states that the risk impact of any of the above should be determined using a blended approach of qualitative analysis, operating experience, engineering judgment, and management standards.

**j. Screen Modification Package**

*The objective of the screen modification package section is to provide a basic description of the sump screen modification.*

- *Provide a description of the major features of the sump screen design modification.*
- *Provide a list of any modifications, such as reroute of piping or other components, relocation of supports, addition of whip restraints and missile shields, etc., necessitated by the sump strainer modifications.*

HNP response:

As previously communicated to the NRC in response to Bulletin 2003-01 (HNP-03-080, dated August 08, 2003), HNP has two independent sumps that are raised structures, 36' long x 11' deep x a maximum of 6' wide, located outside the secondary bio-shield wall on the northeast and southeast sides of the containment building. The nominal floor in containment is at 221' elevation, the top of the sump is at 227' elevation, and the bottom of the sump is at 216' elevation. The original sump screen was a six-piece assembly of vertical convoluted drilled plate screen sections, each 48" wide x 46" tall x 15" deep, equating to a frontal area of 92 square feet for each sump. Each screen section was individually supported internally and along its perimeter by structural steel members. The original trash rack was fabricated from ½" square bars set on 2" centers (1.5" x 1.5" openings) and covered the frontal area of the sump screen. The original drilled plate screen had a total area of 398 square feet per sump and had 0.125" diameter perforations for a total effective (clear opening) area of 159 square feet for each sump (318 square feet for both sumps). The sump screens are protected by a 1.5' high curb. The top of the sump is covered with solid checkered deck plate. Vortex suppressor grating was installed in each sump above the suctions. Attachment 2 of our Bulletin 2003-01 response includes a layout of the containment basement, configuration details of the original sump screen, and a photograph of one of the sumps.

Each recirculation sump is divided into two separate pits (one for the RHR suction and one for the containment spray suction) by a concrete wall. Each concrete wall has a 4" x 18" opening connecting the RHR suction pit and the containment spray suction pit.

During RFO14 (fall of 2007), the original vortex suppressors and convoluted screens were removed. A structural support frame was installed in each of the four sump pits (two pits in each of the two sump structures) and anchored to the walls inside the recirculation sump. To these frames are bolted high-performance "top hat" strainers.

The replacement strainer assemblies consist of a total of 136 (68 per recirculation sump) high-performance top-hat style modules and four (two per recirculation sump) top-hat inspection port modules that provide a total net effective surface area of approximately 6,000 square feet (3,000 square feet per sump). Thirty-five top hat modules are located in each sump pit for a total of seventy top hats per recirculation sump.

Each top-hat module is 66" tall with a 13-3/4" x 14-1/2" baseplate. Each high-performance top-hat module consists of four tubes (12-inch, 10-inch, 7-inch, and 5-inch diameter) fabricated from perforated plate. Each top-hat inspection port module consists of three tubes (12-inch, 10-inch, and 7-inch diameter) fabricated from perforated plate and a non-perforated tube that is five inches in diameter and has a blank flange on top that can be removed to look through the top-hat module. The perforations in all of the perforated plate are 3/32" in diameter. Water enters the perforated-plate surfaces of the top hat modules and flows through the annuli created between the two outer tubes and the two inner tubes. The flow then exits the bottom of the top hats and travels underneath the support frame to the existing RHR and containment spray suction intakes.

Boroscope inspection ports are provided at select locations around each strainer structure. Each boroscope inspection port consists of a 2" pipe welded to a hole cut into a blank plate at the same elevation as the top-hat baseplates. The 2" diameter pipe is four feet long and capped at the top.

Vortex suppressors constructed of standard floor grating are installed above the top-hat modules in each recirculation sump to prevent air from being drawn into the top-hat modules.

The replacement strainer assemblies, including the vortex suppressors, are fabricated of stainless steel and are fully submerged.

Additionally, the trash racks were modified by removing the bottom 12" of the ½" bars such that unimpeded flow will be available to the replacement strainer.

The level instruments and temperature instruments inside the sump structures were located within the sump structures to preclude interference with the replacement sump screens and the vortex suppressor.

**k. Sump Structural Analysis**

*The objective of the sump structural analysis section is to verify the structural adequacy of the sump strainer including seismic loads and loads due to differential pressure, missiles, and jet forces.*

*Provide the information requested in GL 2004-02 Requested Information Item 2(d)(vii).*

> *GL 2004-02 Requested Item 2(d)(vii)*
> *Verification that the strength of the trash racks is adequate to protect the debris screens from missiles and other large debris. The submittal should also provide verification that the trash racks and sump screens are capable of withstanding the loads imposed by expanding jets, missiles, the accumulation of debris, and pressure differentials caused by post-LOCA blockage under flow conditions.*

- *Summarize the design inputs, design codes, loads, and load combinations utilized for the sump strainer structural analysis.*
- *Summarize the structural qualification results and design margins for the various components of the sump strainer structural assembly.*
- *Summarize the evaluations performed for dynamic effects such as pipe whip, jet impingement, and missile impacts associated with high-energy line breaks (as applicable).*
- *If a backflushing strategy is credited, provide a summary statement regarding the sump strainer structural analysis considering reverse flow.*

HNP response:

The modified recirculation sump screens are as described in 3j above.

The modified recirculation sump screen assembly was structurally analyzed and found to meet the design requirements given in the Final Safety Analysis Report (FSAR) for HNP. The load combinations used in this analysis are the same as already defined for structures in safety-related applications at HNP.

Structural evaluations were performed to qualify the new screens, support structure, vortex suppressor and modified trash racks installed in the containment recirculation sumps. This evaluation was by analysis and included the strainer modules as well as the associated supporting structures, the trash racks, and the vortex suppressors. The evaluation was performed using a combination of manual calculations and finite-element analysis using commercially-available computer codes. The evaluations followed the requirements of the plant-specific design specifications.

The design inputs included quality class, design temperature, differential pressure, and material properties. The stainless steel weld filler metal is conservatively assumed to have a minimum tensile strength of 70 ksi.

The strainers are designed for the following loads:

- Seismic Loads—Both the Operating Basis Earthquake (OBE) and the Safe Shutdown Earthquake (SSE) loads are developed from response spectra curves that envelop the response spectra curves for HNP. The structure is considered a "bolted steel structure", and the damping values for seismic loads are taken from Regulatory Guide 1.61 as 4% for the OBE and 7% for the SSE. For the analysis of the top hat support frame a SSE conservative damping value of 4 % was used.
- Live Loads—Live loads include the weight of the debris, which accumulates on the strainer and the differential pressure across the top hat perforated plates. There is no backflushing of the system and therefore no loads due to backflushing.
- Thermal Loads—Thermal expansion is considered in the design and layout of the strainer assemblies. The strainers themselves are free to expand in the vertical direction. In the lateral direction, the seismic supports are gapped such that sufficient clearance exists to accommodate the thermal growth of the strainer assemblies without restraint. The design temperature for the strainers was taken equal to the maximum containment sump water temperature of 244°F. The maximum air temperature inside containment can reach as high as 364.4°F (for a main steam line break); however, this is the peak of a short-duration temperature spike, and the structure would not have time to heat up to this temperature before the containment air temperature would fall back to lower levels. Therefore, the use of the maximum water temperature for material properties and thermal expansion is appropriate. For evaluation of the top hat platform a design temperature of 300°F was used.

Pipe whip and jet impingement were reviewed for their impact on the replacement sump screens. Because the recirculation sump structures are not subject to the effects of pipe whip and jet impingement, the recirculation sump screens inside the sump structures are also not subject to the effects of pipe whip and jet impingement. Similarly, because the recirculation sump structures are between the secondary shield wall and the containment wall, the recirculation sump structures are protected from missiles generated within the secondary shield wall, and the replacement recirculation sump screens are therefore also protected from missiles.

Bounded load combinations for the strainer structure and allowables:

LC No. 1: Dead weight = Sx
LC No. 4: Dead weight + Earthquake (DBE) ≤ 1.6 Sx (Faulted )
LC No. 8: Dead weight + Earthquake (DBE) + Differential pressure ≤ 1.6 Sx (Faulted)
For evaluation of structural steel plates and shapes, including welds, the term "Sx" represents the required section strength based on the elastic design methods and the allowable stress in steel per AISC Specification for Structural Steel Buildings.

The results of the analysis are listed below:

Note: Structural steel and anchorage will be qualified for combination of dead load, seismic load (SSE) (including hydrodynamic mass) and differential pressure of 7 psid, using normal allowable, unless noted otherwise in the body of the calculation.

<u>Top Hat Strainers:</u>
Note: 2% damping used to qualify top hats.

- Structure:
  Bending Stress = 1013 psi < 35251 psi - Acceptable
  Axial Stress = 169 psi < 32821 psi - Acceptable
  Hoop Stress = 560 psi < 2002 psi - Acceptable
- Studs:
  Interaction = 0.63 < 1.0 - Acceptable
- Baseplate:
  Bending Stress = 9014 psi < 16875 psi -Acceptable
- Welding:
  Load = 70 lbs/in < 563 lbs/in - Acceptable

<u>Top Hat Support Structure:</u>

- Baseplates:

  Maximum Plate Stress = 3725 psi which provides an interaction of 0.221 based on an allowable of 0.75 Fy.

  Maximum anchor interaction is 1.018 based on a factor of safety of 4. Only one baseplate has an interaction greater than 1.0. The anchors were assumed to have a minimum embedment of 2.75 inches on all four anchor bolts, although three of the bolts will have a 4-inch embedment. Therefore, the analysis results are conservative.

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- Member Stresses:
  Max. Stress Interaction Ratio:
  For W4x13, @ member 507, max stress ratio = 0.277 < 1.0 - Acceptable
  For C8x18.75, @ most members, max stress ratio = 0.365 < 1.0 – Acceptable
  For L3x2x3/8, @ member 570, max stress ratio = 0.174 < 1.0 – Acceptable
  For L4x3x1/4, @ member 499, stress ratio = 0.154 < 1.0 – Acceptable
  For L3x3x1/4, @member 500 and 510, stress ratio = 0.123 < 1.0 – Acceptable
  For 2" Standard pipe, @ member 1007, max stress ratio = 0.324 < 1.0 – Acceptable
  All members are adequate by comparing to normal AISC allowables.

- Studs and Bolts:
  Maximum Interaction Combined Shear & Tension:
  7/8" Studs on Baseplates – Interaction = 0.76 < 1.0 - Acceptable
  ½" Bolts @ C8 End Connections & W4 to L3 x 2 – Interaction = 0.57 < 1.0 - Acceptable
  5/8" Bolts @ W4 to C8 Connections – Interaction = 0.48 < 1.0 - Acceptable

- Welds:
  Maximum interaction = 0.466 < 1.0 - Acceptable

<u>Vortex Suppressor</u>

- Baseplates:
  Maximum Plate Stress = 1649.5 psi which provides an interaction of 0.10 based on an allowable of 0.75 Fy.
  Maximum anchor interaction is 0.39 based on a factor of safety of 4.
- Member Stresses:
  Max. Stress Interaction Ratio:
  For TS 8 x 4 x 1/4, max stress ratio = 0.87 < 1.0 - Acceptable

  For TS 3 x 3 x 1/4, max stress ratio = 0.46 < 1.0 - Acceptable

  All members are adequate by comparing to normal AISC allowables.

- Studs and Bolts:
  Maximum Interaction Combined Shear & Tension:
  ½" Studs on Baseplates – Interaction = 0.14 < 1.0 - Acceptable

  3/4" Bolts @ TS 4 x 4 x 1/4 End Connections – Interaction = 0.57 < 1.0 - Acceptable

  5/8" Bolts @ W4 to C8 Connections – Interaction = 0.10 < 1.0 - Acceptable

- Welds:
  Maximum interaction = 0.902 < 1.0 - Acceptable

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Modified Outer Trash Rack:
Modification of the trash rack had no significant impact on the structural integrity of the configuration and no detailed analysis was required.

Plant procedure OST-1803 requires the inspection of the sump structures and the sump screens for signs of corrosion, structural distress, or gaps. This procedure was revised to reflect the configuration of the replacement sump screens, but the acceptance criteria were not changed.

HNP does not credit a backflush strategy.

In summary, HNP has evaluated the replacement sump screens and shown that all design requirements are met.

## I. Upstream Effects

*The objective for the upstream effects assessment is to evaluate the flowpaths upstream of the containment sump for holdup of inventory which could reduce flow to and possibly starve the sump.*

*Provide a summary of the upstream effects evaluation including the information requested in GL 2004-02 Requested Information Item 2(d)(iv).*

*GL 2004 Requested Information Item 2(d)(iv)*
*The basis for concluding that the water inventory required to ensure adequate ECCS or CSS recirculation would not be held up or diverted by debris blockage at choke-points in containment recirculation sump return flowpaths.*

- *Summarize the evaluation of the flow paths from the postulated break locations and containment spray washdown to identify potential choke points in the flow field upstream of the sump.*
- *Summarize measures taken to mitigate potential choke points.*
- *Summarize the evaluation of water holdup at installed curbs and/or debris interceptors.*
- *Describe how potential blockage of reactor cavity and refueling cavity drains has been evaluated, including likelihood of blockage and expected holdup.*

HNP response:

As part of the debris-transport analysis, an evaluation of flowpaths necessary to return water to the recirculation sumps was performed. This evaluation identified three flowpaths that could potentially become blocked with debris during recirculation.

The first two flowpaths are through the twenty 18" x 18" scuppers in the secondary shield wall and the three wire-mesh radcon doors in the personnel shield wall. The scuppers have a four-inch wide metal plate bolted horizontally across the center of the scupper to prevent personnel access. The doors stop approximately eight inches above the floor; giving an opening for water to pass through. These doors are seismically qualified. The debris-transport analysis concludes that the number and diversity of flowpaths in the secondary shield wall are such that it is not likely for all twenty scuppers and three doors to become sufficiently plugged with debris to impede the flow of water to outside the secondary shield wall.

The third flowpath is the refueling canal drain. This drain is ten inches in diameter. In the unlikely event of it becoming blocked with debris, water could be held up in the refueling canal. A trash rack is installed to cover the drain, and procedural controls ensure this trash rack is installed at the end of a refueling outage. The fuel transfer canal drain trash rack is designed to remain in place over the drain under combined deadweight and seismic loading. The trash rack is constructed of stainless-steel structural angles and plates resulting in a "cage" that has a typical opening size of approximately 5" x 5" on the top and 5" x 6" on the sides. This will prevent debris capable of clogging the drain line from entering the drain. The trash rack is designed such that water can enter from five sides of the cage. Therefore, the trash rack will not be susceptible to complete blockage, thereby ensuring that water will continue to flow through the trash rack and into the refueling canal drain.

There is a 2" curb around the refueling canal, and the floor is sloped away from the canal. The curbs around the recirculation sumps are eighteen inches high, which is below the minimum water elevation of 223.6 ft (SBLOCA) and 223.9 ft (LBLOCA). Thus, these curbs will not hold up water from the recirculation sumps. Refer to section 3.g for a description of the water hold-up volumes.

As a result of the evaluations performed and physical changes completed, HNP has determined that the upstream effects analysis provides the necessary level of assurance that the required volume of water will be available to the recirculation sump(s) for the function to meet the applicable requirements as set forth in NEI 04-07 and GL 2004-02.

### m. Downstream Effects—Components and Systems

*The objective of the downstream effects, components and systems section is to evaluate the effects of debris carried downstream of the containment sump screen on the function of the ECCS and CSS in terms of potential wear of components and blockage of flow streams. Provide the information requested in GL 04-02 Requested Information Item 2(d)(v) and 2(d)(vi) regarding blockage, plugging, and wear at restrictions and close tolerance locations in the ECCS and CSS downstream of the sump.*

SHEARON HARRIS NUCLEAR POWER PLANT
DOCKET NO. 50-400/LICENSE NO. NPF-63
SUPPLEMENTAL RESPONSE TO NRC GENERIC LETTER 2004-02, "POTENTIAL IMPACT OF DEBRIS BLOCKAGE ON EMERGENCY RECIRCULATION DURING DESIGN BASIS ACCIDENTS AT PRESSURIZED-WATER REACTORS"

*GL 2004-02 Requested Information Item 2(d)(v)*
*The basis for concluding that inadequate core or containment cooling would not result due to debris blockage at flow restrictions in the ECCS and CSS flowpaths downstream of the sump screen (e.g., a HPSI throttle valve, pump bearings and seals, fuel assembly inlet debris screen, or containment spray nozzles). The discussion should consider the adequacy of the sump screen's mesh spacing and state the basis for concluding that adverse gaps or breaches are not present on the screen surface.*

*GL 2004-02 Requested Information Item 2(d)(vi)*
*Verification that close-tolerance subcomponents in pumps, valves, and other ECCS and CSS components are not susceptible to plugging or excessive wear due to extended post-accident operation with debris-laden fluids.*

- *If NRC-approved methods were used (e.g., WCAP-16406-P with accompanying NRC SE), briefly summarize the application of the methods. Indicate where the approved methods were not used or exceptions were taken, and summarize the evaluation of those areas.*
- *Provide a summary and conclusion of downstream evaluations.*
- *Provide a summary of design or operational changes made as a result of downstream evaluations.*

HNP response:

HNP developed calculation HNP-M/MECH-1205, "HNP Downstream Effects for GSI-191" to address downstream effects. This calculation is based on the guidance of WCAP-16406-P, "Evaluation of Downstream Sump Debris Effects in Support of GSI-191", revision 1. HNP plans to revise calculation HNP-M/MECH-1205 to address the Conditions and Limitations in the NRC Safety Evaluation of WCAP-16406-P.

Plant system line-ups, mission times, flows, and pressures used to bound downstream effects are described in the plant calculation. This calculation confirms that ECCS and CSS operation during a limiting LBLOCA is adequate to meet the HNP accident analyses. All components except the water nozzles of the NaOH eductors were evaluated for thirty days of continuous operation. The water nozzles of the NaOH eductors were evaluated for seven days (168 hours) because Attachment 9 of EOP-GUIDE-1, "PATH-1 Guide" directs the operators to consider securing containment spray when the containment pressure drops to the reset point of the containment spray system (8 psig), which corresponds to a time of approximately 24 hours for the maximum-pressure case in the containment analysis. As additional NaOH can be added to the CSAT or through an emergency NaOH addition line, the containment spray pumps must be running to educt this additional solution. HNP's pH calculation shows the initial eduction of the NaOH solution to take a maximum of 5.39 hours; thus, a seven-day mission time allows for restarting the pumps to educt additional NaOH solution. This is consistent with section 4.3 of WCAP-16406-P, which allows selection of plant-specific mission times if the default mission times result in unacceptable wear.

HNP conducted plant-specific bypass testing to quantify and characterize, by both optical microscopy and scanning-electron microscopy (SEM), the fibrous debris that could pass through the replacement recirculation sump screens. This testing showed that 9.15% of the fibrous debris that reaches the screens passes through them. The characterization of the fibrous material that passed through the screens is as follows:

| | |
|---|---|
| Percent less than 250 microns long | 12 |
| Percent less than 500 microns long | 34 |
| Percent less than 750 microns long | 55 |
| Percent less than 1,000 microns long | 75 |
| Maximum fiber length (microns) | 1,906.25 |

These values are the most limiting values from the optical microscopy characterization. The characterization report notes that optical microscopy yields measurements that tend to be of longer fibers instead of the shorter fiber fines. Thus, use of the optical microscopy results instead of the SEM results is conservative in that the optical microscopy results are biased toward longer fiber lengths, and longer fiber lengths are more likely to be trapped by components.

The calculations evaluate the downstream effects of debris ingestion of auxiliary equipment including the valves, heat exchangers, orifices, spray nozzles, eductors, cyclone separators, and instrumentation tubing, following the methodology in WCAP-16406-P. The effects of debris ingested through the recirculation sump strainers during the recirculation mode of the ECCS and CT system include erosive wear, abrasion, and potential blockage of equipment and flow paths. The calculation also assesses changes in system or equipment operation caused by wear, including an evaluation of pump hydraulic performance due to internal wear.

No design or operational changes were identified as a result of this part of the downstream-effects evaluation. In 2001, HNP increased the clearances in the throttle valves in the high-head safety injection (HHSI) branch lines by installing pressure-breakdown orifices in each of the branch lines. The minimum clearance of these throttle valves was then determined to be 0.209 inches, which is greater than twice the diameter (3/32") of the perforations in the replacement sump screens.

SHEARON HARRIS NUCLEAR POWER PLANT
DOCKET NO. 50-400/LICENSE NO. NPF-63
SUPPLEMENTAL RESPONSE TO NRC GENERIC LETTER 2004-02, "POTENTIAL IMPACT OF DEBRIS BLOCKAGE ON EMERGENCY RECIRCULATION DURING DESIGN BASIS ACCIDENTS AT PRESSURIZED-WATER REACTORS"

**n. Downstream effects—Fuel and Vessel**

*The objective of the downstream effects, fuel and vessel section is to evaluate the effects that debris carried downstream of the containment sump screen and into the reactor vessel has on core cooling.*

- *Show that the in-vessel effects evaluation is consistent with, or bounded by, the industry generic guidance (WCAP-16793), as modified by NRC staff comments on that document. Briefly summarize the application of the methods. Indicate where the WCAP methods were not used or exceptions were taken, and summarize the evaluation of those areas.*

HNP response:

Initially, HNP used the methodology of WCAP-16406-P, revision 1, for the evaluation of potential core blockage following a LOCA. Part of this evaluation was performed by AREVA. The AREVA report concludes that fuel blockage will not be a concern provided the volume of fiber that reaches the core is limited to 0.6 $ft^3$. This volume of 0.6 $ft^3$ was determined by multiplying the actual amount of fiberglass needed to cover the underside of the fuel assemblies with a 1/8" thick fiber bed by 0.75 to account for uncertainties. The HNP calculation determined that all of the fiber that bypasses the recirculation sumps screens and is long enough to be caught on the underside of the fuel assemblies is 0.33 $ft^3$; thus, blockage of the fuel assemblies is not a concern. The AREVA evaluation also determines that it is not likely for debris to settle in the lower plenum of the reactor vessel based on the velocities and debris size. Should debris settle in the lower plenum, the volume of the lower plenum, considering a packing density of 50%, is 230 $ft^3$, which is greater than the amount of debris postulated to pass through the replacement sump screens.

The AREVA report also considers blockage of the lower support plate, the lower core plate, and the upper core plate. The smallest hole in the lower support plate and the lower core plate is 0.625 inches in diameter, and the smallest hole in the upper core plate is 5.47 inches in diameter. The diameter of the holes in the recirculation sump screens is 3/32". Thus, blockage due to the collecting of debris in the flow paths of the lower internals and the upper internals is not a concern.

The potential to locally block flow at the fuel spacer grids was also considered in the AREVA evaluation; a one-inch long solid plug around the limiting fuel pin at the peak power location was postulated. It was conservatively shown that the cladding temperature at the center of the plug is 1,029°F, which is well below the 10 CFR 50.46 acceptance criterion of 2,200°F.

An additional detailed evaluation of long-term cooling was also performed in accordance with WCAP-16793-NP, "Evaluation of Long-Term Cooling Considering Particulate, Fibrous, and

Chemical Debris in the Recirculating Fluid," revision 0. This evaluation included review and reconciliation of differences between WCAP assumptions and HNP plant-specific design and postulated post-accident conditions. The HNP evaluation considers the scenarios of clad temperature in a grid location (WCAP section 4.1), mid-span clad temperatures (WCAP section 4.2), the effect of time and chemistry on clad temperature with the LOCADM model (WCAP section 5), and blockage at the fuel assembly inlet (WCAP section 6).

For the clad temperature in a grid location, the HNP evaluation determines that the analyzed values are very close to the HNP values. HNP has a lower heat flux than that used in the WCAP-16793-NP analysis, and the plant-specific grid geometry is reasonably close to that analyzed in WCAP-16793-NP. The plant-specific value of cladding thickness is slightly larger than that used in WCAP-16793-NP, and this difference is evaluated as having a very small impact on cladding temperatures. The HNP evaluation concludes that the plant-specific cladding temperature is reasonably close to the value of 474°F in the WCAP-16793-NP evaluation.

For the mid-span clad temperatures, the HNP evaluation states that the differences between the fuel design evaluated in WCAP-16793-NP and the plant-specific fuel design are not expected to alter the applicability of Table 4-4 of WCAP-16793-NP to HNP. The HNP evaluation concludes that the plant-specific case would result in temperatures below 800°F.

A plant-specific analysis was performed using plant data for input parameters such as sump pH and spray pH, sump temperature, containment temperature, rated reactor power, pellet stack length, and fuel rod outer diameter. The analysis used the WCAP-16793-NP LOCADM model to predict the time-varying peak clad temperature as boiling in the reactor vessel increases the concentrations of materials in the vessel and increases the plate-out of scale due to heat transfer from the clad surface. Four inputs that had a large impact on clad temperature are: sump pH, spray mass flow, containment temperature, and upper plenum pressure. A higher sump pH, lower spray flow, higher containment temperature, and lower upper plenum pressure all result in higher clad temperature. The inputs for HNP were biased such that these quantities were set conservatively. A LOCA deposit thermal conductivity of 0.2 W/m-K was used, which is consistent with WCAP-16793-NP. A maximum crud thickness of 140 microns and maximum oxide thickness of 130 microns were used. No plant-specific refinements were made to the WCAP-16530-NP base model. The values of aluminum release from the WCAP-16530-NP spreadsheet were adjusted in accordance with the guidance contained in Westinghouse letter "LOCADM Guidance for Modification to Aluminum Release", which is in draft form.

To account for fiber that bypasses the sump screens, LOCADM was run with increased quantities of debris in accordance with the "bump-up factor" methodology described in OG-07-534. The results of this LOCADM run show the highest cladding temperature during recirculation is well below the long term core cooling acceptance criterion of 800°F in Appendix

A of WCAP-16793-NP. These results are preliminary pending validation of the LOCADM model in accordance with corporate procedures for software validation.

For blockage at the fuel assembly inlet, the plant-specific evaluation notes that the differences in the values for power distribution between the evaluation in WCAP-16793-NP and HNP are small. The plant-specific evaluation notes that the most adverse vessel design has down flow in the barrel-baffle region; however, HNP has up flow in the barrel baffle region. Two cases were considered: (1) twenty-eight peripheral fuel assembly inlets are debris-free (82% blockage) and (2) only the inlet to one high-power assembly is debris-free (99.4% blockage). The plant-specific evaluation concludes that HNP is bounded by the results of WCAP-16793-NP.

No design or operational changes were identified as a result of this part of the downstream-effects evaluation.

**o. Chemical Effects**

*The objective of the chemical effects section is to evaluate the effect that chemical precipitates have on head loss and core cooling.*

- *Provide a summary of evaluation results that show that chemical precipitates formed in the post-LOCA containment environment, either by themselves or combined with debris, do not deposit at the sump screen to the extent that an unacceptable head loss results, or deposit downstream of the sump screen to the extent that long-term cooling is unacceptably impeded.*
- *Content guidance for chemical effects is provided in Enclosure 3 to a letter from the NRC to NEI dated September 27, 2007 (ADAMS Accession no. ML0726007425).*
  *(1) Sufficient 'Clean' Strainer Area*
    - *Those licensees performing a simplified chemical effects analysis should justify the use of this simplified approach by providing the amount of debris determined to reach the strainer, the amount of bare strainer area and how it was determined, and any additional information that is needed to show why a more detailed chemical effects analysis is not needed.*

  *(2) Debris Bed Formation*
    - *Licensees should discuss why the debris from the break location selected for plant-specific head loss testing with chemical precipitate yields the maximum head loss. For example, plant X has break location 1 that would produce maximum head loss without consideration of chemical effects. However, break location 2, with chemical effects considered, produced greater head loss than break location 1. Therefore, the debris for head loss testing with chemical effects was based on break location 2.*

(3) *Plant-Specific Materials and Buffers*
- *Licensees should provide their assumptions (and basis for the assumptions) used to determine chemical effects loading: pH range, temperature profile, duration of containment spray, and materials expected to contribute to chemical effects.*

(4) *Approach to Determine Chemical Source Term*
- *Licensees should identify the vendor who performed plant-specific chemical effects testing.*

(5) *Separate Effects Decision (Decision Point)*
- *State which method of addressing plant-specific chemical effects is used.*

(6) *AECL Model*
- *Since the NRC staff is not currently aware of the testing approach, the NRC staff expects licensees using it to provide a detailed discussion of the chemical effects evaluation process along with head loss test results.*
- *Licensees should provide the chemical identities and amounts of predicted plant-specific precipitates.*

(7) *WCAP Base Model*
- *For licensees proceeding from block 7 to diamond 10 in the Figure 1 flow chart, justify any deviations from the WCAP base model spreadsheet (i.e., any plant-specific refinements) and describe how any exceptions to the base model spreadsheet affected the amount of chemical precipitate predicted.*
- *List the type (e.g., AlOOH) and amount of predicted plant-specific precipitates.*

(8) *WCAP Refinements*
- *State whether refinements to WCAP-16530-NP were utilized in the chemical effects analysis.*

(9) *Solubility of Phosphates, Silicates, and Al Alloys*
- *Licensees should clearly identify any refinements (plant-specific inputs) to the base WCAP-16530 model and justify why the plant-specific refinement is valid.*
- *For crediting inhibition of aluminium that is not submerged, licensees should provide the substantiation for the following: (1) the threshold concentration of silica or phosphate needed to passivate aluminium, (2) the time needed to reach a phosphate or silica level in the pool that would result in aluminium passivation, and (3) the amount of containment spray time (following the achieved threshold of chemicals) before aluminium that is sprayed is assumed to be passivated.*
- *For any attempt to credit solubility (including performing integrated testing), licensees should provide the technical basis that supports extrapolating solubility test data to plant-specific conditions. In addition, licensees should indicate why the overall chemical effects evaluation remains conservative when crediting solubility given that small amounts of chemical precipitate can produce significant increases in head loss.*
- *Licensees should list the type (e.g., AlOOH) and amount of predicted plant-specific precipitates.*

*(10) Precipitate Generation (Decision Point)*
- *State whether precipitates were formed by chemical injection into a flowing test loop or whether the precipitates are formed in a separate mixing tank.*

*(11) Chemical injection into the Loop*
- *Licensees should provide the one-hour settled volume (e.g., 80 ml of 100 ml solution remained cloudy) for precipitate prepared with the same sequence as with the plant-specific, in-situ chemical injection.*
- *For plant-specific testing, the licensee should provide the amount of injected chemicals (e.g., aluminium), the percentage that precipitates, and the percentage that remains dissolved during testing.*
- *Licensees should indicate the amount of precipitate that was added to the test for the head loss of record (i.e., 100 percent 140 percent).*

*(12) Pre-mix in Tank*
- *Licensees should discuss any exceptions taken to the procedure recommended for surrogate precipitate formation in WCAP-16530.*

*(13) Technical Approach to Debris Transport (Decision Point)*
- *State whether or not near-field settlement is credited.*

*(14) and (14a) Integrated Head Loss Test with Near-Field Settlement Credit*
- *Licensees should provide the one-hour or two-hour precipitate settlement values measured within 24 hours of head loss testing.*
- *Licensees should provide a best estimate of the amount of surrogate chemical debris that settles away from the strainer during the test.*

*(15) and (15a) Head Loss Testing without Near Field Settlement*
- *Licensees should provide an estimate of the amount of debris and precipitate that remains on the tank/flume floor at the conclusion of the test and justify why the settlement is acceptable.*
- *Licensees should provide the one-hour or two-hour precipitate settlement values measured and the timing of the measurement relative to the start of head loss testing (e.g., within 24 hours).*

*(16) Test Termination Criteria*
- *Provide the test termination criteria.*

*(17) Data Analysis*
- *Licensees should provide a copy of the pressure drop curve(s) as a function of time for the testing of record.*
- *Licensees should explain any extrapolation methods used for data analysis.*

*(18) Integral Generation (Alion)*
- *State whether integrated testing performed by Alion is credited.*

*(19) Tank Scaling/Bed Formation*
- *Explain how scaling factors for the test facilities are representative or conservative relative to plant-specific values.*

- *Explain how bed formation is representative of that expected for the size of materials and debris that is formed in the plant specific evaluation.*

*(20) Tank transport*

- *Explain how the transport of chemicals and debris in the test facility is representative or conservative with regard to the expected flow and transport in the plant-specific conditions.*

*(21) 30-day Integrated Head Loss Test*

- *Licensees should provide the plant-specific test conditions and the basis for why these test conditions and test results provide for a conservative chemical effects evaluation.*
- *Licensees should provide a copy of the pressure drop curve(s) as a function of time for the testing of record.*

*(22) Data Analysis Bump Up Factor*

- *Licensees should provide the details and the technical basis that show why the bump-up factor from the particular debris bed in the test is appropriate for application to other debris beds.*

HNP response:

To assess the impact of chemical precipitates on sump screen head loss, prototypical testing was performed. This testing was conducted by Alion Science and Technology in their test tank in Warrenville, Illinois. This testing used tap water maintained between 80°F and 90°F. With the recirculation pump running, a plant-specific debris mixture was added to the test tank. This mixture represented insulation debris, coatings debris, and latent debris. Spargers on the recirculation pump discharge and manual agitation were used to ensure debris was transported to the prototype screens. Following the debris addition, chemical precipitates were added to the tank. Section 3f of this supplemental response discusses the head-loss testing in additional detail. As discussed in section 3c of this supplemental response, HNP determined that there are three breaks with distinctly different debris mixes that could be the limiting break in terms of head loss. As such, HNP tested each of the three debris mixes with the respective chemical precipitates to determine the limiting break in terms of overall head loss. HNP did not participate in integrated thirty-day tests performed by Alion at the VUEZ test facility.

The species and quantities of chemical precipitates were predicted using the WCAP-16530-NP Chemical Model spreadsheet, version 1.1 (transmitted to the industry in letter OG-06-378). No credit was taken for plant-specific refinements to the chemical model as described in WCAP-16785-NP, "Evaluation of Additional Inputs to the WCAP-16530-NP Chemical Model", revision 0. Plant-specific inputs to the WCAP-16530-NP chemical model include the following:

- Post-LOCA containment recirculation pool temperature profile from the HNP containment analysis for the maximum-temperature case for a double-ended pump suction leg (DEPSL) break.

- Post-LOCA containment atmosphere temperature profile from the HNP containment analysis for the maximum-temperature case for a DEPSL break.
- pH profile of the containment spray from the maximum-pH case in the plant pH calculation. The maximum calculated pH of the spray is 10.15.
- pH profile of the sump pool from the maximum-pH case in the plant pH calculation. The maximum calculated pH of the sump is 9.42.
- Submerged aluminum of 159.6 lb /75 $ft^2$ and unsubmerged aluminum of 1,489.9 lb/703.5 $ft^2$
- Debris quantities in the recirculation pool from the debris generation calculation.
- Exposed area of concrete of 7,000 square feet, which bounds the break ZOI area plus non-DBA qualified coatings.
- The maximum calculated recirculation pool volume is used, as it leads to the largest predicted quantities of chemical precipitates.

Some key assumptions used during the calculation of the predicted chemical precipitate quantities include:

- All aluminum components which are not submerged are wetted by containment spray. This is a conservative assumption, as it maximizes the quantity of precipitates that are formed.
- The sump pool is assumed to be unmixed. This is a conservative assumption, as it maximizes the quantity of precipitates that are formed.
- Once the maximum sump pool and containment spray pH values are reached, it is assumed that the pH values do not decrease over time. This is conservative, as it maximizes the quantity of precipitates that are formed. The maximum sump pH is 9.42, and the maximum spray pH is 10.15.
- Containment spray is assumed to run for 24 hours, after which it is secured. This is a reasonable assumption, as Attachment 9 of EOP-GUIDE-1, "PATH-1 Guide" directs the operators to consider securing containment spray when the containment pressure drops to the reset point of the containment spray system (8 psig), which corresponds to a time of approximately 24 hours for the maximum-pressure case in the containment analysis.
- The quantities of Microtherm and Min-K entered into the spreadsheet take credit for the 50% reduction in Microtherm generation and the ZOI of 4D for the Min-K.

Subsequent to the determination of the predicted chemical precipitate quantities, HNP discovered that the sodium hydroxide flowrate allowed by Technical Specifications could be greater than the flowrate used in the calculation of maximum sump and spray pH. Preliminary assessment determined that a higher sump and spray pH would result from the higher flowrate, and that removal of some of the conservatisms in the prediction of chemical precipitate quantities resulted in quantities of chemical precipitates that are bounded by the quantities originally predicted and used in the chemical-effects testing. HNP plans to perform calculational revisions to incorporate the higher sodium-hydroxide flowrate; it is expected that this will reduce some of the conservatisms listed above.

HNP has some scaffolding in containment during normal operations. None of the permanent scaffolding allowed in containment during normal operations contains aluminum. There is some zinc on the scaffold knuckles, and this zinc is accounted for in the hydrogen generation calculation. Additional scaffolding materials that contain zinc are stored in containment, but the manner of storage is such that these materials will not be wetted. Section 6.2.2 of WCAP-16530-NP states that zinc releases are relatively small and can be ignored in chemical effects precipitation modeling.

The results of the spreadsheet modeling are as follows:

| Break Location | Sodium Aluminum Silicate (NAS) (lbs) | Aluminum Oxyhydroxide (AlOOH) (lbs) |
|---|---|---|
| RCS loop (Fiberglass) | 239.7 | 0 |
| At RV nozzle (Microtherm) | 78.4 | 25.0 |
| PZR SRV line (Min-K) | 74.6 | 25.4 |

These values are preliminary, as the WCAP-16530-NP spreadsheet has not been fully validated in accordance with procedure EGR-NGGC-0016 for control of engineering analysis software. Because the WCAP-16530-NP spreadsheet was prepared under the Westinghouse QA program, it is expected that these values will not change as a result of the software validation process.

The chemical precipitates used in the testing were prepared in accordance with the methodology of WCAP-16530-NP. The chemical model developed in this WCAP considers only the release rates of aluminum, calcium, and silicate and provides justification for not including zinc, ferrous materials, copper and nickel. As such, HNP did not consider quantifying uncoated carbon steel and copper. The quantity of zinc in containment is described in the hydrogen generation calculation and is not an input to the model. As described above, a conservative value of uncoated concrete was used as an input to the model.

The one-hour settling volume for each batch of chemical precipitates was determined at the time that the batch was produced. The sodium aluminum silicate batches had one-hour settling volumes greater than or equal to 6.2 ml, and each batch was prepared within fifteen days of being used in the test tank. The aluminum oxyhydroxide batches used in the test with limiting head loss (Min-K insulation was the primary constituent) had one-hour settling volumes greater than or equal to 7.5 ml, and each batch was prepared within three days of being used in the test tank. These settling volumes satisfy the acceptance criterion of a minimum of 4.0 ml in WCAP-

16530-NP as well as the revised acceptance criterion of a minimum of 6.0 ml contained in Westinghouse letter OG-07-408, dated September 12, 2007. The AlOOH batches used in the test with Microtherm as the primary constituent had one-hour settling volumes greater than or equal to 7.4 ml. These batches were prepared approximately four weeks prior to the test; however, the settling volume of one of these batches was re-determined to be 5.2 ml within two days of this test. The settling volume was still within the WCAP-16530-NP acceptance criterion of a minimum of 4.0 ml.

Although settling volumes were not determined within 24 hours of use of the precipitates (the chemical effects testing was conducted before OG-07-408 was issued), the observations from testing performed by PG&E indicates that the chemicals were acceptable, as PG&E determined that NAS does not appreciably change or age over four weeks and the head-loss characteristics of AlOOH conservatively increases over time.

The limiting head loss determined from the tank testing is for a break at the top of the pressurizer cubicle; this head loss is 3.57 ft at test conditions. When adjusted for accident temperature, this head loss is 2.34 ft. A plot of this test's results is included in Attachment 2 of this supplemental response. Plots of the test results for the other two debris mixtures are also included in Attachment 2 of this supplemental response.

The termination criteria for the head loss testing were:

- At least five pool turnovers have occurred, and
- The differential pressure across the debris bed changes by less than or equal to 1% over a one-hour period.

All of the head-loss testing HNP has conducted have satisfied these criteria. As mentioned above, the maximum sump temperature at approximately one day after the initiation of the LOCA is 165.7°F. The sump temperature is 205.9°F at 15,000 seconds (4.17 hrs) following accident initiation. As the sump water cools below 212°F, the NPSHA increases due to the subcooling of the water. At 30 days, the sump temperature is approximately 133°F. At 130°F, the vapor pressure of water is 2.223 psia, resulting in an increase of NPSHA of 28.8 ft. Assuming the most limiting chemical-effects test had head loss that was increasing at 1% per hour at the time the testing was secured, the rate of increase would be 0.036 ft/hr. Assuming this increase would be constant over 720 hours, this would be an increase in head loss of 25.92 ft. Thus, even in the unlikely event that head loss continued to increase for the full thirty days, the subcooling of the water would provide additional margin to ensure adequate NPSH.

As mentioned above, the test tank included a sparger, and manual stirring of the tank was done during testing to preclude debris from accumulating in low-flow areas of the tank. Based on visual observation during testing and during tank clean-out, the amount of debris and precipitates that did not transport to the screens is minimal, and the testing is representative of expected transport during a LOCA.

The tank testing is a conservative representation because containment spray will be secured in accordance with plant procedure once the pressure in containment is below the reset point for containment spray. This will reduce the velocity of water in the sump pool as well as reduce the turbulent kinetic energy in the pool resulting from the spray falling into the pool. Both of these effects will result in more settling of debris in the pool before it reaches the sumps. Scaling is discussed in section 3f of this supplemental response.

**p. Licensing Basis**

*The objective of the licensing basis section is to provide information regarding any changes to the plant licensing basis due to the sump evaluation or plant modifications.*

*Provide the information requested in GL 04-02 Requested Information Item 2(e) regarding changes to the plant licensing basis. The effective date for changes to the licensing basis should be specified. The date should correspond to that specified in the 10 CFR 50.59 evaluation for the change to the licensing basis.*

> *GL 2004-02 Requested Information Item 2(e)*
> *A general description of and planned schedule for any changes to the plant licensing bases resulting from any analysis or plant modifications made to ensure compliance with the regulatory requirements listed in the Applicable Regulatory Requirements section of this GL. Any licensing actions or exemption requests needed to support changes to the plant licensing basis should be included.*

HNP response:

HNP's September 1, 2005, submittal for GL 2004-02 indicated that a license amendment was neither planned nor needed and that HNP would update the FSAR with a description of the detailed deterministic methodology. HNP completed that action in December 2007 under the 10CFR50.59 process. No changes to Technical Specifications have been made or have been identified as needing to be made.

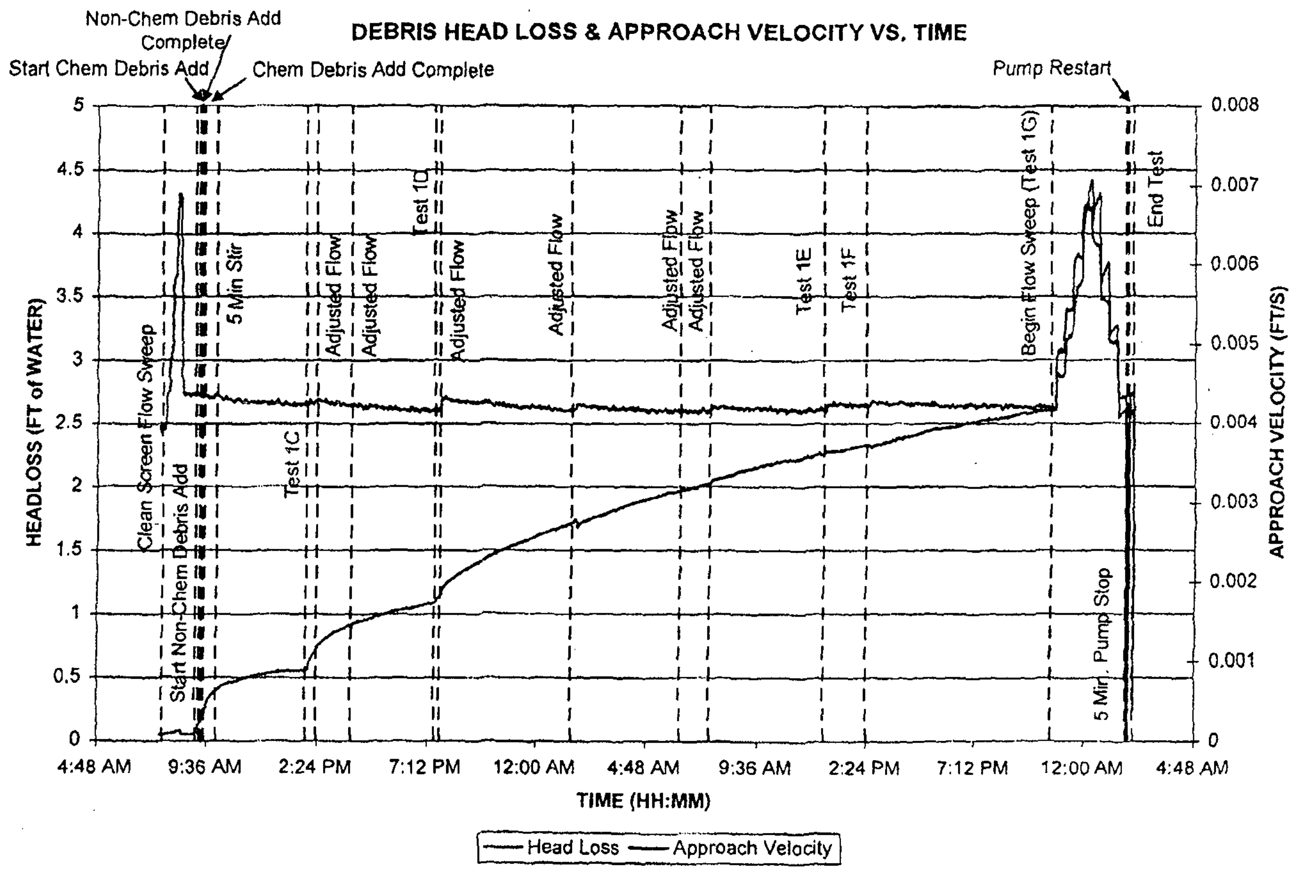



**Figure 3.3.2-6: Test #1 Chemical Effects Head Loss & Approach Velocity vs. Time**

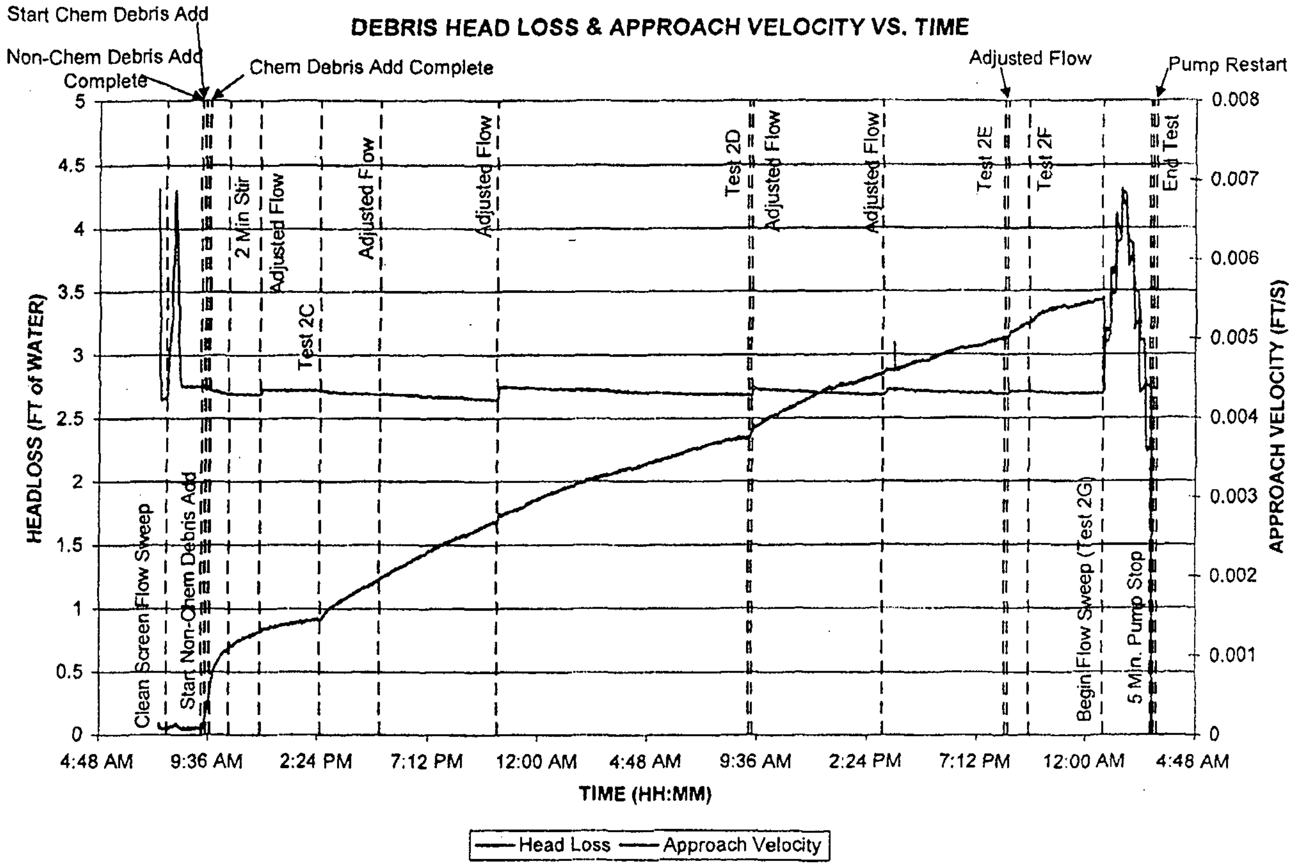



**Figure 3.3.2-9: Test #2 Chemical Effects Head Loss & Approach Velocity vs. Time**

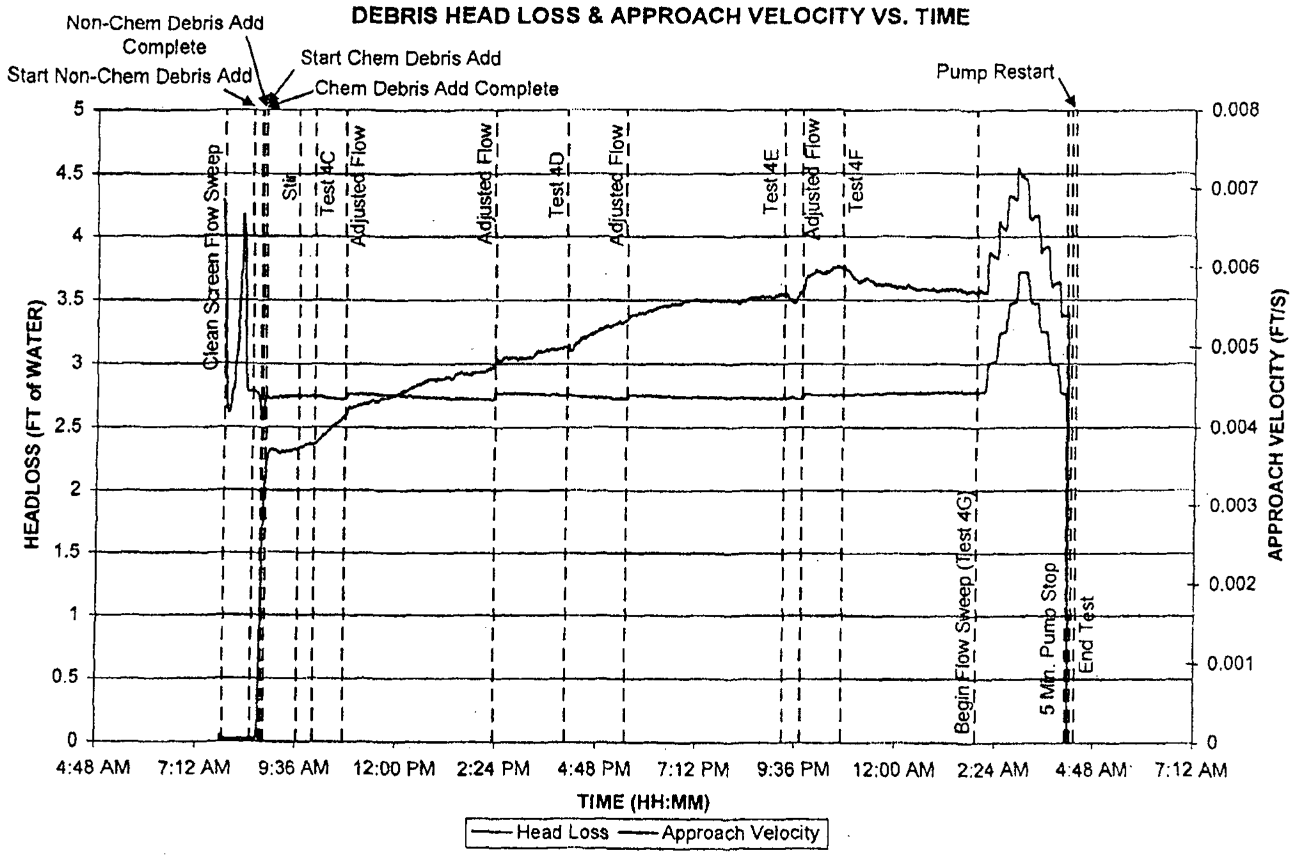
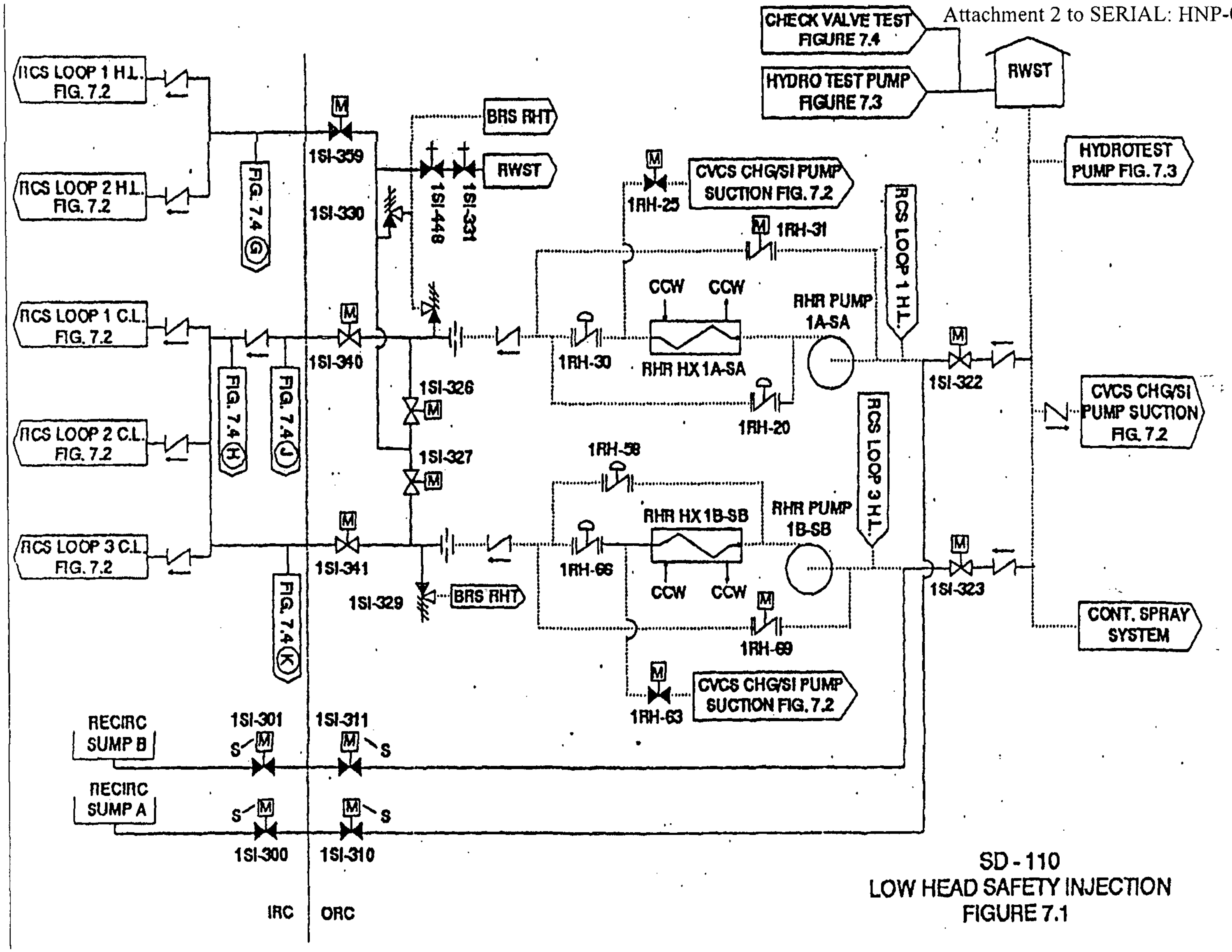
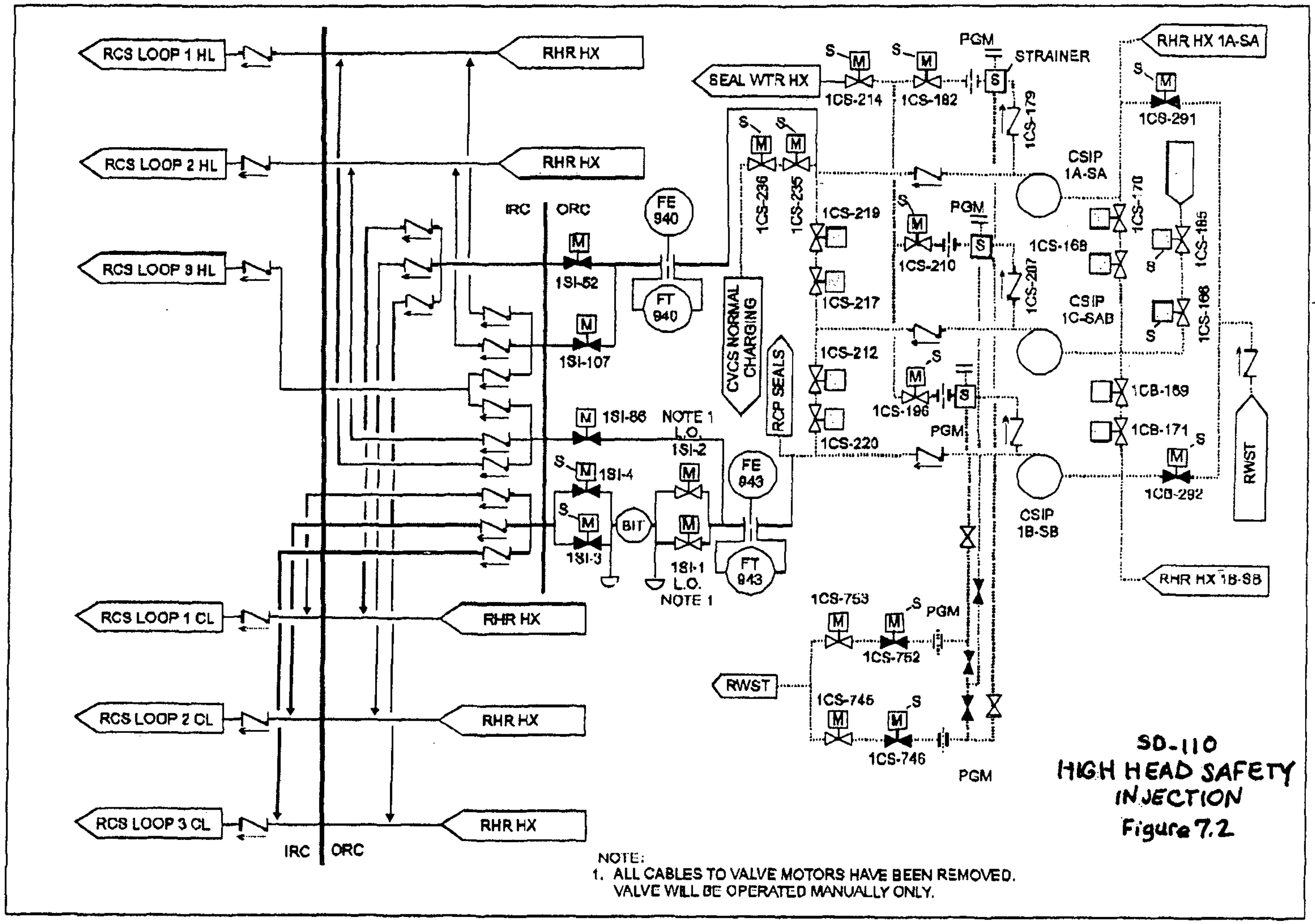


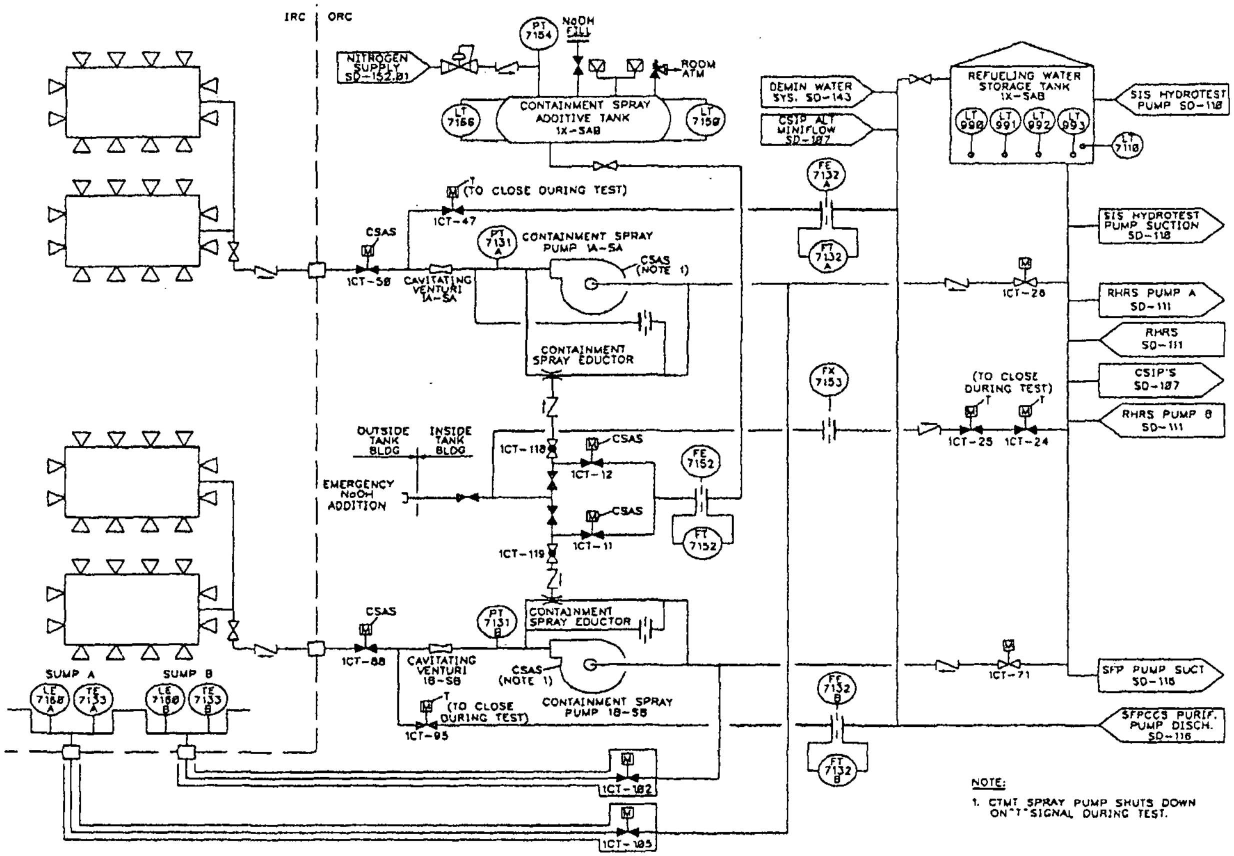

**Figure 3.3.2-15: Test #4 Chemical Effects Head Loss & Approach Velocity vs. Time**




SD - 110
LOW HEAD SAFETY INJECTION
FIGURE 7.1




SD-110
HIGH HEAD SAFETY INJECTION
Figure 7.2




SD-112
CONTAINMENT SPRAY SYSTEM
FIGURE 7.1