NEXTera ENERGY POINT BEACH

December 29, 2017

NRC 2017-0045
10 CFR 50.54(f)

U. S. Nuclear Regulatory Commission
Attn: Document Control Desk
Washington, DC 20555-0001

Re: Point Beach Nuclear Plant, Units 1 and 2
Dockets 50-266 and 50-301
Renewed License Nos. DPR-24 and DPR-27

Updated Final Response to NRC Generic Letter 2004-02

With this letter, NextEra Energy Point Beach, LLC (NextEra) provides an updated final response to Generic Letter (GL) 2004-02, Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized-Water Reactors, for Point Beach Nuclear Plant, Units 1 and 2 (Point Beach). In GL 2004-02, the U.S. Nuclear Regulatory Commission (NRC) requested licensees to evaluate the potential for post-accident debris blockage and debris-laden fluids to impede or prevent Emergency Core Cooling System (ECCS) and Containment Spray System (CSS) recirculation phase performance following a postulated design basis accident, and to implement any plant modifications determined necessary to ensure ECCS and CSS functionality. GL 2004-02 cited the findings of Generic Safety Issue 191 (GSI-191), Assessment of Debris Accumulation on PWR Sump Performance, which identified that recirculation sump clogging at Pressurized Water Reactors (PWR) is a credible concern, and established a schedule for licensee responses.

Attachment 1 to this letter identifies the references cited in this cover letter. In References 1 through 7, Nuclear Management Company, LLC (NMC), as previous licensee for Point Beach, and NextEra (previously named FPL Energy Point Beach, LLC), the current licensee for Point Beach, responded to Generic Letter 2004-02 and to subsequent requests for additional information. The correspondence established commitments for completion of specified corrective actions and provided supplemental information summarizing testing, analyses and modifications that were completed or planned at Point Beach.

In Reference 8, the NRC Commission approved the NRC staff's recommendation to provide licensees three options for resolution of GSI-191, with recognition that licensee measures completed thus far have contributed greatly to the safety of U.S. nuclear power plants. In References 9 and 10, NextEra notified the NRC staff of its selection for GSI-191 resolution in accordance with the options specified in Reference 8 and additionally summarized the remaining GL 2004-02 related corrective actions requiring completion.

Throughout this time, NextEra has implemented plant upgrades, defense in-depth measures and mitigation strategies at Point Beach. Those actions have bolstered the capacity of the containment sump screens, minimized the generation of debris that could affect ECCS and CSS recirculation phase performance, and managed containment sump inventory to ensure proper ECCS and CSS performance. In addition, recent industry and plant-specific analyses have demonstrated that the risk of GSI-191 related failures is very low.

Based upon these significant improvements in plant safety, NextEra hereby rescinds the GSI-191/GL 2004-02 related commitments described in previous correspondence on behalf of Point Beach and submits the enclosed bases for resolution of GSI-191 and thereby closure of GL 2004-02. Consistent with the recommendations specified in Option 2a of Reference 8, upon completion of the regulatory commitments identified in Attachment 2 to this letter, NextEra can conclude with reasonable assurance that the long-term core cooling requirements of 10 CFR 50.46(b)(5) will be satisfied for any design basis accident requiring containment sump recirculation phase performance at Point Beach.

Enclosure 1 to this letter provides NextEra's bases for closure of GL 2004-02 which contains input based on both sound engineering judgment as well as documents verified through a 10 CFR 50 Appendix B program. The inputs from engineering judgment have been prepared, verified, and approved by knowledgeable engineers. The bases for closure include the completion of an alternate evaluation as described in Section 6 of NEI 04-07, Pressurized Water Reactor Sump Performance Evaluation Methodology (Reference 11), using NRC accepted methods as described in the associated safety evaluation (SE) for NEI 04-07 (Reference 12), and a core blockage analysis using the methodology described in WCAP-17788, Comprehensive Analysis and Test Program for GSI-191 Closure (Reference 13). NextEra recognizes that the NRC's review of WCAP-17788 has not been finalized. Accordingly, upon NRC approval of WCAP-17788, the completed in-vessel blockage analysis for Point Beach will be reviewed and if warranted, a reanalysis will be performed within six months following approval of the WCAP-17788 methodology.

Additional plant modifications are planned, as described in Enclosure 1, which serve to further enhance Point Beach's capability to withstand GSI-191 related failures. To assure compliance with the requirements of 10 CFR 50.46(b)(5), NextEra will additionally request by no later than April 2018, an exemption from the single failure requirement in Point Beach General Design Criterion (GDC) 41, Engineered Safety Features Performance Capability, for a select (Region II) range of loss-of-coolant accident (LOCA) break sizes. Accordingly, the assumptions and inputs used to establish the bases for GL 2004-02 closure are consistent with the Point Beach licensing basis pending completion of the remaining planned modifications and approval of a limited exemption from GDC 41. As such, no new changes pursuant to 10 CFR 50.90 are being proposed as a result of this submittal. Upon NRC approval of the limited exemption request and closure of GL 2004-02, the Point Beach updated final safety analysis report (UFSAR) will be reviewed and updated in accordance with 10 CFR 50.71(e).

Section 1 of Enclosure 1 provides NextEra's statement of compliance with the *Applicable Regulatory Requirements* section of GL 2004-02 on behalf of Point Beach. Section 2 of Enclosure 1 describes the corrective actions that were completed in response to GL 2004-02, provides a schedule for the remaining actions requiring completion and lists the margins and conservatisms that were utilized in the analyses. In keeping with the NRC's Revised Content Guide for GL 2004-02 (Reference 14), Section 3 provides an evaluation of the sixteen identified issue areas, including the methodologies employed to arrive at a determination of acceptable performance and their bases. Section 3 also describes key aspects of completed plant modifications, process changes and supporting analyses that were applied in order to demonstrate with high confidence that the risk of GSI-191 related failures at Point Beach has been reduced to an acceptable level. Section 4 lists the documents referenced in Enclosure 1.

Attachment 2 to this letter summarizes the regulatory commitments identified in Enclosure 1. This letter supersedes all prior regulatory commitments identified in References 1 through 7, 9, 10, and related correspondence on behalf of Point Beach.

If you have any questions or require additional information, please contact Mr. Eric Schultz, Licensing Manager, at (920) 755-7854.

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

Executed on December 29, 2017.

Sincerely,

NextEra Energy Point Beach, LLC

Robert Coffey
Site Vice President

Attachments:
Attachment 1 – References
Attachment 2 – Regulatory Commitments

Enclosure 1 – Updated Final Response to NRC Generic Letter 2004-02

cc: USNRC Resident Inspector, Point Beach Nuclear Plant
USNRC Project Manager, Point Beach Nuclear Plant
Administrator, USNRC Region III
PSCW

ATTACHMENT 1

REFERENCES

1. Nuclear Management Company (NMC) letter L-HU-05-004, Nuclear Management Company 90-Day Response to Generic Letter 2004-02, Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized Water Reactors, dated March 7, 2005 (ML050670014)

2. NMC letter NRC 2005-0090, Response to Request for Additional Information on Generic Letter 2004-02, "Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized Water Reactors," dated July 18, 2005 (ML052010273)

3. NMC letter NRC 2005-0109, Nuclear Management Company Response to Generic Letter 2004-02, Potential Impact of Debris Blockage on Emergency Recirculation Durinq Design Basis Accidents at Pressurized-Water Reactors, for Point Beach Nuclear Plant, dated September 1, 2005 (ML052500302)

4. FPL Energy Point Beach, LLC letter NRC 2007-0085, Response to Generic Letter 2004-02, Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized-Water Reactors, dated November 16, 2007 (ML073230345)

5. FPL Energy Point Beach, LLC letter NRC 2008-0013, Supplemental Response to Generic Letter 2004-02. Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized-Water Reactors, dated February 29, 2008 (ML080630613)

6. FPL Energy Point Beach, LLC letter NRC 2009-0033, Response to Request for Additional Information GSI-I 91/GL 2004-02 (TAC NOS. MC4705/4706) Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized Water Reactors, dated April 7, 2009 (ML090980523)

7. NextEra Energy Point Beach, LLC letter NRC 2009-0077, Response to Request for Additional Information GSI-I 91/GL 2004-02 (TAC NOS. MC4705/4706) Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized Water Reactors, dated July 31, 2009 (ML092150636)

8. SECY-12-0093 - Closure Options for Generic Safety Issue - 191, Assessment of Debris Accumulation on Pressurized-Water Reactor Sump Performance, dated July 9, 2012 (ML121310648)

9. NextEra Energy Point Beach, LLC letter NRC 2013-0048, Resolution Option and Implementation Schedule for GSI-191 Closure, dated May 16, 2013 (ML1314A013)

10. NextEra Energy Point Beach, LLC, letter NRC 2013-0088, NextEra Energy Point Beach, LLC Preliminary Schedule for GSI-191 Resolution, dated September 30, 2013 (ML13275A282)

11. Nuclear Energy Institute (NEI) 04-07, Volume 1, Pressurized Water Reactor Sump Performance Evaluation Methodology, Revision 0, December 2004 (ML050550138)

12. NEI 04-07, Volume 2, Pressurized Water Reactor Sump Performance Evaluation Methodology; Safety Evaluation by the Office of Nuclear Reactor Regulation Related to NRC Generic Letter 2004-02, Revision 0, December 6, 2004 (ML050550156)

13. PWR Owners Group to NRC, letter OG-15-296, Submittal of WCAP-17788: "Comprehensive Analysis and Test Program for GSI-191 Closure (PA-SEE-1090)," dated July 17, 2015 (ML15210A668)

14. Revised Content Guide for Generic Letter 2004-02 Supplemental Responses, Enclosure, November 2007 (ML073110278)

ATTACHMENT 2

REGULATORY COMMITMENTS

The following table identifies the regulatory commitments in this document.

COMMITMENT	SCHEDULED COMPLETION DATE
NextEra Energy Point Beach will request a limited exemption from the single failure criterion in Point Beach General Design Criterion (GDC) 41, Engineered Safety Features Performance Capability, for Region II LOCA break sizes.	No later than April 2018
Upon NRC approval of the in-vessel blockage effects methodology of WCAP-17788, the completed in-vessel blockage analysis will be reviewed and if warranted, a reanalysis will be performed. (Section 2, General Description and Schedule for Corrective Actions)	Within 6 months following NRC approval of the WCAP-17788 methodology
A modification is planned to extend the refueling cavity drain lines in the lowest elevation of Containment in Units 1 and 2 (Section 2, General Description and Schedule for Corrective Actions)	U1 – Spring 2019 refueling outage U2 – Fall 2018 refueling outage
A modification is planned to extend the hard cover (drain pan) under Stairway #22 in Unit 1. (Section 2, General Description of and Schedule for Corrective Actions)	Spring 2019 refueling outage
A modification is planned to replace the fibrous insulation on Unit 2 Loop B Reactor Coolant Pump with reflective metal insulation. (Section 2, General Description and Schedule for Corrective Actions)	Fall 2018 refueling outage

Enclosure 1
Updated Final Response to NRC Generic Letter 2004-02

Point Beach Nuclear Power Plant

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Enclosure 1
Updated Final Response to NRC Generic Letter 2004-02

This enclosure provides NextEra Energy Point Beach's (NextEra's) final response to Generic Letter (GL) 2004-02 (Reference 1) in the form of a stand-alone document that supersedes all previous submittals for Point Beach Unit 1 (PBN1) and Point Beach Unit 2 (PBN2). Previous requests for additional information (RAIs) are not addressed in this submittal since this document is providing the description necessary to address the required information delineated in Generic Letter (GL) 2004-02. This enclosure follows the format and guidance provided by the Nuclear Regulatory Commission (NRC) (Reference 2; 3; 4; 5) and addresses all topical areas in those documents. The text from the NRC guidance is presented in italic script.

NRC Request, Summary-Level Description

The GL supplemental response should begin with a summary-level description of the approach chosen. This summary should identify key aspects of design modifications, process changes, and supporting analyses that the licensee believes are relevant or important to the NRC staff's verification that corrective actions to address the GL are adequate. The summary should address significant conservatisms and margins that are used to provide high confidence the issue has been addressed even with uncertainties remaining. Licensees should address commitments and/or descriptions of plant programs that support conclusions.

Summary-Level Description for PBN

The key aspects of the approach chosen by NextEra to resolve the concerns identified in GL 2004-02 are stated below for clarity:

- Extensive design modifications to significantly reduce the potential effects of post-accident debris and latent material on the functions of the emergency core cooling system (ECCS) and containment spray system (CSS) during the recirculation phase of accident mitigation.

- Extensive testing and analysis to determine break locations, identify and quantify debris sources, quantify debris transport, determine upstream and downstream effects, and confirm the recirculation function.

- Extensive changes to plant programs, processes, and procedures to limit the introduction of materials into containment that could adversely impact the recirculation function, and establish monitoring programs to ensure containment conditions will continue to support the recirculation function.

- Application of conservative measures to assure adequate margins throughout the actions taken to address the GL 2004-02 concerns.

More details are provided below for the plant-specific analyses, changes to the licensing basis, improvements in processes and programs, and conservatisms and margins.

Analyses

An extensive debris generation analysis has been performed for PBN1 and PBN2, which determined the debris generated for all break sizes from 0.5 inches up to 31 inches at all Class 1 in-service inspection (ISI) welds at locations inside the first isolation valve where reactor coolant system (RCS) pressure is expected to be present. The locations were analyzed as double ended guillotine breaks (DEGBs), single ended guillotine breaks (SEGBs) (where a closed valve is within 10 pipe diameters), and partial breaks at 45 degree intervals around the circumference of the pipe. This debris generation analysis was an automated evaluation based on a detailed computer-aided design (CAD) model of containment. Additional discussion of the debris generation analysis is provided in the Response to Item 3.b.

There were no reductions in the zone of influence (ZOI) sizes from the accepted values in Nuclear Energy Institute (NEI) Report 04-07 (Reference 6 p. 27) for any materials except qualified coatings and mineral wool. Note that the qualified coatings ZOI was based on testing that has been reviewed and accepted by the NRC. The ZOI size that is being used for qualified coatings and mineral wool is 4.0D. Additional discussion is provided in the Responses to Items 3.b and 3.h.

NextEra has performed extensive testing for strainer head loss and debris bypass (or penetration). The testing used conservative methods including the NRC reviewed protocols for fibrous debris preparation and strainer bypass testing. Additional discussion is provided in the Responses to Items 3.f, 3.n, and 3.o.

The core blockage analysis methodology documented in WCAP-17788 has not yet been finalized and the SE has not been issued by the NRC. The methodology currently contained in WCAP-17788, which is under NRC review, was used to determine the core inlet and in-vessel debris quantities for PBN. These results conservatively used a 30-day debris bypass quantity. Based on the debris limits currently identified in WCAP-17788, PBN meets the limits for both units. Following receipt of the NRC SE on WCAP-17788, any changes from the current methodology will be evaluated to determine if the current results still apply, and if warranted, a reanalysis will be performed.

NextEra has elected to use the Alternate Evaluation Methodology defined in NEI 04-07 Section 6 to address the effects of loss-of-coolant accident (LOCA)-generated debris on ECCS and CSS recirculation functions for PBN1 and PBN2 (Reference 6 pp. 110-127). This is described in more detail in the Alternate Evaluation Methodology section.

Point Beach's use of the Alternate Evaluation Methodology follows the criteria set forth in the Safety Evaluation presented in NEI 04-07, Volume 2. One element of the alternate evaluation methodology includes relaxation of single failure criteria for evaluating Region II breaks. Point Beach has determined that an Exemption Request should be submitted for exemption from Point Beach General Design Criteria (GDC) 41. GDC 41 requires the performance capability of the ECCS to accommodate a single failure. No license amendment request is associated with this change as the station is implementing an alternate evaluation methodology approved by the NRC for its intended purpose. No change is proposed to existing station Safety Analyses. No change is required to the existing station LOCA response procedures.

Changes to the Licensing Basis

The PBN UFSAR was updated in 2007 to reflect the containment sump recirculation strainer perforation size for the replacement strainers. Final changes to the PBN UFSAR will be evaluated after approval of the PBN-specific exemption request and receipt of the final closeout letter from the NRC. The changes will be made consistent with the requirements of 10 CFR 50.71 (e).

Improvements in Processes and Programs

NEE has completed a review of plant procedures, processes, and programs and has updated those procedures and design specifications or standards that will ensure the analysis inputs and assumptions can be maintained.

Conservatisms and Margins

NEE applied conservative measures to assure adequate margins throughout the actions taken to address the GL 2004-02 concerns. The key areas in which these conservative measures were applied are discussed later in the Margins and Conservatisms section.

1. Overall Compliance

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

> *GL2004-02 Requested Information Item 2(a)*
> *Confirmation that the ECCS and CSS recirculation functions under debris loading conditions are or will be in compliance with 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 has been updated to reflect the results of the analysis described above.*

Response to 1:

Confirmation

NEE has completed all necessary analyses, with the exception of NRC acceptance of the in-vessel blockage analysis. NEE has previously completed several plant modifications in PBN1 and PBN2 and is planning future modifications as described in Section 2.

Applicable Regulatory Requirements

The applicable regulatory requirements identified in GL 2004-02 (Table 1-1) are:

10 CFR 50.46 "Acceptance Criteria for Emergency Core Cooling Systems for Light-Water Nuclear Power Reactors"
10 CFR 50.67 "Accident Source Term"
10 CFR 100 "Reactor Site Criteria"

PBN is a pre-GDC plant. The GDCs applicable to Point Beach are described in Table 1-1.

Table 1-1: PBN GL 2004-02 Regulatory Compliance

Regulation	Applicable Requirement	PBN Basis for Compliance with GL 2004-02
10 CFR 50.46 (b)(5)	Long-term cooling. After any calculated successful initial operation of the ECCS, the calculated core temperature shall be maintained at an acceptably low value and decay heat shall be removed for the extended period of time required by the long-lived radioactivity remaining in the core.	• New sump strainers ensure adequate net positive suction head (NPSH) during recirculation with margin for chemical effects. • Replacement of Mineral Wool insulation on each of the pressurizers with reflective metallic insulation (RMI) reduces potential strainer fiber loading. • Replacement of fibrous insulation on the RCPs and main loop with RMI also reduces potential strainer fiber loading. • Programmatic controls ensure that strainer design basis loads will not be exceeded. • Walkdowns and the Sump Water Level Calculation have confirmed that design basis sump water supply will be available. • Downstream effects evaluations confirmed that no other modifications are required to ensure long-term cooling capability is maintained. • Coating adhesion tests confirm that current inspection methods are adequate to control quantity of degraded qualified coatings. • Evaluation of in-vessel chemical effects confirms that fuel temperatures will be maintained at an acceptably low value.
PBN GDC 41	Criterion 41 – Engineered Safety Features Performance Capability. Engineered safety features, such as the emergency core cooling system and the containment heat removal system, shall provide sufficient performance capability to accommodate the failure of any single active component without resulting in undue risk to the health and safety of the public.	PBN will submit an exemption request to the single active component failure criterion separate from this submittal.

Regulation	Applicable Requirement	PBN Basis for Compliance with GL 2004-02
PBN GDC 44	Criterion 44 – Emergency Core Cooling System Capability. An emergency core cooling system with the capability for accomplishing adequate emergency core cooling shall be provided. This core cooling system and the core shall be designed to prevent fuel and clad damage that would interface with the emergency core cooling function and to limit the clad metal-water reaction to acceptable amounts for all sizes of breaks in the reactor coolant piping up to the equivalent of a double-ended rupture of the largest pipe. The performance of such emergency core cooling system shall be evaluated conservatively in each area of uncertainty.	The assurance of long-term cooling capability during recirculation ensures that the design basis emergency core cooling capabilities are maintained.
PBN GDC 52	Criterion 52 – Containment Heat Removal Systems. Where an active heat removal system is needed under accident conditions to prevent exceeding containment design pressure, this system shall perform its required function, assuming failure of any single active component.	The assurance of long-term cooling capability during recirculation ensures that the design basis containment heat removal capabilities are maintained.
PBN GDC 70	Criterion 70 – Control of Releases of Radioactivity to the Environment. The facility design shall include those means necessary to maintain control over the plant radioactive effluents, whether gaseous, liquid, or solid. Appropriate holdup capacity shall be provided for retention of gaseous, liquid, or solid effluents, particularly where unfavorable environmental conditions can be expected to require operational limitations upon the release of radioactive effluents to the environment. In all cases, the design for radioactivity control shall be justified (a) on the basis of 10 CFR 20 requirements, for both normal operations and for any transient situation that might reasonably be anticipated to occur and (b) on the basis of 10 CFR 100 dosage level guidelines for potential reactor accidents of exceedingly low probability of occurrence.	Assurance of long-term cooling capability during recirculation ensures that containment spray capability is maintained which, in turn, ensures that containment atmosphere cleanup capability is preserved.

2. General Description of and Schedule for Correction 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 Requested Information Item

2(b). (Note: All requests for extension should be submitted to the NRC as soon as the need becomes clear, preferably no later than October 1, 2007.)

GL 2004-02 Requested Information Item 2(b)
A general description and implementation schedule for all corrective actions, including any plant modifications that you identify while responding to this generic letter. 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 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.

Response to 2:

The corrective actions to address the concerns identified in GL 2004-02 at PBN consisted of plant modifications, testing and analysis, and changes to plant programs and processes. These actions have been completed in accordance with NextEra regulatory commitments and NRC-approved extensions. The completion dates for future modifications are provided below.

Plant Modifications

- At PBN1 and PBN2 the original sump screens have been removed and replaced with new strainer systems. These systems ensure adequate NPSH during recirculation with margin for chemical effects for Region I breaks. For Region II breaks, these systems ensure adequate NPSH during recirculation when two strainer operation is credited. See the discussion in the Alternate Evaluation Methodology section.
- The mineral wool insulation on the sides of the pressurizers for both units has been replaced with RMI.
- The fibrous insulation on both RCPs in PBN1 have been replaced with RMI. The fibrous insulation on one of the two RCPs in PBN2 have been replaced with RMI. A modification is planned to install RMI on the Loop B RCP in Unit 2 in the Fall of 2018.
- Portions of the fibrous insulation on the Unit 2 main RCS loop piping have been replaced with RMI. Note that the insulation on Unit 1 main RCS loop piping is RMI.
- A 16-inch diameter opening has been bored to connect the normal containment operating sump with the accident sump on each unit. This ensures that in the event of a break at a reactor vessel nozzle there will be an adequate flow path (that will not be blocked by debris) for break flow to return to the strainers without holding up volume in the instrumentation keyway "tower".
- The refueling cavity drain lines in each unit have been relocated to prevent direct impingement on, and ingestion of air into, one of the strainer trains. An additional

modification is planned to extend the drain line in the lowest elevation of Containment in Unit 1 in the Spring of 2019, and a similar change will be made in Unit 2 in the Fall of 2018.

- A hard cover under Stairway #22 in Unit 1 has been installed to protect Strainer A, which is located below the stairway, from debris washed down by containment spray. A modification is planned in the Spring of 2019 to extend the hard cover close to the floor to minimize turbulence and prevent a potentially air entraining cascade of water close to the strainer.
- Debris interceptors on the 8' Elevation, 10' Elevation, and 66' Elevation were installed in Unit 1 in 2008. The original design function of these interceptors was to capture and retain transportable debris. However, this intent was subsequently found to not be viable / defendable, and they are no longer credited with that function. However, the interceptors are credited with slowing and lengthening the flow path from debris sources to the strainers to minimize the transport of debris, and are currently referred to as perforated flow diverters. In 2010, two debris interceptors were permanently removed from the 10' Elevation. A modification is planned to remove two more debris interceptors from the 8' Elevation (reducing the total to three debris interceptors at Unit 1) and a toe plate at the top of Stairway # 22 from the 66' Elevation, since the debris transport analysis has shown that making these modifications has minimal impact on the resolution of GSI-191. The purpose of these modifications is to facilitate personnel access during outages.

Testing and Analyses

The testing and analyses needed to address GL 2004-02 concerns were completed in 2017. The in-vessel blockage analysis was performed using a methodology that is not yet approved by the NRC. Upon NRC approval of the methodology, a review will be performed to determine if the methodology changed from that used to provide the results in this submittal. If the review determines that the methodology used to obtain the results provided in this submittal is the same, then NextEra is not planning any further actions. If the review determines that the methodology has changed to alter the results provided in this submittal, then a reanalysis will be performed and the results provided to the NRC for their review and acceptance. If an updated response to the in-vessel blockage analysis is required, this will be performed within six months following NRC approval of the methodology.

Plant Programs and Processes

Significant program and process changes necessary to address the GL 2004-02 concerns were completed by December 31, 2007.

Procedural controls are in place to reduce and control the amount of loose debris and fibrous material in containment. Procedures require inspection of all accessible areas to verify that no loose debris, fibrous material that could degrade into loose debris, or bubbling/chipping paint is present prior to setting containment integrity. Any entry performed while containment integrity is set requires subsequent walkdowns of areas affected by the entry to confirm no loose debris or foreign material was left in containment.

The maintenance director is in charge of maintaining the general housekeeping of containment, which includes tracking the overall cleanliness of containment and promptly correcting identified deficiencies.

Foreign material exclusion programmatic controls are in place, which ensure that proper work control is specified for debris-generating activities within the containment building. This assists in preventing introduction of foreign material into containment, which could potentially challenge the containment recirculation function. Additionally, the foreign material exclusion program requires that engineering be consulted any time foreign material covers are placed on, or modifications are performed on, the containment sump strainers. Lastly, the containment entry procedure provides additional controls to evaluate foreign materials to be brought into containment and ensure they are removed during at power entries.

PBN engineering change processes and procedures ensure modifications that may affect the ECCS, including sump performance, are evaluated for GL 2004-02 compliance. During engineering change preparation, the process requires specific critical attributes be listed, evaluated, and documented when affected. This includes the introduction of materials into containment that could affect sump performance or lead to equipment degradation. It also includes repair, replacement, or installation of coatings inside containment, including installing coated equipment.

PBN has adopted the industry's standard design change process. The standard process and tools are intended to facilitate sharing of information, solutions and design changes throughout the industry. This process requires activities that affect UFSAR described structure, system, or component (SSC) design functions to be evaluated as a design change in accordance with NextEra's 10 CFR 50 Appendix B program. This includes modifications that would impact the containment sump. Design changes require a final impact review meeting (i.e., final design workshop) and assessment in accordance with 10 CFR 50.59. Additional meetings may be required based on the complexity and risk of the change. A failure modes and effects analysis is required if the design change introduces any new failure modes or changes failure modes for the affected SSCs.

This guidance has been enhanced by an engineering specification that brings together, in one document, the insulation design documents that determine the design basis for the insulation debris component of the containment recirculation strainer design. This specification provides guidance for evaluating and maintaining piping and component insulation configuration within the containment buildings at PBN1 and PBN2. In addition, the PBN procedure for controlling work orders was revised to assure that insulation work inside containment required signoff to the requirements of this specification.

Temporary configuration changes are controlled by plant procedure, which maintain configuration control for non-permanent changes to plant structures, systems, and components while ensuring the applicable technical and administrative reviews and approvals are obtained.

In accordance with 10 CFR 50.65 (Maintenance Rule), an assessment of risk resulting from the performance of maintenance activities is required. Prior to performing maintenance, PBN assesses and manages the increase in risk that may result from the proposed maintenance activities. In general, the risk assessment ensures that the maintenance activity will not adversely impact a dedicated/protected train, which ensures a system is capable of performing its intended safety function.

Licensing Basis

The PBN UFSAR was updated in 2007 to reflect the containment sump recirculation strainer perforation size for the replacement strainers.

Final changes to the PBN UFSAR will be evaluated after approval of the PBN-specific exemption request and receipt of the final closeout letter from the NRC. The changes will be made consistent with the requirements of 10 CFR 50.71 (e).

Alternate Evaluation Methodology

Section 6 of the NEI 04-07 Guidance Report (GR) describes an alternate evaluation methodology for demonstrating acceptable containment sump performance (Reference 7, pp. 6-1 to 6-18). The alternate evaluation methodology proposes separate analysis methods for two distinct break size regions (Reference 6 p. 113):

- Region I:
  - Defined as all breaks up to and including DEGBs on the largest piping connected to the RCS loop piping AND partial breaks on the RCS loop piping up to a diameter of 196.6 in^2 (equivalent to a 15.8-inch diameter break). This is referred to as the alternate break size in the GR (Reference 7, p. 6-1). The terms alternate break size and debris generation break size (DGBS) are used synonymously in the NRC safety evaluation report (SER) (Reference 6 pp. 110-115).
  - Analysis methods must meet the typical design basis rules for a deterministic evaluation.
- Region II:
  - Defined as breaks larger than the Region I break size up to and including DEGBs on the RCS loop piping.
  - Mitigative capabilities must be demonstrated, but the fully deterministic design basis rules do not necessarily apply.

The alternate evaluation methodology can be used to demonstrate reasonable assurance of adequate long term core cooling for the bounding breaks in Region II by allowing for the use of more realistic assumptions and methods, credit for mitigative operator actions, and use of non-safety related equipment. Based on various considerations, the staff determined that the division of the pipe break spectrum proposed for evaluating debris generation is acceptable based on operating experience, application of sound engineering judgment, and consideration of risk-informed principles. Licensees using the methods described in Section 6 of the GR can apply the DGBS for distinguishing between Region I and Region II analyses (Reference 6 p. 114).

As shown in this submittal, there is reasonable assurance that the effects of debris would not result in the loss of long-term core cooling for any of the Region II breaks, and these breaks would be successfully mitigated.

Region I Evaluation

The PBN1 and PBN2 evaluation for Region I considered DEGBs for Class 1 ISI welds on piping connected to the RCS main loops, which have a maximum nominal pipe diameter of 10 inches, as well as postulated 17-inch partial breaks on the main loop piping (including multiple break orientations at each main loop ISI weld location). The debris quantities for the bounding Region I break locations are described in the Response to Item 3.b.

These bounding Region I breaks were evaluated in accordance with NRC-approved methods for a deterministic evaluation (with the exception of the WCAP-17788 methodology, which is still being reviewed by the NRC), and were shown to meet all acceptance criteria. The details of this evaluation are described in Section 3.

Region II Evaluation

The Region II evaluation for PBN1 and PBN2 was limited to breaks larger than 17 inches on the main loop piping, and these breaks were analyzed using bounding DEGB quantities at the worst-case break locations. The debris quantities for the bounding Region II break locations are described in the Response to Item 3.b.

Downstream effects (both in-vessel and ex-vessel) were evaluated for the bounding Region II breaks in accordance with NRC-approved methods for a deterministic evaluation (with the exception of the WCAP-17788 methodology, which is still being reviewed by the NRC), and were shown to meet the relevant acceptance criteria. Therefore, the use of the alternate evaluation methodology is limited to strainer head loss concerns.

The bounding Region II debris quantities exceed the debris quantities that were used in the prototypical strainer head loss testing. Therefore, these breaks cannot be addressed using the standard deterministic methodology and were evaluated using the alternate evaluation methodology. There is reasonable assurance that these breaks would not fail based on:

- Proceduralized operator actions
- Realistic assumptions and methods
- Use of non-safety related equipment

Operator Actions

Following a LOCA, the following sequence of events would occur based on automated actions and operator actions performed in accordance with the plant emergency operating procedures (EOPs) :

- Both trains of RHR pumps and containment spray (CS) pumps would be started automatically taking suction from the refueling water storage tank (RWST) upon receipt of a prerequisite safety actuation signal. The RHR pumps provide safety injection flow to the core via upper plenum injection.
- The injection flow from the residual heat removal (RHR) Train B pump would be checked, and if flow is adequate, the RHR A pump would be stopped to maximize the RWST injection time.
- Both RHR trains would be aligned for recirculation after the RWST level reaches the low level. However, the RHR A pump would not be started at this point resulting in initial debris accumulation being limited to the RHR B Strainer.

- When the RWST reaches the low-low level, the CS A pump would be realigned to take suction from the RHR A pump, which would be started at this time. The RHR A pump would provide flow both to the CS and the core (via upper plenum injection). While both RHR pumps are running, debris would be split essentially equally between the two strainers.
- At the time when the RHR A pump is started and the CS A pump is aligned for recirculation, the RCS injection valves would be throttled for both trains to limit the injection flow.
- Also, the operators would start refill of the RWST with the makeup system at this time.
- After containment spray has operated on recirculation for a set period, the operators would align the SI B pump to take suction from the RHR B pump. This step is taken to provide cold leg injection along with upper plenum injection to prevent boric acid precipitation.
- In addition, following confirmation of chemical addition and containment pressure conditions, the CS A pump would be secured at this time.
- During recirculation, operators monitor containment sump level, RHR pump operation (normal), and low head injection flow (stable) to verify adequate containment sump performance. Core exit thermocouples are also monitored by the operators to determine if core blockage is occurring.
- If containment sump recirculation cannot be verified with the above indications, the operators would enter an emergency contingency action (ECA) procedure. In this procedure, they would monitor for any indications of pump cavitation by observation of the recirculation sump level, CS pump flow, CS pump discharge pressure, RHR pump flow, RHR pump discharge pressure, safety injection (SI) pump flow, SI pump current, or SI pump discharge pressure.
- The operators would try to reestablish adequate core cooling flow by stopping any SI or CS pumps being supplied by the affected RHR pump(s) .
- If necessary, the RHR flow control valve for the affected pump would be adjusted until minimum RHR injection flow, without cavitation, is achieved.
- Also within this procedure, steps would be taken to makeup to the VCT and realign the charging pump to it. At least one charging pump is started to provide core cooling flow with the VCT continuing to receive auto makeup.

Based on these procedural steps, the maximum flow rates for each strainer are shown in Table ABM-1.

Table ABM-1: Maximum Strainer Flow Rates for Two-Train Operation

Event Sequence	Strainer A Flow Rate (gpm)	Strainer B Flow Rate (gpm)
RWST Level Above 34%	0	0
RWST Level Below 34% (RHR B)	0	2,100
RWST Level Below 17% (RHR B, RHR A + CS A)	2,100	1,600
After 2 hours of CS Recirc (RHR B + SI B, RHR A)	1,600	2,100

Analysis

The quantity of debris generated and transported for bounding Region II breaks at both PBN1 and PBN2 is approximately double the quantity that was tested (see the Response to Item 3.b). Both units have independent (and equivalent size) strainers for each train of ECCS. Because both ECCS trains would be placed in service during recirculation by procedure, the ECCS strainers would be able to accommodate more than twice the debris load tested (since the head loss using the tested debris loads did not result in strainer failures).

Operators are directed to start recirculation through both RHR trains (Train A preferentially aligned for containment spray and Train B preferentially aligned for SI), so debris would accumulate approximately equally on both strainers. Because the Train B RHR pump would preferentially be switched over first, the Train B strainer would tend to accumulate more debris. Chemical precipitation would not be expected to occur for several hours, however, which makes it unlikely that the RHR B pump would fail early in the event, even if the conventional debris load exceeds the quantity tested. As described in the Response to Item 3.f, the strainer testing showed that there is available margin with approximately half the quantity of conventional debris and the full quantity of chemical debris that would be generated for a bounding Region I break.

In addition, the procedural steps described above that reduce flow demand on the strainer will result in a reduced head loss across the strainer. This was seen in the testing described in the Response to Item 3.f.4. Flow sweeps were performed for the debris laden strainer and the resulting decrease in head loss was pronounced. Further, industry testing has shown that stopping a pump and then restarting it will result in changes to the debris bed with the resulting final head loss lower than the head loss prior to stopping the pump.

Risk Evaluation

The relaxation of requirements for Region II breaks is appropriate based on the low frequency associated with breaks that are greater than or equal to 15.8 inches. Based on NUREG-1829 Table 7.19, the mean frequency of breaks greater than or equal to 14 inches is only 2.0E-07 yr^{-1} (Reference 8, p. 7-55). In other words, even if all Region II breaks were to fail due to the effects of debris, the risk associated with these failures (in terms of change in core damage frequency, or ΔCDF) would be less than 1.0E-06 yr^{-1}, which is defined as a very small change in Regulatory Guide (RG) 1.174 (Reference 9 pp. 15-17).

Defense-in-Depth

As described in the NEI document with defense-in-depth measures for GSI-191, there are a range of measures at operating pressurized water reactors (PWRs) that either currently exist or could be developed to detect or mitigate potential sump blockage issues (Reference 10, Attachment). Several of these measures are applicable to PBN.

Detection of potential sump blockage issues would be performed as discussed above. During recirculation, operators monitor the containment sump level, and ensure the RHR pump operation is normal and low head injection flow is stable to verify adequate containment sump performance. The operators also monitor the core exit thermocouples for an increase in temperature to determine if core blockage is occurring. If containment sump recirculation cannot be verified with the above indications, the operators would monitor for any indications of pump cavitation by observation of the recirculation sump level, CS pump flow, CS pump discharge pressure, RHR pump flow, RHR pump discharge pressure, safety injection (SI) pump flow, SI pump current, or SI pump discharge pressure. Additional mitigative measures, beyond those previously discussed, which are applicable to PBN, are considered below.

In addition to the ECA procedure for addressing sump blockage described previously under operator actions, there is a separate ECA procedure for loss of containment sump recirculation, which has numerous actions that could be taken to provide core cooling. These include:

- Refilling the affected unit's RWST through various flow paths including normal makeup and transferring water from the fuel transfer canal, the holdup tanks, the unaffected unit's RWST, or the spent fuel pool
- Attempting to establish minimum injection flow with charging pumps
- If sufficient RWST level exists, starting an SI pump and RHR pump at reduced flow rates
- Aligning an SI pump suction to a boric acid storage tank

Additionally, the strainers could be back-flushed by opening the RHR pump suction from the containment valves and the RHR pump suction from the RWST valves to allow the RWST to gravity flow back through the affected strainer. Gravity flow backflush could also be accomplished using the unaffected unit's RWST. While these backflush steps are not currently proceduralized, the valves could be opened for a short amount of time to dislodge debris from the strainer surface and restore NPSH margin. The backflush steps could be added to the sump blockage ECA and could be performed in parallel with other actions.

The proposed procedure changes will be evaluated and the necessary changes made to provide for performance of these actions, and to establish the necessary alignment between the procedures. This evaluation will occur after NRC review and acceptance of the approach provided in this submittal.

PBN1 and PBN2 both use upper plenum injection (UPI) and, as described previously, switch to simultaneous injection after sprays are operated on recirculation for 2 hours. UPI plants have very little potential for core blockage since the coolant is injected at the top of the core. If a debris bed were to form and block flow, the subsequent boiling in the core would disrupt the debris bed and reestablish core cooling.

Finally, even if long term core cooling was lost and core damage did occur, the severe accident mitigation guidelines (SAMGs) for PBN would be implemented to effectively mitigate the event and protect plant personnel and the public.

Conclusion

Region I breaks (including all breaks smaller than 17-inches) have been fully addressed using deterministic methods.

There is also reasonable assurance that long term core cooling can be provided for the bounding Region II breaks based on the proceduralized operator actions and a realistic assessment of the actual accumulation and effects of debris on the ECCS strainers.

Also, the significant margins and conservatisms described in the following section and the ability to use additional mitigative measures such as the EOPs and ECAs as well as the SAMG strategies provide reasonable assurance that all Region II breaks would be successfully mitigated.

Finally, a bounding evaluation shows that the risk associated with loss of long-term core cooling due to the effects of debris is very low.

Margins and Conservatisms

The following margins and conservatisms were utilized in the GSI-191 analysis.

Debris Generation

Margins:

- The quantity of latent debris used to determine the strainer head loss is 150 lbm, but the actual amount of latent debris documented for the plant is 62 lbm for PBN1 and 55 lbm for PBN2. These quantities are well below the quantity used to determine the strainer head loss.
- The amount of miscellaneous debris was conservatively increased to 200 ft^2, rather than using the walkdown values of 120 ft^2 (PBN1) and 152 ft^2 (PBN2).

Conservatisms:

- Shadowing by the reactor or structures was not considered for reactor nozzle breaks. ZOIs at these breaks were truncated to the primary shield wall and a line-of sight cone projecting out the closest primary shield penetration to the radius of the ZOI sphere.
- 100% of unqualified coatings were assumed to fail for all breaks, conservatively maximizing the potential unqualified coatings load in the recirculation pool.
- Qualified coatings inside the ZOI were assumed to fail as 100% particulate, conservatively treating it as the most easily transportable debris type.

Debris Transport

Margins:

- During pool fill, the transport to the inactive reactor cavity was conservatively limited to 15% for fine, small, and large debris. Note that the transport to the inactive cavity without the limitation was calculated to be 71% for PBN1 and 77% for PBN2.

Conservatisms:

- It was conservatively assumed that all unqualified coatings are located in lower containment and fail at the start of the event. This is conservative since it results in 100% of unqualified coatings being present in the pool at the start of recirculation and results in 100% transport of this debris.
- All fine debris blown to upper containment was conservatively assumed to be washed back down by the containment spray flow. This conservatively includes debris blown up onto holdup areas protected from the containment spray path (on the primary shield walls, the shield walls around the pressurizer, and the bottom side of the over-head floor slabs).
- Small pieces of debris on the operating deck were assumed to wash to lower containment without any retention on grating.

- Additional levels of grating below the operating deck were neglected during washdown. This is conservative, since the maximum amount of debris will be washed down to lower containment without any credit for additional retention on gratings.
- Turbulent kinetic energy (TKE) and velocity plots were created to determine the recirculation transport fractions. The TKE sufficient to suspend debris was conservatively assumed to exist at any elevation in the pool, when it may only exist at a discreet elevation. This conservatism results in all applicable debris at that location being assumed to remain in suspension and transport, when in some cases, the TKE would only keep debris at select elevations (such as the pool surface) in suspension.
- The flow of water falling from the reactor coolant system breach was assumed to do so without encountering any structures before reaching the containment pool. This is conservative since any impact with structures would dissipate the momentum of the water and decrease the turbulent energy in the pool.
- When given a size range for insulation debris, the debris was conservatively treated as if it existed entirely at the smaller end of the size range. For example, large pieces of fiberglass debris (larger than 6 inches on a side) were treated as 6 inch pieces. This ignores the fact that larger pieces in the size range would be less easily transported, conservatively increasing transport fractions overall.
- It was assumed that all small and large pieces of Temp-Mat debris would float in the recirculation pool until it is transported to the strainers (100% recirculation transport). This assumption ignores the potential for a portion of the debris to become saturated with water and settle to the floor.
- It was conservatively assumed that fibrous debris fines suspended in the recirculation sump pool would not be captured by equipment or components in containment. Testing has demonstrated that fiber fines will attach themselves to components readily, which would result in a significant reduction of the quantity of fines that would make it to the strainer.
- The debris interceptors that are installed in Unit 1 are not credited with reducing the fine debris load at the strainers. In reality, these debris interceptors would capture some of the fine debris that is generated.

Water Volume and Level

Conservatisms:

- Although it is not possible for an LBLOCA to occur in the safety/relief lines at the top of the pressurizer (because the inner diameter of the piping limits DEGBs to either SBLOCA or MBLOCA), the full volume of the pressurizer is treated as a hold-up volume for LBLOCAs. Note that this hold-up is only applied to breaks at an elevation above the centerline of the main loop piping. This conservatism results in a smaller pool volume in the LBLOCA case as more liquid is held up.

- An additional 5% of the volume held-up due to condensation on the containment surfaces was considered as hold-up for the minimum water level estimates. This conservatism leads to slightly less volume in the sump in the minimum water level estimates.
- Initial RWST level was assumed to be at the Technical Specification minimum level. This is the minimum required water volume for the RWST. Using this smallest value decreases the total amount of inventory creditable for injection, thus minimizing the final pool volume.
- Final RWST level was assumed to be at the low level with instrument uncertainty accounted for in the positive direction (meaning a volume larger than the low level volume remains). This is the maximum amount of water remaining in the RWST post-injection. Using this largest value decreases the total amount of inventory creditable for injection, thus minimizing the final pool volume.
- The pre-LOCA containment atmosphere was assumed to be at 0% relative humidity, and the post-LOCA containment atmosphere was assumed to be at 100% relative humidity. The amount of steam hold-up in the atmosphere was calculated by subtracting the water vapor hold-up pre-LOCA from the steam hold-up post-LOCA; thus, the water vapor hold in the containment atmosphere was maximized, thereby reducing the pool volume.

NPSH

Conservatisms:

- Head loss testing was conducted at a flow rate range equivalent to 2,100 gpm, which is 5% above the maximum RHR flow rate of 2,000 gpm used in the limiting recirculation alignment for RHR NPSH. Head loss data was inserted into NPSH equations without scaling the head loss to a flow rate of 2000 gpm. Since scaling down the flow rate would have reduced the head loss across the strainer, resulting in greater NPSH Margin (NPSHM), this is conservative.
- Head loss testing was conducted using water at 120 °F. Head loss values were inserted into the NPSH equations without scaling the head loss to plant sump temperature. Since scaling up the temperature would have reduced the head loss across the strainer, resulting in greater NPSHM, this is conservative.
- Differential pressure between the strainer suction and RHR suction used for the current NPSH evaluation was determined at the flow rates used in the previous PBN NPSH evaluation. The flow rate previously used for the limiting alignment for RHR NPSHM (PBN1 Case R4A) was 2,088 gpm, which is 4% higher than the maximum RHR flow rate of 2,000 gpm imposed for that recirculation alignment. This differential pressure was inserted into the revised NPSH evaluation without scaling the differential pressure to account for the reduced flow rate. Since scaling the differential pressure to account for the reduced flow rate would have increased NPSHM, this is conservative.

Strainer Structural Analysis

Margins:

- The strainer structural analysis provides margin to design allowable stresses, which ensures that the strainer system will perform its function as long as necessary following an event that requires its use. Response to 3.k.2 contains an itemized strainer component list and the margin for each component, which varies from 1% to 99%.

Conservatisms:

- Use of the code of record (Reference 11) provides the conservatism inherit within the code itself.

Head Loss

Conservatisms:

- The quantity of latent debris used to determine the strainer head loss is 150 lbm, but the actual amount of latent debris documented for the plant is 62 lbm for PBN1 and 55 lbm for PBN2. These quantities are well below the quantity used to determine the strainer head loss.
- A sacrificial strainer area of 150 ft^2 (after 25% overlap is considered) was used when determining the testing parameters. In reality, the actual quantity of miscellaneous debris is 120 ft^2 at PBN1 and 152 ft^2 at PBN2, which would result in a 90 ft^2 (120 ft^2 x 75%) reduction in strainer area at PBN1 and a 114 ft^2 (152 ft^2 x 75%) reduction in strainer area at PBN2.

Penetration

Conservatisms:

- For penetration testing, the number of disks in the test strainer was reduced to 7 from 10 and the disk spacing was increased to 1.75". This decreased the likelihood of the development of a fiber bridge across adjacent disks. Fiber bridges can block flow paths to certain interstitial parts of the strainer, effectively reducing the penetrable surface area of the strainer.

Chemical Effects

Margins:

- The aluminum metal inventory includes a 10% contingency margin.
- For both units, the E-Glass in containment inventory includes a 5% design contingency.
- For both units, the mineral wool in containment inventory includes a 5% design contingency.

Conservatisms:

- Debris quantities used to calculate chemical products bound the maximum amount of debris predicted in the debris generation calculation from the bounding LOCA break in the break location modeled.
- Maximum pH values were conservatively used to increase the calculated aluminum release, and minimum pH values were conservatively used to decrease the calculated aluminum solubility.
- The maximum containment sump pool water mass was conservatively used for the 30-day post-LOCA event in cases where the goal was to determine the maximum calculated aluminum release. The minimum containment sump pool mass was used in separate cases to maximize the aluminum concentration for the purpose of conservatively maximizing the aluminum precipitation temperature.
- Maximum temperature profiles were conservatively assumed for the 30-day post LOCA event to increase the calculated aluminum release.
- All destroyed insulation and latent debris was conservatively assumed to be submerged.
- It was conservatively assumed that the submerged quantity of aluminum would be available to interact with the sump pool, and the unsubmerged quantity of aluminum would be available to interact with the containment spray. This is conservative because some of the listed materials would not be sprayed or would be submerged in a portion of the pool that does not interact with the fluid that recirculates through the containment sump strainer.
- The total quantity of aluminum in solution was assumed to precipitate after the concentration exceeds the calculated solubility limit.
- For pressurizer compartment breaks, it was assumed that the bounding amount of aluminum coatings that could be exposed by a LOCA in the pressurizer compartment would be exposed, instantly destroyed, and present in the containment sump pool to contribute to aluminum release.
- For reactor cavity breaks, it was assumed that the bounding amount of aluminum coatings that could be exposed by a LOCA in the reactor cavity would be exposed, instantly destroyed, and present in the containment sump pool to contribute to aluminum release.

In-Vessel

Conservatisms:

- The values presented for core inlet and total reactor vessel fiber loads in the Response to 3.n.1 are for the entire 30-day mission time. This is conservative because the in-vessel fiber loads should be compared to the acceptance criteria prior to the conclusion of the 30-day mission time according to the methodology in WCAP-17788.

- PBN1 and PBN2 are upper plenum injection (UPI) plants, which reduces the likelihood that fiber accumulation in the core would result in a disruption in core cooling. This is because the ECCS flow is injected into the upper plenum, above the active core region. The high velocity flow from the upper plenum injection nozzles along with boiling that is occurring in the core would disrupt any accumulation of fiber to form a contiguous debris bed resulting in a disruption of core cooling. However, it is conservatively assumed that once the fiber accumulation acceptance limit is reached, the necessary core cooling would be disrupted.

Downstream Effects: LOCADM

Margins:

- Peak Cladding Temperature (PCT) – The maximum PCT in the LOCADM analysis is 358 °F with an acceptance criterion of 800 °F, resulting in a margin of 442 °F.
- Deposition Thickness (DT) – The maximum DT in the LOCADM analysis is 28.8 mils with an acceptance criterion of 50 mils, resulting in a margin of 21.2 mils.

Conservatisms:

- The containment sump pool pH was assumed to remain at the maximum final containment sump pool pH of 9.5 throughout the duration of the event. This maximizes aluminum release over the entire duration of the analysis and increases the potential for deposition.
- The containment sprays were assumed to initiate immediately after a LOCA (time zero) and remain active for the entire thirty-day duration; this maximizes aluminum release over the entire duration of the analysis and increases the potential for deposition.
- The maximum sump temperature profile and the maximum containment temperature profile were used in the analysis because higher temperatures yield conservatively higher amounts of calculated aluminum releases, thereby increasing the total amount of deposition.
- The amount of fibrous debris that bypasses the sump strainer and is available for deposition in the core was assumed to be 100 grams per fuel assembly (g/FA). This value, which is greater than the bypassed fiber mass determined from testing, conservatively accounts for additional operating margins and leads to greater deposition thickness.
- An operating margin of 15% was conservatively added to the quantities predicted in the debris generation calculation for calcium silicate (Cal-Sil), asbestos Cal-Sil, Nukon, low-density fiberglass (LDFG), Temp-Mat, and mineral wool.

Ex-Vessel

Conservatisms:

- Only the minimum volume of recirculating fluid was assumed to be available through the entire mission time. This is conservative because minimizing the mass of recirculating water maximizes the debris concentration, and thus the amount of wear.

- When evaluating the components (other than the pumps and two safety injection valves), a constant wear rate was used (i.e., the debris concentration was assumed to remain constant).
- The erosive wear rate of carbon steel was used to evaluate the erosive wear of the components downstream of the strainer. This is conservative since stainless steel is more resistant to wear than carbon steel.
- The SI pumps were evaluated for the effects of wear with the assumption that they operate continuously for the full 30-day mission time. In reality, it is likely that these pumps would not operate continuously, but instead in brief intervals. Therefore, the wear evaluation in this analysis presents conservative results for the SI pumps at Point Beach.

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.

1. *Describe and provide the basis for the break selection criteria used in the evaluation.*

Response to 3.a.1:

The PBN1 and PBN2 debris generation calculations followed the methodology of NEI 04-07 (Reference 7) and associated NRC SE (Reference 6) with the exception that they analyzed a full range of breaks, not just the worst-case breaks as suggested by NEI 04-07. The purpose of the debris generation calculations was to obtain debris quantities for the full range of possible break scenarios. This method ensures that the most challenging break for Region I and Region II will be identified. The calculations evaluated debris generation quantities for breaks on every in-service inspection (ISI) weld identified within the Class 1 pressure boundary inside the first isolation valve, including breaks at the reactor nozzles. The following types of loss of coolant accident (LOCA) breaks were considered:

- Double-ended guillotine breaks (DEGBs) with the largest break being a DEGB of the 31" cross-over leg,
- Partial breaks, orientated 45° apart, at size increments of 0.5, 2, 4, 6, 8, 10, 12, 14, 17, 20, 23, and 26 inches
- Single-ended guillotine breaks (SEGBs) within 10 pipe diameters of a normally closed isolation valve or termination point.

In the debris generation calculations, three-dimensional computer-aided design (CAD) models of the PBN1 and PBN2 containment buildings were updated to work with ENERCON's BADGER software. BADGER was used to place ZOIs representing possible breaks on every ½" or larger ISI weld identified in containment inside the first isolation valve. Figure 3.a.1-1 shows the graphical representation of these weld locations for PBN1. Figure 3.a.1-2 shows the graphical representation of these weld locations for PBN2.

Per Section 3.3.5.2 of the NRC SE of NEI 04-07, evaluating breaks at equal increments is "only a reminder to be systematic and thorough". The use of Class 1 ISI welds as break locations is both systematic and thorough because they are closer to the components that contain the greatest quantity of debris sources as opposed to a span of straight pipe further way from these sources (see Figures 3.a.1-1 and 3.a.1-2). Also, welds are almost exclusively recognized as likely failure locations because they can have relatively high residual stress, are preferentially-attacked by many degradation mechanisms, and are most likely to have preexisting fabrication defects. Since each of the weld locations were evaluated for determination of the quantity of debris that would be generated, these locations, by observation, represent the limiting break locations.

In the alternate evaluation methodology, the breaks are separated into two regions based on an alternate break size. Breaks less than or equal to the threshold break size (17") are considered to be in Region I. Break sizes greater than the threshold break size are considered to be in Region II. Since the debris generation calculations evaluate the full range of break sizes (up to a DEGB) for each ISI weld in containment inside the first isolation valve, there are a complete set of breaks to choose from for either Region I or Region II analysis.

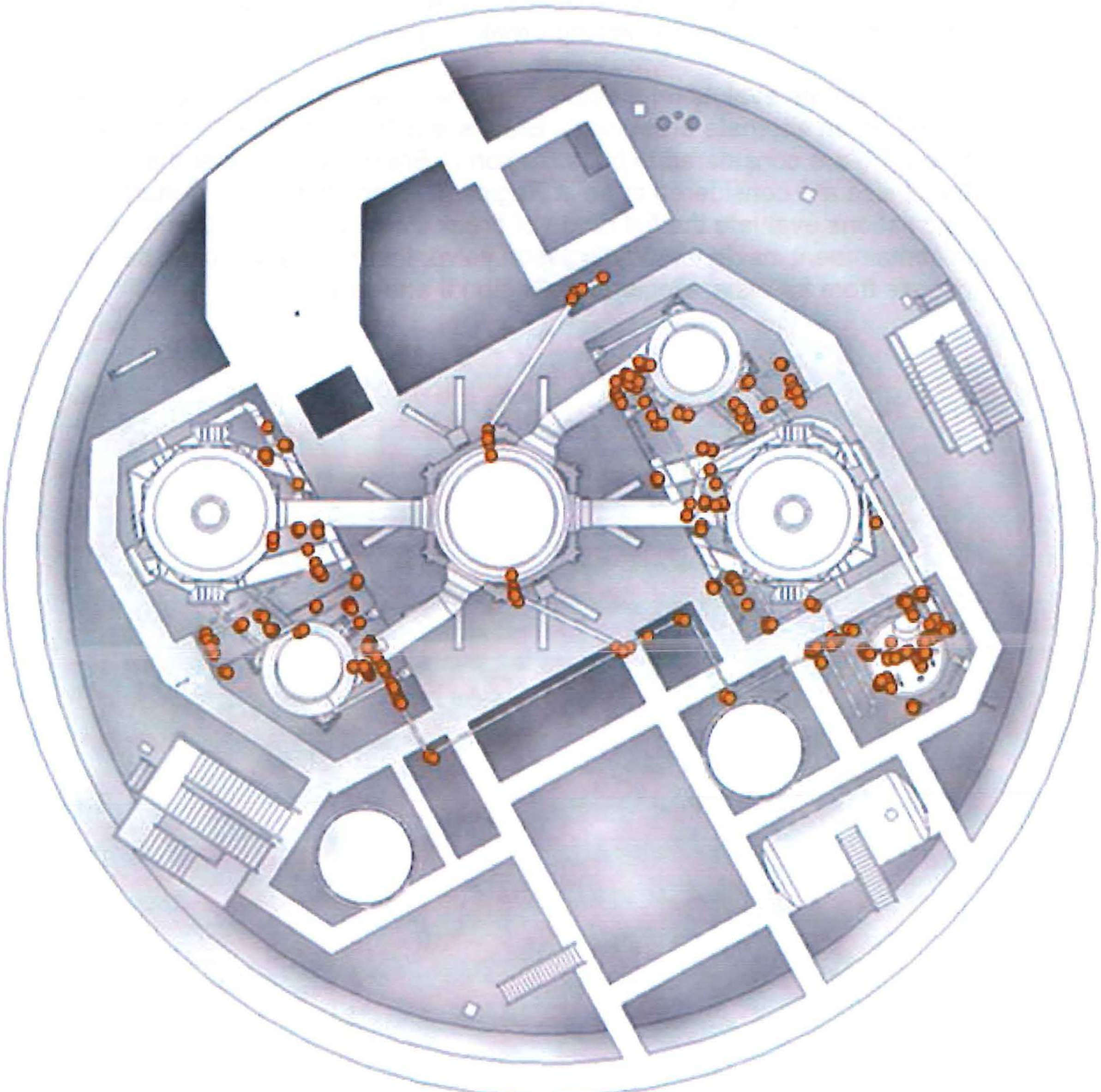


Figure 3.a.1-1: PBN1 Weld Locations Where Postulated LOCAs Occur

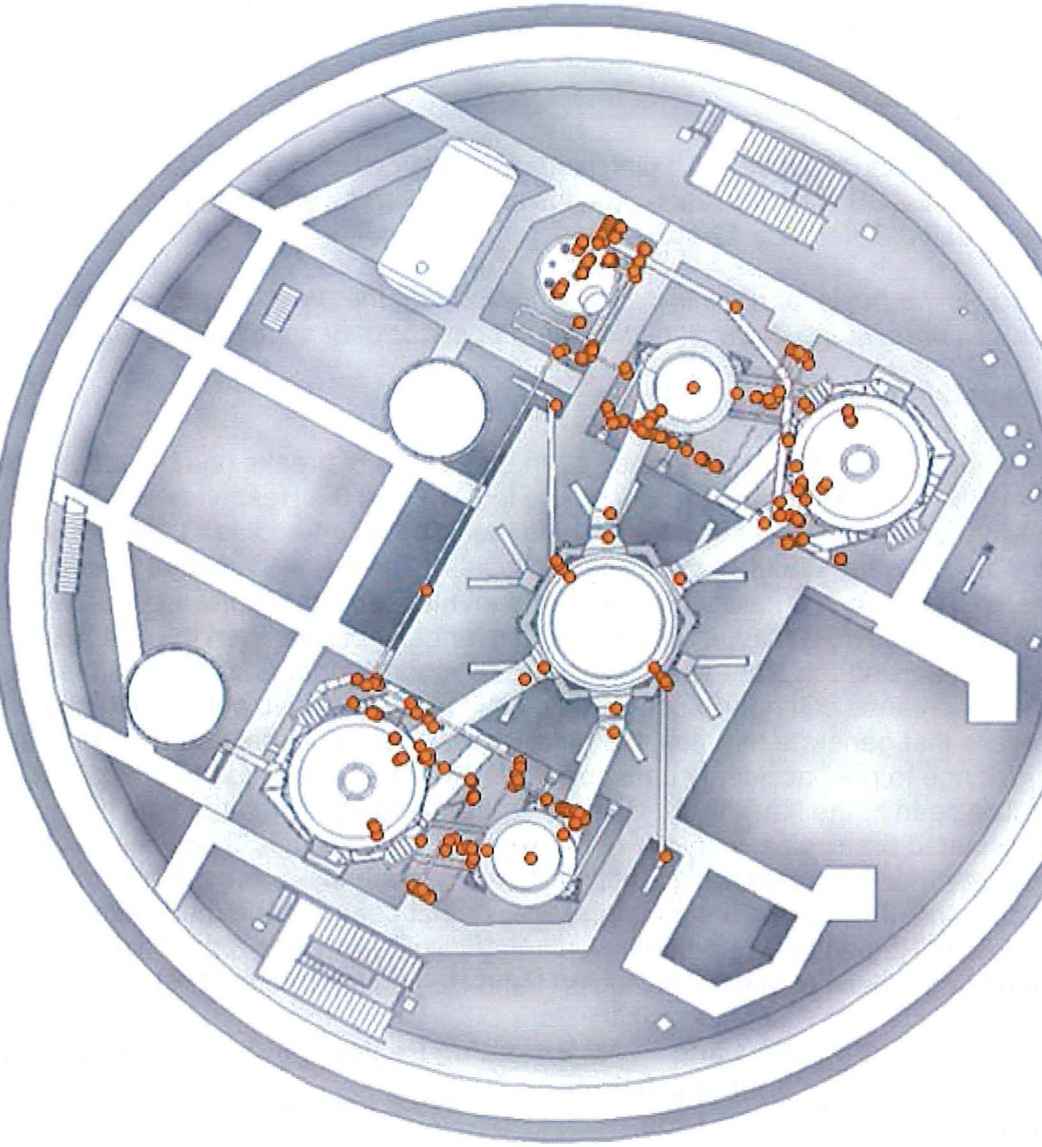


Figure 3.a.1-2: PBN2 Weld Locations Where Postulated LOCAs Occur

The most limiting breaks are those that contain sufficient fiber, Mineral Wool, and Cal-Sil to result in sufficient head loss across the strainer to challenge the NPSH margin. Strainer head loss testing determined the debris quantities that would result in either acceptable or unacceptable strainer head loss.

2. *State whether secondary line breaks were considered in the evaluation (e.g., main steam and feedwater lines) and briefly explain why or why not.*

Response to 3.a.2:

Feedwater and main steam piping were not considered for potential break locations because ECCS in recirculation mode is not required for main steam or feedwater line breaks (Reference 12 pp. 8-9).

3. *Discuss the basis for reaching the conclusion that the break size(s) and locations chosen present the greatest challenge to post-accident sump performance.*

Response to 3.a.3:

The quantities of debris generated by the full range of breaks has been determined for PBN1 and PBN2 (see the Response to 3.a.1 and the Response to 3.b). PBN has performed a GSI-191 assessment using the penetration and head loss test data, as well as the other GSI-191 plant specific inputs. The GSI-191 related phenomena were evaluated in a holistic, time-dependent manner with a software tool called NARWHAL. NARWHAL evaluates the full range of breaks from the BADGER database using the plant-specific inputs and models, and reports which breaks fail the acceptance criteria. Based on this evaluation, PBN was able to determine that breaks that generate the most Cal-Sil and fine fiber would present the greatest challenge to post-accident sump performance. This is because the most frequent failure seen in the NARWHAL runs, as well as the failure with the smallest associated break size, was due to breaks resulting in a Cal-Sil and/or fine fiber quantity that exceeded the quantity used in the head loss tests. Based on this evaluation, it was concluded that the breaks that generate the maximum fine fiber or Cal-Sil in Region I and Region II would be evaluated. Table 3.a.3-1 shows the bounding breaks evaluated in Region I and Region II for both PBN1 and PBN2.

Table 3.a.3-1: PBN1 and PBN2 Bounding Region I and Region II Breaks

Unit	Region	Loop	Limiting Debris Type	Weld Location	Location Description
PBN1	I	B	17" Fine Fiber	RC-34-MRCL-BI-03, 135°	SG Nozzle at Hot Leg
PBN1	I	A	17" Cal-Sil	RC-36-MRCL-AIII-01A, 0°	RCP at Cold Leg
PBN1	II	B	DEGB Fine Fiber	RC-36-MRCL-BII-01	SG Nozzle at Cross-over Leg
PBN1	II	B	DEGB Cal-Sil	RC-34-MRCL-BI-03	SG Nozzle at Hot Leg
PBN2	I	B	17" Fine Fiber	RC-34-MRCL-BI-03, 0°	Hot Leg at Elbow
PBN2	I	A	17" Cal-Sil	RC-34-MRCL-AI-03, 90°	Hot Leg at Elbow
PBN2	II	B	DEGB Fine Fiber	RC-36-MRCL-BII-01A	SG Nozzle at Cross-over Leg
PBN2	II	A	DEGB Cal-Sil	RC-34-MRCL-AI-03	Hot Leg at Elbow

b. Debris Generation/Zone of Influence (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; (2) the amount of debris generated by the break jet forces.

1. *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.*

Response to 3.b.1:

In a PWR reactor containment building, the worst-case pipe break would be a DEGB. In a DEGB, jets of water and steam would blow in opposite directions from the severed pipe. One or both jets could impact obstacles and be reflected in different directions. To take into account the double jets and potential jet reflections, NEI 04-07 (Reference 6, p. vii) (Reference 7, p. 1-3) proposes using a spherical ZOI centered at the break location to determine the quantity of debris that could be generated by a given line break.

For DEGBs, the ZOI is defined as a spherical volume about the break in which the jet pressure is higher than the destruction/damage pressure for a certain type of insulation, coating, or other material impacted by the break jet.

For any break smaller than a DEGB (i.e., a partial break) NEI 04-07, Volume 2 accepts the use of a hemispherical ZOI centered at the edge of the pipe (Reference 6, p. 94). Because these types of breaks can occur anywhere along the circumference of the pipe, the partial breaks were analyzed using hemispheres at eight different angles that are 45° apart from each other around the pipe.

Since different insulation types have different destruction pressures, different ZOIs were determined for each type of insulation. Table 3.b.1-1 shows the primary side break equivalent ZOI radii divided by the break diameter (L/D) for each representative material in the PBN1 and PBN2 containment buildings.

Table 3.b.1-1: Primary Side Break ZOI Radii for PBN1 and PBN2 Insulation Types

Insulation Type	Destruction Pressure (psi)	ZOI Radius/Break Diameter (L/D)
Nukon	6	17.0*
LDFG	6	17.0*
Temp-Mat	10.2	11.7*
Cal-Sil	20*	6.4*
Transco RMI	114	2.0*
Mirror RMI	2.4	28.6*
Asbestos Cal-Sil	20***	6.4***
Qualified Coatings	40*****	4.0**
Mineral Wool Cassettes	114****	4.0****

* NRC SE for NEI 04-07 (Reference 6, p. 30 and II-20)
** Revised Guidance Regarding Coatings Zone of Influence for Review of Final Licensee Responses to Generic Letter 2004-02 (Reference 13 p. 2)
*** The destruction pressure of Asbestos Calcium-Silicate (PBN1 and PBN2) was assumed to be the same as Calcium-Silicate.
**** The destruction pressure of the Mineral Wool Cassettes was assumed to be similar to Transco RMI and the ZOI size was doubled for conservatism.
***** 40 psi corresponds to a 4D ZOI in Table 3-1 of the SER (Reference 6 p. 27)

In some cases, if the ZOI for a particular material is very large (i.e., it has a low destruction pressure or is located on a large pipe); the radius of the sphere may extend beyond robust barriers located near the break. Robust barriers consist of structures, such as concrete walls that are impervious to jet flow and prevent further expansion of the jet. Insulation in the shadow of large robust barriers can be assumed to remain intact to a certain extent (Reference 7, pp. 3-14 through 3-15). Due to the compartmentalization of containment in PBN1 and PBN2, the insulation on the opposite side of the compartment walls can be assumed to remain intact. All ZOIs were truncated to account for robust barriers per NEI 04-07 Volume 2 (Reference 6, p. vii).

Volumetric debris quantities were determined by measuring the interference between a ZOI and its corresponding debris source. This was done within the CAD model environment.

No insulation debris would be generated outside of the ZOIs (Reference 7, pp. 3-19 through 3-20). This practice is considered acceptable by the NRC as stated in the SE for NEI 04-07 (Reference 6, Section 3.4.3.2).

2. *Provide destruction ZOIs and the basis for the ZOIs for each applicable debris constituent.*

Response to 3.b.2:

See the Response to 3.b.1.

3. *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).*

Response to 3.b.3:

No destruction testing was conducted to determine ZOI sizes. PBN1 and PBN2 have applied the ZOI refinement discussed in NEI 04-07 Volume 2 (Reference 6, Section 4.2.2.1.1), which allows the use of debris-specific spherical ZOIs.

The only ZOIs that are being used that are different from those listed in NEI 04-07 are those for mineral wool and qualified coatings. The mineral wool at Point Beach was provided by Transco Products and is encapsulated in stainless steel cassettes. The mineral wool cassettes are virtually identical to that of the original Transco RMI installed at Point Beach but with a different filler material, i.e., mineral wool fibers instead of stainless steel foils. Based on the robust nature of these cassettes, the destruction pressure for the Transco mineral wool is assumed to be equal to the RMI cassettes. However, to account for the difference in filler material, even though the filler provides negligible robustness, the ZOI for the mineral wool cassettes was conservatively increased by a factor of 2 from 2.0D to 4.0D. The ZOI for qualified coatings is discussed in the Response to 3.h.

4. *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 four most limiting locations.*

Response to 3.b.4:

Using the ZOIs listed in this section, the breaks selected in the Response to 3.a, and the size distribution provided in the Response to 3.c of this enclosure, quantities of generated debris for each break case were calculated for each type of insulation. Table 3.b.4-1 and Table 3.b.4-2 show the most limiting DEGB and the most limiting 17" partial break for Cal-Sil and fiber, respectively, as determined in the PBN1 debris generation calculation. Table 3.b.4-3 and Table 3.b.4-4 show the most limiting DEGB and the most limiting 17" partial break for Cal-Sil and fiber, respectively, as determined in the PBN2 debris generation calculation. Note that break generated coatings quantities are provided in the tables for completeness, but are discussed further in the Response to 3.h. The fiber quantities presented in Table 3.b.4-1 through Table 3.b.4-4 have been converted to mass (lb) by multiplying the volumes by their associated density.

Table 3.b.4-1: PBN1 Worst-Case Cal-Sil DEGB and 17" Partial Break

Break Location		**RC-34-MRCL-BI-03**		**RC-36-MRCL-AIII-01A**	
Location Description		Loop B Hot Leg at SG Nozzle		Loop A Cold Leg at RCP	
Break Size		31"		17"	
Break Type		DEGB		Partial (Angle – 0°)	
LDFG (lb)	Fine	27.8		12.5	
	Small	107.3		46.1	
	Large	10.6		11.2	
	Intact	11.4		12.1	
Mineral Wool (lb)	Fine	136.7		22.2	
Temp-Mat (lb)	Fine	0.0		0.0	
	Small	0.0		0.0	
	Large	0.0		0.0	
	Intact	0.0		0.0	
Cal-Sil and Asbestos Cal-Sil (lb)	Fine	618.2		254.0	
	Small	437.0		188.2	
	Intact	829.7		302.3	
Mirror and Transco RMI (ft^2)	Small (<4")	27143		9756	
	Large (≥ 4")	9048		3252	
Dimetcote 6	Fine	101.31 lb	0.34 ft^3	0.00 lb	0.00 ft^3
Amercoat 66	Fine	49.19 lb	0.51 ft^3	0.00 lb	0.00 ft^3
Carboline 195	Fine	37.05 lb	0.34 ft^3	9.94 lb	0.09 ft^3
Phenoline 305	Fine	6.28 lb	0.06 ft^3	1.69 lb	0.02 ft^3

Table 3.b.4-2: PBN1 Worst-Case Fiber DEGB and 17" Partial Break

Break Location		RC-36-MRCL-BII-01		RC-34-MRCL-BI-03	
Location Description		Loop B Crossover Leg at SG Nozzle		Loop B Hot Leg at SG Nozzle	
Break Size		31"		17"	
Break Type		DEGB		Partial (Angle – 135°)	
LDFG (lb)	Fine	27.5		11.3	
	Small	106.0		42.0	
	Large	11.3		9.0	
	Intact	12.1		9.7	
Mineral Wool (lb)	Fine	169.1		73.5	
Temp-Mat (lb)	Fine	0.0		0.0	
	Small	0.0		0.0	
	Large	0.0		0.0	
	Intact	0.0		0.0	
Cal-Sil and Asbestos Cal-Sil (lb)	Fine	382.7		149.6	
	Small	230.9		92.6	
	Intact	690.4		259.7	
Mirror and Transco RMI (ft^2)	Small (<4")	26876		13008	
	Large (≥ 4")	8959		4336	
Dimetcote 6	Fine	87.61 lb	0.29 ft^3	11.01 lb	0.04 ft^3
Amercoat 66	Fine	42.53 lb	0.44 ft^3	5.35 lb	0.06 ft^3
Carboline 195	Fine	50.76 lb	0.47 ft^3	0.02 lb	0.00 ft^3
Phenoline 305	Fine	8.61 lb	0.08 ft^3	0.00 lb	0.00 ft^3

Table 3.b.4-3: PBN2 Worst-Case Cal-Sil DEGB and 17" Partial Break

Break Location		**RC-34-MRCL-AI-03**		**RC-34-MRCL-AI-03**	
Location Description		Loop A Hot Leg at Elbow		Loop A Hot Leg at Elbow	
Break Size		29"		17"	
Break Type		DEGB		Partial (Angle – 90°)	
LDFG and Nukon (lb)	Fine	88.3		13.8	
	Small	270.2		38.0	
	Large	237.9		49.2	
	Intact	257.1		53.2	
Mineral Wool (lb)	Fine	131.5		20.2	
Temp-Mat (lb)	Fine	0.0		0.0	
	Small	0.0		0.0	
	Large	0.0		0.0	
	Intact	0.0		0.0	
Cal-Sil and Asbestos Cal-Sil (lb)	Fine	767.3		187.5	
	Small	514.9		123.9	
	Intact	1152.5		289.9	
Transco RMI (ft^2)	Small (<4")	1116		78	
	Large (≥ 4")	372		26	
Dimetcote 6	Fine	122.87 lb	0.41 ft^3	28.65 lb	0.10 ft^3
Amercoat 66	Fine	59.65 lb	0.61 ft^3	13.91 lb	0.14 ft^3
Carboline 195	Fine	67.10 lb	0.62 ft^3	13.61 lb	0.12 ft^3
Phenoline 305	Fine	9.34 lb	0.09 ft^3	1.89 lb	0.02 ft^3

Table 3.b.4-4: PBN2 Worst-Case Fiber DEGB and 17" Partial Break

<table>
<tr><td colspan="2">Break Location</td><td colspan="2">RC-36-MRCL-BII-01A</td><td colspan="2">RC-34-MRCL-BI-03</td></tr>
<tr><td colspan="2">Location Description</td><td colspan="2">Loop B Crossover Leg at SG Nozzle</td><td colspan="2">Loop B Hot Leg at Elbow</td></tr>
<tr><td colspan="2">Break Size</td><td colspan="2">31"</td><td colspan="2">17"</td></tr>
<tr><td colspan="2">Break Type</td><td colspan="2">DEGB</td><td colspan="2">Partial (Angle – 0°)</td></tr>
<tr><td rowspan="4">LDFG and Nukon (lb)</td><td>Fine</td><td colspan="2">147.4</td><td colspan="2">59.6</td></tr>
<tr><td>Small</td><td colspan="2">498.2</td><td colspan="2">191.3</td></tr>
<tr><td>Large</td><td colspan="2">261.9</td><td colspan="2">135.2</td></tr>
<tr><td>Intact</td><td colspan="2">284.6</td><td colspan="2">146.1</td></tr>
<tr><td>Mineral Wool (lb)</td><td>Fine</td><td colspan="2">196.2</td><td colspan="2">70.8</td></tr>
<tr><td rowspan="4">Temp-Mat (lb)</td><td>Fine</td><td colspan="2">0.0</td><td colspan="2">0.0</td></tr>
<tr><td>Small</td><td colspan="2">0.0</td><td colspan="2">0.0</td></tr>
<tr><td>Large</td><td colspan="2">0.0</td><td colspan="2">0.0</td></tr>
<tr><td>Intact</td><td colspan="2">0.0</td><td colspan="2">0.0</td></tr>
<tr><td rowspan="3">Cal-Sil and Asbestos Cal-Sil (lb)</td><td>Fine</td><td colspan="2">199.6</td><td colspan="2">27.6</td></tr>
<tr><td>Small</td><td colspan="2">139.2</td><td colspan="2">13.1</td></tr>
<tr><td>Intact</td><td colspan="2">310.7</td><td colspan="2">94.8</td></tr>
<tr><td rowspan="2">Transco RMI (ft^2)</td><td>Small (<4")</td><td colspan="2">1246</td><td colspan="2">171</td></tr>
<tr><td>Large (≥ 4")</td><td colspan="2">415</td><td colspan="2">57</td></tr>
<tr><td>Dimetcote 6</td><td>Fine</td><td>148.49 lb</td><td>0.49 ft^3</td><td>24.07 lb</td><td>0.08 ft^3</td></tr>
<tr><td>Amercoat 66</td><td>Fine</td><td>72.09 lb</td><td>0.74 ft^3</td><td>11.69 lb</td><td>0.12 ft^3</td></tr>
<tr><td>Carboline 195</td><td>Fine</td><td>81.53 lb</td><td>0.75 ft^3</td><td>6.01 lb</td><td>0.06 ft^3</td></tr>
<tr><td>Phenoline 305</td><td>Fine</td><td>11.34 lb</td><td>0.11 ft^3</td><td>0.84 lb</td><td>0.01 ft^3</td></tr>
</table>

5. *Provide total surface area of all signs, placards, tags, tape, and similar miscellaneous materials in containment.*

Response to 3.b.5:

Labels, tags, stickers, placards and other miscellaneous or foreign materials were evaluated via walkdown. The amount of foreign materials recorded for PBN1 and PBN2 was 120 ft^2 and 152 ft^2, respectively. However, for conservatism, a total surface area of 200 ft^2 was assumed in the PBN1 and PBN2 debris generation analyses.

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.

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

Response to 3.c.1:

A summary of the material properties of the debris types found within containment are listed in Table 3.c.1-1. See Response to 3.d.3 for the material properties of latent debris.

Table 3.c.1-1: Debris Material Properties

Debris	Distribution	Density (lbm/ft^3)	Characteristic Size (μm)
Nukon/LDFG	See section below	2.4 (bulk) 159 (fiber)	7
Temp-Mat	See section below	11.8 (bulk) 162 (fiber)	9
Mineral Wool	100% Fines	8 (bulk) 90 (fiber)	5-7
Mirror/Transco RMI	75% small pieces 25% large Pieces	-	<4" ≥4"
Cal-Sil	See section below	14.5 (bulk) 144 (particulate)	5
Asbestos Cal-Sil		16 (bulk)	10
Qualified Coatings	100% Particulate	300 (Dimetcote 6 - IOZ) 97.1 (Amercoat 66 - Epoxy) 101.3 (Phenoline 305 - Epoxy) 109 (Carboline 195 - Epoxy)	10
Unqualified and Degraded Coatings	100% Particulate	208 (IOZ) 94 (Epoxy) 98 (Alkyd)	10

Nukon Low-Density Fiberglass Insulation

The debris characteristics for Nukon, and generic LDFG are listed in Table 3.c.1-1.

A baseline analysis of Nukon includes a size distribution with two categories—60 percent small fines, and 40 percent large pieces per NEI 04-07 (Reference 7, Section 3.4.3.3.1). The debris generation calculation used a four-category size distribution based on the guidance in NEI 04-07 Volume 2 (Reference 6, Appendix II and Appendix VI, p. VI-14). This guidance provides an approach for determining a size distribution for low-density fiberglass using the air jet impact test (AJIT) data, with conservatism added due to the potentially higher level of destruction from a two-phase jet. Within the 17.0D ZOI, the size distribution varies based on the distance of the insulation from the break (i.e., insulation debris generated near the break location consists of more small pieces than insulation debris generated near the edge of the ZOI).

Consequently, the following equations were developed to determine the fraction of fines (individual fibers), small pieces (less than 6 inches), large pieces (greater than 6 inches), and intact blankets as a function of the average distance between the break point and the centroid of the affected debris measured in units of pipe diameters (C).

$$F_{LDFG\ fines}(C) = \begin{cases} 0.2 & \text{if } 0 < C \leq 4 \\ -0.01364 \cdot C + 0.2546 & \text{if } 4 < C \leq 15 \\ -0.025 \cdot C + 0.425 & \text{if } 15 < C \leq 17 \end{cases}$$

$$F_{LDFG\ small}(C) = \begin{cases} 0.8 & \text{if } 0 < C \leq 4 \\ -0.0682 \cdot C + 1.0724 & \text{if } 4 < C \leq 15 \\ -0.025 \cdot C + 0.425 & \text{if } 15 < C \leq 17 \end{cases}$$

$$F_{LDFG\ large}(C) = \begin{cases} 0 & \text{if } 0 < C \leq 4 \\ 0.0393 \cdot C - 0.157 & \text{if } 4 < C \leq 15 \\ -0.215 \cdot C + 3.655 & \text{if } 15 < C \leq 17 \end{cases}$$

$$F_{LDFG\ intact}(C) = \begin{cases} 0 & \text{if } 0 < C \leq 4 \\ 0.0425 \cdot C - 0.170 & \text{if } 4 < C \leq 15 \\ 0.265 \cdot C - 3.505 & \text{if } 15 < C \leq 17 \end{cases}$$

Temp-Mat High-Density Fiberglass Insulation

The debris characteristics for Temp-Mat are listed in Table 3.c.1-1.

Similar to Nukon and other types of LDFG, a refinement to the standard methodology was used and takes into account a size distribution for Temp-Mat using AJIT data. The following equations were developed to determine the fraction of fines (individual fibers), small pieces (less than 6 inches), large pieces (greater than 6 inches), and intact blankets as a function of the average distance within an 11.7D ZOI between the break point and the centroid of the affected debris measured in units of pipe diameters (C).

$$F_{Temp-Mat\ Fines}(C) = \begin{cases} 0.333 & \text{if } 0 < C \leq 2 \\ -0.03050 \cdot C + 0.3940 & \text{if } 2 < C \leq 8 \\ -0.0405 \cdot C + 0.474 & \text{if } 8 < C \leq 11.7 \end{cases}$$

$$F_{Temp-Mat\ Smalls}(C) = \begin{cases} 0.667 & \text{if } 0 < C \leq 2 \\ -0.0945 \cdot C + 0.856 & \text{if } 2 < C \leq 8 \\ -0.0271 \cdot C + 0.316 & \text{if } 8 < C \leq 11.7 \end{cases}$$

$$F_{Temp-Mat\ Large}(C) = \begin{cases} 0 & \text{if } 0 < C \leq 2 \\ 0.0601 \cdot C - 0.12 & \text{if } 2 < C \leq 8 \\ -0.0974 \cdot C + 1.144 & \text{if } 8 < C \leq 11.7 \end{cases}$$

$$F_{Temp-Mat\ intact}(C) = \begin{cases} 0 & \text{if } 0 < C \leq 2 \\ 0.0649 \cdot C - 0.13 & \text{if } 2 < C \leq 8 \\ 0.165 \cdot C - 0.93 & \text{if } 8 < C \leq 11.7 \end{cases}$$

Cal-Sil Insulation

The debris characteristics for Cal-Sil and Asbestos Cal-Sil are listed in Table 3.c.1-1.

Similar to Nukon and other types of LDFG, a refinement to the standard methodology was used and takes into account a size distribution for Cal-Sil using jet test data. The following equations are developed to determine the fraction of fines (particulate), small pieces (less than 1 inch up to 3 inches), and intact pieces (remains on the target) as a function of the average distance within a 6.4D ZOI between the break point and the centroid of the affected debris measured in units of pipe diameters (C).

$$F_{Cal-Sil\,Fines}(C) = \begin{cases} 0.5 & \text{if } 0 < C \leq 1.5 \\ -0.06571 \cdot C + 0.5986 & \text{if } 1.5 < C \leq 5 \\ -0.1929 \cdot C + 1.2345 & \text{if } 5 < C \leq 6.4 \end{cases}$$

$$F_{Cal-Sil\,Smalls}(C) = \begin{cases} 0.5 & \text{if } 0 < C \leq 1.5 \\ -0.1043 \cdot C + 0.6614 & \text{if } 1.5 < C \leq 5 \\ -0.0971 \cdot C + 0.6155 & \text{if } 5 < C \leq 6.4 \end{cases}$$

$$F_{Cal-Sil\,intact}(C) = \begin{cases} 0 & \text{if } 0 < C \leq 1.5 \\ 0.17 \cdot C - 0.26 & \text{if } 1.5 < C \leq 5 \\ 0.29 \cdot C - 0.85 & \text{if } 5 < C \leq 6.4 \end{cases}$$

2. *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.*

   Response to 3.c.2:

   See the Response to 3.c.1 for the material and bulk densities of the various types of debris.

3. *Provide assumed specific surface areas for fibrous and particulate debris.*

   Response to 3.c.3:

   Specific surface areas could be calculated for each debris type based on the characteristic diameter described in the Response to 3.c.1. However, testing was used to determine strainer head loss and not an analytical method, so specific surface areas were not calculated or used for the PBN head loss evaluation (see the Response to 3.f).

4. *Provide the technical basis for any debris characterization assumptions that deviate from NRC-approved guidance.*

   Response to 3.c.4:

   The debris characterizations for all debris types follow NRC-approved guidance.

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.

1. *Provide the methodology used to estimate the quantity and composition of latent debris.*

Response to 3.d.1:

The following discussion summarizes the methods used in the latent debris calculation.

The method used to estimate the quantity of latent debris was a representative sampling of containment surfaces as described in the guidance of NEI 04-07 Volume 2 (Reference 6, pp. 45-50). The samples were taken by Masslinn® swipes and the amount of accumulated dust and lint quantified by weight. The fiber content of the latent debris was assumed to be 15% by weight, consistent with NEI 04-07 Volume 2 (Reference 6, p. 50). The balance of the latent debris is assumed to be particulate, also consistent with NEI 04-07 (Reference 6, p. 50).

Samples were taken to determine the latent debris mass distribution per unit area of representative surfaces throughout containment including vertical surfaces such as the liner and walls. These debris densities were then applied to all of the surface areas inside containment to calculate the total amount of latent debris inside containment. The latent debris density was estimated by weighing Masslinn® swipes before and after sampling, and dividing the net weight increase by the sampled surface area.
There were 21 samples taken at each unit, and included a mix of both horizontal and vertical surfaces, as well as surfaces that are routinely decontaminated and those surfaces that are not, such as the top surfaces of overhead duct work, cable trays, etc.

Because of the several different types of insulation used in the two containments, the statistical sample mass collections (e.g., three samples from each category of surface) was not used. PBN used an alternative approach to minimize personnel risk and exposure.

Representative samples were taken from accessible surfaces. Visual observations of these sample locations were compared to visual observations of other surfaces and estimates of bounding debris loadings were made. Although similar in magnitude, the data from PBN1 and the data from PBN2 were used to substantiate unit-specific latent debris source terms for both units.

2. *Provide the basis for assumptions used in the evaluation.*

Response to 3.d.2:

There were three assumptions used in the evaluation of latent debris in containment. These assumptions and their technical bases follow.

Assumption 1: The top surfaces area of the major structural heat sinks are periodically decontaminated.

Basis: Accessible floor areas are routinely wiped down to control contamination spread and to reduce the quantity of latent debris in containment. While there are top surfaces of major structural heat sinks that are not routinely cleaned due to ALARA concerns or inaccessibility (such as the regenerative heat exchanger room, the bottom of the pressurizer cubicle, etc.), most of these areas are also above the El. 8' sump and sheltered from direct spray impingement and washdown. Additional areas were added to account for those areas that are not routinely cleaned. Therefore, assuming that 100% of the floor areas are routinely cleaned over-estimates the total area that is routinely cleaned while not diminishing those areas that are not cleaned. The result is a conservatively high estimate of the routinely cleaned horizontal surface areas.

Assumption 2: The horizontal surface area of containment that is not routinely cleaned, and is subject to direct spray impingement and/or washdown during a LOCA, is equal to the horizontal surface area that is routinely cleaned per Assumption 1.

Basis: The horizontal surface areas not routinely cleaned yet still subject to wash down are primarily limited to those above the refueling floor El. 66'. Horizontal areas above this elevation are very limited, primarily due to the necessity of moving large loads above the floor such as the reactor vessel head, RCP motors, etc. Areas below El. 66' are largely sheltered from direct spray impingement, and only those in the RCS loop compartments may be subjected to scouring during the blowdown phase of a LOCA.

Assumption 3: The vertical surface area of miscellaneous equipment such as cable trays, ladders, tanks, etc. is equal to the vertical surface area of all the major structural heat sinks inside of containment.

Basis: The major structural heat sinks include the containment building wall and all compartment walls. Other major vertical surface areas are equipment such as the steam generators, the pressurizer, the RCP motors, and the reactor vessel. In addition, there are various cable trays, piping, ladders, etc. The vertical surface of any tank or vessel is less than the vertical surface of the compartment surrounding it. Considering that much of the vertical surface areas are sheltered from spray impingement by floors above, and that there is a substantial amount of vertical surface area represented by the containment liner itself, the assumption was considered a reasonable and bounding approximation.

3. *Provide results of the latent debris evaluation, including amount of latent debris types and physical data for latent debris as requested for other debris under c. above.*

Response to 3.d.3:

The quantity of latent debris was assumed to be 150 lbm, but the actual amount of latent debris documented for the plant is 62 lbm for PBN1 and 55 lbm for PBN2. These quantities are well below the quantity used to determine the strainer head loss.
Table 3.d.3-1 lists the assumed latent fiber and particulate constituents and their material characteristics.

Latent debris was assumed to consist of 15 percent fiber and 85 percent particulate by mass per the NRC NEI 04-07 SE (Reference 6, p. 50).

Based on NEI 04-07 Volume 2 (Reference 6, p. 50-52, V-11), the size and density of latent particulate were assumed to be 17.3 μm (specific surface area of 106,000 ft^{-1}) and 168.6 lbm/ft^3 (2.7 g/cm^3), respectively. Additionally, the bulk density and microscopic density of latent fiber were assumed to be 2.4 lbm/ft^3 and 93.6 lbm/ft^3 (1.5 g/cm^3), respectively.

Latent fiber was assumed to have a characteristic size of 5.5 μm. This is reasonably conservative, as it is the smallest fiber diameter listed in Table 3-2 of the general reference for LDFG found in NEI 04-07 (Reference 7, p. 3-28).

Table 3.d.3-1: Latent Fiber and Particulate Constituents

	Latent Debris (lbm)	Bulk Density (lbm/ft^3)	Microscopic Density (lbm/ft^3)	Characteristic Size (μm)
Particulate (85%)	127.5	-	168.6	17.3
Fiber (15%)	22.5	2.4	93.6	5.5
Total	150			

4. *Provide amount of sacrificial strainer surface area allotted to miscellaneous latent debris.*

Response to 3.d.4:

As discussed in the Response to 3.b.5, a total surface area of 200 ft^2 of miscellaneous debris was conservatively assumed in the PBN1 and PBN2 debris generation calculations. This surface area would result in a 150 ft^2 reduction in strainer area (75% of 200 ft^2) (Reference 6, p. 49).

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.

1. *Describe the methodology used to analyze debris transport during blowdown, washdown, pool-fill-up, and recirculation phases of an accident.*

Response to 3.e.1:

The methodology used in the transport analysis is based on the NEI 04-07 guidance and the associated NRC SE (Reference 6) for refined analyses, as well as the refined methodologies suggested by the SE in Appendices III, IV, and VI (Reference 6). The specific effect of each of the four modes of transport was analyzed in the debris transport calculations for each type of debris generated. These modes of transport are:

- Blowdown Transport – the vertical and horizontal transport of debris to all areas of containment by the break jet
- Washdown Transport – the vertical (downward) transport of debris by the containment sprays, break flow, and condensation
- 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
- 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

The logic tree approach was applied for each type of debris listed in the debris generation calculation. The logic tree shown in Figure 3.e.1-1 is slightly different from the baseline. This departure was made to account for certain non-conservative assumptions identified by the NRC SE (Reference 6) including the transport of large pieces, 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.

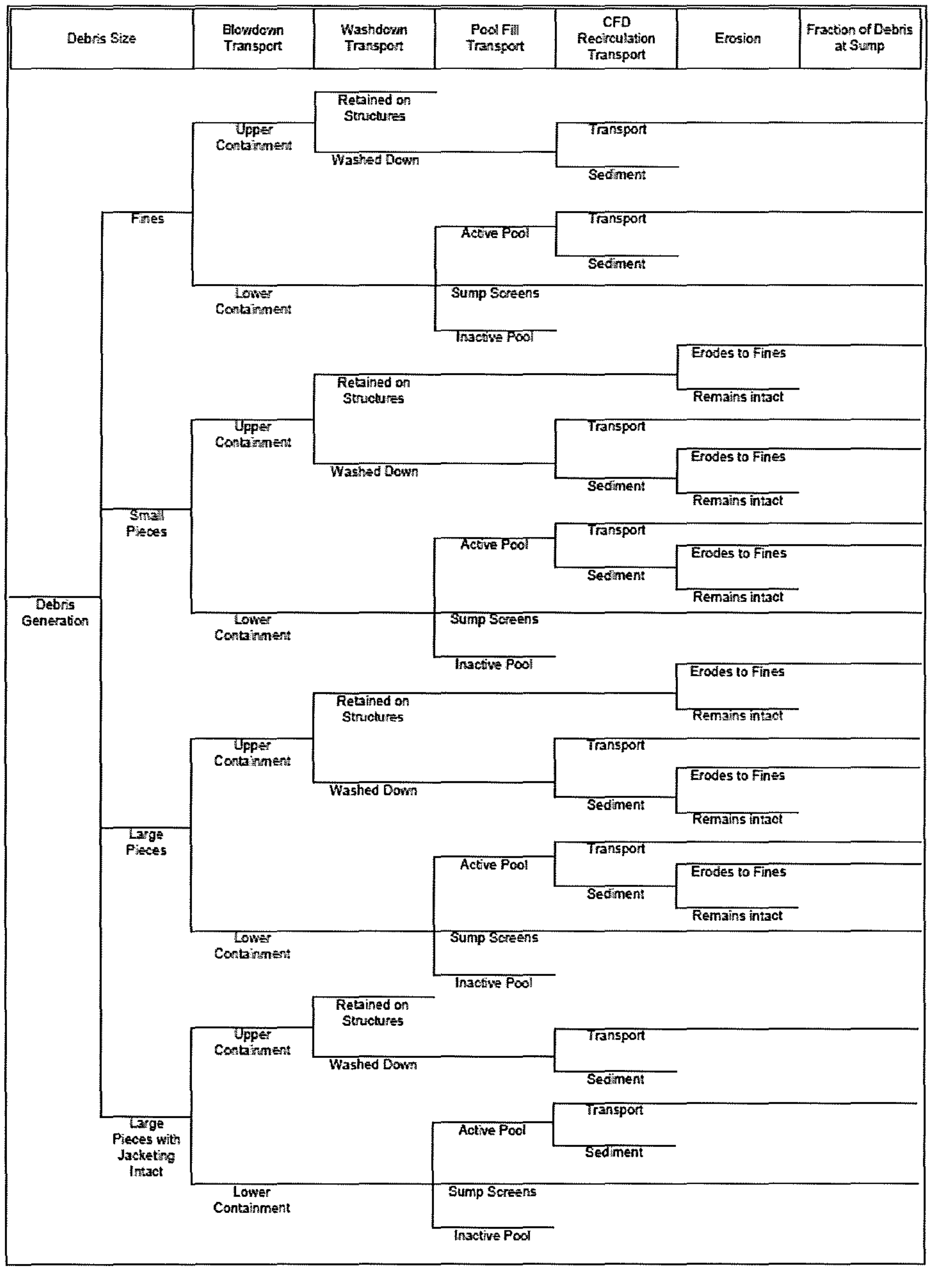


Figure 3.e.1-1: Generic Debris Transport Logic Tree

The basic methodology for the PBN1 and PBN2 transport analysis is summarized below.

1. The CAD model was used to determine break locations and sizes.
2. The debris generation calculation was used to identify debris types and sizes.
3. Potential upstream blockage points were qualitatively addressed.
4. The fraction of debris blown into upper containment and lower containment for each compartment was determined based on the volumes of upper and lower containment.
5. The fraction of debris washed down by containment spray flow was determined along with the locations where the debris would be washed down.
6. The quantity of debris transported to inactive areas or directly to the sump strainers was calculated based on the volume of the inactive and sump cavities proportional to the water volume at the time these cavities are filled.
7. The location of each type/size of debris at the beginning of recirculation was determined based on the break location.
8. A CFD model was developed to simulate the flow patterns that would develop during recirculation.
9. A graphical determination of the transport fraction of each type of debris was made using the velocity and turbulent kinetic energy (TKE) profiles from the CFD model output, along with the determined initial distribution of debris.
10. The initial recirculation transport fractions from the CFD analysis were gathered to determine the final recirculation transport fractions for input into the logic trees.
11. The quantity of debris that could experience erosion due to the break flow or spray flow was determined.
12. The overall transport fraction for each type/size of debris was determined by combining each of the previous steps into logic trees.

Potential Upstream Blockage Points

Potential upstream blockage points were qualitatively addressed in the debris transport calculation. It was determined that there are no upstream blockage points in the PBN1 and PBN2 containment buildings that adversely impact sump level. Upstream effects are discussed in the Response to 3.I.

CFD Model of Containment Recirculation Pool

A diagram showing the significant parts of the CFD model is shown in Figure 3.e.1-2 for PBN1, and Figure 3.e.1-3 for PBN2. The strainer module mass sinks and the various direct and runoff spray regions are highlighted.

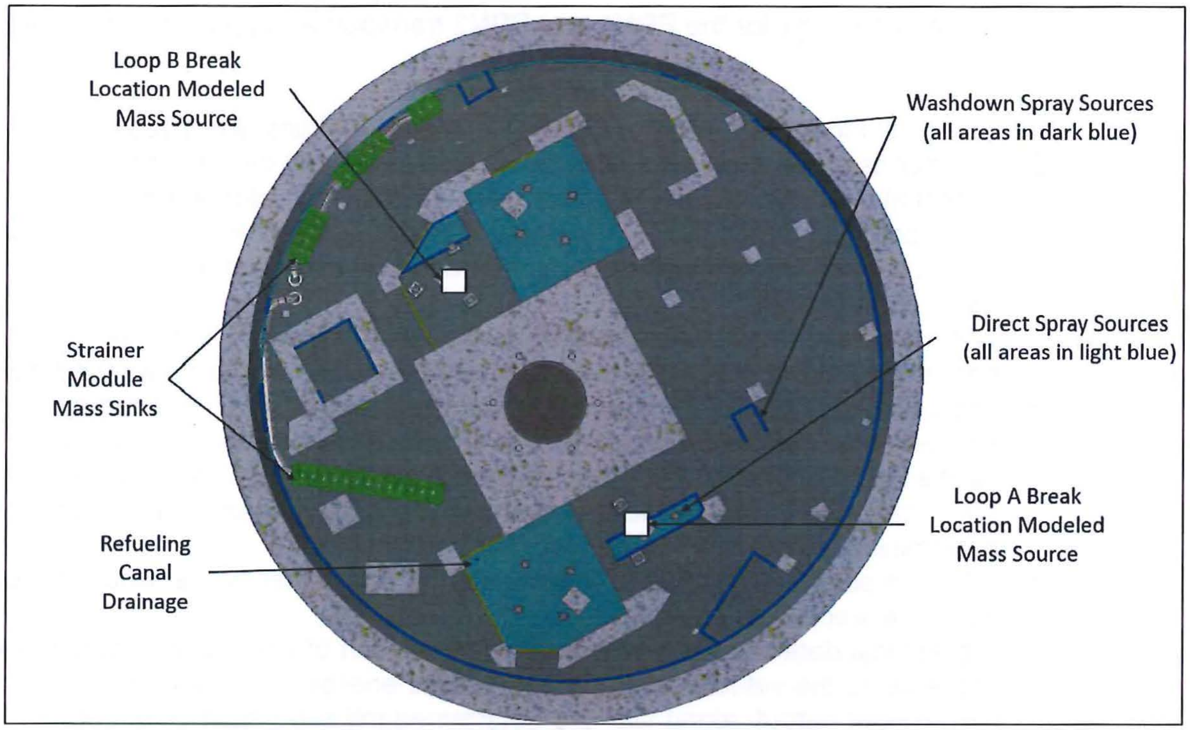


Figure 3.e.1-2: Significant Features in CFD Model (PBN1)

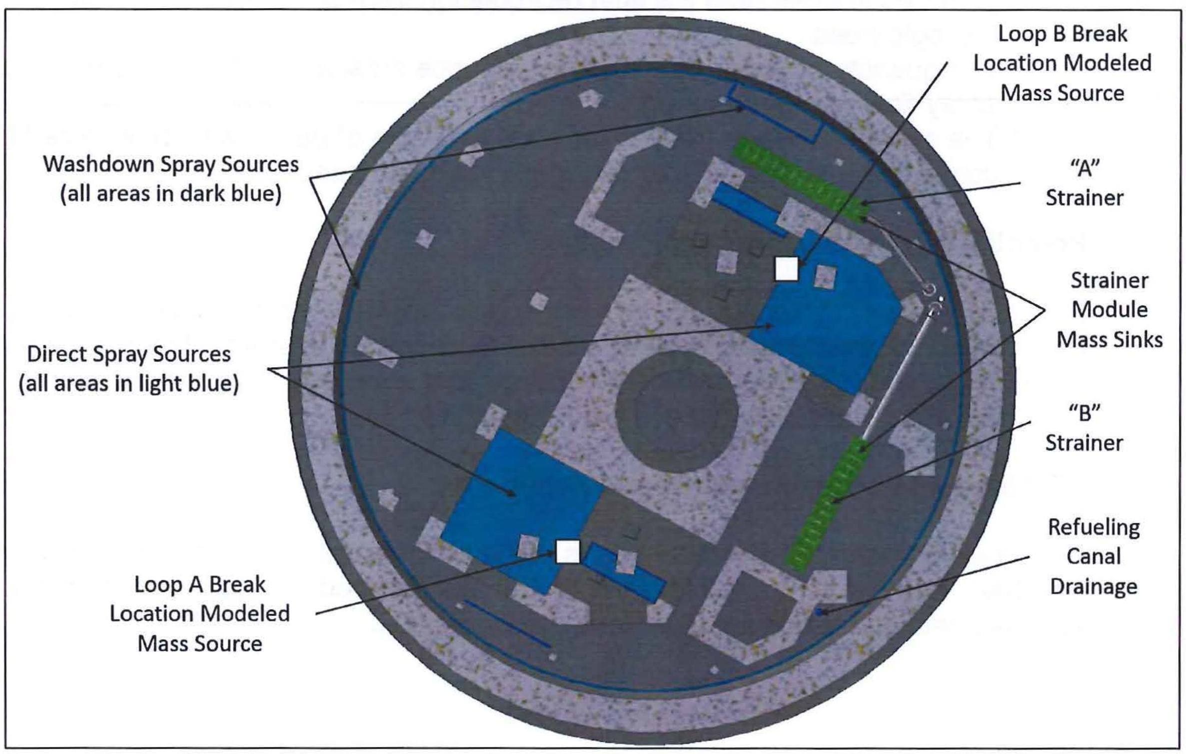


Figure 3.e.1-3: Significant Features in CFD Model (PBN2)

The key CFD modeling attributes/considerations included the following:

Computational Mesh

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 excessively long to run. A 6-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 (8' Elevation and 10' Elevation), the mesh was set to 3 inches tall in order to closely resolve the vicinity (area right above the floor where tumbling velocities are analyzed) of settled debris. The total cell count in the model was 3,904,112 at both PBN1 and PBN2.

Modeling of Containment Spray Flows

Various plan and section drawings, as well as the containment building CAD model, were considered when determining the spray flow path to the pool. Spray water would drain to the pool through many pathways. Some of these pathways include stairways #22 and #23 (PBN1), stairways #38 and #39 (PBN2), and for both units, the steam generator compartments through the open area above the steam generators and RCPs, the keyway (reactor cavity), the 3-inch gap around the periphery, and the 4-inch diameter drain line from the refueling canal. The sprays were defined as regions and populated with discrete mass source particles. The appropriate flow rate and velocity was set for the sprays in each region.

Modeling of Break Flow

The water falling from the postulated break would introduce momentum into the containment pool that influences the flow dynamics. This 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 location of the break to the surface of the pool.

Modeling of the Strainers

The "A" strainer and the "B" strainer at both PBN1 and PBN2 each consist of strainer modules that sit 3 inches above the floor. Each strainer array in the CFD model is modeled as having flow across its surfaces proportional to the area of each strainer. Each unit of stacked disks was modeled to draw flow from all surfaces (including the bottom surface). A negative flow rate was set for the strainer modules, which tells the CFD model to draw the specified amount of water from the pool over the entire exposed surface area of the module obstacle.

Turbulence Modeling

Several different turbulence-modeling approaches can be selected for a Flow-3D calculation. The approaches (ranging from least to most sophisticated) are:

- Prandtl mixing length
- Turbulent energy model
- Two-equation k-ε model
- Renormalized group theory (RNG) model
- Large eddy simulation model

The RNG turbulence model was determined to be the most appropriate for this CFD analysis. The RNG model has a large spectrum of length scales that would likely exist in a containment pool during recirculation. The RNG approach applies statistical methods in a derivation of the averaged equations for turbulence quantities (such as TKE and its dissipation rate). RNG-based turbulence schemes rely less on empirical constants while setting a framework for the derivation of a range of models at different scales.

Steady-State Metrics

The CFD model was started from a stagnant state at a defined pool depth and run long enough for steady-state conditions to develop. A plot of mean kinetic energy was used to determine when steady-state conditions were reached. Checks were also made of the velocity and turbulent energy patterns in the pool to verify that steady-state conditions were reached.

Debris Transport Metrics

The metrics for predicting debris transport during recirculation are the TKE necessary to keep debris suspended, and the flow velocity necessary to tumble sunken debris along the floor or lift it over a curb. Debris transport metrics have been derived or adopted from data. The metrics utilized in the PBN1 and PBN2 transport analyses originate from the following sources.

- NUREG/CR-6772 Tables 3.1, 3.5, and C.19(a) (Reference 14, pp. 16, 22, and C-16)
- NUREG/CR-6808 Figure 5.2, Table 5-1 and Table 5-3 (Reference 15, pp. 5-14, 5-22, and 5-33)

Graphical Determination of Debris Transport Fractions for Recirculation

The following steps were taken to determine what percentage of a particular type of debris could be expected to transport through the containment pool to the emergency sump screens. Detailed explanations of each bullet are provided in the paragraphs below.

- Colored contour velocity and TKE maps were generated from the Flow-3D results in the form of bitmap files indicating regions of the pool through which a particular type of debris could be expected to transport.
- The bitmap images 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.
- Closed polylines were drawn around the contiguous areas where velocity and TKE were high enough that debris could be carried in suspension or tumbled along the floor to the sump strainers for uniformly distributed debris.
- The areas within the closed polylines were determined using an AutoCAD querying feature.
- The combined area within the polylines was compared to the initial debris distribution area.
- The percentage of a particular debris type that would transport to the sump strainers was determined 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 would be transported. The limits on the plots were set according to the minimum TKE or velocity metrics necessary to move each type of debris (refer to the figures that follow). The overlying yellow areas represent regions where the debris would be suspended, and the red areas represent regions where the debris would be tumbled along the floor (see Figure 3.e.1-6 and Figure 3.e.1-7). The yellow TKE portion of the plots is a three-dimensional representation of the TKE. Since the TKE is a three-dimensional representation, the plots do not show the TKE at any specific elevation. Rather, any debris that is shown to be present in this yellow area will transport, regardless of the elevation of TKE in the pool. 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 strainers or transported to less active regions of the pool where it could settle to the floor (blue regions).

The following figures and discussion are presented as an example of how the transport analysis was performed for a generic small debris type. This same approach was used for other debris types analyzed at PBN1 and PBN2.

As shown in Figure 3.e.1-4 (PBN1) and Figure 3.e.1-5 (PBN2), the small debris (depicted by green shading) was initially assumed to be distributed in the vicinity of the break location for a postulated Loop B break in each unit at the beginning of recirculation.

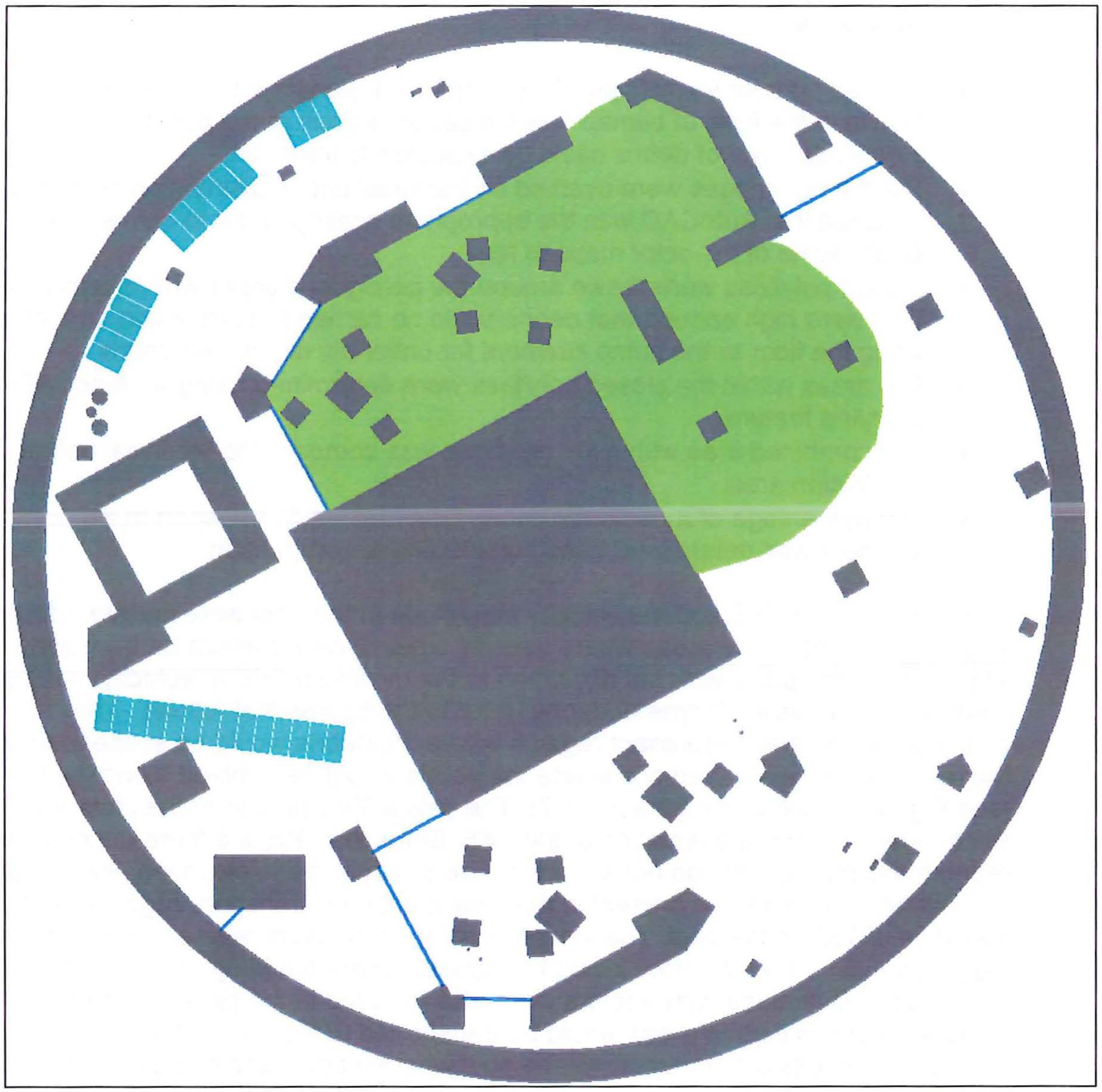


Figure 3.e.1-4: Distribution of Small Debris in Lower Containment (PBN1)

Figure 3.e.1-5: Distribution of Small Debris in Lower Containment (PBN2)

For PBN1, Figure 3.e.1-6 shows that the turbulence (yellow regions) and the velocity (red regions) in the pool (blue regions) generated by the break flow are not high enough to transport the generic small debris present in the pool to the sump strainers during recirculation. Therefore, the transport for small debris blown to lower containment is 0% for PBN1.

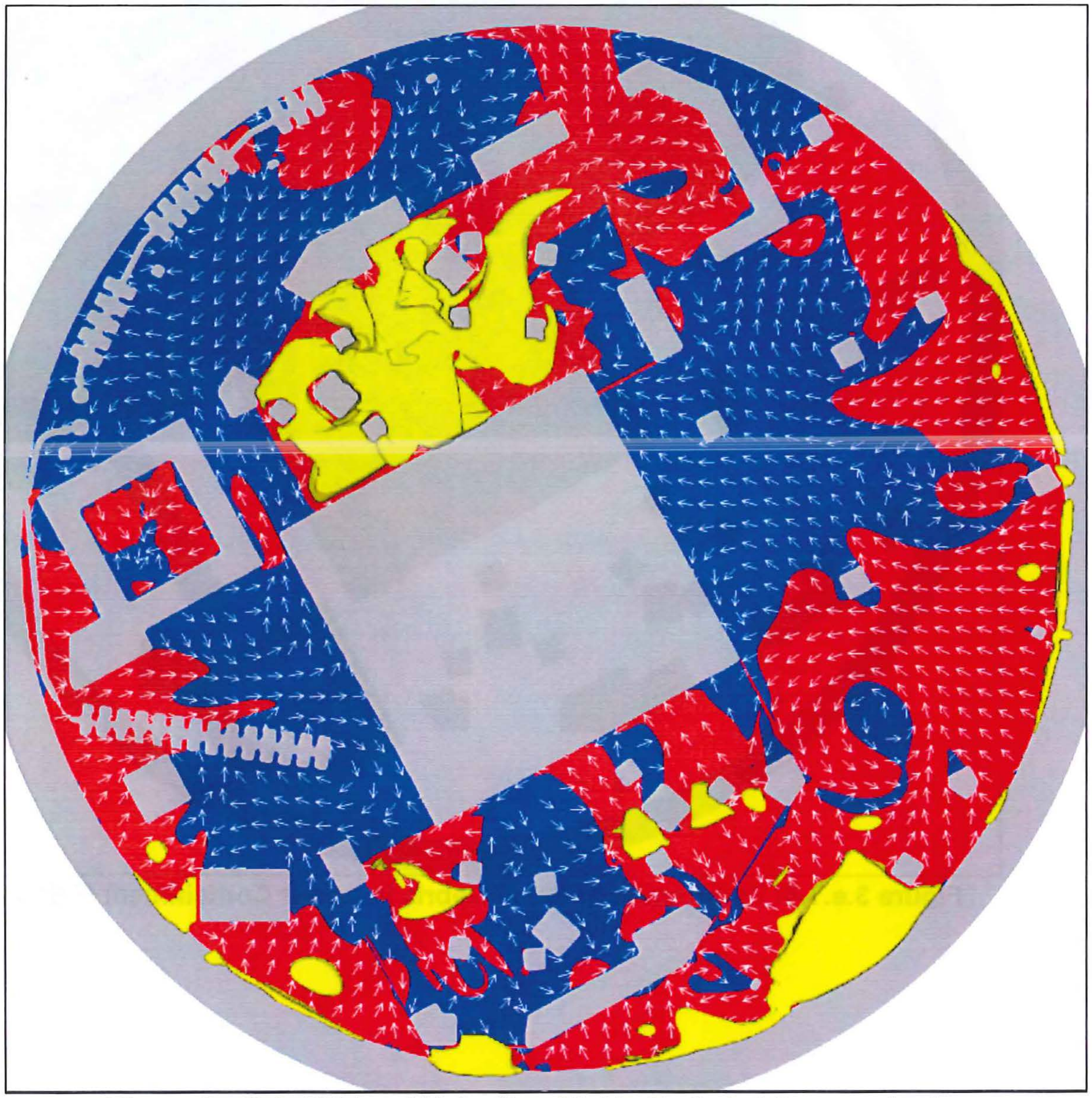


Figure 3.e.1-6: TKE and Velocity with Limits Set at Suspension/ Tumbling of Small Generic Debris (PBN1)

For PBN2, Figure 3.e.1-7 shows that the turbulence (yellow regions) and the velocity (red regions) in the pool (blue regions) generated by the break flow are high enough to transport the generic small debris present in the pool to the sump strainers during recirculation. The initial distribution area (Figure 3.e.1-5) was overlaid on top of the plot showing tumbling velocity, TKE, and flow vectors (Figure 3.e.1-7) to determine the recirculation transport fraction (Figure 3.e.1-8).

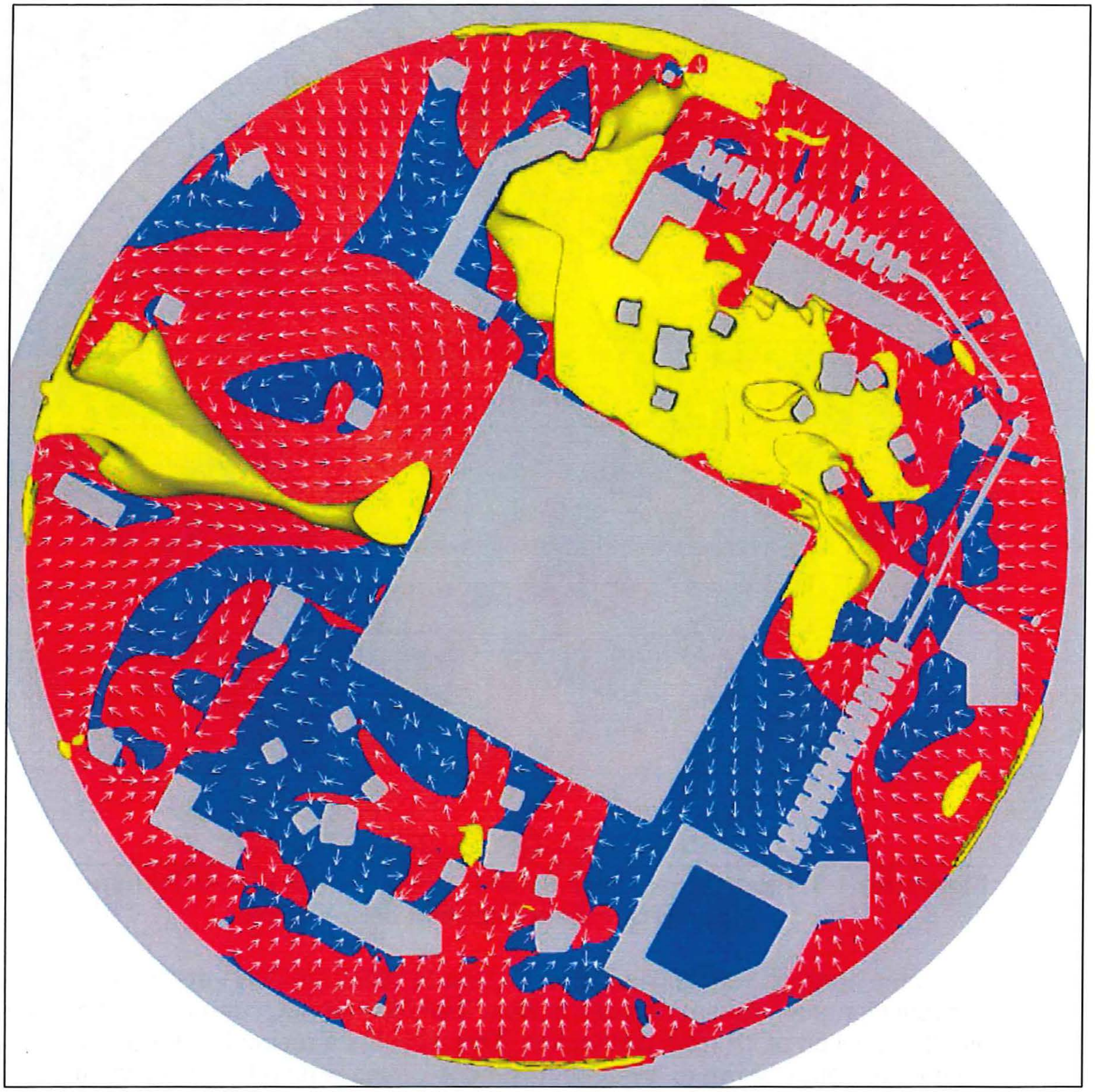


Figure 3.e.1-7: TKE and Velocity with Limits Set at Suspension/ Tumbling of Small Generic Debris (PBN2)

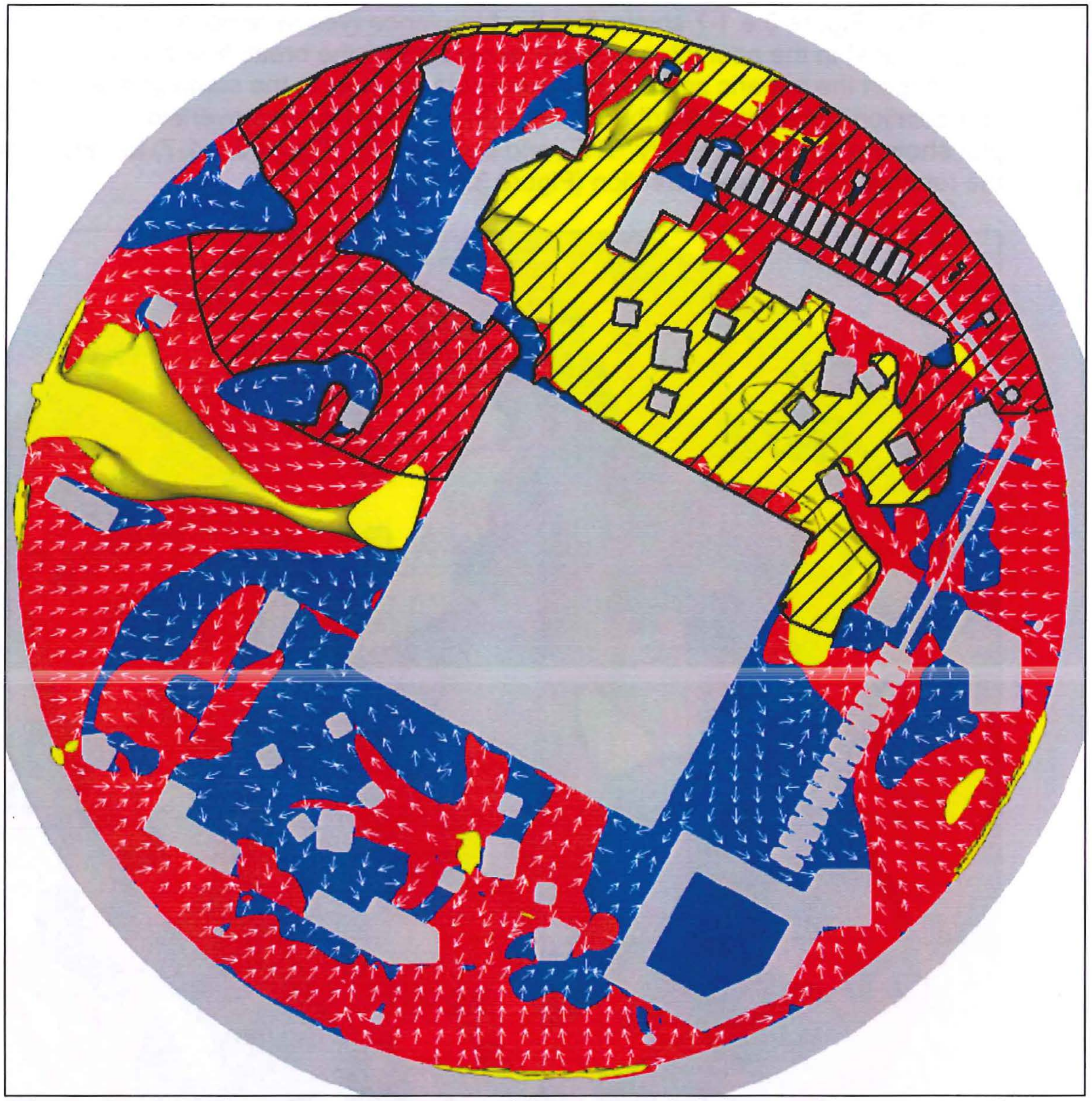


Figure 3.e.1-8: Floor Area where Small Generic Debris Would Transport to the Sump Strainers (hatched area – PBN2)

This same analysis was applied for each type of debris at PBN1 and PBN2. Recirculation-pool transport fractions were identified for each debris type associated with the location of its initial distribution. This includes a recirculation transport fraction for debris blown to lower containment, debris washed down inside the secondary shield wall, and debris washed down through the annulus.

Erosion Discussion

Due to the turbulence in the recirculation pool and the force of break and spray flow, Nukon (PBN2 only), LDFG, Temp-Mat, and Cal-Sil debris may erode into smaller pieces, making transport of this debris to the strainer more likely. To estimate erosion that would occur in the recirculation pools at PBN1 and PBN2, generic 30-day testing was performed. Based on a validation that the results apply to PBN1 and PBN2 (ensuring that the flow rates and turbulence values are similar to what is expected in the PBN1 and PBN2 recirculation pools), an erosion fraction of 10% was assumed for the small and large pieces of fiberglass debris in the pool. An erosion fraction of 17% was assumed for the small chunks of Cal-Sil debris in the pool. This fraction was applied to both transportable debris and settled debris present in the pool to maximize the amount of erosion. For pieces of debris held up on grating above the pool, an erosion fraction of 1% was used for fiberglass debris, and 17% for Cal-Sil debris.

2. *Provide the technical basis for assumptions and methods used in the analysis that deviate from the approved guidance.*

Response to 3.e.2:

The methodology used in the transport analysis was based on and does not deviate from the NRC approved NEI 04-07 guidance and the associated NRC SE for refined analyses, as well as the refined methodologies suggested by the SE in Appendices III, IV, and VI (Reference 6).

3. *Identify any computational fluid dynamics codes used to compute debris transport fractions during recirculation and summarize the methodology, modeling assumptions, and results.*

Response to 3.e.3:

To assist in the determination of recirculation transport fractions, several computational fluid dynamics (CFD) simulations were run using Flow-3D, a commercially available software package.

For PBN1, four break cases form the basis for the debris transport analysis to determine the recirculation transport fractions. These simulations were performed with future modifications (removal of kick-plate at the top of Stairway #22, and removal of Debris Interceptors A2 and A4). Two cases were analyzed for each operational strainer – a break in Loop A and a break in Loop B (a total of four cases). All cases were run with the maximum ECCS flow rate through the strainer (2,200 gpm) and with the minimum water level at the start of full recirculation (4.23 ft) . Using the maximum flow rates and minimum water level maximize the turbulence and velocity in the pool.

For PBN2, four break cases also form the basis for the debris transport analysis to determine the recirculation transport fractions. These simulations were performed with the current plant configuration and the future modification of the refueling canal drain line extension. Two cases were analyzed for each operational strainer – a break in Loop A and a break in Loop B (a total of four cases). All cases were run with the maximum ECCS flow rate through the strainer (2,200 gpm) and with the minimum water level at the start of full recirculation (4.23 ft) . Using the maximum flow rates and the minimum water level maximize the turbulence and velocity in the pool.

In general, a break close to the strainer tends to transport a larger fraction of small and large debris than a break farther from the strainer. The simulation results include a series of contour plots of velocity and TKE. These results have been combined with settling and tumbling velocities from the GSI-191 literature to determine the recirculation transport fractions for all debris types present in the PBN1 and PBN2 containment buildings. See the Response to 3.e.1 for additional discussion of the CFD results.

4. *Provide a summary of, and supporting basis for, any credit taken for debris interceptors.*

Response to 3.e.4:

At PBN1, debris interceptors within the secondary shield wall were not credited for preventing any debris from reaching the strainer. In the CFD model, the interceptors were assumed to be completely blocked during the simulation (debris interceptors were modeled as flow diverters). This conservatively causes all of the flow to be diverted through the open passageways between the steam generator compartments and the annulus to the strainers which increases the velocities in the pool.

No credit was taken for debris interceptors at PBN2.

5. *State whether fine debris was assumed to settle and provide basis for any settling credited.*

Response to 3.e.5:

No credit was taken for settling of fine debris.

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

Response to 3.e.6:

The following debris transport fractions are shown for blowdown, washdown, pool fill, and recirculation. Note that these fractions result in the bounding quantity of debris transported to the strainer. Cells with a "-" in the tables of this subsection represent values that are not applicable (i.e., debris type not generated for a specific location, debris type not available for washdown/pool-fill, etc.).

Blowdown Transport

Table 3.e.6-1 and Table 3.e.6-2 show the bounding (minimum amount of debris remaining in the compartment) blowdown transport fractions as a function of break location and debris type. Note that only the limiting break locations with respect to the maximum overall debris transport fractions are listed in these tables.

Table 3.e.6-1: Blowdown Transport Fractions (PBN1)

Break Location	Debris Type	Transport Fraction		
		To Upper Containment (UC)	To Lower Containment (LC)	Remaining in Compartment
Steam Generator (SG) Compartments	Fines (all)	66%	34%	0%
	Small Fiberglass	57%	30%	13%
	Large Fiberglass	27%	12%	61%
	Intact Fiberglass Blankets	0%	0%	100%
	Small RMI	64%	33%	3%
	Large RMI	40%	15%	45%
	Small Cal-Sil	64%	33%	3%
	Qualified Coatings	66%	34%	0%
	Unqualified Coatings	-	-	-
	Latent Debris	-	-	-
Reactor Cavity	Fines (all)	66%	34%	0%
	Small Fiberglass	57%	30%	13%
	Large Fiberglass	27%	12%	61%
	Intact Fiberglass Blankets	0%	0%	100%
	Small RMI not in Cavity	64%	33%	3%
	Small RMI in Cavity	20%	30%	50%
	Large RMI not in Cavity	40%	15%	45%
	Large RMI in Cavity	0%	0%	100%
	Small Cal-Sil not in Cavity	64%	33%	3%
	Small Cal-Sil in Cavity	20%	30%	50%
	Qualified Coatings	66%	34%	0%
	Unqualified Coatings	-	-	-
	Latent Debris	-	-	-

Break Location	Debris Type	Transport Fraction		
		To Upper Containment (UC)	To Lower Containment (LC)	Remaining in Compartment
Pressurizer Compartment	Fines (all)	66%	34%	0%
	Small Fiberglass	64%	29%	7%
	Large Fiberglass	40%	12%	48%
	Intact Fiberglass Blankets	0%	0%	100%
	Small RMI	-	-	-
	Large RMI	-	-	-
	Small Cal-Sil	65%	33%	2%
	Qualified Coatings	66%	34%	0%
	Unqualified Coatings	-	-	-
	Latent Debris	-	-	-

Table 3.e.6-2: Blowdown Transport Fractions (PBN2)

Break Location	Debris Type	Transport Fraction		
		To Upper Containment (UC)	To Lower Containment (LC)	Remaining in Compartment
SG Compartments	Fines (all)	65%	35%	0%
	Small Fiberglass	57%	31%	12%
	Large Fiberglass	26%	13%	61%
	Intact Fiberglass Blankets	0%	0%	100%
	Small RMI	63%	34%	3%
	Large RMI	40%	20%	40%
	Small Cal-Sil	63%	34%	3%
	Qualified Coatings	65%	35%	0%
	Unqualified Coatings	-	-	-
	Latent Debris	-	-	-
Reactor Cavity	Fines (all)	65%	35%	0%
	Small Fiberglass	57%	31%	12%
	Large Fiberglass	26%	13%	61%
	Intact Fiberglass Blankets	0%	0%	100%
	Small RMI not in Cavity	63%	34%	3%
	Small RMI in Cavity	20%	30%	50%
	Large RMI not in Cavity	40%	20%	40%
	Large RMI in Cavity	0%	0%	100%
	Small Cal-Sil not in Cavity	63%	34%	3%
	Small Cal-Sil in Cavity	20%	30%	50%
	Qualified Coatings	65%	35%	0%
	Unqualified Coatings	-	-	-
	Latent Debris	-	-	-
Pressurizer Compartment	Fines (all)	65%	35%	0%
	Small Fiberglass	63%	30%	7%
	Large Fiberglass	40%	12%	48%
	Intact Fiberglass Blankets	0%	0%	100%
	Small RMI	65%	34%	1%
	Large RMI	45%	25%	30%
	Small Cal-Sil	65%	34%	1%
	Qualified Coatings	65%	35%	0%
	Unqualified Coatings	-	-	-
	Latent Debris	-	-	-

Washdown Transport

Table 3.e.6-3 and Table 3.e.6-4 show the bounding washdown transport fractions (maximum amount of debris washed to lower containment) for each debris type. Note that these transport fractions do not depend on the location of the break. The difference in the fractions between the two units is due to the presence of a curb around the perimeter of the operating deck in PBN1.

Table 3.e.6-3: Washdown Transport Fractions (PBN1)

Debris Type	Transport Fraction		
	Washed Down in Annulus	Washed Down Inside Steam Generator Compartments	Washed Down Refueling Canal (RFC) Drain
Fines/Particulate (all)	59%	24%	17%
Small Fiberglass	59%	19%	17%
Large Fiberglass	59%	0%	17%
Intact Fiberglass Blankets	-	-	-
Small RMI	59%	24%	17%
Large RMI	59%	0%	17%
Small Cal-Sil	59%	24%	17%
Qualified Coatings	59%	24%	17%
Unqualified Coatings	-	-	-
Latent Debris	-	-	-

Table 3.e.6-4: Washdown Transport Fractions (PBN2)

Debris Type	Transport Fraction		
	Washed Down in Annulus	Washed Down Inside Steam Generator Compartments	Washed Down RFC Drain
Fines/Particulate (all)	63%	21%	16%
Small Fiberglass	63%	16%	16%
Large Fiberglass	63%	0%	16%
Intact Fiberglass Blankets	-	-	-
Small RMI	63%	21%	16%
Large RMI	63%	0%	16%
Small Cal-Sil	63%	21%	16%
Qualified Coatings	63%	21%	16%
Unqualified Coatings	-	-	-
Latent Debris	-	-	-

Pool-Fill Transport

The calculation used to determine the portion of debris washed to inactive cavities during pool fill is based on the following equation:

$$x_{pool-fill} = 1 - e^{-\left(\frac{V_{cavity}}{V_{pool}}\right)}$$

Where:

$X_{pool\text{-}fill}$	= Amount of debris transported to cavity during pool fill
V_{cavity}	= Cavity volume
V_{pool}	= Pool volume (sum of active and inactive volumes)

The primary cavity below the floor elevation at PBN1 and PBN2 is the reactor cavity. As the pool fills in the PBN containment, the reactor cavity would fill first. Water would flow through the 16" core bore at the bottom of the keyway in the reactor cavity from the containment floor recirculation pool. The volume of the reactor cavity at a recirculation pool water level of 6 inches was calculated to be 3,267 ft^3 for PBN1 and 3,189 ft^3 for PBN2. The volume of the pool in the recirculation sump at six inches was calculated to be 2,654 ft^3 for PBN1 and 3,189 ft^3 for PBN2.

Inserting these values into the equation above yields a pool fill-up debris transport fraction of 71% for PBN1 and 77% for PBN2. However, debris transport to the inactive cavity was limited to 15% by Section 3.6.3 of the SER (Reference 6).

Table 3.e.6-5 shows the bounding (minimum) pool fill transport fractions as a function of debris type.

Table 3.e.6-5: Pool Fill Transport Fractions (PBN1 and PBN2)

Debris Type	Pool Fill Transport Fraction	
	Directly to Strainer	Inactive Cavity
Fines/Particulate (all)	0%	15%
Small Fiberglass	0%	15%
Large Fiberglass	0%	15%
Intact Fiberglass Blankets	-	-
Small Temp-Mat	0%	15%
Large Temp-Mat	0%	15%
Intact Temp-Mat Blankets	-	-
Small RMI	0%	15%
Large RMI	0%	15%
Small Cal-Sil	0%	15%
Qualified Coatings	0%	15%
Unqualified Coatings	-	-
Latent Debris	0%	15%

Recirculation Transport

For the recirculation transport fractions, four different break cases form the basis for each debris transport analysis, and were evaluated in each of the debris transport calculations. Note that recirculation transport fractions are presented separately for each unit. This is because the location of the strainers and the presence of debris interceptors are different between the two units.

The cases for PBN1 are:

- Case 1: LBLOCA in SG Compartment Loop A, Train A Operational
- Case 2: LBLOCA in SG Compartment Loop A, Train B Operational
- Case 3: LBLOCA in SG Compartment Loop B, Train A Operational
- Case 4: LBLOCA in SG Compartment Loop B, Train B Operational

The cases for PBN2 are:

- Case 1: LBLOCA in SG Compartment Loop A, Train A Operational
- Case 2: LBLOCA in SG Compartment Loop B, Train A Operational
- Case 3: LBLOCA in SG Compartment Loop A, Train B Operational
- Case 4: LBLOCA in SG Compartment Loop B, Train B Operational

It was assumed that for any breaks that could occur in the reactor cavity or in the pressurizer compartment, the recirculation transport fractions for a break inside the secondary shield wall (Loop A or Loop B for a reactor cavity break, and Loop B for a pressurizer break) could be applied.

The bounding (maximum) recirculation transport fractions for fibrous debris as a function of evaluation case are shown in Table 3.e.6-6 and Table 3.e.6-7.

See Response to 3.e.1 for the methodology used for recirculation transport.

Table 3.e.6-6: Recirculation Transport Fractions for Fibrous Debris (PBN1)

Case	Debris Size	Debris in Lower Containment	Debris Washed inside Steam Generator Compartments	Debris Washed in Annulus	Debris Washed down RFC Drain
Case 1	Fines	100%	100%	100%	100%
	Small	0%	8%	21%	0%
	Large	0%	-	0%	0%
	Intact Blankets	-	-	-	-
Case 2	Fines	100%	100%	100%	100%
	Small	0%	0%	7%	0%
	Large	0%	-	4%	0%
	Intact Blankets	-	-	-	-
Case 3	Fines	100%	100%	100%	100%
	Small	0%	0%	3%	0%
	Large	0%	-	0%	0%
	Intact Blankets	-	-	-	-
Case 4	Fines	100%	100%	100%	100%
	Small	0%	0%	7%	0%
	Large	0%	-	4%	0%
	Intact Blankets	-	-	-	-

Table 3.e.6-7: Recirculation Transport Fractions for Fibrous Debris (PBN2)

Case	Debris Size	Debris in Lower Containment	Debris Washed inside Steam Generator Compartments	Debris Washed in Annulus	Debris Washed down RFC Drain
Case 1	Fines	100%	100%	100%	100%
	Small	32%	4%	42%	0%
	Large	0%	-	11%	0%
	Intact Blankets	-	-	-	-
Case 2	Fines	100%	100%	100%	100%
	Small	72%	41%	50%	0%
	Large	11%	-	9%	0%
	Intact Blankets	-	-	-	-
Case 3	Fines	100%	100%	100%	100%
	Small	68%	44%	45%	0%
	Large	0%	-	0%	0%
	Intact Blankets	-	-	-	-
Case 4	Fines	100%	100%	100%	100%
	Small	34%	33%	16%	0%
	Large	0%	-	0%	0%
	Intact Blankets	-	-	-	-

The bounding recirculation transport fractions for Temp-Mat debris as a function of evaluation case are shown in Table 3.e.6-8 and Table 3.e.6-9. It was conservatively assumed that Temp-Mat debris would float in the recirculation pool until it is transported to the vicinity of the strainers, which results in a recirculation transport fraction of 100%.

Table 3.e.6-8: Recirculation Transport Fractions for Temp-Mat (PBN1)

Case	Debris Size	Debris in Lower Containment	Debris Washed inside Steam Generator Compartments	Debris Washed in Annulus	Debris Washed down RFC Drain
Case 1	Fines	100%	100%	100%	100%
	Small	100%	100%	100%	100%
	Large	100%	100%	100%	100%
	Intact Blankets	-	-	-	-
Case 2	Fines	100%	100%	100%	100%
	Small	100%	100%	100%	100%
	Large	100%	100%	100%	100%
	Intact Blankets	-	-	-	-
Case 3	Fines	100%	100%	100%	100%
	Small	100%	100%	100%	100%
	Large	100%	100%	100%	100%
	Intact Blankets	-	-	-	-
Case 4	Fines	100%	100%	100%	100%
	Small	100%	100%	100%	100%
	Large	100%	100%	100%	100%
	Intact Blankets	-	-	-	-

Table 3.e.6-9: Recirculation Transport Fractions for Temp-Mat (PBN2)

Case	Debris Size	Debris in Lower Containment	Debris Washed inside Steam Generator Compartments	Debris Washed in Annulus	Debris Washed down RFC Drain
Case 1	Fines	100%	100%	100%	100%
	Small	100%	100%	100%	100%
	Large	100%	-	100%	100%
	Intact Blankets	-	-	-	-
Case 2	Fines	100%	100%	100%	100%
	Small	100%	100%	100%	100%
	Large	100%	-	100%	100%
	Intact Blankets	-	-	-	-
Case 3	Fines	100%	100%	100%	100%
	Small	100%	100%	100%	100%
	Large	100%	-	100%	100%
	Intact Blankets	-	-	-	-
Case 4	Fines	100%	100%	100%	100%
	Small	100%	100%	100%	100%
	Large	100%	-	100%	100%
	Intact Blankets	-	-	-	-

The bounding recirculation transport fractions for RMI debris as a function of evaluation case are shown in Table 3.e.6-10 and Table 3.e.6-11.

Table 3.e.6-10: Recirculation Transport Fractions for RMI Debris (PBN1)

Case	Debris Size	Debris in Lower Containment	Debris Washed inside Steam Generator Compartments	Debris Washed in Annulus	Debris Washed down RFC Drain
Case 1	Small	0%	0%	0%	0%
	Large	0%	-	0%	0%
Case 2	Small	0%	0%	5%	0%
	Large	0%	-	5%	0%
Case 3	Small	0%	0%	1%	0%
	Large	0%	-	1%	0%
Case 4	Small	0%	0%	5%	0%
	Large	0%	-	5%	0%

Table 3.e.6-11: Recirculation Transport Fractions for RMI Debris (PBN2)

Case	Debris Size	Debris in Lower Containment	Debris Washed inside Steam Generator Compartments	Debris Washed in Annulus	Debris Washed down RFC Drain
Case 1	Small	0%	0%	16%	0%
	Large	0%	-	16%	0%
Case 2	Small	16%	8%	13%	0%
	Large	16%	-	13%	0%
Case 3	Small	0%	0%	0%	0%
	Large	0%	-	0%	0%
Case 4	Small	0%	0%	0%	0%
	Large	0%	-	0%	0%

The bounding recirculation transport fractions for Cal-Sil debris as a function of evaluation case are shown in Table 3.e.6-12 and Table 3.e.6-13.

Table 3.e.6-12: Recirculation Transport Fractions for Cal-Sil Debris (PBN1)

Case	Debris Size	Debris in Lower Containment	Debris Washed inside Steam Generator Compartments	Debris Washed in Annulus	Debris Washed down RFC Drain
Case 1	Particulate	100%	100%	100%	100%
	Small	0%	0%	0%	0%
Case 2	Particulate	100%	100%	100%	100%
	Small	0%	0%	5%	0%
Case 3	Particulate	100%	100%	100%	100%
	Small	0%	0%	2%	0%
Case 4	Particulate	100%	100%	100%	100%
	Small	0%	0%	5%	0%

Table 3.e.6-13: Recirculation Transport Fractions for Cal-Sil Debris (PBN2)

Case	Debris Size	Debris in Lower Containment	Debris Washed inside Steam Generator Compartments	Debris Washed in Annulus	Debris Washed down RFC Drain
Case 1	Particulate	100%	100%	100%	100%
	Small	0%	0%	16%	0%
Case 2	Particulate	100%	100%	100%	100%
	Small	15%	5%	14%	0%
Case 3	Particulate	100%	100%	100%	100%
	Small	0%	0%	0%	0%
Case 4	Particulate	100%	100%	100%	100%
	Small	0%	0%	0%	0%

The bounding recirculation transport fractions for qualified coatings, unqualified coatings, and latent debris as a function of evaluation case are shown in Table 3.e.6-14 and Table 3.e.6-15.

Table 3.e.6-14: Recirculation Transport Fractions for Qualified Coatings, Unqualified Coatings, Latent Debris (PBN1)

Case	Debris Size	Debris in Lower Containment	Debris Washed inside Steam Generator Compartments	Debris Washed in Annulus	Debris Washed down RFC Drain
Case 1	Fine/Particulate	100%	100%	100%	100%
Case 2	Fine/Particulate	100%	100%	100%	100%
Case 3	Fine/Particulate	100%	100%	100%	100%
Case 4	Fine/Particulate	100%	100%	100%	100%

Table 3.e.6-15: Recirculation Transport Fractions for Qualified Coatings, Unqualified Coatings, Latent Debris (PBN2)

Case	Debris Size	Debris in Lower Containment	Debris Washed inside Steam Generator Compartments	Debris Washed in Annulus	Debris Washed down RFC Drain
Case 1	Fine/Particulate	100%	100%	100%	100%
Case 2	Fine/Particulate	100%	100%	100%	100%
Case 3	Fine/Particulate	100%	100%	100%	100%
Case 4	Fine/Particulate	100%	100%	100%	100%

Overall Debris Transport

Transport logic trees were developed for each size and type of debris generated. These trees were used to determine the total fraction of debris that would reach the sump strainers in each of the postulated cases. The overall transport fractions are provided in Table 3.e.6-16 through Table 3.e.6-25.

Table 3.e.6-16: Overall Transport Fractions for a Break in the SG Compartment Break in Loop A (PBN1)

Debris Type	Debris Size		Train A Operational	Train B Operational
LDFG	Fines		95%	95%
	Small Pieces	Transport as Erosion Fines	8%	8%
		Transport as Small Pieces	7%	2%
	Large Pieces	Transport as Erosion Fines	4%	4%
		Transport as Large Pieces	0%	1%
	Intact Blankets		0%	0%
Temp-Mat	Fines		-	-
	Small Pieces	Transport as Erosion Fines	-	-
		Transport as Small Pieces	-	-
	Large Pieces	Transport as Erosion Fines	-	-
		Transport as Large Pieces	-	-
	Intact Blankets		-	-
Mirror RMI	Fines		0%	2%
	Large Pieces		0%	1%
Transco RMI	Fines		0%	2%
	Large Pieces		0%	1%
Mineral Wool	Fines		95%	95%
Cal-Sil	Fines		95%	95%
	Small Pieces	Transport as Erosion Fines	16%	16%
		Transport as Small Pieces	0%	2%
Asbestos Cal-Sil	Fines		95%	95%
	Small Pieces	Transport as Erosion Fines	16%	16%
		Transport as Small Pieces	0%	2%
Qualified Coatings	Particulate		95%	95%
Unqualified Coatings	Particulate		100%	100%
Latent Debris	Particulate/Fiber		85%	85%

Table 3.e.6-17: Overall Transport Fractions for a Break in the SG Compartment in Loop B (PBN1)

Debris Type	Debris Size		Train A Operational	Train B Operational
LDFG	Fines		95%	95%
	Small Pieces	Transport as Erosion Fines	8%	8%
		Transport as Small Pieces	1%	2%
	Large Pieces	Transport as Erosion Fines	4%	4%
		Transport as Large Pieces	0%	1%
	Intact Blankets		0%	0%
Temp-Mat	Fines		95%	95%
	Small Pieces	Transport as Erosion Fines	8%	8%
		Transport as Small Pieces	74%	74%
	Large Pieces	Transport as Erosion Fines	4%	4%
		Transport as Large Pieces	28%	28%
	Intact Blankets		0%	0%
Mirror RMI	Fines		0%	2%
	Large Pieces		0%	1%
Transco RMI	Fines		0%	2%
	Large Pieces		0%	1%
Mineral Wool	Fines		95%	95%
Cal-Sil	Fines		95%	95%
	Small Pieces	Transport as Erosion Fines	16%	16%
		Transport as Small Pieces	1%	2%
Asbestos Cal-Sil	Fines		95%	95%
	Small Pieces	Transport as Erosion Fines	16%	16%
		Transport as Small Pieces	1%	2%
Qualified Coatings	Particulate		95%	95%
Unqualified Coatings	Particulate		100%	100%
Latent Debris	Particulate/Fiber		85%	85%

Table 3.e.6-18: Overall Transport Fractions for a Reactor Cavity Break Loop A (PBN1)

Debris Type	Debris Size		Train A Operational	Train B Operational
LDFG	Fines		95%	95%
	Small Pieces	Transport as Erosion Fines	8%	8%
		Transport as Small Pieces	7%	2%
	Large Pieces	Transport as Erosion Fines	4%	4%
		Transport as Large Pieces	0%	1%
	Intact Blankets		0%	0%
Temp-Mat	Fines		-	-
	Small Pieces	Transport as Erosion Fines	-	-
		Transport as Small Pieces	-	-
	Large Pieces	Transport as Erosion Fines	-	-
		Transport as Large Pieces	-	-
	Intact Blankets		-	-
Mirror RMI	Fines		0%	2%
	Large Pieces		0%	1%
Transco RMI	Fines		0%	2%
	Large Pieces		0%	1%
Transco RMI In Cavity	Fines		0%	1%
	Large Pieces		0%	0%
Mineral Wool	Fines		95%	95%
Cal-Sil	Fines		95%	95%
	Small Pieces	Transport as Erosion Fines	16%	16%
		Transport as Small Pieces	0%	2%
Cal-Sil In Cavity	Fines		95%	95%
	Small Pieces	Transport as Erosion Fines	17%	17%
		Transport as Small Pieces	0%	1%
Asbestos Cal-Sil	Fines		95%	95%
	Small Pieces	Transport as Erosion Fines	16%	16%
		Transport as Small Pieces	0%	2%
Qualified Coatings	Particulate		95%	95%
Unqualified Coatings	Particulate		100%	100%
Latent Debris	Particulate/Fiber		85%	85%

Table 3.e.6-19: Overall Transport Fractions for a Reactor Cavity Break Loop B (PBN1)

Debris Type	Debris Size		Train A Operational	Train B Operational
LDFG	Fines		95%	95%
	Small Pieces	Transport as Erosion Fines	8%	8%
		Transport as Small Pieces	1%	2%
	Large Pieces	Transport as Erosion Fines	4%	4%
		Transport as Large Pieces	0%	1%
	Intact Blankets		0%	0%
Temp-Mat	Fines		95%	95%
	Small Pieces	Transport as Erosion Fines	8%	8%
		Transport as Small Pieces	74%	74%
	Large Pieces	Transport as Erosion Fines	4%	4%
		Transport as Large Pieces	28%	28%
	Intact Blankets		0%	0%
Mirror RMI	Fines		0%	2%
	Large Pieces		0%	1%
Transco RMI	Fines		0%	2%
	Large Pieces		0%	1%
Transco RMI In Cavity	Fines		0%	1%
	Large Pieces		0%	0%
Mineral Wool	Fines		95%	95%
Cal-Sil	Fines		95%	95%
	Small Pieces	Transport as Erosion Fines	16%	16%
		Transport as Small Pieces	1%	2%
Cal-Sil In Cavity	Fines		95%	95%
	Small Pieces	Transport as Erosion Fines	17%	17%
		Transport as Small Pieces	0%	1%
Asbestos Cal-Sil	Fines		95%	95%
	Small Pieces	Transport as Erosion Fines	16%	16%
		Transport as Small Pieces	1%	2%
Qualified Coatings	Particulate		95%	95%
Unqualified Coatings	Particulate		100%	100%
Latent Debris	Particulate/Fiber		85%	85%

Table 3.e.6-20: Overall Transport Fractions for a Pressurizer Compartment Break (PBN1)

Debris Type	Debris Size		Train A Operational	Train B Operational
LDFG	Fines		95%	95%
	Small Pieces	Transport as Erosion Fines	9%	9%
		Transport as Small Pieces	1%	2%
	Large Pieces	Transport as Erosion Fines	5%	5%
		Transport as Large Pieces	0%	1%
	Intact Blankets		0%	0%
Temp-Mat	Fines		95%	95%
	Small Pieces	Transport as Erosion Fines	9%	9%
		Transport as Small Pieces	78%	78%
	Large Pieces	Transport as Erosion Fines	5%	5%
		Transport as Large Pieces	37%	37%
	Intact Blankets		0%	0%
Mirror RMI	Fines		-	-
	Large Pieces		-	-
Transco RMI	Fines		-	-
	Large Pieces		-	-
Mineral Wool	Fines		95%	95%
Cal-Sil	Fines		95%	95%
	Small Pieces	Transport as Erosion Fines	16%	16%
		Transport as Small Pieces	1%	2%
Asbestos Cal-Sil	Fines		95%	95%
	Small Pieces	Transport as Erosion Fines	16%	16%
		Transport as Small Pieces	1%	2%
Qualified Coatings	Particulate		95%	95%
Unqualified Coatings	Particulate		100%	100%
Latent Debris	Particulate/Fiber		85%	85%

Table 3.e.6-21: Overall Transport Fractions for a Break in the SG Compartment in Loop A (PBN2)

Debris Type	Debris Size		Train A Operational	Train B Operational
LDFG	Fines		95%	95%
	Small Pieces	Transport as Erosion Fines	8%	8%
		Transport as Small Pieces	22%	35%
	Large Pieces	Transport as Erosion Fines	4%	4%
		Transport as Large Pieces	1%	0%
	Intact Blankets		0%	0%
Nukon	Fines		95%	95%
	Small Pieces	Transport as Erosion Fines	8%	8%
		Transport as Small Pieces	22%	35%
	Large Pieces	Transport as Erosion Fines	4%	4%
		Transport as Large Pieces	1%	0%
	Intact Blankets		0%	0%
Temp-Mat	Fines		-	-
	Small Pieces	Transport as Erosion Fines	-	-
		Transport as Small Pieces	-	-
	Large Pieces	Transport as Erosion Fines	-	-
		Transport as Large Pieces	-	-
	Intact Blankets		-	-
Transco RMI	Fines		6%	0%
	Large Pieces		4%	0%
Mineral Wool	Fines		95%	95%
Cal-Sil	Fines		95%	95%
	Small Pieces	Transport as Erosion Fines	16%	17%
		Transport as Small Pieces	5%	0%
Asbestos Cal-Sil	Fines		95%	95%
	Small Pieces	Transport as Erosion Fines	16%	17%
		Transport as Small Pieces	5%	0%
Qualified Coatings	Particulate		95%	95%
Unqualified Coatings	Particulate		100%	100%
Latent Debris	Particulate/Fiber		85%	85%

Table 3.e.6-22: Overall Transport Fractions for a Break in the SG Compartment in Loop B (PBN2)

Debris Type	Debris Size		Train A Operational	Train B Operational
LDFG	Fines		95%	95%
	Small Pieces	Transport as Erosion Fines	8%	8%
		Transport as Small Pieces	37%	17%
	Large Pieces	Transport as Erosion Fines	4%	4%
		Transport as Large Pieces	2%	0%
	Intact Blankets		0%	0%
Nukon	Fines		95%	95%
	Small Pieces	Transport as Erosion Fines	8%	8%
		Transport as Small Pieces	37%	17%
	Large Pieces	Transport as Erosion Fines	4%	4%
		Transport as Large Pieces	2%	0%
	Intact Blankets		0%	0%
Temp-Mat	Fines		95%	95%
	Small Pieces	Transport as Erosion Fines	8%	8%
		Transport as Small Pieces	74%	74%
	Large Pieces	Transport as Erosion Fines	4%	4%
		Transport as Large Pieces	28%	28%
	Intact Blankets		0%	0%
Transco RMI	Fines		11%	0%
	Large Pieces		6%	0%
Mineral Wool	Fines		95%	95%
Cal-Sil	Fines		95%	95%
	Small Pieces	Transport as Erosion Fines	17%	17%
		Transport as Small Pieces	9%	0%
Asbestos Cal-Sil	Fines		95%	95%
	Small Pieces	Transport as Erosion Fines	17%	17%
		Transport as Small Pieces	9%	0%
Qualified Coatings	Particulate		95%	95%
Unqualified Coatings	Particulate		100%	100%
Latent Debris	Particulate/Fiber		85%	85%

Table 3.e.6-23: Overall Transport Fractions for a Reactor Cavity Break Loop A (PBN2)

Debris Type	Debris Size		Train A Operational	Train B Operational
LDFG	Fines		-	-
	Small Pieces	Transport as Erosion Fines	-	-
		Transport as Small Pieces	-	-
	Large Pieces	Transport as Erosion Fines	-	-
		Transport as Large Pieces	-	-
	Intact Blankets		-	-
Nukon	Fines		-	-
	Small Pieces	Transport as Erosion Fines	-	-
		Transport as Small Pieces	-	-
	Large Pieces	Transport as Erosion Fines	-	-
		Transport as Large Pieces	-	-
	Intact Blankets		-	-
Temp-Mat	Fines		-	-
	Small Pieces	Transport as Erosion Fines	-	-
		Transport as Small Pieces	-	-
	Large Pieces	Transport as Erosion Fines	-	-
		Transport as Large Pieces	-	-
	Intact Blankets		-	-
Transco RMI	Fines		6%	0%
	Large Pieces		4%	0%
Transco RMI in Cavity	Fines		3%	0%
	Large Pieces		0%	0%
Mineral Wool	Fines		95%	95%
Cal-Sil	Fines		95%	95%
	Small Pieces	Transport as Erosion Fines	16%	17%
		Transport as Small Pieces	5%	0%
Cal-Sil in Cavity	Fines		95%	95%
	Small Pieces	Transport as Erosion Fines	17%	17%
		Transport as Small Pieces	3%	0%
Asbestos Cal-Sil	Fines		95%	95%
	Small Pieces	Transport as Erosion Fines	16%	17%
		Transport as Small Pieces	5%	0%
Asbestos Cal-Sil in Cavity	Fines		95%	95%
	Small Pieces	Transport as Erosion Fines	17%	17%
		Transport as Small Pieces	3%	0%
Qualified Coatings	Particulate		95%	95%
Unqualified Coatings	Particulate		100%	100%
Latent Debris	Particulate/Fiber		85%	85%

Table 3.e.6-24: Overall Transport Fractions for a Reactor Cavity Break Loop B (PBN2)

Debris Type	Debris Size		Train A Operational	Train B Operational
LDFG	Fines		-	-
	Small Pieces	Transport as Erosion Fines	-	-
		Transport as Small Pieces	-	-
	Large Pieces	Transport as Erosion Fines	-	-
		Transport as Large Pieces	-	-
	Intact Blankets		-	-
Nukon	Fines		-	-
	Small Pieces	Transport as Erosion Fines	-	-
		Transport as Small Pieces	-	-
	Large Pieces	Transport as Erosion Fines	-	-
		Transport as Large Pieces	-	-
	Intact Blankets		-	-
Temp-Mat	Fines		-	-
	Small Pieces	Transport as Erosion Fines	-	-
		Transport as Small Pieces	-	-
	Large Pieces	Transport as Erosion Fines	-	-
		Transport as Large Pieces	-	-
	Intact Blankets		-	-
Transco RMI	Fines		11%	0%
	Large Pieces		6%	0%
Transco RMI in Cavity	Fines		6%	0%
	Large Pieces		0%	0%
Mineral Wool	Fines		95%	95%
Cal-Sil	Fines		95%	95%
	Small Pieces	Transport as Erosion Fines	17%	17%
		Transport as Small Pieces	9%	0%
Cal-Sil in Cavity	Fines		95%	95%
	Small Pieces	Transport as Erosion Fines	17%	17%
		Transport as Small Pieces	5%	0%
Asbestos Cal-Sil	Fines		95%	95%
	Small Pieces	Transport as Erosion Fines	17%	17%
		Transport as Small Pieces	9%	0%
Asbestos Cal-Sil in Cavity	Fines		95%	95%
	Small Pieces	Transport as Erosion Fines	17%	17%
		Transport as Small Pieces	5%	0%
Qualified Coatings	Particulate		95%	95%
Unqualified Coatings	Particulate		100%	100%
Latent Debris	Particulate/Fiber		85%	85%

Table 3.e.6-25: Overall Transport Fractions for a Pressurizer Compartment Break (PBN2)

Debris Type	Debris Size		Train A Operational	Train B Operational
LDFG	Fines		95%	95%
	Small Pieces	Transport as Erosion Fines	9%	9%
		Transport as Small Pieces	38%	17%
	Large Pieces	Transport as Erosion Fines	5%	5%
		Transport as Large Pieces	2%	0%
	Intact Blankets		0%	0%
Nukon	Fines		-	-
	Small Pieces	Transport as Erosion Fines	-	-
		Transport as Small Pieces	-	-
	Large Pieces	Transport as Erosion Fines	-	-
		Transport as Large Pieces	-	-
	Intact Blankets		-	-
Temp-Mat	Fines		95%	95%
	Small Pieces	Transport as Erosion Fines	9%	9%
		Transport as Small Pieces	78%	78%
	Large Pieces	Transport as Erosion Fines	5%	5%
		Transport as Large Pieces	38%	38%
	Intact Blankets		0%	0%
Transco RMI	Fines		11%	0%
	Large Pieces		7%	0%
Mineral Wool	Fines		95%	95%
Cal-Sil	Fines		95%	95%
	Small Pieces	Transport as Erosion Fines	16%	16%
		Transport as Small Pieces	9%	0%
Asbestos Cal-Sil	Fines		95%	95%
	Small Pieces	Transport as Erosion Fines	16%	16%
		Transport as Small Pieces	9%	0%
Qualified Coatings	Particulate		95%	95%
Unqualified Coatings	Particulate		100%	100%
Latent Debris	Particulate/Fiber		85%	85%

The transported debris quantities for the most limiting break cases identified in the Response to 3.b.4 are presented below. Overall transport fractions were taken from Table 3.e.6-16 for a Loop A break and Table 3.e.6-17 for a Loop B break for PBN1, and Table 3.e.6-21 for a Loop A break and Table 3.e.6-22 for a Loop B break for PBN2. These values were then applied to the debris generated values from Table 3.b.4-1 and Table 3.b.4-2 for PBN1, and Table 3.b.4-3 and Table 3.b.4-4 for PBN2. Note that the overall transport values developed for a DEGB are bounding for all other breaks (including partial breaks) because the flow rates and water level used for the transport analysis are bounding (maximum flow rates and minimum water levels).

Table 3.e.6-26 and Table 3.e.6-27 show the quantities of debris transported for the worst-case PBN1 Cal-Sil breaks and fiber fines breaks, respectively. Note that the transported amount of fine debris includes the quantity of fines plus the small and large piece fines due to erosion.

Table 3.e.6-26: PBN1 Worst-Case Cal-Sil Breaks Transported Quantities

Break Location		**RC-34-MRCL-BI-03**		**RC-36-MRCL-AIII-01A**	
Location Description		Loop B Hot Leg at SG Nozzle		Loop A Cold Leg at RCP	
Break Size		31"		17"	
Break Type		DEGB		Partial	
LDFG (lb)	Fine	35.42		16.01	
	Small	2.15		3.23	
	Large	0.11		0.00	
	Intact	0.00		0.00	
Mineral Wool (lb)	Fine	129.87		21.09	
Temp-Mat (lb)	Fine	0.00		0.00	
	Small	0.00		0.00	
	Large	0.00		0.00	
	Intact	0.00		0.00	
Cal-Sil and Asbestos Cal-Sil (lb)	Fine	657.21		271.41	
	Small	8.74		0.00	
	Intact	0.00		0.00	
Mirror and Transco RMI (ft^2)	Small (<4")	542.86		0.00	
	Large (≥ 4")	90.48		0.00	
Dimetcote 6	Fine	96.24 lbm	0.32 ft^3	0.00 lbm	0.00 ft^3
Amercoat 66	Fine	46.73 lbm	0.48 ft^3	0.00 lbm	0.00 ft^3
Carboline 195	Fine	35.20 lbm	0.32 ft^3	9.44 lbm	0.09 ft^3
Phenoline 305	Fine	5.97 lbm	0.06 ft^3	1.61 lbm	0.02 ft^3

Table 3.e.6-27: PBN1 Worst-Case Fiber Fines Breaks Transported Quantities

Break Location		**RC-36-MRCL-BII-01**		**RC-34-MRCL-BI-03**	
Location Description		Loop B Crossover Leg at SG Nozzle		Loop B Hot Leg at SG Nozzle	
Break Size		31"		17"	
Break Type		DEGB		Partial (Angle – 135°)	
LDFG (lb)	Fine	35.06		14.46	
	Small	2.12		2.94	
	Large	0.11		0.00	
	Intact	0.00		0.00	
Mineral Wool (lb)	Fine	160.65		69.83	
Temp-Mat (lb)	Fine	0.00		0.00	
	Small	0.00		0.00	
	Large	0.00		0.00	
	Intact	0.00		0.00	
Cal-Sil and Asbestos Cal-Sil (lb)	Fine	400.51		156.94	
	Small	4.62		0.00	
	Intact	0.00		0.00	
Mirror and Transco RMI (ft^2)	Small (<4")	537.52		0.00	
	Large (≥ 4")	89.59		0.00	
Dimetcote 6	Fine	83.23 lbm	0.28 ft^3	10.46 lbm	0.04 ft^3
Amercoat 66	Fine	40.40 lbm	0.42 ft^3	5.08 lbm	0.06 ft^3
Carboline 195	Fine	48.22 lbm	0.45 ft^3	0.02 lbm	0.00 ft^3
Phenoline 305	Fine	8.18 lbm	0.08 ft^3	0.00 lbm	0.00 ft^3

Table 3.e.6-28 and Table 3.e.6-29 show the quantities of debris transported for the worst-case PBN2 Cal-Sil breaks and fiber fines breaks, respectively. Note that the transported amount of fine debris includes the quantity of fines plus the small and large piece fines due to erosion.

Table 3.e.6-28: PBN2 Worst-Case Cal-Sil Breaks Transported Quantities

Break Location		**RC-34-MRCL-AI-03**		**RC-34-MRCL-AI-03**	
Location Description		Loop A Hot Leg at Elbow		Loop A Hot Leg at Elbow	
Break Size		29"		17"	
Break Type		DEGB		Partial	
LDFG and Nukon (lb)	Fine	115.02		18.12	
	Small	94.57		13.30	
	Large	0.00		0.00	
	Intact	0.00		0.00	
Mineral Wool (lb)	Fine	124.93		19.19	
Temp-Mat (lb)	Fine	0.00		0.00	
	Small	0.00		0.00	
	Large	0.00		0.00	
	Intact	0.00		0.00	
Cal-Sil and Asbestos Cal-Sil (lb)	Fine	816.47		199.19	
	Small	0.00		0.00	
	Intact	0.00		0.00	
Transco RMI (ft^2)	Small (<4")	0.00		0.00	
	Large (≥ 4")	0.00		0.00	
Dimetcote 6	Fine	116.73 lbm	0.39 ft^3	27.22 lbm	0.10 ft^3
Amercoat 66	Fine	56.67 lbm	0.58 ft^3	13.21 lbm	0.13 ft^3
Carboline 195	Fine	63.75 lbm	0.59 ft^3	12.93 lbm	0.11 ft^3
Phenoline 305	Fine	8.87 lbm	0.09 ft^3	1.80 lbm	0.02 ft^3

Table 3.e.6-29: PBN2 Worst-Case Fiber Fines Breaks Transported Quantities

Break Location		**RC-36-MRCL-BII-01A**		**RC-34-MRCL-BI-03**	
Location Description		Loop B Crossover Leg at SG Nozzle		Loop B Hot Leg at Elbow	
Break Size		31"		17"	
Break Type		DEGB		Partial (Angle – 0°)	
LDFG and Nukon (lb)	Fine	190.36		77.33	
	Small	184.33		70.78	
	Large	5.24		2.70	
	Intact	0.00		0.00	
Mineral Wool (lb)	Fine	186.39		67.26	
Temp-Mat (lb)	Fine	0.00		0.00	
	Small	0.00		0.00	
	Large	0.00		0.00	
	Intact	0.00		0.00	
Cal-Sil and Asbestos Cal-Sil (lb)	Fine	213.28		28.45	
	Small	12.53		1.18	
	Intact	0.00		0.00	
Transco RMI (ft^2)	Small (<4")	137.06		18.81	
	Large (≥ 4")	24.90		3.42	
Dimetcote 6	Fine	141.07 lbm	0.47 ft^3	22.87 lbm	0.08 ft^3
Amercoat 66	Fine	68.49 lbm	0.70 ft^3	11.11 lbm	0.11 ft^3
Carboline 195	Fine	77.45 lbm	0.71 ft^3	5.71 lbm	0.06 ft^3
Phenoline 305	Fine	10.77 lbm	0.10 ft^3	0.80 lbm	0.01 ft^3

The quantity of latent debris that transports to the strainer is 108.375 lbm latent particulate and 19.125 lbm (7.96875 ft^3) latent fiber for all breaks.

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.

1. *Provide a schematic diagram of the emergency core cooling system (ECCS) and containment spray systems (CSS).*

   Response to 3.f.1:

   See Figure 3.f.1-1 through Figure 3.f.1-3 for ECCS and CSS schematics of PBN1. Although the figures depict the PBN1 installation, they are also representative of the PBN2 systems.

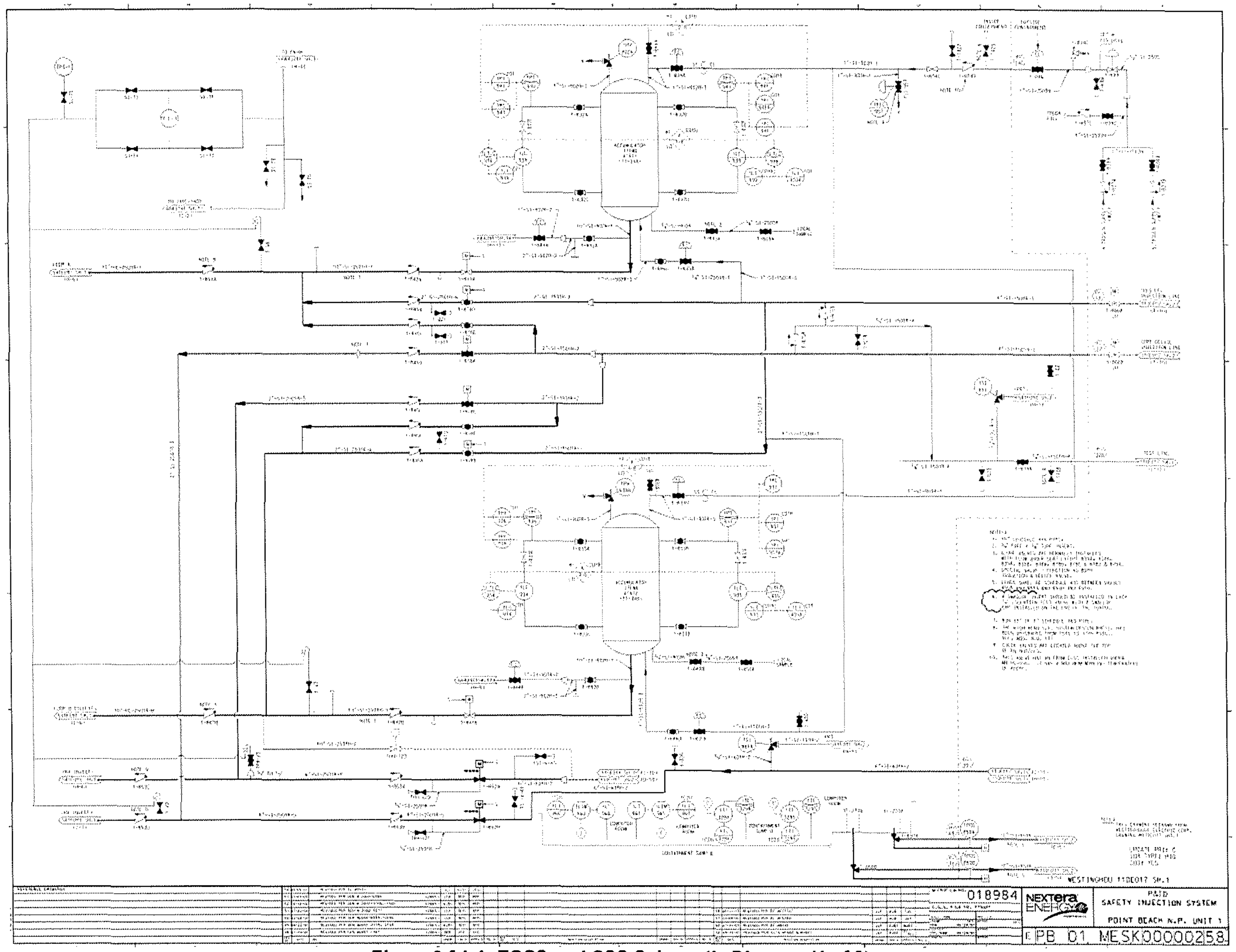


Figure 3.f.1-1: ECCS and CSS Schematic Diagram (1 of 3)

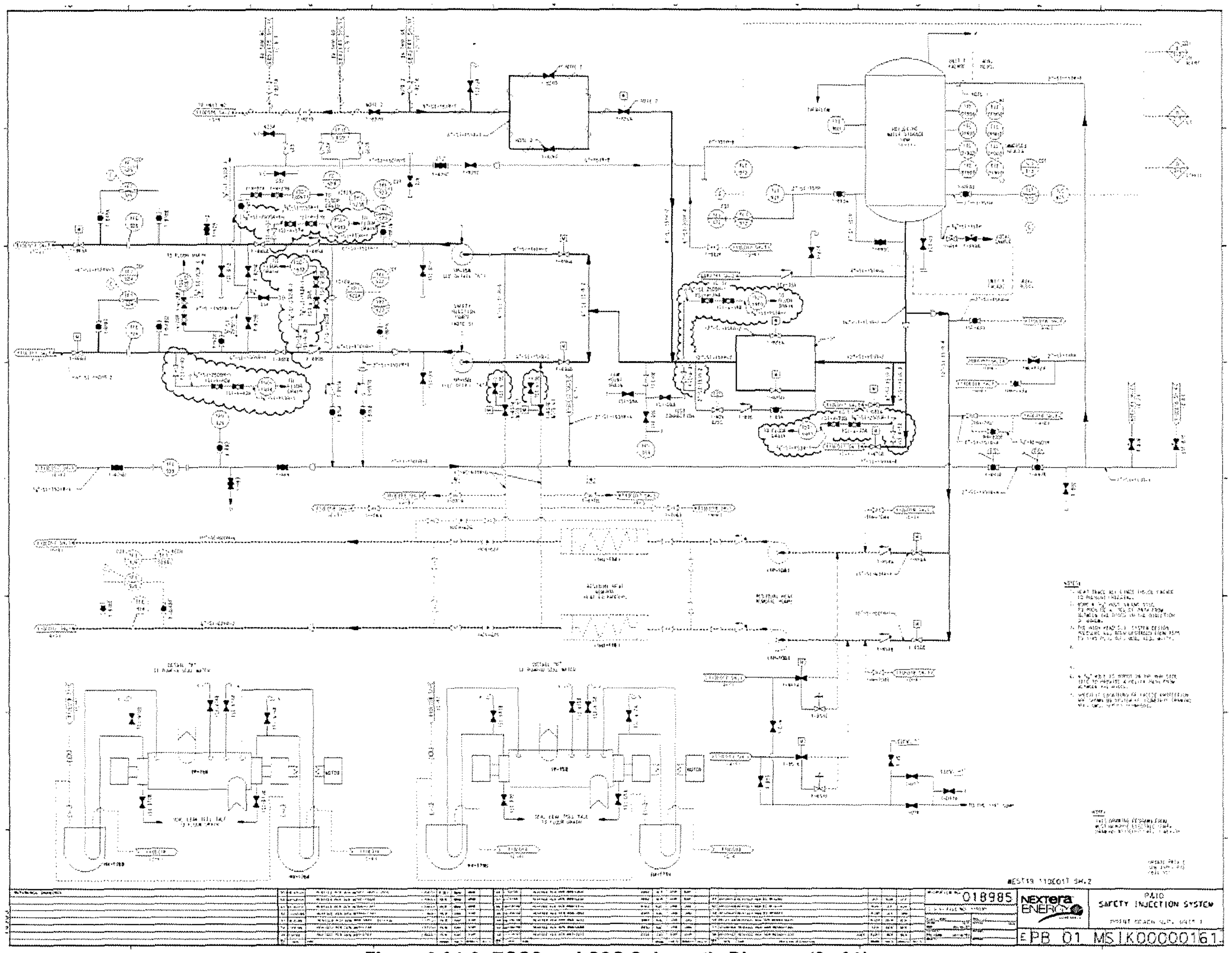


Figure 3.f.1-2: ECCS and CSS Schematic Diagram (2 of 3)

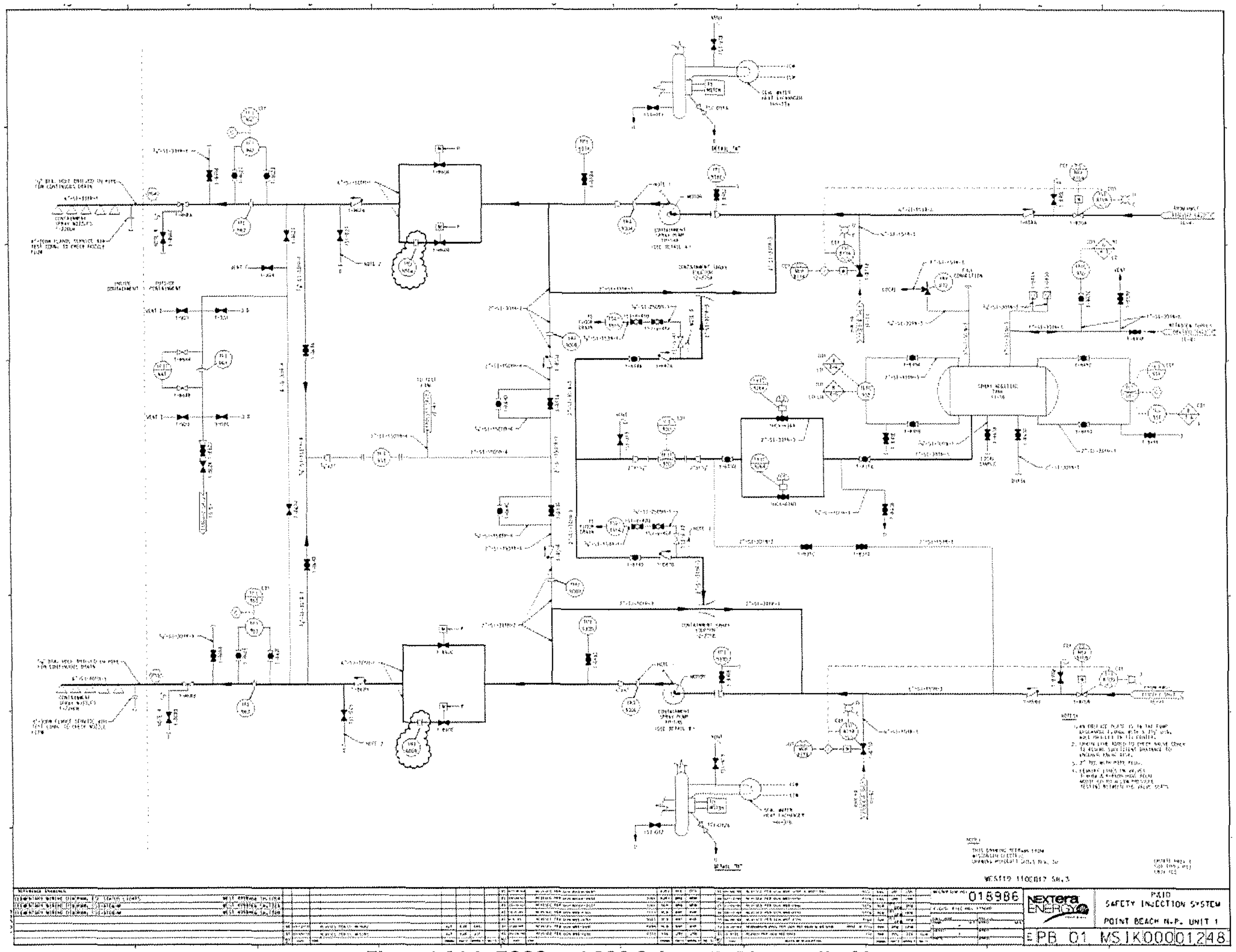


Figure 3.f.1-3: ECCS and CSS Schematic Diagram (3 of 3)

2. *Provide the minimum submergence of the strainer under small-break loss-of-coolant accident (SBLOCA) and large-break loss-of-coolant (LBLOCA) conditions.*

Response to 3.f.2:

Table 3.f.2-1 summarizes the minimum submergence of the strainers at both PBN1 and PBN2.

Table 3.f.2-1: Minimum Strainer Submergence

Break Size	Break Elevation	PBN1 Strainer Submergence (ft)	PBN2 Strainer Submergence (ft)
SBLOCA	Top of the pressurizer	0.17	0.19
SBLOCA	Below the elevation of the top of the hot leg nozzles	0.29	0.31
LBLOCA	Top of the pressurizer	0.17	0.19
LBLOCA	Below the elevation of the top of the hot leg nozzles	0.72	0.74

3. *Provide a summary of the methodology, assumptions, and results of the vortexing evaluation. Provide bases for key assumptions.*

Response to 3.f.3:

Vortex testing was performed on a PBN prototypical strainer module to observe the size, shape, and location of vortices that may develop at different debris loads and strainer submergence levels. The vortex tests were performed during the full-load head loss test described in the Response to 3.f.4. Both clean screen and debris laden vortex tests were performed.

Prior to any debris additions, a vortexing check was performed on the clean strainer. No vortexing was observed with 2 inches of strainer submergence and an approach velocity of 0.00267 ft/s.

Throughout the duration of the test sequence, there were two instances of vortex formation. During the drain operation performed prior to the fourth conventional debris addition of the Full Debris Load (FDL) Test 1, a full-core vortex developed at a strainer submergence of approximately 3 inches. As shown in Figure 3.f.3-1, the water level was increased to approximately 4 inches above the strainer. Vortex formation ceased. During the FDL Test 2, a small vortex formed above the test strainer after the final flow sweep was conducted prior to drain down at a submergence of approximately 4 inches. When the debris laden vortex tests were performed, the test strainer approach velocity was maintained at 0.00267 ft/s or slightly higher.

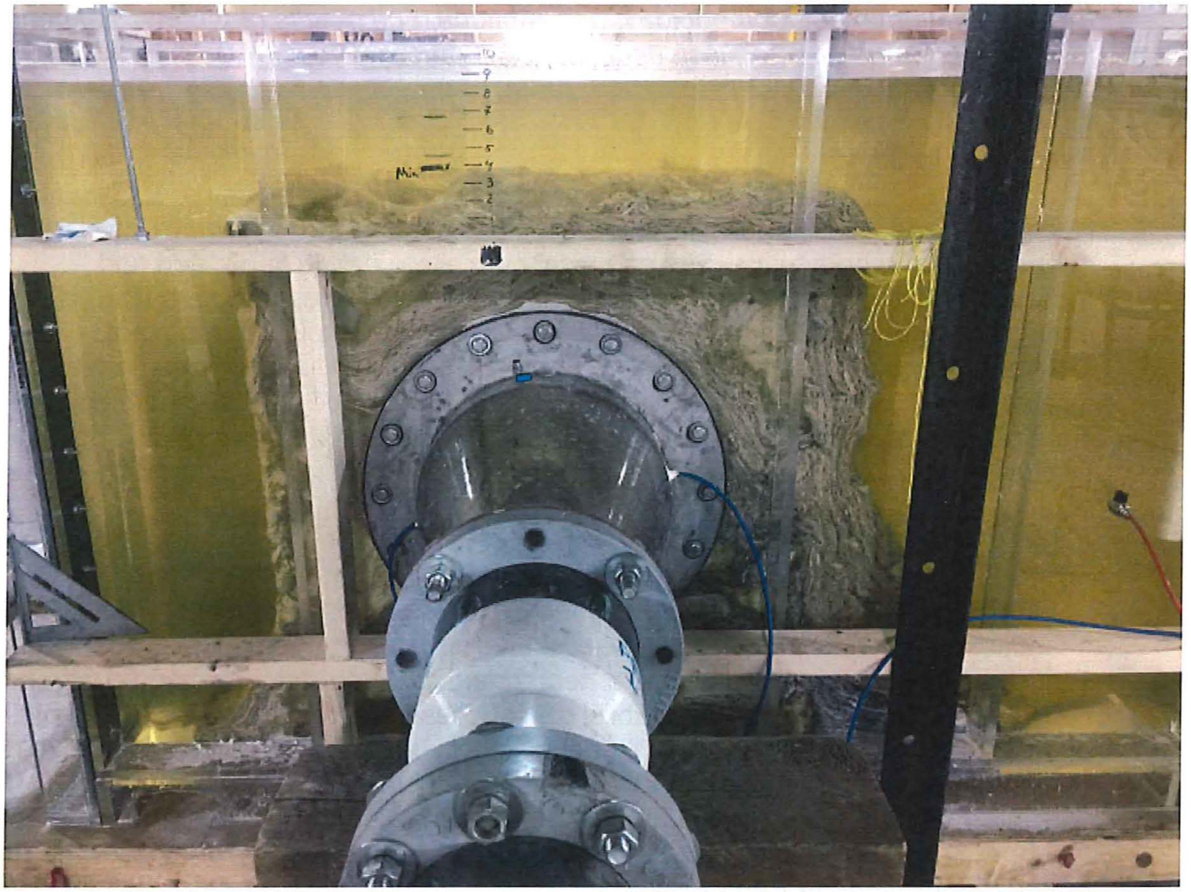


Figure 3.f.3-1: Minimum Submergence Level for Vortexing during Full Debris Load Test 1

The response to 3.g.1 shows a minimum strainer submergence of 0.72 ft (or 8.64 inches) for LBLOCAs on the main loop for PBN1 (0.74 ft for PBN2). Vortexing was only seen at a strainer submergence of less than 4 inches during the flow sweep after the Full Debris Load Test 2. Therefore, it is reasonable to conclude that vortexing will not cause air entrainment for the limiting Region I and Region II breaks (see the Alternate Evaluation Methodology discussion in Section 2).

The Response to 3.g.1 gives a smaller minimum strainer submergence for LOCAs at the top of the pressurizer (0.17 ft or ~ 2 inches). These breaks produce much less debris than those at the primary loop elevation. Additionally, the minimum water levels were calculated at the start of sump recirculation when the strainer is mostly clear of debris. The breaks at the top of the pressurizer would be at the minimum strainer submergence only momentarily while the pool continues to rise due to CS injection from the RWST. Therefore, it is reasonable to conclude that vortexing would not occur based on the clean screen vortex evaluation at 2 inches of submergence.

4. *Provide a summary of methodology, assumptions, and results of prototypical head loss testing for the strainer, including chemical effects. Provide bases for key assumptions.*

Response to 3.f.4:

Head loss tests were performed to measure the head losses caused by conventional debris (fiber and particulate) and chemical precipitate debris generated and transported to the sump strainers following a LOCA. The test program used a test strainer, debris quantities, and flow rates that were prototypical to the plant. Different test cases were performed with the thin bed and full debris load protocols, following the 2008 NRC Staff Review Guidance (Reference 3). Note that two separate test programs were conducted in 2015 and 2016, respectively. The discussion in this section is based on the 2016 test program, unless otherwise noted.

For PBN, target values of debris were established that ranged from the smallest breaks to the largest breaks including both DEGBs and partial breaks. The debris quantities to be tested were then established from these target values. The testing sequence was performed following a "test for success" strategy by starting with the Full Debris Load (FDL) test to establish the success point for a given quantity of fiber and particulates. An additional FDL test was performed for different debris mixtures to ensure the quantities from previous tests were bounded. The Thin Bed (TB) test was informed by the results of FDL tests. A confirmatory test, which also used FDL test protocol, was then performed to ensure that all breaks of 17" or smaller are fully bounded for both PBN1 and PBN2.

Test Setup

The PBN sump strainer system consists of two independent module assemblies of passive strainer disks each attached to their own suction pipe, supplying flow to one ECCS and CS train. The ECCS and CSS are not independent of each other downstream of the strainer. During recirculation, the CS pump in the associated train will be supplied by the RHR pump in that train, as will the SI pump during simultaneous upper plenum and cold leg injection, after the CS pump is stopped. Each strainer assembly consists of a suction pipe and 14 strainer disk modules. The strainer assembly is flow-controlled such that the flow rate through each strainer assembly is uniform. Perforated spacers maintain the horizontal separation between adjacent disks within a strainer module such that a 1" gap exists between the perforated plates of adjacent disks.

Figures 3.f.4-1 and 3.f.4-2 show the test strainer in the test tank as well as the debris introduction section of the test tank, including the mixing lines and hopper inlet. Note that these figures are from the 2015 test program, for which the test set-up was very similar to the 2016 testing. The test strainer assembly consisted of one prototypical 10-disk strainer module with a flow-controlled suction pipe passing through the center (core tube). The total surface area of the test strainer was 136 ft^2. To simulate the module to module clearance, the width of the tank was designed to model the active strainer module length and the 5" module-to-module clearance in the plant.

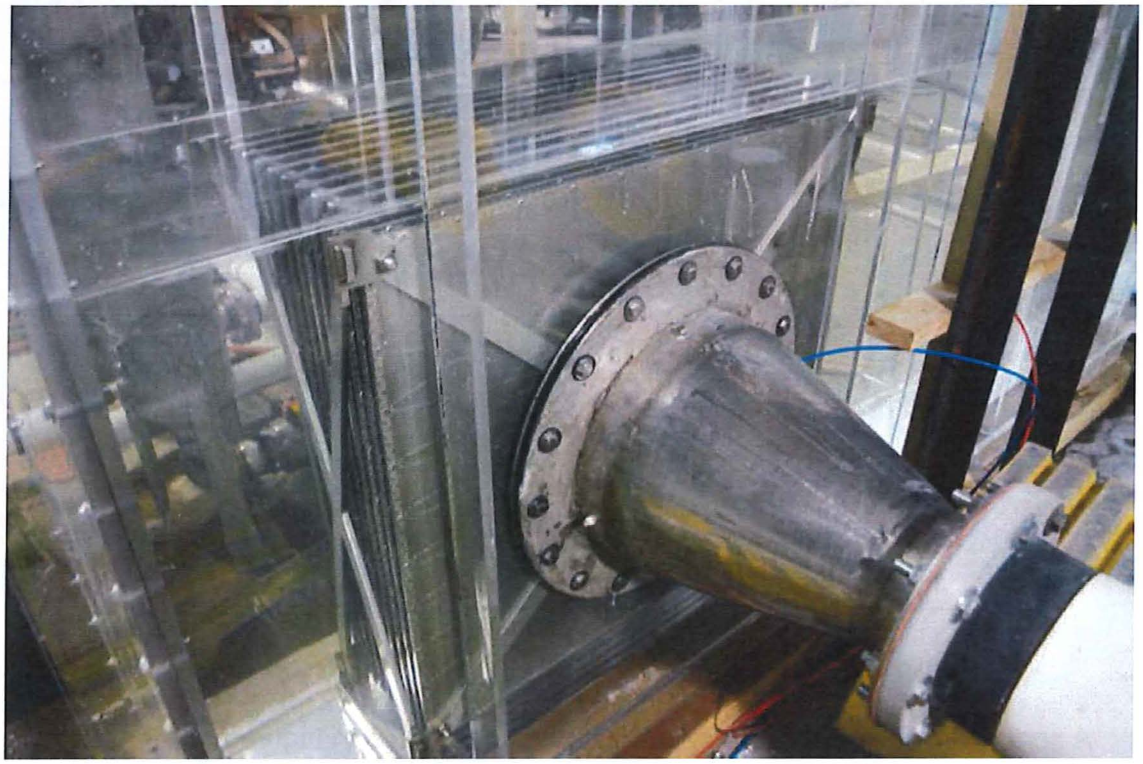


Figure 3.f.4-1: Test Tank and Strainer

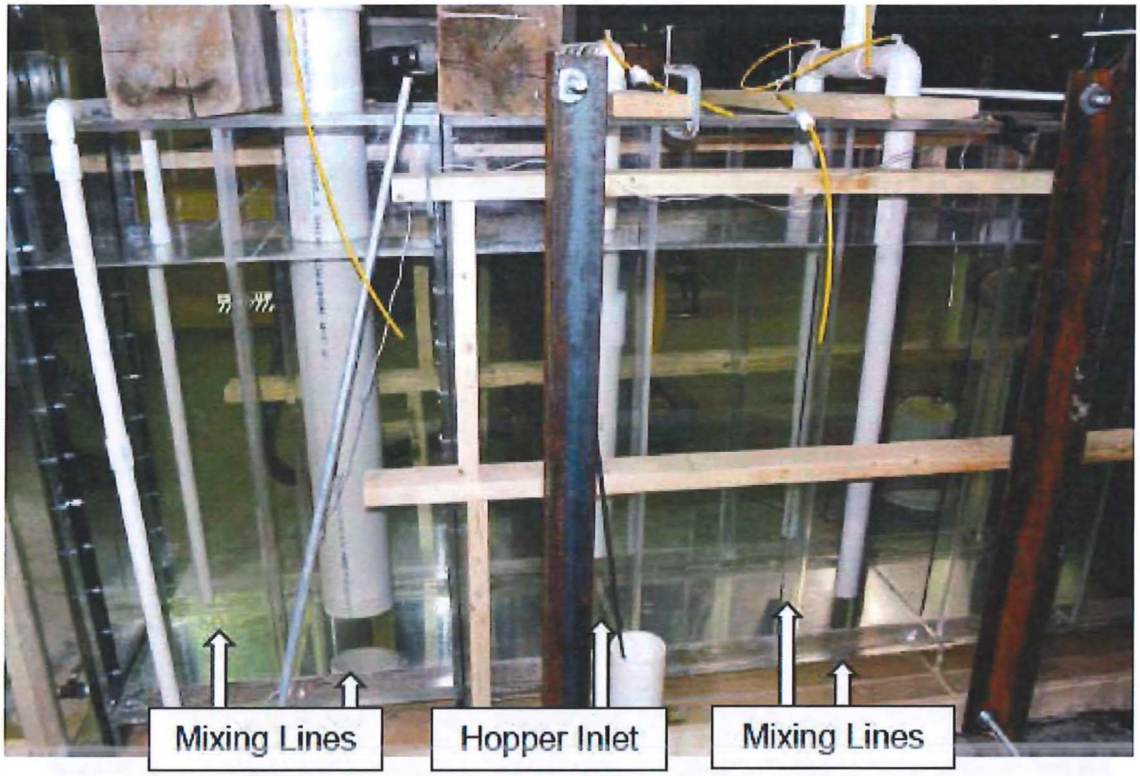


Figure 3.f.4-2: Mixing Lines and Hopper Inlet in the Test Tank

A schematic piping diagram of the test loop is provided in Figure 3.f.4-3. Downstream of the main recirculation pump, a small portion of the flow can be directed through a heat exchanger to control the test loop temperature. A large majority of the flow then passes directly through the mixing nozzle configuration, placed at the upstream end of the test tank (see response to 3.f.12). The remainder of flow that does not travel through the mixing nozzles is divided and the two streams pass through the debris introduction hopper and transition tank respectively. The continuously mixed transition tank was brought online during conventional and chemical precipitate debris introduction to increase the test loop water capacity and decrease the amount of draining required during testing. Flow directed to the debris introduction hopper supplies turbulence through the bottom of the hopper to encourage mixing of the debris slurry. The discharge of the hopper gravity drains into the test tank. The filter bag housings were used only during pre-test cleaning, and were isolated and bypassed during head loss testing.

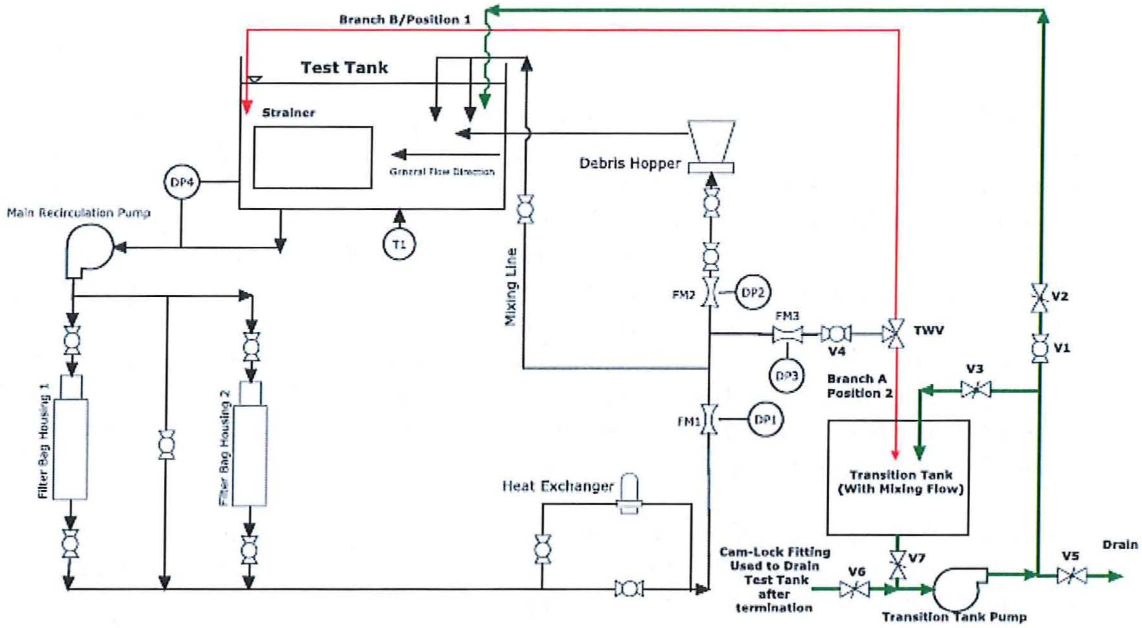


Figure 3.f.4-3: Piping Diagram of Head Loss Test Loop

Test Parameters and Scaling

The test strainer replicated all hydraulic dimensions of the plant strainer except for the number of strainer modules. The test debris quantities and test flow rate were scaled from plant values based on the ratio of test strainer surface area to the plant strainer surface area (1,754.6 ft^2). This strainer surface area was determined by deducting 150 ft^2 from the total surface area of each PBN strainer (1,904.6 ft^2) to account for blockage by miscellaneous debris. For a total plant strainer flow rate of 2,100 gpm, the test flow rate was determined to be 162.8 gpm, which corresponds to a strainer approach velocity of 0.00267 ft/s.

Debris Materials and Preparation

Conventional debris consists of fiber and particulate debris from failed insulation and coatings, and latent materials that could be transported to the sump strainers following a LOCA. PBN has four types of fibrous debris: low density fiberglass (LDFG), Mineral Wool, Temp-Mat, and latent fiber. Nukon and Mineral Wool were the only two fibrous debris types used during testing. Temp-Mat fines were not used since Temp-Mat is not generated for approximately 95% of all postulated breaks. However, an equivalent quantity, by mass, of LDFG fines was used to ensure the total quantity of fine fiber was bounded.

Nukon fines were used as a surrogate to model latent fiber on a basis of similar macroscopic density and characteristic fiber size. Heat treated Nukon sheets were procured and processed right before each test. Some of the Mineral Wool used during testing was heat treated by the testing vendor prior to processing. The required burn out gradient reached approximately half way through the blanket.

Particulate debris sources for PBN include Cal-Sil, qualified and unqualified coatings, and latent particulate. Pulverized Cal-Sil was purchased and used during the test. Due to their similar characteristic sizes and microscopic densities, silica flour, with a material density of 165.4 lbm/ft^3 and a median size of approximately 13.5 microns was used as a surrogate for qualified coatings, unqualified coatings, and the fine particle portion of the actively delaminating qualified coatings. Pressure washed paint chips, with a nominal size of approximately 0.125", were used as a surrogate to model the flat small chip portion of the actively delaminating qualified coatings. The material density of the paint chips was 89.3 lbm/ft^3. Latent particulate was modeled with PCI Dirt and Dust Mix which was procured from PCI and used without additional processing.

Preparation of Nukon and Mineral Wool fiber started by cutting the insulation sheets into approximately 2" by 2" cubes. The base material for both types of debris, ready for fiber fines preparation, is shown in Figure 3.f.4-4.

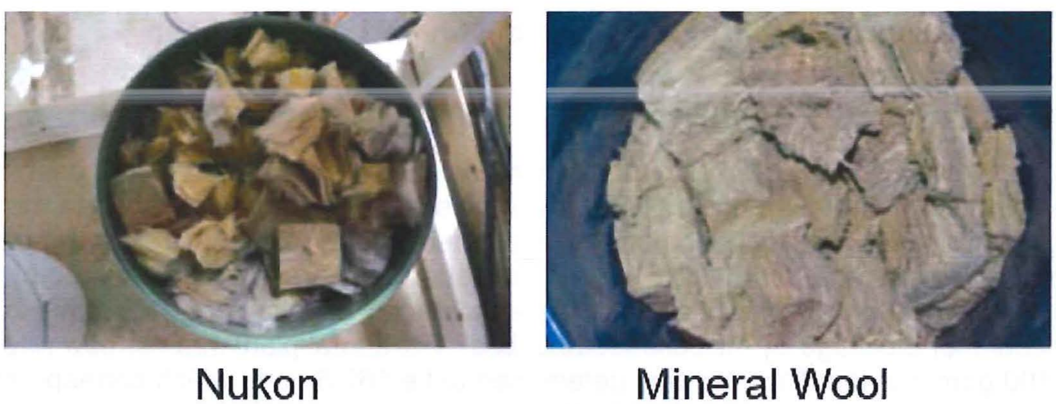
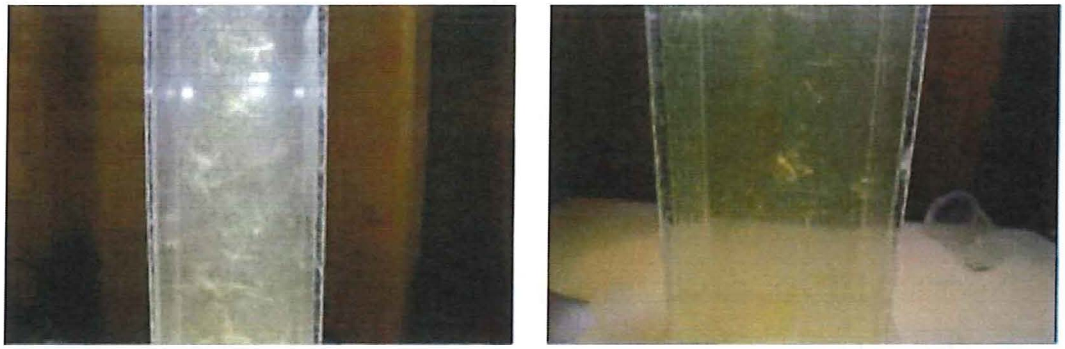


Figure 3.f.4-4: Base Debris Material before Pressure Wash

The required quantity of debris was weighed out per the debris batching schedule. The debris was then wetted in preheated test water and processed into fines following the method developed by NEI (Reference 16). The processing involves pressure washing the debris using a nominal 1,500 psi pressure washer with nozzles that produce a fan-type flow distribution. The nozzle position within the preparation vessel and the amount of time the spray was applied were controlled between debris batches. Prepared fiber fines consisted of primarily Class 2 fibers as defined in NUREG/CR-6224 (Reference 17, Table B-3). Figure 3.f.4-5 shows pictures of the processed fiber samples inside an acrylic column on top of a light table.



Nukon Mineral Wool

Figure 3.f.4-5: Prepared Nukon and Mineral Wool Debris

Silica flour was used as a surrogate for qualified and unqualified epoxy coatings on an equal volume basis. The required quantity of silica flour for a debris batch was first weighed out before being wetted in test water. For the FDL tests, the wetted silica flour was combined with the prepared fibrous debris slurry to form a homogeneous suspension. For the TB test, silica flour was mixed in barrels of heated test water and sufficiently diluted to allow for direct introduction through the debris hopper.

Cal-Sil was prepared in a similar manner as silica flour. For the FDL tests, the desired amount of Cal-Sil was weighed out, wetted with heated test water, and combined with the fibrous debris slurry. For the TB test, Cal-Sil was diluted with sufficient test water to allow for direct introduction through the debris hopper.

The PCI Dirt and Dust Mix, which was used as a surrogate for latent particulate debris, did not require processing. It was introduced in its dry form and sprinkled directly into the test tank upstream of the strainer.

The paint chips were wetted down with test water and repeatedly mixed to minimize the potential for pain chip flotation. For the FDL tests, the paint chips were combined with the homogenous debris slurry prior to introduction. For the TB test, the wetted paint chips were added directly to the debris introduction hopper prior to the fibrous debris. It should be mentioned that the large flat chips and curled chips from the actively delaminating qualified coatings were not introduced during the 2016 test program as it was demonstrated during the 2015 test program that these chips would not transport to the strainer even with agitation.

Sodium aluminum silicate (SAS) was used as the chemical debris surrogate for the head loss testing. The chemical debris was prepared in accordance with and met the acceptance criteria specified in WCAP-16530-NP-A (Reference 18). For chemical precipitate generation, a chemical salt and a base were weighed out to provide a specific chemical concentration in a measured volume of tap water. The prepared chemical debris was continuously mixed until it was added to the test tank.

The 1-hour settling volume for each batch of chemical precipitates was determined at the time the batch was produced. The chemical precipitate settling time was also measured within 24 hours from the time the surrogate was to be used. The specifics of the chemical surrogates used during testing are described in the Response to 3.o.2.12.

Debris Introduction

Full Debris Load (FDL) and Confirmatory Tests

For the FDL and Confirmatory tests, the prepared silica flour, Cal-Sil, paint chips, pressure washed paint chips, and fibrous debris for a given batch were combined in barrels prior to addition into the test loop. The debris was agitated into a homogeneous mixture prior to introduction, and was continuously mixed during introduction to prevent agglomeration and to maintain the concentration as constant as practical. The homogeneous mixture of debris was transferred to the hopper via 5 gallon buckets. Debris additions to the test tank were performed utilizing the debris hopper, which mixed the debris slurry with test loop water before transporting the debris to the upstream end of the test tank. The flow pattern in the hopper caused the debris to be held in suspension, which prevented agglomeration prior to adding the debris to the tank. The dirt and dust for the given batch was added directly to the test tank. To achieve the desired transport of debris in the test tank, five mixing nozzles were implemented. These mixing nozzles maintained turbulence in the test tank to prevent debris from settling.

Thin Bed (TB) Test

During the TB test, the particulate debris was added before any fibrous debris. The prepared silica flour was added first, followed by the introduction of Cal-Sil, pressure washed paint chips, paint chips, and dirt and dust. All of these particulate debris types were introduced through the hopper with the exception of dirt and dust, which was sprinkled directly into the test tank in its dry form. All particulate debris was added in quick succession, and no fiber was added to the test until all particulate was introduced. After all the particulate debris was added to the test tank, homogeneous mixed batches of Nukon and Mineral Wool fines were added through the debris hopper. Note that the fibrous debris was continuously mixed during introduction to prevent agglomeration and to maintain the concentration as constant as practical. The size of each fiber batch was equivalent to a 1/16" theoretical uniform debris bed thickness for the test strainer. The mixing nozzles were utilized for the TB test as well to prevent settling.

After conventional debris introduction was completed for the FDL, TB, and Confirmatory tests, the SAS chemical precipitate debris was added to the test tank in batches. Chemical debris was pumped from the preparation tank into the test tank through a chemical introduction line.

Head Loss Test Cases and Results

Four head loss tests were performed for PBN: two FDL tests, one TB test, and the Confirmatory Test.

PBN FDL Test 1

The total conventional debris loads for the PBN FDL Test 1 are provided in the table below and scaled to equivalent plant debris loads. The peak conventional debris head loss observed for this test is shown in Table 3.f.4-9.

Table 3.f.4-1: Conventional Debris Batches for FDL Test 1

Nukon (lbm)	Mineral Wool (lbm)	Dirt & Dust (lbm)	Cal-Sil (lbm)	Silica Flour (ft^3)	Paint Chips (ft^3)	Pressure Washed Paint Chips (ft^3)
125.0	100.7	108.5	185.0	12.41	0.31	1.21

After all conventional debris was added, the head loss had stabilized, and a flow sweep had been performed, chemical precipitate debris was added to the test tank. The chemical precipitate debris batches for the PBN FDL Test 1 are summarized in the table below and scaled to equivalent plant debris loads. Note that the concentration of the SAS solution is 9.97 g/L. The chemical quantity tested bounds the chemical product debris loads for all breaks in the loop compartment and pressurizer compartment in both units. The FDL Test 1 quantity includes margin above the predicted maximum chemical product debris loads for these breaks.

Table 3.f.4-2: Chemical Debris Batches Added for the FDL Test 1

Batch #	Test SAS Load (kg)
1	38.7
2	52.9
Total	91.6

Figure 3.f.4-6 and Figure 3.f.4-7 show plots of raw head loss test data for the PBN FDL Test 1 with time to identify the key testing activities. Note that the flow rates shown in these figures are at the test scale and the head loss values have not been adjusted to subtract the test strainer's clean screen head loss. The clean screen head loss for FDL Test 1 was 0.03 psi.

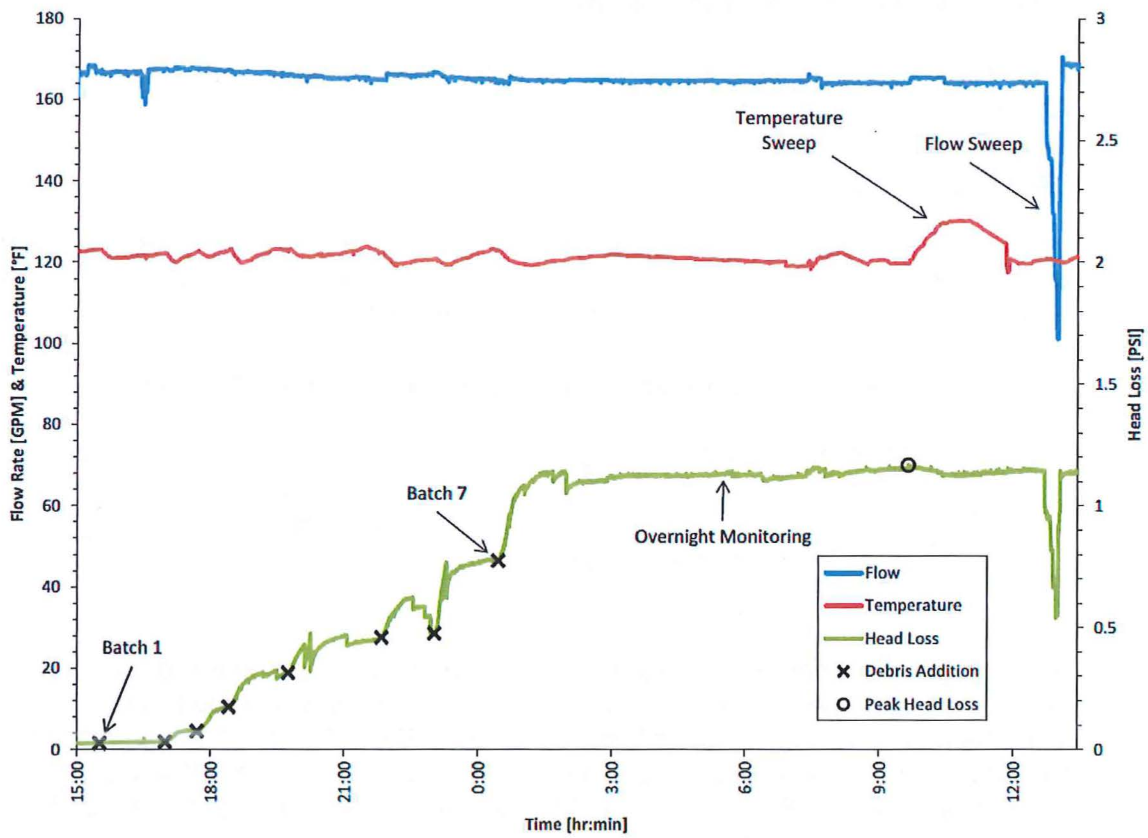


Figure 3.f.4-6: FDL Test 1 Conventional Debris Timeline

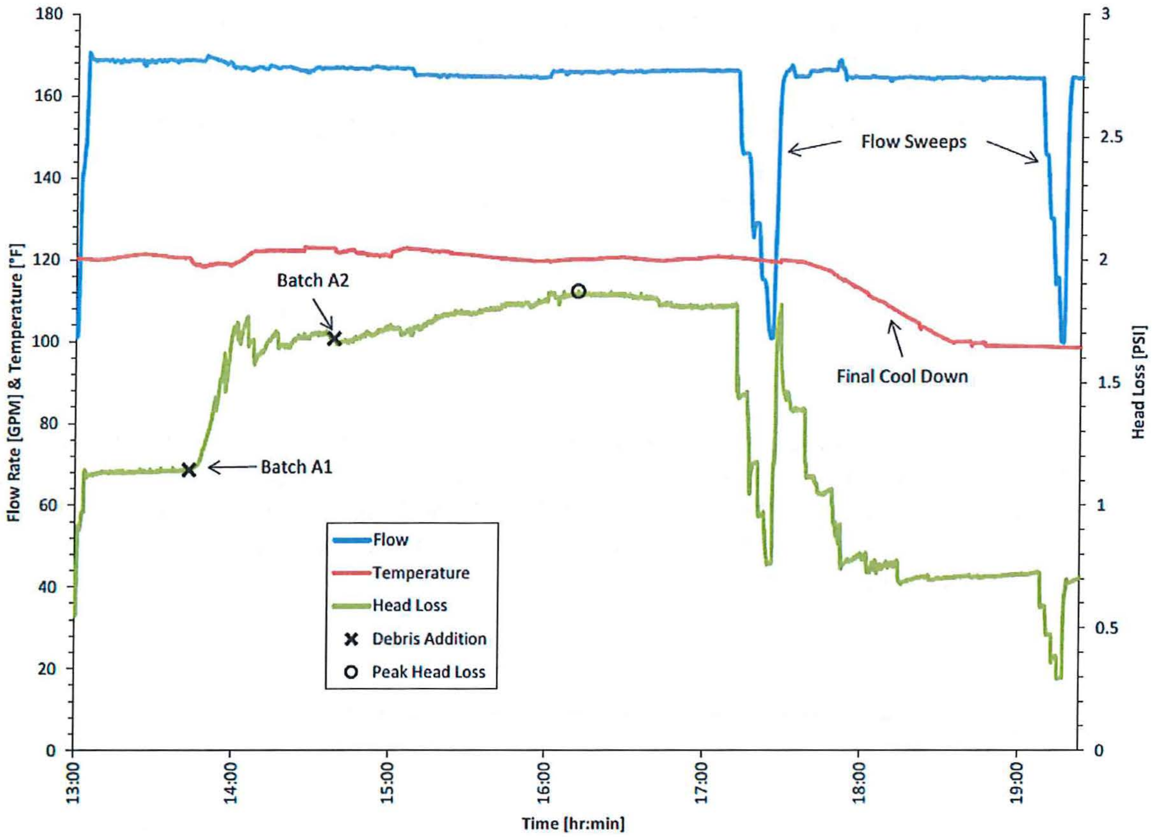


Figure 3.f.4-7: FDL Test 1 Chemical Debris Timeline

PBN FDL Test 2

The conventional debris loads for the PBN FDL Test 2 are provided in the table below and scaled to equivalent plant debris loads. The peak conventional debris head loss observed for this test is shown in Table 3.f.4-9.

Table 3.f.4-3: Conventional Debris Batches for FDL Test 2

Nukon (lbm)	Mineral Wool (lbm)	Dirt & Dust (lbm)	Cal-Sil (lbm)	Silica Flour (ft^3)	Paint Chips (ft^3)	Pressure Washed Paint Chips (ft^3)
70.73	69.29	86.84	307.5	9.64	0.25	0.976

After all conventional debris was added, the head loss had stabilized, and a flow sweep had been performed, chemical precipitate debris was added to the test tank. The chemical precipitate debris batches for the PBN FDL Test 2 are summarized in the table below and scaled to equivalent plant debris loads. Note that the chemical quantity tested bounds the chemical product debris loads for all breaks in the loop compartment and pressurizer compartment in both units.

Table 3.f.4-4: Chemical Debris Batches Added for the FDL Test 2

Batch #	Test SAS Load (kg)
1	29.0
2	48.4
Total	77.4

Figure 3.f.4-8 and Figure 3.f.4-9 show plots of raw head loss test data for the FDL Test 2 with time to identify the key testing activities. Note that the flow rates shown in these figures are at the test scale and the head loss values have not been adjusted to subtract the test strainer's clean screen head loss. The clean screen head loss for FDL Test 2 was 0.03 psi.

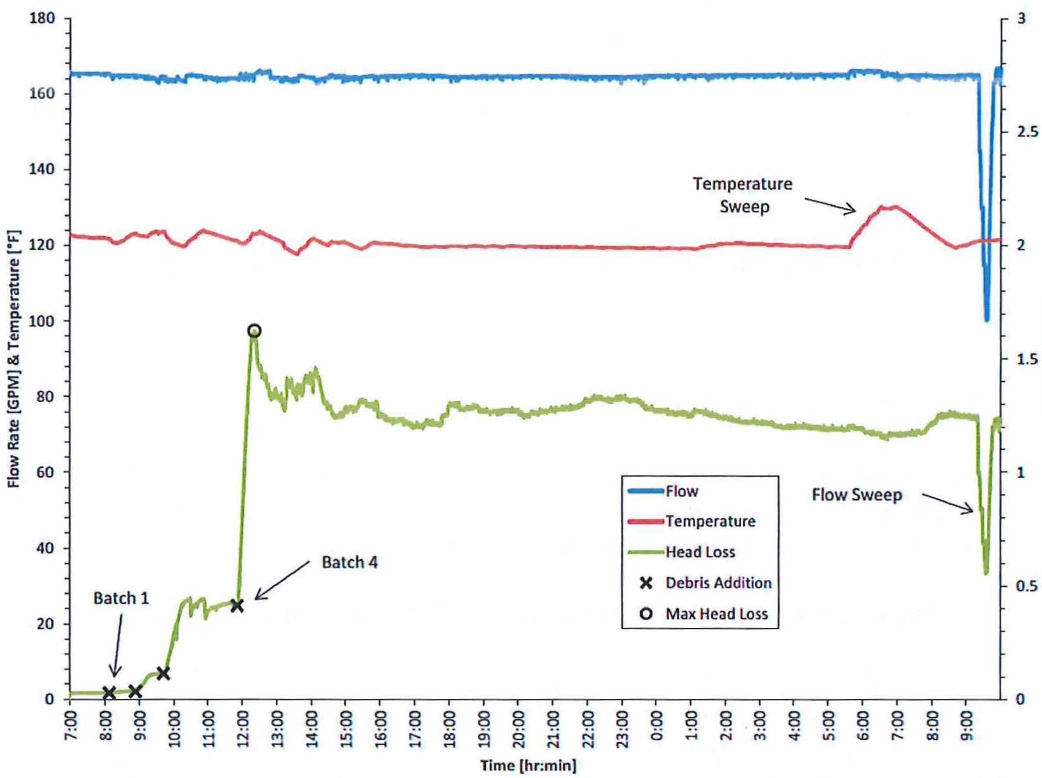


Figure 3.f.4-8: FDL Test 2 Conventional Debris Timeline

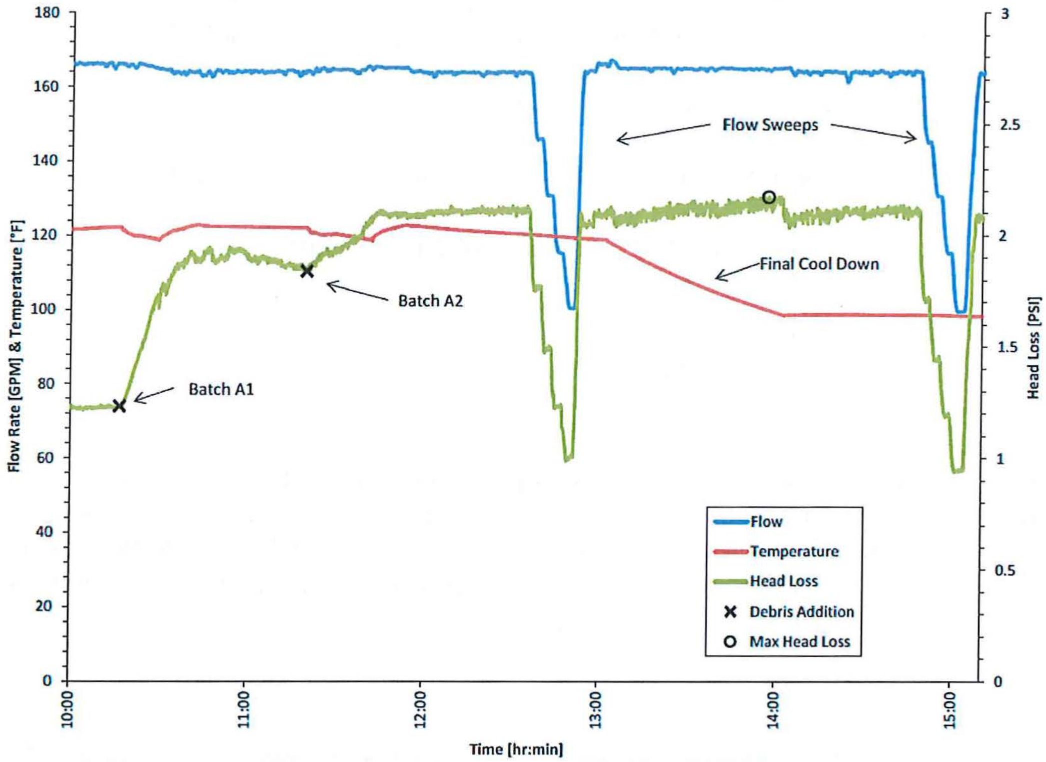


Figure 3.f.4-9: FDL Test 2 Chemical Debris Timeline

PBN Thin-Bed Test

The conventional debris loads for the PBN Thin-Bed Test are summarized in the table below and scaled to equivalent plant debris loads. Six batches of fiber fines were introduced to the Thin-Bed Test, which resulted in a cumulative theoretical uniform debris bed thickness of approximately 3/8". The peak conventional debris head loss observed for this test is shown in Table 3.f.4-9.

Table 3.f.4-5: Conventional Debris Batches Added for the TB Test

Nukon (lbm)	Mineral Wool (lbm)	Dirt & Dust (lbm)	Cal-Sil (lbm)	Silica Flour (ft^3)	Paint Chips (ft^3)	Pressure Washed Paint Chips (ft^3)
60.28	59.05	108.6	384.5	12.03	0.31	1.21

After all conventional debris was added, the head loss had stabilized, and a flow sweep had been performed, chemical precipitate debris was added to the test tank.

The chemical precipitate debris batches for the Thin-Bed Test are summarized in the table below and scaled to equivalent plant debris load. Note that the chemical quantity tested bounds the chemical product debris loads for all breaks in the loop compartment and pressurizer compartment in both units.

Table 3.f.4-6: Chemical Debris Batches Added for the TB Test

Batch #	Test SAS Load (kg)
1	48.4
2	29.0
Total	77.4

Figure 3.f.4-10 and Figure 3.f.4-11 show plots of raw head loss test data for the thin-bed test with time to demonstrate the key testing activities. Note that the flow rates shown in these figures are at the test scale and the head values have not been adjusted to subtract the test strainer's clean screen head loss. The clean screen head loss for Thin-Bed Test was 0.03 psi.

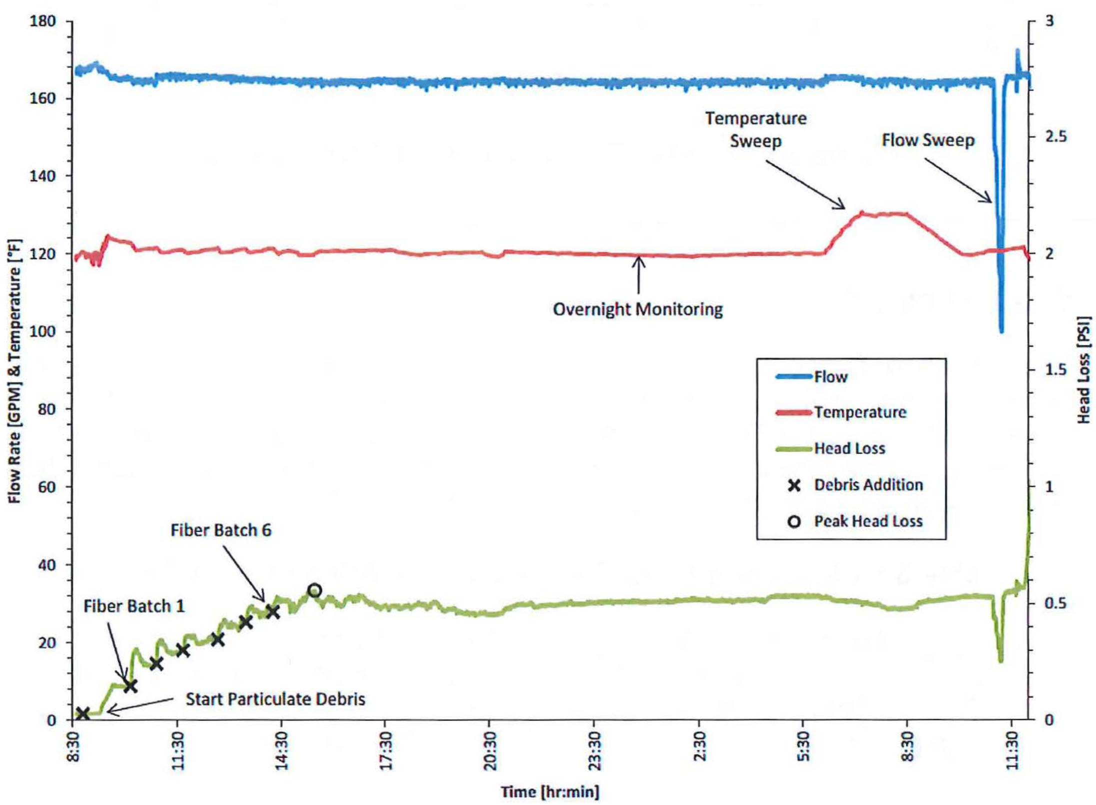


Figure 3.f.4-10: Thin-Bed Test Conventional Debris Timeline

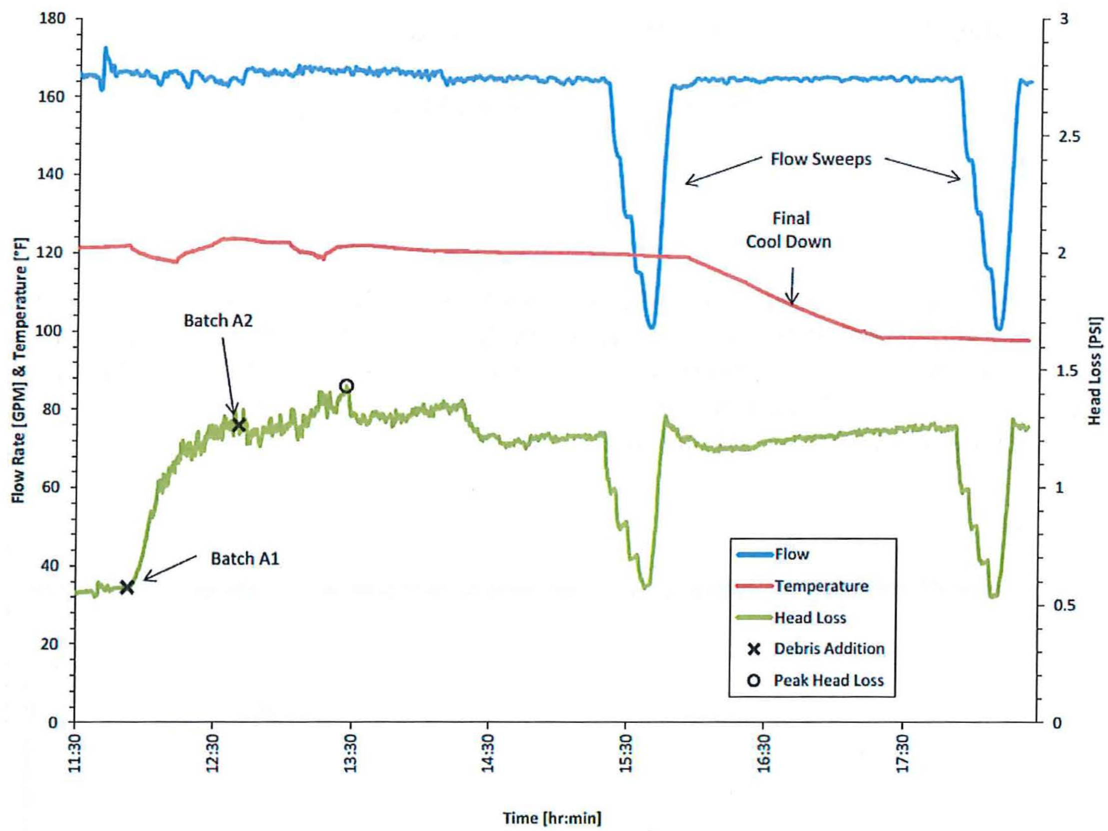


Figure 3.f.4-11: Thin-Bed Test Chemical Debris Timeline

PBN Confirmatory Test

The conventional debris loads for the PBN Confirmatory Test are summarized in the table below and scaled to equivalent plant debris loads. The conventional debris head loss observed for this test is shown in Table 3.f.4-9.

Table 3.f.4-7: Conventional Confirmatory Head Loss Test Debris Batches

Nukon (lbm)	Mineral Wool (lbm)	Dirt & Dust (lbm)	Cal-Sil (lbm)	Silica Flour (ft^3)	Paint Chips (ft^3)	Pressure Washed Paint Chips (ft^3)
27.84	50.61	108.6	298.4	12.01	0.31	1.21

After all conventional debris was added, the head loss had stabilized, and a flow sweep had been performed, chemical precipitate debris was added to the test tank. The chemical precipitate debris batches for the full debris load protocol had loss test are summarized in the table below and scaled to equivalent plant debris loads. Note that the chemical quantity tested bounds the chemical product debris loads for all breaks in the loop compartment and pressurizer compartment in both units.

Table 3.f.4-8: Chemical Debris Batches Added for the Confirmatory Test

Batch #	Test SAS Load (kg)
1	48.4
2	29.0
Total	77.4

Figure 3.f.4-12 and Figure 3.f.4-13 show plots of raw head loss test data for the Confirmatory Test with time to demonstrate the key testing activities. Note that the flow rates shown in this figure are at the test scale and the head loss values have not been adjusted to subtract the test strainer's clean screen head loss. The clean screen head loss for the Confirmatory Test was 0.03 psi.

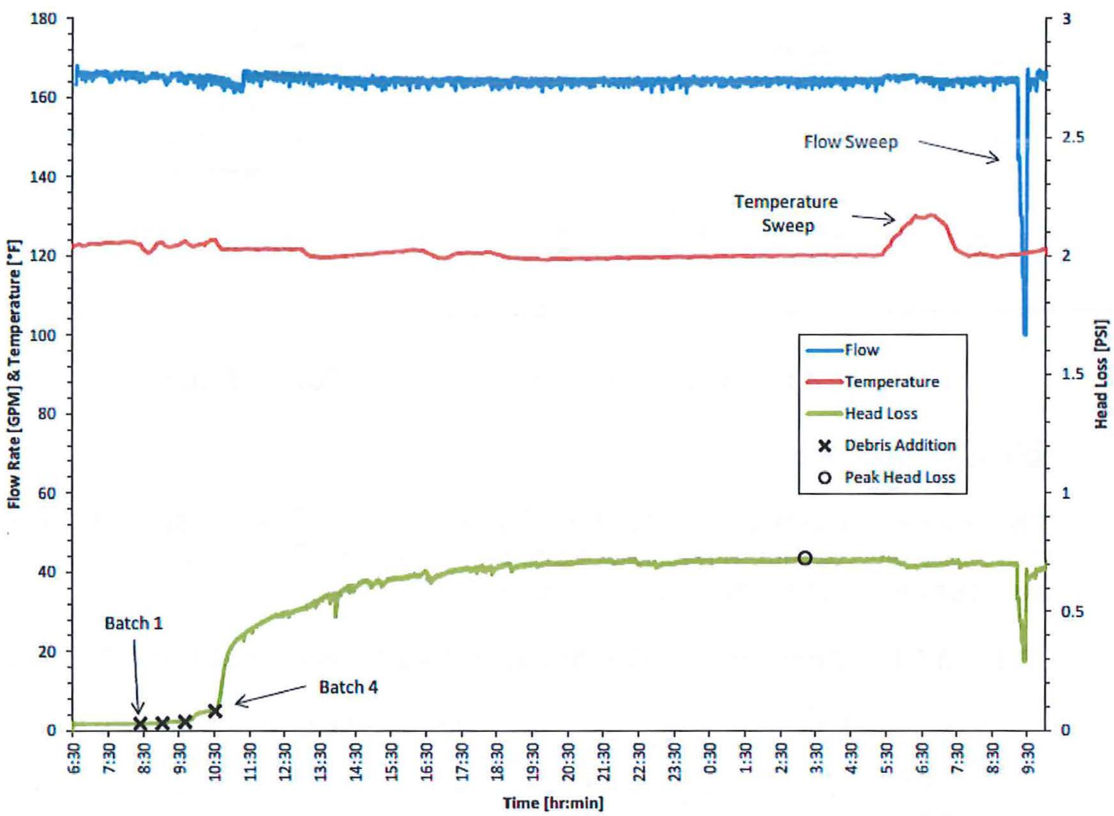


Figure 3.f.4-12: Confirmatory Test Conventional Debris Timeline

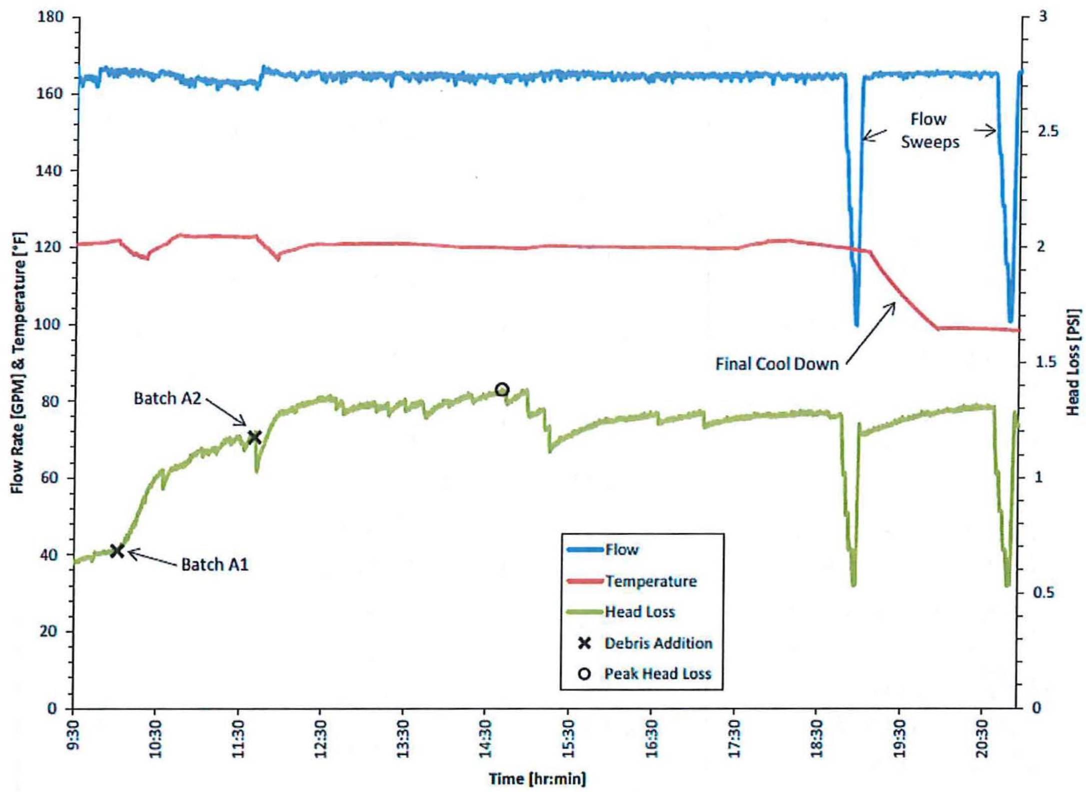


Figure 3.f.4-13: Confirmatory Test Chemical Debris Timeline

Summary of PBN Head Loss Test Data

A summary of the debris head loss results from the PBN tests are provided in the table below. As discussed in the response to 3.f.7, the maximum conventional and chemical debris head losses of the four tests are used to evaluate pump NPSH, void fraction, flashing and strainer integrity for the PBN Region I and Region II breaks.

Table 3.f.4-9: Summary of Debris Head Loss Results

Test Point	Debris Head Loss (psi)	Test Flow Rate (at Plant Scale) (gpm)	Temperature (°F)
PBN FDL Test 1			
Conventional Debris Max Head Loss	1.135	165.7 (2,138)	119.7
Conventional Debris Stable Head Loss	1.12	164.2 (2,119)	119.7
Aluminum Precipitate Max Head Loss	1.84	164 (2,116)	120.1
PBN FDL Test 2			
Conventional Debris Max Head Loss	**1.592**	**165.5 (2,135)**	**123**
Conventional Debris Stable Head Loss	1.159	164.7 (2,125)	119.6
Aluminum Precipitate Max Head Loss	**2.142**	**162.7 (2,099)**	**99.9**
PBN Thin-Bed Test			
Conventional Debris Max Head Loss	0.525	164.9 (2,128)	120
Conventional Debris Stable Head Loss	0.493	164.5 (2,123)	120.1
Aluminum Precipitate Max Head Loss	1.402	162.6 (2,098)	121.7
PBN Confirmatory Test			
Conventional Debris Max Head Loss	0.695	160.2 (2,067)	120.1
Conventional Debris Stable Head Loss	0.684	164.3 (2,120)	120.2
Aluminum Precipitate Max Head Loss	1.352	159.8 (2,062)	119.8

5. *Address the ability of the design to accommodate the maximum volume of debris that is predicted to arrive at the screen.*

Response to 3.f.5:

As discussed in the Response to 3.f.4, the head loss tests used a test strainer that is prototypical to the plant strainer design. Additionally, the test debris loads were scaled based on the ratio of the test strainer surface area and the plant's net strainer surface area. The arrangement of the test strainer with respect to the test tank is representative of the module-to-module spacing in the plant strainer. As a result, the flow profile approaching the test strainer is comparable to that of the plant strainer. Finally, as discussed in the Response to 3.f.7, the debris loads utilized during testing bound all Region I breaks (less than or equal to 17") at PBN1 and PBN2 when assuming single train operation. For the Region II breaks, the maximum debris loads that could occur at the plant are represented by the tested debris quantities when taking credit for two train operation during recirculation (see the Alternate Evaluation Methodology in Section 2 for more details). With these considerations, the impact of debris volume on the plant strainer can be directly determined from the head loss test results. Therefore, the installed strainers have a demonstrated ability to accommodate the maximum volume of debris that is predicted to arrive at the strainers.

6. *Address the ability of the screen to resist the formation of a "thin bed" or to accommodate partial thin bed formation.*

Response to 3.f.6:

The "thin-bed effect" is defined as the relatively high head losses associated with a low-porosity (or high particulate to fiber ratio) debris bed formed by a thin layer of fibrous debris that can effectively filter particulate debris. The PBN head loss testing included a test for thin-bed effects. During this test, the particulate debris was added into the test tank first, followed by six batches of fiber fines with a batch size equivalent to a 1/16-inch theoretical uniform Nukon-equivalent bed thickness (see Table 3.f.4-1). The total theoretical fiber bed thickness after all of the fiber batches was 3/8". This batching schedule allowed the formation of a debris bed with high particulate to fiber ratios. As was demonstrated by testing, the "thin-bed effect" was not observed.

7. *Provide the basis for strainer design maximum head loss.*

Response to 3.f.7:

The PBN head loss testing was performed in accordance with the NRC March 2008 guidance. Both thin bed and full debris load test protocols were followed to ensure that the range of different debris loading conditions were covered by the testing. The test approach velocity corresponds to a plant strainer flow rate of 2,100 gpm, which is the maximum flow rate for a single strainer. Additionally, as discussed in the Response to 3.f.8, the strainer approach velocity was calculated based on a conservatively smaller strainer surface area by excluding the sacrificial area to account for blockage by the miscellaneous debris.

Comparison of Plant and Head Loss Test Conventional Debris Loads

Region I

In order to be certain that the bounding break in Region I was evaluated, the breaks that result in bounding quantities of different debris types were evaluated. At PBN, the bounding Region I breaks consist of the 17" partial break of the main loop that results in a bounding quantity of fine fiber and the 17" partial break of the main loop that results in a bounding quantity of Cal-Sil. It is reasonable to exclude the bounding breaks of other individual debris contributors, such as coatings particulate and latent dirt and dust, since these debris loads are fairly consistent for all breaks and bounding quantities were assessed as part of the head loss tests. The bounding breaks for Region I are listed in the Response to 3.a.3.

As demonstrated later in this section, the debris quantities used in the TB test and FDL2 test bound PBN1 debris loads for all breaks equal to or smaller than 17". The combination of the FDL1 and FDL2 tests can be used to bound PBN2 debris loads for all breaks equal to or smaller than 17". It is therefore reasonable to conclude that the debris head losses for the breaks of 17" and smaller can be quantified from the test results for both units.

Table 3.f.7-1 and Table 3.f.7-2 compare the tested conventional debris loads, which have been converted to the plant scale, with those for the bounding PBN1 and PBN2 Region I breaks, respectively. The unqualified coatings quantities were taken from the Response to 3.h. The ZOI debris loads for the bounding Region I breaks are presented in the Response to 3.e.

Table 3.f.7-1: Comparison of Test Debris Loads with PBN1 Region I Breaks

Debris Type	17" Bounding Cal-Sil Break	17" Bounding Fine Fiber Break	FDL1 Debris Loads	FDL2 Debris Loads	TB Debris Loads	Confirmatory Debris Loads
Total Fine Fiber (lbm)	56.23	103.42	225.70	140.02	119.33	78.45
Dirt & Dust (lbm)	108.38	108.38	108.50	86.84	108.6	108.6
Cal-Sil (lbm)	271.41	156.94	185.0	307.5	384.5	298.4
Paint Particulate (ft^3)	8.42	8.41	12.41	9.64	12.03	12.01
Paint Chips (ft^3)	1.15	1.15	1.52	1.22	1.52	1.52

Table 3.f.7-2: Comparison of Test Debris Loads with PBN2 Region I Breaks

Debris Type	17" Bounding Cal-Sil Break	17" Bounding Fine Fiber Break	FDL1 Debris Loads	FDL2 Debris Loads	TB Debris Loads	Confirmatory Debris Loads
Total Fine Fiber (lbm)	56.44	163.72	225.70	140.02	119.33	78.45
Dirt & Dust (lbm)	108.38	108.38	108.50	86.84	108.6	108.6
Cal-Sil (lbm)	199.19	28.45	185.0	307.5	384.5	298.4
Paint Particulate (ft^3)	11.17	11.07	12.41	9.64	12.03	12.01
Paint Chips (ft^3)	1.38	1.38	1.52	1.22	1.52	1.52

Figure 3.f.7-1 and Figure 3.f.7-2 compare the tested and plant debris loads for fiber fines and Cal-Sil for Units 1 and 2, respectively. Based on these figures and the data shown in Tables 3.f.7-1 and 3.f.7-2, it can be concluded that the PBN head loss test debris loads bound all Region I breaks for each unit. Although the different limiting Region I breaks may be bounded by different tests, the maximum head loss between the four tests is used to evaluate the strainer failure criteria (see the Response to 3.f.4).

1. As shown in Figure 3.f.7-1, the fine fiber and Cal-Sil loads for all breaks of 17" and smaller at PBN1 are bounded by the FDL1, FDL2, and the TB test.
2. As shown in Figure 3.f.7-2, the fine fiber and Cal-Sil loads for all breaks of 17" and smaller at PBN2 are bounded by at least one of the full debris load test (FDL1, FDL2 or Confirmatory test). The Cal-Sil loads of all breaks of 17" and smaller are also bounded by the TB test.
3. Table 3.f.7-1 and 3.f.7-2 indicate that the tested quantities of coatings debris for all four tests is greater than the limiting Region I breaks for each unit.
4. Table 3.f.7-1 and 3.f.7-2 show that the tested latent particulate debris and coatings debris either matched or exceeded the plant quantities.

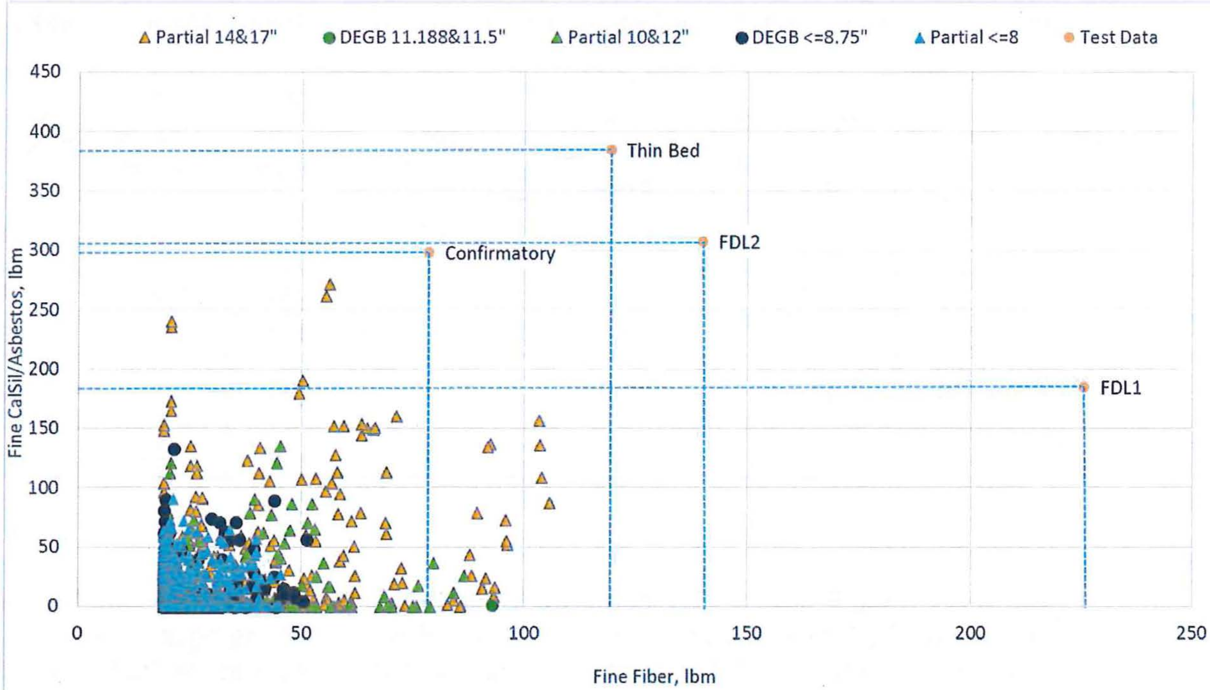


Figure 3.f.7-1 Comparison between Test and PBN1 Plant Debris Loads

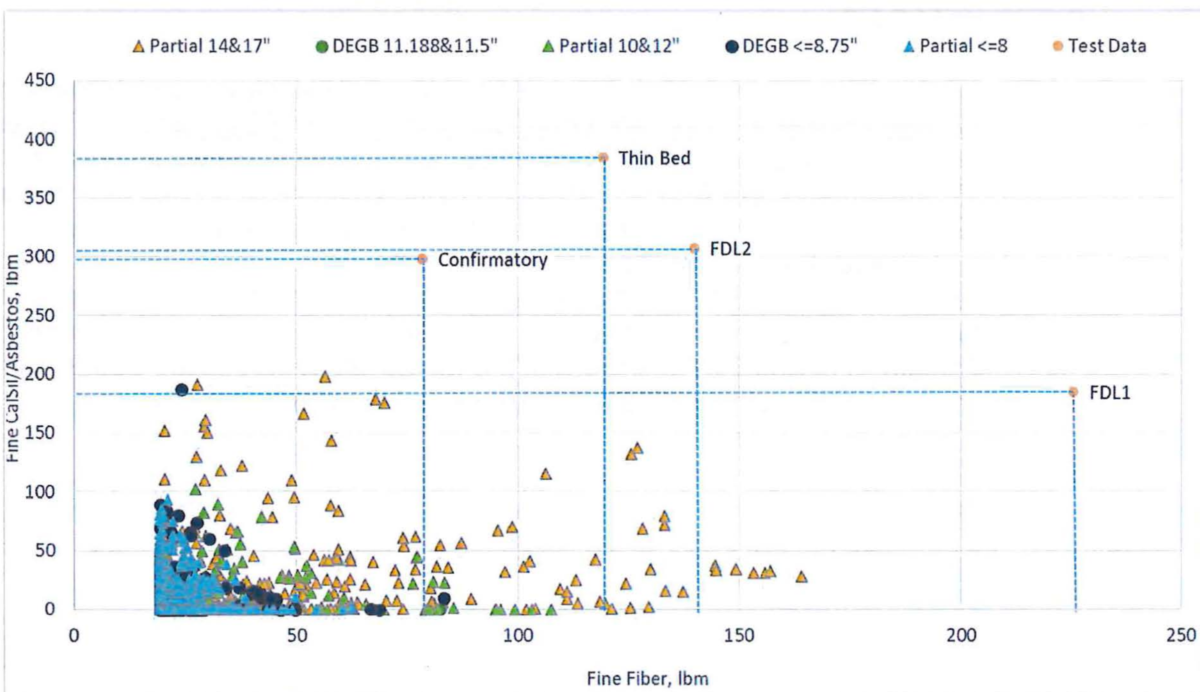


Figure 3.f.7-2 Comparison between Test and PBN2 Plant Debris Loads

Region II

In order to be certain that the bounding break in Region II was evaluated, the breaks that result in bounding quantities of different debris types were evaluated. At PBN, the bounding Region II breaks consist of the DEGB break on the main loop that results in a bounding quantity of fine fiber and the DEGB on the main loop that results in a bounding quantity of Cal-Sil. It is reasonable to exclude the bounding breaks of other individual debris contributors such as coatings particulate and latent dirt and dust, since these debris loads are fairly consistent for all breaks, and bounding quantities were assessed as part of the head loss tests. The bounding breaks for Region II are listed in the Response to 3.a.3.

Figure 3.f.7.3 and Figure 3.f.7.4 show the debris loads from the PBN head loss tests against the debris loads of all breaks at PBN1 and PBN2, respectively. As shown in the figures, although the test debris loads bound the vast majority of Region II breaks, there are outlying points that are not bounded for both units. However, by having both ECCS and CSS trains in operation during recirculation, it can be shown that these tests are appropriate to use for the PBN Region II breaks.

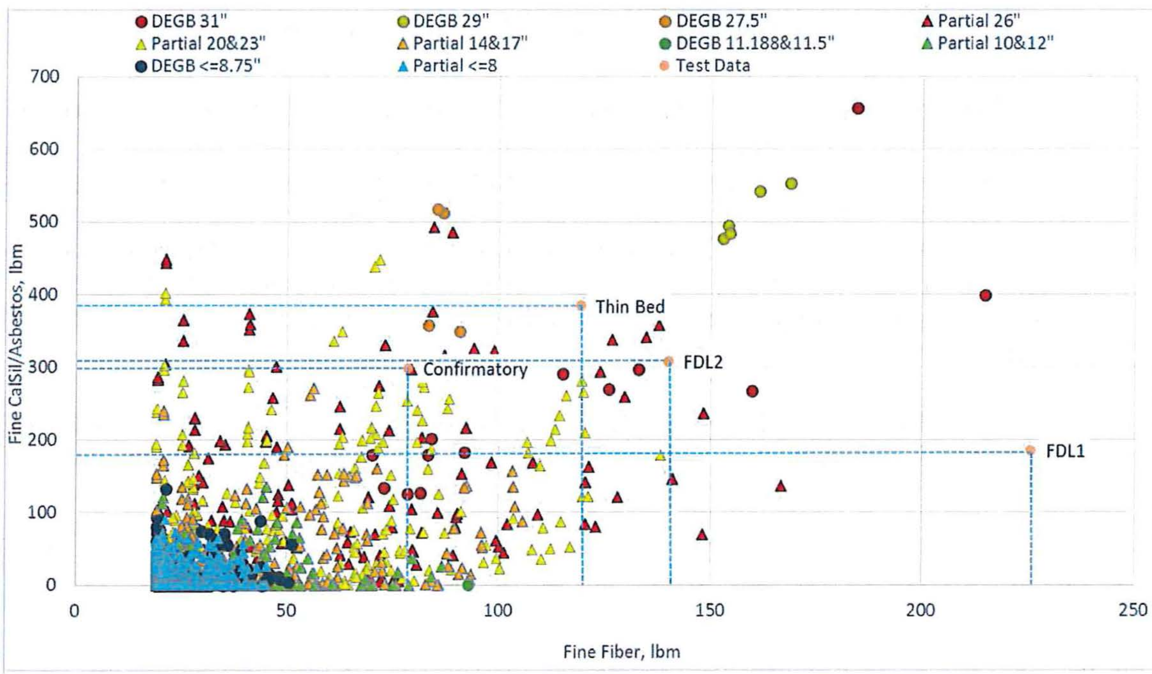


Figure 3.f.7-3 Comparison between Test and PBN1 Plant Debris Loads

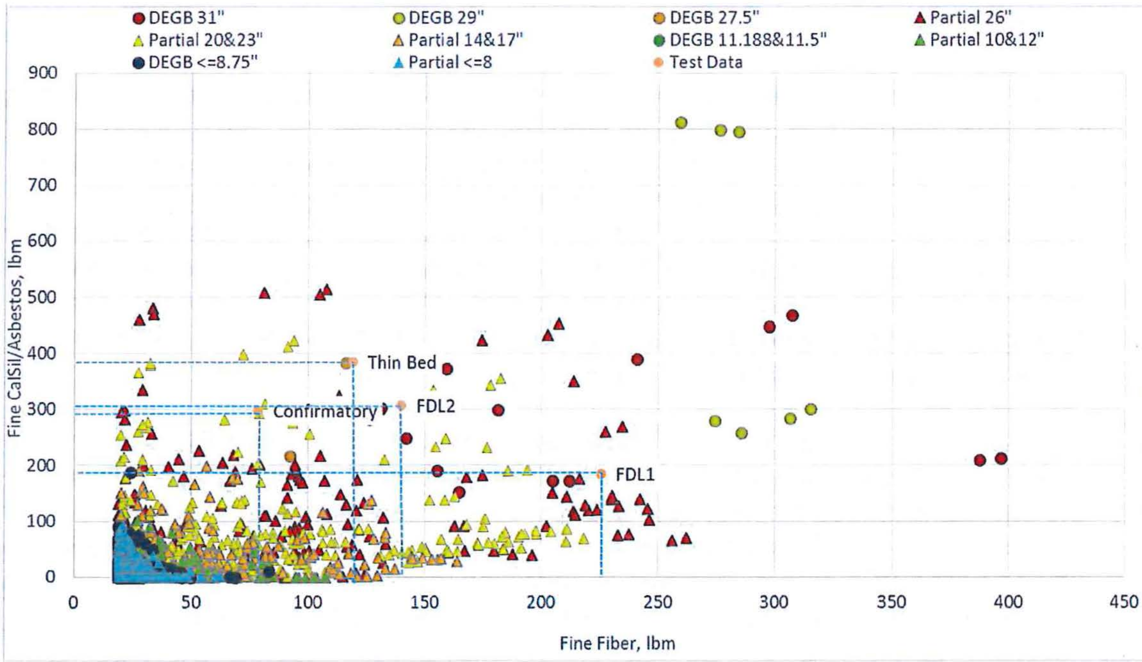


Figure 3.f.7-4 Comparison between Test and PBN2 Plant Debris Loads

The following conditions are credited for the Region II breaks to show that the head loss test results can be applied to the Region II breaks. For deterministic evaluations, only a single strainer is active during recirculation due to the single failure criteria. The emergency operating procedures allow for two train operation during recirculation. When two train operation is credited, the total quantity of debris transported to one operating strainer is reduced by an approximate factor of 2 compared with the single-train case. See the Alternate Evaluation Methodology in Section 2 for additional discussion.

To simulate this action, the PBN NARWHAL model was amended so that both trains were assumed to operate during recirculation. The resulting debris loads at each strainer for the Region II breaks are shown below.

Table 3.f.7-3: Debris Loads with Both Strainers Active for Region II Breaks

Debris Type	PBN1 Strainer Debris		PBN2 Strainer Debris	
	Bounding Cal-Sil Break	Bounding Fine Fiber Break	Bounding Cal-Sil Break	Bounding Fine Fiber Break
LDFG (lbm)	26.99	24.61	65.75	98.11
Mineral Wool (lbm)	64.15	72.77	61.81	87.63
Dirt & Dust (lbm)	54.19	54.19	54.19	54.19
Cal-Sil (lbm)	327.81	199.80	404.01	105.49
Paint Particulate (lbm)	624.69	622.65	802.62	828.44
Paint Chips (lbm)	59.13	59.13	71.24	71.24

Table 3.f.7-4 and Table 3.f.7-5 compare the tested debris loads, which have been converted to the plant scale, with the debris loads for the bounding PBN1 and PBN2 Region II breaks, respectively. Note that the debris loads shown are for a single strainer, and each strainer has identical debris loads due to the symmetry in the PBN NARWHAL model. Also, the coatings debris quantities are output in units of mass from NARWHAL. To make the comparison with the tested quantities, the coatings debris quantities from NARWHAL are converted to volume using a density of 94 lbm/ft^3. This is the smallest density associated with any coating at PBN (see the Response to 3.c.1), and would therefore result in a conservative volume conversion.

Table 3.f.7-4: Comparison of Test Debris Loads with PBN1 Region II Breaks

Debris Type	DEGB Bounding Cal-Sil Break	DEGB Bounding Fine Fiber Break	FDL1 Debris Loads	FDL2 Debris Loads	TB Debris Loads	Confirmatory Debris Loads
Total Fine Fiber (lbm)	91.14	97.38	225.70	140.02	119.33	78.45
Dirt & Dust (lbm)	54.19	54.19	108.50	86.84	108.6	108.6
Cal-Sil (lbm)	327.81	199.8	185.00	307.5	384.5	298.4
Paint Particulate (ft^3)	6.65	6.62	12.41	9.64	12.03	12.01
Paint Chips (ft^3)	0.63	0.63	1.52	1.22	1.52	1.52

Table 3.f.7-5: Comparison of Test Debris Loads with PBN2 Region II Breaks

Debris Type	DEGB Bounding Cal-Sil Break	DEGB Bounding Fine Fiber Break	FDL1 Debris Loads	FDL2 Debris Loads	TB Debris Loads	Confirmatory Debris Loads
Total Fine Fiber (lbm)	127.56	185.74	225.70	140.02	119.33	78.45
Dirt & Dust (lbm)	54.19	54.19	108.50	86.84	108.6	108.6
Cal-Sil (lbm)	404.01	105.49	185.00	307.5	384.5	298.4
Paint Particulate (ft^3)	8.54	8.81	12.41	9.64	12.03	12.01
Paint Chips (ft^3)	0.76	0.76	1.52	1.22	1.52	1.52

As shown, both PBN1 Region II breaks are bounded by the debris loads in the Thin Bed test when considering two train operation during recirculation. The PBN2 bounding fine fiber break is bounded by the FDL1 Test debris loads.

The PBN2 bounding Cal-Sil break is closely represented by the thin bed test debris loads; however, the quantity of Cal-Sil and the quantity of fine fiber exceeds the tested quantity by 19.49 lbm (404.01 lbm compared to 384.52 lbm) and 8.23 lbm (127.56 lbm compared to 119.33 lbm), respectively. To counteract these shortcomings, there is significant margin in the quantity of coatings particulate tested (3.49 ft^3 of coatings surrogate), dirt and dust (54.36 lbm), and paint chips (0.76 ft^3). Taking into account the significant margin in the other debris types, it is reasonable to apply the head loss associated with the thin bed test to the PBN2 limiting Cal-Sil break for Region II.

Comparison of Plant and Head Loss Test Chemical Debris Loads

As shown in the response to 3.f.4, the minimum quantity of SAS used in any of the tests was 77.4 kg at plant scale. This quantity represents the maximum quantity of precipitate expected to be generated for all breaks outside of the reactor cavity, as shown in the Response to 3.o.7. The bounding fiber and Cal-Sil Region I and Region II breaks are all located outside of the reactor cavity; therefore, the quantities of chemical precipitate that is generated for these breaks are bounded by the quantity tested.

The quantity of precipitate generated for the reactor cavity breaks is larger than what was added for any of the tests. However, the quantity of chemicals used in the tests resulted in saturation of the debris bed. This is seen in the head loss response of the tests. For the FDL Test 1, Thin-Bed Test, and Confirmatory Test, the first chemical debris batch resulted in a definitive increase in head loss. However, the second chemical debris batch resulted in a negligible head loss increase. Therefore, the chemical head loss associated with these tests can be used to represent the head loss expected from the chemical loads of the reactor cavity breaks since additional chemicals would not result in an increase in head loss.

Comparison of Plant and Head Loss Test Flow Rates

As discussed in the response to 3.f.3, the maximum flow rate through the strainers is assumed to be 2,100 gpm (approach velocity of 0.00267 ft/s), which is greater than the maximum expected plant flow rate of 2,080 gpm. The minimum test flow rate when the maximum conventional head loss was seen was 164.9 gpm (for the TB test) (see Table 3.f.4-9). This translates to an approach velocity of 0.00270, which bounds the target approach velocity of 0.00267. The approach velocity used during the head loss tests were sufficient during conventional and SAS debris introduction.

8. *Describe significant margins and conservatisms used in head loss and vortexing calculations.*

Response to 3.f.8:

Vortex Formation

Testing was conducted to determine if vortexing is expected to occur. As discussed in the Response to 3.f.3, the vortex tests were performed at both clean strainer and debris-laden conditions.

All vortex evaluations used a strainer approach velocity of 0.00267 ft/s, which is based on a conservatively smaller strainer surface area by accounting for a sacrificial area of 150 ft^2 for miscellaneous debris. The actual reduction in strainer surface area due to blockage by the miscellaneous debris is less than 100 ft^2 at PBN1 (120 ft^2 of miscellaneous debris with 25% overlap) and less than 115 ft^2 at PBN2 (152 ft^2 of miscellaneous debris with 25% overlap). This is conservative as a vortex is more prone to form at higher velocities.

As shown in the response to 3.f.3, plant strainer minimum submergence at the start of the recirculation is compared with the submergence limit established by the debris-laden vortex tests. It should be noted that these tests were performed after all conventional and chemical debris had been added to the test tank. This is conservatively bounding because, at the start of recirculation, the strainer is expected to be clear of debris. Also, the depth of the containment sump pool continues to increase following the start of sump recirculation (due to injection of the CS pumps from the RWST). Therefore, the submergence levels at which vortex formation was evaluated are conservatively low.

Strainer Head Loss

The quantity of latent debris used to determine the strainer head loss is 150 lbm, but the actual amount of latent debris documented for the plant is 62 lbm for PBN1 and 55 lbm for PBN2. These quantities are well below the quantity used to determine the strainer head loss. Similarly, a sacrificial strainer area of 150 ft^2 was used when determining the testing parameters. In reality, the reduction in strainer surface area due to blockage of miscellaneous debris is less than 100 ft^2 at PBN1 and less than 115 ft^2 at PBN2.

As discussed in the Response to 3.f.7, the approach velocities used in the PBN head loss tests are greater than the plant strainer's average approach velocity.

As discussed in the Response to 3.f.10, although the head loss tests were performed at more conservative conditions (lower temperatures and higher flow rate) than those in the actual plant, for conservatism, head loss test data is not scaled to greater temperatures and lower flow rates for NPSH and flashing evaluations.

A significant conservatism is that the debris transport analysis conservatively predicted the quantity of material that would be transported to the strainer. The reality is that a large portion of the debris would never make it to the strainer due to agglomeration effects, the propensity for fiber to become wrapped around or entangled with plant equipment, and the settling of debris in low flow regions. This makes the test results even more conservative.

Another significant conservatism in debris transport is during pool fill. The transport to the inactive (reactor) cavity was conservatively limited to 15% for fine, small, and large debris. Note that the transport to the inactive cavity without the limitation was calculated to be 71% for PBN1 and 77% for PBN2. This makes the tested debris quantities very conservative.

9. *Provide a summary of methodology, assumptions, bases for the assumptions, and results for the clean strainer head loss calculation.*

Response to 3.f.9:

The clean strainer head loss for PBN was calculated by the strainer vendor. Clean strainer head loss test data, from a generic (non-plant specific) PCI prototype, was curve fit to a second-order polynomial function of the strainer's core tube exit velocity. The function was used to calculate the head loss for the PBN strainer disks using the PBN core tube exit velocity. It should be noted that this test performed by the strainer vendor was not part of the debris laden head loss test program described in the Response to 3.f. Since the tested PCI prototype strainer has differences from that installed in PBN, adjustments were made to account for the physical differences between the two designs.

The PCI prototype clean strainer testing used an approach velocity higher than that of the PBN strainer design. Since head loss increases with approach velocity, the head loss through the PCI prototype strainer's perforated plate was expected to be greater than that through the PBN strainer perforated plates. Therefore, for conservatism, no adjustment was made to the perforated plate head loss calculated from the PCI prototype test data.

The PCI prototype strainer had a core tube length of 54 inches, but the PBN strainer has core tube length of 279.44 inches. The additional head loss due to longer length was calculated using the Darcy-Weisbach equation.

The Darcy-Weisbach equation, with head loss coefficients from standard industry handbooks, was also used to model the module to module transition head loss, and head losses inside the attached pipe and fittings. The head loss from the attached pipe to containment outlet was also calculated.

Finally, the head loss was calculated from internal flow restrictions inside the disks caused by the reinforcing wires in the disks. The internal flow restrictions were modeled as an orifice.

The clean strainer head loss was determined to be 0.56 ft at 212 °F (0.24 psi) for a total strainer flow rate of 2,200 gpm.

10. *Provide a summary of methodology, assumptions, bases for the assumptions, and results for the debris head loss analysis.*

Response to 3.f.10:

The total strainer head loss was calculated by combining the debris head losses shown in the Response to 3.f.7 and the clean strainer head loss shown in the Response to 3.f.9. The total strainer head losses, used to evaluate ECCS and CSS pump NPSH, void fraction, flashing and strainer structural integrity for PBN are provided in Table 3.f.10-1.

Table 3.f.10-1: PBN Strainer Head Loss

Clean Strainer Head Loss (psi)	Debris Head Loss (psi)	Total Head Loss (psi)	Notes
0.24	1.59	1.83	Based on conventional debris head loss
	2.14	2.38	Based on aluminum chemical debris head loss

It should be noted that the debris head losses were measured at conditions more conservative (lower temperature and higher flow rate) than the actual plant conditions. For conservatism, scaling was not used to adjust the head losses to actual plant conditions.

The clean strainer head loss was calculated at temperature of 212 °F. The increase in head loss due to a reduction in temperature is negligible.

11. *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.*

Response to 3.f.11:

As shown in the Response to 3.g.1, the strainer is submerged for all breaks at the beginning of recirculation.

12. *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.*

Response to 3.f.12:

No near-field settling was credited in the PBN head loss testing. Sufficient turbulence was maintained in the mixing section of the test tank to ensure that all debris had an opportunity to collect on the surfaces of the test strainer, while not disturbing the debris bed formation. The turbulence was created by five mixing nozzles in the test tank as shown in Figure 3.f.12-1. The placement and size of the five mixing nozzles was carefully chosen to achieve the desired level of turbulence in the test tank without disturbing the debris bed formed on the test strainer.

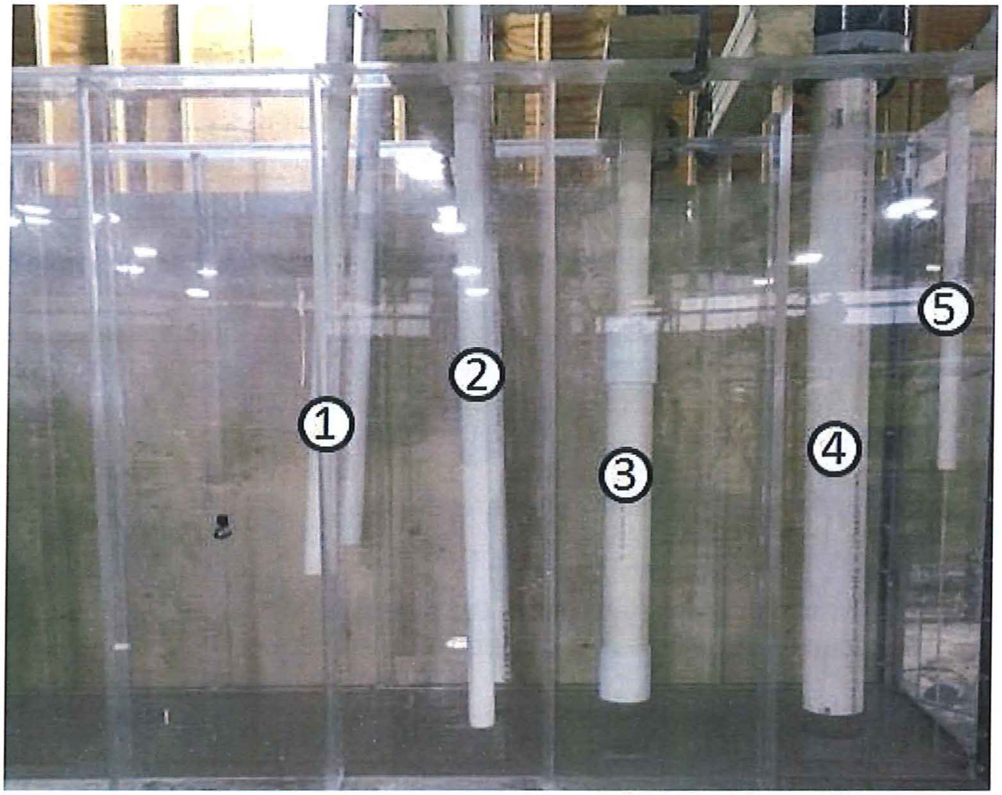


Figure 3.f.12-1: Mixing Nozzles in Test Tank

13. *State whether temperature/viscosity was used to scale the results of the head loss test 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.*

Response to 3.f.13:

See response to 3.f.10.

14. *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.*

Response to 3.f.14:

Flashing would occur if the pressure downstream of the strainer was lower than the vapor pressure at the sump temperature. The pressure downstream of the strainer was calculated by combining the strainer submergence and containment pressure before subtracting the strainer head loss.

Analysis of Flashing

The flashing analysis used the minimum strainer submergence evaluated from the top of the strainer to the minimum sump pool water level. As shown in the Response to 3.g.1, the minimum strainer submergence for an LBLOCA on the main loop is 8.9" (or rounded down to 0.3 psi). The SBLOCA strainer submergence and LBLOCA strainer submergence for breaks above the pressurizer are not considered since the debris quantities, strainer head losses, and post-accident containment conditions for the smaller breaks are less limiting than the LBLOCAs on the main loop piping.

The total strainer head loss was determined by combining the calculated clean strainer head loss and measured debris head loss. The maximum total strainer head loss for PBN is 2.38 psi (see the response to 3.f.10).

The post-accident containment pressure can be expressed as the summation of saturation water pressure at the sump temperature (P_{Vapor}) plus air partial pressure (P_{air}).

Using the information presented above, the pressure downstream of the strainer during the recirculation phase can be calculated as follows:

$$
\begin{aligned}
P_{Strainer} &= P_{Cont} + P_{Submergence} - h_L \\
&= P_{Vapor} + P_{air} + 0.3 \text{ psi} - 2.38 \text{ psi} \\
&= P_{Vapor} + P_{air} - 2.08 \text{ psi}
\end{aligned}
$$

In order to avoid flashing, the pressure downstream of the strainer ($P_{Strainer}$) must be greater than the water vapor pressure at the sump temperature (P_{Vapor}). In other words, the post-accident air partial pressure (P_{air}) needs to be greater than 2.08 psi, as shown in the equation above.

Note that the air partial pressure prior to the accident is greater than 2.08 psi. For PBN1 and PBN2, the minimum pressure the containment is designed to withstand is -2 psig (12.7 psi) . The maximum normal operating containment temperature is 120°F and the corresponding water vapor pressure is 1.69 psia. Assuming a 100% relative humidity, the minimum air partial pressure prior to the accident is therefore 11.01 psi (12.7 – 1.69 psi). Since this pre-accident air partial pressure is much higher than the 2.08 psi required, it is reasonable to conclude that flashing should not occur during the sump recirculation phase.

There are several conservatisms in the analysis for both PBN1 and PBN2:

1. The minimum strainer submergence at the start of recirculation was used. Any increase in sump pool level over time was conservatively neglected.
2. The maximum strainer head loss, which includes the clean strainer, conventional debris, and chemical debris head loss, was used. The head losses calculated or measured at lower temperatures were not adjusted for temperature differences.

3. The most limiting pre-accident operating containment conditions were used to minimize the air partial pressure: highest normal operating containment temperature and minimum normal operating containment pressure.
4. The increase in air partial pressure due to heat-up of the containment atmosphere following an accident was not credited.

Analysis of Degasification

Degasification was evaluated for PBN1 and PBN2 using the NARWHAL software package. The evaluation was performed in a time-dependent fashion, and the recirculation duration was divided into smaller time steps. For each time step, the amount of air that could be released due to the pressure drop across the debris laden strainer was quantified by determining the air solubility decrease as flow travels through the strainer. This information was then used to calculate the void fraction, which was compared with the 2% acceptance limit given in NEI 09-10 (Reference 19 p. 28).

Various post-accident containment and sump conditions were considered. No containment accident pressure was credited for degasification. The containment pressure was assumed to be 14.7 psia for sump temperature at or below 212 °F, and equal to water saturation pressure at the sump temperature for sump temperatures above 212 °F. The evaluation used a strainer submergence calculated from the midpoint of the strainer. Additionally, it was assumed that air released through degasification transports to the pump suction, conservatively neglecting the re-absorption of air due to increase in hydrostatic pressure as it travels to the pump at a lower elevation.

The evaluation for PBN1 and PBN2 showed that the void fraction due to degasification was below the 2% acceptance limit during the sump recirculation phase for both units.

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.

1. *Provide applicable pump flow rates, the total recirculation sump flow rates, sump temperature(s), and minimum containment water level.*

Response to 3.g.1:

Pump/ Sump Flow Rates

The flow rates across the ECCS strainer and corresponding NPSH margins for the operating pumps were analyzed for different recirculation modes at PBN1 and PBN2. The recirculation mode that provides the most significant challenge to RHR

NPSH is when the RHR and SI pumps are aligned in piggyback operation, with RHR pumps providing suction to the SI pumps, and the two providing simultaneous upper plenum and cold leg injection (designated Case R4A) . Per the results of this analysis, a procedural change was implemented to limit the RHR flow rate to 2,000 gpm for this configuration. Therefore, a strainer flow rate of 2,000 gpm was used when evaluating pump NPSH margin. This flow rate is for simultaneous cold leg and upper plenum injection and was shown to be the most limiting case with respect to RHR NPSH margin.

Minimum Water Level

PBN1

The containment water level calculation evaluated bounding minimum sump pool volumes and levels. Table 3.g.1-1 summarizes the results of the containment water level calculation.

The pool floor elevation is 8 ft. The top elevation of the strainers is 11 ft.

The pool height values in Table 3.g.1-1 were calculated by subtracting the pool floor elevation from the water level elevation. The submergence values in Table 3.g.1-1 were calculated by subtracting the top elevation of the strainers from the water level elevations.

Table 3.g.1-1: Minimum Sump Pool Water Levels (PBN1)

Break Size	Break Elevation	Minimum Water Level Elevation (ft)	Pool Height (ft)	Strainer Submergence (ft)
SBLOCA	Top of the pressurizer	11.17	3.17	0.17
SBLOCA	Below the elevation of the top of the hot leg nozzles	11.29	3.29	0.29
LBLOCA	Top of the pressurizer	11.17	3.17	0.17
LBLOCA	Below the elevation of the top of the hot leg nozzles	11.72	3.72	0.72

PBN2

The containment water level calculation evaluated bounding minimum sump pool volumes and levels. Table 3.g.1-2 summarizes the results of the containment water level calculation.

The pool floor elevation is 8 ft. The top elevation of the strainers is 11 ft.

The pool height values in Table 3.g.1-2 were calculated by subtracting the pool floor elevation from the water level elevation. The submergence values in Table 3.g.1-2 were calculated by subtracting the top elevation of the strainers from the water level elevations.

Table 3.g.1-2: Minimum Sump Pool Water Levels (PBN2)

Break Case	Break Elevation	Minimum Water Level Elevation (ft)	Pool Height (ft)	Strainer Submergence (ft)
SBLOCA	Top of the pressurizer	11.19	3.19	0.19
SBLOCA	Below the elevation of the top of the hot leg nozzles	11.31	3.31	0.31
LBLOCA	Top of the pressurizer	11.19	3.19	0.19
LBLOCA	Below the elevation of the top of the hot leg nozzles	11.74	3.74	0.74

Sump Temperature

For the evaluation of NPSH for PBN1 and PBN2, the sump temperature was assumed to be 212°F. The actual sump temperature rises beyond 250°F. Justification for the use of 212°F is provided in the Response to 3.g.2.

2. *Describe the assumptions used in the calculations for the above parameters and the sources/bases of the assumptions.*

Response to 3.g.2:

Pump/Sump Flow Rate

Model Development

A thermal-hydraulic model for the ECCS, using PROTO-FLO, with the capability to run in multiple alignments was used to determine system operating characteristics. The following assumptions were made in the model.

1. It was assumed that for any flow measuring orifice that lacks sufficient information to calculate its effect on flow resistance, a bore diameter consistent with existing system flow orifices in pipe of equal size can be used.

   Basis: The only orifices affected by this assumption are flow measuring orifices, not flow restricting orifices. Flow measuring orifices typically have a negligible effect on the frictional pressure losses in a piping system. Where vendor data was available, a consistent bore size was used for a given pipe size.

2. It was assumed that any change in fluid temperature due to heat addition from the pumps, wall friction, and the surroundings is negligible.

Basis: The minor heat loads imparted by these means have no significant impact on fluid conditions.

3. It was assumed that the input pressure drop vs. flow relationships are at 60°F.

   Basis: This temperature is consistent with typical manufacturing practice.

4. It was assumed that the pressure drop due to the valve stem in the discharge elbow in the RHR pump containment sump suction valves, (2-850A/B) is bounded by increasing the pressure drop of the entrance into the valve through the valve exit elbow (Losses 5-8b) by 30%.

   Basis: This valve's service is to open against a relatively small pressure and therefore the force that must be transmitted to the stem is not excessive. The cross-sectional area of the valve stem is ~ 16 square inches while the flow area of the elbow it is contained in is ~78 square inches resulting in a flow reduction area of 20%. The other sudden contraction accounts for only ~4% of the total pressure drop. Therefore this value is sufficiently conservative.

5. It was assumed that configuration of the pipe elbow where the PBN1 strainer transitions to the 1SI-00850A and 1SI-00850B valves is the same as the PBN2 configuration.

   Basis: This assumption is acceptable since the configuration where the PBN1 and PBN2 SI-00850A and SI-00850B valves project from the containment floor is similar and thus the strainer design is expected to be the same.

<u>NPSH Evaluation</u>

Additional assumptions were made for the purpose of applying the Proto-Flo model to determine RHR pump NPSH. These assumptions are detailed below.

1. It was assumed that the interior of all piping is at the same temperature as the source of its flow (i.e., the containment atmosphere does not transfer heat to the flowstream).

   Basis: This is reasonable based on the high fluid velocities and given that the containment air will undergo rapid cooling after the initiation of containment spray, thereby limiting its capacity to transfer heat to piping.

2. It was assumed that the valve positions will be as noted in existing operations checklists and procedures for transfer to containment sump recirculation.

Minimum Water Level

The significant assumptions used in the water volume calculation are listed as follows.

1. The CAD model is not all-inclusive. That is, various mechanical items are not modeled (e.g., vents, equipment supports, annulus piping, etc.). Other items (e.g., I-beams) were simplified to facilitate more robust computational fluid dynamic analyses. Therefore, the pool level, as a function of pool volume, is lower than if these items were included or resolved in more detail. This is conservative.
2. It was assumed that differences between PBN1 and PBN2 are small enough that a single generic analysis can adequately address both units. This is reasonable since the significant dimensions (e.g., the diameters of the RWSTs, containment buildings, depths of sumps, etc.) are identical. The analyzed flow rates between the two units' containment spray and ECCS have negligible differences. Therefore, using conservative inputs, assumptions, and methods ensure that using data from one of the two units will reasonably reflect the conditions for both units.
3. Fluid densities were calculated as pure water with the exception of solutions composed of NaOH. In the cases where fluid inventories are composed of solutions of water and other constituents (i.e., boric acid, etc.), the resulting density using the assumption of a pure water volume is slightly lower, leading to a negligibly larger final pool volume. Additionally, the masses of the various solutes are negligible with respect to the total mass of the water.
4. It was assumed that the bounding containment pressure, temperature, and sump water temperature values are applicable to SBLOCAs. This is a reasonable assumption when used to calculate the density of the post-LOCA pool inventory and the vapor in containment hold-up, as the pressure and temperatures are expected to be considerably elevated for all LOCA sizes.
5. The inventory of the RCS is assumed to remain relatively constant throughout the operating cycle. This is a reasonable assumption because the RCS is a fixed volume that remains at constant temperature and pressure during full power operation, and any variation in the RCS liquid volume is negligible, considering the magnitude of the RCS liquid volume compared to the RWST liquid volume.
6. It was assumed that LBLOCAs will result in full depressurization of the RCS; therefore, during recirculation, the RCS will retain water up to the elevation of the break.
7. It was assumed that the time duration for manual actions necessary to realign the RHR, SI, and CS pumps from injection from the RWST to recirculation from the containment sump is zero. This is a conservative assumption because it minimizes the amount of water injected into containment, thereby reducing the containment water level.
8. For determining the amount of inventory held up as steam in the containment atmosphere, the pre-LOCA mass of steam was subtracted from the post-LOCA mass of steam. The pre-LOCA mass of steam was determined to be 0 lbm by

assuming a humidity of 0%, and the post-LOCA mass of steam was determined by assuming a humidity of 100%. This is conservative, since it maximizes the atmospheric steam hold-up, thereby reducing the pool water level.

Sump Temperature

A sump temperature of 212°F was assumed for the NPSH evaluation. This is appropriate given the conservative containment pressure used. As discussed in the response to 3.g.13, the containment pressure was assumed to be 14.7 psia for sump temperatures at or below 212 °F. For sump temperatures above 212 °F, the containment pressure was assumed to be equal to the vapor pressure at the corresponding sump temperature, conservatively neglecting any accident pressure or air partial pressure of the containment atmosphere.

The NPSH available was calculated by combining the containment pressure and elevation difference between the sump water level and RHR suction before subtracting the total head loss on the suction side of the pump (including the strainer head loss) and vapor pressure at the sump temperature. For sump temperatures below 212 °F, the vapor pressure is less than the assumed containment pressure of 14.7 psia. Therefore, the difference between the assumed containment pressure and the vapor pressure increases the pump NPSH available and NPSH margin. As a result, the NPSH margin becomes less limiting as temperature drops below 212 °F.

For sump temperatures above 212 °F, the containment pressure was assumed to be equal to the vapor pressure at the corresponding sump temperature. As a result, they cancel each other out when calculating pump NPSH available. The formula for calculating NPSH available then reduces to elevation difference between the sump water level and RHR suction minus total head loss on the pump suction side. Since head loss increases slightly as temperature decreases due to higher water viscosity, it would be slightly more conservative to calculate the NPSH margin at the lower end of this temperature range, 212 °F. Therefore, the NPSH evaluation for this submittal was performed at 212 °F. The water temperature used during head loss testing was 120 °F instead of the expected sump temperature of 212 °F. The head loss value from testing was used in the NPSH calculation. It is conservative to not use head loss scaling from testing temperature to sump temperature

3. *Provide the basis for the required NPSH values, e.g., 3 percent head drop or other criterion.*

Response to 3.g.3:

The NPSH requirements curve provided by the pump vendor were used for establishing the analytical acceptance criteria. The methods used by the vendor were in accordance with the test procedures outlined in the Standards of the Hydraulic Institute.

Because NPSHR data was provided at discrete flow rates, interpolation was required to determine NPSHR at intermediate flow rates of interest. The provided data points and the interpolated values are provided below in Table 3.g.2-1 and Table 3.g.2-2, respectively.

Table 3.g.2-1: RHR A NPSHR as a Function of Flow

NPSHR (ft)	Flow (gpm)
11.0	1,950
12.0	2,050
15.3	2,200

Table 3.g.2-2: RHR A Interpolated NPSHR Values

Description	NPSHR (ft)	Flow (gpm)
PBN2 Case R4A RHR Flow Rate	12.8	2,088
PBN1 Case R4A RHR Flow Rate	12.7	2,084
PBN Revised RHR Flow Rate	11.5	2,000

4. *Describe how friction and other flow losses are accounted for.*

Response to 3.g.4:

Using the as-built isometric drawings, a model of the ECCS system was defined in PROTO-FLO as a network of connecting node points. Pipe data such as length, material, schedule, components, and fittings was gathered from the drawings and other references and entered for each section of pipe in the system.

The piping frictional losses were calculated using the standard Darcy formula with the friction factor determined from an empirical equation. The head losses of the components (e.g., valves, elbows, reducers, and tee junctions) on the pump suction piping were calculated using the loss coefficients from standard industry handbooks.

Debris head loss values were calculated through strainer testing with debris beds, which include both fibrous, particulate and chemical debris, as shown in the Response to 3.f.7.

5. *Describe the system response scenarios for LBLOCA and SBLOCAs.*

Response to 3.g.5:

For an LBLOCA, the RCS undergoes rapid depressurization due to the size of the break. Safety injection is automatically initiated upon an SIAS and the reactor is tripped. The following equipment is activated: SI pumps, RHR pumps, and all injection valves open. Additionally, the charging pumps are started to augment flow of the safety injection system. These pumps take suction from the RWST and inject to the RCS cold legs and reactor. This system line-up is referred to as the ECCS injection phase.

As the energy is released into containment, the containment pressure will increase, and the CSAS will start the CSS pumps.

One RHR pump is required to inject borated water to the core. The high and low head injection flows during the injection phase are sufficient to prevent boric acid precipitation. Cold leg injection flow from the high head pumps is secured prior to the transfer to sump recirculation, but is reinitiated prior to the occurrence of boric acid precipitation in the reactor vessel.

For small breaks, RHR injection into the core is not required. RHR pumps are isolated after a LOCA is determined to be a small break, while SI pumps remain in operation for the injection phase. Atmospheric dump valves are opened to reduce RCS pressure enough to allow low head injection within 6 to 7 hours of the event.

Before the RWST inventory is depleted, the suction source of the pumps must be switched. The RHR system is lined up to take suction from the containment sump when RWST level is less than or equal to 34% and the containment sump contains enough water to provide sufficient NPSH for the RHR pumps. CS pumps are manually realigned to take suction from the RHR pumps in recirculation. The switchover is complete when the suction valves from the RWST for all pumps are manually closed. Containment spray is not necessary for containment cooling after the injection phase, but continues to run for iodine removal.

Approximately 2 hours following switchover to recirculation, the ECCS line-up is modified for simultaneous cold leg and upper plenum injection. For this operating mode, the SI pump takes suction from the RHR pump discharge.

6. *Describe the operational status for each ECCS and CSS pump before and after the initiation of recirculation.*

Response to 3.g.6:

Prior to the initiating event, the ECCS and CSS pumps will be in a state of stand-by readiness. Operation of each pump is described in the sections below.

Residual Heat Removal Pumps

During the injection phase, the RHR pumps are active, drawing suction from the RWST and injecting into the reactor vessel and core barrel. Prior to switchover to recirculation, the RHR pumps are secured. After switchover to recirculation, the RHR pumps are realigned to take suction from the recirculation sump and are restarted to deliver flow to the core and/or to containment spray suction.

Containment Spray System Pumps

During the injection phase, the CS pumps are active, drawing suction from the RWST. Prior to switchover to recirculation, the CS pumps are secured. After RHR switchover to recirculation, the CS A pump is aligned to take suction from RHR A pump discharge and is restarted. The CS A pump is ran for at least two hours in recirculation. After two hours, the CS A pump is secured.

High Head Safety Injection Pumps

During the injection phase, the SI pumps are active, drawing suction from the RWST and injecting into the RCS cold leg and/or the reactor vessel. The SI pumps continue drawing from the RWST until after the RHR pumps are switched over to recirculation, at which time the SI pumps are secured. The SI pumps remain secured until the CS B pump is operated for two hours in recirculation. Afterwards, the CS B pump is secured, and the SI A pump is aligned to take suction from the RHR A pump, with the RHR A pump taking suction from the sump. The SI A pump injects into the RCS cold legs.

7. *Describe the single failure assumptions relevant to pump operation and sump performance.*

Response to 3.g.7:

The single failure scenarios considered are failure of an RHR pump, a CS pump, or an SI pump.

Failure of an RHR pump is equivalent to failure of an entire ECCS train, since CS and SI pumps draw suction from RHR pumps in recirculation This scenario was considered in head loss testing, in which debris loads and flow rates were based on the assumption that a single ECCS train was in operation. Because PBN ECCS suction lines are not interconnected, the failure of one train results in the reduction of the strainer surface area by 50%, effectively doubling the debris load for the strainer train remaining in operation.

Failure of a CS or an SI pump, each of which draw suction from RHR discharge during recirculation, would decrease the available flow paths for the RHR discharge. This will result in a decreased RHR flow rate and increased RHR NPSH margin. Therefore, this condition is not limiting for NPSH evaluation.

For Region II breaks, two train operation may be credited. This operation would result in the break debris load being distributed between the surface area of both strainer trains. For further discussion and details on the how this action impacts the ECCS strainer capabilities for Region II breaks, see the Response to 3.f.7.

8. *Describe how the containment sump water level is determined.*

Response to 3.g.8:

The water volume calculation used the methodology described below:

- A correlation was first developed for the relationship between the containment water level and the water volume using a 3-D CAD model.
- The quantity of water added to containment from the RWST, RCS, SI accumulators, and spray additive tank (SAT) was calculated.
- The quantity of water that is diverted from the containment sump by the following effects was evaluated:
    - Water volume required to fill the CS discharge piping that is empty pre-LOCA.
    - Water in transit from the containment spray nozzles to the containment floor.
    - Water held-up on containment surfaces exposed to containment spray and steam condensation.
    - Steam held-up in the containment atmosphere.
    - RCS re-flood hold-up.
    - Water held-up in the pressurizer cubicle.
    - Water held-up in the sump "A" keyway tower.
    - Hold-up in the refueling canal.
- Given the net mass of water added to the containment floor based on the second and third bullets listed above, the post-LOCA containment water level was calculated using the correlation developed in the first bullet.

The calculation determined bounding minimum containment water levels for LBLOCA and SBLOCA using break size-specific injection volumes and hold-up volumes.

9. *Provide assumptions that are included in the analysis to ensure a minimum (conservative) water level in determining NPSH margin.*

Response to 3.g.9:

The assumptions provided in the Response to 3.g.2 ensure that minimum (conservative) containment water levels are calculated in the containment water volume calculation.

10. *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.*

Response to 3.g.10:

As described in the Response to 3.g.8, the following volumes are treated within the water volume calculation as hold-up volumes that remove water from the containment pool: CS discharge piping (initially empty spray piping), water droplets in transit from the containment spray nozzles, water droplets on containment surfaces formed from exposure to containment spray and steam condensation, and steam held-up in the containment atmosphere.

11. *Provide assumptions (and their bases) as to what equipment will displace water resulting in higher pool level.*

Response to 3.g.11:

The volumes occupied by structures, equipment, and equipment supports, etc. will displace water and result in a higher pool level. Examples such as concrete and structural steels will displace water. These volumes were accounted for in the containment water volume calculation. The 3-D CAD model of containment was used to determine the correlation between the containment pool volume and water level. Smaller equipment, cables, and instruments were excluded from the CAD model and therefore provide some conservatism in the resulting water levels, as stated in the Response to 3.g.2. Figure 3.g.11-1 shows the level of detail of structures and components credited for water displacement in the containment water volume calculation.

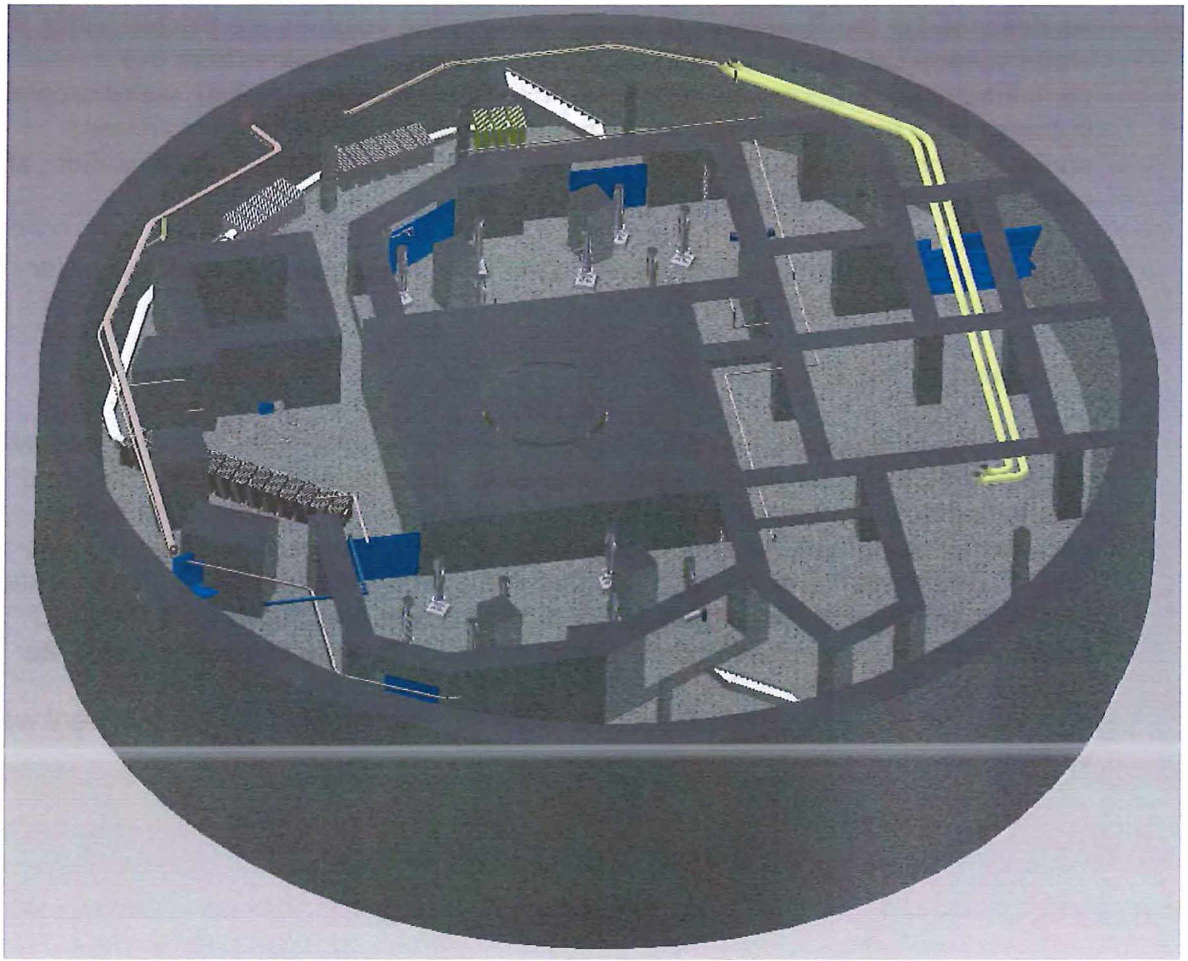


Figure 3.g.11-1: PBN PBN1 Containment CAD Model

12. *Provide assumptions (and their bases) as to what water sources provide pool volume and how much volume is from each source.*

Response to 3.g.12:

The following design inputs provided the basis for water sources and their volumes to determine the minimum containment water level:

- The TS minimum initial RWST level was used for the initial RWST water level. The low level (plus an amount to account for uncertainty) was used for the final RWST water level. The minimum RWST injection volume is 165,787 gal.
- There are two SI accumulators for each unit, and the minimum combined volume of the SI accumulators is 16,458 gal.
- The inventory of the RCS is assumed to remain relatively constant during normal operations. This is a reasonable assumption because during full power operation, the RCS remains at a fixed volume and remains at constant

temperature and pressure. Due to the small volume of the RCS as compared to the RWST and its negligible variation in water volume (as noted in Assumption 5 of Response to 3.g.2), a best estimate value is representative. The best estimate RCS liquid volume is 42,003 gal. The RCS represents both a source of water and a hold-up volume. The mass of water held up in the RCS may be more or less than the initial RCS mass depending on the elevation of the break.

- The minimum volume of water provided by the SAT is 541 gal.

13. *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.*

Response to 3.g.13:

No credit was taken for containment accident pressure in determining NPSHA. Containment pressure is further described in the Response to 3.g.14.

14. *Provide assumptions made which minimize the containment accident pressure and maximize the sump water temperature.*

Response to 3.g.14:

Containment Pressure

As mentioned in the Response to 3.g.13, no containment accident pressure was credited for NPSH evaluation. For sump temperatures equal to or below 212°F, a containment pressure of 14.7 psia was used. For sump temperatures above 212°F, containment pressure was set equal to the vapor pressure corresponding to the sump temperature.

Sump Temperature

The NPSH evaluation was performed at a sump temperature of 212°F. The Response to 3.g.2 justifies the use of this temperature.

15. *Specify whether the containment accident pressure is set at the vapor pressure corresponding to the sump liquid temperature.*

Response to 3.g.15:

As discussed in the Response to 3.g.14, the containment pressure was set at 14.7 psia for sump temperatures below or equal to 212°F. For sump temperatures above 212°F, the containment pressure was set equal to the vapor pressure corresponding to the sump liquid temperature.

16. *Provide the NPSH margin results for pumps taking suction from the sump in recirculation mode.*

Response to 3.g.16:

Table 3.g.16-1 provides a summary of the resulting minimum NPSH margins for the RHR pumps in recirculation mode at various sump temperatures between 120°F and 212°F. These NPSH margins were determined using the strainer head loss from the Response to 3.f.10 and water levels from the Response to 3.g.1. These inputs are the most conservative for all of the postulated Region I breaks at PBN (17" and smaller). Therefore, the resulting NPSH margins are bounding of both units and all Region I breaks.

Table 3.g.16-1 Limiting NPSH Margin vs. Sump Temperature for Region I Breaks

Pool Temperature (°F)	NPSH Margin Before Subtracting Strainer Head Loss (ft-H_2O)	Strainer Head Loss (ft-H_2O)	Net NPSH Margin After Subtracting Strainer Head Loss (ft-H_2O)
212	4.42	4.27[a]	0.14
200	11.84	4.27[a]	7.56
180	21.20	4.27[a]	16.93
160	27.67	5.56[b]	22.11
140	31.98	5.56[b]	26.42
120	34.77	5.56[b]	29.21

[a] This head loss includes clean strainer head loss and conventional debris (fiber and particulate) head loss.

[b] This head loss includes clean strainer head loss, conventional debris (fiber and particulate) head loss and chemical debris (sodium aluminum silicate) head loss.

Since the CS and SI pumps take suction from the RHR pump discharge during recirculation, the NPSH margins for the RHR pumps are more limiting. NPSH evaluation of the CS pumps and SI pumps showed that the NPSH was adequate for all analyzed cases.

As discussed in the Response to 3.f.7, if two-train operation is credited, the debris loads of all Region II breaks are bounded by the PBN head loss test debris loads. Therefore, the measured head loss values are also applicable for the Region II breaks. As a result, the NPSH margins in Table 3.g.16-1 are also the minimum margins for all Region II breaks when two-train operation is credited.

As shown in the table, the minimum net NPSH margin for any given sump temperature is positive. Therefore, adequate NPSH margin is available for PBN1 and PBN2 ECCS and CS pumps to ensure their design functions for Region I breaks and also Region II breaks where two-train operation is credited.

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.

1. *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.*

Response to 3.h.1:

The types of coating and systems used in PBN1 and PBN2 containment are presented in Table 3.h.1-1 and Table 3.h.1-2, respectively.

Qualified Coatings

Table 3.h.1-1: PBN1 Qualified Coatings Systems Used in Debris Generation Analyses

Substrate	Layer	Type	DFT (mil)	Density (lbm/ft^3)
Steel Surfaces	1st Coat	Dimetcote 6 – IOZ	7	300
	2nd Coat	Amercoat 66 – Epoxy	10.5	97.1
		Total	17.5	--
Concrete Walls	1st Coat	Carboline 195 – Epoxy	27.4	109
	2nd Coat	Phenoline 305 – Epoxy	5.0	101.3
		Total	32.4	--
Concrete Floors	1st Coat	Phenoline 305 – Epoxy	10.9	101.3

Table 3.h.1-2: PBN2 Qualified Coatings Systems Used in Debris Generation Analyses

Substrate	Layer	Type	DFT (mil)	Density (lbm/ft^3)
Steel Surfaces	1st Coat	Dimetcote 6 – IOZ	7	300
	2nd Coat	Amercoat 66 – Epoxy	10.5	97.1
		Total	17.5	--
Concrete Walls	1st Coat	Carboline 195 – Epoxy	33.4	109
	2nd Coat	Phenoline 305 – Epoxy	5.0	101.3
		Total	38.4	--
Concrete Floors	1st Coat	Phenoline 305 – Epoxy	10.9	101.3

Unqualified Coatings

Unqualified coatings are those that fail under design basis accident conditions and create debris that could be transported to the containment recirculation strainers. There are several types of unqualified coatings applied over numerous substrates within containment. The quantity and properties of these unqualified coatings are shown in Table 3.h.1-3 for PBN1 and Table 3.h.1-4 for PBN2.

Table 3.h.1-3: PBN1 Unqualified Coatings Quantities Used in Analyses

Coating Type	Volume (ft^3)
IOZ	1.49
Alkyd	4.11
Epoxy (Unqualified)	2.41
[1]ADQ Epoxy	2.46

[1.] Actively Delaminating Qualified

Table 3.h.1-4: PBN2 Unqualified Coatings Quantities Used in Analyses

Coating Type	Volume (ft^3)
IOZ	1.73
Alkyd	5.78
Epoxy (Unqualified)	2.93
[1]ADQ Epoxy	2.96

[1.] Actively Delaminating Qualified

2. *Describe and provide bases for assumptions made in post-LOCA paint debris transport analysis.*

Response to 3.h.2:

The following assumptions related to coatings were made in the PBN1 and PBN2 debris transport analyses:

- It was conservatively assumed that all unqualified coatings are located in lower containment. This is conservative since it results in 100% of unqualified coatings being present in the pool at the start of recirculation and results in 100% transport of this debris type.
- It was assumed that the settling velocity of particulate debris (insulation, dirt/dust, and coatings) can be calculated using Stokes' Law. This is a reasonable assumption since the particulate debris is generally spherical, small in size, and would settle slowly (within the applicability of Stokes' Law). This assumption has been addressed in the San Onofre (Reference 20) and Indian Point (Reference 21) Audit Reports, and it has been concluded that it is not a significant factor with respect to debris transport since no credit is taken for debris settling using this approach.
- Unqualified coatings outside the ZOI were assumed to fail after pool fill has

occurred, so the transport fraction for this debris during pool fill is 0%.

3. *Discuss suction strainer head loss testing performed as it relates to both qualified and unqualified coatings. Identify surrogate material and what surrogate material was used to simulate coatings debris.*

Response to 3.h.3:

PBN has qualified coatings (IOZ and epoxy), unqualified coatings (IOZ and epoxy), and actively delaminating qualified coatings (ADQCs). Silica flour, with a median size distribution of approximately 13.5 microns, was used as a surrogate for qualified coatings, unqualified coatings, and the fine particle portion of the actively delaminating qualified coatings. Pressure washed paint chips, with a nominal size of approximately 0.125", were used as a surrogate to model the flat small chip portion of the ADQCs. See the Response to 3.f.4 for detailed information on coating surrogates and the amount added to the test.

4. *Provide bases for the choice of surrogates.*

Response to 3.h.4:

See the Response to 3.f.4.

5. *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.*

Response to 3.h.5:

The following assumption related to coatings was made in the debris generation calculations:

- Epoxy and alkyd unqualified coatings were assumed to have properties as listed in Table 3.h.1-1 and Table 3.h.1-2.
- Unqualified IOZ was assumed to have a particulate size of 10 μm (Ref. 2, p. 51) and the density of Carbozinc 11 – a typical IOZ used in nuclear power plants – 208 lb/ft^3 (27.81 lb/gal) .
- o Qualified coatings were analyzed within a 4.0D ZOI. This ZOI has been previously accepted by the NRC (Reference 13 p. 2).

The amount of unqualified coatings in containment are quantified based on detailed logs maintained over the life of the plant and are contained in Table 3.h.1-3 and Table 3.h.1-4 for PBN1 and PBN2, respectively. The quantities apply to all breaks, regardless of size or location. The quantity of qualified coatings shown in Table 3.h.5-1 through Table 3.h.5-4 are from the respective worst-case insulation breaks described in the Response to 3.a. The volume values in these tables were calculated using the densities presented in Table 3.h.1-1 and Table 3.h.1-2.

Table 3.h.5-1: PBN1 Qualified Coatings Debris for the Worst-Case Cal-Sil DEGB and 17" Breaks

Break Location	**RC-34-MRCL-BI-03**		**RC-36-MRCL-AIII-01A**	
Location Description	Loop B Hot Leg at SG Nozzle		Loop A Cold Leg at RCP	
Break Size	31"		17"	
Break Type	DEGB		Partial (Angle - 0°)	
Dimetcote 6 (IOZ)	101.3 lbm	0.34 ft^3	0.00 lbm	0.00 ft^3
Amercoat 66 (Epoxy)	49.19 lbm	0.51 ft^3	0.00 lbm	0.00 ft^3
Carboline 195 (Epoxy)	37.05 lbm	0.34 ft^3	9.94 lbm	0.09 ft^3
Phenoline 305 (Epoxy)	6.28 lbm	0.06 ft^3	1.69 lbm	0.02 ft^3

Table 3.h.5-2: PBN1 Qualified Coatings Debris for the Worst-Case Fiber Fines DEGB and 17" Breaks

Break Location	**RC-36-MRCL-BII-01**		**RC-34-MRCL-BI-03**	
Location Description	Loop B Crossover Leg at SG Nozzle		Loop B Hot Leg at SG Nozzle	
Break Size	31"		17"	
Break Type	DEGB		Partial (Angle - 135°)	
Dimetcote 6 (IOZ)	87.61 lbm	0.29 ft^3	11.01 lbm	0.04 ft^3
Amercoat 66 (Epoxy)	42.53 lbm	0.44 ft^3	5.35 lbm	0.06 ft^3
Carboline 195 (Epoxy)	50.76 lbm	0.47 ft^3	0.02 lbm	0.00 ft^3
Phenoline 305 (Epoxy)	8.61 lbm	0.08 ft^3	0.00 lbm	0.00 ft^3

Table 3.h.5-3: PBN2 Qualified Coatings Debris for the Worst-Case Cal-Sil DEGB and 17" Breaks

Break Location	RC-34-MRCL-AI-03		RC-34-MRCL-AI-03	
Location Description	Loop A Hot Leg at Elbow		Loop A Hot Leg at Elbow	
Break Size	29"		17"	
Break Type	DEGB		Partial (Angle - 90°)	
Dimetcote 6 (IOZ)	122.87 lbm	0.41 ft^3	28.65 lbm	0.10 ft^3
Amercoat 66 (Epoxy)	59.65 lbm	0.61 ft^3	13.91 lbm	0.14 ft^3
Carboline 195 (Epoxy)	67.10 lbm	0.62 ft^3	13.61 lbm	0.12 ft^3
Phenoline 305 (Epoxy)	9.34 lbm	0.09 ft^3	1.89 lbm	0.02 ft^3

Table 3.h.5-4: PBN2 Qualified Coatings Debris for the Worst-Case Fiber Fines DEGB and 17" Breaks

Break Location	RC-36-MRCL-BII-01A		RC-34-MRCL-BI-03	
Location Description	Loop B Crossover Leg at SG Nozzle		Loop B Hot Leg at Elbow	
Break Size	31"		17"	
Break Type	DEGB		Partial (Angle - 0°)	
Dimetcote 6 (IOZ)	148.49 lbm	0.49 ft^3	24.07 lbm	0.08 ft^3
Amercoat 66 (Epoxy)	72.09 lbm	0.74 ft^3	11.69 lbm	0.12 ft^3
Carboline 195 (Epoxy)	81.53 lbm	0.75 ft^3	6.01 lbm	0.06 ft^3
Phenoline 305 (Epoxy)	11.34 lbm	0.11 ft^3	0.84 lbm	0.01 ft^3

6. *Describe what debris characteristics were assumed, i.e., chips, particulate, size, distribution and provide bases for the assumptions.*

Response to 3.h.6:

In accordance with the guidance provided in NEI 04-07 (Reference 7, pp. 3-12 through 3-13) and the associated NRC SE (Reference 6 p. 22), the qualified coatings debris within the ZOI and the unqualified coatings were treated as 10 micron particulate. See the Responses to 3.h.1, 3.h.2, and 3.h.3 for additional debris characteristics description. A portion of the failed ADQ coatings were treated as chips. The table below shows the size distribution applied to the ADQ coatings.

Note that the flat large chips and curled chips were not included in the head loss testing because they have been shown not to transport (see the Response to 3.f.4).

Table 3.h.6-1: ADQ Coatings Size Distribution

Size Designation	Size Range (inch)	Percentage of Total Mass
Fines (particles)	0.006	12.38%
Flat Fine Chips	0.015	37.13%
Flat Small Chips	0.125-0.5	9.43%
Flat Large Chips	0.5-2.0	20.53%
Curled Chips	0.5-2.0	20.53%

7. *Describe any ongoing containment coating conditions assessment program.*

Response to 3.h.7:

PBN performs coatings assessments in containment on a refueling interval frequency to ensure the total inventory of coatings debris remains bounded by the design basis for the sump screens. The coatings assessments are controlled by procedure under the PBN protective coatings program. The assessment procedure conforms to the intent of ASTM (Reference 22, Enclosure 1, pg. 28-29).

The coating assessment procedure requires a general visual inspection of all accessible surface areas inside containment, with thorough inspections performed as needed in areas exhibiting degradation including such conditions as flaking, blistering, delamination, cracking, checking, pinholes, rust, or damaged or abraded areas. Coating assessment walkdowns are performed by at least two qualified individuals, including the coating program owner and a quality control inspector. The qualifications of these individuals meet the intent of EPRI and ASTM. The general visual inspection involves comparison of the as-found condition to the previously documented condition, and documenting changes or new conditions that are observed. Where new or further degradation of coatings is noted, a more thorough inspection may be performed to better define the extent and cause of degradation.

Inspections may involve several different techniques including visual inspection, non-destructive tests for dry film thickness, destructive tests for adhesion, and destructive sampling for subsequent chemical analysis. Supplemental inspections and tests are performed in accordance with current industry guidance. Where nonconforming conditions are noted that have not been previously evaluated, or where the condition has further degraded as compared to previous results, the corrective action program is used to identify and evaluate the condition.

The general condition of the containment coatings is summarized in a report, which is issued following each refueling outage. The most recently issued report for each unit contains the log of the total surface area and volume of all unqualified and degraded coatings within the containment, as of the end of the most recent refueling outage. The report also contains a computation of the current operating margin as compared to the volumes of coating debris used in the design and testing of the containment sump strainers.

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 2004-02 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 Coating Deficiencies and Foreign Material in Containment," to the extent that their responses address these specific foreign material control issues.*

In responding to GL2004-02 Requested Information Item 2(f), provide the following:

1. *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.*

Response to 3.i.1:

PBN has implemented a number of actions to enhance containment cleanliness as documented in the response to Bulletin 2003-01. Detailed containment cleanliness procedures exist for unit restart readiness and for containment entry at power. These procedures incorporate the guidance of Nuclear Energy Institute (NEI) 02-01 to minimize miscellaneous debris sources within the containment and ensure the operational readiness of the sump strainers. At the end of each outage, a thorough inspection of containment is performed to ensure the containment is free of loose debris and fibrous material, remove items not approved for storage in containment, and ensure the containment sump strainers and strainer piping can perform their design function.

Additionally, these procedures also satisfy Technical Specification Surveillance 3.5.2.6, "*Verify by visual inspection that the suction inlet to the containment sump is* *not restricted by debris and that the debris strainers show no evidence of structural distress or abnormal corrosion.* Lastly, the maintenance director is in charge of maintaining the general housekeeping of containment, which includes tracking the overall cleanliness of containment and promptly correcting identified deficiencies.

2. *A summary of the foreign material exclusion programmatic controls in place to control the introduction of foreign material into the containment.*

Response to 3.i.2:

Foreign material exclusion programmatic controls are in place at PBN that consider the containment a plant system. This ensures that proper work control is specified for debris-generating activities within containment to prevent introduction of foreign material into containment that could challenge the containment recirculation function. Additionally, the foreign material exclusion program requires that engineering be consulted anytime foreign material covers are placed on or modifications are performed on the containment sump strainers. Note that the foreign material exclusion controls are applicable in Modes 1-4 only. However, the close-out inspection discussed in Response to 3.i.1 is required prior to leaving Mode 5, which works in concert with the foreign material exclusion controls to limit foreign material in containment.

3. *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.*

Response to 3.i.3:

NextEra engineering change processes and procedures ensure modifications that may affect the ECCS, including sump performance, are evaluated for GL 2004-02 compliance. During engineering change preparation, the process requires specific critical attributes be listed, evaluated and documented when affected. This includes the introduction of materials into containment that could affect sump performance or lead to equipment degradation (e.g., GSI-191), including insulation, coated equipment and components, and exposed aluminum. It also includes repair, replacement, or installation of coatings inside of primary containment.

NextEra adopted the industry's standard design change process, including the industry procedure IP-ENG-001 (Reference 23). The standard process and tools are intended to facilitate sharing of information, solutions and design changes throughout the industry. This process requires activities that affect UFSAR described structure, system, or component (SSC) design functions to be evaluated as a design change in accordance with PBN's 10 CFR 50 Appendix B program. This includes modifications that would impact the containment sump. Design changes require a final impact review meeting (i.e., final design workshop) and assessment in accordance with 10 CFR 50.59. Additional meetings may be required based on complexity and risk of the change. A failure modes and effects analysis is required if the design change introduces any new failure modes or changes failure modes for the affected SSCs.

This guidance has been enhanced by an engineering specification that brings together, in one document, the insulation design documents that determine the design basis for the insulation debris component of the containment recirculation strainer design. This specification provides guidance for evaluating and maintaining piping and component insulation configuration within the containment buildings at PBN1 and PBN2.

4. *A description of how maintenance activities including associated temporary changes are assessed and managed in accordance with the Maintenance Rule, 10 CFR 50.65.*

Response to 3.i.4:

Temporary configuration changes are controlled by plant procedure. This process maintains configuration control for non-permanent changes to plant structures, systems, and components while ensuring the applicable technical reviews and administrative reviews and approvals are obtained. If, during power operation conditions, the temporary alteration associated with maintenance is expected to be in effect for greater than 90 days, the temporary alteration is screened, and if necessary, evaluated under 10 CFR 50.59 prior to implementation.

In accordance with 10 CFR 50.65 (Maintenance Rule), an assessment of risk resulting from the performance of maintenance activities is required. Prior to performing maintenance activities (including but not limited to surveillance, post-maintenance testing, and corrective and preventive maintenance), the licensee assesses and manages the increase in risk that may result from the proposed maintenance activities. The scope of the assessment may be limited to those SSCs that a risk-informed evaluation process has shown to be significant to public health and safety. In general, the risk assessment ensures that the maintenance activity will not adversely impact a dedicated/protected train. The dedicated/protected train ensures a system is capable to perform its intended safety function. PBN implements the requirement via procedures.

5. *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.*

   a. *Recent or planned insulation change-outs in the containment which will reduce the debris burden at the sump strainers.*

      Response to 3.i.5.a:

      At PBN, insulation modifications included replacing the mineral wool on the pressurizer from each unit with RMI, replacing the fibrous insulation on both RCPs in PBN1 with RMI, and replacing the fibrous insulation on one of the two RCPs in PBN2 with RMI. Note that the fibrous insulation on the other PBN2 RCP is planned to be replaced with RMI as well. Additionally, the fibrous insulation on the PBN2 main RCS loop piping has been replaced with RMI.

   b. *Any actions taken to modify existing insulation (e.g., jacketing or banding) to reduce the debris burden at the sump strainer.*

      Response to 3.i.5.b:

      There were no additional actions taken (e.g., jacketing or banding) to reduce the debris burden at the sump strainer.

   c. *Modifications to equipment or systems conducted to reduce the debris burden at the sump strainers.*

      Response to 3.i.5.c:

      Debris interceptors were installed in the PBN1 containment. Specific credit was not taken for the reduction of problematic debris transport to the strainer (e.g., fiber fines, particulate fines). In reality, these debris interceptors would likely reduce the potential transport of the debris sources.

   d. *Actions taken to modify or improve the containment coatings program.*

      Response to 3.i.5.d:

      Significant quantities of degraded or unqualified coatings have been remediated by removal, replacement, or qualification by a combination of testing and analysis. Containment coatings are discussed in greater detail in the Response to 3.h.

j. Screen Modification Package

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

1. *Provide a description of the major features of the sump screen design modification.*

Response to 3.j.1:

The intent of the modification was to perform the hardware changes required to bring PBN into conformance with GSI-191 by replacing the original small area screens with screens having a substantially increased surface area.

Original Screens

The original PBN ECCS screens consisted of a single vertical cylindrical screen for each train of ECCS. The screens were fabricated from stainless steel with 1/8" diameter perforations. The screens were each 13.5" in diameter, and 71" tall for each train of ECCS, and were completely enclosed in a single, larger trash rack fabricated from ½" thick stainless steel. 1" wide vertical slots were cut in the surface of the trash rack to admit sump water while excluding larger debris. There were approximately 256 slots that were 6" tall, and approximately 32 slots that were 5" tall. The solid top of the rack served to close off the top of the screens and prevent debris intrusion should the screens become totally submerged (Reference 22, Enclosure 1, pg. 30).

The effective area of each of the original screens was approximately 21 square feet per train if fully submerged. At the time that sump recirculation would have been initiated, the screens would have been only partially submerged with a minimum of ~38" in the sump. The effective area would have then been approximately 11 square feet per train (Reference 22, Enclosure 1, pg. 30).

Replacement Screens

The modification installed a passive, safety-related Sure-Flow® Strainer assembly, engineered and manufactured by Performance Contracting Incorporated (PCI). Originally, each strainer train at PBN1 and PBN2 consisted of 11 strainer modules connected to the respective train's sump outlet pipe. The installations were performed during the spring 2006 and 2007 refueling outages. An additional 3 modules were added to each train in the Fall 2008 and Fall 2009 outages.

Figure 3.j.1-1 and Figure 3.j.1-2 show the general arrangement of the strainer installation at each unit. The effective surface area of each replacement strainer train is 1,904.6 ft^2, more than a 90-fold increase over the area of the original screens if the screens would have been fully submerged. The replacement screens are designed to draw a flow rate of 2,200 gpm evenly across the entire active surface (Reference 22, Enclosure 1, pg. 30), reducing the screen approach velocity to just

0.0026 fps. The replacement strainers would be fully submerged by the time that sump recirculation initiates.

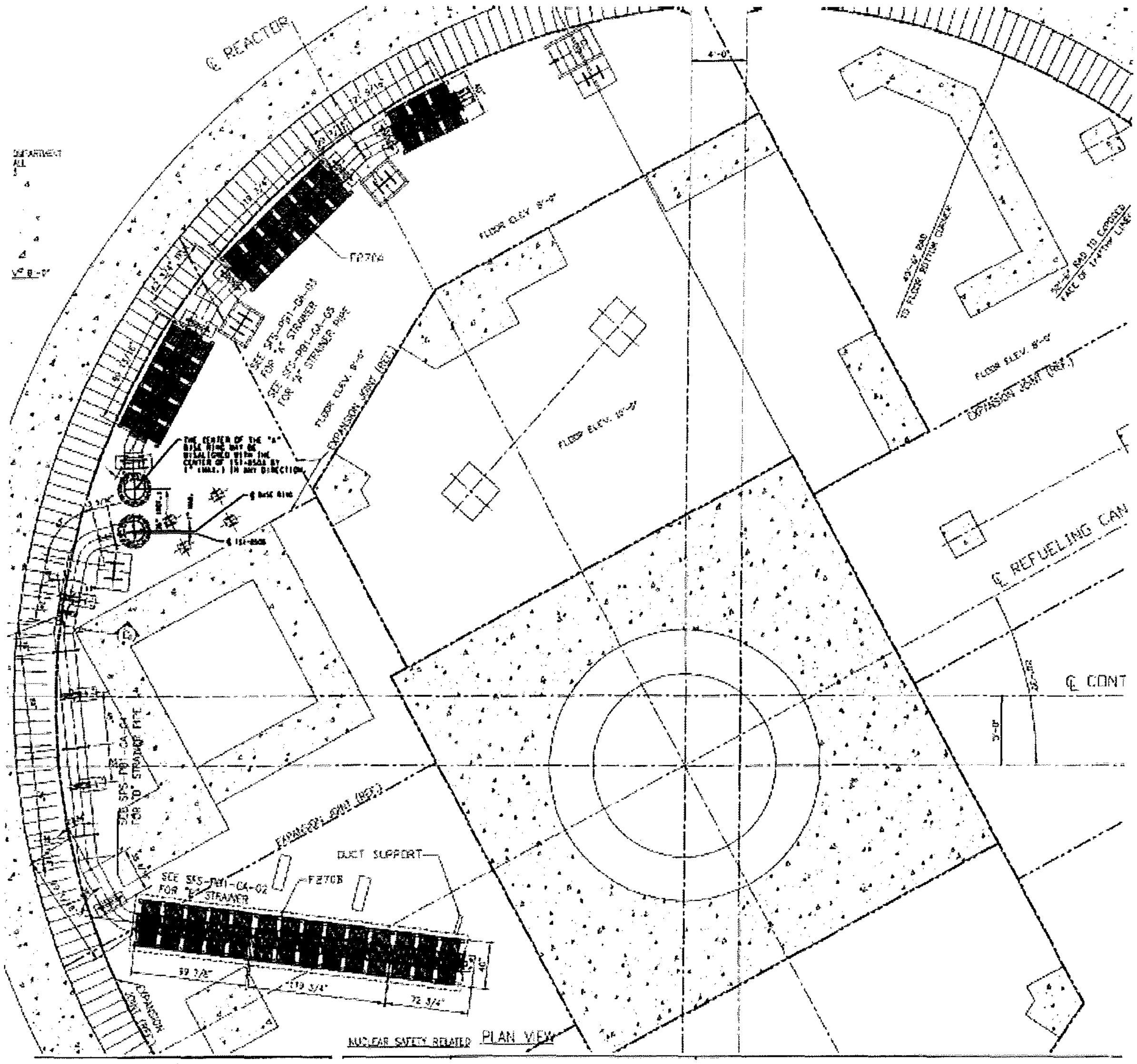


Figure 3.j.1-1: PBN1 ECCS Strainer General Arrangement

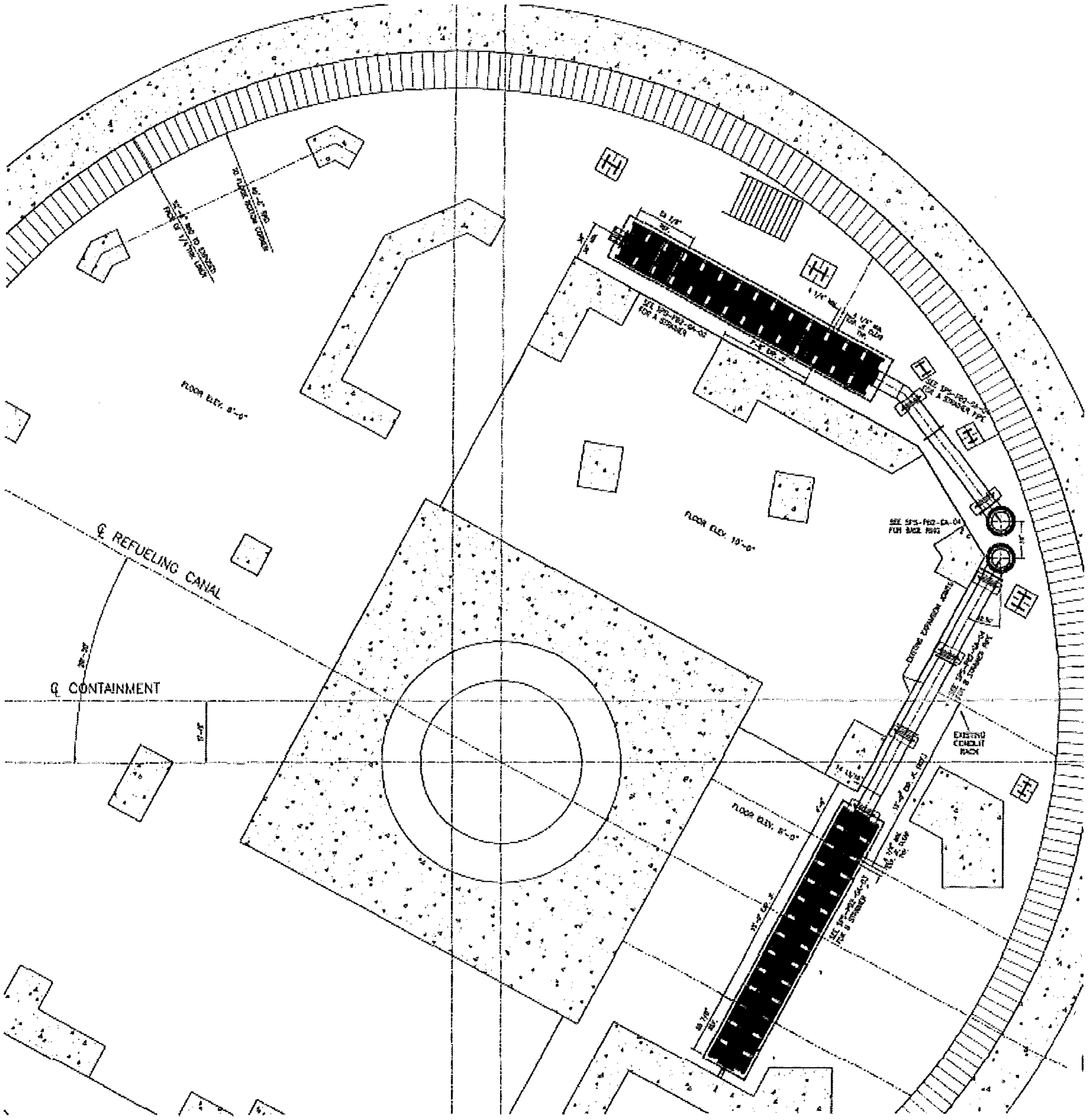


Figure 3.j.1-2: PBN2 ECCS Strainer General Arrangement

The 14 modules in each strainer train consist of a core tube and mounting tracks. The modules are nearly identical with the only difference being the flow control hole sizes in the core tube. Each module is independently supported by pinned connections to a mounting track. The modules are connected with thin gauge stainless steel bands that are used to prevent debris from entering the system between adjacent modules. The bands are secured with a seismic latch. This connection permits relative motion in the axial direction as the core tube can slide relative to the stainless steel bands, and accommodates disassembly for inspection, repair, replacement, or installation of additional modules to extend the assemblies, or "strings," of strainer modules (Reference 22, Enclosure 1, pg. 31).

Figure 3.j.1-3 shows the replacement strainer module. Each module is made of stainless steel perforated sheet with a nominal hole diameter of 0.066". The perforated sheets are riveted together along the outside edge and fitted to the core tube along the inner edges. Because of the convoluted configuration, and internal and external cross bracing, the modules are inherently rugged and do not require an external trash rack to provide protection from larger debris or incidental damage. The bottom active strainer surfaces on the modules are located approximately 3" above the containment floor (Reference 22, Enclosure 1, pg. 31).

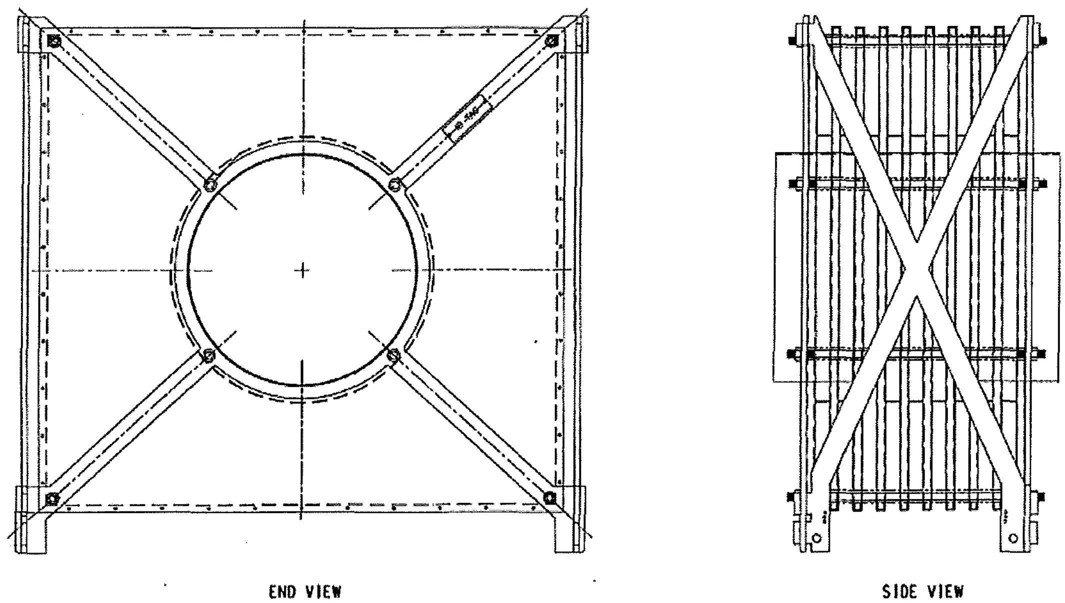


Figure 3.j.1-3: Replacement Strainer Modules (Reference 22, Enclosure 3)

Figure 3.j.1-4 shows the typical strainer installation at PBN. The mounting tracks are secured to the containment floor by anchor bolts. The strainer module strings are connected to the containment outlets by 16" diameter stainless steel piping anchored and supported against the same loading conditions (Reference 22, Enclosure 1, pg. 31).

At the point that the 16" diameter piping turns downward to connect to the containment outlets, the piping transitions to an 18" diameter elbow. The large diameter elbow maximizes the annular flow area between the existing sump outlet valve disk and the elbow wall. The slower velocity also serves to minimize the frictional head loss through this transition into the piping (Reference 22, Enclosure 1, pg. 31).

The strainer core tubes were fabricated from 16" stainless steel pipe. The core tubes have variable sized "windows" cut in the walls to admit flow of strained water from the inside of the perforated strainer sheets. The windows are sized to ensure an even distribution of flow through the entire strainer surface. This provides maximum assurance of even debris loading, while minimizing total head loss and potential for air entrainment (Reference 22, Enclosure 1, pg. 31).

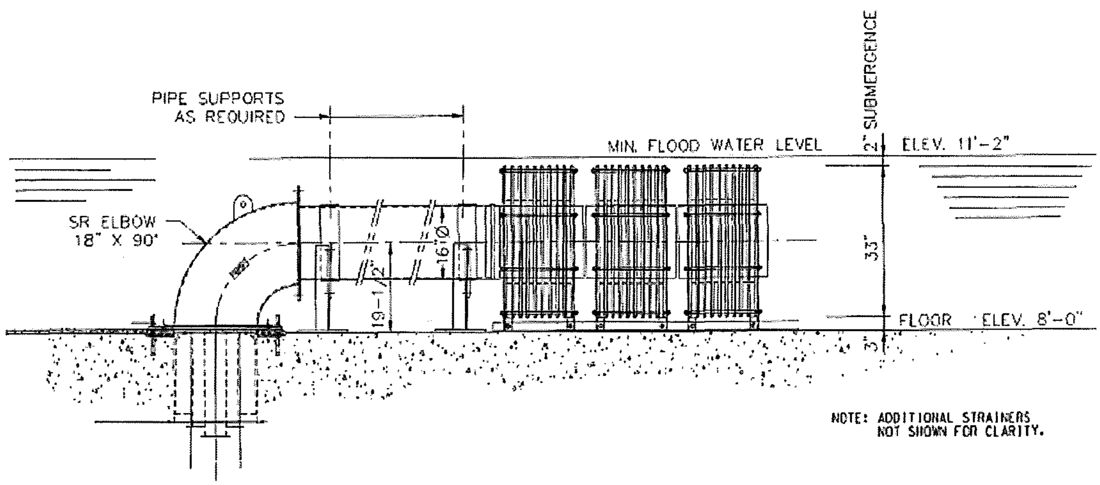


Figure 3.j.1-4: Replacement Strainer Typical Install (Reference 22, Enclosure 3)

2. *Provide a list of any modifications, such as reroute of piping and other components, relocation of supports, addition of whip restraints and missile shields, etc., necessitated by the sump strainer modifications.*

Response to 3.j.2:

There were no plant modifications that were necessitated by the sump strainer modifications.

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 GL2004-02 Requested Information Item 2(d)(vii).

> *GL 2004-02 Requested Information 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.*

1. *Summarize the design inputs, design codes, loads, and load combinations utilized for the sump strainer structural analysis.*

Response to 3.k.1:

Strainer Modules

In PBN1 and PBN2, the containment recirculation sumps and debris interceptors provide filtered suction intake for the RHR pumps. Each strainer assembly is a passive unit (i.e., there are no active components). The strainer assemblies are considered safety related. (See the Response to 3.j for additional description.)

There are two independent strainers at each unit. Each strainer consists of 14 modules. The modules are connected with stainless steel bands that are used to prevent debris from entering the system between adjacent modules. The bands are secured with a seismic latch. This connection permits relative motion in the axial direction as the core tube can slide relative to the stainless steel bands. Each module is made of stainless steel perforated sheet. The perforated sheets are riveted together along the outside edge and fitted to the core tube along the inner edges. The strainer core tubes and extension sleeve are fabricated from 16 inch diameter stainless steel pipe. The end cover is made of solid stainless steel plate.

The loads on the strainer are comprised of weight, pressure, and dynamic loads. The dynamic loads come from two sources, seismic inertia and hydrodynamic drag loads due to sloshing. The strainers are loaded due to the inertia effect from the motion of the containment floor during an earthquake. Hydrodynamic loads on the strainer are due to the motion of the water surrounding the strainer during a seismic event. The weight loads include the weight of the strainer components themselves, and the weight of the debris that accumulates on the strainer. The weight of debris per strainer module is taken as 100 lb per module. The normal operating pressure load is simply the pressure drop across a clean strainer. There are no thermal expansion loads since the strainers are free to expand without restraint. The piping is not rigidly attached to the strainer modules. Therefore, the piping is also free to expand without imposing any thermal loads on the strainers.

Sump Strainer Structural Analysis

The Sump strainers were qualified using a combination of manual calculations generated in Mathcad, as well as finite element analyses using the GTSTRUDL software and the ANSYS software. The strainer frame and assembly was qualified using GTSTRUDL while the perforated strainer plates were qualified using ANSYS.

Applicable Strainer Codes

The detailed evaluations were performed using the rules, as applicable, of ANSI/ASME B31.1 Power Piping 1998 Edition through 1999 Addenda. The use of the ASME Boiler and Pressure Vessel Code is primarily for the qualification of pressure retaining parts of the strainer which are not covered in B31.1 (perforated plate, and internal wire stiffeners). Some parts of the strainers (radial stiffeners, connecting rods, edge channels, seismic stiffeners, etc.) are classified as part of the support structure. These types of components are covered under the AISC 9th Edition. ANSI/AISC N690-1994,"Specification for the Design, Fabrication, and Erection of Steel Safety Related Structures for Nuclear Facilities" was used to supplement the AISC in any areas related specifically to the structural qualification of stainless steel. The strainer also has several components made from thin gage sheet steel, and cold formed stainless sheet steel. Therefore, SEI/ASCE 8-02, "Specification for the Design of Cold-Formed Stainless Steel Structural Members", was used for certain components where rules specific to thin gage and cold form stainless steel should be applicable. The rules for Allowable Stress Design (ASD) as specified in Appendix D of this code were used. This was further supplemented by the AISI Code where the ASCE Code is lacking specific guidance. Finally, guidance was also taken from AWS D1.6, "Structural Welding Code - Stainless Steel" as it relates to the qualification of stainless steel welds. The analysis of the anchorage to the containment concrete slab was in accordance with the Hilti technical Guide.

Load Combinations for the Strainer

The applicable load combinations for the strainers are:

Table 3.k.1-1: Load Combinations for the Strainer

Load Condition	Combination
(1a) Normal Operating	DP + DW
(1b) Normal Operating (Outage/Lift Load)	DW + LL
(2) Upset	DP + DW + WD + OBE
(3) Emergency/Faulted	DP + DW + WD + SSE

Where,
DW= Dead Weight Load
LL= Live Load (additional loads on strainers during outages or during installation, live load is not applicable during operation)
WD= Weight of Debris
DP= Differential Pressure
OBE= Operating Basis Earthquake
SSE=Safe Shutdown Earthquake

Note that combination (3) was classified as Emergency Condition for all ASME Code evaluations and Faulted for all components governed by AISC and ACI Codes. Also note that wind, snow, tornado, and jet force loads are not applicable. Flood loads are considered for Load Combinations 2 and 3. Flood loads consist of the effects due to an earthquake in a submerged condition (sloshing and added mass). There are no hydrostatic pressure loads associated with flooding since the flood waters are present on all sides. Thermal expansion stresses were considered negligible.

Core tube Combinations

The core tube was evaluated as piping per B31.1 Paragraph 104.8 as applicable. Since the B31.1 does not explicitly identify how to incorporate the Emergency SSE loads, PBN used ASME Section III as a guide as discussed in site-specific design requirements.

Table 3.k.1-2: Load Combinations for the Core Tube

B31.1 Eq. No	Load Condition	Load Combination	Allowable Stress
	Normal	DW	1.0 S_h
12 (OBE)	Upset	DW + OBE	1.2 S_h
12 (SSE)	Emergency	DW + SSE	1.8 S_h

Strainer Pressure Retaining Plates Combinations

For the pressure retaining plates, such as the perforated plate and the core tube end cover stiffener plate, the B31.1 Code does not provide any design guidelines as discussed above. For the perforated plate, the equations from Appendix A, Article A-8000 of the ASME B&PV Code, Section III, 1998 Edition through 1999 Addenda was used to calculate the stresses. Note that Article A-8000 refers to Subsection NB for allowable stresses, which are defined in terms of stress intensity limits, S_m. However, in keeping with the B31.1 maximum principal stress design philosophy, principal stresses were calculated and compared to the allowables based on the ASME allowable stress limit, S.

Stress limits for the pressure retaining plates were taken from ASME Section III, subsection NC-3321.

Table 3.k.1-3: Load Combinations for the Pressure Retaining Plates

Load Condition	Stress Type	Allowable Stress	Design Level
Normal/Upset*	Primary Membrane Stress	1.0 Sh	Level A
	Primary Membrane (or Local) +Bending	1.5 Sh	
Emergency	Primary Membrane Stress	1.5 Sh	Level C
	Primary Membrane (or Local) +Bending	1.8 Sh	

* Allowable stresses for Upset condition may be increased by 10% as permitted by NC-3321 (Reference 24)

Strainer Structural Components Combinations

Based on the discussion provided earlier in this section, the allowable stresses on the strainer structural components was based on the AISC 9th Edition. The allowable stress for the SSE Load Combinations was taken from site specific design requirements.

Table 3.k.1-4: Load Combinations for the Strainer Structural Components

Load Condition	Load Combination	Allowable Stress
Normal Operating	1a, 1b	1.0 AISC
Upset	2	1.0 AISC
Faulted	3	1.5 AISC but not to exceed 0.9 Sy

Debris Interceptors (Perforated Flow Diverters)

Like the strainers, the debris interceptors are passive units and intended as pre-filters to the strainers. There are three types designated as A, B, and C. Type A and B debris interceptors consist of structural steel beams supporting grating and a steel perforated plate. Type A interceptors are located on the containment floor at El. 8' while Type B interceptors are located in the windows of the steam generator cubicles at El. 10'. Type C interceptors are 6" high curbs made from stainless steel plate, which is bent into a circular shape and attached to the concrete floor at El. 66'.

Debris Interceptors Structural Analysis

Type A debris interceptors were designed using manual and GTSTRUDL calculations. Type B and C debris interceptors were designed using manual calculations where required for design.

Applicable Debris Interceptor Codes

The detailed evaluations were performed using the rules, as applicable, under the AISC 9th Edition Code and ANSI/AISC N690-1994 Specification.

Table 3.k.1-5: Load Combinations for the Debris Interceptors

1. DL + LL1 + OBE
2. DL + LL2 + OBE
3. DL + LL1 + SSE (Conservative)
4. DL + LL2 + SSE (Conservative)

Where:

DL= Dead load
LL1= Initial differential head across the debris interceptors
LL2= High water level differential head across the debris interceptors

Connecting Piping and Supports

Each sump strainer has two 16-inch diameter pipes that exit the "A" and "B" strainer trains and anchor into the floor. Each section of pipe (the pipe run between the strainer and floor) is connected via flanged sections of pipe up to the strainer assembly.

Piping and Pipe Support Analysis

Mathcad was used to perform the manual calculations for the supports and various other associated piping calculations. AutoPIPE was used for the piping analysis.

Load Combinations for Piping

The piping was evaluated in accordance with ANSI/ASME B31.1 Power Piping 1998 Edition. The Piping supports, baseplates other mounting hardware was evaluated to AISC 9th Edition as permitted in Paragraph 120.2.4 of the B31.1 Code. Additional guidance was also taken from ANSI/AISC N690-1994, SEI/ASCE 8-02 and AWS D1.6 to supplement the AISC in any areas related to the structural qualification of stainless steel. Since the B31.1 does not explicitly identify how to incorporate the emergency SSE loads, PBN used ASME Section III as a guide, as discussed in Section 6.0 of DG-M09.

Table 3.k.1-6: Load Combinations for Piping

B31.1 Eq. No	Load Condition	Load Combination	Allowable Stress
11	Normal	DP + DW	1.0 S_h
12 (OBE)	Upset	DP + DW + OBE	1.2 S_h
12 (SSE)	Emergency	DP + DW + SSE	1.8 S_h
13	Thermal	T1	1.0 S_A

Where,

DW= Dead Weight Load
DP= Differential Pressure
OBE= Operating Basis Earthquake
SSE= Safe Shutdown Earthquake
T1= Thermal Expansion

The thermal expansion stresses were based on a stress range from the ambient condition of 70 °F to the maximum operating condition of 250 °F (ΔT=180 °F) .

Piping Support Structural Components Load Combinations

The allowable stresses on the piping support components were based on the AISC 9th Edition. Also, the allowable stresses for the sump sole plate tabs, bolts, and welds were based on the AISC 9th Edition. The allowable stress for the SSE Load Combinations was taken from Section 6.9 of DG M10.

Table 3.k.1-7: Load Combinations for the Piping Support Structural Components

Load Condition	Load Combination	Allowable Stress
Normal	DW + T1	1.0 AISC
Upset	DW + OBE + T1	1.0 AISC
Faulted	DW + SSE + T1	1.5 AISC but not to exceed 0.9 S_y

2. *Summarize the structural qualification results and design margins for the various components of the sump strainer structural assembly.*

Response to 3.k.2:

The structural margin of the strainer components were calculated using GTSTRUDL structural analysis software.

Strainer Modules for Units 1 & 2

As documented below, the interaction ratio of each subcomponent is less than 1, and therefore is acceptable.

Table 3.k.2-1: Interaction Ratio for the Strainer Modules (Units 1 and 2)

Strainer Component	Calculated	Allowable	Governing load case	Interaction Ratio
External Radial Stiffener (Including Debris Stops)	10.60 ksi (flexure) (1)	21.24 ksi (1)	SSE	0.95
Tension (Connecting) Rods	11.20 ksi (axial) (1) (2)	17.00 ksi (1)	SSE	0.94
Edge Channels (max)	5.29 ksi (flexure) (1)	14.16 ksi (1)	SSE	0.80
Seismic Stiffeners (including Support legs)	3.24 ksi (flexure) (1)	17.70 ksi (1)	OBE	0.92 (3)
Spacers	4.97 ksi (axial) (1)	12.95 ksi (1)	OBE	0.54
Core Tube (Biggest Holes)	0.69 ksi	20.64 ksi	OBE	0.03
Perforated Plate (DP Case)	24.48 ksi	25.80 ksi	OBE	0.95
Perforated Plate (Seismic Case)	10.78 ksi	30.96 ksi	SSE	0.35
Perforated Plate (Edge Channels)	3.82 ksi	25.80 ksi	OBE	0.14
Perforated Plate (Inner Gap)	11.54 ksi	25.80 ksi	OBE	0.45
Wire Stiffener	33.75 ksi	48.75 ksi	OPR	0.69
Perforated Plate (Core Tube End Cap DP Case)	6.88 ksi	14.16 ksi	OBE	0.49
Perforated Plate (Core Tube End Cap Seismic Case)	433 lb (shear) 1329 lb (tension)	2853 lb (shear) 2351 lb (tension)	SSE	0.72
Radial Stiffening Spokes of the End Cover Stiffener	1105 lb/in	3540 lb/in	OBE	0.31

Strainer Component	**Calculated**	**Allowable**	**Governing load case**	**Interaction Ratio**
Circumferential Rings of the End Cover Stiffener	17.591 ksi	21.24 ksi	SSE	0.82
End Cover Sleeve	215 lb (shear) 1329 lb (tension)	2853 lb (shear) 2351 lb (tension)	SSE	0.64
Welds of End Cover	6846 lb/in	7965 lb/in	SSE	0.86
Weld of Radial Stiffener to Core Tube	4.46 ksi	9.46 ksi	SSE	0.47
Weld of Radial Stiffener to Seismic Stiffener	1.34 ksi	2.65 ksi	OBE	0.51
Edge Channel Rivets	95.75 lb	782 lb	OBE	0.13
Inner Gap Hoop Rivets	75 lb	782lb	OBE	0.09
Mounting Pins	2.36 ksi	12.26 ksi	SSE	0.19
Clevis Hitch Pins	8.05 ksi	12.26 ksi	SSE	0.66
Angle Iron Tracks	18.54 ksi	21.24 ksi	SSE	0.87
Expansion Anchors to Floor	1850 lb (tension) 834 lb (shear)	2381 lb (tension) 4294 lb (shear)	SSE	0.97
Angle Iron-to-Angle Iron Track Weld	1.0 ksi	3.98 ksi	SSE	0.25
Module-to-module Sleeve	3.96 ksi	21.24 ksi	SSE	0.19
Module-to-module Latch Connection	812 lb	987 lb	SSE	0.82
Lift Case	3.82 ksi (flexure) (1)	14.16 ksi (1)	LIFT	0.26
Outage Case	2.42 ksi (flexure) (1)	14.16 ksi (1)	Outage	0.19

Notes:
(1) Calculated and allowable values were calculated for the most governing stress components (i.e., axial, flexure, etc.) per AISC manual 9th Edition;
(2) The 10% over-torque effect was not included in the calculated value;
(3) Interaction ratio was calculated based on the slenderness ratio, not by the strength.

Connecting Piping and Supports for Unit 1

As documented below, the interaction ratio of each subcomponent is less than or equal to 1, and therefore is acceptable.

Table 3.k.2-2: Interaction Ratio for the Connecting Piping and Supports (Unit 1)

Component	Calculated	Allowable	Governing Load Case	Interaction Ratio
B Strainer Pipe	2.813 ksi	20.64 ksi	SSE	0.14
Flanges				
Flange Bolting (At Sole Plate)	1.738 in^2	2.27 in^2	SSE	0.77
Flange Bending (At Sole Plate)	16.34 ksi	17.20 ksi	OBE	0.95
Flange Weld to Pipe	2.31 ksi	9.46 ksi	SSE	0.24
Missing Bolts				
Flange Bolts	0.133 in^2	0.14 in^2	SSE	0.93
Flange Bending	17.20 ksi	17.20 ksi	SSE	1.00
Sole Plate Connection				
Sole Plate	4.82 ksi	17.70 ksi	LLRT Testing	0.27
Sole Plate Expansion Anchors	2322 lb (tension) 156 lb (shear)	3133 lb (tension) 1546 lb (shear)	LLRT Testing	0.84
Type PS1/PS2 Restraint				
Angle Normal Stress	15.721 ksi (flexure) 0.522 ksi (axial)	21.24 ksi (flexure) 8.06 ksi (axial)	SSE	0.80
Angle Shear Stress	1.484 ksi	11.80 ksi	SSE	0.13
Expansion Anchors (Type PS1)	1583 lb (tension) 209 lb (shear)	2160 lb (tension) 4157 lb (shear)	SSE	0.78
Expansion Anchors (Type PS2)	1860 lb (tension) 225 lb (shear)	2344 lb (tension) 2614 lb (shear)	SSE	0.87
Baseplate	15.045 ksi	17.70 ksi	SSE	0.85
Weld of Angle to Baseplate	2352 lb/in	3977 lb/in	OBE	0.59

Component	Calculated	Allowable	Governing Load Case	Interaction Ratio
Saddle Plate Bending	2.91 ksi	21.24 ksi	SSE	0.14
Saddle Plate Shear	8.685 ksi	11.80 ksi	SSE	0.74
Saddle Plate Welds	81 lb/in	497 lb/in	OBE	0.16
Saddle Plate Pins	5.58 ksi	18.73 ksi	SSE	0.30
Shear Lugs	0.928 ksi	11.80 ksi	SSE	0.08
Integral Welded Attachments	6.045 ksi	20.64 ksi	OBE	0.29
Type PS3 Restraint				
W6x15 Normal Stress	2.798 ksi 0.180 ksi	9.814 ksi 14.16 ksi	OBE	0.22
W6x15 Shear Stress	0.683 ksi	9.44 ksi	SSE	0.07
Expansion Anchors	1063 lb (tension) 235 lb (shear)	2632 lb (tension) 2604 lb (shear)	SSE	0.49
Baseplate	7.795 ksi	17.70 ksi	SSE	0.44
Weld of W6x15 to Baseplate	393 lb /in	3977 lb/in	SSE	0.10
Angle Normal Stress	11.871 ksi	15.58 ksi	SSE	0.76
Angle Shear Stress	2.155 ksi	9.40 ksi	SSE	0.23
Weld of Angle to W6x15	1329 lb/in	2983 lb/in	SSE	0.45
U-Bolt Normal Load	3.651 ksi	12.90 ksi	SSE	0.28
Type PB1 Restraint				
Stanchion Plate Bolts	1.574 ksi	18.73 ksi	SSE	0.08
Integral Welded Attachments	2.37 ksi	20.64 ksi	OBE	0.11
Other Pipe Components				
Slip Joint	313 lb	438 lb	OBE	0.71

Connecting Piping and Supports for Unit 2

As documented below, the interaction ratio of each subcomponent is less than 1, and therefore is acceptable.

Table 3.k.2-3: Interaction Ratio for the Connecting Piping and Supports (Unit 2)

Component	Calculated	Allowable	Governing Load Case	Interaction Ratio
A Strainer Pipe	1.152 ksi	17.20 ksi	NORM	0.07
B Strainer Pipe	1.434 ksi	20.64 ksi	OBE	0.07
Flanges				

Component	Calculated	Allowable	Governing Load Case	Interaction Ratio
Flange Bolting (At Sole Plate)	1.734 in^2	2.18 in^2	SSE	0.79
Flange Bending (At Sole Plate)	15.308 ksi	17.20 ksi	SSE	0.89
Flange Weld to Pipe (In-line Flanges)	3.85 ksi	9.46 ksi	SSE	0.41
Missing Bolts				
Flange Bolts	0.134 in^2	0.136 in^2	SSE	0.98
Flange Bending	16.33 ksi	17.20 ksi	SSE	0.95
Sole Plate Connection				
Sole Plate	4.82 ksi	17.70 ksi	LLRT Testing	0.27
Sole Plate Expansion Anchors	2322 lb (tension) 203 lb (shear)	3133 lb (tension) 1381 lb (shear)	LLRT Testing	0.89
Pipe Supports				
Angle Normal Stress	7.7 ksi (flexure) 0.689 ksi (axial)	21.24 ksi (flexure) 8.804 ksi (axial)	SSE	0.45
Angle Shear Stress	0.565 ksi	11.80 ksi	SSE	0.05
Expansion Anchors	1614 lb (tension) 118 lb (shear)	1850 lb (tension) 2209 lb (shear)	SSE	0.93
Baseplate	12.397 ksi	21.24 ksi	SSE	0.58
Weld of Angle to Baseplate	891 lb/in	2983 lb/in	OBE	0.30
Saddle Plate Bending	2.442 ksi	21.24 ksi	SSE	0.11
Saddle Plate Shear	0.802 ksi	11.80 ksi	SSE	0.07
Saddle Plate Welds	156 lb/in	497 lb/in	OBE	0.31
Saddle Plate Pins	6.293 ksi	18.73 ksi	SSE	0.34

Debris Interceptors

As documented below, the interaction ratio of each subcomponent is less than 1, and therefore is acceptable.

Table 3.k.2-4: Interaction Ratio for the Debris Interceptors

Component	Type	Calculated	Allowable	Interaction Ratio
Debris Interceptor Panel	A	78.12 lb ft/ft	344 lb ft/ft	0.23
Member A 5x5x3/8 bent plate (EL. 9'-0")	A1	5.83 ksi	14.16 ksi	0.41
Member B 4x4x1/4 bent plate (El. 10'-7")	A1	8.16 ksi	14.16 ksi	0.58
Member C 4x4x1/4 bent plate (El. 11'-0")	A1	10.59 ksi	14.16 ksi	0.75
Member D 6x3x1/4 bent plate (El. 14'-4")	A1	11.93 ksi	14.16 ksi	0.84
Member E 3x3x1/4 bent plate (El. 10'-7")	A1	4.24 ksi	14.16 ksi	0.29
Member F 5 1/4x3x1/4 bent plate (El. 11'-0")	A1	2.4 ksi	14.16 ksi	0.16
Flashing Plates (35A, 35B and 35C)	A1	0.722 ksi	17.7 ksi	0.04
Framing Members (GTSTRUDL)	A2	0.9783	1.2	0.82
Anchor Bolts (1/2" dia. HKB3)	A2	1172 lb (Tension) 646 lb (Shear)	1964 lb (Tension) 2907 lb (Shear)	0.82
A193 Bolts (shear)	A2	7.62 ksi	16.41 ksi	0.46
A193 Bolts (tension)	A2	3.68 ksi	34.38 ksi	0.12
F879 Type 302HQ, CW Machine screws (shear)	A2	2.79 ksi	6.85 ksi	0.41
F879 Type 302HQ, CW Machine screws (tension)	A2	0.91 ksi	14.35 ksi	0.07
Weld (member to member)	A2	349.8 lb/in	1770 lb/in	0.20
Weld (member to embedded plate)	A2	1314 lb/in	1770 lb/in	0.74
Member A 4x4x3/8 bent plate (EL. 8'-6")	A3	3.51 ksi	14.16 ksi	0.25
Member B 4x4x1/4 bent plate (El. 10'-7")	A3	3.09 ksi	14.16 ksi	0.22
Member C 4x4x1/4 bent plate (El. 11'-0")	A3	6.32 ksi	14.16 ksi	0.45
Member D L3x3x3/8 (El. 14'-4")	A3	3.43 ksi	14.16 ksi	0.24
Member E 3x3x1/4 bent plate (El. 10'-7")	A3	2.14 ksi	14.16 ksi	0.15

Component	**Type**	**Calculated**	**Allowable**	**Interaction Ratio**
Member F 5 1/4x3x1/4 bent plate (El. 11'-0")	A3	1.21 ksi	14.16 ksi	0.09
Framing Members (GTSTRUDL)	A4	0.6104	1.2	0.51
Anchor Bolts (1/2" dia. HKB3)	A4	1058 lb (Tension) 511 lb (Shear)	1954 lb (Tension) 2907 lb (Shear)	0.72
A193 Bolts (shear)	A4	7.26 ksi	16.41 ksi	0.44
A193 Bolts (tension)	A4	1.469s ksi	30.83 ksi	0.05
F879 Type 302HQ, CW Machine screws (shear)	A4	5.41 ksi	6.85 ksi	0.79
F879 Type 302HQ, CW Machine screws (tension)	A4	0.69 ksi	14.35 ksi	0.08
Weld (member to embedded plate)	A4	1513 lb/in	1770 lb/in	0.85
Debris Interceptor Panel	B	125.63 lb*ft/ft	343.75 lb*ft/ft	0.37
Support Beams (W6x9) OBE	B	2335 psi (bending - y) 12345 psi (bending - x)	17.7 ksi (bending -y) 15.576 ksi (bending - x)	0.92
Support Beams (W6x9) SSE	B	2420 psi (bending - y) 12913 psi (bending - x)	21.24 ksi (bending - y) 21.24 ksi (bending - x)	0.77
Beam Splice Connection	B	18977 psi	21.24 ksi	0.89
F879 Type 302HQ, CW Machine screws (shear)	B	871 lb	3408 lb	0.26
Flange Splice Weld	B	7.07 in	11.25 in	0.63
Anchor Bolts (1/2" dia. HKB3)	B	661 lb (Tension) 661 lb (Shear)	1359 lb (Tension) 1987 lb (Shear)	0.82
Angle 4x4x3/8 OBE	B	15112 psi	17700 psi	0.85
Angle 4x4x3/8 SSE	B	17033 psi	21240 psi	0.80
Curb Plate (11 GA)	C	17013 psi	17700 psi	0.96
Support Angle (L6x6x1/4)	C	1298 psi	17700 psi	0.07
Anchor Bolts (1/4" dia. HKB3)	C	20.23 lb (Shear) 17.4 lb (Tension)	633 lb (Shear) 660 lb (Tension)	0.06

3. *Summarize the evaluations performed for dynamic effects such as pipe whip, jet impingement, and missile impacts associated with high-energy line breaks (as applicable).*

Response to 3.k.3:

Containment sump recirculation is used when makeup to the RCS is required, and other sources are not available or are of such small volume as to be insufficient. The license and design bases of PBN only credit containment sump recirculation following a LOCA (Reference 22, Enclosure 1, pg. 34). Since sump recirculation is not credited following other potential high energy line breaks (HELBs) such as feedwater or main steam line breaks, the potential dynamic effects of a HELB were not evaluated for the replacement strainers.

In Safety Evaluations dated June 6, 2005, (Reference 25) November 7, 2000, (Reference 26) (and supplemented on February 7, 2005, (Reference 27)), December 15, 2000, (Reference 28) (also supplemented on February 7, 2005), and December 18, 2000, (Reference 29) the NRC reviewed and accepted analyses demonstrating that a rapidly propagating failure of the large bore RCS piping components at PBN is highly unlikely (leak before break analyses). These analyses included the RCS primary loop piping, SI accumulator discharge lines to the RCS, the pressurizer surge line, and the high pressure RHR piping connections to the RCS. As such, consideration of missile impacts or other dynamic effects of a LOCA per 10 CFR 50 General Design Criterion 4 (Plant specific GDC 40) are no longer part of the design bases for PBN.

The replacement screens have been located outside of the thick walled reactor coolant loop compartments and are away from openings in the walls to the extent practicable. The strainers are also inherently robust, owing to the tough and relatively thick material used for the strainer active surfaces (18 gauge stainless steel), the internal reinforcements to prevent deformation under the design differential pressure, the convoluted form that precludes large, unbroken diaphragm surfaces, and the external bracing for seismic loading. As such, they are unlikely to tear or be perforated by incidental impacts from debris or rebounding missiles, tending rather to deform or dent. The strainers in each unit are routed away from each other such that no single missile would be capable of impacting both strainers.

4. *If a backflushing strategy is credited, provide a summary statement regarding the sump strainer structural analysis considering reverse flow.*

Response to 3.k.4:

Back flushing of the sump strainers is not credited in the PBN analysis; therefore, no structural analysis considering reverse flow was performed. If the backflushing strategy proposed in the alternate evaluation methodology is adopted, then a reverse flow analysis will be performed to demonstrate structural adequacy of the strainer assembly.

I. Upstream Effects

The objective of 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 2004-02 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.*

1. *Summarize the evaluation of the flowpaths from the postulated break locations and containment spray washdown to identify potential choke points in the flow field upstream of the sump.*

Response to 3.I.1:

The following areas / items were considered as part of the evaluation to determine potential choke points for flow upstream of the sump:

- Refueling Canal
- Steam Generators
- Annulus in Lower Containment
- Reactor Cavity (reactor cavity breaks only)
- Containment Spray Washdown

Refueling Canal

The refueling canal at both PBN1 and PBN2 is drained by one 4-inch pipe that exits the refueling canal at the floor of the canal.

The entrance to the drain at each unit is covered by a strainer that has two hundred 1-inch diameter holes and sits over the cavity outlet. Figure 3.I.1-1 shows the construction of the refueling canal drain strainer. The strainer consists of a vertical cylinder with a 10" nominal diameter and two horizontal cylinders with a 6" nominal diameter.

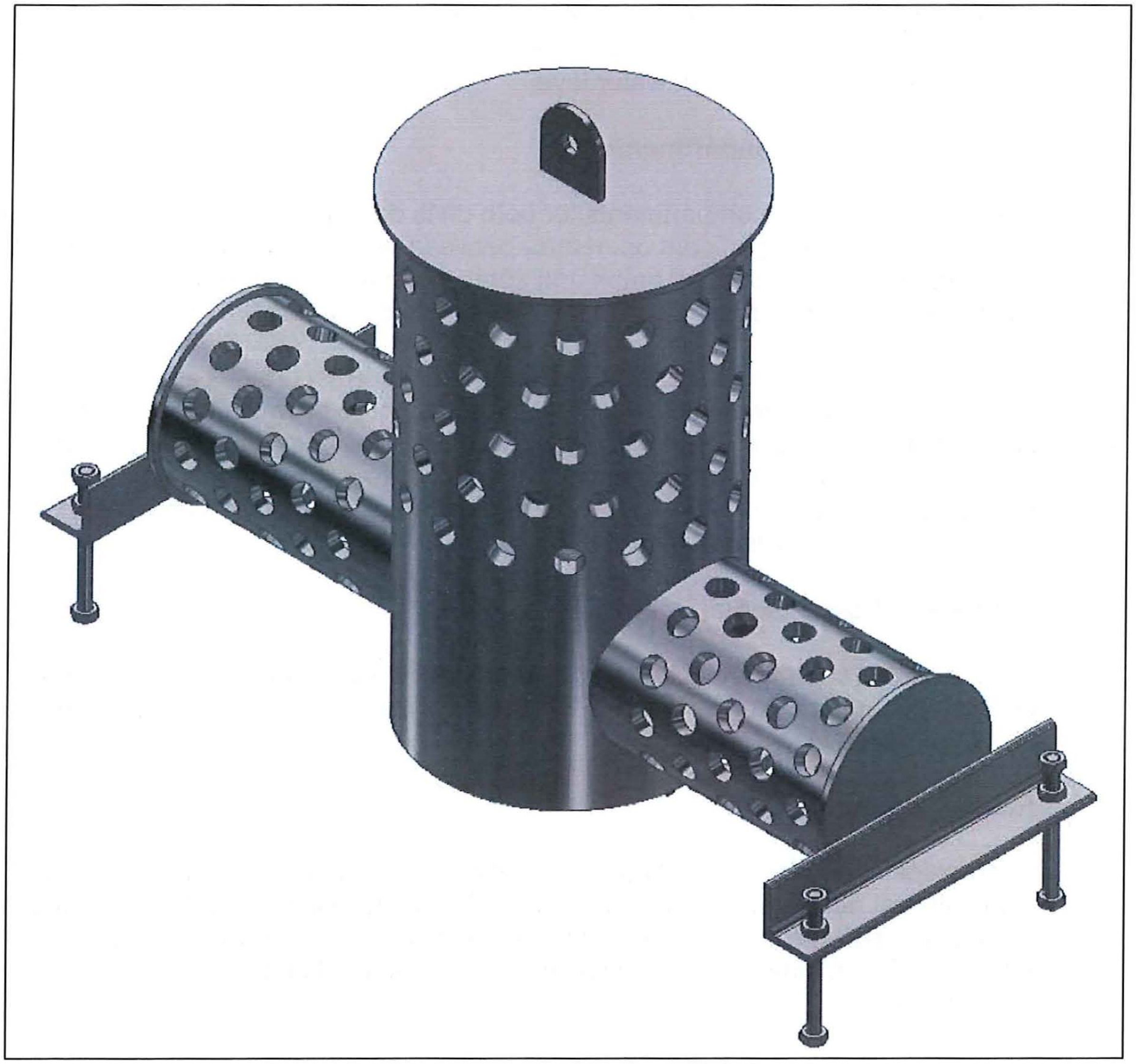


Figure 3.I.1-1: Refueling Canal Strainer

Any sprays falling directly in the refueling canal must flow through the refueling canal drain. It is possible that some debris could accumulate on and around the strainer over the drain. An evaluation was performed that verified water will flow freely through the refueling canal drain and the drain screen would not become obstructed with debris. Further supporting this evaluation is the refueling canal drain blockage testing that was performed for Turkey Point Nuclear Plant. This testing not only tested the refueling cavity drains to determine if they would become blocked by post-accident debris, but also tested the behavior of the debris that was assumed to be blown into the refueling canal as a result of the LOCA. This portion of the testing demonstrated that it requires containment spray flow rates significantly greater than the expected flow rates to cause debris to move of a size that would challenge the ability of the PBN refueling canal drain strainer to provide the assumed flow out of the refueling canal. Even if debris built up around the bottom of the strainer, there would still be sufficient flow area to meet containment water volume analysis assumptions for containment water level.

Steam Generator Compartments

The steam generator compartments for both units do not have a significant amount of grating and have significant open area between potential break locations and the containment floor. Therefore, break and spray water in the steam generator compartments would drain down to the containment pool with limited obstruction.

At the base of each steam generator compartment in PBN1, there are five passageways that communicate with the annulus, three of which have debris interceptors installed. If debris were to block these passageways, water would simply flow out of the steam generator compartments into the annulus through the two open passageways where debris interceptors are not installed (see the Response to 3.l.3 for more information).

Annulus in Lower Containment

In the annulus compartment in lower containment in each unit, the containment geometry is not compartmentalized. Therefore, there are no potential upstream blockage points in the annulus.

Reactor Cavity

For breaks in the reactor cavity (at the reactor vessel nozzles), the reactor cavity would fill first before the recirculation sump. A modification was performed that bored a 16" diameter hole in each unit to allow the two sumps to communicate with each other, which eliminates the potential chokepoint and hold up of water for reactor cavity breaks.

Containment Spray Washdown

Containment spray washdown has a clear path to the containment sump area. Large sections of the floor on each level in containment are covered with grating, and there are unobstructed stairways that allow the water to pass.

A complete evaluation of the containment CAD model, along with a review of the CFD model, indicated no significant areas that would become blocked with debris and hold up water during the sump recirculation phase.

2. *Summarize measures taken to mitigate potential choke points.*

Response to 3.l.2:

There have been several modifications at PBN1 and PBN2 to mitigate potential choke points. The installation of the refueling canal drain strainer was completed prior to Generic Letter 2004-02. In PBN1, two debris interceptors have been removed from the annulus at the 8' Elevation to mitigate potential upstream blockage points in the annulus. A 16" diameter hole was bored through the walls of the incore wall in each unit to allow communication between the reactor cavity and the recirculation sump for reactor cavity breaks.

3. *Summarize the evaluation of water holdup at installed curbs and/or debris interceptors.*

Response to 3.I.3:

Debris interceptors were installed for PBN1 only. These debris interceptors are comprised of stainless steel bar grating with attached stainless steel perforated plate on one side (16 gage ASTM A240, Type 304 stainless steel with ¼" diameter holes, approximately 58% open area). The bar grating consists of 1" x 1/8" bearing bars, spaced 1-3/16" center to center, and cross bars spaced 4" center to center. If debris were to block these passageways, water will simply flow out of the steam generator compartments into the annulus through the two open passageways where debris interceptors are not installed.

Holdup was evaluated in the pressurizer cubicle. There are twelve vent holes located in the pressurizer bottom skirt, whose centerline lies 2'-3/8" above the pressurizer cubicle's floor elevation. The amount of hold-up in the pressurizer compartment is 313 ft^3.

4. *Describe how potential blockage of reactor cavity and refueling cavity drains has been evaluated, including likelihood of blockage and amount of expected holdup.*

Response to 3.I.4:

As discussed in the Response to 3.I.1, the entrance to the refueling canal drains at each unit is covered by a strainer that has 200 1-inch diameter holes and sits over the cavity outlet. Any sprays falling directly in the refueling canal will flow through the refueling canal drain. In the evaluation of the drain strainer, it was assumed that some blockage of the lower holes will occur resulting in a ponded volume of water that is held up. The calculated amount of holdup volume is 438 gallons.

m. Downstream Effects – Components and Systems

The objective of the downstream effects, components and systems section is to evaluate the effect 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 2004-02 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.

> *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 the 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.*

1. *If NRC-approved methods were used (e.g., WCAP-16406-P-A with accompanying NRC SE), briefly summarize the application of the methods. Indicate where the approved methods were not used or where exceptions were taken, and summarize the evaluation of those areas.*

Response to 3.m.1:

PBN developed a calculation to address ex-vessel (i.e., component and systems) downstream effects. The calculation was developed in accordance with PWROG WCAP-16406-P-A, Revision 1. The limitations and conditions provided in the NRC SER were addressed as part of the evaluations and it was shown that the WCAP-16406-P-A methodology was appropriate for use at PBN.

The following methodology was employed in the ex-vessel downstream effects evaluation. The evaluation did not use any unapproved methods or take any exceptions to NRC-approved methods.

Maximum Debris Ingestion Determination

Blockage and wear of the ECCS and CSS components and piping in the post-LOCA recirculation flowpaths downstream of the sump screen were addressed within the downstream effects evaluations. The adequacy of the sump screens' mesh spacing or strainer hole size (nominal hole diameter of 0.066 inches as described in the Response to 3.j.1) was conservatively addressed by assuming that the maximum amount of particulate debris transports to the strainers and passes through the strainers. Additionally, the evaluation used a quantity of fiber debris that passes through the strainers (100 g/FA), which is greater than the actual plant value of 46 g/FA, evaluated from the large scale fiber penetration testing data. The ex-vessel downstream effects evaluations were based on this maximum amount of ingested debris (see Initial Debris Concentrations below).

Initial Debris Concentrations

Initial debris concentrations were developed using the assumptions and methodology described in Chapter 5 of WCAP-16406-P-A. Additionally, for conservatism, the maximum amounts of fiber and particulate debris transported to the strainer were assumed to pass through the strainer. The total maximum initial debris concentration was determined to be 1,991.9 ppm, with fiber debris contributing 22.5 ppm, and particulate and coating debris contributing 1,969.4 ppm (1,991.9 ppm – 22.5 ppm).

Flowpaths and Alignment Review

Both trains of the ECCS and CSS were reviewed to ensure that all of the flowpaths and components impacted by the debris passing through the sump screens were considered. Documents used for this effort included piping and instrumentation diagrams (P&IDs) and other plant design documents as applicable.

Component Blockage and Wear Evaluations Methodology

All component evaluations were performed based on WCAP-16406-P-A. Components addressed in the evaluations include pumps, heat exchangers, orifices, spray nozzles, instrumentation tubing, system piping, and valves required for the post-LOCA recirculation mode of operation of the ECCS and CSS. The evaluations included the following steps:

- Identifying all components in the ECCS and CSS flowpaths (see Flowpaths and Alignment Review above).
- Applying the appropriate wear models for pumps. Pumps experience erosive wear and abrasive wear due to debris ingestion. Two abrasive wear models were developed in WCAP-16406-P-A including a free flowing abrasive wear model and the Archard abrasive wear model. Each model was used as appropriate in the evaluations.
- Applying the appropriate erosive wear model for heat exchangers, orifices, spray nozzles, system piping, and valves.
- Evaluating the potential for plugging of heat exchanger tubes, orifices, spray nozzles, system piping, and valves by comparing the maximum debris size

expected to be ingested through the sump screen to the clearances within the components.
- Evaluating the potential for debris sedimentation for system piping, heat exchanger tubes, and valves that move or reposition post-LOCA (and must go fully closed) by comparing line velocity to minimum line velocity required to avoid sedimentation (line velocity greater than 0.42 ft/s) .
- Evaluating the potential for debris collection in the instrument sensing lines.

2. *Provide a summary and conclusions of downstream evaluations.*

Response to 3.m.2:

The following is the summary of results and conclusions of the downstream effects evaluations:

ECCS/CSS Pumps

The evaluation for pumps addressed the effects of debris ingestion through the sump screen on three aspects of operability (hydraulic performance, mechanical-shaft seal assembly performance, and mechanical performance). The hydraulic and mechanical performances of the ECCS and CSS pumps were determined to not be negatively affected by the recirculating sump debris. Based on the mechanical shaft seal assembly evaluation, the performance of the RHR and SI pump mechanical shaft seals were determined to be satisfactory with regard to the debris laden fluid following the postulated LOCA for the mission time of 30 days. The mission time of the CSS pumps is 6 hours. The performance of the CSS pump mechanical shaft seals were determined to be satisfactory during this mission time as well.

ECCS/CSS Valves

WCAP-16406-P-A provides the criteria for wear and plugging analysis for ECCS and CSS valves due to debris laden fluid.

Table 3.m.2-1 and Table 3.m.2-2 contain a summary of the criteria that would necessitate an evaluation. The valves that do not meet these criteria are not critically impacted by wear and plugging due to debris laden fluid.

Table 3.m.2-1: Valve Evaluation Blockage Criteria

Valve Type	Size (inches)	Position During the Event
Gate	≤ 1	Open
Globe	≤ 1-1/2	Open
Globe	> 1 (Cage Guide)	Open
Check Valves/ Stop Check	≤ 1	Open
Butterfly	< 4	Throttled < 20°
Globe Valves	All	Throttled
Hermetically Sealed Valves	All	Open

Table 3.m.2-2: Valve Evaluation Erosive Criteria

Valve Type	Size (inches)	Position During the Event
Globe	All	Throttled
Butterfly	All	Throttled

Note that if a valve is intended to be throttled during accident mitigation, it shall be evaluated for erosive wear regardless of valve type. Based on this criteria, the valve population at PBN was reviewed and the individual valves were classified as "Not Critical" or "Evaluation Required". The valves that were determined to be "Not Critical" did not warrant further evaluation, but those valves identified as "Evaluation Required" received a more detailed evaluation.

Valves were evaluated for blockage in the downstream effects evaluations. It was determined that all valves passed the acceptance criteria for the blockage evaluation.

Valves were evaluated for debris sedimentation. The line velocities for all valves analyzed were found to be greater than 0.42 ft/s; thus, debris sedimentation was not an issue.

Valves were evaluated for erosive wear. The initial debris concentration of 1,991.9 ppm was used to calculate the initial wear rate and was assumed to remain constant for most of the valves. A few valves required that the debris depletion refinement be implemented. The assumed large debris was depleted over time using a depletion coefficient of $\lambda = 0.07$, as recommended by WCAP-16406-P-A. Note that large debris consists of particulates greater than or equal to 100 µm, coatings greater than or equal to 400 µm, and all fibers. The new wear rate was calculated each hour for a total of 720 hours. It was found that the increase in valve flow area due to erosion for all valves that were evaluated is considered negligible. The limiting valves for erosive wear at PBN are the reactor vessel injection gate valves, 1&2-SI-852-A/B. The total wear of 6.76 mil resulted in a maximum change in flow area of 2.75%, which is within the acceptance criteria of 3%.

ECCS/CSS Heat Exchangers, Orifices, Spray Nozzles, and System Piping

Heat exchangers, orifices, spray nozzles, and system piping were evaluated for the effects of erosive wear for an initial concentration of 1,991.9 ppm over the mission time of 30 days. The erosive wear on these components was determined to be insufficient to affect system performance.

The smallest clearance found for PBN heat exchangers, orifices, spray nozzles, and system piping in the ECCS recirculation flow path is 0.375 inches, for the CS Nozzles. The maximum diameter of downstream debris was conservatively assumed to be 0.0726", which is 110% of the sump screen hole size. Therefore, no blockage of the ECCS flow path is expected with the maximum debris diameter of 0.0726 inches.

System piping and heat exchanger tubing was evaluated for plugging based on system flow and material settling velocities. For all piping, the minimum flow velocity was found to be greater than 0.42 ft/s, the minimum velocity required to prevent debris sedimentation. All system piping passed the acceptance criteria for plugging due to sedimentation.

ECCS/CSS Instrumentation Tubing

Instrumentation tubing (or sensing lines) was evaluated for debris settling. According to WCAP-16406-P-A, Section 8.6.6, instrument tubing is designed to remain water solid without taking flow from the process stream. This prevents direct introduction of debris laden fluid into the instrument tubing. Settling of the debris is the only process by which the debris is introduced into the instrument tubing. Since the sensing lines are water solid and stagnant, the introduction of either fibrous or particulate debris by flow into the sensing lines is not possible. The terminal settling velocities of the debris sources in the process streams are small by comparison to the process fluid velocities; therefore, introduction of debris by settling into the instrument tubing is not expected. Furthermore, the plant walkdowns showed that all instrument taps into the process piping are from the horizontal position to the upper half of the piping. This excludes the possibility of debris settling in the subjected instrument tubing. Therefore, blockage and wear of ECCS or CSS instrument tubing due to debris laden fluid are not expected.

3. *Provide a summary of design or operational changes made because of downstream evaluations.*

Response to 3.m.3:

There have been no design or operation changes made because of downstream evaluations.

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 screens and into the reactor vessel has on core cooling.

1. *Show that the in-vessel effects evaluation is consistent with, or bounded by, the industry generic guidance (WCAP-16793-NP), 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 where exceptions were taken, and summarize the evaluation of those areas.

Response to 3.n.1:

In-vessel downstream effects for PBN were evaluated per the methodology in WCAP-16793-NP (Reference 30), the associated NRC SE (Reference 31), WCAP-17788-P, and WCAP-17788-NP (Reference 32). The evaluation included the following:

1. Peak cladding temperature (PCT) due to deposition of debris on fuel rods (WCAP-16793-NP).
2. Deposition thickness (DT) due to collection of debris on fuel rods (WCAP-16793-NP).
3. Amount of fiber accumulation at reactor core inlet and inside reactor vessel (WCAP-17788-P).

These analyses concluded that post-accident long-term core cooling (LTCC) will not be challenged by deposition of debris on the fuel rods, accumulation of debris at the core inlet, or accumulation of debris in the heated region of the core for all postulated LOCAs inside containment. A brief summary of the relevant testing and analyses is provided below as it was used to inform the WCAP evaluations.

PBN Fiber Penetration Testing

PBN conducted fiber penetration testing for both units in 2014. Because of the similarity of the PBN1 and PBN2 strainers, penetration testing for both units was conducted in a single testing program.

The purpose of the PBN testing was to collect time-dependent fiber penetration data for the plant strainer. Three large-scale tests were conducted with test parameters selected to be representative of the most conservative conditions (temperature, debris quantity and composition, and water chemistry). The test results were used to derive a model to quantify fiber penetration for the PBN strainer at plant conditions.

<u>Test Loop Design</u>

The test loop included an acrylic test tank, which housed a test strainer at its downstream end, and various piping and flow components. Water was circulated by a pump through the test strainer, a fiber filtering system, and other loop components (see Figure 3.n.1-1). The fiber filtering system consisted of two parallel in-line filter bag housings, which allowed for one filter bag to be online at all times even during swap of filter housings. The bypass line around the filter bags was isolated for the duration of the test. Downstream of the filter bags, a heat exchanger and control valves allowed for the loop temperature to be controlled. Likewise, the flow elements downstream of the heat exchanger provided the necessary information to allow the pump frequency to be manipulated to achieve the desired flow rates. Recirculating test water flowed into the test tank through the mixing lines and the debris hopper line. One mixing line was placed at the downstream end of the test tank behind the strainer to prevent debris settling, while the remaining mixing lines and debris introduction line were at the upstream end of the tank.

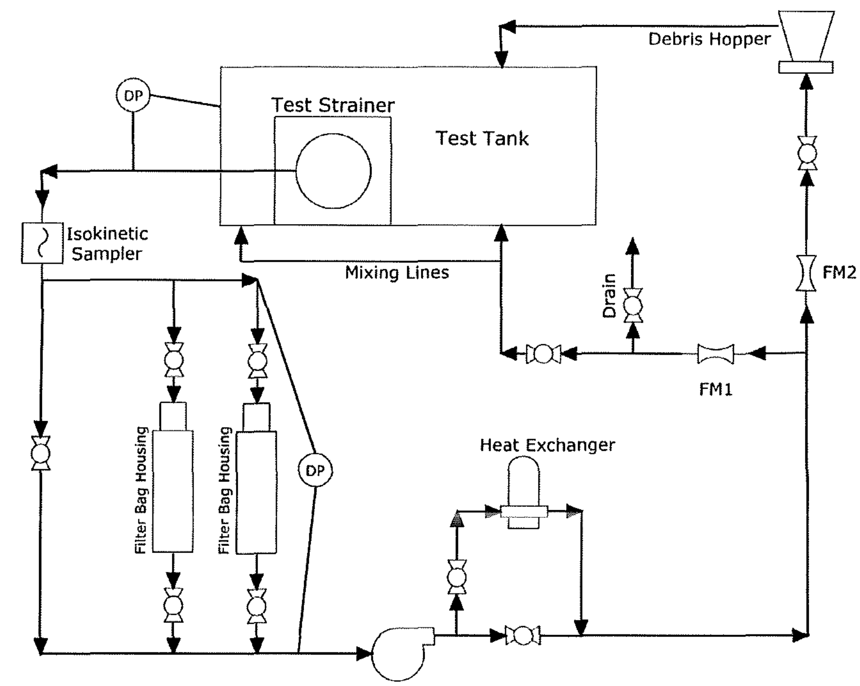


Figure 3.n.1-1: Penetration Test Loop P&ID

The test tank had a rectangular geometry, as shown in Figure 3.n.1-2 below. Debris was introduced in the high-agitation region located at the upstream end of the test tank. This region was equipped with two hydraulic mixing lines to create adequate mixing and prevent the debris from settling. This mixing motion kept fiber in suspension without disturbing the fiber bed on the strainer. The strainer region was designed such that the spacing between the test strainer disk faces and adjacent tank walls imitated the module-to-module spacing at the plant. Enough space was left between the strainer and the rear wall to model the open space on both sides of the strainer modules along the length of most strainer assemblies at PBN 1 and PBN 2.

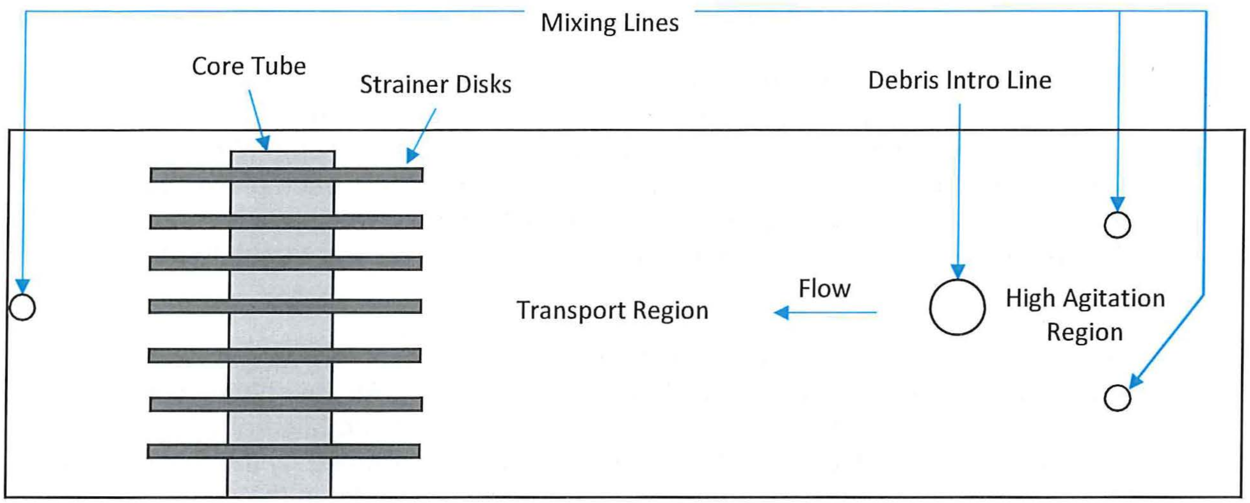


Figure 3.n.1-2 General Arrangement of Test Tank (Plan view)

The effectiveness of the agitation region for each of the penetration tests is shown in Table 3.n.1-1, which documents the quantity of fiber that did not transport to the strainer and was collected from the high agitation or transport regions after the conclusion of each test.

Table 3.n.1-1: Summary of Useful Fiber Transport Tests

Test #[1]	Gross Fiber Added (g)	Non-Transported Fiber (g)	Net Fiber Added (g)	% of Fiber Transport
1	12,946	1,068	11,878	91.8%
2	12,946	933	12,012	92.8%
3	5,178	0	5,178	100%

Test Strainer

The test strainer for penetration testing was a prototypical strainer module that matched the key design parameters (i.e., all disks dimensions, including perforated plate thickness, hole diameter, pitch, etc.) of the plant strainer. The test strainer was similar to that used in head loss testing (as described in the Response to 3.f.4) with the only difference that 3 of the 10 disks in a prototypical module were removed. The overall width of the module between the end disks was preserved, and the remaining disks were relocated to evenly fill the gap. Because the strainer modules are flow-controlled, the disk locations along the length of the core tube does not affect the flow distribution among the disks. This modification nearly doubled the gap between adjacent disks to prevent a fiber bridge from forming across adjacent disks. The core tube slots corresponding to the removed disks were covered by gap rings to prevent a path for flow to bypass the remaining perforated disks. This promoted fiber penetration by preserving penetrable strainer area. The total surface area of the test strainer was 95.1 ft^2.

Debris Types and Preparation

Each of the three tests used different debris types, with the percentage of each noted in parentheses: Test 1 included Nukon (40.7%) and Mineral Wool (59.3%); Test 2 included Nukon (28.8%), Mineral Wool (67.7%), and Temp-Mat (3.5%); and Test 3 used only Nukon. Fiber debris types at PBN include each of the tested debris types and low-density fiberglass (LDFG) and latent fiber, which were substituted with Nukon due to similarity in characteristics. Only fiber fines were used in penetration testing.

All fiber fines were prepared according to the NEI protocol following the same procedures used for the head loss tests (Reference 33). All fiber types were heat-treated to simulate aging of fiber from hot pipes. Nukon and Mineral Wool were heat-treated by the debris vendor. Temp-Mat was heat treated by the testing vendor by placing an equal mass of untreated Nukon and Temp-Mat in the oven until the Nukon binder was burnt out. Temp-Mat batches were then created with equal parts heat-treated and non-heat-treated Temp-Mat.

Debris was weighed out into batches and was then pressure-washed with test water following the NEI protocol. For batches with multiple fiber types, each type of fiber was prepared separately. The duration of pressure washing was specific to the fiber type and batch size, and was controlled to achieve a fiber size distribution predominately meeting the Class 2 requirements per NUREG/CR-6224 (Reference 34, Appendix B, Table B-3). Figure 3.n.1-1 shows the prepared debris after pressure washing.

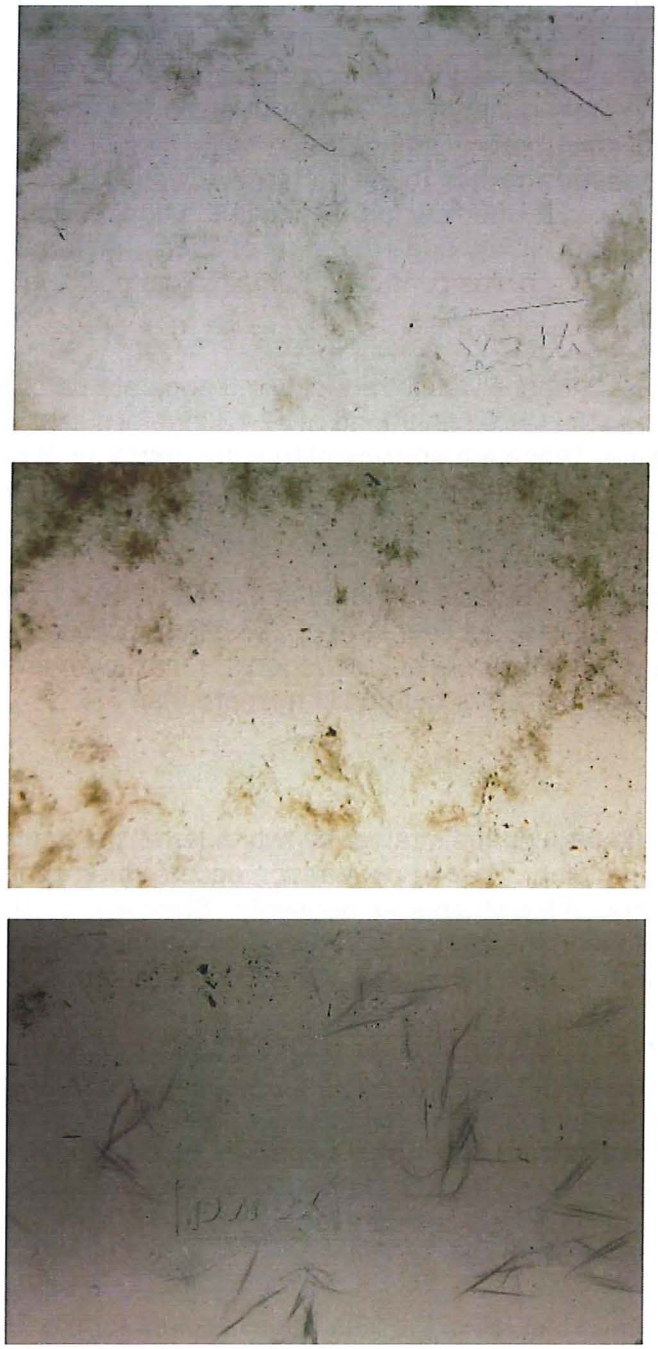


Figure 3.n.1-1: Nukon (Top), Mineral Wool (Center), and Temp-Mat (Bottom) Fines Prepared for PBN Penetration Testing

For batches consisting of multiple fiber types, after each debris type was separately pressure washed, the prepared debris was mixed together in a barrel and stirred to form a homogeneous debris slurry prior to introduction.

Debris Introduction

Fine fiber debris was introduced to the high agitation region of the test tank via the debris hopper. The prepared debris slurry was transferred from the barrel to the hopper using 5 gallon buckets. During this process, the debris slurry was stirred to promote a homogeneous mixture in the barrel. Additionally, the debris transported into the tank was mixed by the flow turbulence in the hopper and the mixing region of the test tank to break up any agglomeration of fibers that formed. For each batch, the debris introduction rate was controlled to maintain a prototypical debris concentration in the test tank.

For Test 1 and Test 2, debris was introduced in 8 separate batches of increasing sizes, resulting in a total tested fiber load of 524.3 lbm for Test 1 and 530.2 lbm for Test 2 at plant scale. These are equivalent to a theoretical uniform bed thickness of 1.5". Each of these tests bounded the maximum total fiber fines debris loads of both units by more than 30%.

For Test 3 (Nukon only), debris was introduced in 5 separate batches of increasing sizes, resulting in a total tested fiber load of 228.5 lbm, equivalent to a theoretical uniform bed thickness of 0.5". Test 3 bounded the maximum fiber fines debris loads of all 23" breaks and smaller for both units by more than 5%.

Debris Capture

Fiber can penetrate through the strainer by two different mechanisms: prompt penetration and shedding. Prompt penetration occurs when fiber reaching the strainer travels through the strainer immediately. Shedding occurs when fiber that already accumulated on the strainer migrates through the bed and ultimately travels through the strainer. Both mechanisms were considered during testing.

Fibers that passed through the strainer were collected by the in-line filters downstream of the test strainer, upstream of the pump. All of the flow downstream of the strainer travelled through the 1-micron filter bags before returning to the test tank. The capture efficiency of the filter bags was verified to be above 98 percent. The filtering system allowed the installation of two sets of filter bags in parallel lines such that one set of filter bags could be left online at all times, even during periods in which filter bags were swapped.

Before and after each test, all of the filter bags required for the test were uniquely marked and dried, and their weights were recorded. The weight gain of the filter bags during testing was used to quantify fiber penetration. After testing, the debris-laden filter bags were rinsed with deionized (DI) water to remove residual chemicals before being dried and weighed. When processing the filter bags, in either clean or debris laden state, the bags were placed in an oven for at least an hour before being cooled and weighed inside a humidity-controlled chamber. This process was repeated for each bag until two consecutive bag weights (taken at least 1 hour apart) were within 0.05 g of each other.

A clean filter bag was placed online before a debris batch was introduced to the test tank, and was left online for a minimum of three pool turnovers (PTOs) to capture the prompt fiber penetration. For batches 1 and 3 and the final batch (batch 8 for Tests 1 and 2, and batch 5 for Test 3), two additional filter bags were used to capture the fiber penetration due to shedding. For each test, the total test duration exceeded the time after event occurrence at which simultaneous cold leg and upper plenum injection takes place. This approach allowed the testing to capture time-dependent fiber penetration data, which was used to develop a model for the rate of fiber penetration as a function of fiber quantity on the strainer. Before each debris addition, the test tank and debris hoppers were visually checked to verify that all introduced debris had transported to the strainer.

Test Parameters

The test water used for fiber penetration testing had a chemical composition prototypical to PBN. The plant condition selected for testing was that of the minimum boron concentration of 0.22 mol/l and the maximum pH of 9.404. This condition was represented in testing with a boron concentration of 0.2 mol/l and a pH of 9.5. This water chemistry corresponds to the maximum pH condition at the plant and was chosen based on small scale testing results which showed that water chemistry was not a significant contributor to penetration quantity. Test water was prepared by adding pre-weighed boron to DI water per the prescribed concentration and then adding sodium hydroxide buffer until the prescribed pH was achieved.

A strainer approach velocity of 0.0027 ft/s was determined from plant operating conditions and used for the PBN fiber penetration testing. This velocity was based on the maximum recirculation flow rate per train through a reduced strainer train surface area (1804.6 ft^2 vs. total strainer surface area of 1904.6 ft^2). Accounting for a reduction in strainer train surface area led to increased approach velocity, which is conservative. It should be noted, on the other hand, that the strainer train area reduction was *not* considered when the penetration test results were scaled to plant scale. Rather, the penetration results were scaled up according to the ratio of the whole strainer train area to the test strainer area. Because the strainer train area reduction was not carried forward into the results scaling, the results are conservative.

Strainer Penetration Model Development

Data gathered from the PBN fiber penetration tests were used to develop a model for quantifying the strainer fiber penetration under plant conditions. The model was developed per the following steps:

- General governing equations were developed to describe both the prompt fiber penetration and shedding through the strainer as a function of time and fiber quantity on the strainer. The equations contain coefficients whose values were determined separately for each test based on the test results.
- The test results were fit to the governing equations using various optimization techniques to refine the coefficient values. This produced a unique set of equations, and thus a unique penetration model for each test. Figure 3.n.1- compares the fiber penetration results of Test 3 (shown as circles) with the fiber penetration quantities determined by applying the Test 3 model to the test conditions (shown as blue solid line). As Figure 3.n.1- shows, the model results adequately represent the test data.

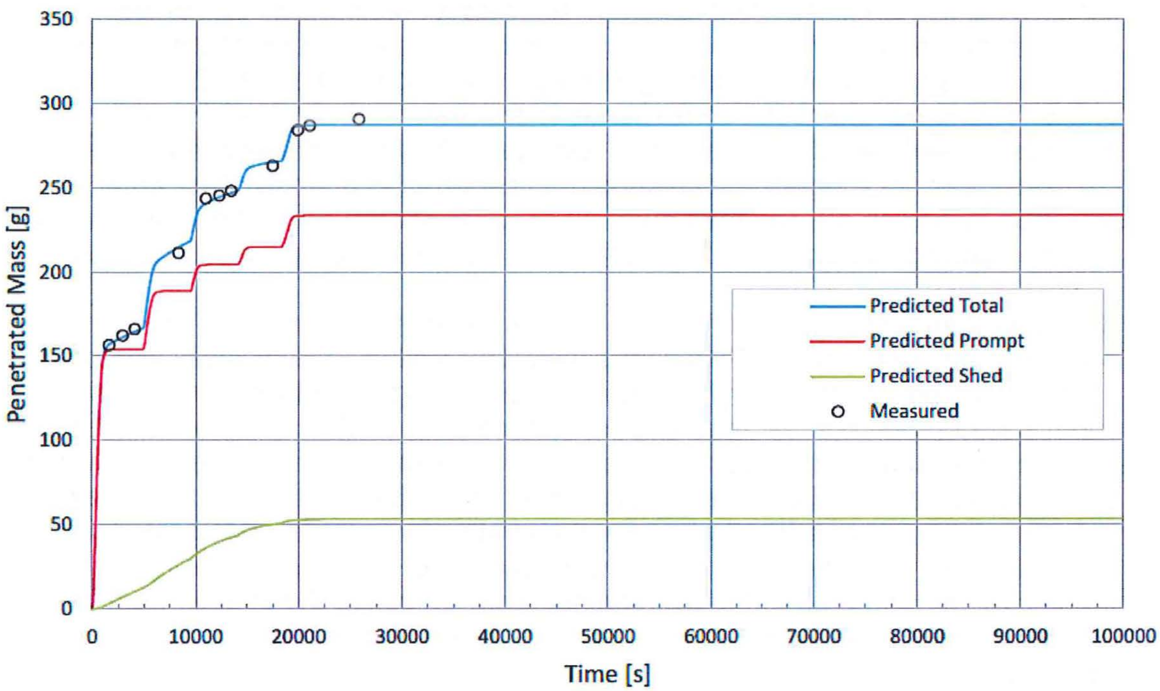


Figure 3.n.1-3: PBN Test 3 Penetration Model Fit

Using the methodology outlined above, one fiber penetration model was derived for each test. Because only three specific debris compositions were tested, a comparison of the three models was performed to determine which model is more conservative and can be used to conservatively assess debris penetration for breaks with intermediate debris compositions. Figure 3.n.1-4 shows a comparison of the fiber penetration percentage of added fiber based on measured fiber penetration quantities for all three tests. The figure shows that Test 3 had the highest average penetration percentages out of the three breaks.

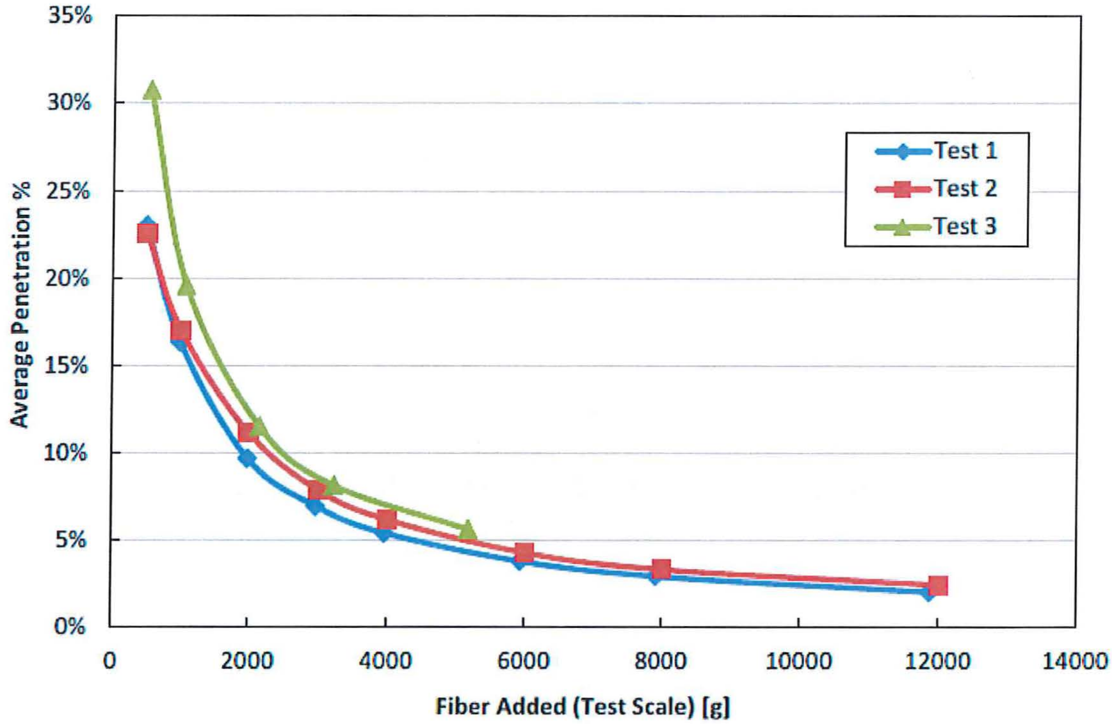


Figure 3.n.1-4: Average Penetration % vs Fiber Added (Test Scale)

To verify that the Test 3 penetration model results in the most conservative output, the Test 3 model was applied to Test 1 and Test 2 conditions. The results of this application are shown in Figure 3.n.1-5 and Figure 3.n.1-6. These figures show that use of the Test 3 model results in more fiber penetration than that measured from either of the other tests. Because the Test 3 model results in larger fiber penetration quantities than the other two models under identical conditions, it can be concluded that the Test 3 model is the most conservative model for any debris composition. Therefore, the Test 3 model may be conservatively applied to breaks of intermediate debris compositions (i.e., with a Nukon percentage greater than Test 1 or Test 2) up to the maximum debris load tested among all penetration tests.

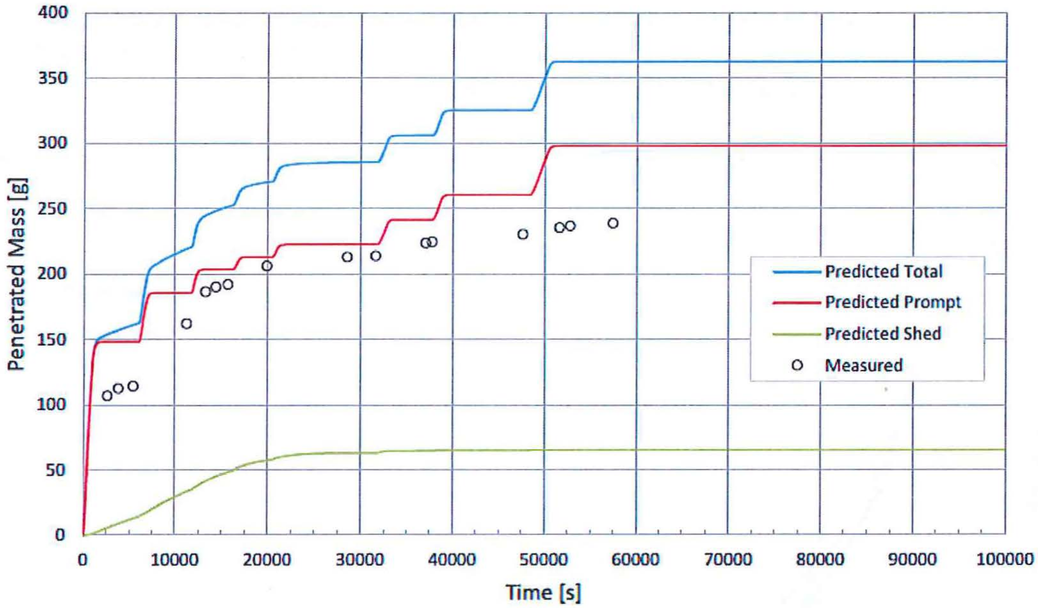


Figure 3.n.1-5: Test 3 Model Applied to Test 1 Conditions

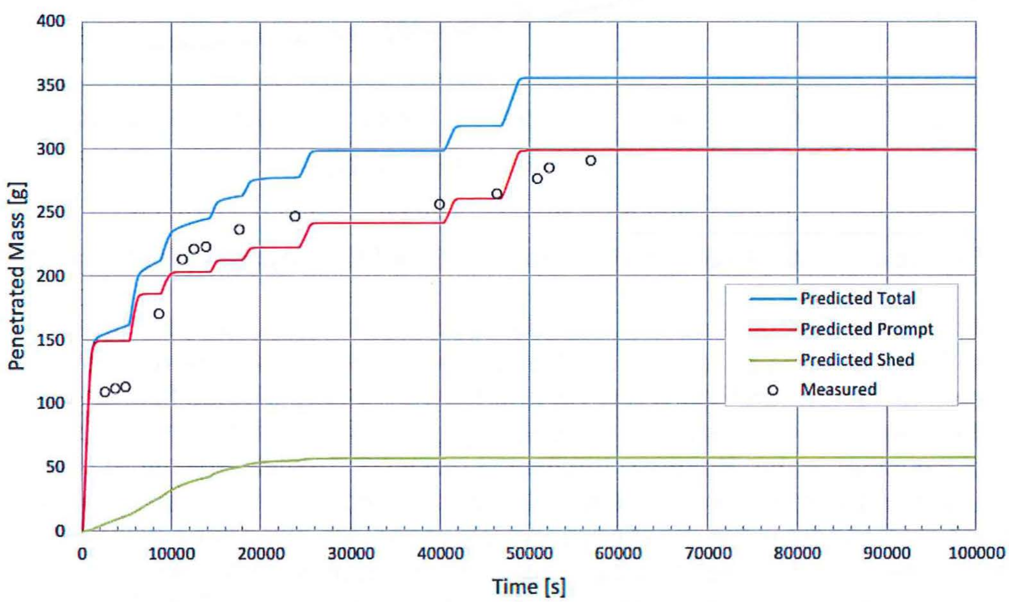


Figure 3.n.1-6: Test 3 Model Applied to Test 2 Conditions

The penetration models from the previous step can be used to determine the prompt fiber penetration fraction and shedding fraction for a given time and amount of fiber accumulated on the strainer. Coupled with a fiber transport model, a time-dependent evaluation can be performed to quantify the total amount of fiber that could pass through the strainer under certain plant conditions.

An example application of the Test 3 model is shown below. The Test 3 correlation was used to determine the total fiber penetration quantity for plant conditions related to the largest fiber break. For the time-dependent analysis, the recirculation duration was divided into smaller time steps. For each time step, the fiber penetration rates and quantities were calculated. Figure 3.n.1-7 shows the resulting cumulative fiber penetration through the strainer over time.

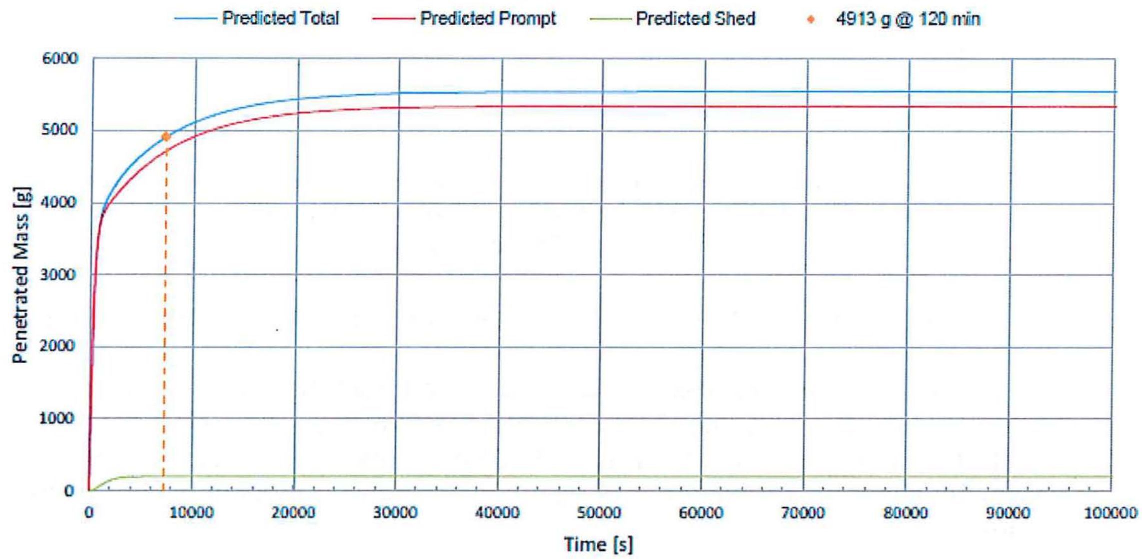


Figure 3.n.1-7: Test 3 Penetration Model at Plant Scale

Figure 3.n.1-8 shows the prompt fiber penetration fraction as a function of fiber quantity on the strainer derived using the Test 3 fiber penetration model for the same conditions as Figure 3.n.1-7. As expected, the prompt penetration fraction decreases as a fiber debris bed forms on the strainer.

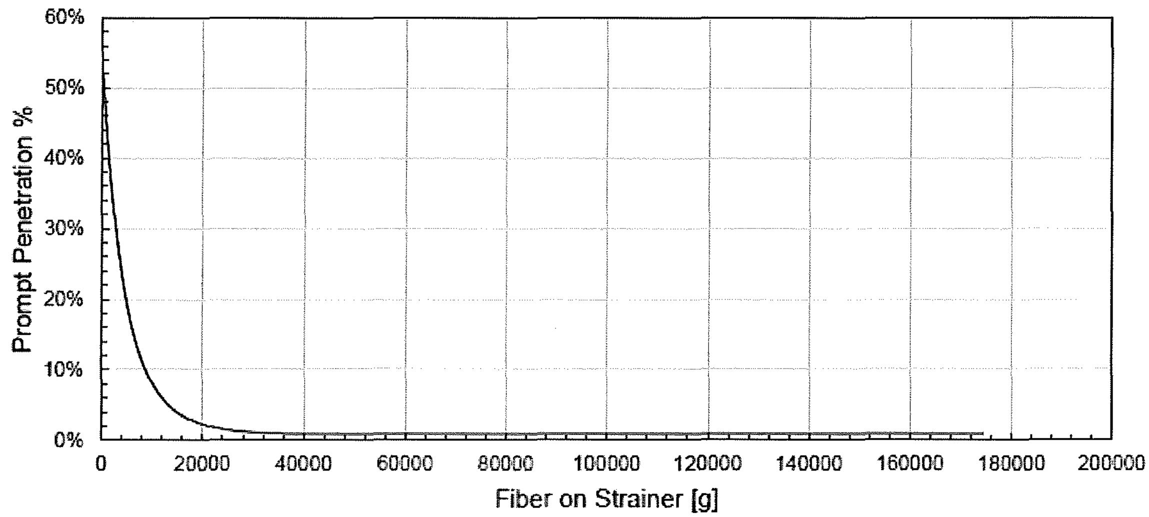


Figure 3.n.1-8: PBN Prompt Fiber Penetration Fraction Strainer Model

Figure 3.n.1-9 shows the shedding rate calculated from the Test 3 model as a function of time for the same plant conditions as Figure 3.n.1-7. Note that shedding penetration depends on the fiber quantity on the strainer and time. As shown in the figure, the shedding rate decreases over time for a given amount of fiber on the strainer.

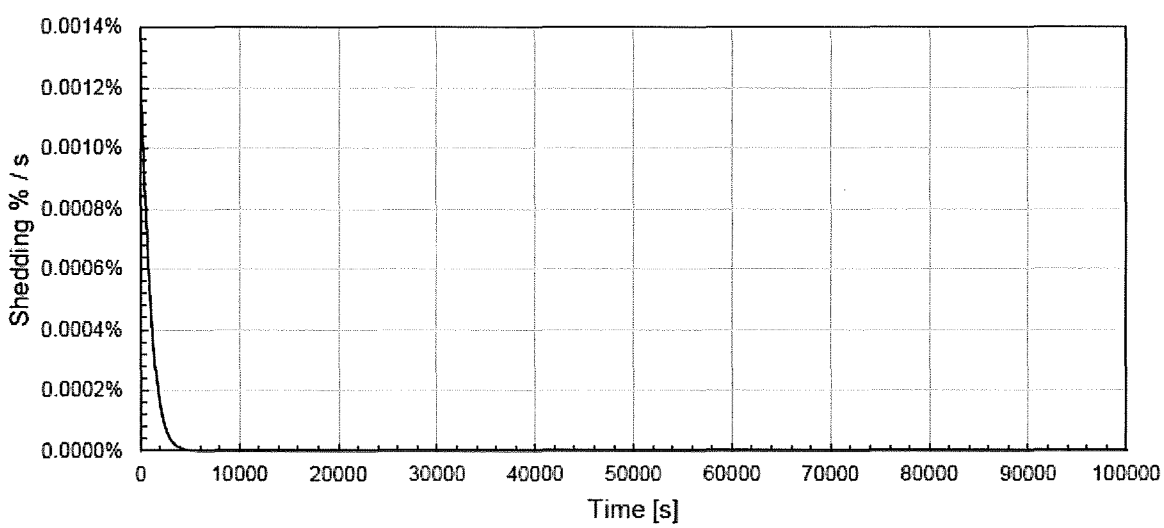


Figure 3.n.1-9: PBN Shedding Rate Calculated from High Flow Correlation

In-Vessel Effects Evaluations

Peak Cladding Temperature and Deposition Thickness

The LOCA deposition model (LOCADM), which is contained as part of WCAP-16793-NP (Revision 2), was used to determine the scale thickness due to deposition of debris that passes through the strainer on the fuel rod surfaces and the resulting peak cladding temperature. The limitations and conditions of this WCAP were addressed as part of the evaluation and it was shown that the WCAP-16793-P methods and values were appropriate to use for PBN.

The calculated scale thickness was then combined with the thickness of existing fuel cladding oxidation and crud build-up to determine the total deposition thickness. The calculated total deposition thickness and peak cladding temperature were compared with the acceptance criteria provided in WCAP-16793-NP. Note that the evaluation also considered the applicable requirements and recommendations from subsequent Pressurized Water Reactor Owners Group (PWROG) letters.

Two different cases were considered in this evaluation per the WCAP: minimum initial ECCS sump volume (Case 1) and maximum initial ECCS sump volume (Case 2). Table 3.n.1-5 below summarizes the peak cladding temperature and total deposition thickness (DT) for these two cases.

Table 3.n.1-5: Summary of PCT and DT for Cases 1 and 2

Case	PCT (°F)		DT (mils)	
	Results	Acceptance Criteria	Results	Acceptance Criteria
Case 1: Minimum Initial Sump Pool Volume	358	< 800	28.8	< 50
Case 2: Maximum Initial Sump Pool Volume	357		21.1	

For either case, the PCT is much lower than the acceptance criterion of 800 °F, and the DT value is well within the acceptance criterion of 50 mils. Therefore, deposition of post-LOCA debris and chemical precipitate product on the fuel rods will not block the LTCC flow through the core or create unacceptable local hot spots on the fuel cladding surfaces.

The 15 g/FA fiber limit at the reactor core inlet given in WCAP-16793-NP (Reference 30, Section 10.2) was not used. Instead, accumulation of fiber on the reactor core inlet and inside the reactor vessel was evaluated using the WCAP-17788-P methodology and acceptance criteria as discussed in the following section.

The NRC Safety Evaluation of WCAP-16793-NP provided analysis and recommendations on the use of Westinghouse's WCAP-16793-NP, Revision 2 methodology and identified 14 limitations and conditions that must be addressed. The responses to these limitations and conditions are summarized below.

1. Assure the plant fuel type, inlet filter configuration, and ECCS flow rate are bounded by those used in the FA testing outlined in Appendix G of the WCAP. If the 15 g/FA acceptance criterion is used, determine the available driving head for an HL break and compare it to the debris head loss measured during the FA testing. Compare the fiber bypass amounts with the acceptance criterion given in the WCAP.

   Response:

   This limitation and condition (LAC) is associated with the 15 g/FA limit established in WCAP-16793-NP, which does not apply to PBN1 and PBN2. In-vessel fiber accumulation was not calculated using WCAP-16793-NP, but it was evaluated using the methodology from the WCAP-17788-P report.

2. Each licensee's GL 2004-02 submittal to the NRC should state the available driving head for an HL break, ECCS flow rates, LOCADM results, type of fuel and inlet filter, and amount of fiber bypass.

   Response:

   This LAC is associated with the 15 g/FA limit established in WCAP-16793-NP, which does not apply to PBN1 and PBN2. In-vessel fiber accumulation was not calculated using WCAP-16793-NP, but it was evaluated using the methodology from the WCAP-17788-P report.

3. If a licensee credits alternate flow paths in the reactor vessel in their LTCC evaluations, justification is required through testing or analysis.

   Response:

   This LAC is associated with the 15 g/FA limit established in WCAP-16793-NP, which does not apply to PBN1 and PBN2. In-vessel fiber accumulation was not calculated using WCAP-16793-NP, but it was evaluated using the methodology from the WCAP-17788-P report.

4. The numerical analyses discussed in Sections 3.2 and 3.3 of the WCAP should not be relied upon to demonstrate adequate LTCC.

   Response:

   The fuel blockage modeling concerns discussed in Sections 3.2 and 3.3 of WCAP-16793-NP are not applicable to the LOCADM analysis for PBN1 and PBN2. In-vessel fiber accumulation was not calculated using WCAP-16793-NP, but it was evaluated using the methodology from the WCAP-17788-P report.

5. The SE requires that a plant must maintain its debris load within the limits defined by the testing (e.g., 15 g/FA), and any debris amounts greater than those justified by generic testing in the WCAP must be justified on a plant-specific basis.

   Response:

   This LAC is associated with the 15 g/FA limit established in WCAP-16793-NP, which does not apply to PBN1 and PBN2. In-vessel fiber accumulation was not calculated using WCAP-16793-NP, but it was evaluated using the methodology from the WCAP-17788-P report.

6. The debris acceptance criterion can only be applied to fuel types and inlet filter configurations evaluated in the WCAP FA testing.

   Response:

   This LAC is associated with the 15 g/FA limit established in WCAP-16793-NP, which does not apply to PBN1 and PBN2. In-vessel fiber accumulation was not calculated using WCAP-16793-NP, but it was evaluated using the methodology from the WCAP-17788-P report.

7. Each licensee's GL 2004-02 submittal to the NRC should compare the PCT from LOCADM with the acceptance criterion of 800°F.

   Response:

   The bounding PCT for PBN1 and PBN2 was determined to be 358°F, which is well within the acceptance criterion of 800°F.

8. When utilizing LOCADM to determine PCT and DT, the aluminum release rate must be doubled to more accurately predict aluminum concentrations in the sump pool in the initial days following a LOCA.

   Response:

   The appropriate methodology was followed with regard to increasing the aluminum release rate in the LOCADM analysis.

9. If refinements specific to the plant are made to the LOCADM to reduce conservatisms, the licensee should demonstrate that the results still adequately bound chemical product generation.

   Response:

   The LOCADM runs for PBN1 and PBN2 do not employ any conservative-reducing refinements specific to the plant. Therefore, no additional justification is required.

10. The recommended value for scale thermal conductivity of 0.11 BTU/(h-ft-°F) should be used for LTCC evaluations.

    Response:

    As stated in Appendix E of WCAP-16793-NP (Ref. 2.1. Page E-16), the recommended thermal conductivity of 0.11 BTU/(h-ft-°F) can be converted to 0.2 W/m-K, which was used in the analysis.

11. The licensee's submittals should include the means used to determine the amount of debris that bypasses the ECCS sump strainer and the fiber loading at the fuel inlet expected for the HL and CL break scenarios. Licensees should provide the debris loads, calculated on a fuel assembly basis, for both the HL and CL break cases in their GL 2004-02 responses.

    Response:

    This LAC is associated with the 15 g/FA limit established in WCAP-16793-NP, which does not apply to PBN1 and PBN2. In-vessel fiber accumulation was not calculated using WCAP-16793-NP, but it was evaluated using the methodology from the WCAP-17788-P report.

12. Plants that can qualify a higher fiber load based on the absence of chemical deposits should ensure that tests for their conditions determine limiting head losses using particulate and fiber loads that maximize the head loss with no chemical precipitates included in the tests. In this case, licensees must also evaluate the other considerations discussed in the first LAC.

    Response:

    This LAC is associated with the 15 g/FA limit established in WCAP-16793-NP, which does not apply to PBN1 and PBN2. In-vessel fiber accumulation was not calculated using WCAP-16793-NP, but it was evaluated using the methodology from the WCAP-17788-P report.

13. The size distribution of the debris used in the FA testing must represent the size distribution of fibrous debris expected to pass through the ECCS sump strainer at the plant.

    Response:

    This LAC is associated with the 15 g/FA limit established in WCAP-16793-NP, which does not apply to PBN1 and PBN2. In-vessel fiber accumulation was not calculated using WCAP-16793-NP, but it was evaluated using the methodology from the WCAP-17788-P report.

14. Each licensee's GL 2004-02 submittal to the NRC should not utilize the "Margin Calculator" as it has not been reviewed by the NRC.

Response:

The evaluation for PBN1 and PBN2 does not use the "Margin Calculator".

In summary, the evaluation showed that the peak cladding temperature and total deposition thickness due to accumulation of debris on the fuel rods met the acceptance criteria and did not cause any failures.

Accumulation of Fiber inside Reactor Vessel

During the post-LOCA sump recirculation phase, debris that passes through the strainer could accumulate at the reactor core inlet or inside the reactor vessel and challenge LTCC. This effect was evaluated for both hot leg break (HLB) and cold leg break (CLB) scenarios using the upper plenum injection (UPI) methodology of WCAP-17788-P. The evaluation used time-dependent fiber penetration fractions obtained from PBN testing based on plant-specific inputs, as described earlier in this response. The penetration fraction varies with the amount of fiber on the strainer and the amount of time passed since the onset of recirculation.

The evaluation was performed using the NARWHAL software for both units. The NARWHAL model used the methodology from WCAP-17788-P to evaluate each break in a self-consistent and time-dependent manner. These evaluations are summarized below.

Hot Leg Breaks

For an HLB, the largest core inlet and total reactor vessel fiber loads were 8.1 and 10.7 g/FA, respectively, for both PBN1 and PBN2. These results were compared to the limits contained in WCAP-17788, which is currently in NRC review, and were found to be acceptable. The core inlet and total reactor vessel fiber loads presented are total 30-day values.

Cold Leg Breaks

The same case was also run for CLB analysis. The largest 30-day total reactor vessel fiber loads for PBN1 and PBN2 are 39.5 and 46.0 g/FA, respectively. These results were compared to the limits contained in WCAP-17788, which is currently in NRC review, and were found to be acceptable.

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.

1. *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 core cooling is unacceptably impeded.

Response to 3.o.1:

The chemical effects strategy for PBN1 and PBN2 includes:

- Quantification of chemical precipitates using the WCAP-16530-NP-A methodology. The limitations and conditions of this WCAP were addressed as part of the evaluation and it was shown that the WCAP-16530-NP-A methods and values were appropriate to use for PBN.
- Introduction of those pre-prepared precipitates in prototypical strainer testing.
- Application of an aluminum solubility correlation to determine the maximum precipitation temperature.
- Time-based determination of acceptable head losses.
- Extrapolation of the resulting head losses to 30 days.

As discussed in the Response to 3.a.1, PBN1 and PBN2 have determined the debris generated at all ISI welds on the primary RCS piping inside containment. The amount/mass of chemical precipitates was quantified for several cases which bound the amount of LOCA generated debris for the spectrum of break cases. Other plant-specific inputs such as pH, temperature, aluminum quantity, and spray times were selected to maximize the generated amount of precipitates. These amounts were scaled by the ratio of the test strainer area to the plant-strainer surface area and are compared with the chemical debris quantities used in the prototypical strainer tests to determine the resulting head loss across the strainers. Before the chemical debris portion of the tests were conducted, the SAS was prepared according to the WCAP-16530-NP-A recipes and was verified to meet the settling criteria within 24 hours of the test. During the test, a fiber and particulate debris bed was established on the strainer surfaces, the stabilization criteria was satisfied, and the pre-prepared precipitates were added to the test tank in batches. See the Response to 3.f.4 for further details on the head loss measured after introduction of chemical precipitates.

See the in-vessel effects evaluations in the Response to 3.n.1 for the evaluation of chemical precipitate deposition on the fuel rod surfaces.

2. *Content guidance for chemical effects is provided in Enclosure 3 dated March 2008 to a letter from the NRC to NEI.*

Response to 3.o.2:

The NRC identified evaluation steps in "NRC Staff Review Guidance Regarding Generic Letter 2004-02 Closure in the Area of Plant-Specific Chemical Effect Evaluations" in March of 2008 (Reference 5). PBN responses to the GL supplemental content evaluation steps are summarized below. The numbering of the following subsections to the Response to 3.o.2 follow the numbering scheme provided in Section 3 and Figure 1 of the March 2008 guidance (Reference 5, pp. 8-

23). Figure 3.o.2.22-1 (provided at the end of the Response to 3.o) highlights the PBN chemical effects evaluation process using the flow chart in Figure 1 of the March 2008 guidance (Reference 5, p. 8).

1. *<u>Sufficient 'Clean' Strainer Area</u>: 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.*

   Response to 3.o.2.1:

   PBN is not crediting clean strainer area to perform a simplified chemical effects analysis. See Figure 3.o.2.22-1.

2. *<u>Debris Bed Formation</u>: 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, produces greater head loss than break location 1. Therefore, the debris for head loss testing with chemical effects should be based on break location 2.*

   Response to 3.o.2.2:

   One thin-bed and three full debris load head loss tests were completed for PBN. These tests were used to develop the head loss contributions from conventional debris and aluminum precipitates. Full debris load test loads were organized to bound all prototypical debris loads for Region I breaks. For the thin-bed test, a debris bed that was saturated with particulate debris was formed. Chemical precipitate was added to these tests as described in the Response to 3.f.4. See the Response to 3.f.10 for additional chemical head loss information.

3. *<u>Plant-Specific Materials and Buffers</u>: 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.*

   Response to 3.o.2.3:

   The chemical model requires a number of plant-specific inputs. Each input was chosen to maximize the calculated quantity and minimize the solubility (aluminum only) of the chemical precipitates.

   PBN uses sodium hydroxide (NaOH) to buffer the post-LOCA containment sump pool to a final pH between 7.0 and 9.5. The injection spray delivers the NaOH to the containment sump pool and is buffered to a maximum pH of 10.5. The pH values used for chemical release were conservatively high, and the pH value used for aluminum solubility was conservatively low. Different pH values for release and solubility were combined in a non-physical way, bounding the effects of all potential pH profile variations.

Acids generated through radiolysis may decrease the Containment Sump Pool pH over the 30-day post-LOCA event. The net effect of these acids over 30 days is conservatively bounded both by a decrease in pH from 8.25 to 7.0 and by a decrease in pH from 9.5 to 8.25 at PBN Containment Sump Pool conditions. Therefore, the chemical product cases were divided into two sets to bound the possible pH variations. One set of cases used a pH value of 9.5 for aluminum release and a pH value of 8.25 for aluminum solubility. The second set of cases used a pH value of 8.25 for aluminum release and a pH value of 7.0 for aluminum solubility. The pH values are summarized in Table 3.o.2.3-1:

Table 3.o.2.3-1: PBN pH Values

Design Input	pH
Injection Spray pH Used To Determine Chemical Release Rates	10.5
Sump and Recirculation Spray pH Used To Determine Chemical Release Rates Cases: A, C, E, G, O, Q	9.5
Sump and Recirculation Spray pH Used To Determine Chemical Release Rates Cases: B, D, F, H, I, J, K, L, P, R, S, T	8.25
Sump pH Used To Determine Aluminum Solubility Cases: A, C, E, G, O, Q	8.25
Sump pH Used To Determine Aluminum Solubility Cases: B, D, F, H, I, J, K, L, P, R, S, T	7.0

Injection sprays were assumed to begin immediately post-LOCA. The recirculation phase starts at 3,398.34 s (56.639 min) post-LOCA for the minimum ECCS case; after which, the containment spray pH would be the same as the containment sump pool pH. The containment sprays were assumed to be terminated at 14,400 s (4 hr) post-LOCA which exceeds the expected termination time.

Bounding containment sump pool and containment temperature profiles were used to maximize chemical release rates. The temperature profiles are shown in Table 3.o.2.3-2.

Table 3.o.2.3-2: Temperature Profiles used to Determine Chemical Release Rates

Time (s)	Post-LOCA Sump Temperature (°F)
1	188
2	188
10	250
20	257
40	220
100	243
200	243
1000	263
1500	263
2000	238
10000	200
20000	181
100000	148
200000	138
1000000	113
2000000	108
2592000	104

Time (s)	Post-LOCA Containment Temperature (°F)
1	204
2	240
10	280
100	272
200	268
1000	285
2000	260
3000	244
10000	208
14400	208

The total amount of concrete assumed to be exposed and submerged in the containment sump pool was 10,000 ft^2. The quantity of chemical precipitates was negligibly impacted by this large assumed surface area of exposed concrete. Therefore, exposed concrete is not a significant impact to chemical product generation in the PBN post-LOCA containment sump pool and is not tracked for this purpose.

The containment sump pool was assumed to be well mixed. This assumption conservatively maximizes aluminum release by not considering the concentration gradient that would form around submerged source materials at low pool velocity conditions.

At PBN1, the total amount of unsubmerged aluminum exposed to containment sprays is 306.25 ft^2 (including contingency). The total amount of submerged aluminum exposed to the containment sump fluid at PBN1 is 16.67 ft^2 (including contingency). The mass of these unsubmerged and submerged aluminum metals is in excess of the total aluminum released into the containment sump pool, and therefore, no limit was set on the quantity released from these sources. These values do not include metallic aluminum paint, which varies in quantity from case to case. Metallic aluminum paint was assumed to immediately dissolve due to the high surface area to mass ratio.

At PBN2, the total amount of unsubmerged aluminum exposed to containment sprays is 298.61 ft^2 (including contingency). The total amount of submerged aluminum exposed to the containment sump fluid at PBN2 is 29.17 ft^2 (including contingency). The mass of these unsubmerged and submerged aluminum metals is in excess of the total aluminum released into the containment sump pool, and therefore, no limit was set on the quantity released from these sources. These values do not include metallic aluminum paint. Metallic aluminum is present for pressurizer compartment and reactor cavity breaks since insulation materials holding these coatings in place would otherwise remain intact. Metallic aluminum paint is assumed to immediately dissolve due to the high surface area to mass ratio.

Minimum and maximum water mass cases were run to determine both maximum generation of precipitates and maximum precipitation temperatures, since aluminum release rates from some materials are concentration dependent. At PBN1 and PBN2, the maximum containment sump pool mass that is available for chemical dissolution is 2,809,684 lbm. The minimum containment sump pool mass that is available for chemical dissolution is 2,273,584 lbm. Consistent with the WCAP-16530-NP-A methodology, the total mass was assumed to be present immediately post-LOCA.

Table 3.o.2.3-3 summarizes the remaining material inputs for each case. The material quantities are bounding for the listed containment areas. The cases where a compartment is not listed are bounding for all compartments with the exception of the pressurizer compartment and reactor cavity.

Table 3.o.2.3-3: Case Specific Inputs

Case	E-Glass (LDFG & Latent)	Cal-Sil (incl. Asbestos)	Mineral Wool	Metallic Al Paint
Case A: PBN1, sump pH of 9.5 – 8.25, Max Sump	189.5 lbm	1,374.1 lbm	178.8 lbm	0 lbm
Case B: PBN1, sump pH of 8.25 – 7.0, Max Sump	189.5 lbm	1,374.1 lbm	178.8 lbm	0 lbm
Case C: PBN2, sump pH of 9.5 – 8.25, Max Sump	1,275.1 lbm	684.6 lbm	206.0 lbm	0 lbm
Case D: PBN2, sump pH of 8.25 – 7.0, Max Sump	1,275.1 lbm	684.6 lbm	206.0 lbm	0 lbm
Case E: PBN1, sump pH of 9.5 – 8.25, Pressurizer Compartment, Max Sump	191.4 lbm	132.1 lbm	0 lbm	4.5 lbm
Case F: PBN1, sump pH of 8.25 – 7.0, Pressurizer Compartment, Max Sump	191.4 lbm	132.1 lbm	0 lbm	4.5 lbm
Case G: PBN2, sump pH of 9.5 – 8.25, Pressurizer Compartment, Max Sump	224.5 lbm	106.5 lbm	10.9 lbm	4.5 lbm
Case H: PBN2, sump pH of 8.25 – 7.0, Pressurizer Compartment, Max Sump	224.5 lbm	106.5 lbm	10.9 lbm	4.5 lbm
Case I: PBN1, sump pH of 8.25 – 7.0, Min Sump	189.5 lbm	1,374.1 lbm	178.8 lbm	0 lbm
Case J: PBN2, sump pH of 8.25 – 7.0, Min Sump	1,275.1 lbm	684.6 lbm	206.0 lbm	0 lbm
Case K: PBN1, sump pH of 8.25 – 7.0, Pressurizer Compartment, Min Sump	191.4 lbm	132.1 lbm	0 lbm	4.5 lbm

Case	E-Glass (LDFG & Latent)	Cal-Sil (incl. Asbestos)	Mineral Wool	Metallic Al Paint
Case L: PBN2, sump pH of 8.25 – 7.0, Pressurizer Compartment, Min Sump	224.5 lbm	106.5 lbm	10.9 lbm	4.5 lbm
Case O: PBN1, sump pH of 9.5 – 8.25, Reactor Cavity, Max Sump	35.7 lbm	164.2 lbm	2.3 lbm	15.6 lbm
Case P: PBN1, sump pH of 8.25 – 7.0, Reactor Cavity, Max Sump	35.7 lbm	164.2 lbm	2.3 lbm	15.6 lbm
Case Q: PBN2, sump pH of 9.5 – 8.25, Reactor Cavity, Max Sump	41.7 lbm	330.1 lbm	0.53 lbm	15.6 lbm
Case R: PBN2, sump pH of 8.25 – 7.0, Reactor Cavity, Max Sump	41.7 lbm	330.1 lbm	0.53 lbm	15.6 lbm
Case S: PBN1, sump pH of 8.25 – 7.0, Reactor Cavity, Min Sump	35.7 lbm	164.2 lbm	2.3 lbm	15.6 lbm
Case T: PBN2, sump pH of 8.25 – 7.0, Reactor Cavity, Min Sump	41.7 lbm	330.1 lbm	0.53 lbm	15.6 lbm

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

Response to 3.o.2.4:

PBN is using the separate chemical effects approach to determine the chemical source term. Alden Research Laboratory, Inc. performed the head loss testing in their test lab in Holden, MA.

5. *Separate Effects Decision (Decision Point): Within this part of the process flow chart, two different methods of assessing the plant-specific chemical effects have been proposed. The WCAP-16530-NP-A study (Box 7 WCAP Base Model) uses predominantly single-variable test measurements. This provides baseline information for one material acting independently with one pH-adjusting chemical at an elevated temperature. Thus, one type of insulation is tested at each individual pH, or one metal alloy is tested at one pH. These separate effects are used to formulate a calculational model, which linearly sums all of the individual effects. A second method for determining plant-specific chemical effects that may rely on single-effects bench testing is currently being developed by one of the strainer vendors (Box 6, AECL).*

Response to 3.o.2.5:

PBN is using the WCAP-16530-NP-A chemical effects base model to determine the chemical source term. The application of an aluminum solubility correlation to determine a maximum precipitate formation temperature is discussed in the Response to 3.o.2.8 and Response to 3.o.2.9.i.

6. *AECL Model:*

i. *Since the NRC is not currently aware of the complete details 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.*

Response to 3.o.2.6.i:

This question is not applicable because PBN is not using the AECL model. See Figure 3.o.2.22-1.

ii. *Licensees should provide the chemical identities and amounts of predicted plant-specific precipitates.*

Response to 3.o.2.6.ii:

This question is not applicable because PBN is not using the AECL model. See Figure 3.o.2.22-1.

7. *WCAP Base Model:*

i. *Licensees proceeding from block 7 to diamond 10 in the Figure 1 flow chart [in Enclosure 3 dated March 2008 to a letter from the NRC to NEI* (Reference 5, p. 8)*] should 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.*

Response to 3.o.2.7.i:

The PBN chemical model quantifies chemical precipitates using the WCAP-16530-NP-A (Reference 18) methodology with the following two deviations:

1. The application of an aluminum solubility correlation to determine a maximum precipitate formation temperature is discussed in the Response to 3.o.2.9.i.
2. The use of a new base model spreadsheet that follows the WCAP-16530-NP-A methodology

An aluminum solubility correlation was used to determine a maximum precipitate formation temperature, which effectively delays the onset of aluminum precipitation. Therefore, to allow for time-based head loss acceptance criteria, a new spreadsheet was developed to include the requirement in the SE to double the aluminum release rate from aluminum metal over the initial 15 days. The spreadsheets also allows for separate accounting of “thick” aluminum (not mass limited), “thin” aluminum (mass limited), and aluminum assumed to dissolve immediately into the sump (coatings) . Additionally, the aluminum solubility was used to conservatively decrease the aluminum concentration after precipitation occurs, which increases the rate of release from insulation materials and concrete post-precipitation. As shown in Figure 3.o.2.7.i-1 and Figure 3.o.2.7.i-2, the ICET 1 test results were simulated using the new spreadsheet and compared with the measured aluminum concentrations. The results verify that the new spreadsheet does not under-predict ICET 1 aluminum release and, therefore, can be used for time-based acceptance criteria in accordance with the WCAP-16530-NP-A SE.

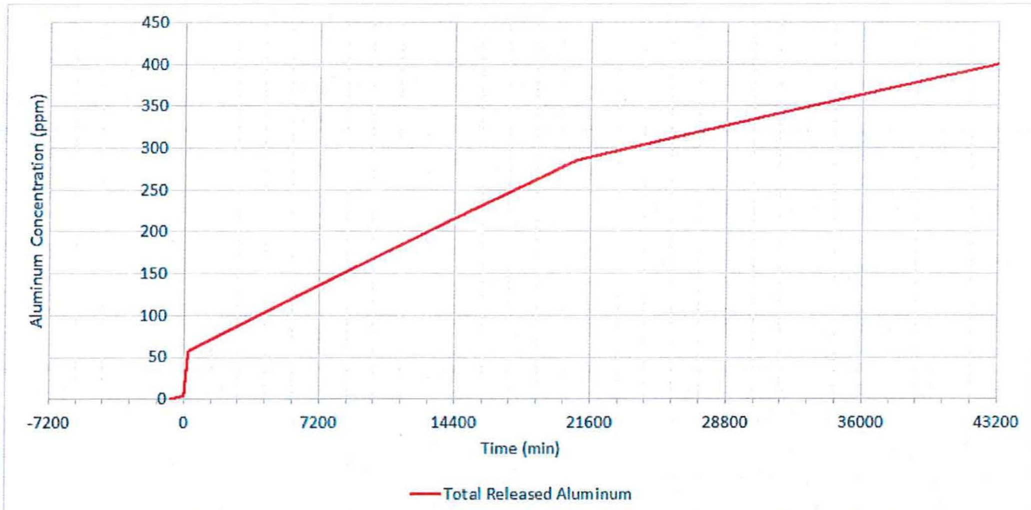


Figure 3.o.2.7.i-1: Simulation of ICET 1 Al Concentration

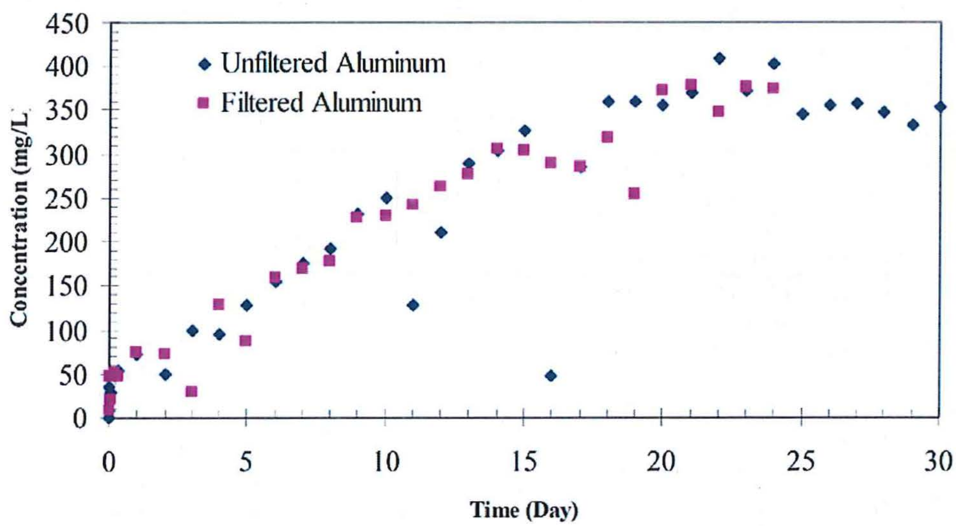


Figure 3.o.2.7.i-2: Measured Aluminum Concentrations in ICET 1

ii. Licensees should list the type (e.g., AlOOH) and amount of predicted plant-specific precipitates.

Response to 3.o.2.7.ii:

Table 3.o.2.7.ii-1 provides the released aluminum mass, formed precipitates, and maximum aluminum precipitation temperatures that were calculated for multiple cases. See the Response to 3.o.2.3 for a description of the inputs for each chemical product case. Note that, per the WCAP-16530-NP-A Safety Evaluation, both aluminum precipitates are acceptable surrogates for aluminum precipitate in head loss testing, and AlOOH, when predicted to form, is converted to the stoichiometric equivalent amount of SAS (based on aluminum) for head loss testing.

Table 3.o.2.7.ii-1: Summary of Precipitate Quantities and Precipitation Temperatures

Case	Total Al Released	Al Precipitation Temperature	$NaAlSi_3O_8$	AlOOH
Case A: PBN1, sump pH of 9.5 – 8.25, Max Sump	7.0 kg	101.2°F	68.3 kg	-
Case B: PBN1, sump pH of 8.25 – 7.0, Max Sump	5.5 kg	142.8°F	53.9 kg	-
Case C: PBN2, sump pH of 9.5 – 8.25, Max Sump	8.0 kg	103.5°F	77.5 kg	-
Case D: PBN2, sump pH of 8.25 – 7.0, Max Sump	6.1 kg	143.8°F	59.1 kg	-
Case E: PBN1, sump pH of 9.5 – 8.25, Pressurizer Compartment, Max Sump	7.1 kg	101.6°F	69.4 kg	-
Case F: PBN1, sump pH of 8.25 – 7.0, Pressurizer Compartment, Max Sump	5.9 kg	149.2°F	57.3 kg	-
Case G: PBN2, sump pH of 9.5 – 8.25, Pressurizer Compartment, Max Sump	7.6 kg	102.7°F	73.9 kg	-
Case H: PBN2, sump pH of 8.25 – 7.0, Pressurizer Compartment, Max Sump	6.1 kg	149.1°F	58.9 kg	-
Case I: PBN1, sump pH of 8.25 – 7.0, Min Sump	5.5 kg	146.3°F	53.4 kg	-
Case J: PBN2, sump pH of 8.25 – 7.0, Min Sump	6.0 kg	147.1°F	58.2 kg	-
Case K: PBN1, sump pH of 8.25 – 7.0, Pressurizer Compartment, Min Sump	5.9 kg	152.9°F	57.2 kg	-
Case L: PBN2, sump pH of 8.25 – 7.0, Pressurizer Compartment, Min Sump	6.0 kg	152.8°F	58.7 kg	-
Case O: PBN1, sump pH of 9.5 – 8.25, Reactor Cavity, Max Sump	12.1 kg	110.9°F	66.4 kg	11.8 kg
Case P: PBN1, sump pH of 8.25 – 7.0, Reactor Cavity, Max Sump	10.9 kg	160.3°F	65.6 kg	9.3 kg
Case Q: PBN2, sump pH of 9.5 – 8.25, Reactor Cavity, Max Sump	12.5 kg	111.3°F	121.3 kg	-
Case R: PBN2, sump pH of 8.25 – 7.0, Reactor Cavity, Max Sump	11.0 kg	160.3°F	106.7 kg	-
Case S: PBN1, sump pH of 8.25 – 7.0, Reactor Cavity, Min Sump	10.9 kg	164.1°F	64.0 kg	9.7 kg
Case T: PBN2, sump pH of 8.25 – 7.0, Reactor Cavity, Min Sump	11.0 kg	164.0°F	106.7 kg	-

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

Response to 3.o.2.8:

Refinement to the model for aluminum solubility is discussed in the Response to 3.o.2.9.i. No other refinements to the WCAP-16530-NP-A methodology were used.

9. *Solubility of Phosphates, Silicates and Al Alloys:*

   i. *Licensees should clearly identify any refinements (plant-specific inputs) to the base WCAP-16530-NP-A model and justify why the plant-specific refinement is valid.*

   Response to 3.o.2.9.i:

   The base WCAP-16530-NP-A model assumes that aluminum precipitates form immediately upon the release of aluminum into solution. However, as justified in the Response to 3.o.2.7.i, the PBN chemical model includes the following application of an aluminum solubility correlation to determine formation temperature and timing.

   The aluminum solubility limit was determined using Equation 3.o.2.9-1, developed by Argonne National Laboratory (ANL) .

$$C_{Al,sol} = \begin{cases} 26980 \cdot 10^{(pH+\Delta pH)-14.4+0.0243T}, & \text{if } T \leq 175\ °F \\ 26980 \cdot 10^{(pH+\Delta pH)-10.41+0.00148T}, & \text{if } T > 175\ °F \end{cases} \qquad \text{(Equation 3.o.2.9-1)}$$

   Nomenclature:

   ΔpH = pH change due to radiolysis acids
   T = solution temperature, °F

   The aluminum solubility limit equation was used to determine the temperature and timing of aluminum precipitation and to determine the aluminum concentration in solution for use in the aluminum release equations for concrete and insulation. When precipitation was predicted by this equation, the full amount of aluminum released was assumed to precipitate. The aluminum solubility limit equation was not used to reduce the predicted quantity of precipitate by crediting the amount remaining in solution.

   ii. *For crediting inhibition of aluminum that is not submerged, licensees should provide the substantiation for the following: (1) the threshold concentration of* *silica or phosphate needed to passivate aluminum, (2) the time needed to reach a phosphate or silicate level in the pool that would result in aluminum passivation, and (3) the amount of containment spray time (following the achieved threshold of chemicals) before aluminum that is sprayed is assumed to be passivated.*

Response to 3.o.2.9.ii:

Silicon and phosphate inhibition of aluminum release were not credited. See the Response to 3.o.2.9.i.

iii. *For any attempts 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 amount of chemical precipitate can produce significant increases in head loss.*

Response to 3.o.2.9.iii:

Reductions in precipitate quantity due to residual solubility of aluminum after precipitation occurs was not credited. See the Response to 3.o.2.9.i.

iv. *Licensees should list the type (e.g., AlOOH) and amount of predicted plant-specific precipitates.*

Response to 3.o.2.9.iv:

The type and amount of plant-specific precipitates are provided in the Response to 3.o.2.7.ii.

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

Response to 3.o.2.10:

As discussed in the Response to 3.o.2.12, PBN pre-mixed surrogate chemical precipitates in a separate mixing tank for chemical head loss testing. The direct chemical injection method was not used in head loss testing.

11. *Chemical Injection into the Loop:*

i. *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.*

Response to 3.o.2.11.i:

The direct chemical injection method was not used in head loss testing for PBN. See Figure 3.o.2.22-1.

ii. *For plant-specific testing, the licensee should provide the amount of injected chemicals (e.g., aluminum), the percentage that precipitates, and the percentage that remains dissolved during testing.*

Response to 3.o.2.11.ii:

The direct chemical injection method was not used in head loss testing for PBN. See Figure 3.o.2.22-1.

iii. *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 of the amount calculated for the plant).*

Response to 3.o.2.11.iii:

The direct chemical injection method was not used in head loss testing for PBN. See Figure 3.o.2.22-1.

12. *Pre-Mix in Tank: Licensees should discuss any exceptions taken to the procedure recommended for surrogate precipitate formation in WCAP-16530-NP-A.*

Response to 3.o.2.12:

The WCAP-16530-NP-A precipitate formation methodology for SAS was followed with no exceptions.

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

Response to 3.o.2.13:

PBN chemical effects testing used hydraulic and manual agitation and turbulence in the test tank to ensure that essentially all debris analyzed to reach the strainer in the plant reached the strainer in head loss testing. PBN did not credit any near field settlement in head loss testing. Refer also to the Response to 3.f.4.

14. *Integrated Head Loss Test with Near-Field Settlement Credit:*

i. *Licensees should provide the one-hour or two-hour precipitate settlement values measured within 24 hours of head loss testing.*

Response to 3.o.2.14.i:

PBN is not crediting near field settlement of chemical precipitate in chemical head loss testing. See Figure 3.o.2.22-1.

ii. *Integrated Head Loss Test with Near-Field Settlement Credit: Licensees should provide a best estimate of the amount of surrogate chemical debris that settles away from the strainer during the test.*

Response to 3.o.2.14.ii:

PBN is not crediting near field settlement of chemical precipitate in chemical head loss testing. See Figure 3.o.2.22-1.

15. *Head Loss Testing Without Near Field Settlement Credit:*

i. *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.*

Response to 3.o.2.15.i:

Measures taken during the test, as described in the Response to 3.f.12, to keep debris suspended and transportable to the test strainer, prevented notable settling of debris or precipitate.

ii. *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).*

Response to 3.o.2.15.ii:

The maximum allowable clear volume at the top of a 10 mL sample of SAS precipitates after one hour of settling was 4 mL. The precipitates were continuously mixed and used within 24 hours of the execution of a successful settling test.

16. *Test Termination Criteria: Licensees should provide the test termination criteria.*

Response to 3.o.2.16:

The head loss test was terminated once the total planned chemical precipitate quantity had been added and the head loss had stabilized. Note that the head loss was considered to have stabilized when there was less than a 1% change in two consecutive 30 minute intervals. The debris bed in this state was characterized using both a temperature sweep and a flow sweep. Since all predicted chemical debris was added to the test and the head loss was allowed to stabilize for an extended period of time, the test termination criteria was satisfied. See Figure 3.o.2.16-1 as an example of the limiting test sequence.

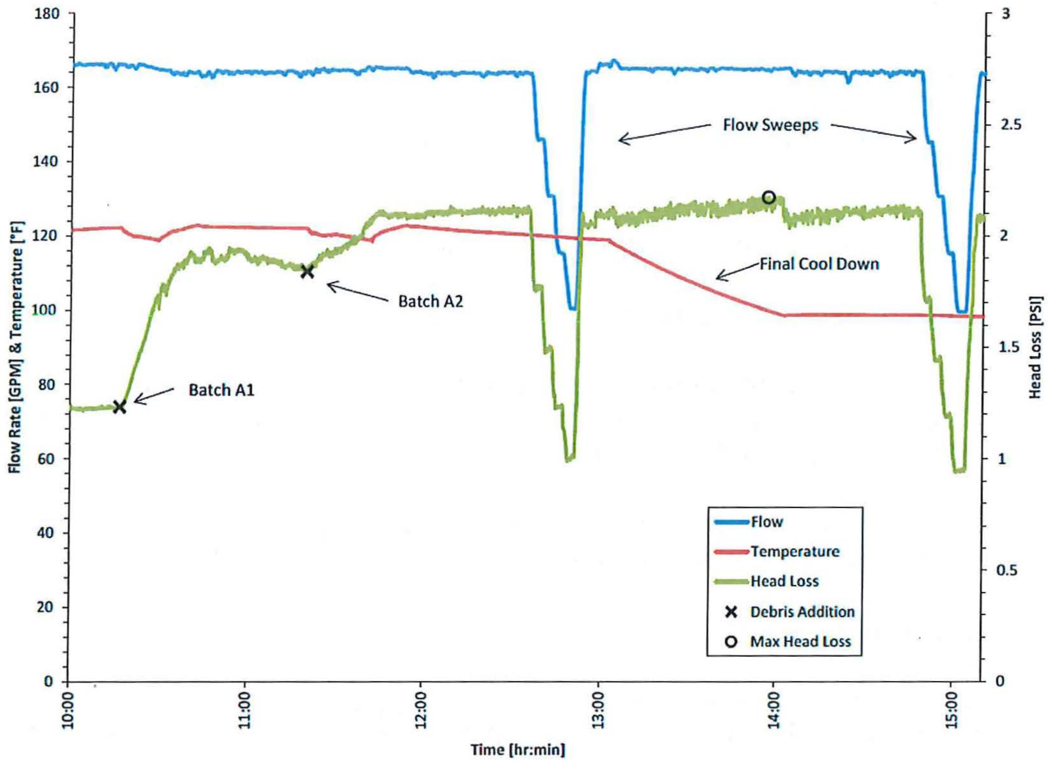


Figure 3.o.2.16-1: FDL Test 2 Chemical Debris Timeline

17. *Data Analysis:*

   i. *Licensees should provide a copy of the pressure drop curve(s) as a function of time for the testing of record.*

   Response to 3.o.2.17.i:

   See the Response to 3.o.2.16 for the pressure drop curve of the limiting test sequence.

   ii. *Licensees should explain any extrapolation methods used for data analysis.*

   Response to 3.o.2.17.ii:

   Extrapolation methods were not used because the chemical head loss had stabilized. As shown in Figure 3.o.2.16-1, the measured head loss varied very little over time before the first flow sweep. See the Response to 3.o.2.16.

18. *Integral Generation (Alion): Licensees should explain why the test parameters (e.g., temperature, pH) provide for a conservative chemical effects test.*

   Response to 3.o.2.18:

   PBN is using the separate chemical effects approach to determine the chemical source term. This section is not applicable to the PBN chemical effects analysis. See Figure 3.o.2.22-1.

19. *Tank Scaling / Bed Formation:*

   i. *Explain how scaling factors for the test facilities are representative or conservative relative to plant-specific values.*

   Response to 3.o.2.19.i:

   PBN is using the separate chemical effects approach to determine the chemical source term. This section is not applicable to the PBN chemical effects analysis. See Figure 3.o.2.22-1.

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

   Response to 3.o.2.19.ii:

   PBN is using the separate chemical effects approach to determine the chemical source term. This section is not applicable to the PBN chemical effects analysis. See Figure 3.o.2.22-1.

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

Response to 3.o.2.20:

PBN is using the separate chemical effects approach to determine the chemical source term. This section is not applicable to the PBN chemical effects analysis. See Figure 3.o.2.22-1.

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.*

Response to 3.o.2.21:

PBN is using the separate chemical effects approach to determine the chemical source term. This section is not applicable to the PBN chemical effects analysis. See Figure 3.o.2.22-1.

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.*

Response to 3.o.2.22:

PBN is using the separate chemical effects approach to determine the chemical source term. This section is not applicable to the PBN chemical effects analysis. See Figure 3.o.2.22-1.

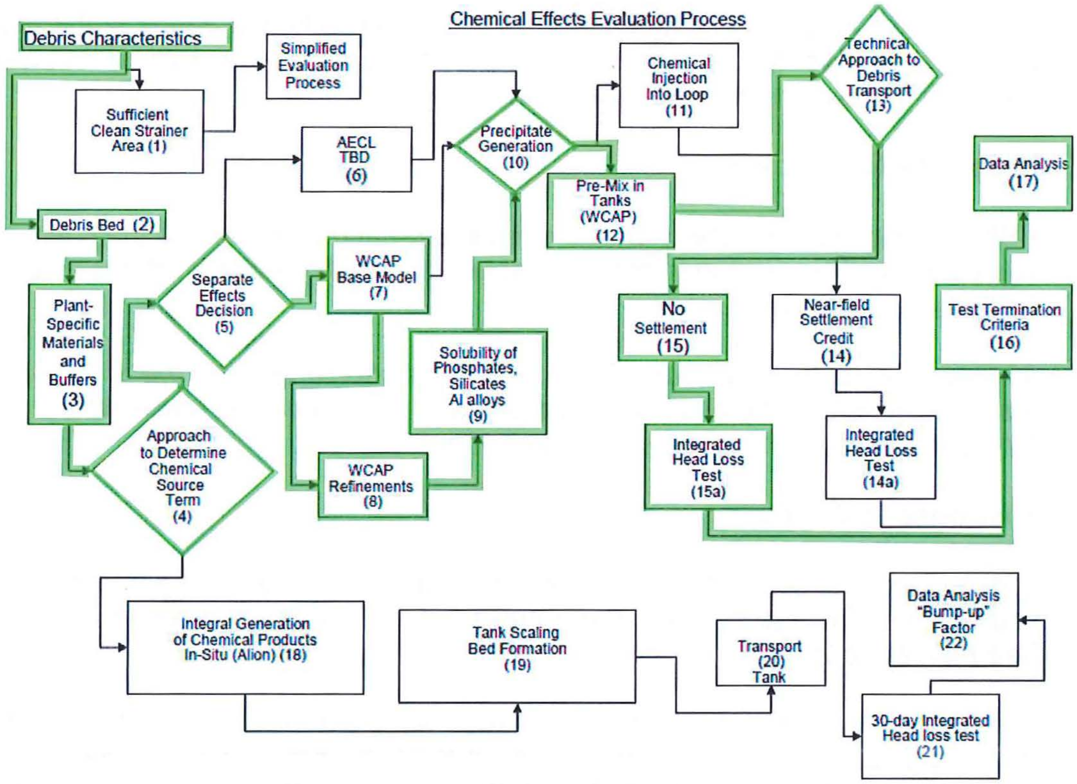


Figure 3.o.2.22-1: Chemical Effects Evaluation Process for PBN (Reference 5 p. 8)

p. Licensing Basis

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

1. *Provide the information requested in GL 2004-02 Requested Information Item 2(e) regarding changes to the plant-licensing basis. The effective date for changes to the licensing basis should be specified. This 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.

Response to 3.p.1:

The PBN UFSAR was updated in 2007 to reflect the containment sump recirculation strainer perforation size for the replacement strainers. Final changes to the PBN UFSAR will be evaluated after approval of the PBN-specific exemption request and receipt of the final closeout letter from the NRC. The changes will be made consistent with the requirements of 10 CFR 50.71 (e).

4. References

1. **NRC Generic Letter 2004-02 (ML042360586).** Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized Water Reactors. September 13, 2004.
2. **NRC Revised Content Guide (ML073110278).** Revised Content Guide for Generic Letter 2004-02 Supplemental Responses. November 2007.
3. **NRC Staff Review Guidance (ML080230038).** NRC Staff Review Guidance Regarding Generic Letter 2004-02 Closure in the Area of Strainer Head Loss and Vortexing. March 2008.
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5. **NRC Staff Review Guidance (ML080380214).** NRC Staff Review Guidance Regarding Generic Letter 2004-02 Closure in the Area of Plant-Specific Chemical Effects Evaluation. March 2008.
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8. **NUREG-1829 Volume 1.** Estimating Loss-of-Coolant Accident (LOCA) Frequencies Through the Elicitation Process. April 2008.
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11. **AISC Manual of Steel Construction.** AISC Manual of Steel Construction: Allowable Stress Design. July 1989. 9th Edition.
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14. **NUREG/CR-6772.** GSI-191: Separate Effects Characterization of Debris Transport in Water. August 2002.
15. **NUREG/CR-6808.** *Knowledge Base for the Effect of Debris on Pressurized Water Reactor Emergency Core Cooling Sump Performance.* February 2003.
16. **Nuclear Energy Institute.** ZOI Fibrous Debris Preparation: Processing, Storage, and Handling. January 2012. Revision 1.
17. **NUREG/CR-6224.** Parametric Study of the Potential for BWR ECCS Strainer Blockage Due to LOCA Generated Debris. October 1995.
18. **WCAP-16530-NP-A.** Evaluation of Post-Accident Chemical Effects in Containment Sump Fluids to Support GSI-191. March 2008.
19. **NEI Guidance Report NEI 09-10.** Guidelines for Effective Prevention and Management of System Gas Accumulation. April 2013. Revision 1a-A.
20. **ML070950240.** San Onofre Nuclear Generating Station Unit 2 and Unit 3 GSI-191 Generic Letter 2004-02 Corrective Actions Audit Report.
21. **ML082050433.** Indian Point Energy Center Corrective Actions for Generic Letter 2004-02.
22. **FPL letter NRC2008-0013 (ML080630613).** Supplemental Response to Generic Letter 2004-02, Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized-Water Reactors. February 29, 2008.
23. **Nuclear Industry Procedure IP-ENG-001.** Standard Design Process. *Revision C, September 8, 2016.*
24. **ASME B&PV Code.** *Section III, Division 1, Subsections NB, NC, and Appendices.* 1998 Edition, through 1999 Addenda.
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32. **WCAP-17788-NP, Volume 3.** Comprehensive Analysis and Test Program for GSI-191 Closure (PA-SEE-1090)-Cold Leg Break (CLB) Evaluation Method for GSI-191 Long-Term Cooling. December 2014.
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