FPL

DEC 2 0 2017

L-2017-210
GL 2004-02

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

Re: St. Lucie Units 1 and 2
Docket Nos. 50-335 and 50-389
Renewed Facility Operating Licenses DPR-67 and NPF-16

Updated Final Response to NRC Generic Letter 2004-02

With this letter, Florida Power & Light Company (FPL) 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 St. Lucie Nuclear Units 1 and 2 (St. Lucie). 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 system functionality. GL 2004-02 cited the findings of Generic Safety Issue (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 documents referenced herein. In References 1 and 2 of Attachment 1, FPL, the licensee for St. Lucie, submitted responses to the information requested in GL 2004-02. In References 3 through 13, FPL responded to requests for additional information that the NRC determined were necessary to complete its review, established commitments for completion of specified corrective actions and provided supplemental information summarizing testing, analyses and modifications that were planned or completed at St. Lucie.

In Reference 14, 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 contributed greatly to the safety of U.S. nuclear power plants. In Reference 15, FPL notified the NRC staff of its selection for GSI-191 resolution in accordance with the options specified in Reference 14 and additionally summarized the remaining GL 2004-02 related corrective actions requiring completion.

Throughout this time, FPL has implemented plant upgrades, defense in-depth measures and mitigation strategies at St. Lucie that 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, FPL hereby rescinds the GSI-191/GL 2004-02 related commitments described in previous correspondence on behalf of St. Lucie and submits the enclosed bases for resolution of GSI-191 and thereby closure of GL 2004-02. Consistent with the recommended methodology specified in Option 2a of Reference 14, FPL 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 St. Lucie.

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Enclosure 1 to this letter provides FPL's bases for closure of GL 2004-02. The bases for closure includes a core blockage analysis using the methodology described in WCAP-17788, Comprehensive Analysis and Test Program for GSI-191 Closure (Reference 16). FPL 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 St. Lucie will be reviewed and if warranted, a reanalysis will be performed.

Additionally, changes to the St. Lucie licensing basis have been implemented which allowed FPL to complete plant modifications that have enhanced St. Lucie's capability to withstand GSI-191 related failures and thereby assure compliance with the the long-term cooling requirements of 10 CFR 50.46(b)(5). Accordingly, the assumptions and inputs used to establish the bases for GL 2004-02 closure are consistent with the St. Lucie licensing basis and no new changes pursuant to 10 CFR 50.90 are being proposed as a result of this submittal. Upon NRC acceptance of FPL's closure of GL 2004-02, the updated final safety analysis reports (UFSARs) for St. Lucie Units 1 and 2 will be reviewed to determine if further changes to the licensing basis are appropriate in accordance with 10 CFR 50.71(e).

Section 1 of Enclosure 1 provides FPL's statement of compliance with the *Applicable Regulatory Requirements* section of GL 2004-02 on behalf of St. Lucie. 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 significant margins and conservatisms that were utilized in the analyses. In keeping with the NRC's Revised Content Guide for GL 2004-02 (Reference 17), Section 3 of Enclosure 1 provides an evaluation of the sixteen identified issue areas, including the methodologies employed to arrive at a determination of acceptable performance and their bases for use. 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 St. Lucie has been reduced to an acceptable level. Section 4 lists the documents referenced in Enclosure 1.

This letter contains the following regulatory commitment (below). This letter supersedes all prior regulatory commitments identified in References 1 through 13, Reference 15, and related correspondence on behalf of St. Lucie.

Regulatory Commitment

> Upon NRC approval of WCAP-17788, *Comprehensive Analysis and Test Program for GSI-191 Closure*, the completed in-vessel blockage analysis for St. Lucie will be reviewed and if warranted, a reanalysis will be performed within six months following approval of the WCAP-17788 methodology. (Enclosure 1, Section 2, General Description of and Schedule for Corrective Actions)

If you have any questions or require additional information, please contact Mr. Michael Snyder, St. Lucie Licensing Manager, at (772) 467-7036.

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

Executed on DEC 2 0 2017

Sincerely,

Daniel DeBoer

Daniel DeBoer
Site Director - St. Lucie Nuclear Plant, Units 1 and 2
Florida Power & Light Company

Attachment 1 - List of References
Enclosure 1 - Updated Final Response to NRC Generic Letter 2004-02

cc: USNRC Regional Administrator, Region II
USNRC Project Manager, St. Lucie Nuclear Plant, Units 1 and 2
USNRC Senior Resident Inspector, St. Lucie Nuclear Plant, Units 1 and 2
Ms. Cindy Becker, Florida Department of Health

ATTACHMENT 1

REFERENCES

1. Florida Power and Light (FPL) Company/FPL Energy Seabrook LLC letter L-2005-034, NRC Generic Letter 2004-02 Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized Water Reactors, dated March 4, 2005 (ADAMS Accession Number ML050670429)

2. FPL/FPL Energy Seabrook LLC letter L-2005-181, NRC Generic Letter 2004-02, Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized Water Reactors - Second Response, September 1, 2005 (ADAMS Accession Number ML052490339)

3. FPL/FPL Energy Seabrook LLC letter L-2005-145, NRC Generic Letter 2004-02 Request for Additional Information Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized Water Reactors, dated July 20, 2005 (ADAMS Accession Number ML052080038)

4. FPL/FPL Energy Seabrook LLC letter L-2007-155, Request for Extension of Completion Date of the St. Lucie Unit 1, St. Lucie Unit 2 and Turkey Point Unit 3, Generic Letter 2004-02 Actions, dated December 7, 2007 (ADAMS Accession Number ML073450338)

5. FPL letter L-2007-194, Response to Questions Regarding Request for Extension of Completion Date of the St. Lucie Unit 1, St. Lucie Unit 2 and Turkey Point Unit 3 Generic Letter 2004-02 Actions, dated December 20, 20074 (ADAMS Accession Number ML080090147)

6. FPL letter L-2008-030, Supplemental Response to NRC Generic Letter 2004-02, Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized-Water Reactors, dated February 27, 2008 (ADAMS Accession Number ML080650560)

7. FPL letter L-2008-137, Supplemental Response to NRC Generic Letter 2004-02, Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized-Water Reactors, dated June 30, 2008 (ADAMS Accession Number ML081840513)

8. FPL letter L-2008-235, Request for Extension of the Completion Date of the St. Lucie Unit 1 NRC Generic Letter 2004-02 Actions, dated October 29, 2008 (ADAMS Accession Number ML082900487)

9. FPL letter L-2009-085, Response to NRC Request for Additional Information, dated April 16, 2009 (ADAMS Accession Number ML091130222)

10. FPL letter L-2009-084, Response to NRC Request for Additional Information, dated April 22, 2009 (ADAMS Accession Number ML091210225)

11. FPL letter L-2009-179, Updated Supplemental Response to NRC Generic Letter (GL) 2004-02, Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized-Water Reactors, dated July 30, 2009 (ADAMS Accession Number ML092170370)

12. FPL letter L-2009-180, Additional Responses to the NRC's Request for Additional Information, dated July 30, 2009 (ADAMS Accession Number ML092160596)

13. FPL/FPL Energy Seabrook LLC/FPL Energy Point Beach LLC letter L-2012-323, Strainer Fiber Bypass Test Protocol, dated August 10, 2012 (ADAMS Accession Number ML12228A330)

14. Staff Requirements Memorandum - SECY-12-0093 - Closure Options for Generic Safety Issue - 191, Assessment of Debris Accumulation on Pressurized-Water Reactor Sump Performance, dated December 14, 2012 (ADAMS Accession Number ML12349A378)

15. FPL letter L-2013-168, Path Forward for Resolution of GSI-191, dated May 15, 2013, (ADAMS Accession Number ML13149A269)

16. Westinghouse WCAP-17788, Volume 1, Comprehensive Analysis and Test Program for GSI-191 Closure, Revision 0, July 2015 (ADAMS Accession No. ML15210A669)

17. Revised Content Guide for Generic Letter 2004-02 Supplemental Responses, Enclosure, November 2007 (ADAMS Accession No. ML073110278

ENCLOSURE 1

Updated Final Response to NRC Generic Letter 2004-02
St. Lucie Nuclear Plant, Units 1 and 2

Table of Contents

This enclosure provides Florida Power and Light's (FPL's) final response to Generic Letter (GL) 2004-02 (Reference 1)[JT1] in the form of a stand-alone document that supersedes all previous GL 2004-02 submittals for St. Lucie Unit 1 (PSL1) and Unit 2 (PSL2). Previous Requests for Additional Information (RAIs) are not specifically addressed in this submittal since this document is providing the information necessary to address the required information delineated in GL 2004-02. This enclosure follows the format and guidance provided by the Nuclear Regulatory Commission (NRC) (Reference 2; 3; 4; 5)[JT2] and addresses all topical areas in those documents. The text from the NRC guidance is presented in italic script.

This enclosure contains input based on both sound engineering judgement as well as documents verified through a 10 CFR 50 Appendix B program. The inputs from engineering judgement have been prepared, verified, and approved by knowledgeable engineers.

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 PSL

The key aspects of the approach chosen by FPL 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.
- Changes to the PSL1 and PSL2 licensing basis, including Technical Specification (TS) changes, to reflect the plant modifications, and the change to a mechanistic sump strainer blockage evaluation.
- 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 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 PSL1 and PSL2, which determined the debris generated for all break sizes from 0.5 inches up to 42 inches at all circumferential Class I in-service inspection (ISI) welds (and longitudinal welds at PSL1) 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 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 Volume 1 (Reference 6 p. 27)[JT3] for any materials except qualified coatings, which used a ZOI size based on testing that has been reviewed and accepted by the NRC (Reference 7 p. 2)[JT4]. The ZOI size that is being used for qualified coatings is 4.0D. Additional discussion is provided in the Responses to 3.b and 3.h.

FPL has performed extensive testing for strainer head loss and debris bypass (or penetration). A portion of the PSL1 head loss testing was observed by the NRC at the test facility. The testing used conservative methods including the NRC reviewed protocols for fibrous debris preparation (Reference 8)[JT5] and strainer bypass testing.[JT6] Additional discussion is provided in the Responses to 3.f, 3.n, and 3.o.

The core blockage analysis methodology documented in WCAP-17788 (Reference 9) [JT7]has not yet been finalized and the safety evaluation (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 PSL1 and PSL2. These results conservatively used a 30-day debris bypass quantity (see the Response to 3.n.1). PSL1 and PSL2 meet the debris limits currently identified in WCAP-17788, with the assumption that PSL2 has completely transitioned to AREVA fuel, which is more limiting than the Westinghouse fuel that is being phased out (Reference 10)[JT8]. 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.

Changes to the Licensing Basis

FPL had previously completed changes to the PSL1 and PSL2 updated final safety analysis report (UFSAR) to recognize the mechanistic evaluation of the effect of post-accident debris on the ECCS and CSS recirculation function, as described in this letter. It is not anticipated that further changes to either unit's UFSAR will be required, but the UFSARs will be reviewed after NRC acceptance of information presented in this submittal to determine if any further changes are necessary.

If changes are determined to be necessary, then the UFSAR updates will occur after receipt of the final closeout letter from the NRC. This is discussed in the Response to 3.p.

FPL has incorporated NRC-approved TS changes for increased water level in the refueling water tank (RWT) at PSL1 and PSL2 to ensure a sufficient quantity of water is available to enable the containment recirculation function to operate as required in the post-loss of coolant accident (LOCA) environment.

Improvements in Processes and Programs

FPL has completed a review of plant procedures, processes, and programs and has updated those procedures, processes, and programs that will ensure the analysis inputs and assumptions can be maintained. This is discussed in the Response to 3.i. The changes to those programs and processes determined to be necessary to support the transition to the mechanistic evaluation methodology licensing basis were in place prior to, or at the time of the change to the licensing basis.

Conservatisms and Margins

FPL 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

FPL has completed all necessary analyses, with the exception of NRC acceptance of the in-vessel blockage analysis, and has updated the PSL licensing basis to reflect that the ECCS and CSS recirculation functions under debris loading conditions are in compliance with the regulatory requirements listed in the Applicable Regulatory Requirements section of GL 2004-02. FPL has completed all associated plant modifications in PSL1 and PSL2.

Applicable Regulatory Requirements

The applicable regulatory requirements identified in GL 2004-02 (Table 1-1 and Table 1-2) 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"

The Construction Permit for the St. Lucie Unit 1 Nuclear Plant was issued on July 1, 1970 and preceded the publication of the (AEC) "General Design Criteria for Nuclear Power Plants" (10 CFR 50, Appendix A, February 20, 1971).

Table 1-1: PSL1 GL 2004-02 Regulatory Compliance

Regulatory Statute	Applicable Requirement	PSL1 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 NPSH during recirculation with new margins based on revised debris transport calculations, and head loss testing with chemical precipitates. • Replacement of Thermal-Wrap insulation on the pressurizer upper head with RMI (reflective metallic insulation) reduces potential strainer fiber loading. • Walkdowns, Sump Water Level Calculation, and TS increase in the minimum RWT volume from 401,800 gallons to 477,360 gallons (Reference 11)[JT9] have confirmed that design basis sump water supply will be available. • Removal of cyclone separators and installation of new HPSI pump seals ensure long term operation. • Downstream effects evaluations confirmed that no other modifications are required to ensure long-term cooling capability is maintained. • Downstream fuel and in-vessel evaluations demonstrate that long term post-LOCA core cooling will be maintained with acceptably low fuel temperatures • Coating adhesion tests confirm that current inspection methods are adequate to control quantity of degraded qualified coatings.
10 CFR 50, Appendix A, GDC 35	Criterion 35--Emergency core cooling. A system to provide abundant emergency core cooling shall be provided. The system safety function shall be to transfer heat from the reactor core following any loss of reactor coolant at a rate such that (1) fuel and clad damage that could interfere with continued effective core cooling is prevented and (2) clad metal-water reaction is limited to negligible amounts.	The assurance of long-term cooling capability during recirculation ensures that the design basis emergency core cooling capabilities are maintained.
10 CFR 50, Appendix A, GDC 38	Criterion 38--Containment heat removal. A system to remove heat from the reactor containment shall be provided. The system safety function shall be to reduce rapidly, consistent with the functioning of other associated systems, the containment pressure and temperature following any loss-of-coolant accident and maintain them at acceptably low levels.	The assurance of long-term cooling capability during recirculation ensures that the design basis containment heat removal capabilities are maintained.

Regulatory Statute	Applicable Requirement	PSL1 Basis for Compliance with GL 2004-02
10 CFR 50, Appendix A, GDC 41	Criterion 41--Containment atmosphere cleanup. Systems to control fission products, hydrogen, oxygen, and other substances which may be released into the reactor containment shall be provided as necessary to reduce, consistent with the functioning of other associated systems, the concentration and quality of fission products released to the environment following postulated accidents, and to control the concentration of hydrogen or oxygen and other substances in the containment atmosphere following postulated accidents to assure that containment integrity is maintained.	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.

Table 1-2: PSL2 GL 2004-02 Regulatory Compliance

Regulatory Statute	Applicable Requirement	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 NPSH during recirculation with new margins based on revised debris transport calculations and head loss testing with chemical precipitates. • Walkdowns, Sump Water Level Calculation, and TS increase in the minimum RWT volume from 417,100 gallons to 477,360 gallons (Reference 11)[JT10] have confirmed that design basis sump water supply will be available. • Removal of cyclone separators and installation of new HPSI pump seals ensure long term operation. • Removal of cyclone separators and installation of new CS pump seals ensure long term operation. • Downstream components and systems evaluations demonstrate long term post-LOCA operation of equipment, including demonstration that ECCS/CSS recirculation pumps can operate for long term post-LOCA. • Downstream fuel and in-vessel evaluations demonstrate that long term post-LOCA core cooling will be maintained with acceptably low fuel temperatures. • Coating adhesion tests confirm that current inspection methods are adequate to control quantity of degraded qualified coatings to bound assumptions in debris calculations.
10 CFR 50, Appendix A, GDC 35	Criterion 35--Emergency core cooling. A system to provide abundant emergency core cooling shall be provided. The system safety function shall be to transfer heat from the reactor core following any loss of reactor coolant at a rate such that (1) fuel and clad damage that could interfere with continued effective core cooling is prevented and (2) clad metal-water reaction is limited to negligible amounts.	The assurance of long-term cooling capability during recirculation ensures that the design basis emergency core cooling capabilities are maintained.
10 CFR 50, Appendix A, GDC 38	Criterion 38--Containment heat removal. A system to remove heat from the reactor containment shall be provided. The system safety function shall be to reduce rapidly, consistent with the functioning of other associated systems, the containment pressure and temperature following any loss-of-coolant accident and maintain them at acceptably low levels.	Assurance of long-term cooling capability during recirculation for the CS pumps ensures that the design basis containment heat removal capabilities are maintained.

Regulatory Statute	Applicable Requirement	Basis for Compliance with GL 2004-02
10 CFR 50, Appendix A, GDC 41	Criterion 41--Containment atmosphere cleanup. Systems to control fission products, hydrogen, oxygen, and other substances which may be released into the reactor containment shall be provided as necessary to reduce, consistent with the functioning of other associated systems, the concentration and quality of fission products released to the environment following postulated accidents, and to control the concentration of hydrogen or oxygen and other substances in the containment atmosphere following postulated accidents to assure that containment integrity is maintained.	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 Corrective Actions:

Provide a general description of actions taken or planned, and dates for each. For actions planned beyond December 31, 2007, reference approved extension requests or explain how regulatory requirements will be met as per 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 GL. Efforts to implement the identified actions should be initiated no later than the first refueling outage starting after April 1, 2006. All actions should be completed by December 31, 2007. Provide justification for not implementing the identified actions during the first refueling outage starting after April 1, 2006. If 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 PSL consisted of plant modifications, testing and analysis, changes to plant programs and processes, and changes to the licensing basis. These actions have been completed in accordance with FPL regulatory commitments and NRC-approved extensions. The completion dates for these actions are provided below.

Plant Modifications

- At PSL1 and PSL2 the original sump screens have been removed and replaced with new strainer systems in Spring 2007 [JT11]and Fall 2007,[JT12] respectively. These systems ensure adequate pump NPSH margins during recirculation.
- At PSL1, Calcium Silicate (Cal-Sil) insulation on selected piping in containment was reinforced with a banding system in Spring 2007 [JT13]to increase the destruction pressure of the insulation, should it be subject to the forces of a LOCA jet. Note that the debris generation analysis did not take credit for this modification (potentially reducing the ZOI size for Cal-Sil).
- At PSL1, the Thermal-Wrap fibrous insulation on the pressurizer upper head replaced with Darchem stainless steel RMI in Fall 2005.[JT14] This modification will reduce strainer fiber loads for potential pipe breaks in the pressurizer compartment.

- At PSL2, the Nukon fibrous insulation on the steam generators was replaced with Transco stainless steel RMI in Fall 2007.[JT15] This modification will reduce strainer fiber loads for potential pipe breaks inside the secondary shield wall.
- The pumps listed below had the seals and cyclone separators replaced with a seal system that does not use cyclone separators or rely on the pumped water for flushing and cooling the mechanical seals. The new seal systems will prevent the potential failure of shaft seals that could be caused by the carryover of debris in the pumped water when the pumps take suction of potentially debris-laden fluid from the containment strainer systems while operating in recirculation mode.
    - PSL1 HPSI pumps – Spring 2007 [JT16]
    - PSL2 HPSI pumps – Fall 2007 [JT17]
    - PSL2 CS pumps – Fall 2007 [JT18]
- At PSL1 and PSL2, the TS minimum RWT water volume has been increased from 401,800 gallons (Unit 1) and 417,100 gallons (Unit 2) to 477,360 gallons (both units) (Reference 11)[JT19].

Testing and Analyses

The testing and analyses needed to address GL 2004-02 concerns were completed by December 31, 2016. 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 FPL is not planning any further actions. If the review determines 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 materials in containment. Procedures require inspection of all accessible areas to verify that no loose debris, fibrous materials 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 site functional area manager (SFAM) has been placed 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 evaluate for adverse impact 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.

PSL engineering change processes and procedures ensure modifications that may affect the ECCS, including sump performance, are evaluated for impact on the inputs and assumptions used for the response to GL 2004-02. 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 of primary containment including installing coated equipment.

PSL has adopted the industry's standard change process, including the industry procedure IP-ENG-001. 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 FPL'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.

The containment closeout procedure was updated to include all of the strainer system components in the final containment closeout inspection. The effect of these changes is to ensure that all components (strainer modules, piping, and pipe connections) are inspected, and that there are no holes, gaps, or tears greater than 1/16 inch in any strainer system component.[JT20]

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 reviews 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, PSL 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 licensing basis changes needed to address the GL 2004-02 concerns consist of UFSAR changes related to the plant modifications implemented to resolve the concerns identified in GL 2004-02, TS changes related to a change in the minimum required RWT water level, and licensing basis changes to reflect the mechanistic evaluation of the effect of post-accident debris on the ECCS and CSS recirculation functions.

It is not anticipated that further changes to either Unit's UFSAR will be required, but the UFSARs will be reviewed after NRC acceptance of information presented in this submittal to determine if any further changes are determined to be necessary. If changes are determined to be necessary, then the UFSAR updates will occur after receipt of the final closeout letter from the NRC.

Margins & Conservatisms

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

Debris Generation

Margins:

- The amount of latent debris at PSL1 and PSL2 was conservatively increased to 100 lbm, rather than using the walkdown value (67.4 lbm).[JT21]
- The amount of transportable miscellaneous debris at PSL1 and PSL2 was conservatively increased to 133 ft^2, rather than using the walkdown value (24.4 ft^2).[JT22]
- The quantities of unqualified coatings were conservatively increased over the values from the coating logs by 4% at PSL1 and 10% at PSL2 (see the Response to 3.h.5).

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.[JT23]
- Unqualified coatings were given a 100% failure rate for all breaks, conservatively maximizing the potential unqualified coatings load in the recirculation pool.[JT24]
- Qualified epoxy was assumed to fail as 100% particulate, conservatively treating it as the most easily transportable debris type.[JT25]
- No reduction in Cal-Sil ZOI size was credited for the reinforced banding system installed on selected piping at PSL1.[JT26]

Debris Transport

Conservatisms:

- During pool fill-up, the transport to the inactive cavity (reactor cavity) was conservatively limited to 15% for fine debris. Note that the transport to the inactive cavity without the limitation was calculated to be 71%.[JT27]
- It was conservatively assumed that all unqualified coatings are located in lower containment and would fail at the start of the event (t=0). 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.[JT28]

- 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).[JT29]
- Small pieces of debris on the concrete operating deck after blowdown were assumed to wash to lower containment without any retention on grating.[JT30]
- 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.[JT31]
- 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.[JT32]
- 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.[JT33]
- 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 (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.[JT34]
- It was assumed that all Temp-Mat debris would float in the recirculation pool until it was 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.[JT35]
- 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.[JT36]

Water Volume and Level

Conservatisms:

- It was assumed that the bounding containment pressure, temperature, and sump water temperature values are applicable to small-break loss of coolant accidents (SBLOCAs). This is a reasonable assumption when used to calculate the densities of injection volumes and hold-up volumes, as the pressure and temperatures are expected to be considerably elevated for all LOCA sizes.[JT37]
- Maximum temperature values for the RWT, safety injection tanks (SIT), boric acid make-up tanks (BAMT), RCS, and sodium-hydroxide (NaOH) or hydrazine (N_2H_4) were used when calculating water volumes adjusted to the minimum sump temperature at recirculation actuation signal (RAS). This conservatively minimizes the volume of water released into the containment sump, thereby minimizing the containment sump volume.[JT38]
- Many of the components and structures that exist in containment at the pool level were conservatively neglected resulting in less displacement of pool water and a resulting lower level (see the Response to 3.g.11).

NPSH

Margins:

- After accounting for debris and clean strainer head losses, the containment spray pump at PSL1 has an NPSH margin of 14.39 ft (larger at lower temperatures).[JT39]
- After accounting for debris and clean strainer head losses, the low pressure safety injection (LPSI) pump at PSL1 has an NPSH margin of 17.92 ft (larger at lower temperatures).[JT40]
- After accounting for debris and clean strainer head losses, the HPSI pump at PSL1 has an NPSH margin of 1.43 ft.[JT41]
- For PSL1, the total strainer head losses used to evaluate pump NPSH margins for sump temperatures at or below 153 °F were based on the chemical debris head loss due to aluminum precipitates. As shown in the Response to 3.o.2, aluminum precipitate will not form until the sump temperature is below 98.2 °F.
- At PSL1, the large-break loss of coolant accident (LBLOCA) flow rate used to calculate the NPSH margin was higher than the maximum design flow rate. This conservatively maximizes the NPSH required and minimizes the NPSH available (see the Response to 3.g.1).
- After accounting for debris and clean strainer head losses, the containment spray pump at PSL2 has an NPSH margin of 4.97 ft (larger at lower temperatures).[JT42]
- After accounting for debris and clean strainer head losses, the HPSI pump at PSL2 has an NPSH margin of 3.52 ft (larger at lower temperatures).[JT43]

Conservatisms:

- NPSH margins are based on minimum containment water levels.[JT44]

Strainer Structural Analysis

Margins:

- The strainer system analysis (which includes strainer structure, piping, pipe supports) provides margin to design allowable stresses, which ensures that the strainer system will perform its function as long as is necessary following an event which requires its use. Table 3.k.2-2 through Table 3.k.2-5 for PSL1, and Table 3.k.2-6 and Table 3.k.2-7 for PSL2 in the Response to 3.k.2 contain itemized strainer component lists and the margins for each component.

Conservatisms:

- The system only operates once containment is flooded with water and the entire system is fully submerged, following a LOCA event. Thereafter, during steady state recirculation mode operation, the maximum differential pressure across the strainer is produced.[JT45] The strainer assembly weight, debris weight and crush pressure (differential pressure) is included in the maximum earthquake analysis (SSE) to develop the stresses and loads on the strainer (see the Response to 3.k.1, Table 3.k.1-1 and Table 3.k.1-2 for PSL1, Table 3.k.1-5 and Table 3.k.1-6 for PSL2).
- Use of the codes of record provide the conservatism inherit within the code itself.

Head Loss

Conservatisms:

- When evaluating vortexing, the minimum strainer submergence at the start of recirculation is used. Any increase in sump pool level over time was conservatively neglected.[JT46]
- 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. Additionally, chemical debris will not form until the pool temperature drops below 98.2°F for PSL1 and 120.8 °F for PSL2.[JT47]
- As discussed in the Response to 3.f.7, the tested chemical debris loads bound the plant debris load with a large margin for both PSL1 and PSL2.

- When evaluating flashing, the pre-LOCA minimum air partial pressure of the containment atmosphere was considered. This minimum air partial pressure was determined based on the most limiting pre-accident containment operating conditions: technical specifications highest normal operating containment temperature and technical specifications minimum normal operating containment pressure. Additionally, the increase in air partial pressure due to heat-up of the containment atmosphere following an accident was not credited (see the Response to 3.f.14).

Penetration

Conservatisms:

- No particulate debris was used in penetration testing.[JT48] Particulate debris hastens bed formation by filling gaps and plugging holes within the network of entangled fibers on the strainer. This, in turn, increases head loss across the debris bed, causing increased bed compression. The combination of these effects results in a reduction of available paths for fiber to traverse its way through the debris bed and through the strainer perforations. Thus, the exclusion of particulate debris for penetration testing is conservative.
- The most conservative value from the prototypical range of plant parameters was selected for large-scale testing. Plant parameters (approach velocity, water chemistry) were investigated for their impact on penetration quantity in small-scale testing. Those parameter values that led to the greatest penetration quantities were used in large scale testing.[JT49] At PSL1, it was inconclusive in the small-scale testing if a higher or lower approach velocity would generate more penetration. Therefore, two different large-scale tests were run, which varied the approach velocity.[JT50]
- Every other disk was removed from the test strainers in order to increase the gap between adjacent disks. 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. Therefore, the prevention of fiber bridges is conservative.[JT51]

Chemical Effects

Margins:

- For PSL1, the maximum calculated aluminum precipitate mass is 7.0 kg [JT52]and the minimum aluminum precipitate mass used in testing (scaled to the plant) is 122.1 kg (see the Response to 3.f.4); therefore, there is an aluminum precipitate mass margin of 115.1 kg.
- For PSL2, the maximum calculated aluminum precipitate mass is 2.1 kg [JT53]and the minimum aluminum precipitate mass used in testing (scaled to the plant) is 56.9 kg (see the Response to 3.f.4); therefore, there is an aluminum precipitate mass margin of 54.8 kg.

Conservatisms:

- Debris quantities bound the maximum amount of debris predicted from the bounding LOCA break.[JT54]
- Maximum pH values are conservatively assumed to increase the calculated aluminum release and minimum pH values are conservatively assumed to decrease the calculated aluminum solubility.[JT55]
- The maximum containment sump pool mass is conservatively assumed to increase the calculated aluminum release in aluminum release cases.[JT56]
- The minimum containment sump pool mass is conservatively assumed to increase the calculated maximum aluminum precipitation temperature in aluminum solubility cases.[JT57]
- Maximum temperature profiles are conservatively assumed.[JT58]
- All destroyed and latent debris is conservatively assumed to be submerged.[JT59]
- All unsubmerged aluminum in containment is assumed to be exposed to containment spray for the full 30-day duration of the event.[JT60]
- The total quantity of aluminum in solution is assumed to precipitate after the concentration exceeds the calculated solubility limit.[JT61]
- The total quantity of dissolved calcium is assumed to precipitate as calcium phosphate immediately upon release into solution (at PSL2 only).[JT62]

In-Vessel

Conservatisms:

- When calculating the in-vessel fiber load, the operation of containment spray was minimized by assuming a single CS pump failure and minimum operation time. This input directed more fiber that passed through the strainers to the reactor (see the Response to 3.n.1).
- The time at which simultaneous hot and cold leg injection occurs was delayed in the in-vessel modeling. This maximizes the duration of cold leg recirculation during which a higher fraction of debris can reach the core inlet (see the Response to 3.n.1).
- The values presented for core inlet and total reactor vessel fiber loads are for the entire 30-day mission time. This is conservative because the eventual acceptance criteria from WCAP-17788 will be compared to the in-vessel fiber loads before the conclusion of the 30-day mission time (see the Response to 3.n.1).

LOCADM (Loss of Coolant Accident Deposition Model)

Margins:

- The maximum peak cladding temperature (PCT) in the LOCADM analysis for PSL1 is 392.7 °F with an acceptance criterion of 800 °F, resulting in a margin of 407.3 °F.[JT63]
- The maximum PCT in the LOCADM analysis for PSL2 is 386.9 °F with an acceptance criterion of 800 °F, resulting in a margin of 413.1 °F.[JT64]
- The maximum deposition thickness (DT) in the LOCADM analysis for PSL1 is 18.65 mils with an acceptance criterion of 50 mils, resulting in a margin of 31.35 mils.[JT65]
- The maximum DT in the LOCADM analysis for PSL2 is 14.34 mils with an acceptance criterion of 50 mils, resulting in a margin of 35.66 mils.[JT66]

Conservatisms:

- When calculating fuel rod debris deposition thickness and peak clad temperature, the entire fine particulate, fine fiber, and chemical precipitate loads were assumed to be available to collect on the fuel rods with no credit taken for accumulation on the strainer.
- The containment sump pool pH is assumed to remain at the maximum final containment sump pool pH throughout the duration of the analysis.[JT67]
- 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.[JT68]
- The amount of fibrous debris which bypasses the sump strainer and is available for deposition in the core is assumed to be 100 grams per fuel assembly (g/FA). This value, which is greater than the bypassed fiber mass determined from testing, can be used for operating margin or as a conservatism because it leads to a greater deposition thickness.[JT69]

Ex-Vessel

Conservatisms:

- The minimum sump pool volume following an SBLOCA was combined with the maximum debris loads from a LBLOCA to determine the debris concentration.[JT70] This is conservative because minimizing the mass of recirculating water maximizes the debris concentration, and thus the amount of wear. Additionally, water volumes such as portions of the RCS inventory or the volume of water in the residual heat removal (RHR) piping could also be proven to be part of the recirculation flow path, but were conservatively excluded for the downstream effects calculations.
- The debris concentration was calculated assuming 100% bypass of all fiber fines.[JT71] Penetration testing has shown that bypass for fiber fines at PSL1 and PSL2 is much lower than 100%. Therefore, this assumption conservatively increases the debris concentration, and thus the amount of wear.
- Although the actual maximum spherical size particulate that is expected to bypass the strainer is 0.066 inches for PSL1 and 0.06875 inches for PSL2, the maximum particulate size that bypasses the strainer was conservatively assumed to be 0.100 inches for the downstream effects evaluations.[JT72]
- The quantities of transported debris at PSL1 and PSL2 have been revised since the downstream effects evaluations were performed. It was determined that the revised transported debris quantities would result in lower debris concentrations than those used in the downstream effects evaluations.[JT73] Therefore, the downstream effects evaluations were performed using conservatively high debris concentrations.

3. Specific Information Regarding Methodology for Demonstrating Compliance:

3.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 PSL1 and PSL2 debris generation calculations [JT74]followed the methodology of NEI 04-07 Volume 1 and the associated NRC SE on NEI 04-07 (Reference 12 pp. 3-5 - 3-26, 4-1 - 4-5; 6 pp. 12-35, 85-91, respectively),[JT75] with the exception that they analyzed a full range of breaks, rather than just the worst-case breaks as suggested by NEI 04-07 Volume 1. The purpose of the calculations was to obtain debris quantities for a range of possible break scenarios. The calculations evaluated debris generation quantities for breaks on every circumferential ISI weld (and longitudinal welds at PSL1) within the Class 1 pressure boundary inside the first isolation valve, including breaks at the reactor nozzles.[JT76] The following types of LOCA breaks were considered:

- DEGBs with the largest break being a DEGB of the 42" hot leg,
- Partial breaks, orientated 45 degrees apart, at size increments of 0.5, 2, 4, 6, 8, 10, 12, 14, 17, 20, 23, and 26 inches.
- SEGBs within 10 pipe diameters of a normally closed isolation valve or termination point (at PSL1 only).

In the debris generation calculations, three-dimensional (3D) CAD models of the PSL1 and PSL2 containment buildings were updated to work with ENERCON's BADGER software. BADGER was used to place ZOIs representing possible breaks on every circumferential ISI weld (and longitudinal welds at PSL1) inside the first isolation valve in containment. Figure 3.a.1-1 shows the graphical representation of these weld locations for PSL1 and Figure 3.a.1-2 shows the graphical representation of these weld locations for PSL2.[JT77]

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" (Reference 6 p. 17)[JT78]. 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 Figure 3.a.1-1 and Figure 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.[JT79] 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.

Breaks were also evaluated incrementally along the straight sections of piping at PSL1 that contain longitudinal welds.[JT80] The distance between these break locations was one-half the inside diameter of the piping segment.[JT81] For example, for the 42" ID piping, DEGBs were taken at approximately every 21". This approach ensured the bounding break location could be determined, which in all cases was determined to be at an elbow or nozzle weld location (see the Response to 3.a.3). As the PSL1 longitudinal weld evaluation showed that the limiting locations were at nozzles and elbows, and due the similarity in design between PSL1 and PSL2, it was judged that the results would be the same for PSL2.

As discussed in the Response to 3.b.1, the insulation types at PSL1 and PSL2 include RMI, Cal-Sil, and a variety of fibrous insulation types. As RMI tends to be a non-problematic debris source for non-pit type strainers (Reference 3 pp. Appendix A p. 4-5),[JT82] maximizing the generation of Cal-Sil and fibrous insulation was the focus of the break selection process. The combination of Cal-Sil and fiber can form tight debris beds with limited porosity, which can cause high head losses even at low approach velocities (Reference 3 pp. Appendix A p. 4-5).[JT83] The breaks presented in the Response to 3.a.3 maximize the quantities of these problematic debris types.

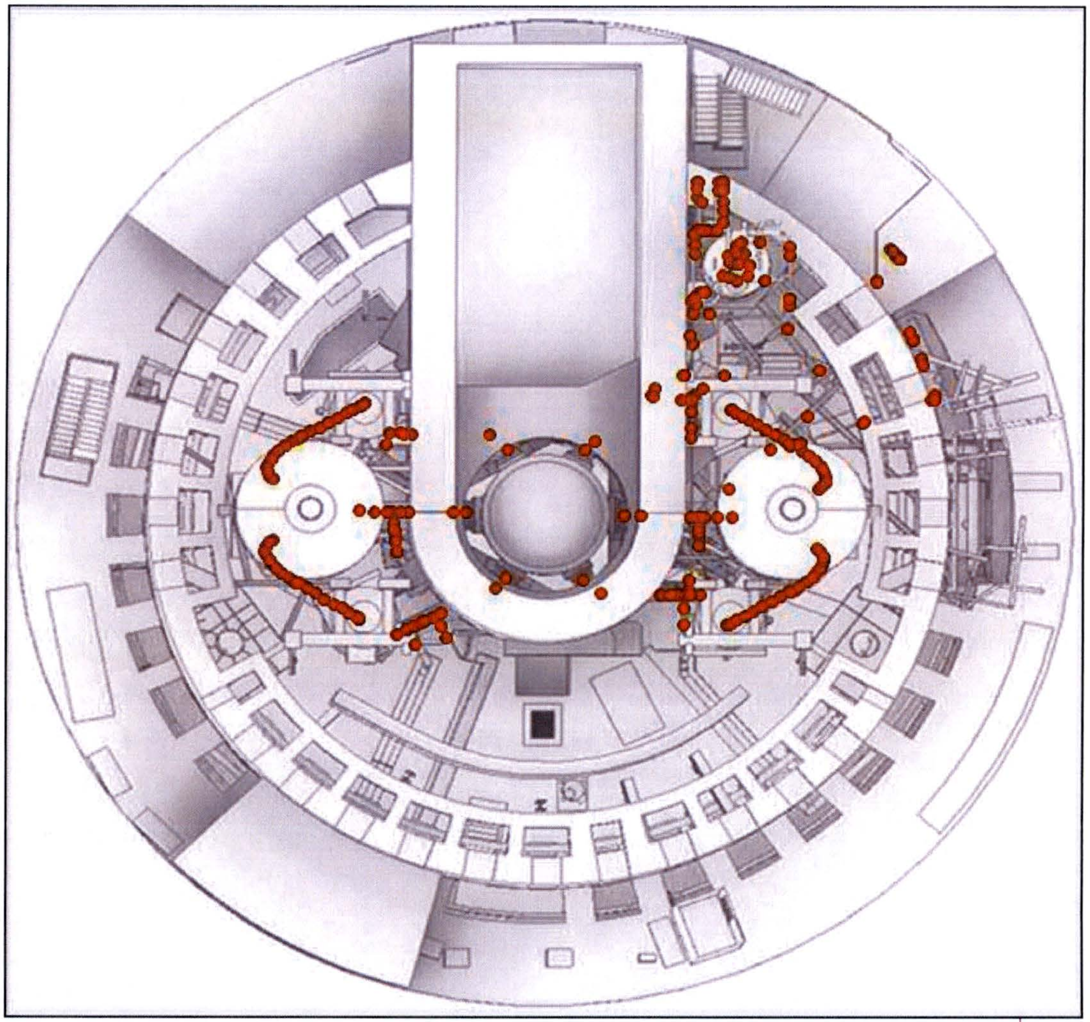

Figure 3.a.1-1: PSL1 Weld Locations Where Postulated LOCAs Occur[JT84]

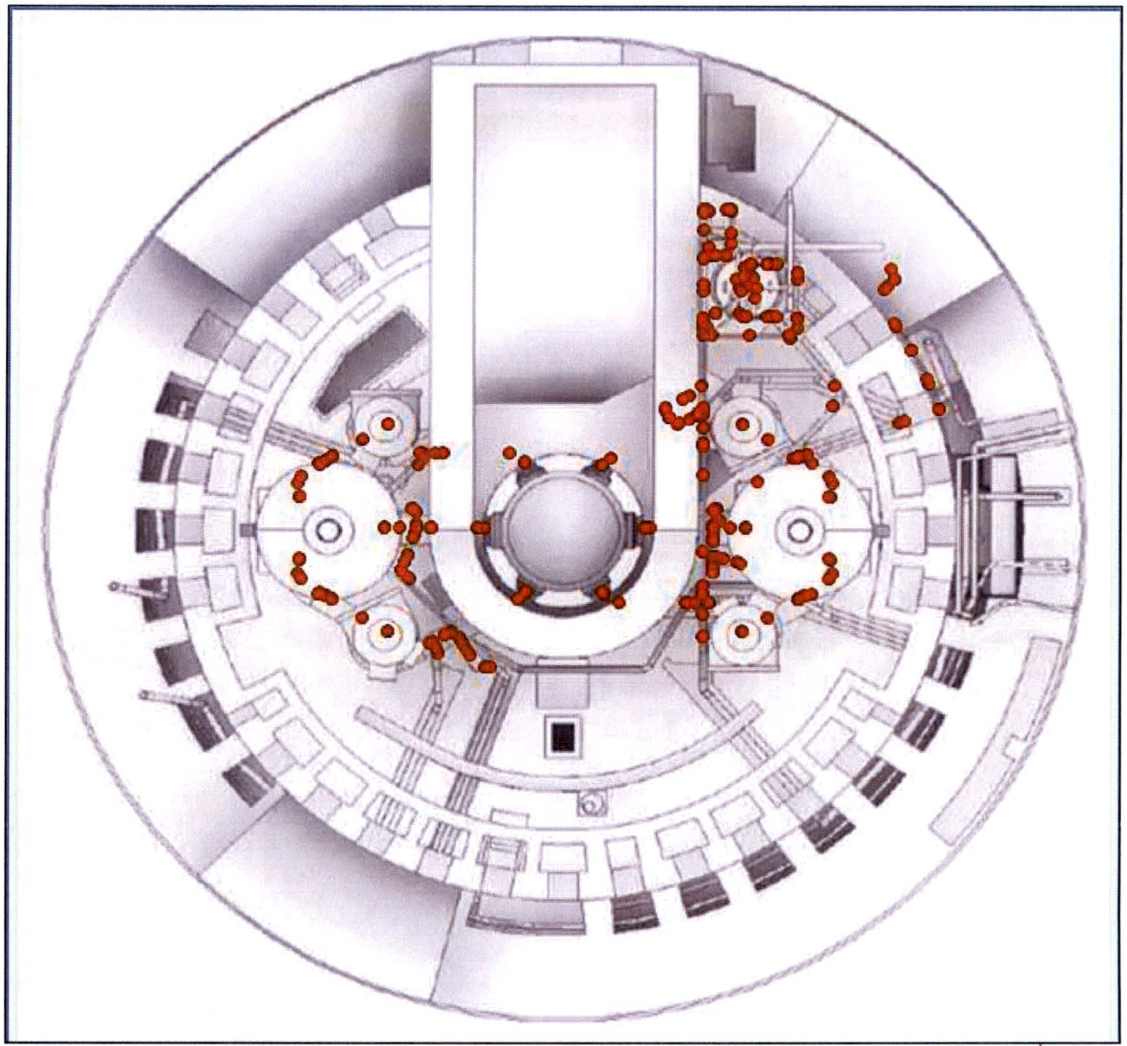

Figure 3.a.1-2: PSL2 Weld Locations Where Postulated LOCAs Occur[JT85]

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.[JT86]

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 debris generation calculations for PSL1 and PSL2 take into account a spectrum of break sizes on every ISI weld within the Class 1 pressure boundary.[JT87] The purpose of these calculations is to characterize the debris generation of the widest possible set of possible break scenarios. This set includes the debris generated by the worst-case scenario LOCAs (DEGBs on the main loop piping).

Given that most large breaks generate similar quantities of debris from latent dirt/dust, miscellaneous debris (stickers, tags, labels, tape), coatings in the ZOI (particulate), and unqualified coatings, the breaks that present the greatest challenge to post-accident sump performance are breaks that generate limiting amounts of Cal-Sil and fibrous debris (as discussed in the Response to 3.a.1). Areas with the potential to generate significant quantities of Cal-Sil and fibrous debris were identified.

In each loop, the two most bounding breaks that maximize the debris load from these materials were chosen; see Table 3.a.3-1 for descriptions of these locations and see the Response to 3.b.4 for quantities. At PSL1, the same break locations in each loop generate the bounding quantities of both Cal-Sil and fibrous debris, thus four break locations (instead of eight) are shown. At PSL2, one break location in each loop generates bounding quantities of both Cal-Sil and fibrous debris, thus six break locations (instead of eight) are shown.

Table 3.a.3-1: PSL1 and PSL2 Two Worst-Case Cal-Sil/Fiber Breaks for Each Loop[JT88]

Unit	Loop	Limiting Debris Type	Weld Location	Location Description
PSL1	A	Both Fiber and Cal-Sil	1-SGA-W16 & RC-114-FW-2000	Steam Generator (SG) Nozzle at Hot Leg
PSL1	A	Both Fiber and Cal-Sil	RC-114-7-503	Hot Leg Elbow
PSL1	B	Both Fiber and Cal-Sil	1-SGB-W16 & RC-123-FW-2000	SG Nozzle at Hot Leg
PSL1	B	Both Fiber and Cal-Sil	RC-123-1-503	Hot Leg Elbow
PSL2	A	Both Fiber and Cal-Sil	313-N4-3204-2-JW103-S/C010	SG Nozzle at Hot Leg
PSL2	A	Cal-Sil	RC-114-FW-2010	SG Nozzle at Hot Leg
PSL2	A	Fiber	RC-114-401-771	Hot Leg Elbow
PSL2	B	Both Fiber and Cal-Sil	314-N4-3204-2-JW103-S/C010	SG Nozzle at Hot Leg
PSL2	B	Cal-Sil	RC-123-FW-2010	SG Nozzle at Hot Leg
PSL2	B	Fiber	RC-123-201-771	Hot Leg Elbow

3.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; and (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 pressurized water reactor (PWR) reactor containment building, the worst-case pipe break would typically 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 Volume 1 (Reference 12, p. 1-3; 6, p. vii) [JT89]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 ZOIs are defined in the analysis as a spherical volume about the break in which the jet pressure is higher than the destruction/damage pressure for certain types of insulation, coatings, or other materials impacted by the break jet.

For any break smaller than a DEGB (i.e., a partial break), the NRC SE on NEI 04-07 accepts the use of a hemispherical ZOI centered at the edge of the pipe (Reference 6, p. 117). [JT90]Because these types of breaks could occur anywhere along the circumference of the pipe, the partial breaks were analyzed using hemispheres at eight different angles that are 45 degrees apart from each other around the pipe.[JT91]

Because different insulation types have different destruction pressures, insulation-specific ZOIs were determined. 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 PSL1 and PSL2 containment buildings.

Table 3.b.1-1: ZOI Radii for PSL1 and PSL2 Insulation Types[JT92]

Insulation Type	Destruction Pressure (psi)	ZOI Radius/Break Diameter (L/D)
Unjacketed and Jacketed Nukon	6	17.0*
Generic Low-Density Fiberglass	6	17.0***
Thermal-Wrap (PSL1 only)	6	17.0***
Temp-Mat (PSL1 only)	10.2	11.7*
Mirror Reflective Metal Insulation (RMI)	2.4	28.6*
Transco RMI	114	2.0*
Calcium Silicate	20*	6.4*
Qualified Coatings	40****	4.0**

* NRC SE on NEI 04-07 (Reference 6 pp. 30 and II-20)[JT93]

** Revised Guidance Regarding Coatings Zone of Influence for Review of Final Licensee Responses to Generic Letter 2004-02 (Reference 7 p. 2)[JT94]

*** The destruction pressure of generic fiberglass (PSL1 and PSL2) and Thermal-Wrap (PSL1 only) were assumed to be the same as Nukon due to their similar destruction pressures and as-fabricated densities[JT95]

**** 40 psi corresponds to a 4D ZOI in Table 3-1 of the SER (Reference 6 p. 27)[JT96]

Reinforcing stainless steel bands were installed on selected sections of Cal-Sil insulated piping in PSL1 during outage SL1-21 (Spring 2007). The banding system consists of ½-inch wide stainless steel bands that are installed around the outside of the insulation jacket. The bands are spaced approximately 3 inches on center. Tests to determine the efficacy of the banding system were conducted by Westinghouse utilizing the facilities of Wyle Laboratories.[JT97] This banding was installed in anticipation of NRC acceptance of the blowdown testing that was performed, which did not occur. For conservatism, no credit for banding was taken in the debris generation analysis and a 6.4D ZOI was used on all Cal-Sil (see Table 3.b.1-1).

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 12, pp. 3-14 through 3-15).[JT98] Due to the compartmentalization of containment in PSL1 and PSL2,[JT99] the insulation on the opposite side of the compartment walls can be assumed to remain intact. However, the steam generator compartments share an opening where a break jet could extend, so this was accounted for by including destruction of some of the insulation in these areas. All ZOIs were truncated to account for robust barriers per the NRC SE on NEI 04-07 (Reference 6 p. vii)[JT100]. ZOIs at the reactor nozzle break locations were also analyzed.[JT101]

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.[JT102] No insulation debris would be generated outside of the ZOIs (Reference 12,pp. 3-19 through 3-20).[JT103] This practice is considered acceptable by the NRC as stated in the SER on NEI 04-07 (Reference 6, Section 3.4.3.2)[JT104].

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:

PSL1 and PSL2 applied the ZOI refinement discussed in the NRC SE on NEI 04-07 (Reference 6, Section 4.2.2.1.1)[JT105], which allows the use of debris-specific spherical ZOIs.

The only ZOI that is different from those listed in NEI 04-07 Volume 1 is the ZOI for qualified coatings. This is discussed in the Response to 3.h.

In addition, FPL determined that there is approximately 128.5 ft^2 of polyvinyl chloride (PVC) jacketing on conduits inside of PSL1 containment. Post-LOCA qualification testing has confirmed that the jacketing remains attached and does not become a coating-like debris that can transport to the sump. A negligible amount (less than 1%) of PVC coating debris was generated during testing. Hence, analyzed debris loading assumptions are maintained.[JT106]

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 shows the quantities of debris generated for the two most limiting DEGB locations for each loop at PSL1.[JT107] These break locations were limiting for both Cal-Sil and fiber quantities. Table 3.b.4-2 shows the quantities of debris generated for the two most limiting DEGB locations with respect to Cal-Sil at PSL2.[JT108] Table 3.b.4-3 shows the quantities of debris generated for the two most limiting DEGB locations with respect to fiber at PSL2. 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.4-3 have been converted to mass (lbm) by multiplying the volumes by their associated density.

Table 3.b.4-1: PSL1 Two Worst-Case Breaks for Each Loop

Break Location		**1-SGB-W16 & RC-123-FW-2000**		**RC-123-1-503**		**1-SGA-W16 & RC-114-FW-2000**		**RC-114-7-503**	
Location Description		SG B Nozzle at Hot Leg		Hot Leg B Elbow		SG A Nozzle at Hot Leg		Hot Leg A Elbow	
Break Size		42"		42"		42"		42"	
Break Type		DEGB		DEGB		DEGB		DEGB	
Nukon, LDFG, and Thermal-Wrap (lbm)	Fine	367.1		353.0		351.7		339.5	
	Small	1,266.1		1,198.7		1,218.8		1,159.5	
	Large	578.5		610.7		537.6		568.5	
	Intact	625.0		659.8		580.8		614.2	
Temp-Mat (lbm)	Fine	4.8		4.8		38.5		36.6	
	Small	8.1		8.1		71.6		65.6	
	Large	2.8		2.7		10.1		13.9	
	Intact	3.0		2.9		10.9		15.0	
Cal-Sil (lbm)	Fine	893.9		883.5		701.9		679.0	
	Small	631.6		641.8		523.1		503.0	
	Intact	1,200.6		1,108.6		821.6		808.3	
Transco and Mirror RMI (ft^2)	Small (<4")	11,556		11,768		10,953		11,165	
	Large (≥4")	3,852		3,923		3,651		3,722	
Carbozinc 11	Fine	169.12 lbm	0.81 ft^3	170.75 lbm	0.82 ft^3	52.42 lbm	0.25 ft^3	53.41 lbm	0.26 ft^3
Phenoline 305	Fine	205.17 lbm	2.03 ft^3	218.98 lbm	2.16 ft^3	126.36 lbm	1.25 ft^3	141.27 lbm	1.39 ft^3
Carboline 195	Fine	188.41 lbm	1.75 ft^3	211.20 lbm	1.96 ft^3	169.62 lbm	1.57 ft^3	195.01 lbm	1.81 ft^3

Table 3.b.4-2: PSL2 Two Worst-Case Cal-Sil Breaks for Each Loop

Break Location		**313-N4-3204-2-JW103-S/C010**		**RC-114-FW-2010**		**314-N4-3204-2-JW103-S/C010**		**RC-123-FW-2010**	
Location Description		SG A Nozzle at Hot Leg		SG A Nozzle at Hot Leg		SG B Nozzle at Hot Leg		SG B Nozzle at Hot Leg	
Break Size		42"		42"		42"		42"	
Break Type		DEGB		DEGB		DEGB		DEGB	
Nukon and LDFG (lbm)	Fine	330.4		330.4		470.0		470.0	
	Small	1,203.3		1,203.3		1,670.5		1,670.5	
	Large	338.4		338.4		598.4		598.4	
	Intact	365.4		365.4		646.4		646.4	
Cal-Sil (lbm)	Fine	37.7		37.7		27.0		27.0	
	Small	28.6		28.6		21.0		21.0	
	Intact	41.8		41.8		27.8		27.8	
Transco and Mirror RMI (ft^2)	Small (<4")	1,039		1,039		1,049		1,049	
	Large (≥4")	346		346		350		350	
Carbozinc 11	Fine	42.7 lbm	0.21 ft^3	42.7 lbm	0.21 ft^3	65.3 lbm	0.31 ft^3	65.3 lbm	0.31 ft^3
Phenoline 305	Fine	113.8 lbm	1.12 ft^3	113.8 lbm	1.12 ft^3	139.7 lbm	1.38 ft^3	139.7 lbm	1.38 ft^3
Carboline 195	Fine	158.1 lbm	1.47 ft^3	158.1 lbm	1.47 ft^3	180.6 lbm	1.68 ft^3	180.6 lbm	1.68 ft^3

Table 3.b.4-3: PSL2 Two Worst-Case Fiber Breaks for Each Loop

Break Location		**313-N4-3204-2-JW103-S/C010**	**RC-114-401-771**	**314-N4-3204-2-JW103-S/C010**	**RC-123-201-771**
Location Description		SG A Nozzle at Hot Leg	Hot Leg A Elbow	SG B Nozzle at Hot Leg	Hot Leg B Elbow
Break Size		42"	42"	42"	42"
Break Type		DEGB	DEGB	DEGB	DEGB
Nukon and LDFG (lbm)	Fine	330.4	326.9	470.0	470.6
	Small	1,203.3	1,180.0	1,670.5	1,661.9
	Large	338.4	364.8	598.4	630.6
	Intact	365.4	394.0	646.4	681.2
Cal-Sil (lbm)	Fine	37.7	35.8	27.0	25.5
	Small	28.6	26.6	21.0	18.6
	Intact	41.8	42.2	27.8	31.6
Transco and Mirror RMI (ft^2)	Small (<4")	1,039	977	1,049	989
	Large (≥4")	346	326	350	330
Carbozinc 11	Fine	42.7 lbm; 0.21 ft^3	44.9 lbm; 0.22 ft^3	65.3 lbm; 0.31 ft^3	67.6 lbm; 0.32 ft^3
Phenoline 305	Fine	113.8 lbm; 1.12 ft^3	121.1 lbm; 1.20 ft^3	139.7 lbm; 1.38 ft^3	144.0 lbm; 1.42 ft^3
Carboline 195	Fine	158.1 lbm; 1.47 ft^3	168.8 lbm; 1.57 ft^3	180.6 lbm; 1.68 ft^3	185.9 lbm; 1.73 ft^3

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 two walkdowns at PSL2. The amount of transportable miscellaneous foreign materials found by the walkdowns was 24.4 ft^2.[JT109] Based on the similarity between units, as well as the similarity in procedures for labeling, the PSL2 data is considered applicable for PSL1. However, for conservatism, a total surface area of 133 ft^2 was assumed in the PSL1 and PSL2 debris generation analyses.[JT110]

3.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.[JT111]

Table 3.c.1-1: PSL1 and PSL2 Debris Material Properties

<table>
<tr><th>Debris</th><th>Distribution</th><th>Density (lbm/ft³)</th><th>Characteristic Size (μm)</th></tr>
<tr><td>Nukon/Generic LDFG</td><td rowspan="2">See Following Section</td><td rowspan="2">2.4 (bulk)
159 (fiber)</td><td>7</td></tr>
<tr><td>Thermal-Wrap</td><td>5.5</td></tr>
<tr><td>Temp-Mat</td><td>See Following Section</td><td>11.8 (bulk)
162 (fiber)</td><td>9</td></tr>
<tr><td>Mirror/Transco RMI</td><td>75% Small Pieces
25% Large Pieces</td><td>-</td><td><4”
≥4”</td></tr>
<tr><td>Cal-Sil</td><td>See Following Section</td><td>14.5 (bulk)
144 (particulate)</td><td>5</td></tr>
<tr><td rowspan="3">Qualified Coatings</td><td rowspan="3">100% Particulate</td><td>208 (Carbozinc 11 – inorganic zinc (IOZ))</td><td rowspan="3">10</td></tr>
<tr><td>101.3 (Phenoline 305 - Epoxy)</td></tr>
<tr><td>107.7 (Carboline 195 - Epoxy)</td></tr>
<tr><td rowspan="4">Unqualified and Degraded Coatings</td><td rowspan="4">100% Particulate</td><td>208 (Degraded IOZ)</td><td rowspan="4">10</td></tr>
<tr><td>98 (Enamel on RCPs)</td></tr>
<tr><td>297 (Cold Galvanizing on Ducts)</td></tr>
<tr><td>208 (IOZ on Pipes)</td></tr>
</table>

Nukon, Generic, and Thermal-Wrap Low-Density Fiberglass Insulations

The debris characteristics for Nukon, generic low-density fiberglass (LDFG), and Thermal-Wrap 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 Volume 1 (Reference 12, Section 3.4.3.3.1).[JT112] The debris generation calculation uses a four-category size distribution based on the guidance in the NRC SE on NEI 04-07 (Reference 6, Appendix II and Appendix VI, p. VI-14). [JT113]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 break diameter (C).[JT114]

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

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

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

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

Temp-Mat High-Density Fiberglass Insulation (PSL1 Only)

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 that 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 break diameter (C).[JT115]

$$F_{Temp-Mat\ Fines}(C) = \begin{cases} 0.333 & \text{if } 0 < C \leq 2 \\ -0.03050 \cdot C + 0.3940 & \text{if } 2 < C \leq 8 \\ -0.0405 \cdot C + 0.474 & \text{if } 8 < C \leq 17 \end{cases}$$

$$F_{Temp-Mat\ Small}(C) = \begin{cases} 0.667 & \text{if } 0 < C \leq 2 \\ -0.0945 \cdot C + 0.856 & \text{if } 2 < C \leq 8 \\ -0.0271 \cdot C + 0.316 & \text{if } 8 < C \leq 17 \end{cases}$$

$$F_{Temp-Mat\ Large}(C) = \begin{cases} 0 & \text{if } 0 < C \leq 2 \\ 0.0601 \cdot C - 0.12 & \text{if } 2 < C \leq 8 \\ -0.0974 \cdot C + 1.14 & \text{if } 8 < C \leq 17 \end{cases}$$

$$F_{Temp-Mat\ Intact}(C) = \begin{cases} 0 & \text{if } 0 < C \leq 2 \\ 0.0649 \cdot C - 0.13 & \text{if } 2 < C \leq 8 \\ 0.165 \cdot C - 0.93 & \text{if } 8 < C \leq 17 \end{cases}$$

Cal-Sil Insulation

The debris characteristics for 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 that 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), smalls (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 break diameter (C).[JT116]

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

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

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

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 PSL head loss evaluations (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.

3.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:

Walkdowns have been completed for PSL2 specifically for the purpose of characterizing latent and miscellaneous debris.[JT117] These walkdowns utilized the guidance in NEI 02-01 and the NRC SE on NEI 04-07.[JT118]

The NRCs SE on NEI 04-07 (Reference 6, p. 44)[JT119] recommended that walkdowns be performed to assess debris sources inside containment. A walkdown plan and procedure were developed and implemented to determine the amount of foreign debris in the PSL2 containment.[JT120] These walkdowns were conducted without any preconditioning or pre-inspections. Consequently, the debris found during the walkdowns is characteristic of approximately 23 years of operation under the existing housekeeping programs. These walkdowns were conducted and consequently, the debris found during the walkdowns is considered representative of normal plant operation under the existing housekeeping programs.

Samples were collected from eight surface types; floors, containment liner, ventilation, cable trays, walls, equipment, piping and grating.[JT121] For each surface type, a minimum of four samples were collected, bagged, and weighed to determine the quantity of debris that was collected.[JT122] A statistical approach was used to estimate an upper limit of the mean debris loading on each surface.[JT123] The horizontal and vertical surface areas were conservatively estimated.[JT124] The total latent debris mass for a surface type is the upper limit of the mean debris loading multiplied by the conservatively estimated area for that surface type, and the total latent debris is the sum of the latent debris for each surface type.[JT125]

Two PSL2 containment walkdowns were performed for the purpose of identifying and measuring plant labels, stickers, tape, tags, and other debris. Based on the walkdown data, the quantity of transportable miscellaneous debris in the PSL2 containment is estimated to be 24.4 ft^2. PSL1 and PSL2 are of a similar design, and the procedures for labeling are similar between PSL1 and PSL2. Therefore, the miscellaneous debris will be similar.[JT126] As discussed in the Response to 3.b.5, a total surface area of 133 ft^2 of miscellaneous debris was conservatively assumed in the PSL1 and PSL2 debris generation calculations.

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

Response to 3.d.2:

Walkdowns were not completed at PSL1, as it was assumed that the PSL2 walkdowns were representative of the PSL1 latent and miscellaneous debris quantities.[JT127] This was deemed reasonable as PSL1 and PSL2 are of a similar design, the internal containment horizontal and vertical surface areas are similar, the procedures for containment closeout are the same, and the organizations who perform these procedures are the same.[JT128] Also, the quantity of latent and miscellaneous debris assumed to exist was conservatively increased in order to bound the value found during the walkdowns.[JT129] See the Response to 3.d.3 for further discussion.

See the Response to 3.d.3 for assumptions regarding material properties of latent debris.

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:

Latent debris includes dirt, dust, lint, paint chips, fines, and shards of loose thermal insulation fibers that could potentially transport to the sump strainers during recirculation. Latent debris can be introduced into containment several ways, including deterioration of items such as insulation and coatings, and by personnel tracking in particulate and fibers from outside containment. The quantity of latent debris is provided in the debris generation calculations.[JT130] A walkdown at PSL2 was performed to measure quantities of latent debris, and the total quantity was calculated based on those samples.[JT131] The total amount of latent debris calculated was 67.4 lbm, but 100 lbm is assumed in the debris generation calculations [JT132]to provide ample operating margin. Table 3.d.3-1 lists the assumed latent fiber and particulate constituents and their material characteristics.

Latent debris is assumed to consist of 15 percent fiber and 85 percent particulate by mass per the NRC SE on NEI 04-07 (Reference 6 p. 50)[JT133]. Based on the NRC SE on NEI 04-07 (Reference 6, pp. 50-52, V-11)[JT134], 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 is 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 low-density fiberglass found in NEI 04-07 Volume 1 (Reference 12, p. 3-28)[JT135].

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%)	85	-	168.6	17.3
Fiber (15%)	15	2.4	93.6	5.5
Total	100			

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 133 ft^2 of miscellaneous debris was conservatively assumed. This surface area would result in a 100 ft^2 reduction in strainer area (75% of 133 ft^2) (Reference 6 p. 49)[JT136].

3.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 the 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 Volume 1 guidance (Reference 12)[JT137] and the associated NRC SE on NEI 04-07 for refined analyses, as well as the refined methodologies suggested by the NRC SE on NEI 04-07 in Appendices III, IV, and VI (Reference 6)[JT138]. The specific effect of each of four modes of transport was analyzed in the debris transport calculations [JT139]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, and break flow
- Pool Fill-Up Transport – the transport of debris by break and containment spray flows from RWT 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 determined from the debris generation calculation. The logic tree shown in Figure 3.e.1-1 is slightly different from the baseline guidance. This departure was made to account for certain non-conservative assumptions identified by the NRC SE on NEI 04-07 (Reference 6)[JT140] 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.

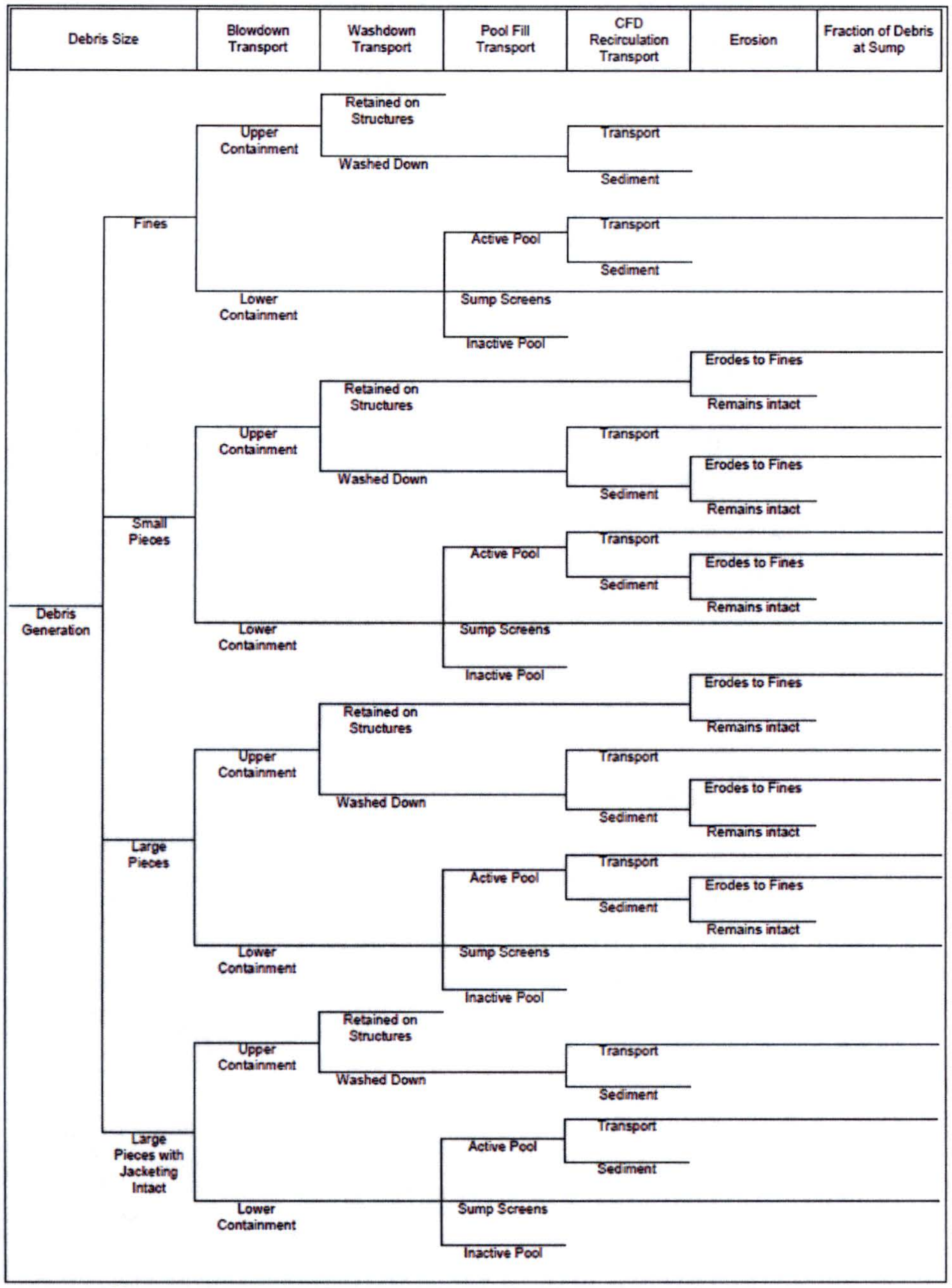

Figure 3.e.1-1: Generic Debris Transport Logic Tree

The basic methodology for the PSL1 and PSL2 transport analyses is summarized as follows:[JT141]

1. The CAD model was provided as input to determine break locations and sizes.
2. The debris generation calculation was provided as input into the calculation for 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 computational fluid analysis (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 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 for each unit. It was determined that there are not any upstream blockage points in the PSL1 and PSL2 containment buildings.[JT142] Upstream effects are discussed in the Response to 3.l.

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 PSL1, and Figure 3.e.1-3 for PSL2.[JT143] The strainer module mass sinks and the various direct and runoff spray regions are highlighted.

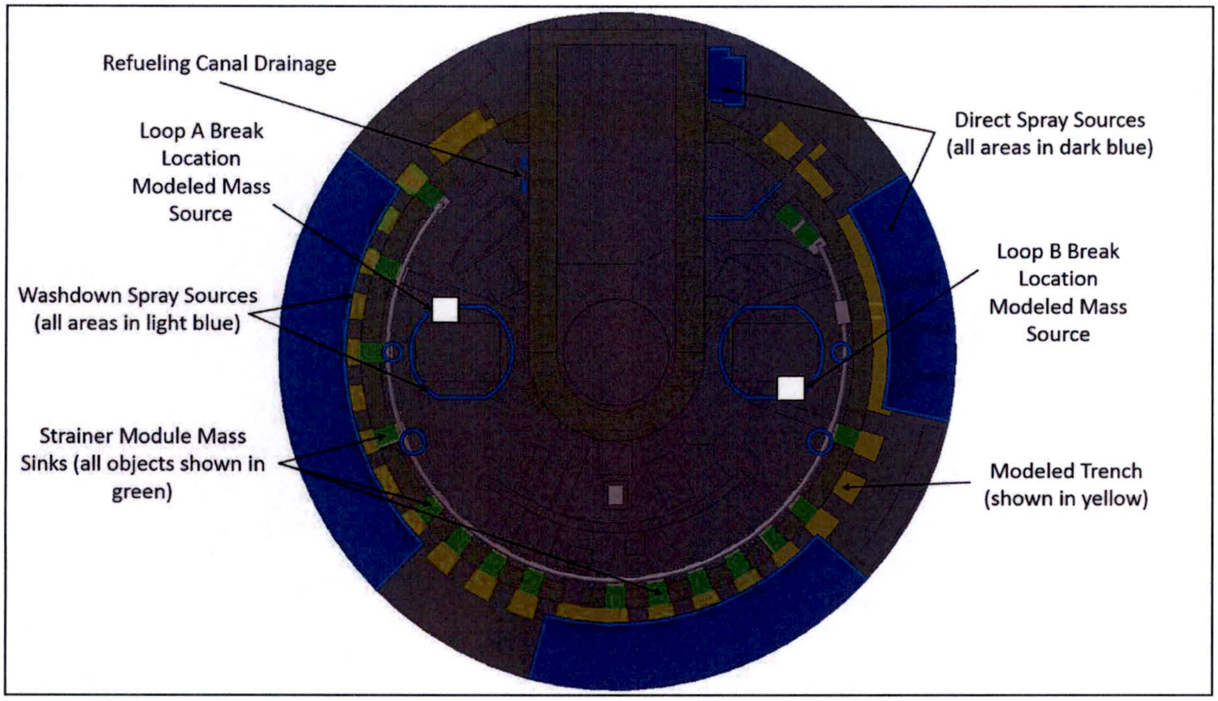

Figure 3.e.1-2: PSL1 Significant Features in CFD Model

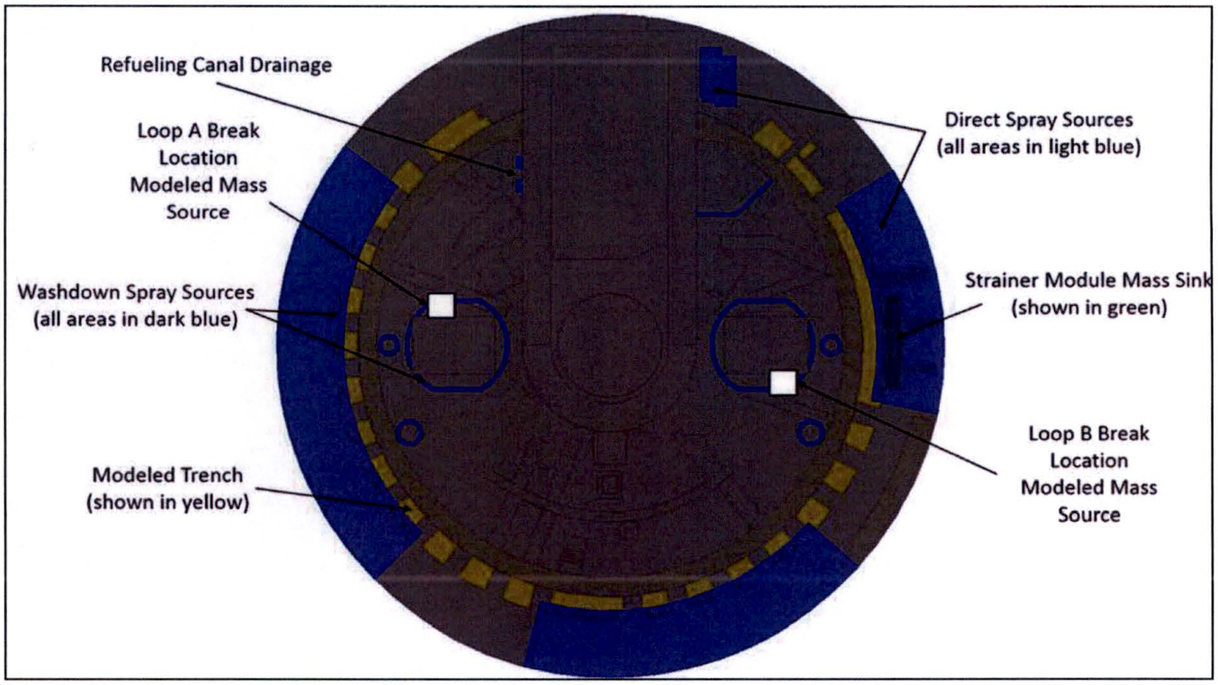

Figure 3.e.1-3: PSL2 Significant Features in CFD Model

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, 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 6,400,000 for PSL1, and 3,891,200 for PSL2.[JT144]

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 the steam generator compartments through the open area above the steam generators, through the annulus via the various sections of grating, and through the refueling canal drains. 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.[JT145]

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.[JT146]

Modeling of the Strainers

There are multiple strainers that make up the strainer array at PSL1. The flow split to each strainer was obtained using the data from the clean strainer head loss calculation. The percentage of flow to each strainer was calculated by dividing the flow rate to each strainer by the total flow rate. Each of the strainer modules were modeled as a mass sink. This tells the CFD model to draw the specified amount of water from the recirculation pool over the entire exposed surface area of the module.[JT147]

The strainer module at PSL2 is comprised of one strainer. The strainer stack was modeled as a mass sink. This tells the CFD model to draw the specified amount of water from the recirculation pool over the entire exposed surface area of the stack.[JT148]

Modeling the Trench

The trench below the containment floor at the 18' elevation was modeled as a porous object to best represent the open space between the piping that is present in the trench. From various CAD drawings and by examining the CAD model, it was determined that the trench contains a few pipes varying from ¾-inch to 6-inch in diameter. The ratio of the cross-sectional areas of the pipes and the trench was calculated to determine the porosity of the trench. This ratio was calculated to be 98.91% for PSL1, and 98.93% for PSL2. To maintain conservatism, an object porosity of 98% was applied to the trench in the CFD model, since a reduced area would increase the velocity in the trench. Note that snubbers and miscellaneous steel structures are present in the trenches, but are not considered in the derivation of the porous object, since these do not affect the flow characteristics in the trench as flow can readily pass by them to the various strainer module locations.[JT149]

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 emergency 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.[JT150]

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.[JT151]

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 PSL1 and PSL2 transport analyses originate from the sources as follows:

- NUREG/CR-6772 Tables 3.1, 3.5, and C.19(a) (Reference 13 pp. 16, 22, and C-16)[JT152]
- NUREG/CR-6808 Figure 5.2, Tables 5-1 and 5-3 (Reference 14 pp. 5-14, 5-22, and 5-33)[JT153]

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 following paragraphs:[JT154]

- 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 CAD 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 a CAD 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. 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.1-8). 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 PSL1 and PSL2.

As shown in Figure 3.e.1-4 (PSL1) and Figure 3.e.1-5 (PSL2), the small debris (depicted by green shading) was initially assumed to be uniformly distributed in the vicinity of the break location and the strainers at the beginning of recirculation.

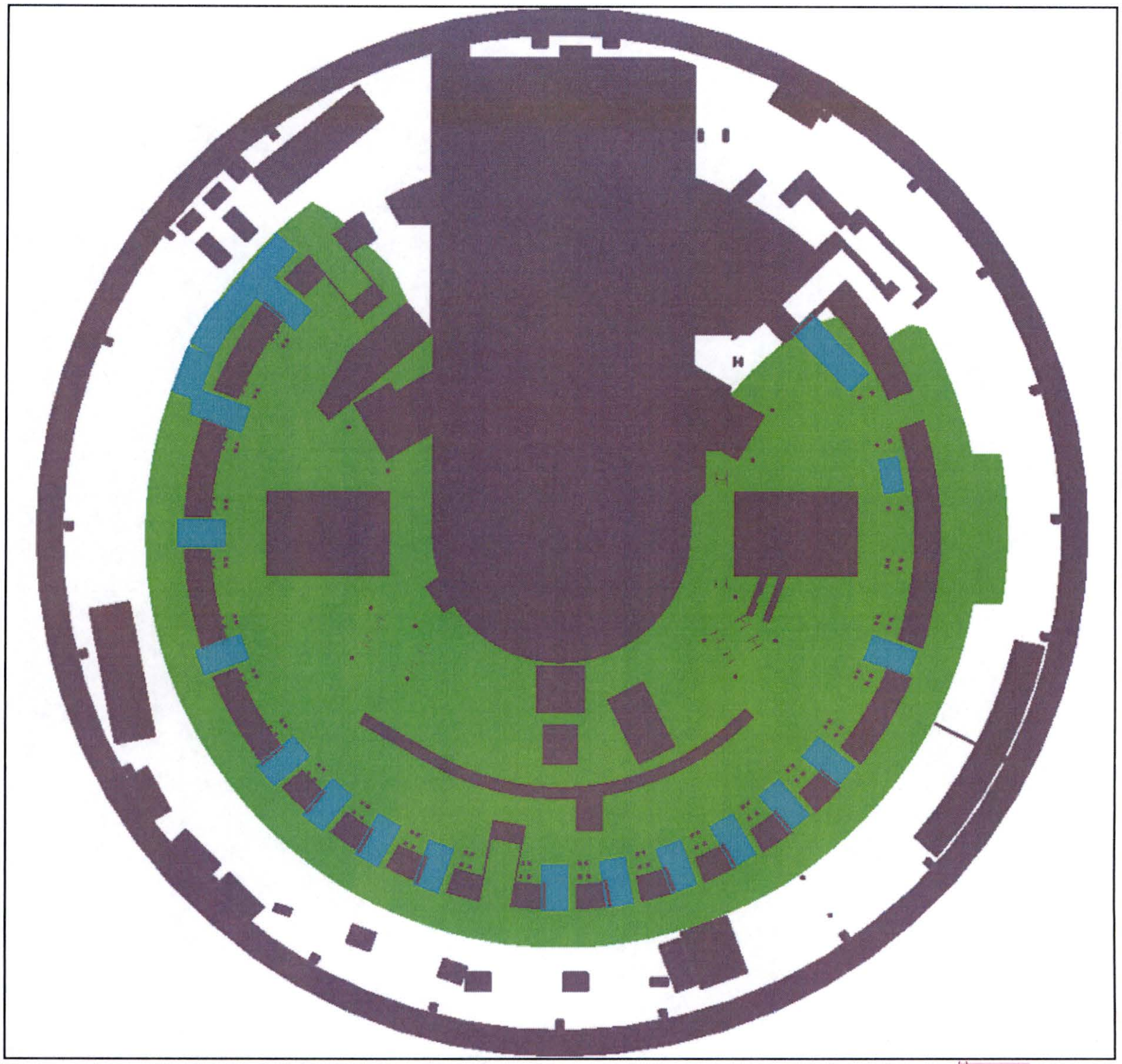

Figure 3.e.1-4: PSL1 Distribution of Small Debris in Lower Containment [JT155]

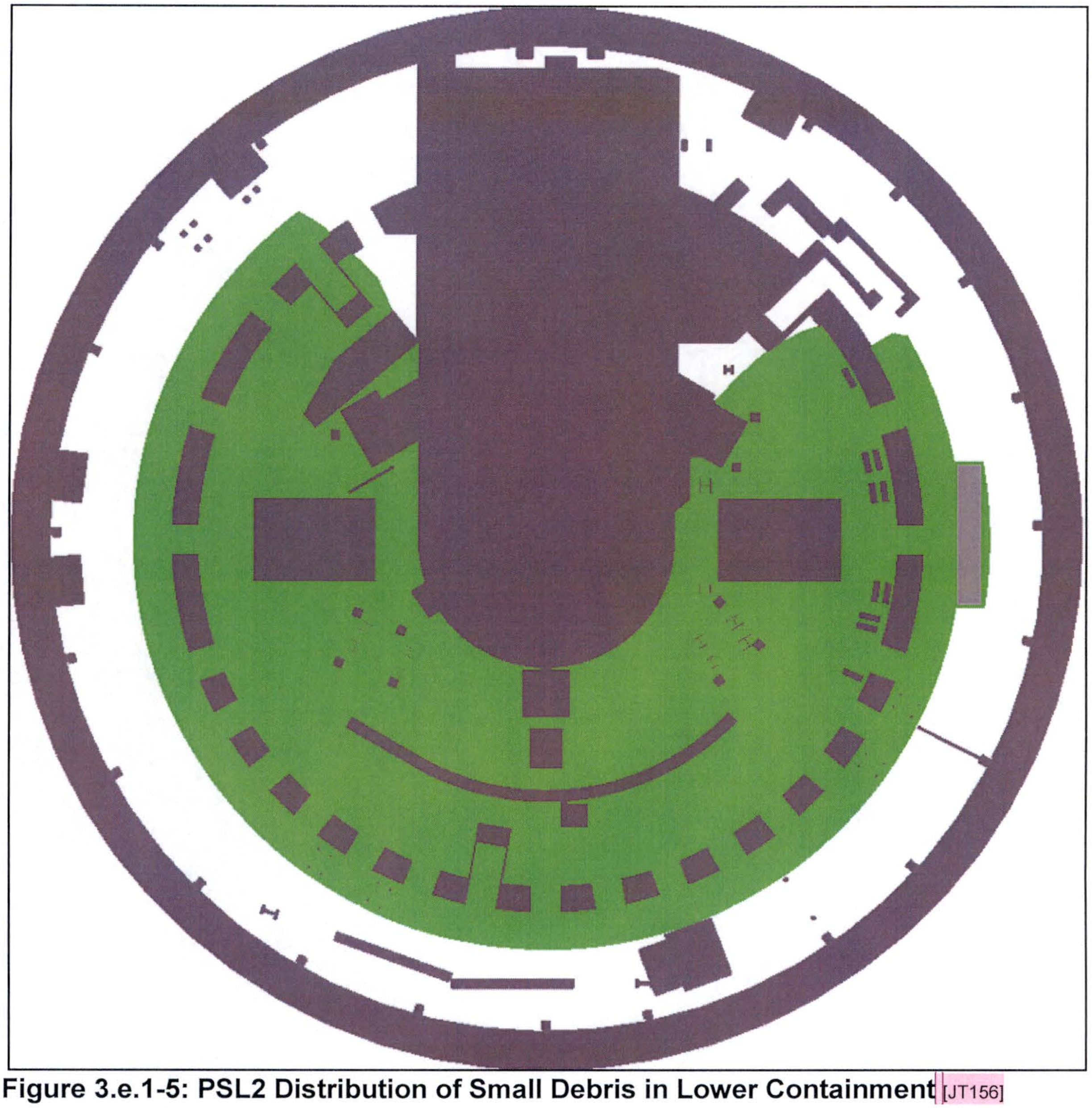

Figure 3.e.1-5: PSL2 Distribution of Small Debris in Lower Containment [JT156]

For PSL1, Figure 3.e.1-6 shows that the turbulence (yellow regions) and the velocity (red regions) in the pool (blue regions) are high enough to transport the generic small debris to the sump strainers during recirculation. The initial distribution area (Figure 3.e.1-4) was overlaid on top of the plot showing tumbling velocity, TKE, and flow vectors (Figure 3.e.1-6) to determine the recirculation transport fraction, represented by the hatched portion (Figure 3.e.1-7).

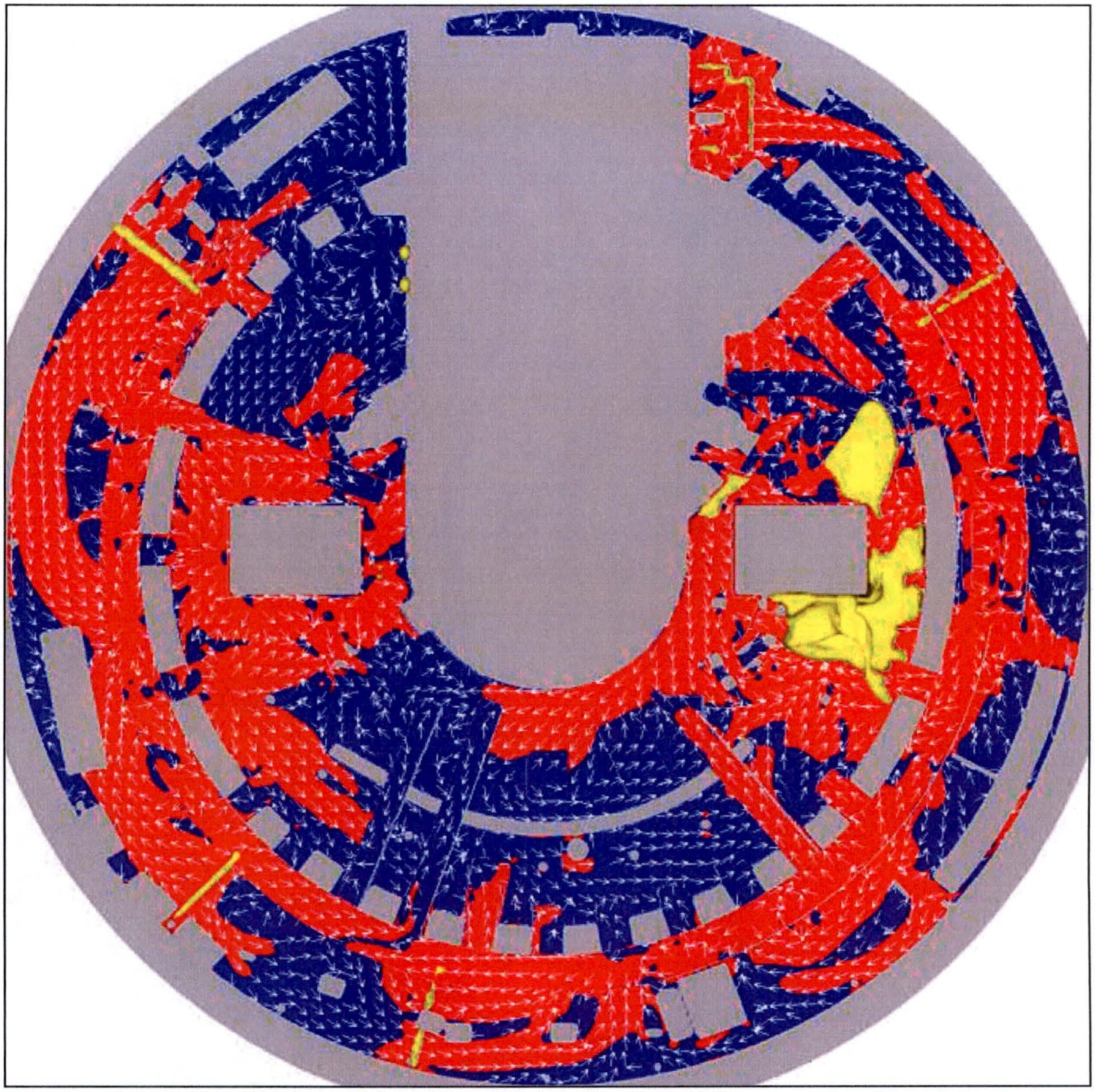

Figure 3.e.1-6: PSL1 TKE and Velocity with Limits Set at Suspension/Tumbling of Small Generic Debris[JT157]

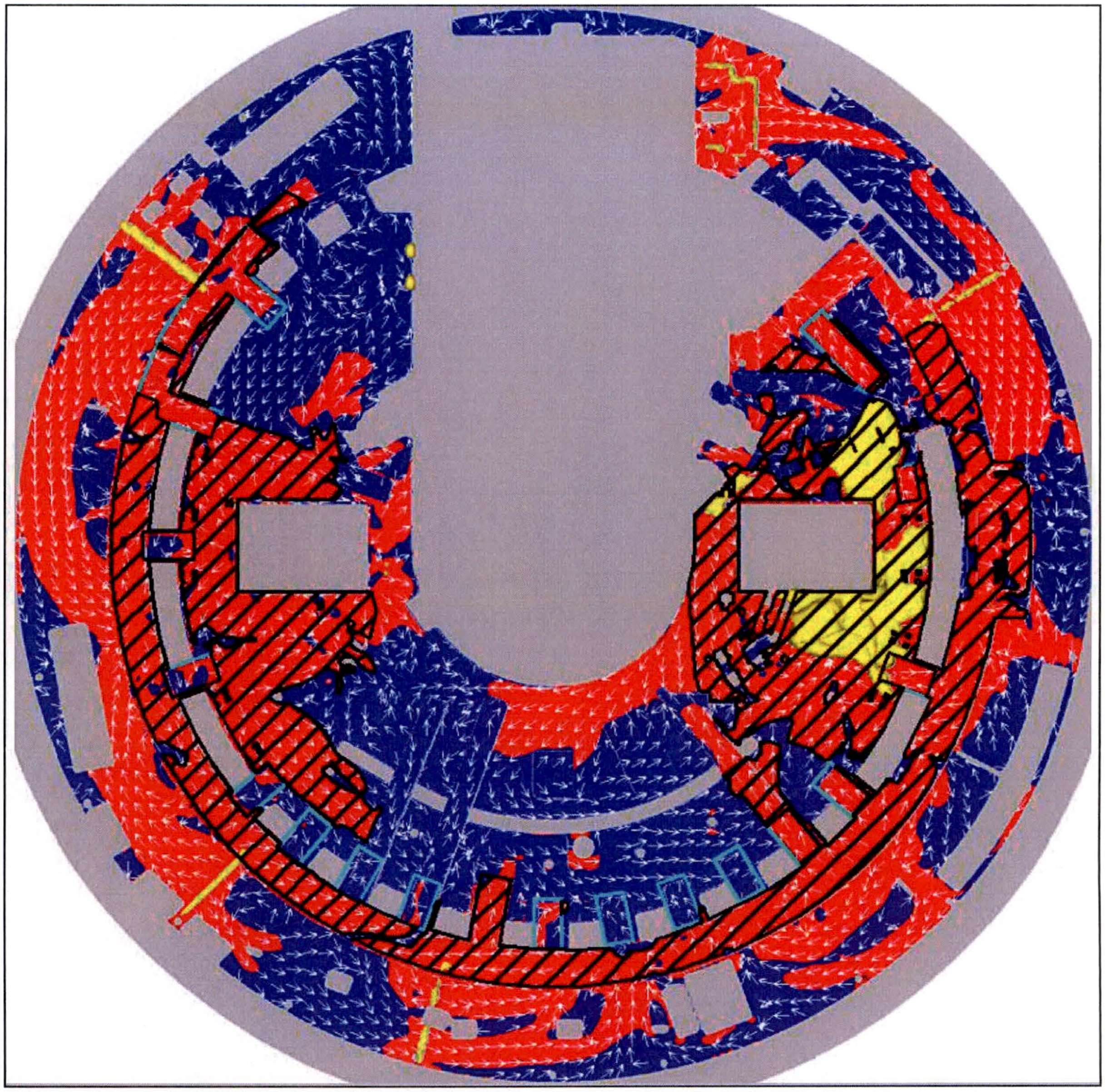

Figure 3.e.1-7: PSL1 Floor Area where Small Generic Debris Would Transport to the Sump Strainers (Hatched Area) [JT158]

For PSL2, Figure 3.e.1-8 shows that the turbulence (yellow regions) and the velocity (red regions) in the pool (blue regions) are high enough to transport the generic small debris 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.1-8) to determine the recirculation transport fraction, represented by the hatched portion (Figure 3.e.1-9).

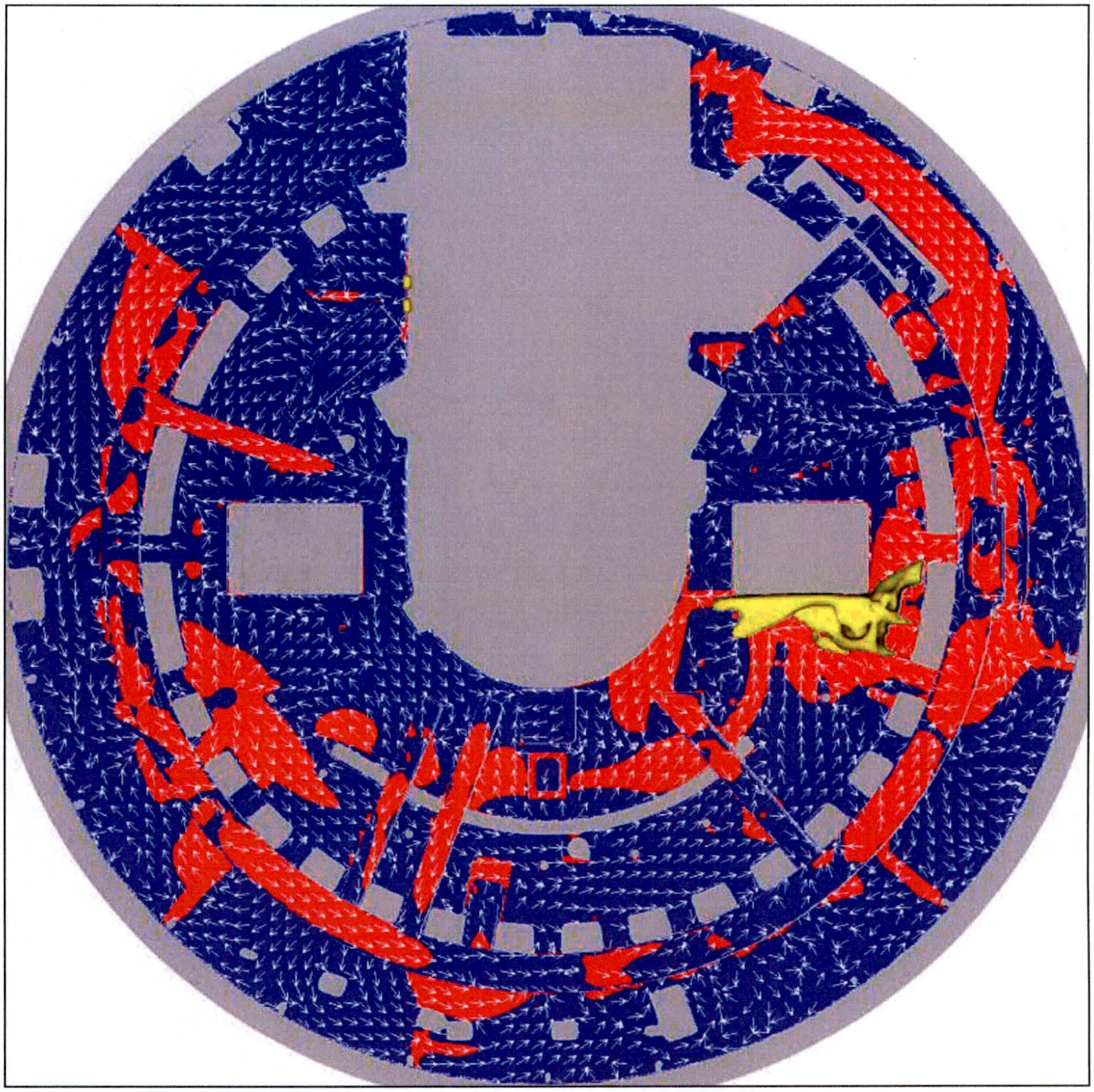

Figure 3.e.1-8: PSL2 TKE and Velocity with Limits Set at Suspension/Tumbling of Small Generic Debris [JT159]

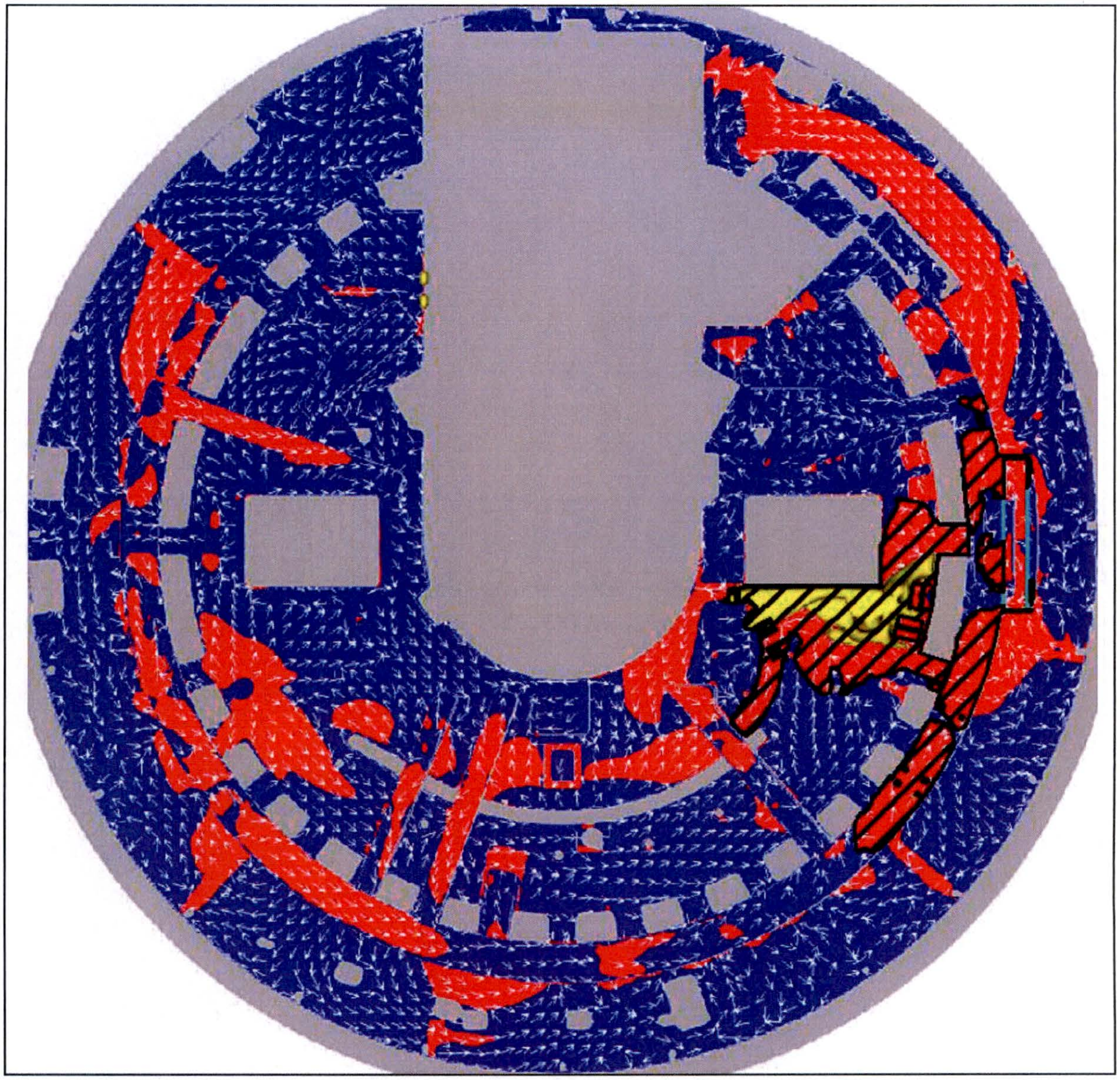

Figure 3.e.1-9: PSL2 Floor Area where Small Generic Debris Would Transport to the Sump Strainers (Hatched Area) [JT160]

The same analysis was applied for each type of debris at PSL1 and PSL2. 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, generic fiberglass, Nukon, Thermal-Wrap, 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 PSL1 and PSL2, generic 30-day erosion testing was performed.[JT161] Based on a validation that the test results apply to PSL1 and PSL2 (ensuring that flow rates and turbulence values are similar to what is expected in the PSL1 and PSL2 recirculation pools), an erosion fraction of 10% is used for the small and large pieces of fiberglass debris in the pool.[JT162] An erosion fraction of 17% is assumed for the small chunks of Cal-Sil debris in the pool. This fraction was applied to both transportable debris and sediment 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.[JT163]

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 is based on and does not deviate from the approved NEI 04-07 Volume 1 guidance and the NRC SE on NEI 04-07 for refined analyses, as well as the refined methodologies suggested by the SE in Appendices III, IV, and VI (Reference 6)[JT164].

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 CFD simulations were performed using Flow-3D, a commercially available software package. [JT165]

At PSL1, three break cases form the basis for the debris transport analysis to determine the recirculation transport fractions – a Loop A break (2 train operation), a Loop B break (2 train operation), and a Loop B break (single train failure). Cases were chosen to represent and bound the different LOCA scenarios that could occur at PSL1. All cases were run with maximum ECCS flow rates (total HPSI and CSS flow rate of 3,663 gpm per train) and with the minimum water level right above the strainer (23.66 ft).[JT166] Using the maximum flow rates and minimum water level maximize the turbulence and velocity in the pool.
At PSL2, three break cases also form the basis for the debris transport analysis to determine the recirculation transport fractions – a Loop A break (single train), a Loop

B break (single train), and a Loop B break (2 train operation). Cases were chosen to represent and bound the different LOCA scenarios that could occur at PSL2. All cases were run with maximum ECCS flow rates (total HPSI and CSS flow rate of 5,498 gpm for one train operation and 8,556 gpm for two train operation) and with the minimum water level right above the strainer (23.38 ft).[JT167] Using the maximum flow rates and minimum water level maximize the turbulence and velocity in the pool.

In general, a break close to the sump tends to transport a larger fraction of small and large debris than a break farther from the sump. 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 PSL1 and PSL2 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:

No credit was taken for debris interceptors.

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-up, 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-up, etc.).

Blowdown Transport

Table 3.e.6-1 and Table 3.e.6-2 show the bounding (the 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 (annulus breaks are not bounding with respect to debris generated and transported, so they are not listed in these tables).

Table 3.e.6-1: PSL1 Blowdown Transport Fractions [JT168]

Break Location	Debris Type	Transport Fraction		
		To Upper Containment (UC)	To Lower Containment (LC)	Remaining in Compartment
Steam Generator Compartments	Fines/Particulate (all)	82%	18%	0%
	Small Fiberglass	51%	49%	0%
	Large Fiberglass	25%	75%	0%
	Intact Fiberglass Blankets	0%	0%	100%
	Small RMI	60%	40%	0%
	Large RMI	30%	70%	0%
	Small Cal-Sil	60%	40%	0%
	Qualified Coatings	82%	18%	0%
	Unqualified Coatings	-	-	-
	Latent Debris	-	-	-
Reactor Cavity	Fines (all)	82%	18%	0%
	Small Fiberglass	51%	49%	0%
	Large Fiberglass	25%	75%	0%
	Intact Fiberglass Blankets	0%	0%	100%
	Small RMI not in Cavity	60%	40%	0%
	Small RMI in Cavity	30%	20%	50%
	Large RMI not in Cavity	30%	70%	0%
	Large RMI in Cavity	0%	0%	100%
	Small Cal-Sil	60%	40%	0%
	Qualified Coatings	82%	18%	0%
	Unqualified Coatings	-	-	-
	Latent Debris	-	-	-
Pressurizer Compartment	Fines (all)	82%	18%	0%
	Small Fiberglass	80%	17%	3%
	Large Fiberglass	50%	15%	35%
	Intact Fiberglass Blankets	0%	0%	100%
	Small RMI	82%	18%	0%
	Large RMI	60%	18%	22%
	Small Cal-Sil	82%	18%	0%
	Qualified Coatings	82%	18%	0%
	Unqualified Coatings	-	-	-
	Latent Debris	-	-	-

Table 3.e.6-2: PSL2 Blowdown Transport Fractions [JT169]

Break Location	Debris Type	Transport Fraction		
		To Upper Containment (UC)	To Lower Containment (LC)	Remaining in Compartment
Steam Generator Compartments	Fines (all)	81%	19%	0%
	Small Fiberglass	50%	50%	0%
	Large Fiberglass	25%	75%	0%
	Intact Fiberglass Blankets	0%	0%	100%
	Small RMI	60%	40%	0%
	Large RMI	30%	70%	0%
	Small Cal-Sil	60%	40%	0%
	Qualified Coatings	81%	19%	0%
	Unqualified Coatings	-	-	-
	Latent Debris	-	-	-
Reactor Cavity	Fines (all)	81%	19%	0%
	Small Fiberglass	50%	50%	0%
	Small Fiberglass in Cavity	25%	25%	50%
	Large Fiberglass	25%	75%	0%
	Large Fiberglass in Cavity	0%	0%	100%
	Intact Fiberglass Blankets	0%	0%	100%
	Small RMI not in Cavity	60%	40%	0%
	Small RMI in Cavity	30%	20%	50%
	Large RMI not in Cavity	30%	70%	0%
	Large RMI in Cavity	0%	0%	100%
	Small Cal-Sil	60%	40%	0%
	Qualified Coatings	81%	19%	0%
	Unqualified Coatings	-	-	-
	Latent Debris	-	-	-
Pressurizer Compartment	Fines (all)	81%	19%	0%
	Small Fiberglass	79%	18%	3%
	Large Fiberglass	50%	15%	35%
	Intact Fiberglass Blankets	0%	0%	100%
	Small RMI	-	-	-
	Large RMI	-	-	-
	Small Cal-Sil	-	-	-
	Qualified Coatings	81%	19%	0%
	Unqualified Coatings	-	-	-
	Latent Debris	-	-	-

Washdown Transport

Table 3.e.6-3 shows 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.

Table 3.e.6-3: PSL1 and PSL2 Washdown Transport Fractions[JT170]

Debris Type	Transport Fraction		
	Washed Down in Annulus	Washed Down Inside SSW	Washed Down RFC Drains
Fines/Particulate (all)	76%	12%	12%
Small Fiberglass	61%	12%	12%
Large Fiberglass	0%	12%	12%
Intact Fiberglass Blankets	-	-	-
Small RMI	76%	12%	12%
Large RMI	0%	12%	12%
Small Cal-Sil	76%	12%	12%
Qualified Coatings	76%	12%	12%
Unqualified Coatings	-	-	-
Latent Debris	-	-	-

Pool Fill-Up Transport

The equation used to determine the portion of debris washed to inactive cavities during pool fill-up is based on the following equation:[JT171]

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

Where:

$X_{fill-up}$ = Amount of debris transported to cavity during pool fill-up
V_{cavity} = Cavity volume
V_{pool} = Pool volume

The primary cavities below the floor elevation at PSL1 and PSL2 are the electrical tunnel/reactor cavity and the normal sump cavity. These two cavities are connected and were assumed to be surrounded by a 6-inch curb (a 6-inch curb surrounds the entrance to the electrical tunnel but not the normal sump cavity). The volume of the electrical tunnel/reactor cavity was calculated to be 16,630 ft^3 and the volume of the pool at 6-inches (including the trench) was calculated to be 13,560 ft^3. [JT172]

Inserting these values into the equation above yields a pool fill-up transport of 71%, (limited to 15% by Section 3.6.3 of the NRC SE on NEI 04-07 (Reference 6 pp. 79-80))[JT173] to the inactive cavity (electrical tunnel/reactor cavity and normal sump).[JT174]

It was assumed that 25% of the fine debris present in the trenches at PSL1 and PSL2 would transport directly to the strainers during pool-fill.[JT175]

Table 3.e.6-4 shows the bounding (minimum) pool fill-up transport fractions as a function of debris type.

Table 3.e.6-4: PSL1 and PSL2 Pool Fill-Up Transport Fractions[JT176]

Debris Type	Pool Fill-Up Transport Fraction	
	Directly to Strainer	Inactive Cavity
Fines/Particulate (all)	25%	15%
Small Fiberglass	0%	0%
Large Fiberglass	0%	0%
Intact Fiberglass Blankets	-	-
Small RMI	0%	0%
Large RMI	0%	0%
Small Cal-Sil	0%	0%
Qualified Coatings	25%	15%
Unqualified Coatings	0%	0%
Latent Debris	25%	15%

Recirculation Transport

For the recirculation transport fractions, three different break cases form the basis for each debris transport analysis, and were evaluated for PSL1 [JT177]and three different cases for PSL2 in the debris transport calculations.[JT178] Note that recirculation transport fractions are presented separately for each unit. This is because the flow rates, water levels, location of the strainers, and recirculation procedures are different between the two units.

The cases for PSL1 are:

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

The cases for PSL2 are:

- Case 1: LBLOCA in SG Compartment Loop A, One Train Operational
- Case 2: LBLOCA in SG Compartment Loop B, One Train Operational
- Case 3: LBLOCA in SG Compartment Loop B, Two Trains 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.[JT179]

The bounding (maximum) recirculation transport fractions for LDFG debris types as a function of evaluation case are shown in Table 3.e.6-5 and Table 3.e.6-6.

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

Table 3.e.6-5: PSL1 Recirculation Transport Fractions for LDFG Fibrous Debris

[JT180]

Case	Debris Size	Debris in Lower Containment	Washed Inside Secondary Shield Wall	Washed In Annulus	Washed Down RFC
Case 1	Fines	100%	100%	100%	100%
	Small	50%	66%	49%	0%
	Large	5%	12%	-	0%
	Intact Blankets	-	-	-	-
Case 2	Fines	100%	100%	100%	100%
	Small	55%	75%	67%	0%
	Large	9%	17%	-	0%
	Intact Blankets	-	-	-	-
Case 3	Fines	100%	100%	100%	100%
	Small	33%	45%	43%	0%
	Large	5%	14%	-	0%
	Intact Blankets	-	-	-	-

Table 3.e.6-6: PSL2 Recirculation Transport Fractions for LDFG Fibrous Debris

[JT181]

Case	Debris Size	Debris in Lower Containment	Washed Inside Secondary Shield Wall	Washed In Annulus	Washed Down RFC
Case 1	Fines	100%	100%	100%	100%
	Small	2%	0%	12%	0%
	Large	0%	0%	-	0%
	Intact Blankets	-	-	-	-
Case 2	Fines	100%	100%	100%	100%
	Small	11%	20%	13%	0%
	Large	2%	7%	-	0%
	Intact Blankets	-	-	-	-
Case 3	Fines	100%	100%	100%	100%
	Small	23%	45%	20%	0%
	Large	7%	12%	-	0%
	Intact Blankets	-	-	-	-

The bounding recirculation transport fractions for Temp-Mat debris (PSL1 only) as a function of evaluation case are shown in Table 3.e.6-7. It was assumed that Temp-Mat debris would float in the recirculation pool until it is transported to the vicinity of the strainers, [JT182]which results in a recirculation transport fraction of 100%.

Table 3.e.6-7: PSL1 Recirculation Transport Fractions for Temp-Mat Debris[JT183]

Case	Debris Size	Debris in Lower Containment	Washed Inside Secondary Shield Wall	Washed In Annulus	Washed Down RFC
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	-	-	-	-

The bounding recirculation transport fractions for RMI debris as a function of evaluation case are shown in Table 3.e.6-8 and Table 3.e.6-9.

Table 3.e.6-8: PSL1 Recirculation Transport Fractions for RMI Debris [JT184]

Case	Debris Size	Debris in Lower Containment	Washed Inside Secondary Shield Wall	Washed In Annulus	Washed Down RFC
Case 1	Small	14%	16%	13%	0%
	Large	14%	16%	-	0%
Case 2	Small	15%	23%	12%	0%
	Large	15%	23%	-	0%
Case 3	Small	7%	17%	3%	0%
	Large	7%	17%	-	0%

Table 3.e.6-9: PSL2 Recirculation Transport Fractions for RMI Debris [JT185]

Case	Debris Size	Debris in Lower Containment	Washed Inside Secondary Shield Wall	Washed In Annulus	Washed Down RFC

Case	Debris Size	Debris in Lower Containment	Washed Inside Secondary Shield Wall	Washed In Annulus	Washed Down RFC
Case 1	Small	0%	0%	0%	0%
	Large	0%	0%	-	0%
Case 2	Small	2%	7%	0%	0%
	Large	2%	7%	-	0%
Case 3	Small	7%	13%	11%	0%
	Large	7%	13%	-	0%

The bounding recirculation transport fractions for Cal-Sil 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: PSL1 Recirculation Transport Fractions for Cal-Sil Debris [JT186]

Case	Debris Size	Debris in Lower Containment	Washed Inside Secondary Shield Wall	Washed In Annulus	Washed Down RFC
Case 1	Particulate	100%	100%	100%	100%
	Small	18%	20%	23%	0%
Case 2	Particulate	100%	100%	100%	100%
	Small	19%	26%	17%	0%
Case 3	Particulate	100%	100%	100%	100%
	Small	9%	18%	5%	0%

Table 3.e.6-11: PSL2 Recirculation Transport Fractions for Cal-Sil Debris [JT187]

Case	Debris Size	Debris in Lower Containment	Washed Inside Secondary Shield Wall	Washed In Annulus	Washed Down RFC
Case 1	Particulate	100%	100%	100%	100%
	Small	0%	0%	0%	0%
Case 2	Particulate	100%	100%	100%	100%
	Small	3%	7%	0%	0%
Case 3	Particulate	100%	100%	100%	100%
	Small	6%	8%	11%	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.6-12.

Table 3.e.6-12: PSL1 and PSL2 Recirculation Transport Fractions for Qualified Coatings, Unqualified Coatings, Latent Debris [JT188]

Case	Debris Size	Debris in Lower Containment	Washed Inside Secondary Shield Wall	Washed In Annulus	Washed Down RFC
Case 1	Fine/Particulate	100%	100%	100%	100%
Case 2	Fine/Particulate	100%	100%	100%	100%
Case 3	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.6-13 through Table 3.e.6-18.

Table 3.e.6-13: PSL1 Overall Transport Fractions for a Break Inside the Secondary Shield Wall (SSW)[JT189]

Debris Type	Debris Size		1 Train	2 Train
Generic Fiberglass	Fines		97%	97%
	Small Pieces	Transport as Erosion Fines	9%	9%
		Transport as Small Pieces	29%	47%
	Large Pieces	Transport as Erosion Fines	8%	8%
		Transport as Large Pieces	4%	7%
	Intact Blankets		0%	0%
Nukon	Fines		97%	97%
	Small Pieces	Transport as Erosion Fines	9%	9%
		Transport as Small Pieces	29%	47%
	Large Pieces	Transport as Erosion Fines	8%	8%
		Transport as Large Pieces	4%	7%
	Intact Blankets		0%	0%
Thermal-Wrap	Fines		97%	97%
	Small Pieces	Transport as Erosion Fines	9%	9%
		Transport as Small Pieces	29%	47%
	Large Pieces	Transport as Erosion Fines	8%	8%
		Transport as Large Pieces	4%	7%
	Intact Blankets		0%	0%
Temp-Mat	Fines		97%	97%
	Small Pieces	Transport as Erosion Fines	9%	9%
		Transport as Small Pieces	83%	83%
	Large Pieces	Transport as Erosion Fines	8%	8%
		Transport as Large Pieces	73%	73%
	Intact Blankets		0%	0%
Mirror RMI	Fines		5%	13%
	Large Pieces		6%	11%
Transco RMI	Fines		5%	13%
	Large Pieces		6%	11%
Non-banded Cal-Sil	Fines		97%	97%
	Small Pieces	Transport as Erosion Fines	17%	17%
		Transport as Small Pieces	6%	14%
Banded Cal-Sil	Fines		97%	97%
	Small Pieces	Transport as Erosion Fines	17%	17%
		Transport as Small Pieces	6%	14%
Qualified Coatings	Particulate		97%	97%
Unqualified Coatings	Particulate		100%	100%
Latent Debris	Particulate/Fiber		85%	85%

Table 3.e.6-14: PSL1 Overall Transport Fractions for a Reactor Cavity Break [JT190]

Debris Type	Debris Size		1 Train	2 Train
Generic Fiberglass	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		97%	97%
	Small Pieces	Transport as Erosion Fines	9%	9%
		Transport as Small Pieces	29%	47%
	Large Pieces	Transport as Erosion Fines	8%	8%
		Transport as Large Pieces	4%	7%
	Intact Blankets		0%	0%
Thermal-Wrap	Fines		97%	97%
	Small Pieces	Transport as Erosion Fines	9%	9%
		Transport as Small Pieces	29%	47%
	Large Pieces	Transport as Erosion Fines	8%	8%
		Transport as Large Pieces	4%	7%
	Intact Blankets		0%	0%
Temp-Mat	Fines		97%	97%
	Small Pieces	Transport as Erosion Fines	9%	9%
		Transport as Small Pieces	83%	83%
	Large Pieces	Transport as Erosion Fines	8%	8%
		Transport as Large Pieces	73%	73%
	Intact Blankets		0%	0%
Mirror RMI	Fines		5%	13%
	Large Pieces		6%	11%
Transco RMI	Fines		5%	13%
	Large Pieces		6%	11%
Transco RMI (inside cavity)	Fines		3%	7%
	Large Pieces		0%	0%
Non-banded Cal-Sil	Fines		97%	97%
	Small Pieces	Transport as Erosion Fines	17%	17%
		Transport as Small Pieces	6%	14%
Banded Cal-Sil	Fines		97%	97%
	Small Pieces	Transport as Erosion Fines	17%	17%
		Transport as Small Pieces	6%	14%
Qualified Coatings	Particulate		97%	97%
Unqualified Coatings	Particulate		100%	100%
Latent Debris	Particulate/Fiber		85%	85%

Table 3.e.6-15: PSL1 Overall Transport Fractions for a Pressurizer Compartment Break [JT191]

Debris Type	Debris Size		1 Train	2 Train
Generic Fiberglass	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		97%	97%
	Small Pieces	Transport as Erosion Fines	9%	9%
		Transport as Small Pieces	28%	45%
	Large Pieces	Transport as Erosion Fines	4%	4%
		Transport as Large Pieces	2%	3%
	Intact Blankets		0%	0%
Thermal-Wrap	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		97%	97%
	Small Pieces	Transport as Erosion Fines	9%	9%
		Transport as Small Pieces	77%	77%
	Large Pieces	Transport as Erosion Fines	4%	4%
		Transport as Large Pieces	28%	28%
	Intact Blankets		0%	0%
Mirror RMI	Fines		-	-
	Large Pieces		-	-
Transco RMI	Fines		5%	13%
	Large Pieces		3%	5%
Non-banded Cal-Sil	Fines		97%	97%
	Small Pieces	Transport as Erosion Fines	17%	17%
		Transport as Small Pieces	5%	14%
Banded Cal-Sil	Fines		-	-
	Small Pieces	Transport as Erosion Fines	-	-
		Transport as Small Pieces	-	-
Qualified Coatings	Particulate		97%	97%
Unqualified Coatings	Particulate		100%	100%
Latent Debris	Particulate/Fiber		85%	85%

Table 3.e.6-16: PSL2 Overall Transport Fractions for a Break Inside the SSW [JT192]

Debris Type	Debris Size		1 Train	2 Train
LDFG	Fines		97%	97%
	Small Pieces	Transport as Erosion Fines	10%	9%
		Transport as Small Pieces	10%	18%
	Large Pieces	Transport as Erosion Fines	8%	8%
		Transport as Large Pieces	2%	5%
	Intact Blankets		0%	0%
Nukon	Fines		97%	97%
	Small Pieces	Transport as Erosion Fines	10%	9%
		Transport as Small Pieces	10%	18%
	Large Pieces	Transport as Erosion Fines	8%	8%
		Transport as Large Pieces	2%	5%
	Intact Blankets		0%	0%
Mirror RMI	Fines		1%	9%
	Large Pieces		2%	5%
Transco RMI	Fines		1%	9%
	Large Pieces		2%	5%
Cal-Sil	Fines		97%	97%
	Small Pieces	Transport as Erosion Fines	17%	17%
		Transport as Small Pieces	1%	7%
Qualified Coatings	Particulate		97%	97%
Unqualified Coatings	Particulate		100%	100%
Latent Debris	Particulate/Fiber		85%	85%

Table 3.e.6-17: PSL2 Overall Transport Fractions for a Reactor Cavity Break [JT193]

Debris Type	Debris Size		1 Train	2 Train
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		97%	97%
	Small Pieces	Transport as Erosion Fines	10%	9%
		Transport as Small Pieces	10%	18%
	Large Pieces	Transport as Erosion Fines	8%	8%
		Transport as Large Pieces	2%	5%
	Intact Blankets		0%	0%
Nukon (inside cavity)	Fines		97%	97%
	Small Pieces	Transport as Erosion Fines	10%	10%
		Transport as Small Pieces	5%	8%
	Large Pieces	Transport as Erosion Fines	10%	10%
		Transport as Large Pieces	0%	0%
	Intact Blankets		0%	0%
Mirror RMI	Fines		1%	9%
	Large Pieces		2%	5%
Mirror RMI (inside cavity)	Fines		1%	4%
	Large Pieces		0%	0%
Transco RMI	Fines		-	-
	Large Pieces		-	-
Cal-Sil	Fines		97%	97%
	Small Pieces	Transport as Erosion Fines	17%	17%
		Transport as Small Pieces	1%	7%
Qualified Coatings	Particulate		97%	97%
Unqualified Coatings	Particulate		100%	100%
Latent Debris	Particulate/Fiber		85%	85%

Table 3.e.6-18: PSL2 Overall Transport Fractions for a Pressurizer Compartment Break [JT194]

Debris Type	Debris Size		1 Train	2 Train
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		97%	97%
	Small Pieces	Transport as Erosion Fines	9%	9%
		Transport as Small Pieces	9%	16%
	Large Pieces	Transport as Erosion Fines	4%	4%
		Transport as Large Pieces	1%	2%
	Intact Blankets		0%	0%
Mirror RMI	Fines		-	-
	Large Pieces		-	-
Transco RMI	Fines		-	-
	Large Pieces		-	-
Cal-Sil	Fines		-	-
	Small Pieces	Transport as Erosion Fines	-	-
		Transport as Small Pieces	-	-
Qualified Coatings	Particulate		97%	97%
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 in the following tables. Overall debris transport fractions were taken from Table 3.e.6-13 for PSL1, and Table 3.e.6-16 for PSL2 and applied to the debris generated values from Table 3.b.4-1 for PSL1, and Table 3.b.4-2 and Table 3.b.4-3 for PSL2.[JT195]

Table 3.e.6-19 shows the quantities of debris transported for the two most limiting break cases for each loop at PSL1.[JT196] These break locations were limiting for both Cal-Sil and fiber quantities. 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.6-19: PSL1 Transported Debris for the Two Worst-Case Breaks for Each Loop

<table>
<tr><th colspan="2">Break Location</th><th colspan="2">1-SGB-W16 & RC-123-FW-2000</th><th colspan="2">RC-123-1-503</th><th colspan="2">1-SGA-W16 & RC-114-FW-2000</th><th colspan="2">RC-114-7-503</th></tr>
<tr><td colspan="2">Location Description</td><td colspan="2">SG B Nozzle at Hot Leg</td><td colspan="2">Hot Leg B Elbow</td><td colspan="2">SG A Nozzle at Hot Leg</td><td colspan="2">Hot Leg A Elbow</td></tr>
<tr><td colspan="2">Break Size</td><td colspan="2">42"</td><td colspan="2">42"</td><td colspan="2">42"</td><td colspan="2">42"</td></tr>
<tr><td colspan="2">Break Type</td><td colspan="2">DEGB</td><td colspan="2">DEGB</td><td colspan="2">DEGB</td><td colspan="2">DEGB</td></tr>
<tr><td rowspan="4">Nukon, LDFG, and Thermal Wrap (lbm)</td><td>Fine</td><td colspan="2">516.32</td><td colspan="2">499.15</td><td colspan="2">493.85</td><td colspan="2">479.15</td></tr>
<tr><td>Small</td><td colspan="2">595.07</td><td colspan="2">563.39</td><td colspan="2">572.84</td><td colspan="2">544.97</td></tr>
<tr><td>Large</td><td colspan="2">40.50</td><td colspan="2">42.75</td><td colspan="2">37.63</td><td colspan="2">39.80</td></tr>
<tr><td>Intact</td><td colspan="2">0.00</td><td colspan="2">0.00</td><td colspan="2">0.00</td><td colspan="2">0.00</td></tr>
<tr><td rowspan="4">Temp-Mat (lbm)</td><td>Fine</td><td colspan="2">5.61</td><td colspan="2">5.60</td><td colspan="2">44.60</td><td colspan="2">42.52</td></tr>
<tr><td>Small</td><td colspan="2">6.72</td><td colspan="2">6.72</td><td colspan="2">59.43</td><td colspan="2">54.45</td></tr>
<tr><td>Large</td><td colspan="2">2.04</td><td colspan="2">1.97</td><td colspan="2">7.37</td><td colspan="2">10.15</td></tr>
<tr><td>Intact</td><td colspan="2">0.00</td><td colspan="2">0.00</td><td colspan="2">0.00</td><td colspan="2">0.00</td></tr>
<tr><td rowspan="3">Cal-Sil (lbm)</td><td>Fine</td><td colspan="2">974.46</td><td colspan="2">966.10</td><td colspan="2">769.77</td><td colspan="2">744.14</td></tr>
<tr><td>Small</td><td colspan="2">88.42</td><td colspan="2">89.85</td><td colspan="2">73.23</td><td colspan="2">70.42</td></tr>
<tr><td>Intact</td><td colspan="2">0.00</td><td colspan="2">0.00</td><td colspan="2">0.00</td><td colspan="2">0.00</td></tr>
<tr><td rowspan="2">Transco and Mirror RMI (ft^2)</td><td>Small (<4”)</td><td colspan="2">1502</td><td colspan="2">1530</td><td colspan="2">1424</td><td colspan="2">1451</td></tr>
<tr><td>Large (≥ 4”)</td><td colspan="2">424</td><td colspan="2">432</td><td colspan="2">402</td><td colspan="2">409</td></tr>
<tr><td>Carbozinc 11</td><td>Fine</td><td>164.05 lbm</td><td>0.79 ft^3</td><td>165.63 lbm</td><td>0.80 ft^3</td><td>50.85 lbm</td><td>0.24 ft^3</td><td>51.81 lbm</td><td>0.25 ft^3</td></tr>
<tr><td>Phenoline 305</td><td>Fine</td><td>199.01 lbm</td><td>1.97 ft^3</td><td>212.41 lbm</td><td>2.10 ft^3</td><td>122.57 lbm</td><td>1.21 ft^3</td><td>137.03 lbm</td><td>1.35 ft^3</td></tr>
<tr><td>Carboline 195</td><td>Fine</td><td>182.76 lbm</td><td>1.70 ft^3</td><td>204.86 lbm</td><td>1.90 ft^3</td><td>164.53 lbm</td><td>1.52 ft^3</td><td>189.16 lbm</td><td>1.76 ft^3</td></tr>
</table>

Table 3.e.6-20 shows the quantities of insulation debris transported for the two most limiting Cal-Sil break locations for each loop at PSL2.[JT197]

Table 3.e.6-20: PSL2 Transported Debris for the Two Worst-Case Cal-Sil Breaks for Each Loop

<table>
<tr><th colspan="2">Break Location</th><th colspan="2">313-N4-3204-2-JW103-S/C010</th><th colspan="2">RC-114-FW-2010</th><th colspan="2">314-N4-3204-2-JW103-S/C010</th><th colspan="2">RC-123-FW-2010</th></tr>
<tr><td colspan="2">Location Description</td><td colspan="2">SG A Nozzle at Hot Leg</td><td colspan="2">SG A Nozzle at Hot Leg</td><td colspan="2">SG B Nozzle at Hot Leg</td><td colspan="2">SG B Nozzle at Hot Leg</td></tr>
<tr><td colspan="2">Break Size</td><td colspan="2">42"</td><td colspan="2">42"</td><td colspan="2">42"</td><td colspan="2">42"</td></tr>
<tr><td colspan="2">Break Type</td><td colspan="2">DEGB</td><td colspan="2">DEGB</td><td colspan="2">DEGB</td><td colspan="2">DEGB</td></tr>
<tr><td rowspan="4">Nukon and LDFG (lbm)</td><td>Fine</td><td colspan="2">455.86</td><td colspan="2">455.86</td><td colspan="2">654.12</td><td colspan="2">654.12</td></tr>
<tr><td>Small</td><td colspan="2">216.59</td><td colspan="2">216.59</td><td colspan="2">300.69</td><td colspan="2">300.69</td></tr>
<tr><td>Large</td><td colspan="2">16.92</td><td colspan="2">16.92</td><td colspan="2">29.92</td><td colspan="2">29.92</td></tr>
<tr><td>Intact</td><td colspan="2">0.00</td><td colspan="2">0.00</td><td colspan="2">0.00</td><td colspan="2">0.00</td></tr>
<tr><td rowspan="3">Cal-Sil (lbm)</td><td>Fine</td><td colspan="2">41.43</td><td colspan="2">41.43</td><td colspan="2">29.76</td><td colspan="2">29.76</td></tr>
<tr><td>Small</td><td colspan="2">2.00</td><td colspan="2">2.00</td><td colspan="2">1.47</td><td colspan="2">1.47</td></tr>
<tr><td>Intact</td><td colspan="2">0.00</td><td colspan="2">0.00</td><td colspan="2">0.00</td><td colspan="2">0.00</td></tr>
<tr><td rowspan="2">Transco and Mirror RMI (ft^2)</td><td>Small (<4”)</td><td colspan="2">94</td><td colspan="2">94</td><td colspan="2">94</td><td colspan="2">94</td></tr>
<tr><td>Large (≥ 4”)</td><td colspan="2">17</td><td colspan="2">17</td><td colspan="2">18</td><td colspan="2">18</td></tr>
<tr><td>Carbozinc 11</td><td>Fine</td><td>41.42 lbm</td><td>0.20 ft^3</td><td>41.42 lbm</td><td>0.20 ft^3</td><td>63.34 lbm</td><td>0.30 ft^3</td><td>63.34 lbm</td><td>0.30 ft^3</td></tr>
<tr><td>Phenoline 305</td><td>Fine</td><td>110.39 lbm</td><td>1.09 ft^3</td><td>110.39 lbm</td><td>1.09 ft^3</td><td>135.51 lbm</td><td>1.34 ft^3</td><td>135.51 lbm</td><td>1.34 ft^3</td></tr>
<tr><td>Carboline 195</td><td>Fine</td><td>153.36 lbm</td><td>1.43 ft^3</td><td>153.36 lbm</td><td>1.43 ft^3</td><td>175.18 lbm</td><td>1.63 ft^3</td><td>175.18 lbm</td><td>1.63 ft^3</td></tr>
</table>

Table 3.e.6-21 shows the quantities of insulation debris transported for the two most limiting fiber breaks locations for each loop at PSL2.[JT198] 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.6-21: PSL2 Transported Debris for the Two Worst-Case Fiber Breaks for Each Loop

Break Location		**313-N4-3204-2-JW103-S/C010**	**RC-114-FW-771**	**314-N4-3204-2-JW103-S/C010**	**RC-123-201-771**
Location Description		SG A Nozzle at Hot Leg	Hot Leg A Elbow	SG B Nozzle at Hot Leg	Hot Leg B Elbow
Break Size		42"	42"	42"	42"
Break Type		DEGB	DEGB	DEGB	DEGB
Nukon and LDFG (lbm)	Fine	455.86	452.48	654.12	656.50
	Small	216.59	212.40	300.69	299.14
	Large	16.92	18.24	29.92	31.53
	Intact	0.00	0.00	0.00	0.00
Cal-Sil (lbm)	Fine	41.43	39.25	29.76	27.90
	Small	2.00	1.86	1.47	1.30
	Intact	0.00	0.00	0.00	0.00
Transco and Mirror RMI (ft^2)	Small (<4")	94	88	94	89
	Large (≥ 4")	17	16	18	17
Carbozinc 11	Fine	41.42 lbm / 0.20 ft^3	43.55 lbm / 0.21 ft^3	63.34 lbm / 0.30 ft^3	65.57 lbm / 0.31 ft^3
Phenoline 305	Fine	110.39 lbm / 1.09 ft^3	117.47 lbm / 1.16 ft^3	135.51 lbm / 1.34 ft^3	139.68 lbm / 1.38 ft^3
Carboline 195	Fine	153.36 lbm / 1.43 ft^3	163.74 lbm / 1.52 ft^3	175.18 lbm / 1.63 ft^3	180.32 lbm / 1.68 ft^3

The quantity of latent debris that transports to the strainers is 72.25 lbm latent particulate and 12.75 lbm (5.3125 ft^3) latent fiber for all breaks.[JT199]

3.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 and Figure 3.f.1-2 for ECCS and CSS schematics of PSL1 and PSL2, respectively.

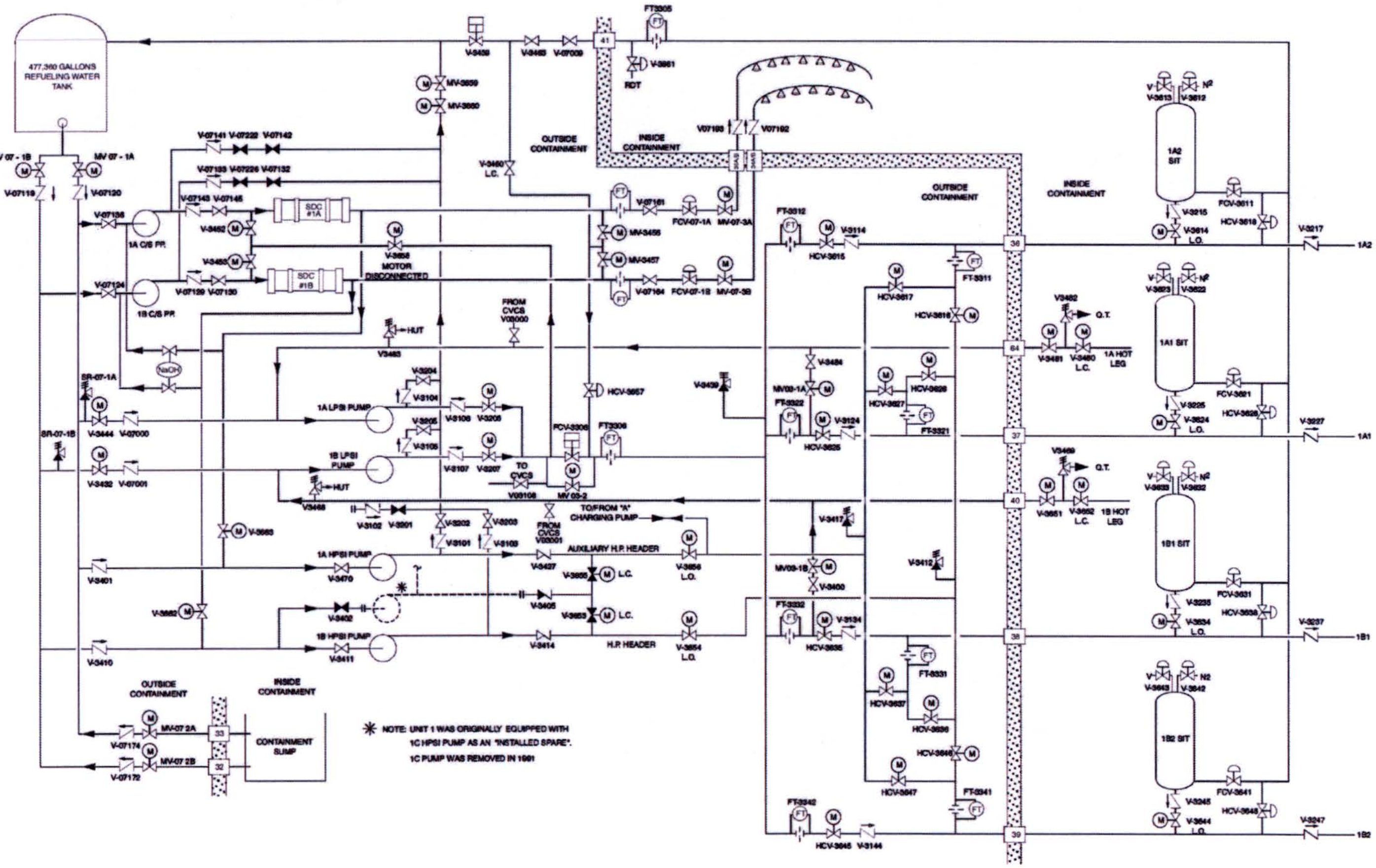

Figure 3.f.1-1: PSL1 Emergency Core Cooling System and Containment Spray System Schematic [JT200]

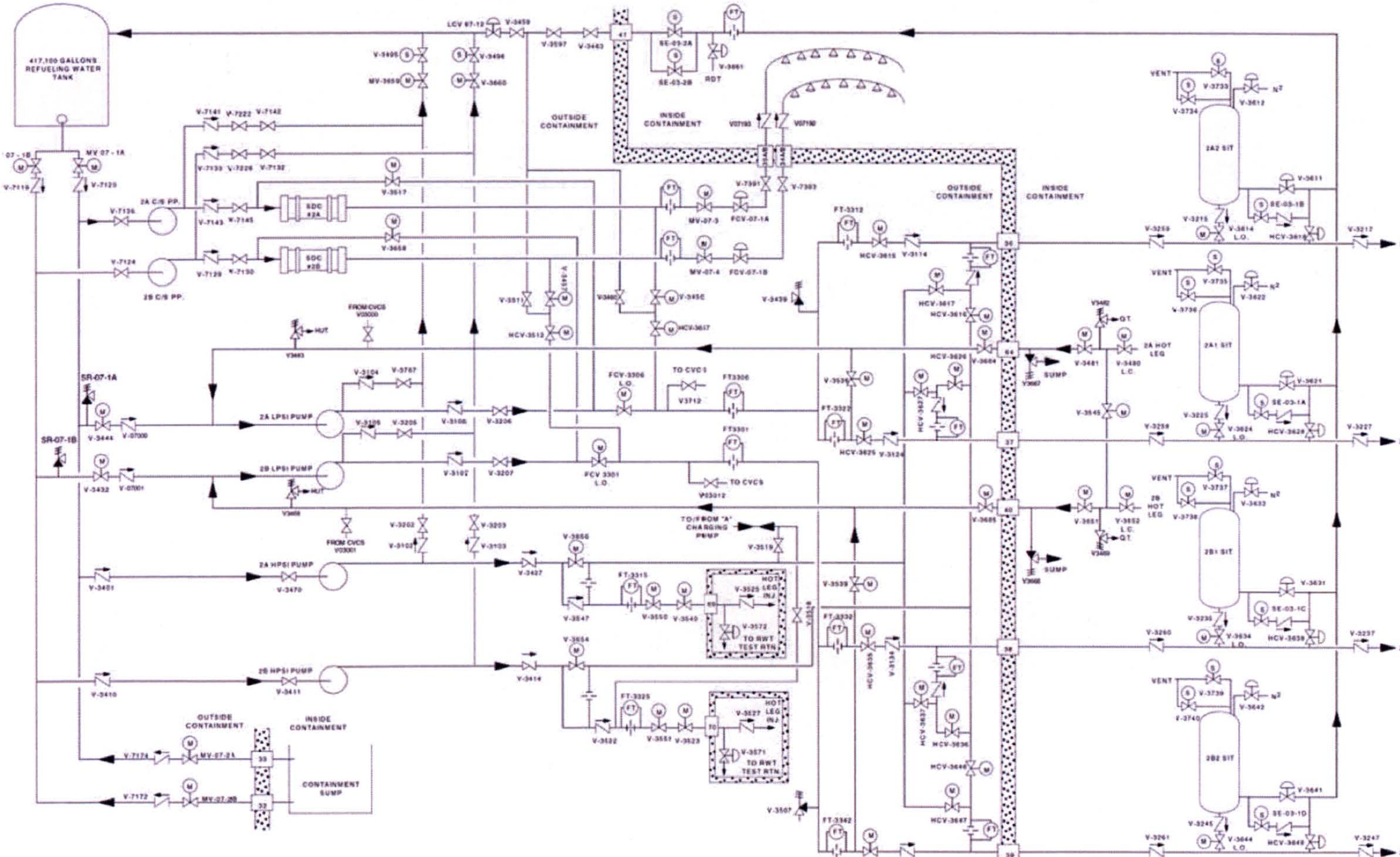

Figure 3.f.1-2: PSL2 Emergency Core Cooling System and Containment Spray System Schematic [JT201]

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:

The containment water level calculation evaluated bounding minimum sump pool volumes and levels for SBLOCAs and LBLOCAs. Table 3.f.2-1 and Table 3.f.2-2 summarize the results of the containment water level calculation for PSL1 and PSL2, respectively. See the Response to 3.g.1 for more details.

Table 3.f.2-1: PSL1 Minimum Sump Pool Water Levels

Break Size	Minimum Water Level Elevation (ft)	Pool Height (ft)	Strainer Submergence (ft)
SBLOCA	23.15 [JT202]	5.15	0.54
LBLOCA	23.66 [JT203]	5.66	1.05

Table 3.f.2-2: PSL2 Minimum Sump Pool Water Levels

Break Size	Minimum Water Level Elevation (ft)	Pool Height (ft)	Strainer Submergence (ft)
SBLOCA	22.74 [JT204]	4.74	0.91
LBLOCA	23.38 [JT205]	5.38	1.55

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

Response to 3.f.3:

Response for PSL1

The flow rate of one CSS train at the time of recirculation is 3,663 gpm, and this flow rate occurs when the HPSI pump is operating in "piggy-back" mode.[JT206] The flow rate through the strainer during two train operation is 7,326 gpm, which corresponds to an average approach velocity of 0.00232 ft/s for a total net strainer surface area of 7,044 ft^2.[JT207] These design flow rates were determined in a system analysis performed in support of extended power uprate (EPU). As shown in the Response to 3.g.1, the minimum water level results in a strainer submergence of 6.5" for SBLOCAs and 12.6" for LBLOCAs at start of recirculation.

Vortex testing was incorporated into the head loss test program and described in the Response to 3.f.4, for PSL1. A clean strainer vortex test was performed prior to addition of conventional and chemical debris to the test tank. The strainer was submerged 1 inch and the test flow rate was increased from 400 gpm (approach velocity of 0.00247 ft/s) to 1,000 gpm (approach velocity of 0.00618 ft/s) in approximately 200 gpm increments, and vortexing was not observed under these conditions.[JT208] While chemical debris batches were introduced to the test tank during testing, the water level in the test tank was regularly reduced to a strainer submergence of 6.5".[JT209] Vortexing was not observed at any time during the test.[JT210] The nominal flow rate during head loss testing was 417 gpm,[JT211] corresponding to an approach velocity of 0.00258 ft/s.

Vortexing was not observed during the head loss test when the submergence of the clean strainer was less the plant minimum strainer submergence, and vortexing was not observed when the debris laden strainer's submergence was equal to the plant's SBLOCA minimum submergence of 6.5". In addition, the strainer approach velocity during testing was greater than the plant strainer approach velocity. Therefore, vortexing during sump recirculation is not a concern for PSL1.

Response for PSL2

For conservatism, the sump flow rate from two CS pumps and two HPSI pumps at the time of recirculation is established at 8,556 gpm,[JT212] which corresponds to an average approach velocity of 0.00353 ft/s for a total net strainer surface area of 5,407 ft^2.[JT213] As shown in the Response to 3.g.1, the minimum water level results in a strainer submergence of 10.9" for SBLOCAs and 18.6" for LBLOCAs at start of recirculation.

Vortex testing was incorporated into the PSL2 head loss test program, as described in the Response to 3.f.4. A clean screen vortex test was performed prior to addition of conventional and chemical debris to the test tank. The strainer submergence was reduced down to 1 inch [JT214]at the nominal test flow rate of 562 gpm [JT215](approach velocity of 0.00354 ft/s for a test strainer surface area of 353.9 ft^2),[JT216] and vortexing was not observed to occur. At the end of conventional debris addition and chemical debris addition, the strainer submergence was reduced to 10.4" and no vortexing was observed.[JT217]

Vortexing did not occur during the head loss test when the submergence of the clean strainer or debris laden strainer was less than the plant's minimum strainer submergence. In addition, the test strainer approach velocity was greater than the plant strainer approach velocity. Therefore, vortexing during sump recirculation is not a concern for PSL2.

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

Response to 3.f.4:

Head loss tests were performed for each unit 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 of each unit used a test strainer, debris quantities, and flow rates that were prototypical to the plant strainer.[JT218] Different test cases were performed with the thin-bed and full debris load protocols, following the 2008 NRC Staff Review Guidance (Reference 3)[JT219].

The objective of the full debris load test protocol is to measure debris head losses associated with the fiber, particulate and chemical debris quantities calculated to transport to the sump strainer after a LOCA. The objective of the thin-bed test protocol is to measure debris head losses associated with the maximum particulate debris quantities postulated to occur with the minimum amount of fiber on the strainer required to filter particulate out of the water.

Three head loss tests are discussed in this response for PSL1. Two head loss tests followed the full debris load protocol and one test followed the thin-bed protocol. In this submittal, the two full debris load protocol tests are referred to as PSL1 Full Debris Load Test 1 and PSL1 Full Debris Load Test 2, respectively. The thin-bed test is referred to as the PSL1 Thin-Bed Test.

Two head loss tests are discussed in this response for PSL2. One head loss test followed the full debris load protocol and one test followed the thin-bed protocol. In this submittal, the two tests are referred to as PSL2 Full Debris Load Test, and PSL2 Thin-Bed Test, respectively.

Response for PSL1

Test Setup

The PSL1 containment sump recirculation strainer consists of multiple modules and each module features a number of perforated strainer disks installed on top of a plenum. The plenums of different modules were connected by suction piping. The majority of the modules in the plant are installed inside a keyway that penetrates the secondary shield wall. The modules are also partially obstructed by one or more horizontal suction pipes that are part of the strainer design. There are six different strainer module configurations at PSL1. The test facility was designed to represent the most common module configuration. The keyway was modeled using three acrylic boxes along the sides and the top of the test strainer module, and one obstructing suction pipe was modeled using a pipe in the test tank with the same outside diameter as that installed in the plant. The modeled keyway and suction pipe dimensions relative to the test strainer matched those of the plant strainers.[JT220]

The test strainer module had 13 prototypical strainer disks and were mounted on a prototypical plenum. The test strainer disks and plenum matched all dimensions (such as perforated plate thickness, hole opening size, and hole pitch) of the plant strainer modules. Suction was taken from the top of the plenum to match the plant strainer (Figure 3.f.4-2). The surface area of the test strainer module was 360.6 ft^2.[JT221]

The test strainer, modeled keyway, and suction pipe were installed in a test tank (see Figure 3.f.4-1 and Figure 3.f.4-2). The test tank consisted of two mixing sections, one on each side of the strainer. The "front" side of the test strainer, as designated in Figure 3.f.4-2, models the side of the plant strainer that faces the reactor vessel. The other side of the strainer is referred to as the "rear" side and models the side of the plant strainer facing away from the reactor vessel. Debris and recirculating test loop water flow, which provided mixing, was introduced both on the front side and rear side of the test strainer to represent how debris would reach a plant strainer module installed inside a keyway. The test loop debris introduction and recirculation flow to the front and rear sides of the strainer was split approximately 50/50, except when small pieces of fiber were introduced into the test tank. See discussion on debris introduction section below.[JT222]

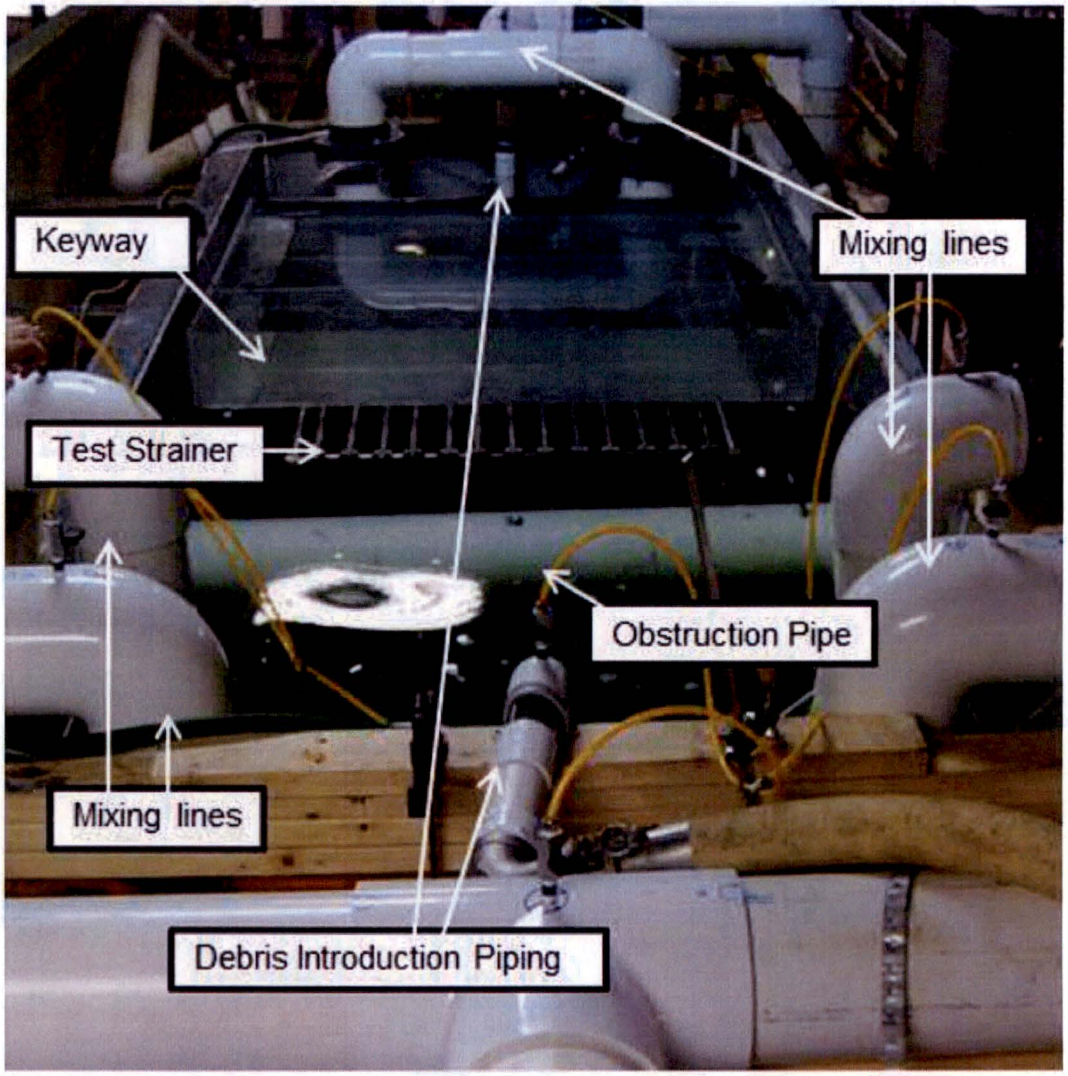

Figure 3.f.4-1: PSL1 Head Loss Test Tank and Strainer [JT223]

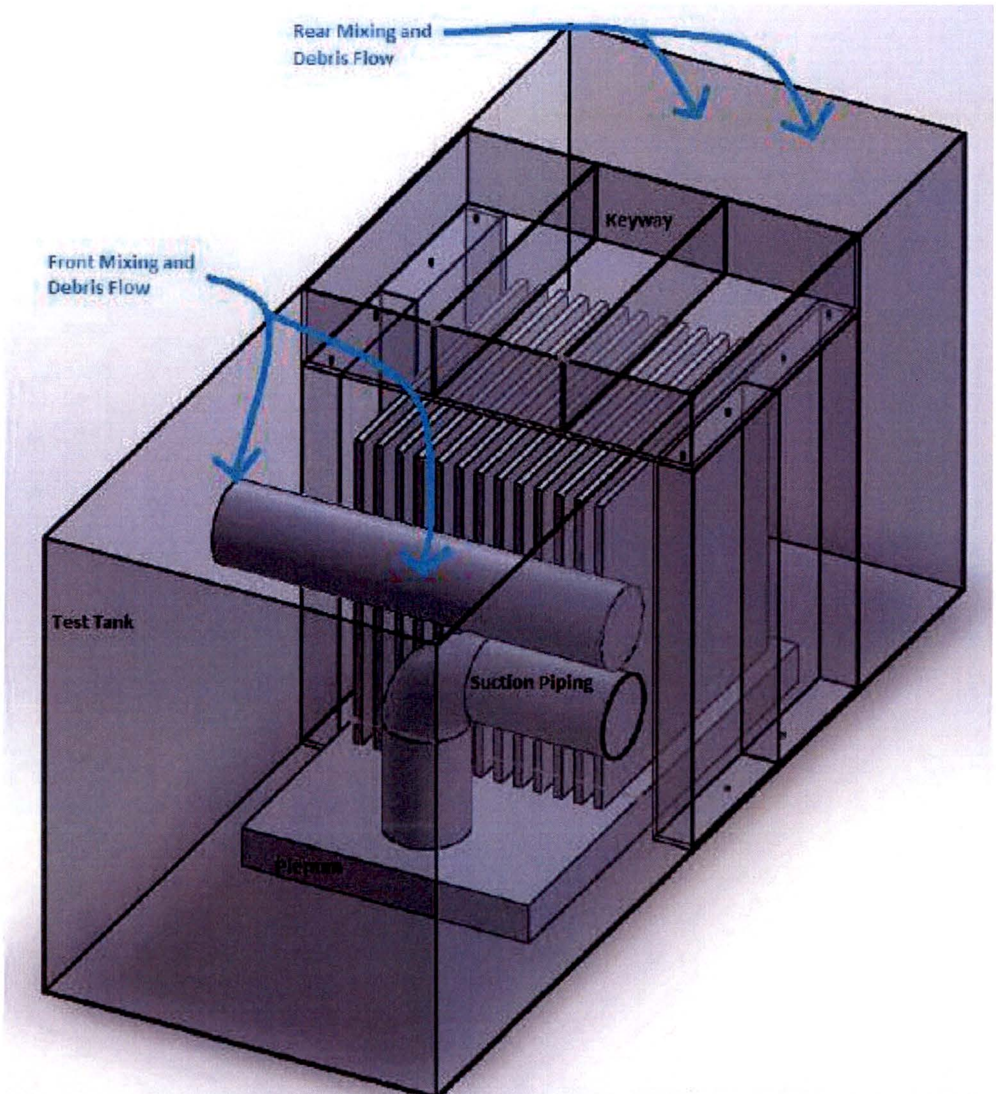

Figure 3.f.4-2: PSL1 Isometric of Head Loss Test Strainer Assembly Inside the Test Tank [JT224]

A schematic piping diagram of the test loop is provided in Figure 3.f.4-3. Note that the filter bag housings were used to clean the test loop before each test but were bypassed during head loss testing. The test loop had a recirculation pump that took suction from the plenum and returned the water back into the test tank. The return flow exits into the tank were located such that the turbulence from the flow did not affect the debris bed on the test strainer, but allowed for thorough mixing of debris in the water column as it was introduced into the test tank. Flow elements were used to measure the flow rate through the test loop and the flow split between the front and rear of the strainer. Flow control valves, and heating and cooling loops were used to control the test flow rate and water temperature.[JT225] The test water was maintained at 120°F ±5 °F [JT226]during conventional and chemical debris introduction. After chemical debris introduction was completed and the head loss was allowed to stabilize (change in head loss is less than 1% per hour)[JT227], the test loop temperature was decreased to approximately 100 °F.[JT228]

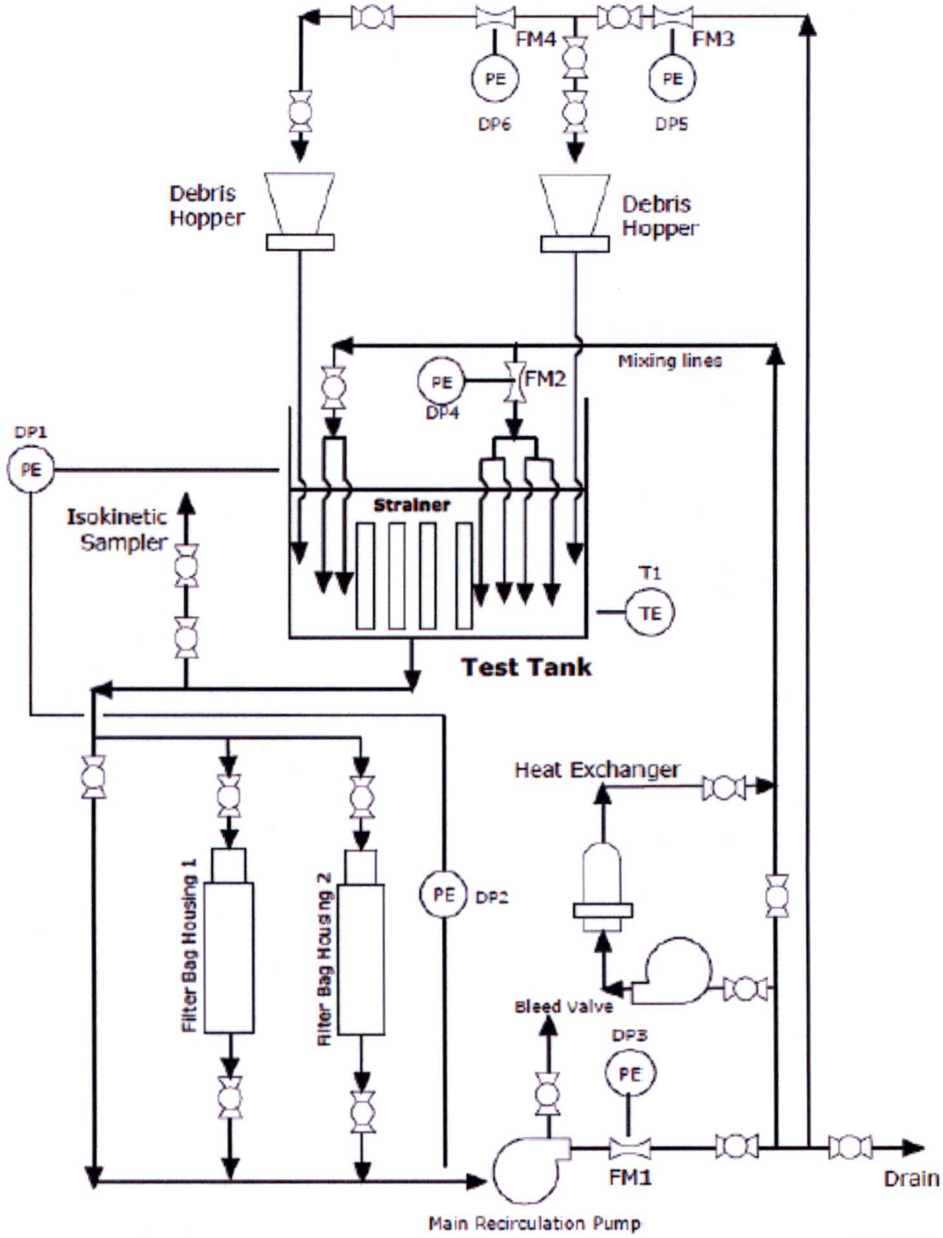

Figure 3.f.4-3: PSL1 Piping Diagram of Head Loss Test Loop[JT229]

Test Parameters and Scaling

The test strainer replicated all hydraulic dimensions of the plant strainer. The test debris quantities and test flow rate were scaled from plant values based on the ratio of the test strainer surface area (360.6 ft^2, stated above) to plant strainer net surface area (7,044 ft^2)[JT230]. Margin was added to the test flow rate, and as a result the test strainer approach velocity (0.0026 ft/sec)[JT231] bounds the plant strainer average approach velocity (0.0023 ft/sec)[JT232]. For a test strainer area of 360.6 ft^2, the nominal test flow rate was 417 gpm.[JT233] Head losses were measured at a range of flow rates (flow sweeps), both on the clean strainer and after addition of debris, as discussed later in this response. The Response to 3.f.10 has additional discussion on correcting test data to plant conditions.[JT234]

Debris Materials and Preparation

The following materials were used as conventional debris for head loss testing: Nukon, Temp-Mat, pulverized acrylic (or paint base material), pulverized Cal-Sil, and PCI Dirt/Dust mix.[JT235] The method of preparation prior to introduction to the test tank for each material is discussed below.

Nukon fines were used as a surrogate for latent fiber, as recommended in NEI 04-07 Volume 1 (Reference 12)[JT236] and the associated NRC SE on NEI 04-07 (Reference 6)[JT237]. Nukon was also used to represent fines and small pieces of low density fiberglass insulation debris. Temp-Mat was used in head loss testing so a surrogate was not required.

Nukon and Temp-Mat fines were prepared in accordance with the NEI fibrous debris preparation protocol (Reference 8)[JT238]. Nukon fiberglass sheets were cut into approximately 2" x 2" squares, and the heat treated base blanket material was examined for a binder burn-out gradient reaching halfway through the blanket. Temp-Mat was pre-shredded by the vendor since the material is very tough, and heat treated. Each batch of Temp-Mat fines consisted of an equal amount of heat treated and non-heat treated Temp-Mat.

After being weighed out into required batches, Nukon or Temp-Mat pieces were placed inside a debris preparation vessel that included a manifold with three high pressure nozzles. Nukon debris was prepared separately from Temp-Mat. Test water was added to the vessel using a low pressure water spray until the fiber debris was completely wetted and a slurry was formed. The debris was then sprayed with test water pressurized to 1500 psi. The initial amount of water, the high pressure spray nozzle position within the vessel, and the amount of time the high pressure spray was applied were controlled during debris preparation so that fine fiber batches had similar characteristics. Acceptable debris characteristics were documented by photographing each batch of prepared debris over a light table.[JT239] Fiber fines were acceptable once their composition was predominantly Class 2 fibers as defined in NUREG/CR-6224 (Reference 15 pp. Table B-3)[JT240], consisting mainly of individual fibers with lesser quantities of fiber shards and small clumps. See Figure 3.f.4-4 for photographs of Nukon and Temp-Mat fines prepared using this process.[JT241]

Figure 3.f.4-4: Nukon (left) and Temp-Mat (right) Fines Prepared for PSL1 Head Loss Testing [JT242]

Preparation of Nukon small pieces (Nukon smalls) was similar to the Nukon fines except the Nukon sheets were cut into sizes of 2" x 2", 2" x 4", 1" x 4" and 1" x 6". Nukon small batches were split into equal parts (by weight): one part consisting of 2" x 2" and 2" x 4" pieces and the other part consisting of 1" x 4" and 1" x 6" pieces. Each part was sprayed with high pressure test water in the debris preparation vessel until the acceptability criteria were reached and, afterwards, the equal parts were mixed together before introduction. Temp-Mat small pieces (Temp-Mat smalls) were prepared similar to the Temp-Mat fines except the high-pressure spray time was reduced so that the acceptability requirements of small pieces were achieved. Small pieces of fiber (fiber smalls) were acceptable once their composition ranged from fines all the way up to measurable pieces on the order of several inches (<6"). Once the high pressure spray duration time was determined for the acceptability criteria to be reached, all batches of similar debris size were prepared with the same spray time.[JT243] See Figure 3.f.4-5 for photographs of Nukon and Temp-Mat small pieces prepared using this process.[JT244]

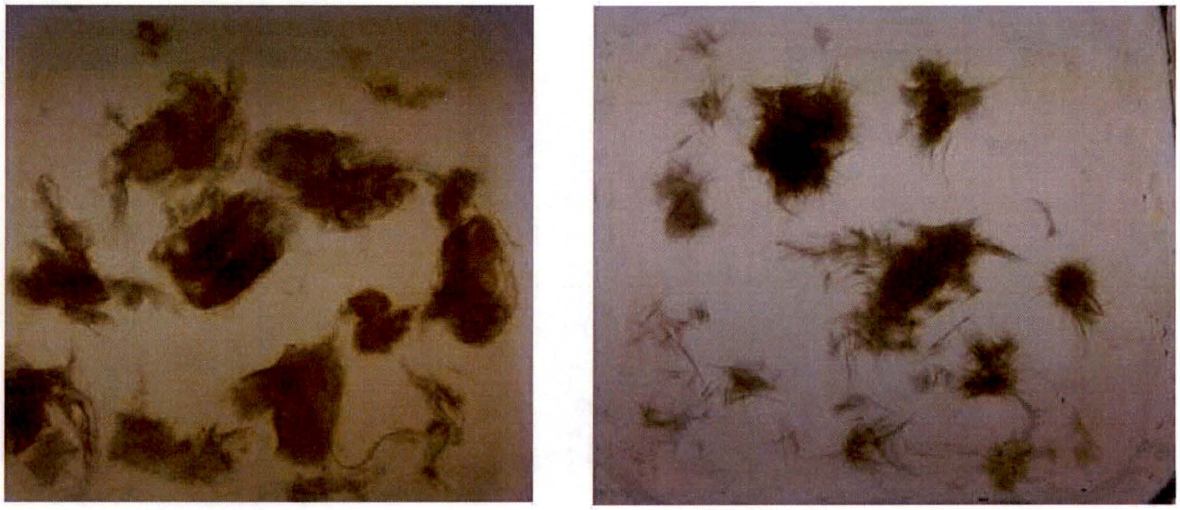

Figure 3.f.4-5: Nukon (left) and Temp-Mat (right) Small Pieces Prepared for PSL1 Head Loss Testing [JT245]

Pulverized acrylic was used a surrogate for failed coatings (epoxy, enamel, IOZ, and cold galvanizing) on an equal volume basis, and had a median size of 12.7 μm.[JT246] The required amount of pulverized acrylic for a debris batch was weighed out and placed in a bucket. The particulate was then wetted with test water while being gently stirred to avoid the formation of foam.[JT247]

Pulverized Cal-Sil was prepared for test introduction using a similar method as the pulverized acrylic. The PCI dirt/dust mix was used as a surrogate for latent particulate.[JT248]

Two types of chemical debris surrogates were used for the head loss testing: sodium aluminum silicate (SAS) and AlOOH. The chemical debris was prepared in accordance with WCAP-16530-NP-A (Reference 16)[JT249] and met the settling volume acceptance requirements specified in WCAP-16530-NP-A. See the Response to 3.o.2.12 for additional information.

Debris Introduction

As previously discussed, Nukon and Temp-Mat debris was prepared separately. The fiber debris slurry for the individual fiber types of a given batch were combined with each other before introduction. The combined fiber slurry was gently mixed with a paddle to avoid agglomeration.[JT250]

For the full debris load tests, the prepared particulates (pulverized acrylic, pulverized Cal-Sil, and PCI dirt/dust mix) of a given batch was added to the fiber slurry and gently stirred until a homogenous fiber and particulate debris mixture was formed. The fiber and particulate slurry was added to the test loop via the debris introduction hoppers or flume. The hoppers used a portion of recirculating loop flow to suspend the debris slurry with fiber fines as it was added into the hopper and carried to the front and rear mixing regions of the test tank. The hopper functioned to provide mixing prior to introduction to prevent agglomeration of the debris materials. The mixing regions used recirculating test loop water to help transport the debris to the strainer and minimize debris settling. A small flume was set up to introduce the slurry of fiber smalls towards the center of the mixing region. Small pieces were only introduced in the mixing region on the front side of the strainer.[JT251]

There was one difference between the debris introduction sequences of the two full debris load protocol tests. For the PSL1 Full Debris Load Test 1, particulate was added to fiber fines and fiber smalls batches, and fiber fines and smalls batches were alternately introduced into the test tank. For the PSL1 Full Debris Load Test 2, particulate debris was only added to the fiber fines batches. All of the fine fiber batches used in the test were introduced into the tank before the fiber smalls were added.[JT252]

For the PSL1 Thin-Bed Test, the pulverized acrylic and pulverized Cal-Sil were individually introduced to the test loop via the debris introduction hoppers, and the PCI dirt/dust mix was added directly to the test tank's mixing regions. All particulate debris was added in quick succession, and no fiber was added to the test until all particulate was introduced. Nukon fiber fines were incrementally added in small batches until a particulate filtering debris bed was formed on the test strainer. Each fiber batch was equivalent to a 1/16" thick theoretical uniform debris bed. A particulate filtering debris bed was observed to form when the test loop water began to clear and when the incremental change in head loss from a batch of fiber fines was observed to be smaller than the preceding batches. No fiber small pieces were used for the thin-bed test.[JT253]

After conventional debris introduction and debris bed characterization (flow sweep) were completed for each test, chemical precipitate debris was added to the test tank. SAS and AlOOH were simultaneously added in several batches to the test loop via a pump and hose from the chemical precipitate debris storage tanks. Once chemical precipitate debris introduction was completed, another flow sweep was performed, the test loop was cooled to about 100 °F, and a final flow sweep was performed.[JT254]

Head Loss Test Cases and Results

PSL1 Full Debris Load Test 1

The total conventional debris load for the PSL1 Full Debris Load Test 1 is provided in Table 3.f.4-1 and scaled to equivalent plant debris loads. The peak conventional debris head loss observed for this test is shown in Table 3.f.4-7.

Table 3.f.4-1: Conventional Debris Quantities for the PSL1 Full Debris Load Test 1 [JT255]

Dirt & Dust (lbm)	Pulverized Acrylic (ft^3)	Cal-Sil (lbm)	Nukon Fines (lbm)	Nukon Small Pieces (lbm)	Temp-Mat Fines (lbm)	Temp-Mat Small Pieces (lbm)
71.23	11.67	1229	542.5	570.9	6.060	6.450

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 PSL1 Full Debris Load Test 1 are summarized in Table 3.f.4-2 and scaled to equivalent plant debris loads.

Table 3.f.4-2: Chemical Precipitate Debris Batches for the PSL1 Full Debris Load Test 1 [JT256]

Batch ID	AlOOH (kg)	SAS (kg)	Aluminum Precipitated (kg)
C1	14.47	19.3	8.5
C2	18.66	25	10.98
C3	20.92	27.88	12.29
C4	18.99	25	11.11
C5	16.56	22.15	9.73
C6	20.92	27.88	12.29
C7	20.92	27.88	12.29
C8	22.03	29.3	12.93
C9	20.92	27.88	12.29
C10	21.72	28.58	12.72
C11	19.3	25.73	11.33
C12	4.82	6.43	2.83
C13	28.15	0	12.66
C14	11.74	0	5.27
C15	14.16	0	6.37
Total	**274.28**	**293.01**	**153.59**

Head loss increased relatively quickly when the first several batches of chemicals were added to the test tank. However, the incremental change in head loss declined as subsequent batches were added. After Batch C9 was introduced, a peak chemical debris head loss was observed, followed by a decrease in head loss. Batches C10-C12 were introduced but the head loss did not exceed the peak recorded earlier.[JT257]

During addition of Batch C13, the top of the keyway became buoyant and lifted off the top of the test strainer. A spike in head loss was observed when the keyway was pushed back down by test personnel and returned into place. The head loss was allowed to stabilize for approximately 3 hours.[JT258] Over this time, the head loss decreased and recovered to the same value before the key way lifted off, as shown in Figure 3.f.4-6. Once stabilized, two additional batches of chemicals were introduced into the tank and had a negligible effect on the head loss. Chemical debris batches were no longer added because a decreasing head loss occurred accompanying chemical debris batch additions.[JT259] The maximum chemical debris head loss for the PSL1 Full Debris Load Test 1 is considered to be the first peak observed after introducing Batch C9 (see Figure 3.f.4-6). The test results are provided in Table 3.f.4-7.[JT260]

Figure 3.f.4-6 shows a plot of raw head loss test data for the PSL1 Full Debris Load Test 1 with time to identify 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.

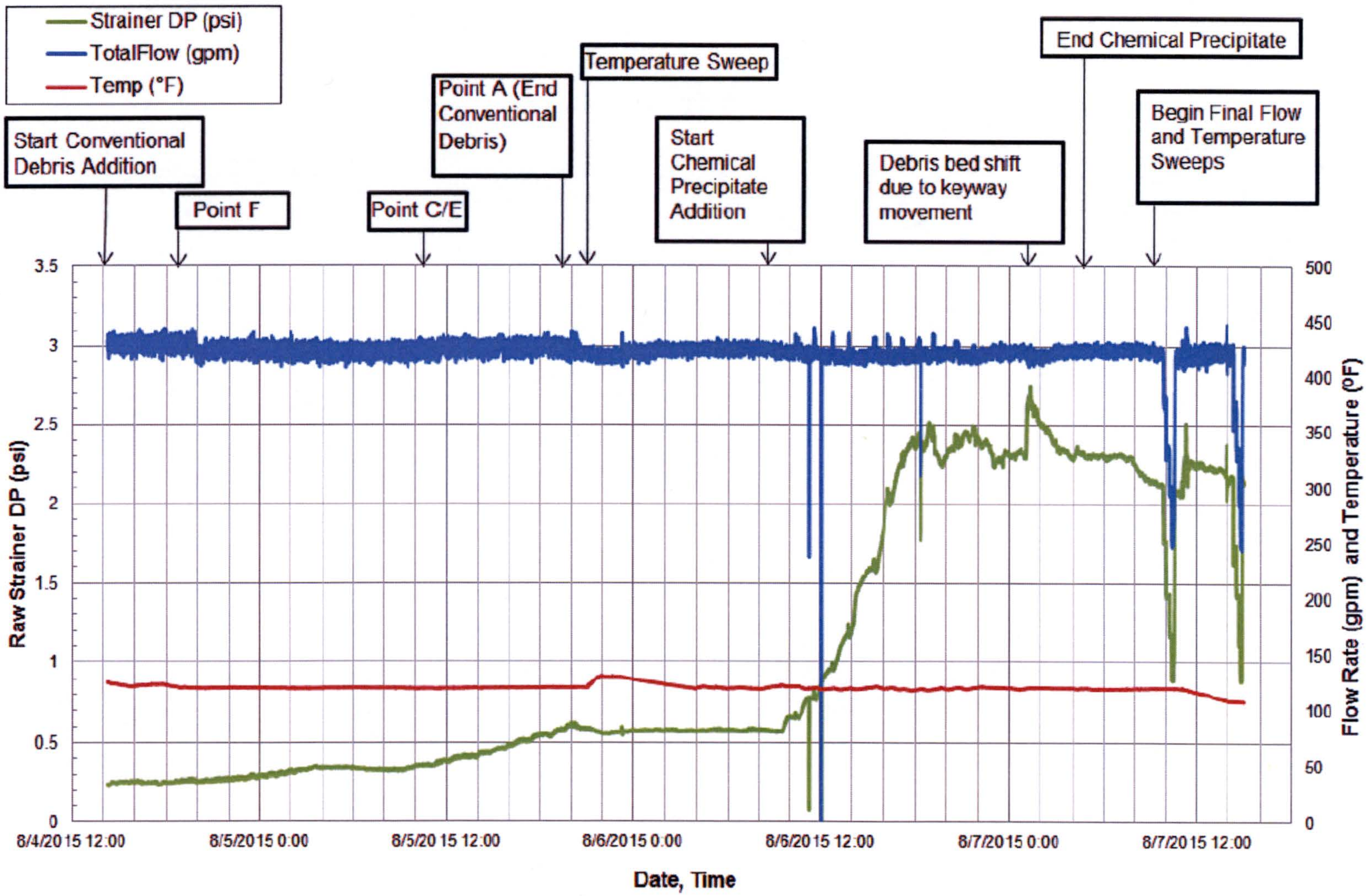

Figure 3.f.4-6: PSL1 Full Debris Load Test 1 Timeline [JT261]

PSL1 Full Debris Load Test 2

The conventional debris load for the PSL1 Full Debris Load Test 2 is provided in Table 3.f.4-3 and scaled to equivalent plant debris loads. The peak conventional debris head loss observed for this test is shown in Table 3.f.4-7.

Table 3.f.4-3: Conventional Debris Quantities for the PSL1 Full Debris Load Test 2 [JT262]

Dirt & Dust (lbm)	Pulverized Acrylic (ft^3)	Cal-Sil (lbm)	Nukon Fines (lbm)	Nukon Small Pieces (lbm)	Temp-Mat Fines (lbm)	Temp-Mat Small Pieces (lbm)
72.28	11.30	883.8	548.7	558.2	49.67	57.26

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 PSL1 Full Debris Load Test 2 are summarized in Table 3.f.4-4 and scaled to equivalent plant debris load.[JT263]

Table 3.f.4-4: Chemical Precipitate Debris Batches for the PSL1 Full Debris Load Test 2 [JT264]

Batch ID	AlOOH (kg)	SAS (kg)	Aluminum Precipitated (kg)
C1	15.88	21.98	9.42
C2	19.36	27.11	11.51
C3	19.69	27.11	11.66
C4	19.85	27.84	11.8
C5	19.85	27.84	11.8
C6	19.85	27.84	11.8
C7	19.69	27.11	11.66
C8	20.78	28.58	12.29
C9	20.32	27.84	12.01
C10	20.63	28.58	12.23
C11	20.16	27.84	11.94
C12	19.85	27.84	11.8
C13	20	27.84	11.88
Total	**255.91**	**355.35**	**151.8**

Head loss increased relatively quickly when the first several batches of chemicals were added to the test tank. However, the incremental change in head loss declined as subsequent batches were added. Eventually, additional batches were not resulting in higher head loss peaks. Chemical debris batches were no longer added when a firm head loss plateau occurred accompanying chemical debris batch additions. The maximum chemical debris bed head loss observed during PSL1 Full Debris Load Test 2 is shown in Table 3.f.4-7.

Figure 3.f.4-7 shows a plot of raw head loss test data for the full debris load test with time to identify 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.

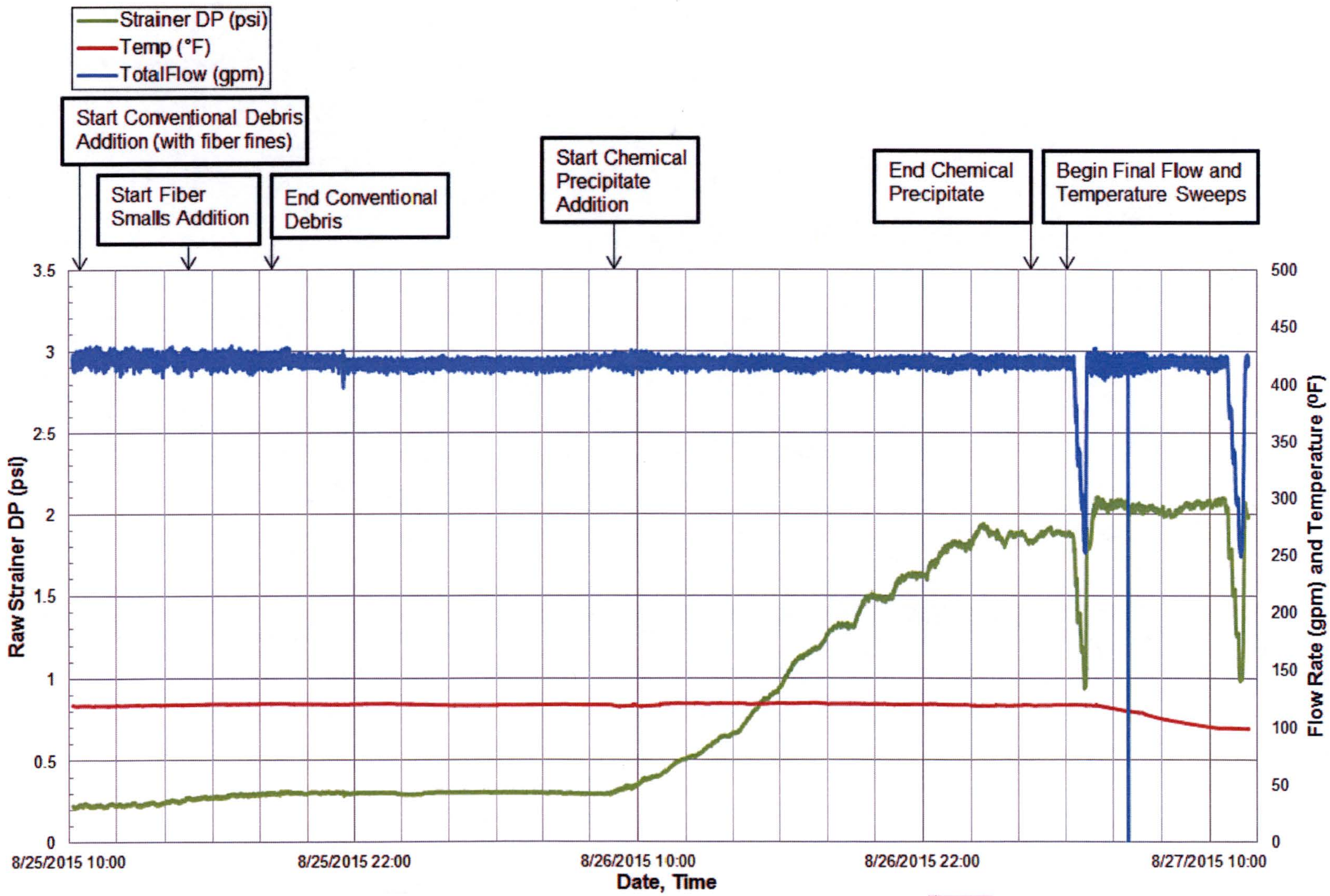

Figure 3.f.4-7: PSL1 Full Debris Load Test 2 Timeline [JT265]

PSL1 Thin-Bed Test

The conventional debris load for the PSL1 Thin-Bed Test is summarized in Table 3.f.4-5 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 3/8". The peak conventional debris head loss observed for this test is shown in Table 3.f.4-7.

Table 3.f.4-5: Conventional Debris Quantities for the PSL1 Thin-Bed Test [JT266]

Dirt & Dust (lbm)	Pulverized Acrylic (ft^3)	Cal-Sil (lbm)	Nukon Fines (lbm)
72.30	11.70	1171	528.4

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 head loss test are summarized in Table 3.f.4-6 and scaled to equivalent plant debris load.[JT267]

Table 3.f.4-6: Chemical Precipitate Debris Batches for the PSL1 Thin-Bed Test

[JT268]

Batch ID	AlOOH (kg)	SAS (kg)	Aluminum Precipitated (kg)
C1	14.75	25.08	9.22
C2	21.82	36.9	13.62
C3	22.74	38.36	14.18
C4	22.44	38.36	14.05
C5	22.29	37.64	13.91
C6	22.89	39.11	14.34
C7	22.6	38.36	14.12
C8	23.21	39.85	14.55
C9	22.6	38.36	14.12
Total	**195.34**	**332.02**	**122.11**

Similar to the full debris load tests, the head loss increased relatively quickly, but at a much lower rate, when the first several batches of chemicals were added to the test tank. However, the incremental change in head loss declined as subsequent batches were added. Eventually, additional batches did not result in higher head loss peaks. Chemical debris batches were no longer added when a decreasing head loss occurred accompanying chemical debris batch additions. The maximum chemical debris bed head loss observed during the PSL1 Thin Bed Test is shown in Table 3.f.4-7.[JT269]

Figure 3.f.4-8 shows a plot 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 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.

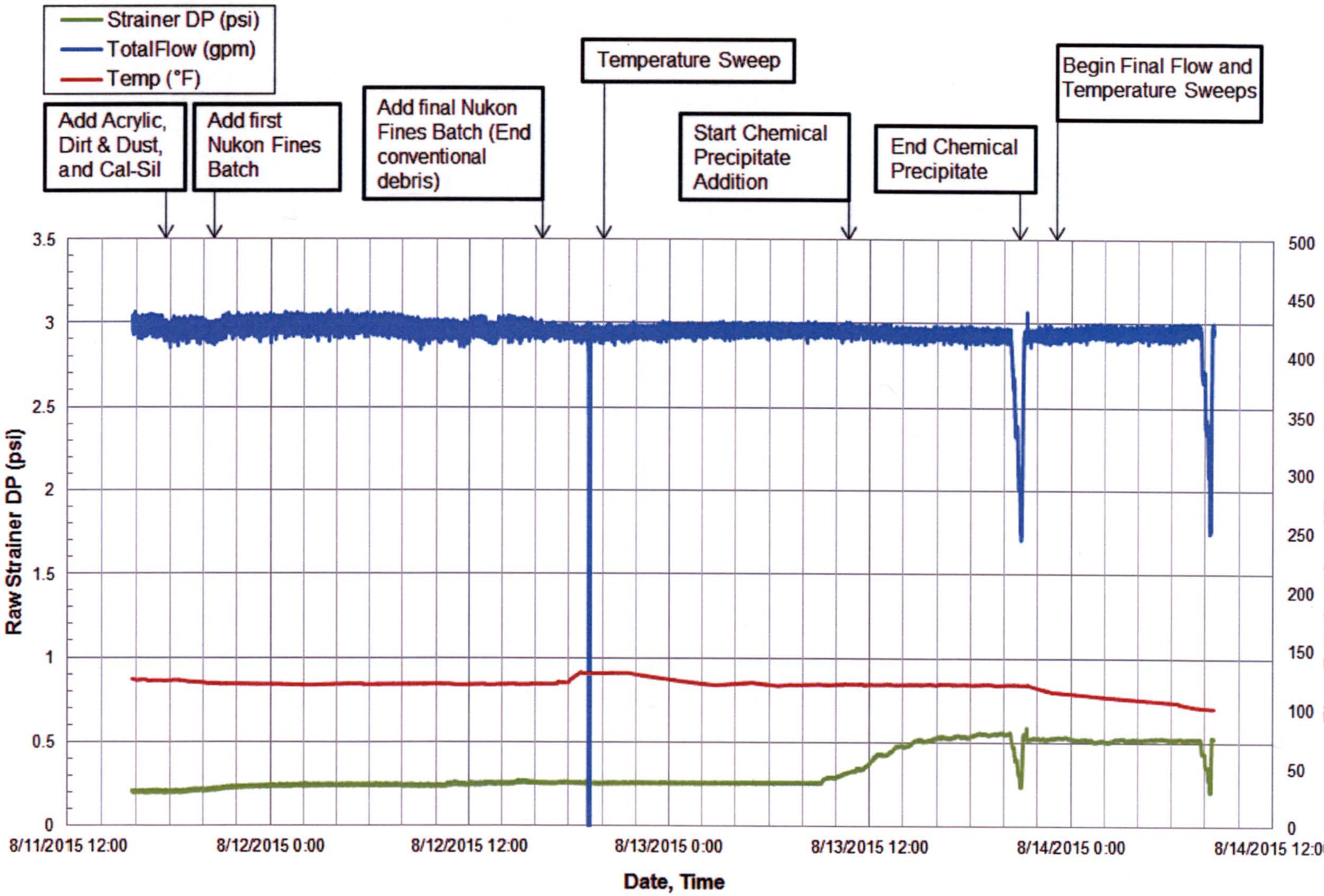

Figure 3.f.4-8: PSL1 Thin-Bed Test Timeline [JT270]

Summary of PSL1 Head Loss Test Data

A summary of the debris head loss results from the PSL1 tests are provided in Table 3.f.4-7. As discussed in the Response to 3.f.7, the maximum conventional and chemical debris head losses of the three tests were used to evaluate pump NPSH, void fraction, flashing and strainer integrity for PSL1. These maximum debris head losses are bold faced in Table 3.f.4-7. The clean screen head loss of the test strainer ranged from 0.19 psi to 0.21 psi for a test flow rate range between 417 gpm and 434 gpm and a nominal temperature of 120 °F.

Table 3.f.4-7: Summary of PSL1 Head Loss Test Results

Test Point	Debris Head Loss (psi)	Test Flow Rate (at Plant Scale) (gpm)	Temperature (°F)
PSL1 Full Debris Load Test 1 [JT271]			
Conventional Debris Max Head Loss	**0.41**	**432.4 (8,447)**	**120.4**
Conventional Debris Stable Head Loss	0.38	423.2 (8,267)	120.2
Aluminum Precipitate Max Head Loss	**2.32**	**413.2 (8,071)**	**117.8**
Aluminum Precipitate Stable Head Loss	2.10	424.9 (8,300)	119.2
PSL1 Full Debris Load Test 2 [JT272]			
Conventional Debris Max Head Loss	0.10	426.5 (8,331)	120.8
Conventional Debris Stable Head Loss	0.08	421.4 (8,232)	119.9
Aluminum Precipitate Max Head Loss	1.73	415.8 (8,122)	119.1
Aluminum Precipitate Stable Head Loss	1.65	418.0 (8,165)	119.8
PSL1 Thin-Bed Test [JT273]			
Conventional Debris Max Head Loss	0.06	427.5 (8,351)	120.0
Conventional Debris Stable Head Loss	0.05	423.2 (8,267)	121.4
Aluminum Precipitate Max Head Loss	0.35	414.4 (8,095)	120.2
Aluminum Precipitate Stable Head Loss	0.35	417.8 (8,161)	120.0

Response for PSL2

Test Setup

The test facility was designed to represent the strainer installation at PSL2. The strainer modules in the plant are adjacent to each other and mounted on top of a common plenum box and have horizontally stacked disks around a core tube. The test tank and strainer were designed to model a plant strainer module and the gaps between two adjacent modules and behind the strainer. The test tank features wing walls so that flow and debris were directed to the test strainer.[JT274]

The test strainer was comprised of two modules stacked on top of each other. The core tube of the top module was connected to the core tube of lower module which replicates the plant configuration. Each module contained 15 prototypical strainer disks (30 disks total) that were 24" by 40", and the two stacked modules were separated by a steel stiffener plate that matches the plant strainer design. The test strainer disks matched all dimensions of the plant strainer (such as perforated plate thickness, hole opening size, and hole pitch). The lower module's core tube was attached to a fabricated plenum at the bottom of the test strainer. The test plenum had a smaller height than the plant strainer plenum. As a result, the test strainer assembly is closer to the tank floor than the plant strainer is to the containment trench floor. This is conservative since it allows debris to more easily transport to the test strainer than it would to the plant strainer.[JT275] The surface area of the test strainer module was 353.9 ft^2.[JT276]

The test strainer and plenum were installed in a test tank (see Figure 3.f.4-9 and Figure 3.f.4-10). Wing walls were configured to match the spacing in the plant between adjacent strainer stacks. The wing walls also helped ensure that a larger amount of debris transported to the front of the strainer, with less transporting over the top of the strainer. A space between the rear of the strainer disks and the back wall was included in the design to conservatively represent the configuration of the installed plant strainer. The test tank consisted of an upstream mixing section. Debris and recirculating test loop water flow, which provided mixing, was introduced upstream of test strainer.[JT277]

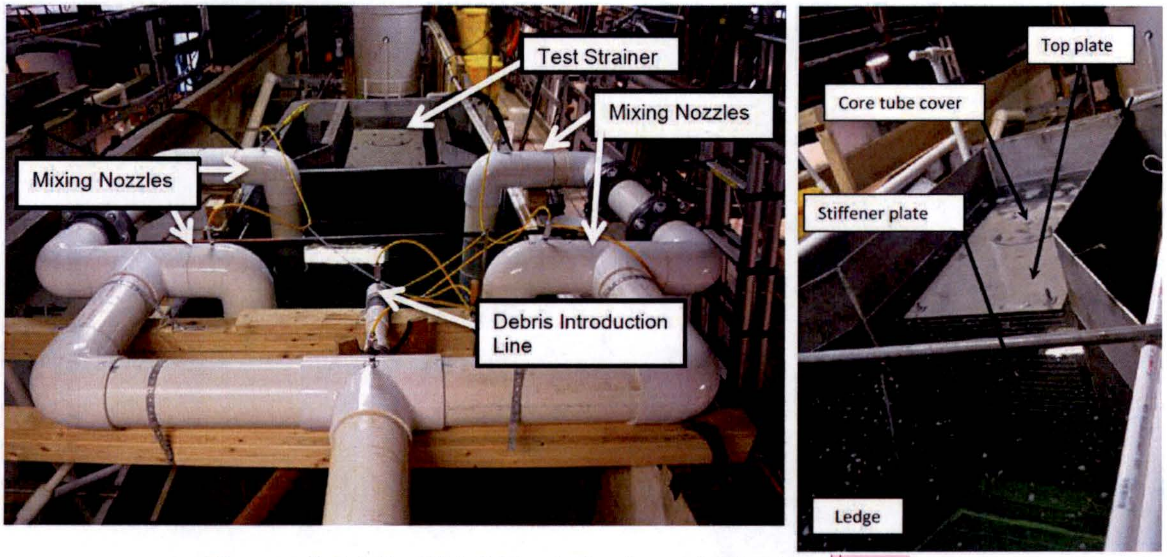

Figure 3.f.4-9: PSL2 Test Tank and Strainer [JT278]

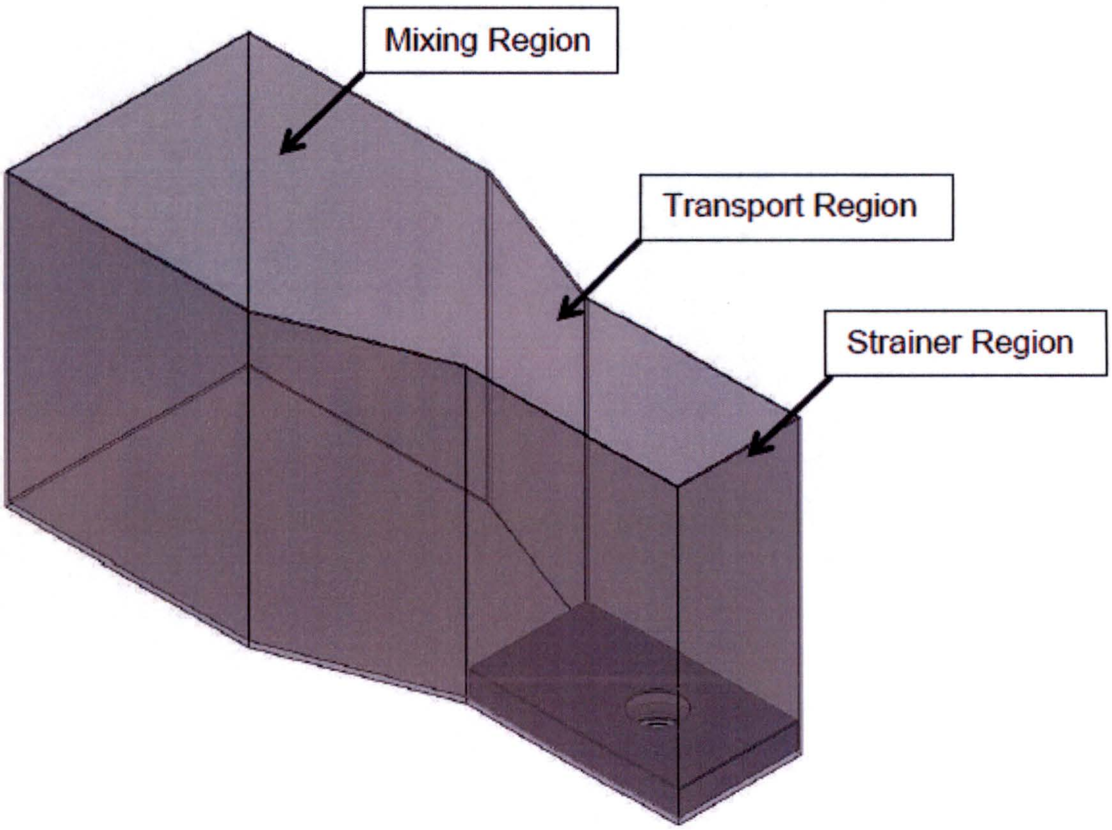

Figure 3.f.4-10: PSL2 Isometric of Head Loss Test Tank [JT279]

A schematic piping diagram of the test loop is provided in Figure 3.f.4-11. Note that the filter bag housings were used for cleaning the test loop before testing, but were bypassed during head loss testing. The test loop had a recirculation pump that took suction from the plenum and returned the water back into the test tank. The return flow exits into the tank were located such that the turbulence from the flow did not affect the debris bed on the test strainer, but allowed for thorough mixing of debris in the water column as it was introduced into the test tank. Flow elements were used to measure the flow rate through the test loop and debris hopper. Flow control valves, and heating and cooling loops were used to control the test flow rate and water temperature.[JT280]

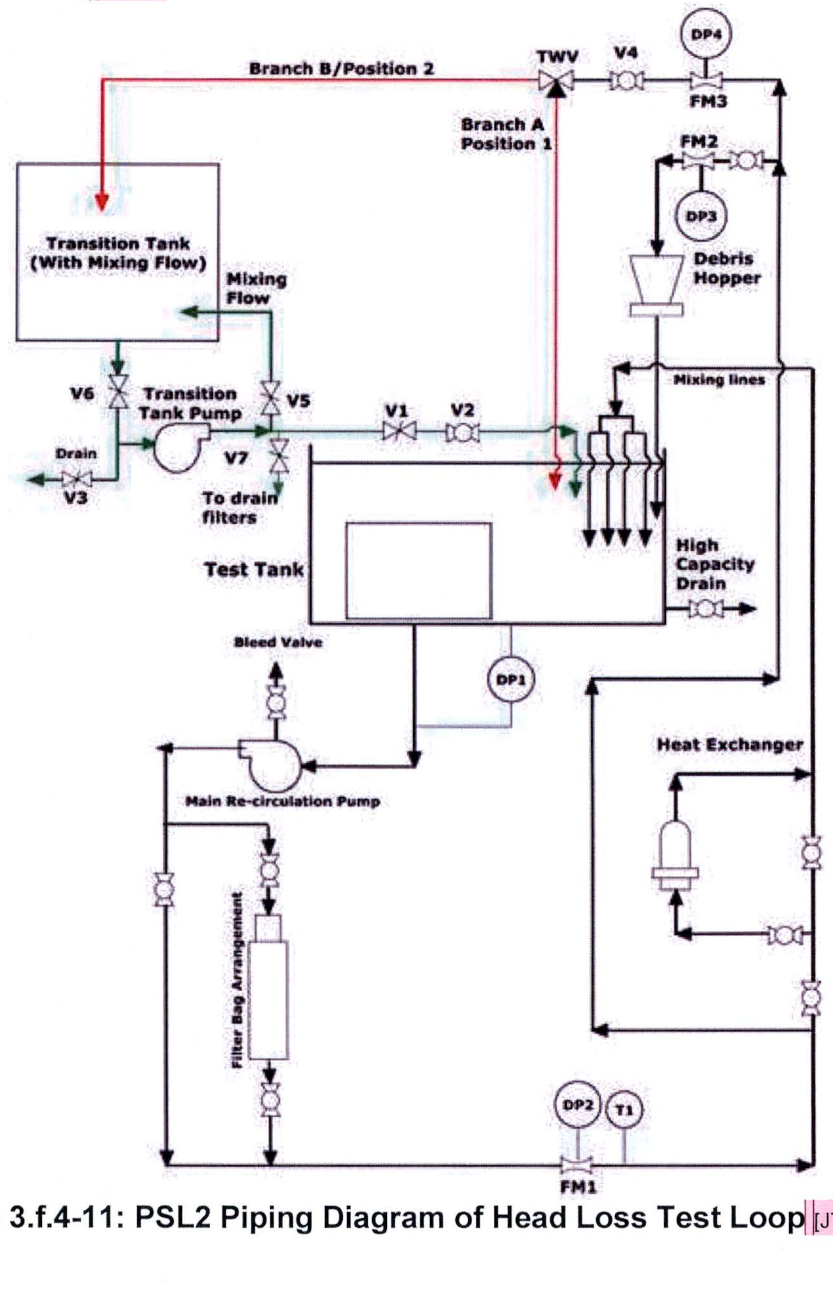

Figure 3.f.4-11: PSL2 Piping Diagram of Head Loss Test Loop[JT281]

The test loop also included a continuously mixed transition tank that 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.[JT282] The test water was maintained at around 120 °F ±5 °F [JT283]during conventional and chemical debris introduction. After chemical debris introduction was completed, the test loop temperature was decreased to approximately 100 °F.[JT284]

Test Parameters and Scaling

The test strainer replicated all hydraulic dimensions of the plant strainer. The test debris quantities and test flow rate were scaled from plant values based on the ratio of the test strainer surface area [JT285]to plant strainer net surface area. Two flow rates were used during head loss testing to accurately model the plant's operation. A higher flow rate was used for the introduction of conventional debris and calcium phosphate chemical debris, and this flow rate resulted in an approach velocity of 0.00354 ft/sec. A lower flow rate was used during and after the introduction of AlOOH and SAS chemical debris, and this flow rate resulted in an approach velocity of 0.00206 ft/sec.[JT286] The corresponding test flow rates are 562 gpm and 327 gpm for the high flow and low flow conditions, respectively.[JT287] As discussed later in this response, flow sweeps were performed on the clean strainer and after addition of debris by measuring head losses for a range of flow rates. The Response to 3.f.10 has additional discussion on correcting test data to plant conditions.

Debris Materials and Preparation

The following materials were used as conventional debris for head loss testing: Nukon, pulverized acrylic (or paint base material), pulverized Cal-Sil, and PCI Dirt/Dust mix. The method of preparation prior to introduction to the test tank for each material is discussed below.

Nukon fines were used as a surrogate for latent fiber, as recommended in NEI 04-07 Volume 1 (Reference 12) [JT288]and the associated NRC SE on NEI 04-07 (Reference 6)[JT289]. Nukon was also used to represent fines and small pieces of low density fiberglass insulation debris.

Nukon fines were prepared in accordance with the NEI fibrous debris preparation protocol (Reference 8)[JT290]. Nukon fiberglass sheets were cut into approximately 2" x 2" squares, and the heat treated base blanket material was examined for a binder burn-out gradient reaching halfway through the blanket.

After being weighed out into required batches, Nukon pieces were then placed inside a debris preparation vessel that included a manifold with three high pressure nozzles. Test water was added to the vessel using a low pressure water spray until the fiber debris was completely wetted and a slurry was formed. The debris was then sprayed with test water pressurized to 1500 psi. The initial amount of water, the high pressure spray nozzle position within the vessel, and the amount of time the high pressure spray was applied were controlled during debris preparation so that fine fiber batches had similar characteristics. Acceptable debris characteristics were documented by photographing each batch of prepared debris over a light table. Fiber fines were acceptable once their composition was predominantly Class 2 fibers as defined in NUREG/CR-6224 (Reference 15 pp. Table B-3)[JT291], consisting mainly of individual fibers with lesser quantities of fiber shards and small clumps. See Figure 3.f.4-12 a photograph of Nukon fines prepared using this process.

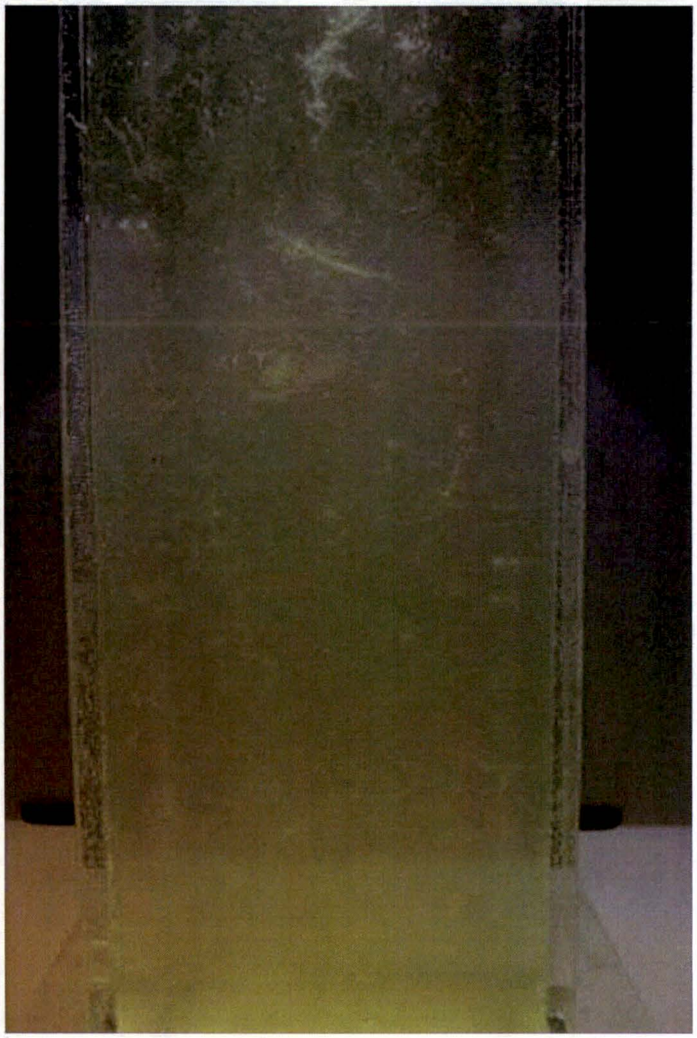

Figure 3.f.4-12: Nukon Fines Prepared for PSL2 Head Loss Testing [JT292]

Preparation of Nukon smalls was similar to the Nukon fines except the Nukon sheets were cut into sizes of 2" x 2", 2" x 4", 1" x 4" and 1" x 6". Nukon small batches were split into equal parts (by weight): one part consisting of 2" x 2" and 2" x 4" pieces and the other part consisting of 1" x 4" and 1" x 6" pieces. Each part was sprayed with high pressure test water in the debris preparation vessel until the acceptability criteria were reached and, afterwards, the equal parts were mixed together before introduction. Small pieces of fiber were acceptable once their composition ranged from fines all the way up to measurable pieces on the order of several inches (<6"). Once the high pressure spray duration time was determined for the acceptability criteria to be reached, all batches of similar debris size were prepared with the same spray time. See Figure 3.f.4-13 for a photograph of Nukon small pieces prepared using this process.

Figure 3.f.4-13: Nukon Small Pieces Prepared for PSL2 Head Loss Testing [JT293]

Pulverized acrylic was used as a surrogate for failed coatings (epoxy, enamel, IOZ, and cold galvanizing) on an equal volume basis, and had a median size of 12.7 μm.[JT294] The required amount of pulverized acrylic for a debris batch was weighed out and placed in a bucket. The particulate was then wetted with test water while being gently stirred to avoid the formation of foam.

Pulverized Cal-Sil was prepared for test introduction using a similar method as the pulverized acrylic. The PCI dirt/dust mix was used as a surrogate for latent particulate.

Three types of chemical debris surrogates were used for the head loss testing: calcium phosphate, SAS and AlOOH. The chemical debris was prepared in accordance with WCAP-16530-NP-A (Reference 16) [JT295]and met the settling volume acceptance requirements specified in WCAP-16530-NP-A. See the Response to 3.o.2.12 for additional information.

Debris Introduction

For the PSL2 Full Debris Load Head Loss Test, the prepared particulate debris (pulverized acrylic, pulverized Cal-Sil, and PCI dirt/dust mix) of a given batch was added to the fiber fines slurry and gently mixed until a homogenous fiber and particulate debris mixture was formed. The fine fiber and particulate slurry was added to the test loop via the debris introduction hopper. The hopper used a portion of recirculating loop flow to suspend the debris slurry as it was added into the hopper and carry it to the mixing region of the test tank. The mixing region used recirculating test loop water to help transport the debris to the strainer and minimize debris settling. All fiber fines and particulates were added to the test before any small pieces of fiber were introduced. Once all fiber fines and particulate were introduced to the test tank, a small flume was set up to introduce the slurry of fibrous small pieces towards the center of the mixing region.

For the PSL2 Thin-Bed Test, the pulverized acrylic and pulverized Cal-Sil were individually introduced to the test loop via the debris introduction hopper, and the PCI dirt/dust mix was added directly to the test tank's mixing region. All particulate debris was added in quick succession, and no fiber was added to the test until all particulate was introduced. Nukon fiber fines were incrementally added in small batches until a particulate filtering debris bed was formed on the test strainer. Each fiber batch was equivalent to a 1/16" thick theoretical uniform debris bed. A particulate filtering debris bed was observed to form when the test loop water began to clear and when the head loss increase from a batch of fiber fines was observed to be smaller than the preceding batches. No fiber small pieces were used for the thin-bed test.

After conventional debris introduction and head loss was stable, (change in head loss is less than 1% per hour) debris bed characterization (flow sweep) was completed for each test. Afterwards, batches of calcium phosphate were added to the test tank until the total amount added was equivalent to the plant load, and the head loss was stabilized. The flow rate was then reduced to model the plant's operation, followed by simultaneous addition of SAS and AlOOH in batches via a pump and hose from the chemical precipitate debris storage tanks. Once SAS and AlOOH debris introduction was completed and head loss stabilized, another flow sweep was performed, the test loop was cooled to about 100 °F, and a final flow sweep was performed.[JT296]

Head Loss Test Cases and Results

PSL2 Full Debris Load Test

The conventional debris load for the PSL2 Full Debris Load Test is summarized in Table 3.f.4-8 and scaled to equivalent plant debris loads. The peak conventional debris head loss observed during this test is shown in Table 3.f.4-12.

Table 3.f.4-8: Conventional Debris Quantities for the PSL2 Full Debris Load Test
[JT297]

Dirt & Dust (lbm)	Pulverized Acrylic (ft^3)	Cal-Sil (lbm)	Nukon Fines (lbm)	Nukon Smalls (lbm)
72.27	10.67	45.54	735.3	301.4

After all conventional debris was added and the head loss had stabilized, calcium phosphate was added to the test tank, followed by head loss stabilization, the flow reduction, head loss stabilization, then SAS and AlOOH additions. The total chemical precipitate debris load for the full debris load protocol head loss test are summarized in Table 3.f.4-9 and scaled to equivalent plant debris load.[JT298] The maximum debris head loss observed during calcium phosphate addition is shown in Table 3.f.4-12.

Table 3.f.4-9: Chemical Precipitate Debris Batches for the PSL2 Full Debris Load Test [JT299]

Batch ID	Calcium Phosphate (kg)	AlOOH (kg)	SAS (kg)	Aluminum Precipitated (kg)
CP1	21.34	0	0	0
CP2	55.37	0	0	0
CP3	14.65	0	0	0
A1	0	48.89	62.64	28.45
A2	0	48.89	62.64	28.45
Total	**91.36**	**97.78**	**125.28**	**56.90**

SAS and AlOOH were simultaneously added to the test tank, and the head loss increase from these chemical precipitates was very small. The flow rate was increased to the same flow rate used during addition of conventional debris and calcium phosphate. It was observed that the head loss returned nearly to the same value as that before addition of SAS and AlOOH. This confirmed that SAS and AlOOH were not increasing head loss, and the introduction of chemical precipitates was completed. The peak debris head loss observed during SAS and AlOOH introduction is shown in Table 3.f.4-12.[JT300]

Figure 3.f.4-14, Figure 3.f.4-15, and Figure 3.f.4-16 show a plot of raw head loss test data with time. Key testing activities during conventional debris, calcium phosphate, and SAS and AlOOH introduction are labeled. Note that the flow rates shown in these figures are at test scale and the head loss values shown have not been adjusted to subtract the test strainer's clean screen head loss.[JT301]

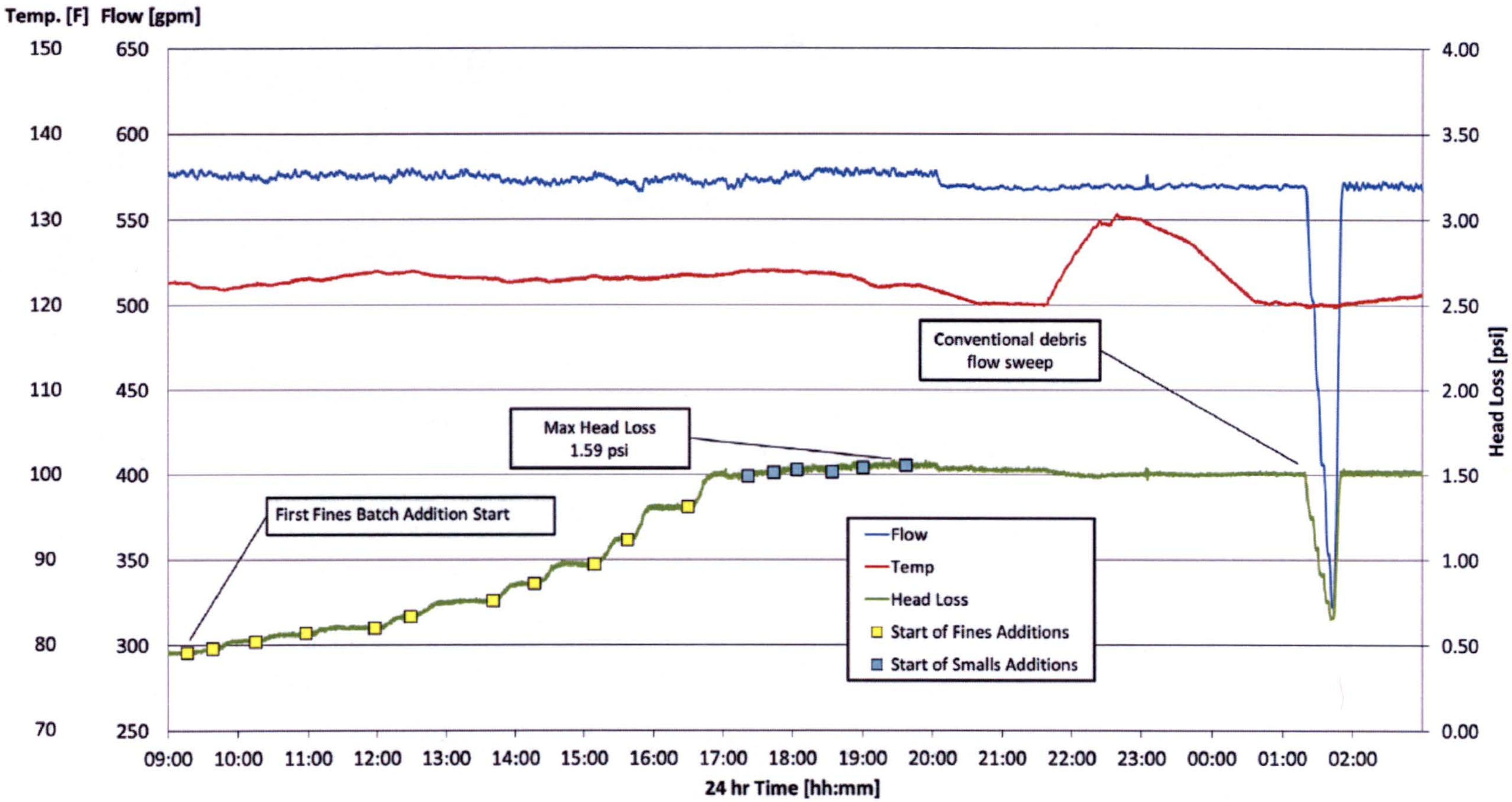

Figure 3.f.4-14: PSL2 Full Debris Load Test Conventional Debris Timeline [JT302]

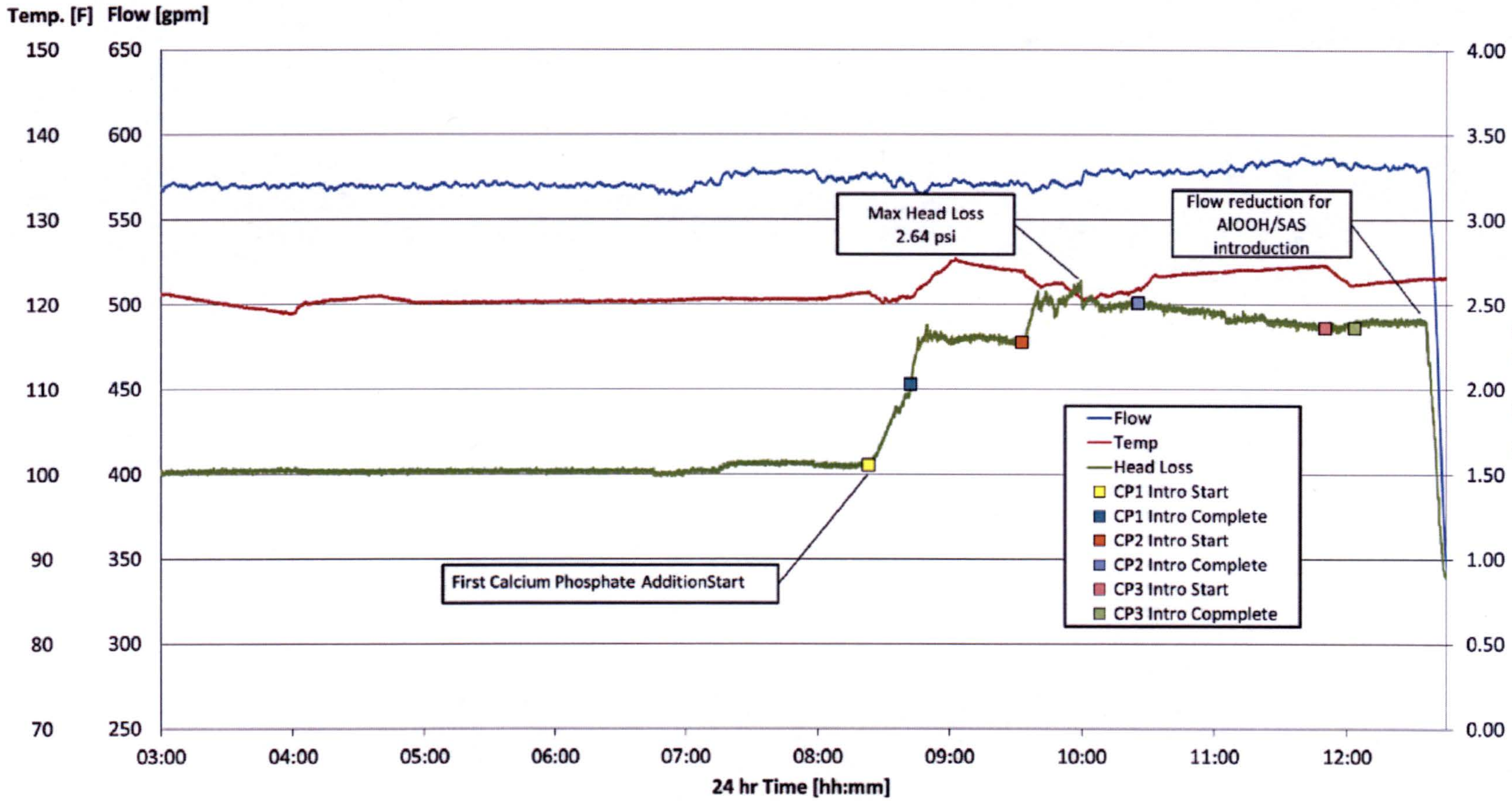

Figure 3.f.4-15: PSL2 Full Debris Load Test Calcium Phosphate Timeline [JT303]

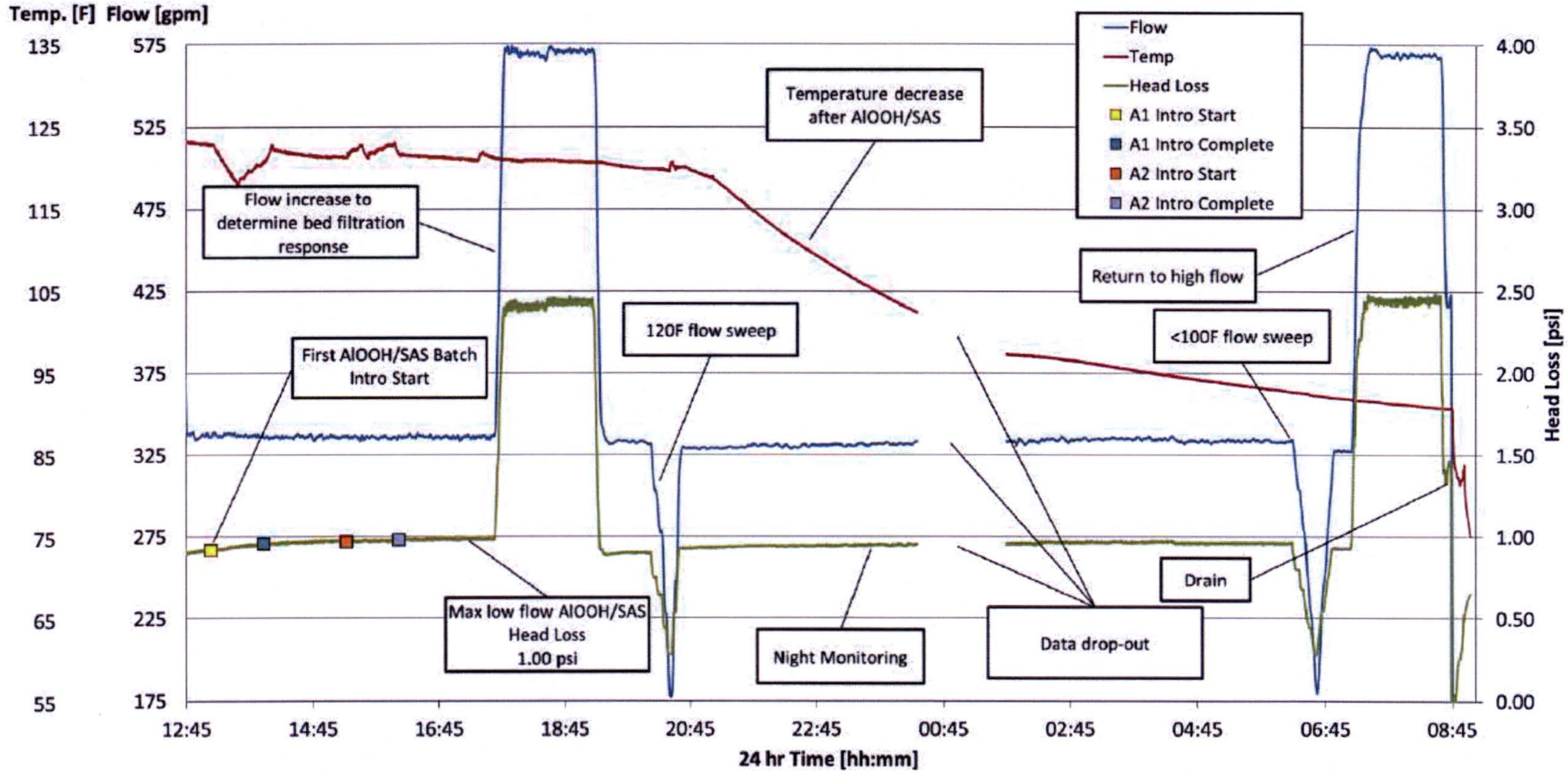

Figure 3.f.4-16: PSL2 Full Debris Load Test SAS and AlOOH Timeline [JT304]

PSL2 Thin-Bed Test

The conventional debris load for the PSL2 Thin-Bed Test is summarized in the table below and scaled to equivalent plant debris loads. Two batches of fiber fines were introduced to the thin-bed test, which resulted in a cumulative theoretical uniform debris bed thickness of 1/8". Also, as described in the beginning portion of the Response to 3.f.4, fiber fines were added until the test tank had cleared of particulate debris. The peak conventional debris head loss observed during this test is shown in Table 3.f.4-12.

Table 3.f.4-10: Conventional Debris Quantities for the PSL2 Thin-Bed Head Loss Test [JT305]

Dirt & Dust (lbm)	**Pulverized Acrylic (ft^3)**	**Cal-Sil (lbm)**	**Nukon Fines (lbm)**
72.43	10.67	45.54	135.2

After all conventional debris was added and the head loss had stabilized, calcium phosphate was added to the test tank, followed by SAS and AlOOH. The total chemical precipitate debris load for the full debris load protocol head loss test are summarized in Table 3.f.4-11 and scaled to equivalent plant debris load.[JT306] The maximum debris head loss observed during calcium phosphate addition is shown in Table 3.f.4-12.

Table 3.f.4-11: Chemical Debris Batches for the PSL2 Thin-Bed Head Loss Test
[JT307]

Batch ID	**Calcium Phosphate (kg)**	**AlOOH (kg)**	**SAS (kg)**	**Aluminum Precipitated (kg)**
CP1	23.02	0	0	0
CP2	48.34	0	0	0
CP3	20.00	0	0	0
A1	0	42.81	60.99	25.55
A2	0	47.53	65.09	28.10
A3	0	46.48	63.54	27.46
A4	0	44.48	54.83	25.67
A5	0	20.23	0	9.11
Total	**91.36**	**201.53**	244.45	**115.89**

SAS and AlOOH were simultaneously added to the test tank. The first few batches of SAS and AlOOH resulted in very small increases in head loss, and the fifth batch did not increase head loss. Chemical debris introduction was therefore ended after the fifth batch. The peak debris head loss during SAS and AlOOH introduction is shown in Table 3.f.4-12.[JT308]

Figure 3.f.4-17, Figure 3.f.4-18, and Figure 3.f.4-19 show a plot of raw head loss test data with time and point out key testing activities during conventional debris, calcium phosphate, and SAS and AlOOH introduction. Note that the flow rates shown in these figures are at test scale and the head loss values have not been adjusted to subtract the test strainer's clean screen head loss.[JT309]

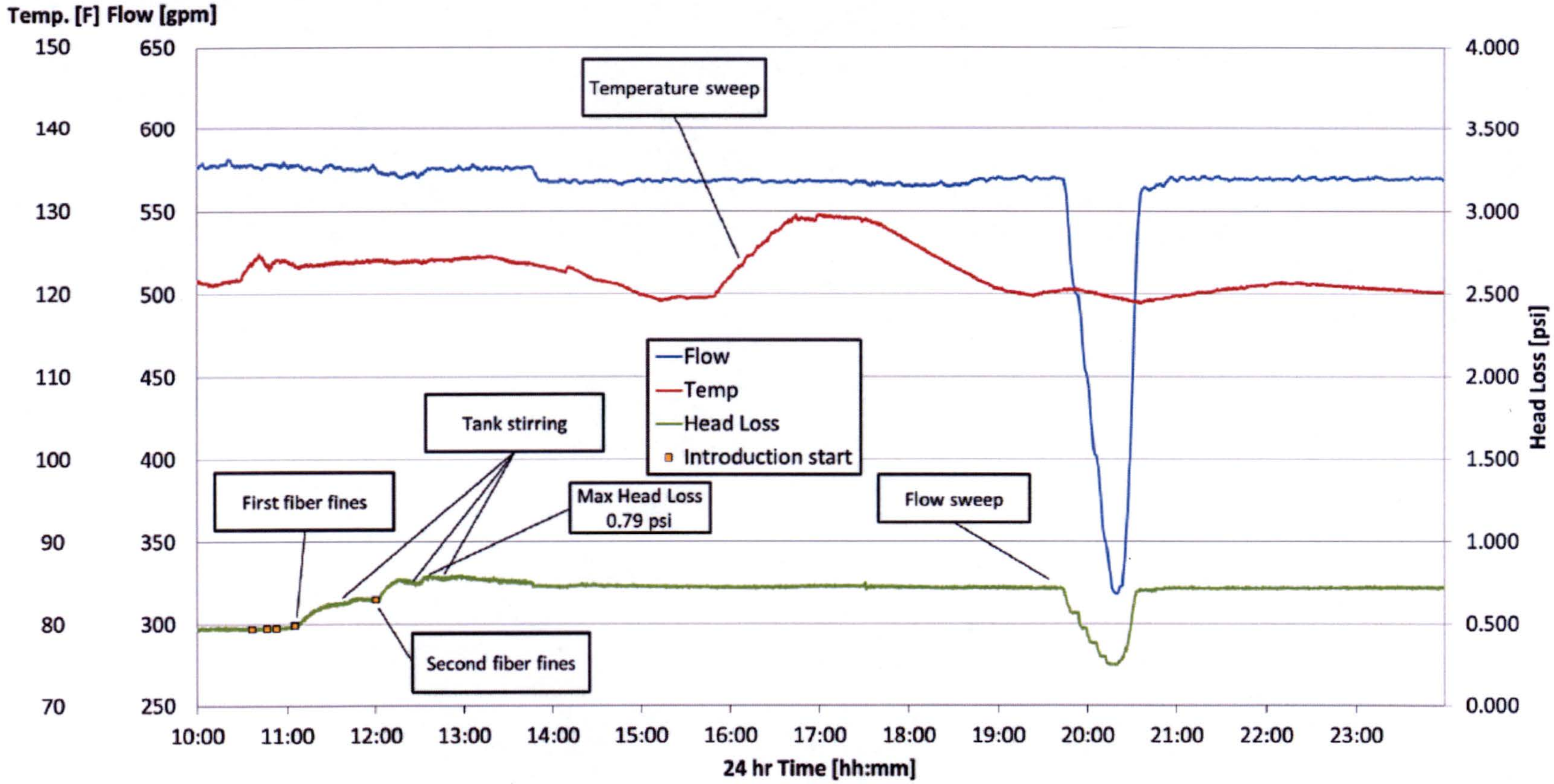

Figure 3.f.4-17: PSL2 Thin-Bed Test Conventional Debris Timeline [JT310]

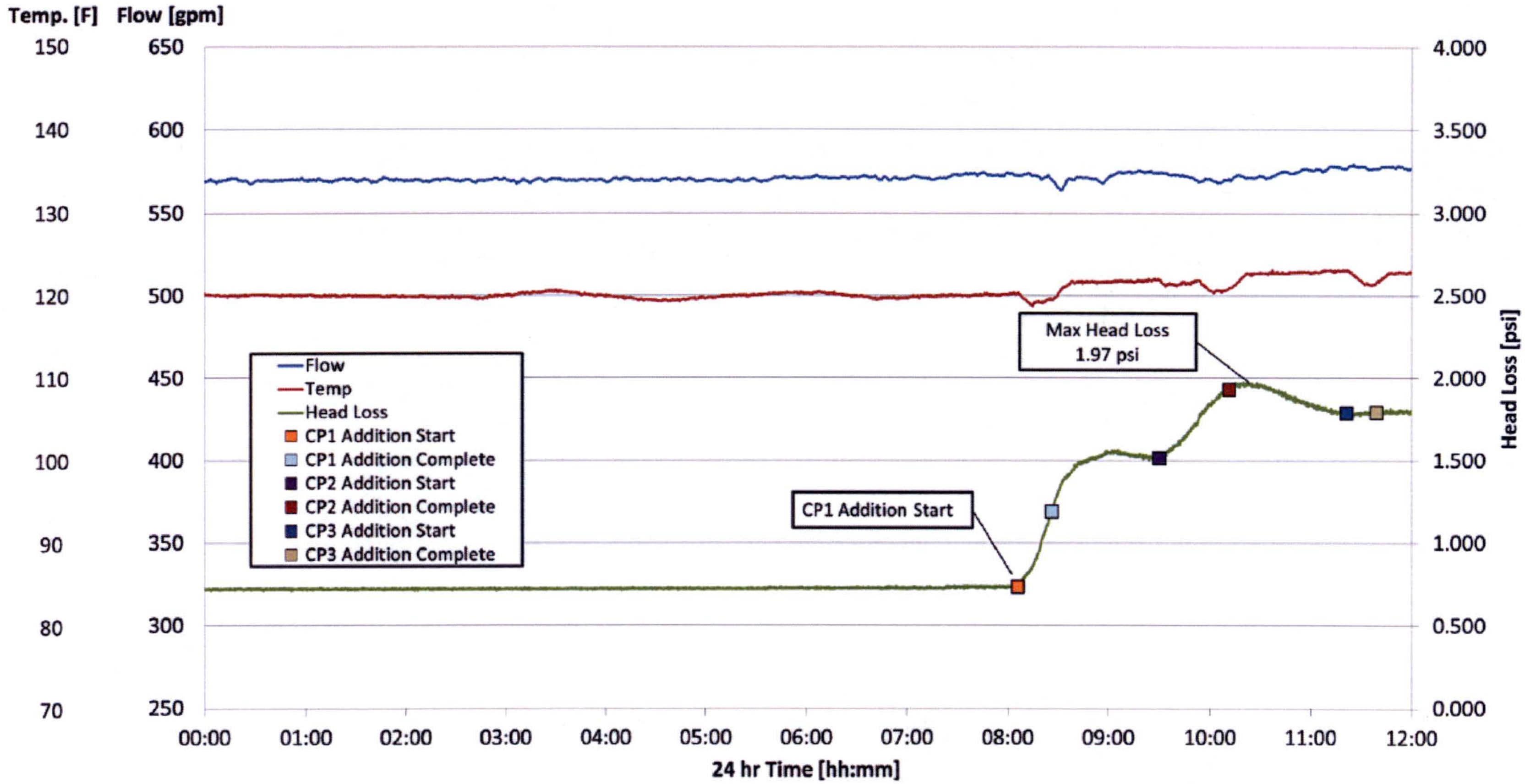

Figure 3.f.4-18: PSL2 Thin-Bed Test Calcium Phosphate Timeline [JT311]

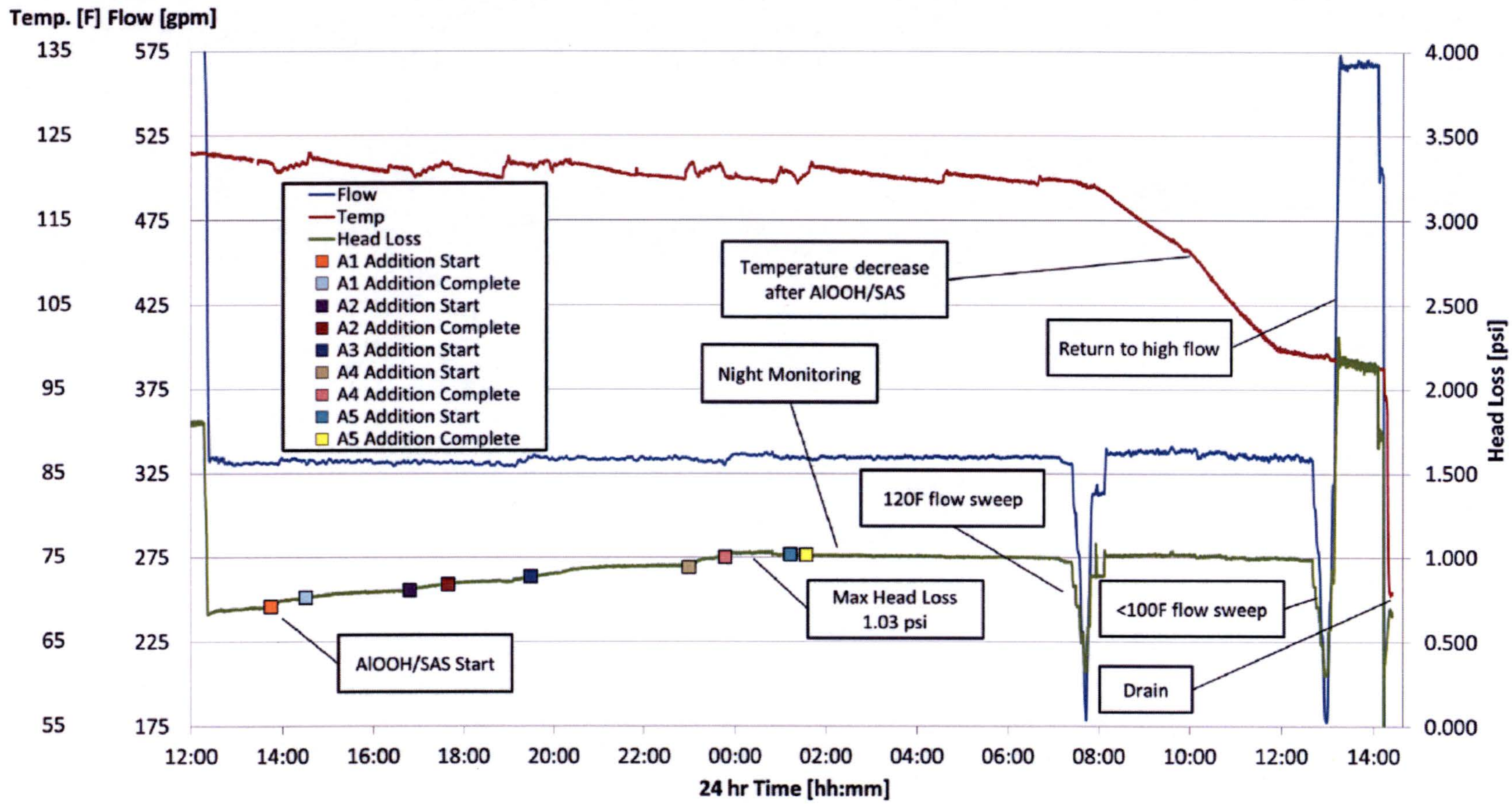

Figure 3.f.4-19: PSL2 Thin-Bed Test SAS and AlOOH Timeline [JT312]

Summary of PSL2 Head Loss Test Data

A summary of the head loss results from the PSL2 tests are provided in the table below. As discussed in the Response to 3.f.7, the maximum conventional, calcium phosphate and aluminum precipitate debris head losses of the two tests are used to evaluate pump NPSH, void fraction, flashing and strainer integrity for PSL2. These maximum head losses are bold faced in Table 3.f.4-12. The clean screen head loss of the test strainer ranged from 0.44 psi to 0.46 psi for a test flow range between 560 gpm to 571 gpm and nominal temperature of 120 °F.

Table 3.f.4-12: Summary of PSL2 Head Loss Test Results

Test Point	Debris Head Loss (psi)	Test Flow Rate (at Plant Scale) (gpm)	Temperature (°F)
PSL2 Full Debris Load Test [JT313]			
Conventional Debris Max Head Loss	**1.13**	**571 (8,724)**	**122.3**
Conventional Debris Stable Head Loss	1.09	568 (8,678)	120.2
Calcium Phosphate Max Head Loss	**2.20**	**560 (8,556)**	**120.9**
Calcium Phosphate Stable Head Loss	1.94	582 (8,892)	122.8
Aluminum Precipitate Max Head Loss	0.85	328 (5,011)	122.4
Aluminum Precipitate Stable Head Loss	0.76	334 (5,103)	120.2
PSL2 Thin-Bed Test [JT314]			
Conventional Debris Max Head Loss	0.34	566 (8,648)	124.1
Conventional Debris Stable Head Loss	0.27	568 (8,678)	119.6
Calcium Phosphate Max Head Loss	1.52	568 (8,678)	122.8
Calcium Phosphate Stable Head Loss	1.33	578 (8,831)	122.8
Aluminum Precipitate Max Head Loss	**0.88**	**331 (5,057)**	**119.9**
Aluminum Precipitate Stable Head Loss	0.82	331 (5,057)	119.7

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 test strainers that are prototypical to the plant strainer designs. 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 models the configuration in the vicinity of the plant strainer. For PSL1, the test setup represented the more restrictive geometry of plant strainer by modeling a strainer module installed inside a keyway. For PSL2, the test setup modeled the more restrictive geometry of the plant strainer for a module between two adjacent strainer stacks. Additionally, the clearance between the back of the PSL2 test strainer and test tank modeled the strainer inside the containment trench. Finally, as discussed in the Response to 3.f.7, the full debris load tests for PSL1 and PSL2 represented the maximum debris loads that could occur at the plant. With these considerations, the impact of debris volume on the plant strainer can be directly determined from the head loss test results.

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 across a thin bed of fibrous debris, which can sufficiently filter particulate debris to form a dense (or high particulate to fiber ratio) debris bed. As discussed in the Response to 3.f.4, the PSL1 and PSL2 head loss testing included a test to measure head loss for a dense debris bed. During this test, the full particulate load was added into the test tank first, followed by fiber fines in batches equivalent to a 1/16" theoretical uniform bed thickness. This batching schedule allowed the formation of a debris bed with a high particulate to fiber ratio. As a result, any thin-bed effects, should they occur, would be captured by the measured head losses. The thin-bed protocol test resulted in lower conventional and chemical debris head losses than the full debris load protocol head loss test for both PSL1 and PSL2, and the "thin-bed" effect head losses are bounded by full debris load head losses.

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

Response to 3.f.7:

Response for PSL1

Comparison of Plant and Head Loss Test Flow Rates

As discussed in the Response to 3.f.3, the flow rate through the strainers is 7,326 gpm with an approach velocity of 0.00232 ft/s. During head loss testing, the nominal test flow rate was 417 gpm.[JT315] This flow rate corresponds to an approach velocity of 0.00258 ft/s during conventional and chemical precipitate debris introduction. The approach velocity used during the head loss tests therefore bounds the plant condition.

Comparison of Plant and Head Loss Test Conventional Debris Loads

Table 3.f.7-1 compares the conventional debris loads of four PSL1 bounding breaks with those used in the PSL1 head loss tests. The plant debris loads are based on Table 3.e.6-19 except for the unqualified coatings and latent debris. The quantities of individual coating types are combined to determine the total volume of qualified coatings. The unqualified coatings quantities are determined by combining the volumes of all subtypes from Table 3.h.1-2 (converted from the mass values with margin). The total coatings particulate debris loads shown in Table 3.f.7-1 are calculated by combining the volumes of qualified coatings and unqualified coatings. The latent debris quantities are from the Response to 3.e.6. The debris loads for PSL1 Full Debris Load Tests 1 and 2 and Thin-Bed tests are from Table 3.f.4-1, Table 3.f.4-3, and Table 3.f.4-5, respectively.

Table 3.f.7-1: Summary of PSL1 Plant and Test Debris Loads

Break Location	**1-SGB-W16 & RC-123-FW-2000**	**RC-123-1-503**	**1-SGA-W16 & RC-114-FW-2000**	**RC-114-7-503**	**PSL1 Full Debris Load Test 1**	**PSL1 Full Debris Load Test 2**	**PSL1 Thin-Bed Test**
Location Description	**SG B Nozzle at Hot Leg**	**Hot Leg B Elbow**	**SG A Nozzle at Hot Leg**	**Hot Leg A Elbow**			
Nukon Fines (lbm)	516.32	499.15	493.85	479.15	542.5	548.7	528.4
Latent Fiber (lbm)	12.75	12.75	12.75	12.75			
Temp-Mat Fines (lbm)	5.61	5.6	44.6	42.52	6.06	49.67	-
Total Fiber Fines (lbm)	**534.68**	**517.5**	**551.2**	**534.42**	**548.6**	**598.4**	**528.4**
Cal-Sil Fines (lbm)	**974.46**	**966.10**	**769.77**	**744.14**	**1,229**	**883.8**	**1,171**
Qualified Coatings (ft^3)	4.46	4.8	2.97	3.36	11.67	11.30	11.70
Unqualified Coatings (ft^3)	6.86	6.86	6.86	6.86			
Total Coatings Particulates (ft^3)	**11.32**	**11.66**	**9.83**	**10.22**			
Latent Particulate (lbm)	**72.25**	**72.25**	**72.25**	**72.25**	**71.23**	**72.28**	**72.30**

As shown in Table 3.f.7-1, the total fiber, Cal-Sil, and total coatings particulate debris loads of the two Loop B breaks (1-SGB-W16 & RC-123-FW-2000, RC-123-1-503) and one of the Loop A breaks (RC-114-7-503) are bounded by PSL1 Full Debris Load Test 1. The total fiber, Cal-Sil, and total coatings particulate debris loads of the remaining Loop A break (1-SGA-W16 & RC-114-FW-2000) are bounded by the PSL1 Full Debris Load Test 2. The Cal-Sil, total coatings particulate, and latent particulate debris loads of all four breaks are bounded by those used in the PSL1 Thin-Bed test.

As shown in Table 3.f.4-7, the PSL1 Full Debris Load Test 1 resulted in the highest peak conventional debris head loss. Therefore, the maximum PSL1 conventional debris head loss that would occur for the plant debris load is determined by the results of PSL1 Full Debris Load Test 1, as bold faced in Table 3.f.4-7.

Comparison of Plant and Head Loss Test Chemical Debris Loads

Table 3.f.7-2 compares the bounding chemical debris loads of PSL1 (see the Response to 3.o.2.7.ii) with those used in the PSL1 head loss tests (see the Response to 3.f.4).

Table 3.f.7-2: PSL1 Chemical Precipitate Debris Loads

	Plant Chemical Debris Loads	PSL1 Full Debris Load Test 1	PSL1 Full Debris Load Test 2	PSL1 Thin-Bed Test
Total Aluminum Precipitated (kg)	7.0	153.6	151.8	122.1

As shown in Table 3.f.7-2, the total precipitated aluminum quantities for the chemical debris loads used for the three PSL1 tests are greater than that predicted for the plant and therefore bound plant conditions with respect to chemical effects. Note that the large discrepancy is due to utilizing the aluminum values shown in the FSAR to calculate the amount of precipitate added to the test. Later, a walkdown was performed where the actual amount of aluminum in containment was documented to be significantly less and the precipitate loads were re-calculated.[JT316] As discussed in the Response to 3.f.4, the introduction of chemical debris was ended after it was confirmed that the added debris had no impact on head loss. As shown in Table 3.f.4-7, the PSL1 Full Debris Load Test 1 resulted in the highest peak chemical debris head loss. Therefore, the maximum PSL1 chemical debris head loss for the plant debris load is determined by the results of PSL1 Full Debris Load Test 1, as bold faced in Table 3.f.4-7.

Response for PSL2

Comparison of Plant and Head Loss Test Flow Rates

As discussed in the Response to 3.f.3, the flow rate through the plant strainers is 8,556 gpm (approach velocity of 0.00353 ft/s). During the full debris load and thin-bed tests, the nominal test flow rate was 562 gpm [JT317](approach velocity of 0.00354 ft/s) during conventional and calcium phosphate debris introduction. The approach velocity used during the head loss tests is higher than and bounds the plant condition.

By analysis, aluminum precipitates will not form until the sump temperature has cooled to 120.8 °F,[JT318] and by this time one of the containment spray pumps will be secured.[JT319] As a result, the plant strainer flow rate from one CS pump and 2 HPSI pumps is 4,963 gpm [JT320](approach velocity of 0.00205 ft/s). As discussed in the Response to 3.f.4, AlOOH and SAS debris was added to the test tank when the nominal test flow rate was 327 gpm, corresponding to an approach velocity of 0.00206 ft/s. The approach velocity used during the head loss tests therefore bounds plant conditions.

Comparison of Plant and Head Loss Test Conventional Debris Loads

Table 3.f.7-3 compares the conventional debris loads of the PSL2 bounding breaks with those used in the PSL2 head loss tests. The plant debris loads are based on Table 3.e.6-20 and Table 3.e.6-21 except for the unqualified coatings and latent debris. The quantities of individual coating types are combined to determine the total volume of qualified coatings. The unqualified coatings quantities are determined by combining the volumes for all subtypes from Table 3.h.1-3 (converted from the mass values with margin). The total coatings particulate debris loads shown in Table 3.f.7-3 are calculated by combining the volumes of qualified coatings and unqualified coatings. The latent debris quantities are from the Response to 3.e.6. The debris loads for PSL2 Full Debris Load Test and Thin-Bed Test are from Table 3.f.4-8 and Table 3.f.4-10, respectively.

Table 3.f.7-3: Summary of PSL2 Plant and Test Debris Loads

Break Location	**RC-123-201-771**	**RC-123-FW-2010**	**314-N4-3204-2-JW103-S/C010**	**RC-114-401-771**	**RC-114-FW-2010**	**313-N4-3204-2JW103-S/C010**	**PSL2 Full Debris Load Test**	**PSL2 Thin-Bed Test**
Location Description	**Hot Leg B Elbow**	**SG B Nozzle at Hot Leg**	**SG B Nozzle at Hot Leg**	**Hot Leg A Elbow**	**SG A Nozzle at Hot Leg**	**SG A Nozzle at Hot Leg**		
Nukon Fines (lbm)	656.5	654.12	654.12	452.48	455.86	455.86	735.3	135.2
Latent Fiber (lbm)	12.75	12.75	12.75	12.75	12.75	12.75		
Total Fiber Fines (lbm)	**669.25**	**666.87**	**666.87**	**465.23**	**468.61**	**468.61**	**735.3**	**135.2**
Cal-Sil Fines (lbm)	27.9	29.76	29.76	39.25	41.43	41.43	45.54	45.54
Qualified Coatings (ft^3)	3.37	3.27	3.27	2.89	2.72	2.72	10.67	10.67
Unqualified Coatings (ft^3)	7.31	7.31	7.31	7.31	7.31	7.31		
Total Coatings Particulates (ft^3)	**10.68**	**10.58**	**10.58**	**10.2**	**10.03**	**10.03**		
Latent Particulate (lbm)	**72.25**	**72.25**	**72.25**	**72.25**	**72.25**	**72.25**	**72.27**	**72.43**

As shown in Table 3.f.7-3, the total fiber, Cal-Sil, total coatings particulate, and latent particulate debris loads of all breaks are bounded by the PSL2 Full Debris Load Test. The Cal-Sil, total coatings particulate, and latent particulate debris loads of all breaks are bounded by the PSL2 Thin-Bed Test within rounding differences.

As shown in Table 3.f.4-12, the PSL2 Full Debris Load Test resulted in higher peak conventional debris head loss than the thin-bed test. Therefore, the maximum PSL2 conventional debris head loss that would occur for the plant debris load is determined by the results of PSL2 Full Debris Load Test, as bold faced in Table 3.f.4-12.

Comparison of Plant and Head Loss Test Chemical Debris Loads

Table 3.f.7-4 compares the bounding chemical debris loads of PSL2 (see the Response to 3.o.2.7.ii) with those used in the PSL2 head loss tests (see the Response to 3.f.4).

Table 3.f.7-4: PSL2 Chemical Precipitate Debris Loads

	Plant Chemical Debris Loads	**PSL2 Full Debris Load Test**	**PSL2 Thin-Bed Test**
Calcium Phosphate	91.3	91.36	91.36
Total Aluminum Precipitated (kg)	2.1	56.90	115.81

As shown in Table 3.f.7-4, the total chemical debris loads used for the PSL2 tests are greater than that predicted for the plant and therefore bound the plant conditions with respect to chemical effects. Note that the large discrepancy is due to utilizing the aluminum values shown in the FSAR to calculate the amount of precipitate added to the test. Later, a walkdown was performed where the actual amount of aluminum in containment was documented to be significantly less and the precipitate loads were re-calculated.[JT321] Table 3.f.4-12 shows that the PSL2 Full Debris Load Test resulted in a higher calcium phosphate debris head loss than the thin-bed test. Therefore, the maximum PSL2 calcium phosphate chemical debris head loss for the plant debris load is determined by the results of the full debris load test, as bold faced in Table 3.f.4-12. For the aluminum chemical debris head loss, the higher peak head loss of the thin-bed test is taken as the maximum value for PSL2, which is also bold faced in Table 3.f.4-12.

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

Response to 3.f.8:

Vortex Testing

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.

For PSL1, all vortex tests used strainer approach velocities greater than those expected for the plant strainer (0.00232 ft/s, see the Response to 3.f.3). The clean strainer vortex test used strainer approach velocities of 0.00247 ft/s – 0.00618 ft/s. A strainer approach velocity of 0.00258 ft/s was used for the debris laden vortex test.

The clean strainer vortex test conservatively used a submergence of 1", which is less than the 6.5" minimum submergence from an SBLOCA. The debris laden vortex test used the 6.5" minimum submergence from an SBLOCA and a debris load from an LBLOCA. This combination of low water level and large debris load conservatively bounds plant conditions.

For PSL2, all vortex tests used strainer approach velocities greater than those expected for the plant strainer (0.00353 ft/s, see the Response to 3.f.3). The clean strainer vortex tests used a strainer approach velocity of 0.00354 ft/s. This approach velocity was also used for the debris laden vortex test.

The clean strainer and debris laden strainer vortex tests used submergences of 1" and 10.4", respectively, which are both less than the 10.9" minimum submergence from an SBLOCA. The debris laden vortex test used a debris load from an LBLOCA. This combination of a low water level and a large debris load conservatively bounds plant conditions.

Strainer Head Loss

The plant quantity of latent debris used to determine the strainer head loss is 100 lbm, but the actual amount of latent debris documented for the plant is only 67.4 lbm (see the Response to 3.d.3). Additionally, as stated in the Response to 3.b.5, the amount of transportable miscellaneous debris (tags and labels) in the debris generation calculation was conservatively assumed be 133 ft^2, which bounds the 24.4 ft^2 identified in containment during the walkdown. This 133 ft^2 of miscellaneous debris results in a 100 ft^2 (133 ft^2 x 75% (Reference 6 p. 49)[JT322]) reduction of total strainer surface area (i.e., sacrificial strainer area). The sacrificial strainer area conservatively used in the head loss tests to determine equivalent plant flow rates and debris loads was 200 ft^2.

As discussed in the Response to 3.f.7, the total quantities of conventional debris used for the PSL1 and PSL2 full debris load tests were greater than the maximum amount of conventional debris calculated to transport to the sump for each respective unit. Furthermore, the amount of coatings particulate debris used in the head loss tests was compared to the amount of unqualified coatings in the plant plus an additional 4% margin for PSL1 and 10% for PSL2 (see Table 3.h.1-2 and Table 3.h.1-3 in the Response to 3.h.5).

As discussed in the Response to 3.f.7, the approach velocities used in the PSL1 and PSL2 head loss tests were greater than the plant strainer's average approach velocities.

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 rates) than those in the actual plant, for conservatism, head loss test data was 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. Testing required extraordinary measures to ensure fine debris would be transported to the strainer during the test.[JT323] 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.

As discussed in the Response to 3.f.7, the tested chemical debris loads bound the plant debris load with a large margin for both PSL1 and PSL2.

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

Response to 3.f.9:

Response for PSL1

As shown in Figure 3.j.1-2 of this submittal, the PSL1 containment sump recirculation strainer is made up of several modules distributed throughout containment. Each of the modules is connected to one of four pipe headers, and modules that are connected to the same header are considered a strainer section. The four pipe headers are connected to a common manifold box. Two suction lines go from the manifold box to the ECCS and CSS Train A and Train B pumps, respectively.[JT324]

A formula was derived for calculating the clean strainer head loss for given flow rates of Train A and Train B and sump temperature. The strainer flow was distributed such that the head losses between any section and the manifold box were equalized. This approach reflects the actual flow conditions through the strainer at clean strainer conditions, since water entering the strainer always follows the path of least resistance. An iterative head loss calculation for each section was performed using a system of simultaneously solved equations until the calculated head loss was balanced for each section by varying the flow rates of different sections.[JT325]

The solution process contains the following steps.[JT326]

1. Model strainer disk geometry in CFD with a slice of rear plenum beneath it to determine the channel K factor for each prototypical disk design using the perforated plate and wire cloth K factors as inputs.
2. Determine end section K factors at the plenum outlet for each of the four types of plenum designs by balancing the flows from the disk channels to the plenum outlet so that the head losses for all flow paths are equal.
3. Develop a system of head loss expressions for all of the strainer sections as functions of strainer section flow rates. For end sections, the K factors calculated in Step 2 should be added to the K factors calculated for all components downstream of the rear plenum outlet to the manifold, including the 12" header pipe. For through sections, the same flow balancing done in Step 2 for all disk channels should be applied to determine the flow and head loss added by these sections.
4. Estimate a value of the run head loss that is shared by all parallel flow paths through the sections to the manifold.
5. Adjust flow rates of all end sections and through section channels until the head loss between any section and the manifold box converges to the acceptance criterion.
6. Calculate the total strainer flow rate by combining all of the strainer section flow rates and compare it with the target flow rate. If the difference is less than the acceptance criterion, the balancing calculation is finished. Otherwise, Steps 4 and 5 must be repeated with a new guessed run head loss value.
7. Determine the run K factors at the inlet to the manifold based on the run head loss and velocity in the 12" header pipe.
8. Model the manifold in CFD to determine the manifold K factors for each train for the five flow cases using the run K factors as inputs.
9. Apply first degree regression methodology with two independent variables to the manifold K factors to determine the coefficients for the manifold K factor correlation as a function of flow rates to Trains A and B.
10. Determine the suction piping losses for each train including the manifold, friction, and bend head losses. These are added to the run head loss to determine the CSHL for each train.
11. Repeat Steps 3 – 10 for all flow cases and apply second degree regression methodology with two independent variables (flow rates of Train A and B) to

the CSHL values to determine the coefficients for the CSHL correlation for each train as a function of flow rates to Trains A and B.

12. Repeat Steps 4 – 10 for all flow cases for the other two temperatures to determine the average scaling factor for each temperature. Apply a quadratic regression line to determine coefficients for the temperature scaling factor.

For the solution process, the following acceptance criteria were imposed.[JT327]

1. For all strainer sections, the head losses between any end section or thru section channel and the manifold box must be equalized within 1%.
2. The total flow rate of all sections must be equalized to the desired total strainer flow rate within 1%.

A quadratic equation with the form shown below is used to determine the clean screen head loss of the PSL1 strainer:[JT328]

$$h_{L,CSHL} = \left(a_0 + a_1 T + a_2 T^2\right)\left(b_1 Q_A + b_2 Q_B + b_3 Q_A^2 + b_4 Q_A Q_B + b_5 Q_B^2\right)$$

Where,
T = Temperature of the containment sump, °F
Q_A = Flow rate of Train A, gpm
Q_A = Flow rate of Train A, gpm

The correlation coefficients to solve the equation determined using the process described above are provided in Table 3.f.9-1.

Table 3.f.9-1: Clean Strainer Head Loss Correlation Equation Coefficients [JT329]

Temperature Coefficients	Trains A and B		Units
a_0	1.035		-
a_1	-3.52E-04		°F^{-1}
a_2	7.84E-07		°F^{-2}
Flow Coefficients	**Train A**	**Train B**	**Units**
b_1	2.65E-05	2.53E-06	ft/gpm
b_2	2.53E-06	-2.54E-05	ft/gpm
b_3	7.43E-08	1.47E-08	ft/gpm^2
b_4	2.43E-08	3.41E-08	ft/gpm^2
b_5	1.47E-08	9.73E-08	ft/gpm^2

The clean strainer head loss was determined to be 2.69 ft-H_2O at 191 °F (or 1.13 psi) when the total Train A flow rate is 4,065 gpm with one CS pump in operation, and Train B flow rate is 4,469 gpm with one CSS and one LPSI pumps in operation during simultaneous hot and cold leg recirculation injection.[JT330]

Response for PSL2

The clean strainer head loss for the PSL2 sump strainer 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 PSL2 strainer disks using the PSL2 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 PSL2, adjustments were made to account for the physical differences between the two designs.[JT331]

The PCI prototype clean strainer testing used an approach velocity higher than that of the PSL2 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 PSL2 strainer perforated plates. Therefore, for conservatism, no adjustment was made to the perforated plate head loss calculated from the PCI prototype test data.[JT332]

The PCI prototype strainer had a core tube length of 54 inches, but the PSL2 strainer has core tube length of 117.25 inches. The additional head loss due to longer length was calculated using the Darcy-Weisbach equation.[JT333] The relative roughness coefficient was assumed to be 0.001 for the internal flow of the core tube.[JT334]

The Darcy-Weisbach equation, with head loss coefficients from standard industry handbooks, was also used to model the head loss for the flow exiting the core tubes into the plenum and flow through the plenum itself, which takes into account a reduced cross-sectional area in the plenum because of structural supports. The head loss due to flow in the plenum was calculated in sections due to flow rate increasing as more strainer stacks closer to the suction inlet contribute to the total flow in the plenum.[JT335]

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.[JT336]

To account for uncertainties, the calculated head loss for each component was increased by 10%, and the head loss determined from the PCI prototype test data was increased by 6%.[JT337] All of these head losses (including the head loss due to flow from the plenum into the suction pipe) were summed to determine the maximum overall clean strainer head loss: 1.21 ft-H_2O for water at 210 °F (or 0.50 psi) and a total strainer flow rate of 8,570 gpm.

10. *Provide a summary of the 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. Refer to each individual section for the specific head loss value used.

Response for PSL1

The total strainer head losses, used to evaluate ECCS and CS pump NPSH, void fraction, flashing and strainer structural integrity for PSL1 are provided in Table 3.f.10-1. The clean strainer head loss is from the response to 3.f.9 and the debris head losses are from Table 3.f.4-7.

Table 3.f.10-1: PSL1 Strainer Head Loss

Clean Strainer Head Loss (psi)	Debris Head Loss (psi)	Total Head Loss (psi)	Notes
1.13	0.41	1.54	Based on conventional debris head loss
	2.32	3.45	Based on debris head loss after addition of aluminum chemical precipitate

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 a temperature of 191 °F. The increase in head loss due to a reduction in temperature is negligible.

Response for PSL2

The head losses, used to evaluate ECCS and CS pump NPSH, void fraction, flashing and strainer structural integrity for PSL2 are provided in Table 3.f.10-2. The clean strainer head loss is from the response to 3.f.9 and the debris head losses are from Table 3.f.4-12.

Table 3.f.10-2: PSL2 Strainer Head Loss

Clean Strainer Head Loss (psi)	Debris Head Loss (psi)	Total Head Loss (psi)	Notes
0.50	1.13	1.63	Based on conventional debris head loss
	2.20	2.70	Based on debris head loss after addition of calcium phosphate
	0.88*	1.38	Based on debris head loss after addition of aluminum chemical precipitate

*As discussed in the Response to 3.f.7, this debris head loss is at a reduced strainer flow rate after a CS pump is secured which occurs before aluminum precipitate debris forms.

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 a temperature of 210 °F. The increase in head loss due to 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 stated in the Response to 3.g.1, the PSL1 and PSL2 strainers stay fully submerged for all break sizes and the entire duration of sump recirculation. Therefore, no failure criteria other than loss of NPSH margin and strainer structural failure were considered).

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 for head loss testing. Sufficient turbulence was provided in the tank to ensure that all debris had an opportunity to become suspended in the water column and transport to the test strainer. The level of turbulence was also controlled to avoid disturbing the debris bed formation.

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:

As stated in the Response to 3.f.10, scaling was not used to adjust the measured debris head losses to actual plant conditions.

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 can be calculated by combining the strainer submergence and containment pressure before subtracting the strainer head loss.

Analysis of Flashing

PSL1 Response:

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 is 12.6" (or rounded down to 0.4 psi) for an LBLOCA. The SBLOCA strainer submergence was not considered since the debris quantities, strainer head losses and post-accident containment conditions for the smaller breaks are less limiting than the LBLOCAs.

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 PSL1 is 3.45 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:

$$\begin{aligned} P_{Strainer} &= P_{Cont} + P_{Submergence} - h_L \\ &= P_{Vapor} + P_{air} + 0.4 \text{ psi} - 3.45 \text{ psi} \\ &= P_{Vapor} + P_{air} - 3.05 \text{ psi} \end{aligned}$$

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 3.05 psi, as shown in the equation above.

Note that the air partial pressure prior to the accident is greater than 3.05 psi. For PSL1, the minimum normal operating containment pressure is -0.49 psig [JT338]or 14.2 psia. The maximum normal operating containment temperature is 120 °F [JT339]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 12.5 psi (14.2 – 1.69 psi). Since this pre-accident air partial pressure is much higher than the 3.05 psi required, it is reasonable to conclude that flashing should not occur during the sump recirculation phase.

PSL2 Response:

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 is 18.6" (or conservatively rounded down to 0.6 psi) for an LBLOCA. The SBLOCA strainer submergence was not considered since the debris quantities, strainer head losses and post-accident containment conditions for the smaller breaks are less limiting than the LBLOCAs.

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 PSL2 is 2.70 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:

$$\begin{aligned} P_{Strainer} &= P_{Cont} + P_{Submergence} - h_L \\ &= P_{Vapor} + P_{air} + 0.6 \text{ psi} - 2.70 \text{ psi} \\ &= P_{Vapor} + P_{air} - 2.1 \text{ psi} \end{aligned}$$

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 2.1 psi, as shown in the equation above.

Note that the air partial pressure prior to the accident is greater than 2.1 psi. For PSL2, the minimum normal operating containment pressure is -0.42 psig [JT340]or 14.28 psia. The maximum normal operating containment temperature is 120 °F [JT341]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 12.6 psi (14.28 – 1.69 psi). Since this pre-accident air partial pressure is much higher than the 2.1 psi required, it is reasonable to conclude that flashing should not occur during the sump recirculation phase.

There are several conservatisms in the flashing analysis for both PSL1 and PSL2:

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. Additionally, chemical debris would not form until the pool temperature drops to below 98.2 °F for PSL1 and 120.8 °F for PSL2.[JT342]
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

The pressure drop experienced by the flow as it travels through the debris bed and sump strainer structure could cause dissolved air to be released and carried to the pump suction. This was evaluated for PSL1 and PSL2 using the NARWHAL software package.[JT343] 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 decrease in air solubility as flow travels through the strainer. This information was used to calculate the void fraction, which was compared with the 2% acceptance limit given in NEI 09-10 (Reference 17 p. 28)[JT344].

Various post-accident containment and sump conditions were considered. No containment accident pressure was credited for the degasification evaluation. The containment pressure was assumed to be 14.7 psia for sump temperatures at or below 212 °F, and equal to water saturation pressure at the sump temperature for sump temperatures above 212 °F.[JT345] The evaluation used a strainer submergence calculated from the mid-height of the strainer.[JT346] Additionally, it was assumed that air released through degasification transports to the pump suction,[JT347] conservatively neglecting the redissolution of air due to increases in hydrostatic pressure at lower elevations.

The evaluation for PSL1 and PSL2 showed that void fraction due to degasification was below the 2% acceptance limit during the sump recirculation phase for both units.[JT348]

3.g. Net Positive Suction Head (NPSH)

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:

PSL1 Pump and Sump Flow Rates

For a LBLOCA, a rapid depressurization of the RCS occurs due to the size of the break.[JT349] Safety injection is automatically initiated upon a safety injection actuation signal (SIAS). The reactor is tripped by the reactor protection system and the turbine is tripped coincident with a reactor trip. The following equipment is activated: HPSI pumps, LPSI pumps, and all HPSI and LPSI injection valves open. As the energy is released into containment, the containment pressure will increase and the containment spray actuation signal (CSAS) will start the CS pumps. In addition to starting the CS pumps, CSAS will also open the NaOH storage tank isolation valves to allow flow of the solution into the CSS via an eductor. The NaOH tank isolation valves will remain open until the low-low level of the NaOH storage tanks is reached.

Once the RCS pressure drops below SIT pressure, the tanks will discharge their contents into the RCS cold legs.[JT350] For a hot leg break, the injection flow passes from the cold legs, through the core, into the hot legs, and out the break. Therefore, core heat removal is via forced flow of injection water through the core. For cold leg breaks and once reflooding is complete, the hydraulic balance will cause most of the injection flow to spill out of the break. The only flow into the core will be that required to make-up the boil-off in the core. With either type of break, water will spill from the RCS into the containment and eventually to the containment sump. During this time, water from the RWT will be ultimately routed to the containment sump by either injection flowing into the RCS and out the break or from the CSS.

RAS is activated upon a low level in the RWT due to drawdown by the HPSI system, LPSI system, and CSS. When RAS is activated the HPSI system and CSS are aligned to recirculation mode and the LPSI pumps are automatically tripped.[JT351] It should be noted that the operators verify the LPSI pumps are tripped prior to completing their actions for transferring to the recirculation mode of core and containment cooling. Simultaneous hot and cold leg injection is initiated by restarting a LPSI pump 4 to 6 hours after a LOCA occurs.[JT352] Note that this is the preferred system alignment, which also results in the highest strainer flow rate.

The LBLOCA flow rate across the strainer used to calculate the NPSH margin is 8,534 gpm.[JT353] While this is greater than the maximum design flow rate determined in a system analysis performed in support of EPU (as used in Response to 3.f), it is conservative to use the larger flow rate for the NPSH evaluation because it maximizes the NPSH required and minimizes the NPSH available. The maximum flow rate is made up of the following components:

- Two CS pumps at 4,065 gpm each [JT354]
- One LPSI pump at 404 gpm for hot leg recirculation
- Total recirculation sump flow is 8,534 gpm

The HPSI pump flow rate is 640 gpm per pump.[JT355] However, because operators are procedurally directed to align the HPSI pump suction to CSS discharge ("piggy back" mode) during recirculation, the HPSI flow is included in the CS pump flow above.[JT356]

For the single failure case in which one CS pump fails, a higher pre-EPU CS pump flow rate for the operating CS pump is assumed. The total sump flow rate in this scenario is 5,494 gpm. This maximum flow rate is made up of the following components:[JT357]

- One CS pump at 4,450 gpm (including a piggy-back HPSI pump at 640 gpm)
- One HPSI pump at 640 gpm on the same train as the failed CS pump
- One LPSI pump at 404 gpm for hot leg recirculation

PSL2 Pump and Sump Flow Rates

For a LBLOCA, a rapid depressurization of the RCS occurs due to the size of the break. Safety injection is automatically initiated upon SIAS. The reactor is tripped by the reactor protective system and the turbine is tripped coincident with a reactor trip. The following equipment is activated: HPSI pumps, LPSI pumps, all HPSI and LPSI injection valves open, and containment fan coolers start. As the energy is released into containment, the containment pressure will increase and CSAS will start the CS pumps.

Once the RCS pressure drops below SIT pressure, the tanks will discharge their contents into the RCS cold legs.[JT358] For a hot leg break, the injection flow passes from the cold legs, through the core, into the hot legs, and out the break. Therefore, core heat removal is via forced flow of injection water through the core. For cold leg breaks and once reflooding is complete, the hydraulic balance will cause most of the injection flow to spill out of the break. The only flow into the core will be that required to make-up the boil-off in the core. With either type of break, water will spill from the RCS into the containment and eventually to the containment sump. During this time, water from the RWT will be ultimately routed to the containment sump by either injection flowing into the RCS and out the break or from the CSS. Prior to the end of the RWT injection phase, the operator will shut down one of the operating CS pumps. This operation is conducted per procedural verification of proper

containment pressure, containment fan cooler operation, and safety injection flow.[JT359]
RAS is activated upon a low level in the RWT due to drawdown by the HPSI system, LPSI system, and CSS. When RAS is activated, the HPSI system and CSS are aligned to recirculation mode and the LPSI pumps are automatically tripped.[JT360] It should be noted that the operators verify the LPSI pumps are tripped prior to completing their actions for transferring to the recirculation mode of core and containment cooling. Simultaneous hot and cold leg injection is initiated by aligning one HPSI pump to inject into the hot leg 4 to 6 hours after a LOCA occurs.[JT361]

The LBLOCA flow rate across the strainer used to calculate the NPSH margin is 5,750 gpm. The maximum flow rate is made up of the following components:[JT362]

- One CS pump at 4,350 gpm
- Two HPSI pumps at 1,400 gpm per pump
- Total recirculation sump flow is 5,750 gpm

PSL1 Minimum Water Level

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 18 ft,[JT363] and the top elevation of the PSL1 strainers is 22.61 ft.[JT364]

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

Break Size	Minimum Water Level Elevation (ft)	Pool Height (ft)	Strainer Submergence (ft)
SBLOCA	23.15[JT365]	5.15	0.54
LBLOCA	23.66 [JT366]	5.66	1.05

PSL2 Minimum Water Level

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 18 ft,[JT367] and the top elevation of the PSL2 strainers is 21.83 ft.[JT368]

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

Break Size	Minimum Water Level Elevation (ft)	Pool Height (ft)	Strainer Submergence (ft)
SBLOCA	22.74 [JT369]	4.74	0.91
LBLOCA	23.38 [JT370]	5.38	1.55

PSL1 Sump Temperature

The maximum sump water temperature during recirculation is 191 °F.[JT371] This is also the temperature at which the minimum NPSH margin occurs.[JT372]

PSL2 Sump Temperature

The maximum sump water temperature during recirculation is 192 °F.[JT373] This is also the temperature at which the minimum NPSH margin occurs.

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

Response to 3.g.2:

PSL1 Pump and Sump Flow Rates

The following assumptions were made in association with flow rates during the calculation of NPSH margin:

- The flow rate was conservatively assumed to apply for the duration of the event, 30 days. The flow rate includes simultaneous hot and cold leg recirculation,[JT374] which is not initiated until 4 to 6 hours into the event.[JT375]
- Strainer head loss, including chemical effects, was determined by testing.[JT376]
- It was assumed that the operators have verified that both LPSI pumps are stopped following RAS, as instructed per site procedure.
- It was assumed that the pumps would be operating at their maximum pump curves during the recirculation phase.[JT377]
- The bounding NPSH case for the HPSI pumps when taking suction from the recirculation sump was determined assuming the failure of a CS pump. The basis for this approach was to maximize flow through the single operating HPSI pump in a train and to minimize the available NPSH[JT378],[JT379] see the Response to 3.g.7.

PSL2 Pump and Sump Flow Rates

The following assumptions were made in association with flow rates during the calculation of NPSH margin:

- The flow rate was conservatively assumed to apply for the duration of the event, 30 days. The flow rate includes simultaneous hot and cold leg recirculation, which is not initiated until 4 to 6 hours into the event.[JT380]
- Strainer head loss, including chemical effects, was determined by testing.[JT381]
- It was assumed that the operators have verified that both LPSI pumps and one CS pump are stopped following RAS, as instructed per site procedure.
- It was assumed that the pumps would be operating at their maximum pump curves during the recirculation phase.[JT382]

PSL1 and PSL2 Minimum Water Level

The significant assumptions used in the water volume calculation are listed as follows:[JT383]

- During an SBLOCA that leads to containment sump recirculation, the volumes of the RWT, SIT, BAMT, and $NaOH/N_2H_4$ tanks spill to the containment floor.
- The net volume of material added to PSL1 by the replacement of containment sump screens is 240 ft^3, and the net volume of material added to PSL2 by the replacement of containment sump screens is 75 ft^3. This material was assumed to all be located below EL 21' as the volume above EL 21' is minimal compared to the volume below EL 21'.
- During an SBLOCA, the entire RCS water volume including pressurizer was assumed to be continuously replenished by the ECCS water.
- The re-flooded or replenished RCS water was assumed to be in equilibrium with the sump water at RAS.
- It was assumed that the bounding containment pressure and bounding containment temperature values are applicable to SBLOCAs. This is a reasonable assumption when used to calculate the volume of water vapor held-up in the containment atmosphere, as the pressure and temperature are expected to be considerably elevated for all LOCA sizes.[JT384]

PSL1 Sump Temperature

The following assumptions were made in association with sump temperature during the calculation of NPSH margin:

- The containment sump water temperature at RAS varies depending on the break size, location, and single active failure assumption. Note that since the NPSH margins for CSS and LPSI pumps are calculated as a function of sump water temperature, the exact sump water temperature at RAS has minimal effect on the NPSH calculation, and was assumed negligible.[JT385]
- Piping losses were calculated based on a Reynolds number at a constant low temperature of 65 °F, which is conservative, since at lower temperatures the Reynolds number is less and the pressure drop is higher.[JT386]
- The water temperature used during head loss testing was ~120 °F instead of the expected sump temperature of 191 °F. The head loss value from testing was used in the NPSH calculation. It is conservative not to adjust the measured head loss from test temperature to sump temperature.[JT387]

PSL2 Sump Temperature

The following assumptions were made in association with sump temperature during the calculation of NPSH margin:

- The containment sump water temperature at RAS varies depending on the break size, location, and single active failure assumption. Note that since the NPSH margins for CSS and HPSI pumps are calculated as a function of sump water temperature, the exact sump water temperature at RAS has minimal effect on the NPSH calculation, and was assumed to be negligible.[JT388]
- A constant piping friction factor of 0.012 (Reference 18 pp. A-26)[JT389] was assumed for all temperatures. This value was conservatively calculated at 192 °F, 5,750 gpm and was based on clean commercial steel pipe with flow in a zone of complete turbulence.[JT390]
- The water temperature used during head loss testing was 120 °F instead of the expected sump temperature of 192 °F. The head loss value from testing was used in the NPSH calculation. It is conservative not to use head loss scaling from testing temperature to sump temperature.[JT391]

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

Response to 3.g.3:

The basis for the required NPSH values used in calculating NPSH margin is the information provided from the original manufacturer's certified pump test curves at the maximum expected pump flow rates.[JT392] The 3 percent head drop criterion was used in pump NPSH testing (Reference 19 p. 57).[JT393]

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

Response to 3.g.4:

Frictional and flow losses were calculated and included in the NPSH margin for all piping and equipment from the sump strainers to the inlet of the ECCS and CS pumps. The piping frictional loss was calculated using the standard Darcy formula with the friction factor determined from an empirical equation (Reference 18 pp. A-24)[JT394]. 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.[JT395] Strainer losses were calculated as part of the clean screen head loss value. See the Response to 3.f.9.

Debris head loss values were calculated through strainer testing with debris beds, which included fibrous, particulate, and chemical debris.

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

Response to 3.g.5:

See the Response to 3.g.1.

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

Response to 3.g.6:

PSL1 Pump Operational Status

Prior to the initiating event, the ECCS and CS pumps will be in a state of stand-by readiness.

Safety Injection Pumps
In the event of a LOCA, both HPSI and LPSI pumps start automatically on receipt of SIAS. During the injection phase, these pumps take suction from the RWT and deliver water to the RCS cold leg. During transfer to RAS, the LPSI pumps are shutdown. In preparation for the recirculation phase, operators are procedurally directed to align the HPSI pump suction to CSS discharge ("piggy back" mode). Once simultaneous hot and cold leg injection is started, one LPSI pump is started at a low flow (404 gpm) as discussed in the Response to 3.g.1.

Containment Spray System Pumps
The CS pumps can be actuated manually from the control room or automatically on receipt of CSAS. These signals start the CS pumps and open the discharge valves to the spray headers. During the injection phase, the CS pumps take suction from the RWT. As discussed in the Response to 3.g.1, the pump suction is manually switched to the containment recirculation sump upon RAS.

PSL2 Pump Operational Status

Prior to the initiating event, the ECCS and CS pumps will be in a state of stand-by readiness.

Safety Injection Pumps
In the event of a LOCA, both HPSI and LPSI pumps start automatically on receipt of SIAS. During the injection phase, these pumps take suction from the RWT and deliver water to the RCS cold leg. During transfer to RAS, the LPSI pumps are shutdown. HPSI pump suction is aligned directly to the recirculation sump.

Containment Spray System Pumps

The CS pumps can be actuated manually from the control room or automatically on receipt of CSAS. These signals start the CS pumps and open the discharge valves to the spray headers. During the injection phase, the CS pumps take suction from the RWT. As discussed in the Response to 3.g.1, only one CS pump is running just prior to RAS, and the pump suction is manually switched to the containment recirculation sump upon RAS.

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

Response to 3.g.7:

Response for PSL1

Two single failure scenarios are relevant to sump strainer performance. First, is the failure of an operating LPSI pump to trip on receipt of RAS. It is expected that the operator would take action to trip this pump manually during verification of RAS actions, one of which is to "ENSURE LPSI Pumps STOPPED".[JT396] Thus, this condition is expected to be temporary or short term.

Second, is the failure of an operating CS pump. During recirculation, in the event that CSAS is not actuated coincident with SIAS or a CS pump fails, an operating HPSI pump (aligned for piggy-back mode) will continue to take suction from the containment sump.[JT397] It was conservatively assumed in this scenario that the containment spray pumps are operating at a higher flow rate prior to pump failure. The total sump flow rate is 9,304 gpm (two CS pumps at 4,450 gpm each, two HPSI pumps at 640 gpm each (piggy back), and one LPSI pump a 404 gpm). Once the CS pump fails the flow is assumed to be 5,494 gpm (4,450 gpm CS pump + 640 gpm HPSI pump + 404 gpm LPSI pump).[JT398] It was assumed that the flow rate of the HPSI pump in the same train as the failed CS pump does not decrease after the failure occurs. See the Response to 3.g.16 for failure case results.

Response for PSL2

Two single failure scenarios are relevant to sump strainer performance. First, is the failure of an operating LPSI pump to trip on receipt of RAS. It is expected that the operator would take action to trip this pump manually during verification of RAS actions, one of which is to "ENSURE LPSI Pumps STOPPED".[JT399] Thus, this condition is expected to be temporary or short term.

Second, is the failure of an operating HPSI pump valve. In this scenario, the valve remains wide open allowing the HPSI pump to reach runout flows. Pump runout flow is 700 gpm, and was used to calculate NPSH margin, see the Response to 3.g.1.

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

Response to 3.g.8:

The water volume calculations used the methodology described below when calculating the minimum containment sump water level:

1. A function was first developed for the relationship between the containment water level and the water volume.[JT400]
2. The quantity of water added to containment from the RWT, pressurizer, RCS, SITs, $NaOH/N_2H_4$ tanks, and BAMTs was calculated.[JT401]
3. The quantity of water that is diverted from the containment sump by the following effects was evaluated:[JT402]
    - Water volume required to fill the CSS 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.
    - Water held-up in the refueling cavity
    - Water held-up as steam in the containment atmosphere.
    - Water held-up due to re-flood of RCS (LBLOCA only).
    - Water held-up due to replenishing RCS (SBLOCA only).
4. Given the net volume of water added to the containment floor based on Items 2 and 3 listed above, the post-LOCA containment water level was calculated using the function developed in Item 1.

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 is used 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 were 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 were treated within the water volume calculation as hold-up volumes that remove water from the containment pool: CSS 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.[JT403]

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

Response to 3.g.11:

No assumptions were made regarding equipment that would displace water.

The reactor support steel, concrete support pads, concrete structures, the reactor vessel, the reactor drain tank, containment sump pumps, HVAC fans,[JT404] and the containment sump screens [JT405]were credited as displacing water in the containment pool.

Equipment that was not considered in the analysis to displace water in the containment pool includes structural steel supports, stairways, ladders, platforms, grating and cover plates; HVAC ducting (will be flooded during recirculation); electrical trays, conduit, cables, and wire; fuel transfer and up-ender equipment; neutron detector equipment; piping and piping restraint structures; and steam generator sliding base structures.[JT406] By not considering these structures and equipment for water displacement, the sump pool level was conservatively minimized.

Figure 3.g.11-1 is a depiction of the lower level of containment, which shows structures and components both credited and not credited for water displacement in the containment water volume calculation.

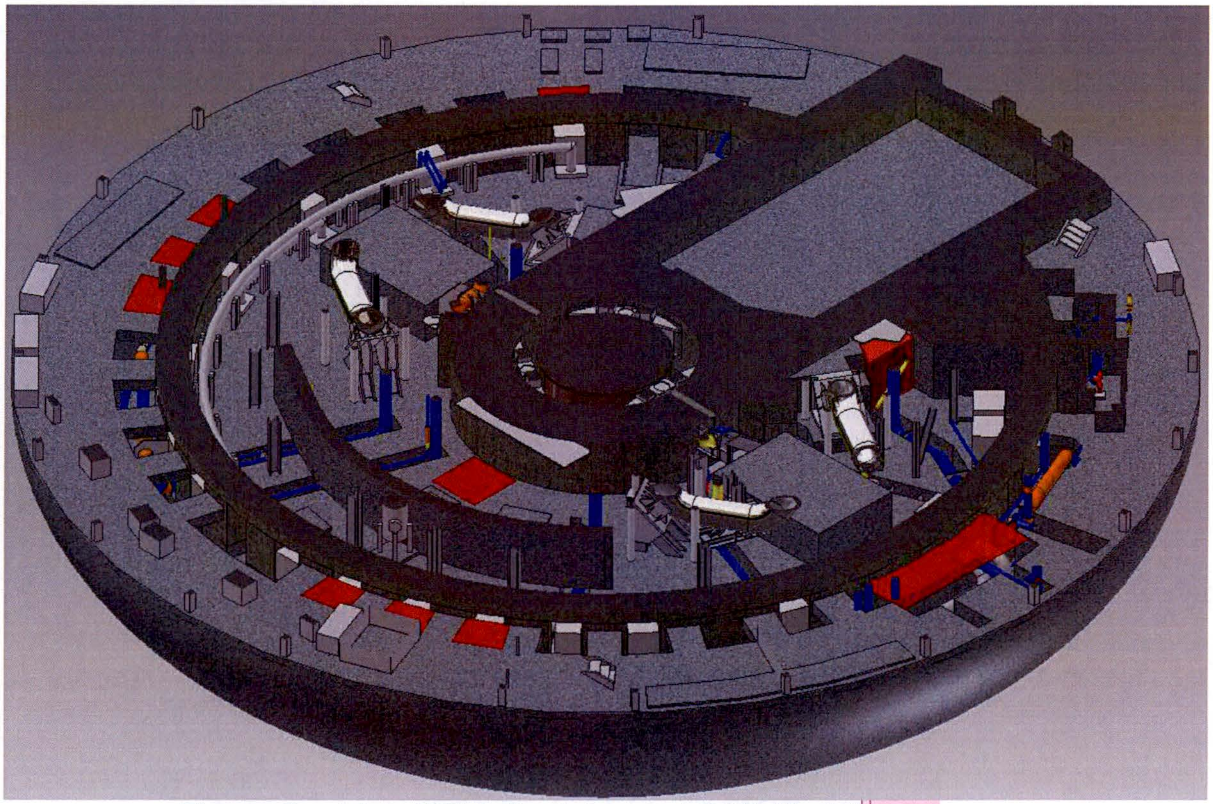

Figure 3.g.11-1: PSL1 Containment CAD Model [JT407]

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 design inputs in Table 3.g.12-1 provide the basis for water sources and their volumes to determine the minimum containment water level. Applicable assumption (and their bases) are provided in the Response to 3.g.2.

Table 3.g.12-1: PSL1 and PSL2 Water Source Volumes[JT408]

Source	Unit	Volume (ft^3)	Basis
RWT	1	55,690	Min. available RWT water volume adjusted to min. sump temp. at RAS
	2	52,304	
Pressurizer	1	363	Min. available pressurizer water volume adjusted to min. sump temp. at RAS
	2	484	
RCS	1	6,873	Min. available RCS water volume adjusted to min. sump temp. at RAS
	2	7,174	
$NaOH/N_2H_4$ Tanks	1	540	Min. available NaOH (PSL1) or N_2H_4 (PSL2) water volume adjusted to min. sump temp. at RAS
	2	91	
SITs	1	4,395	Min. available SIT water volume adjusted to the min. sump temp. at RAS
	2	5,726	
BAMT	1	731	Min. available BAMT water volume adjusted to the min. sump temp. at RAS
	2	724	

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 available NPSH at PSL1 or PSL2. See 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:

PSL1 Containment Accident Pressure

Containment accident pressure was not credited in determining available NPSH at PSL1. The PSL1 Tech Spec minimum containment pressure is -0.49 psig.[JT409] The temperature at which the water vapor pressure is equal to this minimum containment pressure is approximately 210 °F (Reference 20 p. 86)[JT410]. For the range of temperatures used for NPSH calculation, 120 °F to 191 °F,[JT411] the containment pressure was conservatively assumed to be 11.14 psia,[JT412] which is lower than the Tech Spec minimum containment pressure.

PSL2 Containment Accident Pressure

Containment accident pressure was not credited in determining available NPSH at PSL2. The PSL2 Tech Spec minimum containment pressure is -0.42 psig.[JT413] The temperature at which the water vapor pressure is equal to this minimum containment pressure is approximately 211 °F (Reference 20 p. 86)[JT414]. For the range of temperatures used for NPSH calculation, 120 °F to 192 °F,[JT415] the containment pressure was conservatively assumed to be 13.57 psia,[JT416] which is lower than the Tech Spec minimum containment pressure.

Sump Temperature

At PSL1, the EPU analysis has shown that the containment sump temperature will not surpass 191 °F. Thus, for the NPSH margin calculation, the maximum sump temperature was set to the limiting plant sump temperature of 191 °F.[JT417]

At PSL2, the EPU analysis has shown that the containment sump temperature will not surpass 192 °F. Thus, for the NPSH margin calculation, the maximum sump temperature was set to the limiting plant sump temperature of 192 °F.[JT418]

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

Response to 3.g.15:

See the Responses to 3.g.14.

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

Response to 3.g.16:

PSL1 NPSH Margin Results

Table 3.g.16-1 provides a summary of the minimum NPSH margins for the LPSI and CS pumps in recirculation mode at various sump temperatures between 120 °F and 191 °F with and without accounting for the total strainer head losses. The total strainer head losses include the clean strainer head loss, conventional debris (particulate and fiber) head loss (for sump temperatures above 153 °F), and chemical debris head loss (for sump temperatures at or below 153 °F). Bounding head loss values, as given in the Response to 3.f.10, were used in the evaluation.

One conservatism for this approach is that the chemical debris head loss due to aluminum precipitate was used for sump temperatures at or below 153 °F while, as shown in the Response to 3.o.2, aluminum precipitation will not occur until the sump temperature is below 98.2 °F. As shown in Table 3.g.16-1, the minimum net NPSH margin of the CSS and LPSI pumps for any given sump temperature is positive. Therefore, adequate NPSH margin is available for the CSS and LPSI pumps to ensure their design functions.

Table 3.g.16-1: PSL1 Limiting NPSH Margin vs. Sump Temperature [JT419]

Pool Temp (°F)	CS Pump NPSH Margin Before Strainer Head Losses (ft)	CS Pump NPSH Margin After Strainer Head Losses (ft)	LPSI Pump NPSH Margin Before Strainer Head Losses (ft)	LPSI Pump NPSH Margin After Strainer Head Losses (ft)
120	32.76	24.66	36.29	28.19
130	32.46	24.36	35.99	27.89
140	31.53	23.43	35.06	26.96
150	30.07	21.97	33.60	25.50
160	28.16	24.51	31.69	28.04
170	25.69	22.04	29.22	25.57
180	22.41	18.76	25.94	22.29
190	18.51	14.86	22.04	18.39
191	18.04	14.39	21.57	17.92

Table 3.g.16-2 shows the bounding NPSH margin for the HPSI pump in the event of a CS pump failure as described in the Response to 3.g.7. When the CS pump fails, the HPSI pump within the same train will continue to take suction from the sump. For this case, the CS pump flow rate has been selected to be conservatively higher than the normal recirculation flow rate to maximize losses, and minimize available NPSH. The NPSH margin value shown in this table includes all head losses from the piping system, the strainer, and debris.

Table 3.g.16-2: PSL1 Minimum NPSH Margin During CS Pump Failure Scenario [JT420]

Pool Temp (°F)	HPSI Pump NPSH Margin Including All Losses (ft)
191	1.43

PSL2 NPSH Margin Results

Table 3.g.16-3 provides a summary of the minimum NPSH margins for the HPSI and CS pumps in recirculation mode at various sump temperatures between 120 °F and 192 °F. Note that no credit was taken for the reduction in the CS pump flow rate [JT421]for evaluation of NPSH margin.

Table 3.g.16-3: PSL2 Limiting NPSH Margin vs. Sump Temperature [JT422]

Pool Temp (°F)	CS Pump NPSH Margin Before Strainer Head Losses	CS Pump NPSH Margin After Strainer Head Losses	HPSI Pump NPSH Margin Before Strainer Head Losses	HPSI Pump NPSH Margin After Strainer Head Losses
120	28.92	22.58	27.47	21.13
130	27.96	21.62	26.50	20.16
140	26.64	20.30	25.19	18.85
150	24.91	18.57	23.46	17.12
160	22.70	16.36	21.25	14.91
170	19.92	13.58	18.47	12.13
180	16.48	10.14	15.03	8.69
190	12.26	5.92	10.81	4.47
192	11.31	4.97	9.86	3.52

Table 3.g.16-3 shows the NPSH margins with and without accounting for the total strainer head losses. The total strainer head losses include the clean strainer head loss and the maximum chemical debris head loss, as shown in the Response to 3.f.10. Since the minimum net NPSH margin for any given sump temperature is positive, adequate NPSH margin is available for the PSL2 ECCS pumps to ensure their design functions.

3.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 (IOZ) primer, Ameron 90 epoxy finish coat.*

Response to 3.h.1:

Qualified Coatings

The types of qualified coatings and systems used in containment are presented in Table 3.h.1-1.[JT423]

Table 3.h.1-1: PSL1 and PSL2 Qualified Coatings Systems Used in Debris Generation Analyses

Substrate	Layer	Type	DFT (mil)	Density (lbm/ft^3)
Steel Surfaces	1^{st} Coat	Carbozinc 11 – IOZ	5	208
	2^{nd} Coat	Phenoline 305 – Epoxy	6	101.3
		Total	11	
Concrete Surfaces	1^{st} Coat	Carboline 195 – Epoxy Primer/Surfacer	20	107.7
	2^{nd} Coat	Phenoline 305 – Epoxy	12	101.3
		Total	32	

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, including various types of IOZ, enamel, and cold galvanizing.[JT424] The quantity and properties of these unqualified coatings are shown in Table 3.h.1-2 for PSL1 and Table 3.h.1-3 for PSL2.

Table 3.h.1-2: PSL1 Unqualified Coatings Debris Load

Coating Type	Surface Area (ft^2)	Volume (ft^3)	Density (lbm/ft^3)	Coatings Log Mass (lbm)	Mass + 4% Margin (lbm)	Characteristic Size (μm)
Degraded Coatings (IOZ)	1,916	2.4	208	499	519	10
Enamel (on RCPs)	2,776	1.16	98	114	119	10
Cold Galvanizing on Ducts	7,025	2.34	297	348*	362	10
IOZ on Pipes	5,589	1.86	208	387	402	10

*See 3.h.5 for the 50% failure rate of cold galvanizing

Table 3.h.1-3: PSL2 Unqualified Coatings Debris Load

Coating Type	Surface Area (ft^2)	Volume (ft^3)	Density (lbm/ft^3)	Coatings Log Mass (lbm)	Mass + 10% Margin (lbm)	Characteristic Size (μm)
Degraded Coatings (IOZ)	826	0.89	208	185	204	10
Enamel (on RCPs)	2,776	2.31	98	226	249	10
Cold Galvanizing on Ducts	7,025	2.34	297	348*	383	10
IOZ on Pipes	6,854	2.28	208	474	521	10

*See 3.h.5 for the 50% failure rate of cold galvanizing

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 PSL1 and PSL2 debris transport analyses:

- It was conservatively assumed that all unqualified coatings are located in lower containment and fail at the start of the event (t=0). 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.[JT425]

- 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 21)[JT426] and Indian Point (Reference 22)[JT427] 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.[JT428]
- Unqualified coatings outside the ZOI are assumed to fail after pool fill-up has occurred, so the transport fraction for this debris during pool fill-up is 0%.[JT429]

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

Response to 3.h.3:

Particulates originating from failed coatings were modeled with pulverized acrylic with a median size of 12.7 μm.[JT430]

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

Response to 3.h.4:

The pulverized acrylic used as a surrogate for failed coatings was used on an equal volume basis and has a median size of 12.7 μm, similar to that of the assumed size (Table 3.c.1-1) of the failed coatings.[JT431]

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 assumptions related to coatings were made in the debris generation calculation:

- The qualified coating systems at PSL1 were used for the PSL2 debris generation analysis. This was deemed reasonable as PSL1 and PSL2 are of a similar design and the internal containment horizontal and vertical surfaces are similar.[JT432]
- Unqualified IOZ coatings were assumed to have a density of 208 lbm/ft^3 based on the properties of Carbozinc 11. This is reasonable because Carbozinc 11 is a typical IOZ coating.[JT433]

- Degraded coatings were assumed to be IOZ. This is conservative because IOZ is much denser than other coatings types.[JT434]
- All unqualified coatings were assumed to have a particulate size of 10 µm.[JT435] This was found acceptable in the NRC SE on NEI 04-07 (Reference 6 p. 22)[JT436].
- The amount of degraded/unqualified coatings were from the coatings log.[JT437] These values were conservatively increased by 4% at PSL1 (see Table 3.h.1-2) and 10% at PSL2 (see Table 3.h.1-3).
- The cold galvanized unqualified coating on ducts is assumed to have the properties of ZRC cold galvanizing compound.[JT438] This is reasonable because ZRC is a typical cold galvanizing compound. Additionally, it is assumed to fail at a rate of 50%. This has been accepted by the NRC (Reference 23 p. 22; 24).[JT439]
- Qualified coatings were analyzed within a 4.0D ZOI. This ZOI has been previously accepted by the NRC (Reference 7 p. 2)[JT440].

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.1-2 and Table 3.h.1-3 for PSL1 and PSL2, respectively. The quantities apply to all breaks, regardless of size or location.

The quantity of qualified coatings shown in Table 3.h.5-1, Table 3.h.5-2, and Table 3.h.5-3, are from the respective worst-case insulation breaks.[JT441] The volume values in these tables were calculated using the densities presented in Table 3.h.1-1.

Table 3.h.5-1: PSL1 Qualified Coatings Debris for the Two Worst-Case Breaks for Each Loop

Break Location	**1-SGB-W16 & RC-123-FW-2000**		**RC-123-1-503**		**1-SGA-W16 & RC-114-FW-2000**		**RC-114-7-503**	
Location Description	SG B Nozzle at Hot Leg		Hot Leg B Elbow		SG A Nozzle at Hot Leg		Hot Leg A Elbow	
Break Size	42"		42"		42"		42"	
Break Type	DEGB		DEGB		DEGB		DEGB	
Carbozinc 11 (IOZ)	169.12 lbm	0.81 ft^3	170.75 lbm	0.82 ft^3	52.42 lbm	0.25 ft^3	53.41 lbm	0.26 ft^3
Phenoline 305 (Epoxy)	205.17 lbm	2.03 ft^3	218.98 lbm	2.16 ft^3	126.36 lbm	1.25 ft^3	141.27 lbm	1.39 ft^3
Carboline 195 (Epoxy)	188.41 lbm	1.75 ft^3	211.20 lbm	1.96 ft^3	169.62 lbm	1.57 ft^3	195.01 lbm	1.81 ft^3

Table 3.h.5-2: PSL2 Qualified Coatings Debris for the Two Worst-Case Cal-Sil Breaks for Each Loop

Break Location	**313-N4-3204-2-JW103-S/C010**		**RC-114-FW-2010**		**314-N4-3204-2-JW103-S/C010**		**RC-123-FW-2010**	
Location Description	SG A Nozzle at Hot Leg		SG A Nozzle at Hot Leg		SG B Nozzle at Hot Leg		SG B Nozzle at Hot Leg	
Break Size	42"		42"		42"		42"	
Break Type	DEGB		DEGB		DEGB		DEGB	
Carbozinc 11 (IOZ)	42.7 lbm	0.21 ft^3	42.7 lbm	0.21 ft^3	65.3 lbm	0.31 ft^3	65.3 lbm	0.31 ft^3
Phenoline 305 (Epoxy)	113.8 lbm	1.12 ft^3	113.8 lbm	1.12 ft^3	139.7 lbm	1.38 ft^3	139.7 lbm	1.38 ft^3
Carboline 195 (Epoxy)	158.1 lbm	1.47 ft^3	158.1 lbm	1.47 ft^3	180.6 lbm	1.68 ft^3	180.6 lbm	1.68 ft^3

Table 3.h.5-3: PSL2 Qualified Coatings Debris for the Two Worst-Case Fiber Breaks for Each Loop

Break Location	**313-N4-3204-2-JW103-S/C010**		**RC-114-401-771**		**314-N4-3204-2-JW103-S/C010**		**RC-123-201-771**	
Location Description	SG A Nozzle at Hot Leg		Hot Leg A Elbow		SG B Nozzle at Hot Leg		Hot Leg B Elbow	
Break Size	42"		42"		42"		42"	
Break Type	DEGB		DEGB		DEGB		DEGB	
Carbozinc 11 (IOZ)	42.7 lbm	0.21 ft^3	44.9 lbm	0.22 ft^3	65.3 lbm	0.31 ft^3	67.6 lbm	0.32 ft^3
Phenoline 305 (Epoxy)	113.8 lbm	1.12 ft^3	121.1 lbm	1.20 ft^3	139.7 lbm	1.38 ft^3	144.0 lbm	1.42 ft^3
Carboline 195 (Epoxy)	158.1 lbm	1.47 ft^3	168.8 lbm	1.57 ft^3	180.6 lbm	1.68 ft^3	185.9 lbm	1.73 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 Volume 1 (Reference 12 pp. 34, 35)[JT442] and the associated NRC SE on NEI 04-07 (Reference 6 p. 22)[JT443], all coating debris was treated as 10-micron particulate.[JT444] See the Response to 3.h.1, 3.h.2, and 3.h.5 for additional coating debris characteristics description.

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

Response to 3.h.7:

PSL1 and PSL2 Containment Coating Condition Assessment Program [JT445]

The current program for controlling the quantity of unqualified/degraded coatings includes two separate inspections by qualified personnel during each refueling outage, and notification of plant management prior to restart if the volume of unqualified/degraded coatings approaches pre-established limits.

The first inspection takes place at the beginning of every refueling outage, when areas and components from which peeling coatings have the potential for falling into the reactor cavity are inspected by the FPL Coating Supervisor. The second inspection takes place at the end of every refueling outage when the condition of containment coatings is assessed by a team (including the Nuclear Coating Specialist) using guidance from EPRI Technical Report 1003102. Accessible coated areas of the containment and equipment are included in the second inspection. Plant management is notified prior to restart if the volume of unqualified/degraded coatings approaches pre-established limits.

The initial coating inspection process is a visual inspection. The acceptability of visual inspection as the first step in monitoring of containment building coatings is validated by EPRI Technical Report 1014883. Following identification of degraded coatings, the degraded coatings are repaired per procedure if possible. For degraded coatings that are not repaired, areas of coatings determined to have inadequate adhesion are removed, and the Nuclear Coatings Specialist assesses the remaining coating to determine if it is acceptable for use. The assessment is by means of additional nondestructive and destructive examinations as appropriate.

3.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:

PSL has procedural controls in place to reduce and control the amount of loose debris and fibrous materials in containment.[JT446] The Housekeeping and Cleanliness Control Methods procedure requires inspection of all accessible areas to verify that no loose debris, fibrous materials that could degrade into loose debris, or bubbling/chipping paint is present prior to setting containment integrity. In addition, 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.[JT447] The responsible Department Supervisor shall ensure by daily inspection that, when work is complete, no loose debris is left inside containment which could transport to the sump strainers.[JT448]

The Maintenance SFAM has been placed in charge of maintaining the general housekeeping of containment, which includes tracking the overall cleanliness of containment and promptly correcting identified deficiencies.[JT449]

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 PSL1 and PSL2, that consider the containment building as a plant system.[JT450] This ensures that proper work control is specified for debris-generating activities within the containment building in order to prevent introduction of foreign material into the 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.[JT451] Lastly, the containment entry procedure provides additional controls for foreign materials to be brought into containment and ensure they are removed during at-power entries.[JT452]

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 affected critical attributes be listed, evaluated, and documented when affected.[JT453] This includes the introduction of materials into containment that could affect sump performance or lead to equipment degradation (e.g., GSI-191).

NextEra implemented the industry's Standard Design Change Process including the industry procedure IP-ENG-001 (Reference 25)[JT454]. 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 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 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.

Procedures have been written for inspection of the new strainer system, and the containment close-out procedure has been updated.[JT455] The new procedure requires that there are no holes, gaps, or tears greater than 1/16 inch (0.0625 inch) in any component of the strainer system (e.g., including connections).[JT456] The containment closeout procedure was updated to include all of the strainer system components in the final containment closeout inspection. The effect of these changes is to ensure that all components (strainer modules, piping, and pipe connections) are inspected, and that there are no holes, gaps, or tears greater than 1/16 inch in any strainer system component.

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.[JT457]

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. PSL implements the requirement via procedures.[JT458]

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:

   The pressurizer insulation at PSL1 was changed from Transco Thermal-Wrap blankets, Transco RMI, and Nukon insulation, to Darchem stainless steel RMI.[JT459] This modification would reduce fiber loads at the strainer from potential pipe breaks in the pressurizer cubicle compartment. There have not been other recent or planned insulation change-outs at PSL1 that would reduce the debris burden at the sump strainers.

   The insulation on the steam generator at PSL2 was changed from Nukon blankets to Transco stainless steel RMI.[JT460] This modification would reduce fiber loads at the strainer from potential pipe breaks inside the secondary shield wall. There have not been other recent or planned insulation change-outs at PSL2 that would reduce the debris burden at the sump strainers.

   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:

   Actions have been taken to modify existing insulation to reduce the potential debris burden at the sump strainers. Stainless steel bands have been installed over the Cal-Sil thermal piping insulation for selected areas of piping in containment at PSL1.[JT461] The banding system consists of ½-inch wide stainless steel bands that are installed around the outside of the insulation jacket. The bands are spaced approximately 3 inches on center. Tests to determine the efficacy of the banding system were conducted by Westinghouse utilizing the facilities of Wyle Laboratories.[JT462] Note that the debris generation analysis did not take credit for the installation of this banding system and reduction in Cal-Sil ZOI size (see the Response to 3.b.2). The banding will enhance the overall sturdiness of the piping insulation.[JT463]

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

Response to 3.i.5.c:

There have not been any modifications made to equipment or systems to reduce the debris burden at the sump strainers.

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

Response to 3.i.5.d:

The programmatic controls related to coatings are provided in the Response to 3.h.7.

3.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:

PSL1 and PSL2 have different strainer configurations. Thus, this response subsection is broken into two sections, one for each unit.

PSL1 Screen Modification Package [JT464]

The original sump screens have been completely replaced with a single, non-redundant, distributed sump strainer system that consists of 21 strainer modules and interconnecting piping. Figure 3.j.1-1 provides an overview of containment layout and the general location of strainer modules. The strainer system uses the General Electric (GE) discreet modular stacked disc strainers. The strainer surface design area is approximately 8,275 ft^2.

The new strainer system is completely passive (i.e., it does not have any active components or rely on backflushing). However, this design value includes surface area of perforated plate blocked by disk internal structural members. The unobstructed perforated plate surface area of the strainer disks was calculated as 7,244 ft^2. [JT465] This reduced strainer area value was used in the evaluations and testing referenced in this submittal.

As in the original sump screen design, the new distributed strainer system serves both ECCS suction intakes. Because the original PSL1 strainer did not utilize redundant sump strainers, this is not a departure from the existing design basis. It is consistent with the current design basis, Technical Specifications, and regulatory commitments for PSL1. Because a single non-redundant strainer system is used, the system has been designed such that there is no credible passive failure mechanism that could render both ECCS trains inoperable. Active strainer failure mechanisms are not considered because the strainer system is completely passive. The strainer system structural design is discussed in the Response to 3.k.1.

The strainer modules use an arrangement of parallel, rectangular strainer disks that have exterior debris capturing surfaces of perforated plate covered with woven wire mesh. The wire mesh decreases the head loss across the strainer plates by breaking up debris beds. Each strainer disk, constructed of two plates, has an open interior to channel disk flow downward to the strainer plenum. The disks are mounted on the discharge plenum, which channels disk flow to the interconnecting suction piping. Type 304 or other austenitic stainless steel is used as the primary material of construction.

The strainer perforations are nominal 1/16th-inch diameter holes.

The strainer modules are grouped together into 4 groups (see Figure 3.j.1-2). Each group is piped separately to the strainer manifold where the total strainer flow is combined. The manifold is connected to the recirculation suction inlets by two outlet pipes, one for each ECCS inlet.

The outlet pipes from the strainer manifold terminate at the ECCS recirculation suction inlets. Debris intrusion is prevented by an interface collar and backing plate installed at the suction inlets.

The entire strainer system is designed and situated to be fully submerged at the minimum containment water level during recirculation. Perforated passive vents are provided to preclude air entrapment during containment flood-up prior to recirculation. During flood-up, water would fill the strainer system from the bottom up, forcing air out of the perforated vents, thereby venting the system. Because the vents are below the containment water level prior to the start of recirculation, air will not be sucked in through the perforated panels. Venting is passive and uses perforations at least as small as the strainer perforated plate. Fabrication and installation tolerances of equipment are such that debris larger than allowable cannot bypass the strainer system. Therefore, debris retention capacity of the entire system is at least as good as the strainer modules.

The strainer modules and suction manifold (see Figure 3.j.1-3, Figure 3.j.1-4, and Figure 3.j.1-5) are designed in accordance with ASME Section III Subsection NC (Class 2 components) or NF (supports). The capability of the strainer perforated plate disks as structural members is based on the equivalent plate approach as specified by ASME Section III Article A-8000. Modification of existing supports or design of new supports is in accordance with AISC, 9th Edition or ASME Section III, Subsection NF.

The capability of the strainer system to accommodate the maximum mechanistically determined debris volume has been confirmed by testing and analysis as discussed in the Response to 3.f.4. The volume of debris at the screen is discussed in the Response to 3.e.6. The capability to provide the required NPSH with this debris volume is discussed in the Response to 3.g. The capability to structurally withstand the effects of the maximum debris volume is discussed in the Response to 3.k.1.

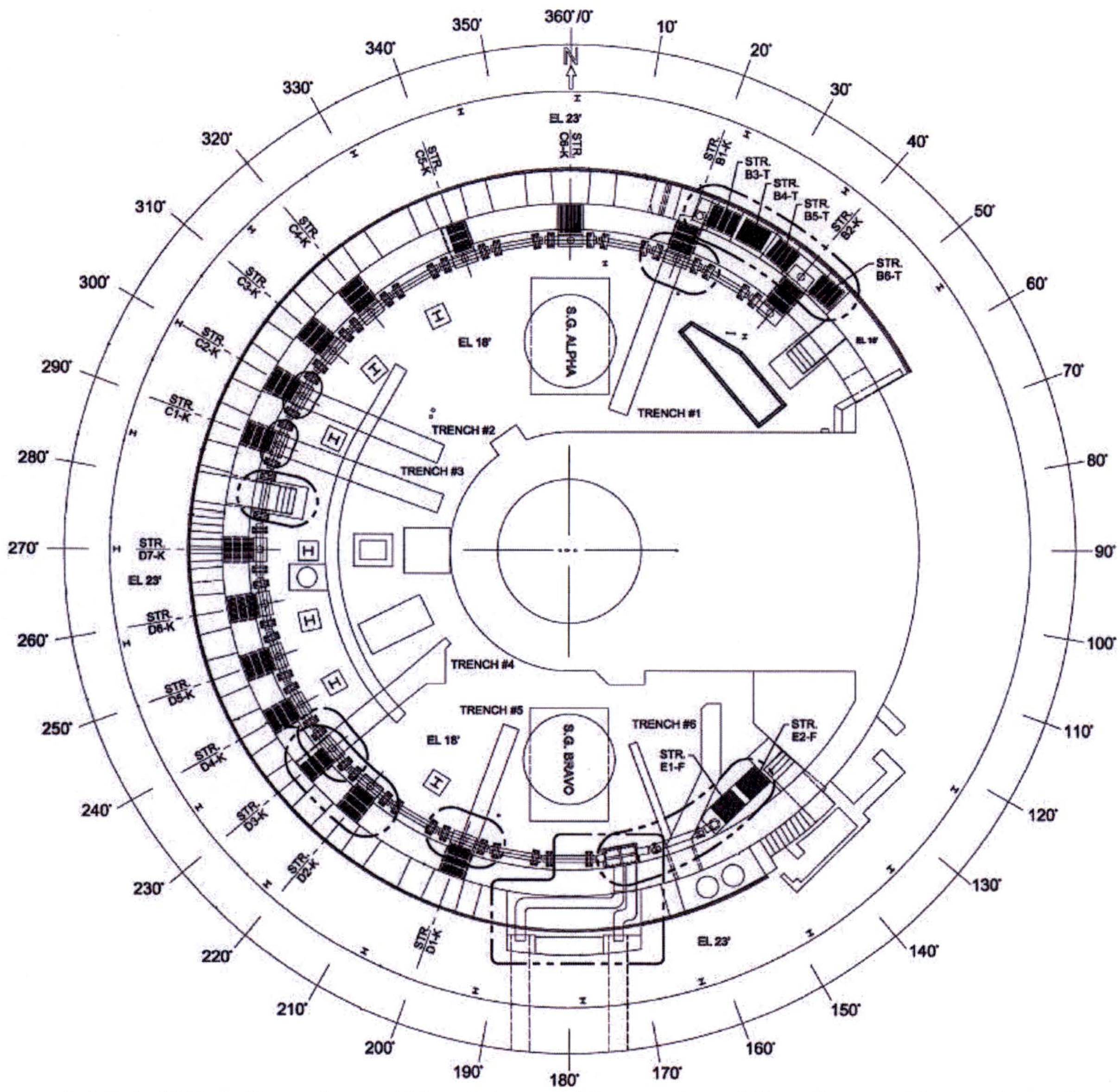

Figure 3.j.1-1: PSL1 Overview of Containment Layout and the General Location of Strainer Modules [JT466]

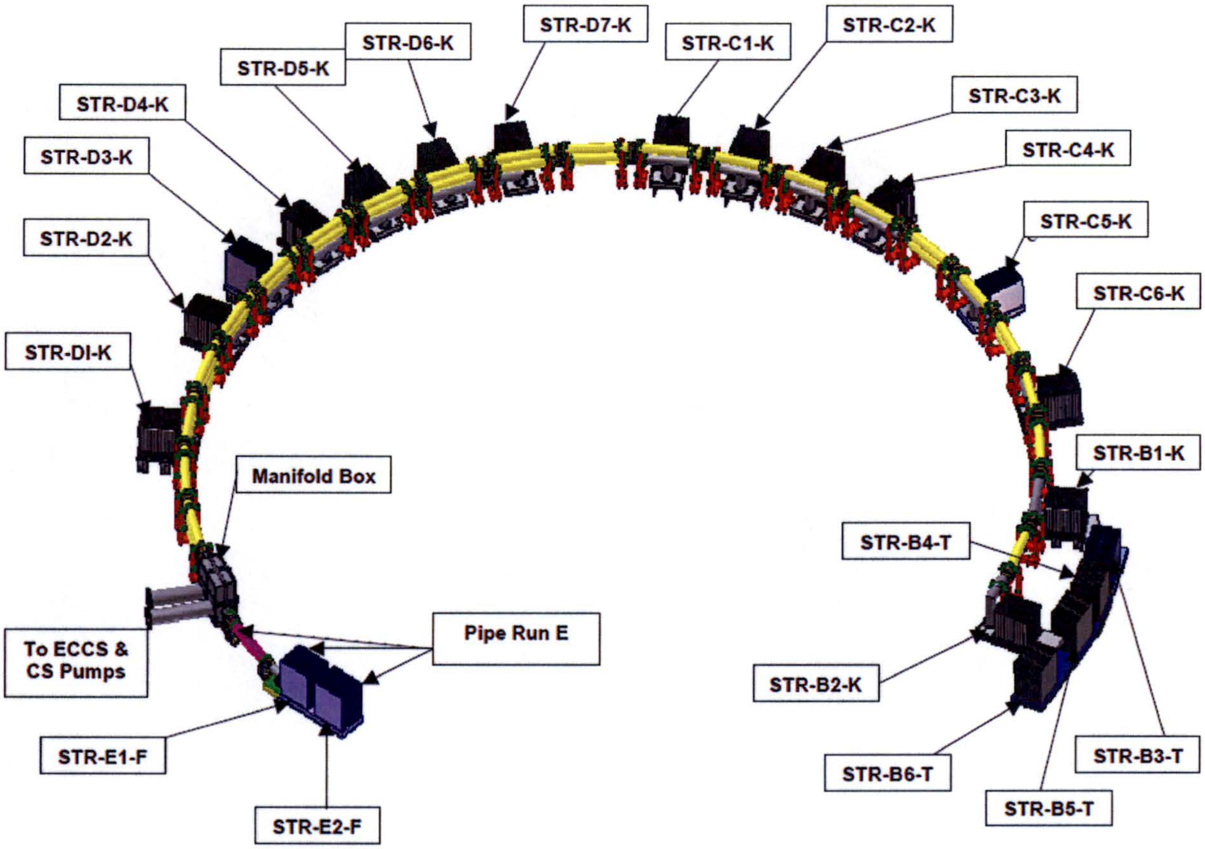

Figure 3.j.1-2: PSL1 Sump Strainer Layout [JT467]

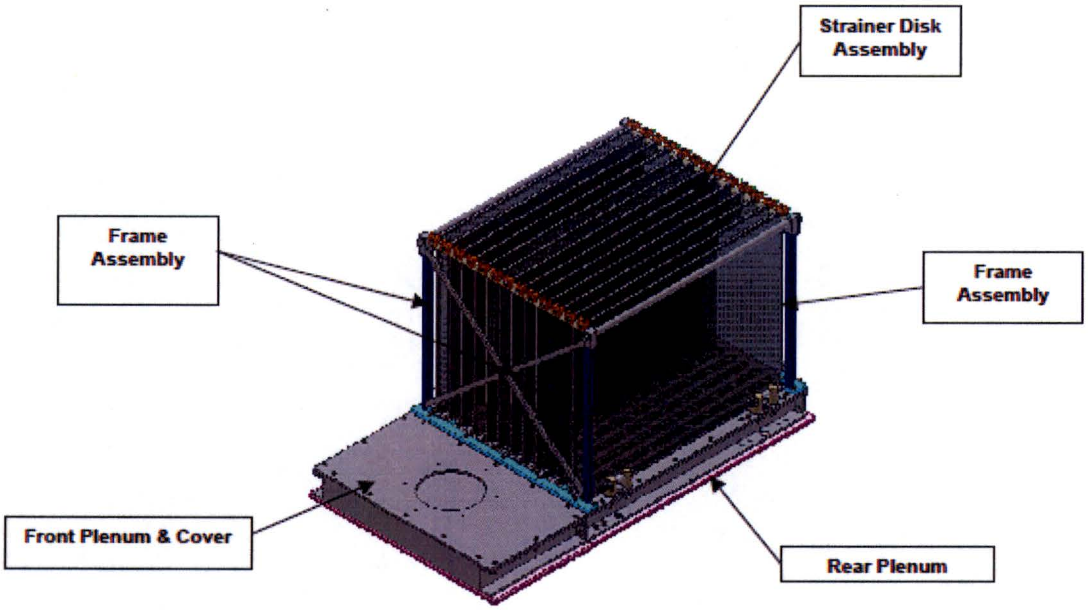

Figure 3.j.1-3: PSL1 Keyway Strainer Assembly – Typical [JT468]

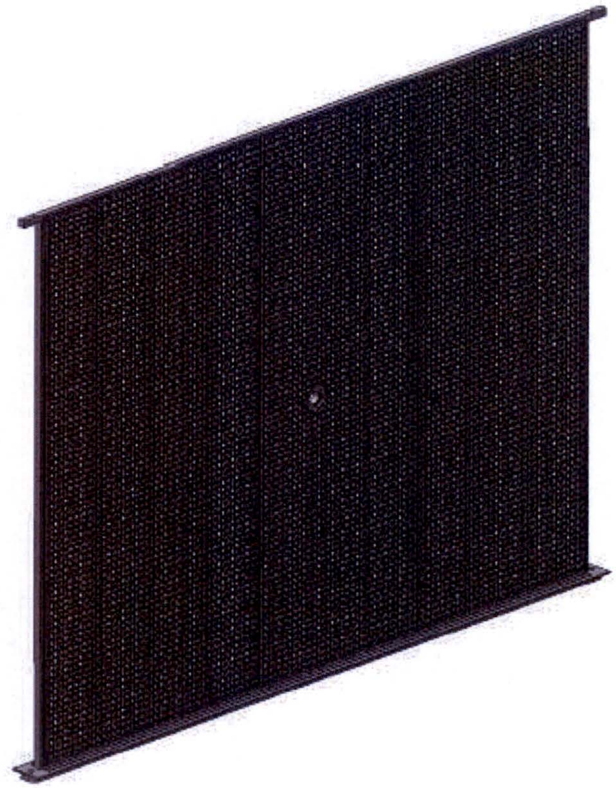

Figure 3.j.1-4: PSL1 Strainer Disk Assembly – Typical [JT469]

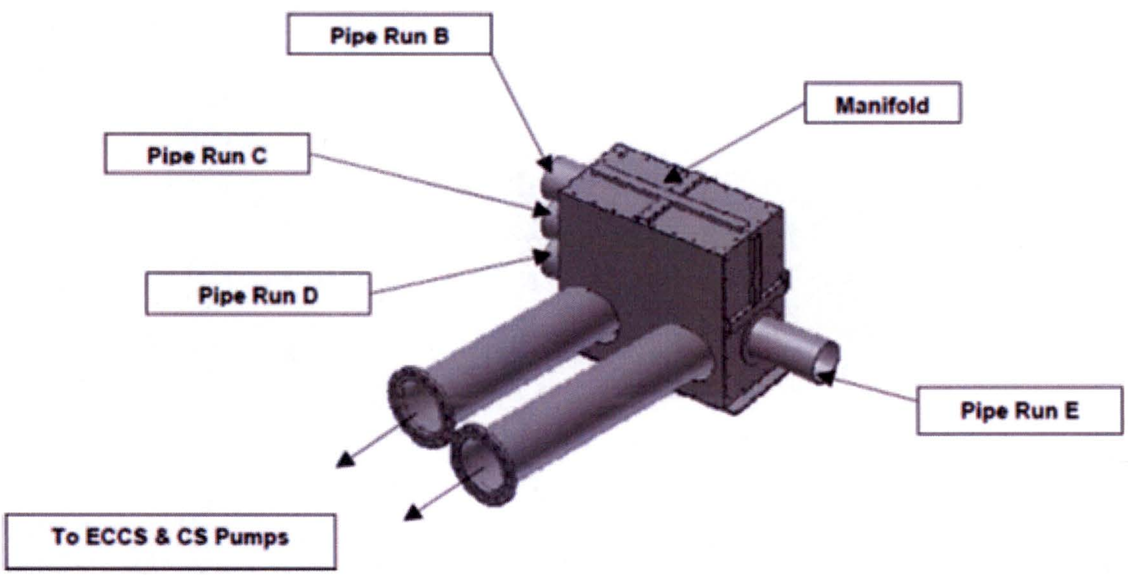

Figure 3.j.1-5: PSL1 Manifold Assembly [JT470]

PSL2 Screen Modification Package [JT471]

The PSL2 containment recirculation sump is open on both ends to a large recirculation trench that goes around the perimeter of the reactor containment and would carry most of the post-LOCA recirculation flow. Figure 3.j.1-6 provides a general overview of containment layout at the 18 ft elevation showing the trash racks which lead to the perimeter trench, and the general location of the containment recirculation sump. As shown in Figure 3.j.1-8, the bottom of the trench, approximately 12 ft elevation, is open to the containment recirculation sump which has a floor elevation of approximately 7 ft 7 inches.

The containment recirculation sump contains the reactor drain tank, including related mechanical equipment, instrumentation, and piping. This was also the location for the original containment recirculation sump screens and is the location of the new ECCS sump strainer system.

The installed PSL2 strainer system has eight separate vertically installed strainer stacks with a lower plenum box. This is mounted on the lower containment recirculation suction piping housing. Two separate recirculation intake pipes are located inside of the lower housing on the east and west ends of the recirculation sump. An instructional top view, side view, and isometric view of the strainer system are provided in Figure 3.j.1-7, Figure 3.j.1-8, and Figure 3.j.1-9, respectively. Strainer stacks 5, 6, 7, and 8 service the east end of the containment recirculation sump, for the Train "A" recirculation pipe intake, and stacks 1, 2, 3, and 4 service the west end for Train "B". An accordion divider plate with 1/16 inch holes is installed in the plenum which prevents any transport of large particles between the east and west strainer system. This helps to provide physical protection in the lower sump while still maintaining a degree of hydraulic coupling to balance head loss differences.

A strainer stack is an assembly of strainer modules that generally has 11 or 15 disks in each module. The modules have stiffener plates and are connected with tension rods into a strainer stack. Each of the disks is 1/2 inch thick with an internal separation gap between disks of 1 inch. The disks are hollow and have perforations of 1/16 inch diameter on the tops, bottoms, and sides. A flow control tube with flow slots for each disk runs from the top disk to the bottom, and is of varying diameters for each of the modules as it progresses from the top to the bottom of the strainer stack. A typical end strainer stack is shown in Figure 3.j.1-10.

As shown in Figure 3.j.1-9, the strainer stacks are of three basic designs. This was necessary to assure proper fit-up in the sump due to space interference limitations in the sump area. The hydraulic strainer designs of stacks 1 through 4 and 5 through 8 are all based on achieving a low approach velocity to the strainer perforations of approximately 0.0034 ft/sec, and closely balancing each ECCS/CSS train to a flow of approximately 4,250 gpm. Hence, the strainer area on each train is approximately equal to half of the total 5,607 ft^2 of strainer surface area.

The original sump screens have been replaced with the strainer system discussed above. The new strainer system is passive and does not rely on active features such as backflushing or other mechanical devices.

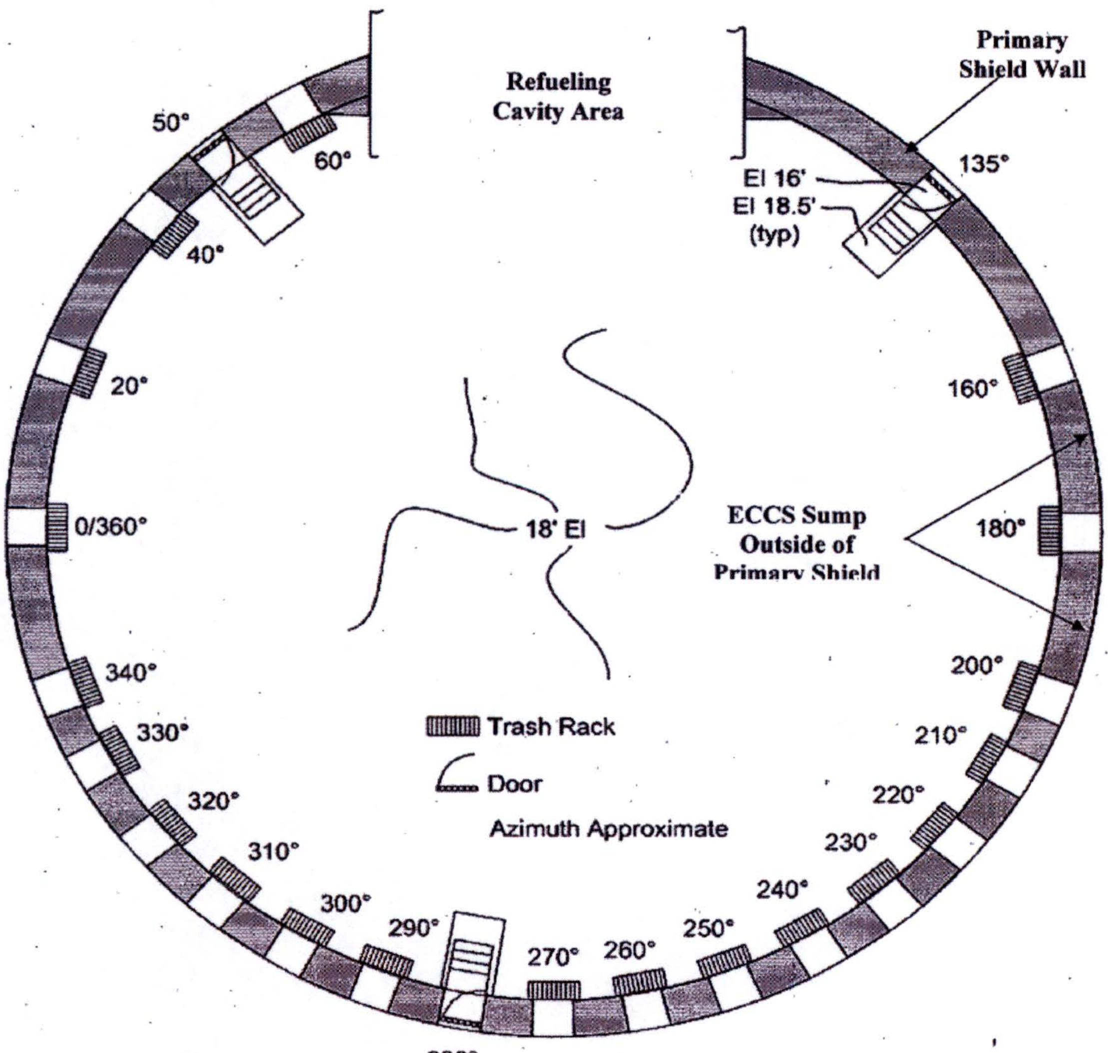

Figure 3.j.1-6: PSL2 Containment Trash Racks and Sump Location [JT472]

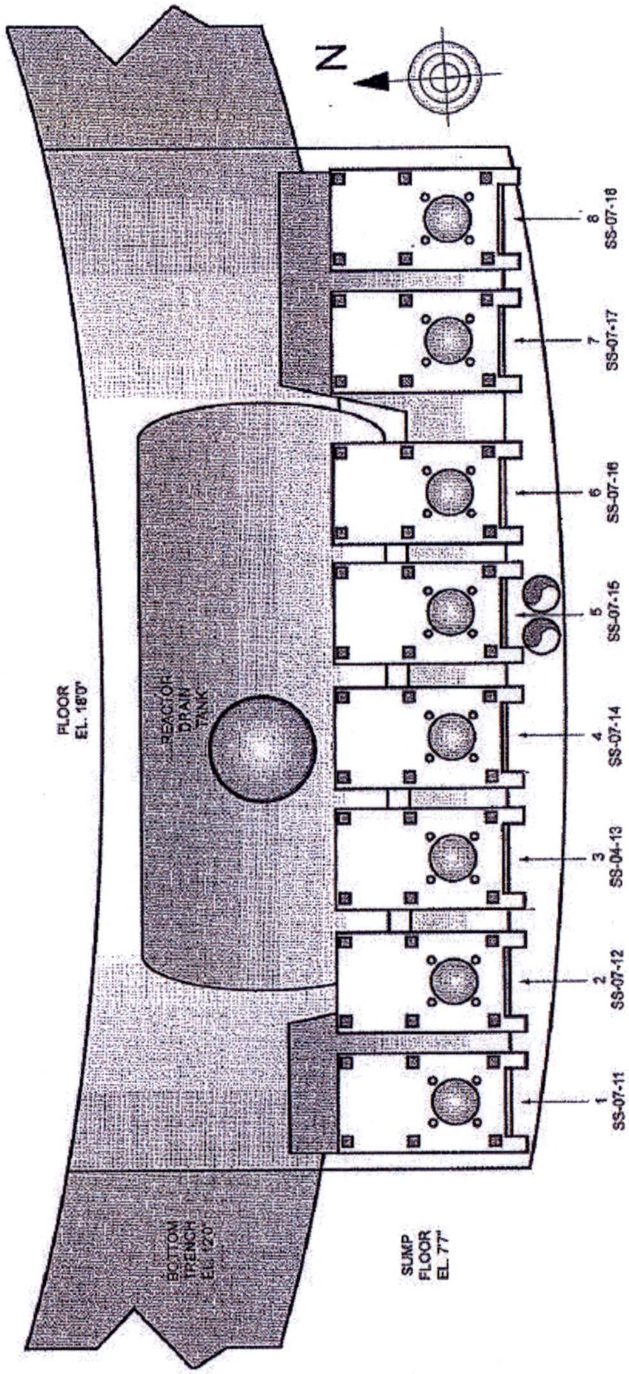

Figure 3.j.1-7: PSL2 Containment Recirculation Sump Strainers – Top View [JT473]

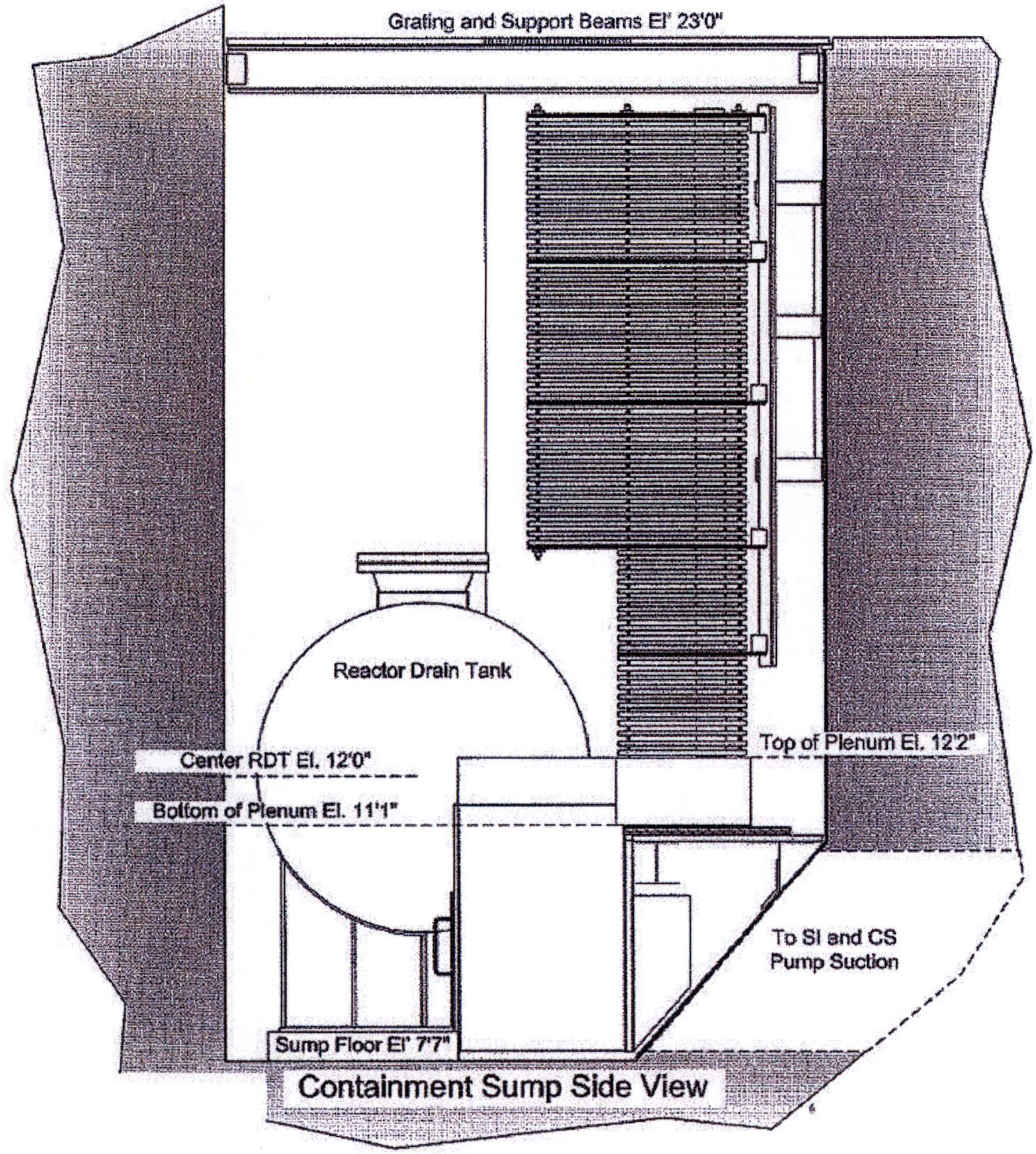

Figure 3.j.1-8: PSL2 Containment Sump Strainer System – Side View [JT474]

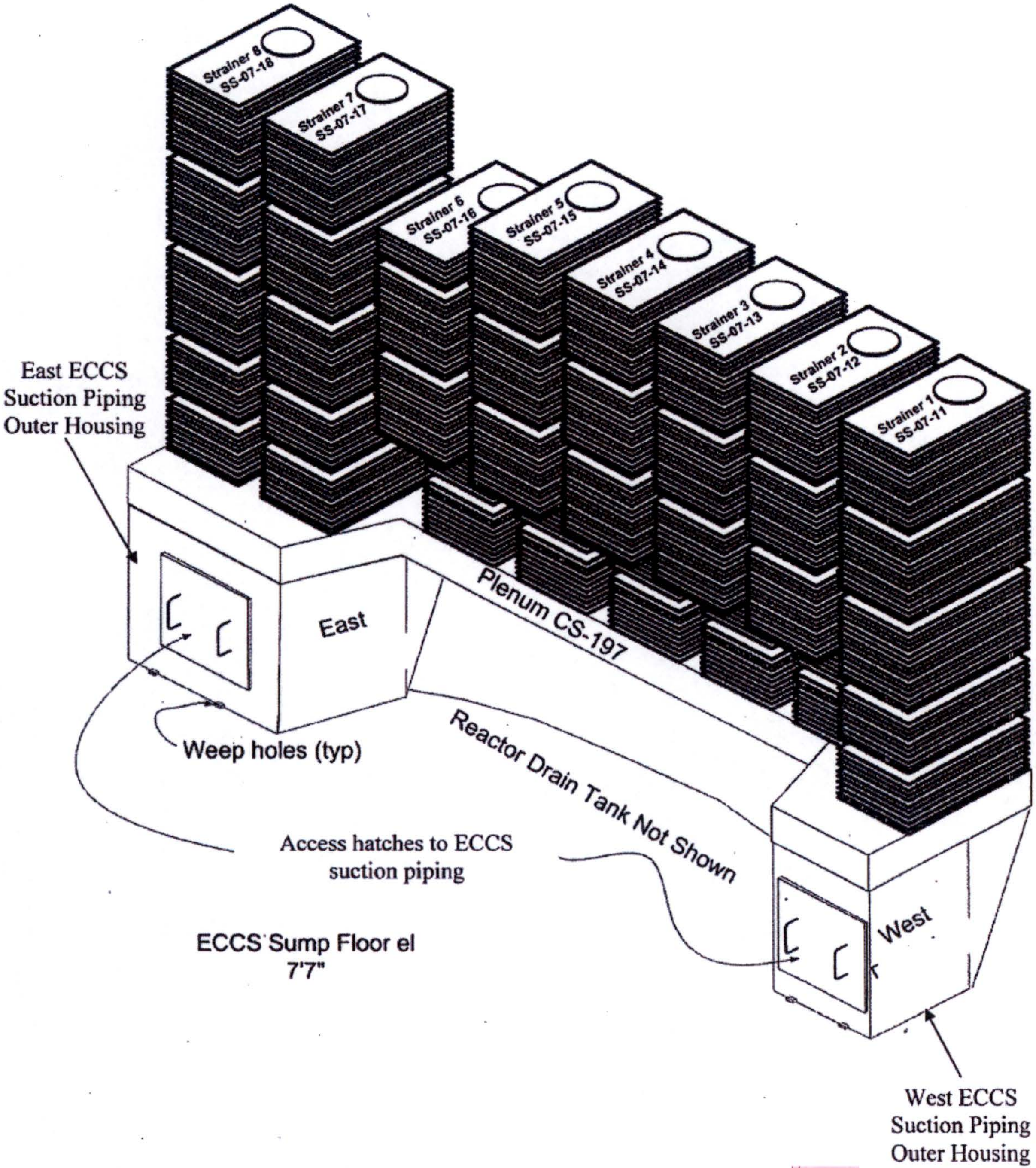

Figure 3.j.1-9: PSL2 Containment Sump Isometric View [JT475]

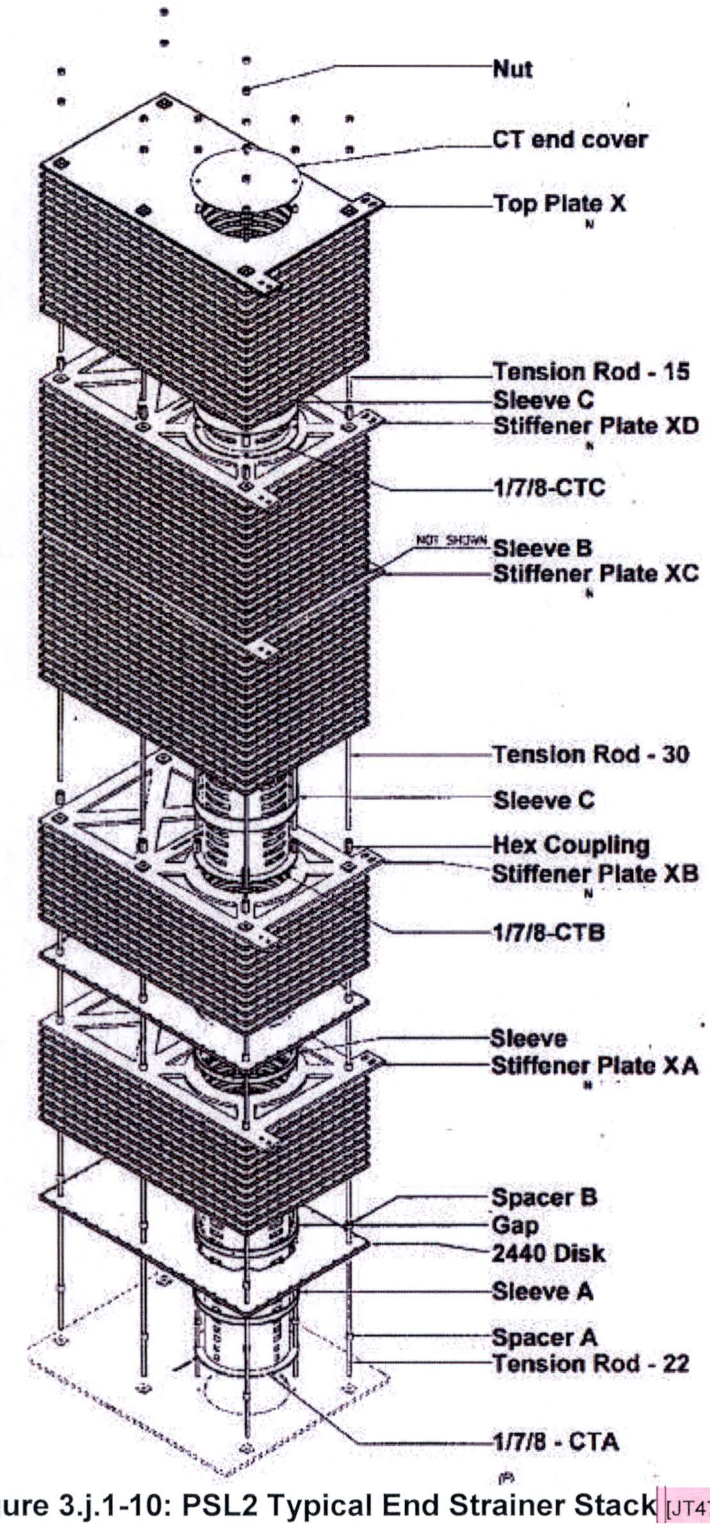

Figure 3.j.1-10: PSL2 Typical End Strainer Stack [JT476]

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:

Other changes associated with the modification included relocating and/or reconfiguring existing components to remove interferences associated with the strainer installation. Modifications included:

- At PSL1, one additional modification was completed that supports the new strainer installation. This modification created two 22-inch diameter core bores for the 18-inch piping that connects the suction manifold to the ECCS inlets. The core bores are a nominal 22-inch diameter to allow for a circumferential gap between the 18-inch nominal piping and the bioshield concrete. The configuration has been analyzed to be acceptable with regard to bioshield structural integrity.[JT477]
- At PSL2, the installation of the sump strainer system required the removal of the original sump screen system, relocation of Trisodium Phosphate Dodecahydrate (TSP) baskets, and the removal or modification of other in-sump piping and supports. These included:[JT478]
  - Removal of the original sump screens and most of the original framing.
  - Six of the TSP containers that were originally installed in the sump were removed and relocated to the recirculation trenches.
  - Three sections of Safety Injection System Piping were rerouted and re-supported.
  - The reactor drain tank level instrumentation tubing, nitrogen and primary makeup water supply lines, and drain and vent lines were modified including supports as necessary.
  - Modification of the gallery steel and supports at the 23-foot elevation and the removal of an unneeded pipe whip restraint.

3.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:

PSL1 and PSL2 have different strainer configurations. Thus, this response subsection is broken into two sections, one for each unit.

PSL1 Sump Structural Analysis [JT479]

The previous sump strainer system has been completely replaced by a new distributed strainer system. The new system is passive, and does not utilize backflushing. It is described in the Response to 3.j. Assurance that the strainer system is inspected for adverse gaps or breaches prior to concluding an outage is discussed in the Response to 3.i.

The new strainer system is comprised of several components. Twenty one (21) strainer modules are connected by four (4) pipe runs that terminate at a common suction manifold. The common manifold is connected to the ECCS/CSS suction inlets by piping that runs through two (2) horizontal 22-inch nominal diameter core bores in the 4 foot thick secondary shield wall. The pipe runs that connect the strainer modules and common suction manifold are 12-inch stainless steel, schedule 10S. The pipe runs that connect the common manifold to the ECCS/CSS suction inlets are 18-inch stainless steel, schedule 10S. The strainers and associated piping have been designed to withstand a crush pressure of 20 psi.[JT480] The maximum head loss with chemical precipitates experienced by the strainers is 2.32 psi as shown in Table 3.f.4-7, which is much less than the design strength for maximum differential pressure.

The system only operates once the containment is filled with water, and the entire system is fully submerged. The system is designed to vent during containment flood up, so there is no requirement to be leak tight. However, the strainer components and piping systems are designed using ASME Section III as a guide where applicable.[JT481] The component anchorages and piping supports are designed following the AISC Manual of Steel Construction.[JT482]

For purposes of describing the structural analysis, it is useful to divide the strainer system into the following components:

- Strainer modules (disks and plenums)
- Common manifold
- Piping and pipe supports
- The anchorages for the strainer plenums and manifold box
- The horizontal 22" diameter core bores through the 4'-0" thick secondary shield wall.

The strainer module and manifold element stresses were determined using the ANSYS computer program, and the allowable stresses were obtained from ASME Section III Appendices. Weld stresses for the strainer modules were evaluated by ANSYS, the Blodgett method, or hand calculation, and allowable stresses were obtained from ASME Section III Appendices. Expansion anchor load requirements were evaluated against ANSYS, specialty software, or hand calculations and evaluated using the allowable stresses.[JT483] The manifold is a box shaped structure and meets the structural design requirements. The strainer module is a more complex structure, and the structural loads and load combinations are summarized in Table 3.k.1-1 and Table 3.k.1-2

Table 3.k.1-1: PSL1 Strainer Module Loads and Load Combinations [JT484]

Load	Strainer Load Combination
1	$D + L + E_1$
2	$D + L' + E_2$
3	$D + L + T + E_1$
4	$D + L' + T + E_2$
5	$D + L + T + E'_1$
6	$D + L + L' + T_A + F_1$
7	$D + L + T_A + E'_2 + P_{CR}$

Table 3.k.1-2: PSL1 Structural Load Symbols [JT485]

Symbol	Load Definition
D	Dead Load, in air
L'	Debris Weight Submerged plus Hydrodynamic Mass
L	Live Load, Outage Maintenance Personnel
F_1	Flow Initiation Transient Momentum Load
T	Normal Operating Thermal Load
T_A	Accident Thermal Load
E_1	Earthquake Load, OBE in air
E_2	Earthquake Load, OBE in water
E'_1	Earthquake Load, SSE in air
E'_2	Earthquake Load, SSE in water
P_{CR}	Differential (Crush) Pressure

PSL1 Sump Strainer Piping and Pipe Support Analysis

The 12-inch pipe runs that connect the strainer modules and common suction manifold have specially designed pipe clamps that allow for thermal expansion. The interface and pipe support configuration for the 18-inch pipe runs are designed such that negligible loads are imposed on the ECCS/CSS guard pipes and containment penetrations.[JT486]

Piping was analyzed using hand calculations and a Sargent & Lundy (S&L) proprietary finite element modeling computer program PIPSYSW.[JT487] Pipe supports were analyzed using hand calculations. Expansion anchor base plates for pipe supports, strainer and manifold anchorages were analyzed using hand calculations and an S&L proprietary finite element modeling computer program APLAN. The core bores are qualified using hand calculations. The piping, pipe supports, anchorages and core bores were qualified using the allowable stress method. Portions of the core bore were qualified using ultimate strength design. The results of the calculation indicate the interaction ratios for the strainer, piping and supports are below 1.0, and they meet the acceptance criteria for all applicable loadings. With regard to trash racks, the GE design is robust and the trash rack function is incorporated into the strainer module design. Separate trash racks are not required. This is consistent with the original PSL1 strainer/sump design, which did not have separate trash racks.[JT488]

The piping load combination is summarized in Table 3.k.1-3 and Table 3.k.1-4. The structural qualification of the piping and supports for the piping were evaluated via separate calculations.[JT489]

Table 3.k.1-3: PSL1 Pipe Load Combinations [JT490]

Load Case	Stress Combination
Eqn. 8	DPRS + WGHT + THRU
Eqn. 9B	DPRS + WGHT + THRU +/- OBEI
Eqn. 9D	DPRS + WGHT + THRU +/- SSEI
Eqn. 10	TRN1

For the piping stress evaluations, pressure stress (DPRS), weight stress (WGHT) and thrust stress (THRU) are combined algebraically and then combined with the seismic inertia (OBEI, SSEI) load.

The connecting piping was analyzed using S&L computer program PIPSYSW. [JT491] The connecting piping was designed and analyzed in accordance with ASME III Subsection NC (Class 2 components). The analyses confirmed that the pipe stresses are below the Code allowable limits and generates the bounding loads for the supports on the East and West piping. [JT492]

Table 3.k.1-4: PSL1 Pipe Support Load Combinations [JT493]

Load Case	Stress Combination
Level A	WGHT or WGHT + THR1 or WGHT + THR2 or WGHT + THRU or WGHT + THRU + THR1 or WGHT + THRU + THR2
Level B	WGHT +/- OBEI or WGHT+ THR1 +/- OBEI or WGHT+ THR2 +/- OBEI or WGHT+ THRU +/- OBEI or WGHT+ THR1 + THRU +/- OBEI or WGHT+ THR2 + THRU +/- OBEI
Level D	WGHT +/- SSEI or WGHT+ THR1 +/- SSEI or WGHT+ THR2 +/- SSEI or WGHT+ THRU +/- SSEI or WGHT+ THR1 + THRU +/- SSEI or WGHT+ THR2 + THRU +/- SSEI

For calculating support loads, the weight (WGHT), thermal (THR1, THR2) and/or thrust load (THRU) are added algebraically and then combined with seismic loads.

PSL2 Sump Structural Analysis [JT494]

A general description of the strainers is provided in the Response to 3.j.1. Figure 3.j.1-3 and Figure 3.j.1-4 show the strainer stacks, lower plenum box, and the east and west containment recirculation piping housings. The recirculation piping housings, some of the original supporting members, and new support bracing were used in the installation of the strainer system. The new plenum box and strainer stacks are supported by this original and reinforced portion of the structural steel. As discussed below in greater detail, for structural analysis, two separate problems were evaluated using the GTSTRUDL Code: 1) the strainer stacks and their attachment to side walls and top of the plenum, and 2) the plenum box and lower piping housings were analyzed together as one integrated plenum assembly, and this is referred to as such in the balance of this discussion.

Strainer Stack Analysis:

Each stack is essentially supported independently by the tube steel/angle iron supports and can be analyzed as an individual unit. Strainer Stacks #2 through #5 and #6 are all nearly identical overhanging strainer stacks, except that Stack #6 has five fewer disks. Hence, analysis of one of the other taller overhanging stacks bounds this stack. Stacks 1, 7, and 8 are full stacks and are identical except for minor variances in the wall attachment assembly. As discussed below, two analyses were conducted, one for an overhanging stack and the second for a full stack.

The remaining potential loads for the Operating Basis Earthquake and Safe Shutdown Earthquake load combinations for the strainer system are provided in Table 3.k.1-5.

Table 3.k.1-5: PSL2 Potential OBE and SSE Load Combinations [JT495]

Load Combination	Loads	Allowable	Applicable Environmental Condition
LC1	D + L	1.0 S	Sump is dry or flooded
LC2	D + L + E	1.0 S	Sump is dry or flooded
LC3	$D + L + T_0$	1.5 S	Sump is dry or flooded
LC4	$D + L + T_0 + E$	1.5 S	Sump is dry or flooded
LC5	$D + L + T_0 + E'$	1.6 S	Sump is dry or flooded
LC6	$D + L + T_a$	1.6 S	Sump is dry or flooded
LC7	$D + L + T_a + E$	1.6 S	Sump is dry or flooded
LC8	$D + L + T_a + E'$	1.6 S	Sump is dry or flooded
D = Dead Weight Load component			
L = Live Loads			
T_0 = Thermal loads at maximum normal operating temperature			
T_a = Thermal loads at maximum accident design temperature			
E = Operating Basis Earthquake loads			
E' = Safe Shutdown Earthquake loads			
S = The required section strength based on elastic design methods and the allowable stresses			

Two load combination cases were analyzed in the GTSTRUDL strainer models to envelope the load combinations; an operating basis earthquake case and a safe shutdown earthquake case. Load Combination 4, LC4, bounds Cases 1 and 3. In order to represent LC2 and LC4 in the calculations, the ratio of the yield stresses and water densities (at 80 °F and 240 °F) are used to calculate an allowable of 1.19S.[JT496] The use of this conservative Allowable and the LC4 load case in the strainer model runs conservatively bounds the service load conditions.

Load Combination 8, LC8, bounds the factored load conditions, Cases 5 through 7, since it assumes higher temperature stresses and the earthquake stresses are higher than the operating basis earthquake. The resulting load combinations used in the analysis are provided in Table 3.k.1-6.

Table 3.k.1-6: PSL2 OBE and SSE Load Combinations for GTSTRUDL Models
[JT497]

Load Combination	Loads	Allowable	Applicable Environmental Condition
LC4	$D + L_{deb} + L_{dp} + T_0 + E_w$	1.19 S	Sump is submerged @ 120 °F
LC8	$D + L_{deb} + L_{dp} + T_a + E'_w$	1.6 S	Sump is submerged @ 240 °F
D = Dead Weight Load of strainer components			
L_{deb} = Debris Weight Live Load			
T_{dp} = Differential Pressure Live Load (across a debris covered strainer)			
T_0 = Thermal loads at 120 °F			
T_a = Thermal loads at 140 °F			
E = Operating Basis Earthquake loads			
E' = Safe Shutdown Earthquake loads			
S = The required section strength based on elastic design methods and the allowable stresses			

The strainer components are designed to meet code acceptance requirements of the AISC Manual of Steel Construction, 9th Edition, or the ASME Boiler & Pressure Vessel Code, Section III, 1971 Edition including 1973 Addenda for stainless steel. Other design and code usage for strainer components includes [JT498]

Material Strengths at Elevated Temperatures: The material properties for stainless steel materials are used at elevated temperatures associated with the load combination and are taken from ASME B&PV Code, Section II, Part D, Material Properties, 1998 Edition

Plenum Plates and Side Channels: Plate membrane stress and bending stress are evaluated following the more limiting allowable stress in AISC or NC-3821.5-1.

Stainless Steel Members in Compression: Allowable stresses for stainless steel members in compression are from ANSI/AISC-N690, and members in tension, shear, bending, or bearing are from AISC

Strainer Perforated Plates: Equations from Appendix A, Article A-8000 of the ASME B&PV Code, Section III, 1971 Edition through Winter 1973 addenda (Ref. [3]) are used to calculate perforated plate stresses.

Disk Rims: The disk rim and the attached perforated plate work as a combined section to resist bending loads and are based on the design guidelines of SEI/ASCE 8-02 Standard for Cold-Formed Stainless Steel Structural Members.

Welds: Welds for non-pressure strainer support components are qualified per the AISC 9th Edition.

Rivets: Rivet capacities are based on testing, with a factor of safety calculated according to Standard SEI/ASCE 8-02 as supplemented by AISI Specification for the Design of Cold-Formed Steel Structural Members, 1996 Edition.

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

Response to 3.k.2:

PSL1 Sump Structural Analysis

The strainer module structural qualification results are summarized in Table 3.k.2-1 and Table 3.k.2-2.

Table 3.k.2-1: PSL1 Strainer Module Stress Ratio Results [JT499]

Component	Governing Load Combination	Calculated Normal Stress (psi)	Allowable Stress (psi)	Interaction Ratio
Plenum Cover	7	5,514	22,500	0.245
Plenum Rib	7	11,971	22,500	0.532
Plenum Box	7	9,679	22,500	0.430
Plenum Joint	7	19,399	22,500	0.862
Wedge	3	10,454	19,900	0.525
Tie Rod	7	3,781	22,500	0.168
Ribs	7	7,536	22,500	0.335
Main Frame	7	7,912	22,500	0.352
Composite Plate	2	2,080	19,900	0.105
	NOTE 2	0.040	0.040	1.0
Plenum Weld	7	1,703	13,300 NOTE 3	0.128
Main Frame Weld	7	2,170	13,300 NOTE 3	0.163
Perforated Plate to Frame Weld	7	2,436	13,300 NOTE 3	0.183
Frame to Rib Weld	7	5,221	13,300 NOTE 3	0.393
Weld for beam 1 Bottom	NOTE 4	3,726	9,877	0.377
Weld for beam 2 Bottom	NOTE 4	2,569	9,877	0.260
Weld for beam 3 Bottom	NOTE 4	1,846	9,877	0.187
Weld for beam 4 Bottom	NOTE 4	1,419	9,877	0.144
Weld for beam 5 Bottom	NOTE 4	1,215	9,877	0.123
Weld for beam 6 Bottom	NOTE 4	1,169	9,877	0.118
Weld for beam 7 Bottom	NOTE 4	1,238	9,877	0.125
Weld for beam 8 Bottom	NOTE 4	1,864	9,877	0.189
Weld for beam 9 Bottom	NOTE 4	2,457	9,877	0.249
Weld for beam 10 Bottom	NOTE 4	3,040	9,877	0.308
Weld for beam 11 Bottom	NOTE 4	5,221	9,877	0.529
Weld for beam 1 Up	NOTE 4	2,584	9,877	0.262
Weld for beam 2 Up	NOTE 4	1,476	9,877	0.149
Weld for beam 3 Up	NOTE 4	988	9,877	0.100
Weld for beam 4 Up	NOTE 4	577	9,877	0.058
Weld for beam 5 Up	NOTE 4	220	9,877	0.022
Weld for beam 6 Up	NOTE 4	291	9,877	0.029
Weld for beam 7 Up	NOTE 4	395	9,877	0.040
Weld for beam 8 Up	NOTE 4	880	9,877	0.089

Component	Governing Load Combination	Calculated Normal Stress (psi)	Allowable Stress (psi)	Interaction Ratio
Weld for beam 9 Up	NOTE 4	1,413	9,877	0.143
Weld for beam 10 Up	NOTE 4	2,130	9,877	0.216
Weld for beam 11 Up	NOTE 4	3,760	9,877	0.381
Weld Between Frame Edge and Perforate Plate – Edge 1	NOTE 4	2,435.7	9,877	0.247
Weld Between Frame Edge and Perforate Plate – Edge 2	NOTE 4	1,728.7	9,877	0.175
Weld Between Frame Edge and Perforate Plate – Edge 3	NOTE 4	2,235.5	9,877	0.226
Weld Between Frame Edge and Perforate Plate – Edge 4	NOTE 4	1,180.4	9,877	0.120

Notes: 1 Stress Interaction Ratio = ASME Code Stress Limit at 300°F / Calculated Stress
2 Deflection Ratio = Deflection Limit at 240 F / Calculated Deflection
3 Allowable Stresses are per ASME Code
4 Reaction load calculated in the interface of fillet weld; based on worst-case load combination.

Table 3.k.2-2 provides the results of the enveloping strainer support anchorage and manifold anchorage.

Table 3.k.2-2: PSL1 Main Strainer Module and Manifold Support Structure Anchorage Analysis Results[JT500]

Component	Calculated Stress/Force		Code Allowable		Interaction Ratio
	Tension	Shear	Tension	Shear	
GE Strainer (Long)					
6 Anchors - ½" Bolt (3 ½" Embed)	0.803 kip	0.732 kip	1.768 kip	2.615 kip	0.734
5 Anchors - ½" Bolt (2 ¼" Embed)	0.803 kip	0.602 kip	1.19 kip	2.232 kip	0.944
Base Plate	7.933 ksi		22.5 ksi		0.353
GE Strainer (Trench)					
4 - ½" Machine Bolts (With One Oversized Bolt Hole)	0.77 kip	0.952 kip	2.761 kip	1.473 kip	0.925
Plate Bending	4.417 ksi		16.875 ksi		0.262
Bracket Plate	6.49 ksi		16.875 ksi		0.385
Concrete Anchors Mounting Brackets to Wall - ½" dis. SS bolts	0.524 kip	1.923 kip	1.768 kip	2.853 kip	0.971
1.5" Edge Distance Requirement for ½" Dia. HKB3	-	0.145 kip	-	0.291 kip	0.499
Manifold					
Manifold Bolting (embed at 5")	1.659 kip	3.353 kip	5.648 kip	7 kip	0.773
Plate Bending	11.433 ksi		16.875 ksi		0.678

PSL1 Sump Strainer Piping and Pipe Support Analysis

The piping supports were designed to AISC with allowable stresses based on the AISC manual of Steel Construction, 13th Edition (Reference 26).[JT501] In all cases the loads were applied in the direction that generated the maximum stress levels, and the analyses confirmed that the supports met the acceptance criteria.[JT502] The support analysis considered typical worst case configurations.[JT503] All other support conditions are enveloped by the analysis of these support types. The results of the calculation indicate the interaction ratios for the strainer pipe supports for 12" and 18" diameters pipe, auxiliary steel support members, straps, machine bolts, standard support components (i.e. struts and brackets), expansion concrete anchors and plates are below 1.0, and they meet the acceptance criteria for all applicable loadings[JT504].

Table 3.k.2-3: PSL1 Pipe Stress Interaction Ratios for 18" Pipe [JT505]

	Stress Eqn. (per Table 3.k.1-3)	Stresses (psi)			Interaction Ratio	
		Calculated		Code Allowable	Normal	Faulted
		Normal	Faulted			
East Piping	8	2,230	10,600	16,600	0.134	0.639
	9B	2,570	11,800	19,920	0.129	0.592
	9D	2,790	12,400	22,500	0.124	0.551
	10	210	684	27,650	0.008	0.025
West Piping	8	1,550	10,500	16,600	0.093	0.633
	9B	1,910	12,100	19,920	0.096	0.607
	9D	2,100	12,800	22,500	0.093	0.569
	10	1,170	3,800	27,650	0.042	0.137

Table 3.k.2-4: PSL1 Pipe Stress Interaction Ratios for 12" Pipe[JT506]

Stress Eqn. (per Table 3.k.1-3)	Stresses (psi)		Interaction Ratio
	Calculated Stress	Code Allowable	Normal Faulted
8	3960	16,600	0.238
9B	4670	19,920	0.235
9D	5100	22,500	0.227
10	N.A.	N.A.	N.A.

Table 3.k.2-5: PSL1 Pipe Support Interaction Ratios[JT507]

Component	Calculated Stress		Code Allowable		Interaction Ratio
	Tension	Shear	Tension	Shear	
12" typical pipe support configuration					
¾" SS HKB3	944 lbs	196 lbs	2,059 lbs	3,907 lbs	0.509
Base Plate	4.529 ksi		16.875 ksi		0.268
Weld (two vertical TS members)	0.54 kip		2.25 kip		0.237
12" Guide type Supports – lateral load only three pipes – no stiffener					
¾" SS HKB3	Ok (See Note 1)				
Base Plate	Ok (See Note 1)				
12" pipe support with 3 Guides					
½" SS HKB3	0.338 kip	0.136 kip	1.19 kip	2.232 kip	0.345
Base plate	1.203 ksi		16.875 ksi		0.071
HSS member	6.064 ksi		13.5 ksi		0.449
Weld	1.692 kip/in		3.375 kip/in		0.501
Bolts for the strap	0.0625 kip		2.761 kip		0.023
Strap	6.45 ksi		13.5 ksi		0.478
Typical Support Case 1 - 2 anchors, 1 guide					
¾" SS HKB3	Ok (See Note 1)				
Base Plate	Ok (See Note 1)				
½" SS HKB3	0.944 kip	0.196 kip	1.423 kip	2.232 kip	0.751
Typical Support Case 2 – 2 anchors only					
¾" SS HKB3	Ok (See Note 1)				
Plate	Ok (See Note 1)				
½" SS HKB3	0.803 kip	0.187 kip	1.19 kip	2.232 kip	0.759
Typical 12" Pipe Supports with 2 Guides					
½" SS HKB3	1.003 kip	0.152 kip	1.19 kip	2.232 kip	0.91
Line E Supports					
¾" SS HKB3	0.715 kip	0.499 kip	2.059 kip	1.954 kip	0.603
Base plate	6.709 ksi		16.875 ksi		0.398
¾" plate	0.51 ksi (axial)	2.404 ksi (lat)	13.5 ksi	16.875 ksi	0.18
E2- ½" SS HKB3	1.282 kip	0.362 kip	1.77 kip	2.853 kip	0.852
Base plate	3.019 ksi		16.875 ksi		0.179
E2 -Gusset plate	0.285 kip/in		2.2 kip/in		0.13
18 in. Pipe East-West Supports					
Node 32 East – 1" C/S HKB3	2.439 kip	0.868 kip	5.155 kip	3.229 kip	0.742
Node 32 East –base plate	13.006 ksi		23.925 ksi		0.544
Node 32A East – ¾" SS HKB3	2.486 kip	1.143 kip	5.155 kip	3.229 kip	0.836
Node 32A East – base plate	21.159 ksi		23.925ksi		0.884
Node 32 East- Weld	1.451 kip/in		3.987 kip/in		0.364

Component	Calculated Stress		Code Allowable		Interaction
Node 60 East – weld check	1.533 kip/in		3.987 kip/in		0.385
Support CS-197-R4 (Node 60 East)					
TS 5x5x3/8	11.146 ksi		19.14 ksi		0.582
¾" CS HKB3	1.488 kip	0.529 kip	3.065 kip	5.013 kip	0.591
Base plate	8.081 ksi		23.925 ksi		0.338
2- 2" Welds	2.001 kip		9.844 kip		0.203
Bracket to 5x5x1/2 plate	1.742 kip/in		3.712 kip/in		0.469
Node 92 West – ¾" C/S HKB3	1.703 kip	1.006 kip	2.513 kip	4.978 kip	0.88
Node 92 West – base plate	12.974 ksi		23.9375 ksi		0.542
Node 40 West – ¾ C/S HKB3	1.674 kip	0.187 kip	2.513 kip	4.978 kip	0.704
Node 40 West – base plate	8.927 ksi		23.9375 ksi		0.373
Node 60 West – ¾" C/S HKB3	0.755 kip	0.083 kip	2.513 kip	5.353 kip	0.317
Node 60 West – base plate	4.029 ksi		23.9375 ksi		0.168
Node 45 East – ¾" C/S HKB3	1.278 kip	0.57 kip	2.513 kip	4.978 kip	0.623
Node 45 East – base plate	6.814 ksi		23.9375 ksi		0.285
Support WM-388-H7					
4x4x1/4 TS (bending)	0.94 ksi		23.76 ksi		0.04
4x4x1/4 TS (shear)	0.27 ksi		14.4 ksi		0.019
3/16" fillet	0.109 in		0.1875 in		0.58
W6x20 Aux Steel (bending)	4.195 ksi		21.6 ksi		0.194
½" A307 Bolts (shear)	1.508 kip		4.712 kip		0.32
3/16" Weld – W6x20	1.663 kip/in		2.7 kip/in		0.616
3/16" Weld – W8x17	1.163 kip/in		1.65 kip/in		0.705
L3x3x3/8 Clip Angle (shear)	2.011 ksi		14.4 ksi		0.14
L3x3x3/8 Clip Angle (bending)	4.525 ksi		21.6 ksi		0.21
Weld at 60 and 32 to W6x20	1.911 kip/in		3.712 kip/in		0.515
W8x17(bending)	9.973 ksi		21.6 ksi		0.462
W8x17 (shear)	2.533 ksi		14.4 ksi		0.176
5/8" A307 bolts	1.778 kip		6.14 kip		0.29
3/16" weld to W8x17 anchor plate	1.471 kip/in		2.7 kip/in		0.545
5/8 Phillips red head anchors	0.5534 kip		1.2 kip		0.461
Support CS-191-R1 and CS-192-R1					
Stitch welds	1.29 kip/in		3.19 kip/in		0.404

Component	Calculated Stress		Code Allowable		Interaction
HSS 3x3x1/4 (Axial)	2.898 ksi		18.343 ksi		0.158
CEA at Anchor 3	1.25 kip	1.293 kip	3.805 kip	5.013 kip	0.587
Base plate	10.16 ksi		23.9 ksi		0.425
Support CS-196-R3					
¾" CS HKB3	1.25 kip	1.063 kip	3.065 kip	3.907 kip	0.68
Base plate	13.33 ksi		23.925 ksi		0.557
Tube member (bending)	11.746 ksi		25.2 ksi		0.466
Weld to base plate	0.051 in		0.218 in		0.236
WM-388-H4 and WM-391-H1					
½" SS HKB3	0.2 kip	0.212 kip	1.768 kip	2.853 kip	0.188
Base plate (bending)	0.446 ksi		16.5 ksi		0.027

Note 1: The results of evaluations for this type of supports with three lines produced conclusions identical to those of the evaluation of 3D supports with three lines. A modification consisting of providing additional plate stiffener was required for this support type. Subsequent finite element models were run in S&L APLAN software for the 3D supports with stiffeners added to the plates to reduce the interaction ratio to less than 1.

PSL2 Sump Structural Analysis

Each stack is essentially supported independently by the tube steel/angle iron supports and can be analyzed as individual units. The disk faces, gap disks, gap rings, grill wire stiffeners, and end cover, are not included in the models (except for their mass). The interaction ratios for the components in the models are provided in Table 3.k.2-6. The results of this calculation indicate the interaction ratios for the strainer assembly components are below 1.0, and that the strainers meet the acceptance criteria for all applicable loadings.

Table 3.k.2-6: PSL2 Interaction Ratios for Strainer Assembly Components Results

[JT508]

Strainer Component	Governing Load Combination	Calculated (psi)	Allowable (psi)	Interaction Ratio
Intermediate Radial Stiffeners	**LC8-SSE**	20,632	28,656	0.72
Tension Rods	**LC8-SSE**	16,277	22,925	0.71
Spacers	**LC8-SSE**	24,210	25,217	0.96
Edge Channels	**LC8-SSE**	9,820	27,280	0.36
Core Tube (Biggest Holes)	**LC8-SSE**	2,700	30,000	0.09
Core Tube Mating Flange	**LC8-SSE**	3,725	28,656	0.13
Hex Couplings	**LC8-SSE**	6,113	76,416	0.08
Clip Angles	**LC8-SSE**	12,003	27,280	0.44
Vertical Angle Iron (support)	**LC8-SSE**	21,205	28,656	0.74
Tube Steel (support)	**LC8-SSE**	3,940	43,782	0.09

Strainer Component	Governing Load Combination	Calculated (psi)	Allowable (psi)	Interaction Ratio
Disk Faces	**LC4-OBE**	17,520	29,340	0.60
Disk Rims	**LC8-SSE**	8,023	22,925	0.35
Wire Stiffener	**LC8-SSE**	28,930	57,312	0.50
Gap Disk (enveloping sleeve B)	**LC4-OBE**	3,520	29,340	0.12
Gap Disk stiffening ring	**LC8-SSE**	4,872	28,656	0.17
Sleeve C (enveloping sleeve A)	**LC8-SSE**	2,580	28,656	0.09
End Cover	**LC8-SSE**	3,710	28,660	0.13
Weld of Core Tube to Mating Flange	**LC8-SSE**	50	481	0.10
Weld of Tube Steel to Vertical Angle Iron	**LC8-SSE**	3,920	4,455	0.88
Weld of Tube Steel to Sump Wall Steel Plate	**LC8-SSE**	1,960	5,440	0.36
Clip Angle Bolts	**LC8-SSE**	3,576	27,510	0.13
Disk Face Rivets	**LC8-SSE**	203	1,141	0.18
Gap Disk Rivets	**LC4-OBE**	93	1,141	0.08
Sump Wall Steel Embedment Plate	**LC8-SSE**	6,000	7,950	0.75

Integrated Plenum Analysis:

The interaction ratios for the components in this model are provided in Table 3.k.2-7. The results of this calculation indicate the interaction ratios for the plenum components are below one, and that the strainers meet the acceptance criteria for all applicable loadings.

Table 3.k.2-7: PSL2 Interaction Ratios for Plenum Assembly Components Results[JT509]

Plenum Component	Governing Load Combination	Calculated (1) (psi)	Allowable (1) (psi)	Interaction Ratio
Channel Box Channels	**LC8-SSE**	15,127	22,920	0.66
Spacer Rods inside Plenum	**LC8-SSE**	5,820	20,810	0.28
Angle Framing	**LC8-SSE**	21,750	22,920	0.95
Support Plate Beams	**LC8-SSE**	5,445	28,660	0.19
W8x31, C.S.	**LC8-SSE**	5,600	31,140	0.18
Tube Steel Posts	**LC8-SSE**	3,920	43,780	0.09
Internal Pipe Posts	**LC8-SSE**	12,900	17,020	0.76
Stiffener Plates	**LC8-SSE**	21,530	22,920	0.94
Lower Internal C-shape Braces	**LC8-SSE**	7,793	22,920	0.34
Top Cover, Bottom Cover, Side Plates	**LC8-SSE**	26,365	28,660	0.92
Plenum Channel Web	**LC8-SSE**	16,909	28,660	0.59
Angle Local Flange	**LC8-SSE**	3,150	28,660	0.11
Plenum Channel Local Flange	**LC8-SSE**	8,870	28,660	0.31
Channel Splice Bolt	**LC8-SSE**	15,200	27,610	0.55
Channel Splice Weld & Plate	**LC8-SSE**	15,845	22,920	0.69
Channel Corner Welds	**LC4-OBE**	8,758	15,910	0.55
Cover Plate Bolts	**LC4-OBE**	17,810	18,730	0.95
Cover Plate Hole Patches	**LC8-SSE**	50,280	55,260	0.91
Support Plate Bolts	**LC8-SSE**	21,490	27,610	0.78
Stiffener Angle End Bolting	**LC4-OBE**	18,490	18,730	0.99
Tube Steel End Welds	**LC8-SSE**	4,200	23,760	0.18
Support Plate-to-Plate Welds	**LC8-SSE**	8,050	22,920	0.35
Angle-to-Channel Welds	**LC4-OBE**	5,720	15,910	0.36
Channel Brace-to-Angle Welds	**LC4-OBE**	7,096	15,910	0.45
Corner Angle to Lower	**LC8-SSE**	7,960	22,920	0.35

Plenum Component	Governing Load Combination	Calculated [(1)] (psi)	Allowable [(1)] (psi)	Interaction Ratio
Angle Weld				
Horizontal Angle to Angle Weld	**LC4-OBE**	12,400	15,910	0.78
Vertical Angle at Ledge to Lower Angle Weld	**LC4-OBE**	2,328	15,910	0.15
Stiffener Angle to Plate Weld	**LC4-OBE**	6,784	15,910	0.43
Stiffener Plate to Plate Weld	**LC4-OBE**	6,120	15,910	0.38
Plenum Flow Deflector	**LC4-OBE**	8,940	22,500	0.40
Concrete Expansion Anchors 1a	**LC8-SSE**	1,270	1,740	0.73
Concrete Expansion Anchors 2	**LC8-SSE**	880	1,800	0.49
Embedment Plate W2 on Ledge	**LC4-OBE**	1,035	7,950	0.13
Corner Angle / Bolt at Ledge	**LC8-SSE**	18,320	28,660	0.64
Embedment Plate South Wall	**LC8-SSE**	3,350	7,950	0.42
WT6x13.5, C.S., Existing	**LC8-SSE**	8,580	23,760	0.36

Footnotes: (1) Calculated and allowable values are calculated for the most governing stress component (i.e., axial or bending, etc) per AISC manual 9th Edition;

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:

The PSL1 strainer system is no longer protected by the secondary biological shield wall as was the original sump screen. Analyses and walkdowns have been performed which confirm that the strainer modules, interconnecting piping, manifold and appurtenances are not subject to HELB jet impingement, pipe whip or missiles. The analyses assumed a HELB ZOI of 10D. The approved "leak-before-break" methodology was used to eliminate the RCS loops from consideration. Therefore, dynamic effects due to breaks in the RCS loops were not considered in the structural analysis/design of the strainer system. Main steam and feedwater piping were eliminated from review because breaks in these lines do not require the plant to enter into recirculation mode.[JT510]

The PSL2 Strainer Assemblies are located outside of the concrete biological shield and are therefore not subject to pipe reaction forces or high energy line break jet loads from Reactor Coolant System or other ASME Code Class 1 piping. An evaluation of the ASME Code Class 2 and 3 piping in the general area of the strainers determined that there were no high energy line breaks that would result in a LOCA and require reliance on the strainer system. A two inch charging pump line that was located along the wall, did qualify as a high energy line. However, break cone analysis of the line shows no direct impact on the strainer assemblies. Hence, it was determined that the structural load analysis of the Strainer Assemblies did not require consideration for pipe reaction loads or high energy line jets. Since the strainer system is outside the biological shield wall and down in the containment sump, there is no potential missile hazard from pipe breaks. It is further noted that the strainer assemblies are passive and do not employ mechanical or hydraulic cleaning or flushing following a LOCA, hence, there are none of these forces on the strainers.[JT511]

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:

Backflushing of the sump strainers, or any other active approach, is not credited at PSL1 or PSL2;[JT512] therefore, no structural analysis considering reverse flow is required.

3.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
- Secondary Shield Wall
- ECCS Trench
- Containment Spray Washdown
- Upstream Blockage Points Walkdown

Refueling Canal

The refueling canal is drained by two 6" diameter drains located in sidewalls centered at the 22' elevation (centerline is 6" above the refueling canal floor), and one 3" diameter floor drain at the bottom of the canal.[JT513] These drains do not have a protective screen and the bottom of the sidewall drains are 3" above the refueling canal floor.[JT514] Any sprays falling directly in the refueling canal must flow through the refueling canal drains.

Because of the size and location, the 3" floor drain does have the potential for blockage; however, the orientation of the two 6" side drains makes it difficult for debris to block flow through these drains.[JT515] Therefore, water is expected to flow freely from the refueling canal through the two 6" drains in the sidewall. The sidewall drains are about 6' in length (they go directly through the cavity wall and drain on the other side).[JT516]

Secondary Shield Wall

The lower containments at both PSL1 and PSL2 consist of two compartments – the containment area inside the secondary shield wall and the annulus outside the secondary shield wall. The area inside the secondary shield wall is connected to the annulus by a number of keyways and walkway openings that penetrate the secondary shield wall through much of the circumference of containment.[JT517]

At PSL1, the strainer modules are placed around containment in or near the secondary shield wall keyways, and in the 12' Elevation ECCS trench in the annulus of containment. The keyways around containment would not be a potential upstream blockage point since the water would reach the strainers in the keyways or in the ECCS trench by the various trenches that connect from inside the secondary shield wall to the annulus around containment.[JT518]

At PSL2, trash racks cover the keyways.[JT519] The strainer is located in the ECCS trench (bottom elevation of plenum is 11'-0".[JT520] Water would not get held up inside the secondary shield wall since it would be able to flow to the strainer through the various trenches that connect from inside the secondary shield wall to the annulus around containment.

ECCS Trench

Since the majority of the strainers at PSL1 are not located directly in the ECCS trench, this is not a potential upstream blockage point at PSL1.

There are 20 trash racks located at the secondary shield wall on the 18-foot elevation in the keyway openings. ECCS flow from an RCS break would travel through these racks and dump into the ECCS trench that has a bottom elevation of approximately 12 feet. The trash racks prevent large debris from entering the ECCS trench and transporting to the recirculation sump screens. The strainer system is open to the ECCS trench on both ends of the containment recirculation sump. The openings in the trash racks between the steel bars are approximately ¾-inch. A calculation was performed which estimated the flow rate, from the 18-foot elevation through the trash racks, at approximately 0.04 ft/sec. At this low flow rate it would be difficult for large debris to even reach the trash racks. Because of the large size of the racks, the low approach velocity, the quantity of them, and the relatively large size of the openings between slats, debris could not fully block all of the trash racks and prevent the flow of water past the shield wall into the ECCS trench.[JT521] There is also a direct flow path from the inner annulus via a portal (i.e. personnel access opening) directly into the sump and grated areas above the sump from the 23' elevation.[JT522]

Furthermore, in the long-term recirculation mode, only one CS pump would be operating and much of this spray flow would enter the sump from the 23' floor elevation outside of the secondary shield wall, bypassing the trash racks. Hence, for long term cooling out of the break location, flow across the 18-foot floor elevation would be limited to the HPSI pumps and a portion of one CS pump. With the minimum sump level for a LBLOCA, flow into the ECCS trench is not expected to be impeded at the trash racks. Large debris would likely gather at the bottom of the trash racks, allowing continued flow through the higher part of the racks.[JT523]

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 that allows the water to pass.

A complete evaluation of the containment CAD model, along with a review of the CFD model, indicated that no significant flow paths would become blocked with debris and hold up water during the sump recirculation phase.[JT524]

Upstream Blockage Point Walkdowns

Walkdowns were conducted in both PSL1 and PSL2 containment buildings, specifically to evaluate ECCS recirculation flow paths [JT525]to support the conclusions previously stated above. The walkdowns utilized the guidance in NEI 02-01, NEI 04-07 Volume 1, and the NRC SE on NEI 04-07.

The information obtained during the walkdowns confirmed that water would not be held up by choke points or otherwise prevented from reaching the ECCS strainer systems.[JT526]

Special attention was paid to the refueling canal, which is drained by two 6-inch nominal diameter pipes, to support the conclusions previously stated above. These pipes are oriented horizontally with the bottom of the pipe approximately 3 inches above the refueling canal floor. They are not screened or capped. Because of the size and orientation of these drain pipes they will not create a choke point that would retain water in the refueling canal. However, because the pipes are 3 inches above the floor, it is assumed that the water below 3 inches was held up and does not reach the sump.[JT527]

Other specific NEI and NRC concerns that were addressed in the walkdown are itemized below.

- All passages have sufficient flow clearances such that choke points are not expected.[JT528]
- Curbs and ledges within the flow paths were found to be unable to retain water from returning to the sump area. Curbs at upper elevations had at least one open side to allow the free flow of water to the ground floor.[JT529]
- No potential choke points were observed at upper elevations, including floor grates, which would be expected to retain fluid from reaching the containment floor.[JT530]
- The containment floor was surveyed for choke points formed by equipment, components and other obstructions. Where equipment congestion did occur, other flow paths were available so as to not restrict water flow.[JT531]
- At PSL1, there are no gates or trash racks in the recirculation flow paths (including the ECCS trench).[JT532]
- At PSL2, the ECCS trench contains a significant amount of piping and pipe supports in some areas. Since the ECCS trench is protected from the intrusion of large debris by the trash racks on the 18' elevation, the ECCS trench is not expected to be clogged by debris. There is also a direct flow path from the inner annulus via a portal (i.e. personnel access opening) directly into the sump and grated areas above the sump from the 23' elevation.[JT533]
- At PSL2, scaffold and lead blanket storage boxes located on the 23' elevation were identified to have no significant impact on flow modeling and do not create any new chokepoints due to their location and construction.[JT534] Note that these were modeled in the CAD model of containment[JT535]and therefore, were analyzed in the debris transport calculation since the CAD model was input into the CFD model.

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

Response to 3.I.2:

Per the Response to 3.I.1, no measures were necessary to mitigate potential choke points.

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

Response to 3.I.3:

Per the Response 3.I.1, there are not any significant curbs or debris interceptors that would hold up water at PSL1 or PSL2. Therefore, no evaluation was performed.

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:

Per Response to 3.I.1, the refueling canal drains were evaluated as a potential upstream blockage point. It is concluded that because the bottom of the two 6" diameter sidewall drains are 3 inches above the refueling canal floor, the orientation does not allow for flow to be blocked from the 6" refueling canal drains once the 3-inch water level is reached assuming the horizontal 3" refueling canal floor drain is blocked by debris.

3.m. Downstream Effects – Components and Systems

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

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 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:

PSL1 and PSL2 performed evaluations to address ex-vessel downstream effects in accordance with WCAP-16406-P-A (Reference 27)[JT536] and the NRC SE (Reference 6)[JT537]. The limitations and conditions provided in the NRC SE were addressed as part of the evaluations and it was shown that the WCAP-16406-P-A methodology was appropriate for use at PSL1 and PSL2. All refinements or modifications that were applied to the WCAP-16406-P-A methodology are described below.

The following methodology was employed in the ex-vessel downstream effects evaluations at PSL1 [JT538]and PSL2.[JT539]

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 screens were addressed within the downstream effects evaluations. Each unit has screens with a nominal hole diameter of 1/16 inches.[JT540] The adequacy of the sump screens' mesh spacing or strainer hole size was conservatively addressed by assuming that the maximum spherical size of particulate debris that can pass through the strainer is 0.100 in. The actual maximum spherical size particulate that is expected to pass through the strainer system and into the ECCS and CSS recirculation flow paths is documented as 0.066 inches for PSL1 and 0.06875 inches for PSL2.[JT541]

Additionally, the maximum quantity of fines debris transported to the sump strainers for each debris type was assumed. Of these maximum quantities, 100% of fiber, Cal-Sil, qualified coatings, and latent particulate that are generated and transported as fines were assumed to bypass the strainer. For unqualified coatings, the size distribution presented in WCAP-16406-P-A (Reference 27 p. Appendix I) [JT542]was used to determine what percentage of debris was small enough to bypass the strainer. For RMI, the size distribution presented in Appendix VI of the NRC SE on NEI 04-07 (Reference 6) [JT543]was curve fit [JT544]and applied to determine the percentage of debris small enough to bypass the strainer.[JT545]

An inspection procedure is in place to ensure that adverse gaps or breaches are not present on the screen surface that would invalidate the previously stated assumptions.[JT546]

Initial Debris Concentrations

Initial debris concentrations were developed using the assumptions and methodology described in Chapter 5 of WCAP-16406-P-A (Reference 27)[JT547]. For PSL1, the total maximum initial debris concentration was determined to be 2,398.43 ppm, with fiber debris contributing 347.55 ppm, and particulate and coatings debris contributing 2,050.88 ppm.[JT548] For PSL2, the total maximum initial debris concentration was determined to be 1,780.78 ppm, with fiber debris contributing 382.53 ppm, and particulate and coating debris contributing 1,398.24 ppm.[JT549] Note that the quantities of transported debris at PSL1 and PSL2 have been revised since the debris concentrations above were calculated and used to evaluate downstream effects. It was determined that the revised transported debris quantities would result in lower debris concentrations. Therefore, the downstream effects evaluations performed using the concentrations above are conservative and acceptable for use in the resolution of GSI-191.[JT550]

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-laden recirculation flow were considered. Documents used for this effort included piping and instrumentation diagrams (P&IDs), and other plant documents as applicable.[JT551]

The components within the recirculation flow-paths were categorized as either "smaller", "further evaluation required", "larger", or "excluded". The "smaller" category contains components with flow clearances known to be physically too small to pass the debris.[JT552] The "further evaluation required" category includes components that are determined by industry guidance to have the potential to become plugged under debris loading.[JT553] The "larger" category includes components with clearances sufficiently large enough to pass recirculation debris without causing blockage, and the "excluded" category contains components for which industry guidance suggests are not susceptible to debris blockage.[JT554]

Component Blockage and Wear Evaluations Methodology

All component evaluations were performed based on WCAP-16406-P-A (Reference 27)[JT555]. Components addressed in the evaluations include pumps, heat exchangers, orifices, flow elements, spray nozzles, instrumentation tubing, system piping, and valves required for the post-LOCA recirculation mode of operation of the ECCS and CSS.[JT556] The evaluations included the following steps:

- Identifying all components in the ECCS and CSS recirculation flowpaths (see Flowpaths and Alignment Review above) (Reference 27).[JT557]
- 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 the free-flowing abrasive wear model and Archard abrasive wear model. Each model was used as appropriate in the evaluations.[JT558]
- Applying the appropriate erosive wear model for heat exchangers, orifices, flow elements, spray nozzles, system piping, and valves.[JT559]
- Determine which components may not meet the performance and/or integrity requirements over the mission life due to erosion or plugging and require further evaluation and possible replacement (Reference 27 pp. 8-21)[JT560].
- 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.[JT561]

- Evaluating the potential for debris sedimentation inside system piping, heat exchanger tubing and valves that move or reposition during post-LOCA recirculation phase (and must go fully closed) by comparing operating line velocity to minimum line velocity required to avoid sedimentation (0.42 ft/s).[JT562]
- Evaluating the potential for debris collection in the instrument sensing lines.[JT563]

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/CS pumps

The evaluation for pumps addressed the effects of debris ingestion through the sump screen on three aspects of operability: hydraulic performance (flow rate degradation), mechanical-shaft seal assembly performance (external leakage), and dynamic performance (vibration).[JT564] For both PSL1 and PSL2, the hydraulic and dynamic performance of the ECCS and CS pumps were determined to not be negatively affected by the recirculating sump debris.[JT565] None of the ECCS or CS pumps have cyclone separators in the seal injection/seal cooling lines. The HPSI pumps at both units, as well as the CS pumps at PSL2 previously had cyclone separators installed in the seal cooling supply lines. However, these pumps have since been modified to use closed-cycle cooling systems. All ECCS and CS pumps now use an API Plan 23 piping arrangement, which precludes the injection of debris laden post-LOCA fluids into the seal cavity chamber.[JT566] The mechanical shaft seal assembly performance evaluation found that the CS pumps for PSL1 have carbon backup bushings. However, engineering justification was provided after the seal cooling modifications described above for the continued use of the CS pumps' carbon backup bushings at PSL1 based on the closed-cooling loop system precluding the introduction of debris.[JT567] The CS pumps for PSL2 have backup bushings made of bronze material, and are therefore acceptable.[JT568]

When evaluating pump wear as part of the hydraulic performance evaluation, a modification to the WCAP-16406-P-A methodology was used to refine the distribution of abrasive versus erosive particulate debris. WCAP-16406-P-A considers 50 microns to be the constant lower threshold size for abrasive debris (which is equal to 40% the smallest radial running clearance of the hypothetical pump considered therein) (Reference 27 pp. F-26)[JT569]. The PSL1 and PSL2 analyses used 40% the actual wear ring gap at any given time to define the threshold for abrasive-sized particulate. In other words, as the wear ring gap opens due to wear over time, the threshold size for abrasive debris increased and the amount of abrasive debris is reduced. However, the amount of abrasive debris that was reduced was assumed to contribute to erosive wear.[JT570]

The evaluation for pumps determined that the effects of debris ingestion through the screen is not an issue with regard to hydraulic performance, mechanical-shaft seal assembly performance, and dynamic performance.

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 (Reference 27 pp. 8-28)[JT571]. Table 3.m.2-1 and Table 3.m.2-2 are 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 Guided)	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 (Reference 27 pp. Table 8.2-2, p 8-27)[JT572]

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

Valves were evaluated for blockage in the downstream effects evaluations. Valves that were determined to be "larger" or "excluded" did not warrant further evaluation, but those valves identified as "further evaluation required" received a more detailed evaluation.[JT573] It was determined that all valves passed the acceptance criteria for the blockage evaluation. There were no valves in the "smaller" category.[JT574]

Valves were evaluated for debris sedimentation. Valves identified as "larger" or "excluded" did not require additional analysis, but valves identified as "further evaluation required" were analyzed further. The line velocities for all valves analyzed was found to be greater than 0.42 ft/s, thus, debris sedimentation was not an issue. There were no valves in the "smaller" category.[JT575]

Valves were screened to determine if an evaluation of the wear impact was required. It was determined that none of the valves in the post-LOCA recirculation flow path are manually throttled, and therefore did not require a calculation to determine the extent of erosion.[JT576]

ECCS/CSS Heat Exchangers, Flow Restrictions, and System Piping

Heat exchanger tubes, flow restrictions, and system piping were evaluated for the effects of erosive wear for the initial debris concentrations presented in the Response to 3.m.1 over the mission time of 30 days. The erosive wear on these components was determined to be insufficient to affect system performance.[JT577]

The smallest clearance found for PSL1 and PSL2 heat exchangers, orifices, flow elements, spray nozzles, and system piping in the recirculation flowpaths that were not categorized as "excluded" is 0.152 inches for the PSL1 LPSI pump seal cooler.[JT578] The maximum diameter of downstream debris was conservatively assumed to be 0.100 inches. Therefore, no blockage of the flowpaths is expected.[JT579]

System piping and heat exchanger tubing was evaluated for plugging based on system flow and material settling velocities. For all piping and heat exchanger tubing, 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 and heat exchanger tubing passed the acceptable criteria for plugging due to sedimentation.[JT580]

ECCS/CSS Instrumentation Tubing

Instrumentation tubing (or sensing lines) was evaluated for debris settling from the process streams. Instrument tubing is designed to remain water solid without taking flow from the process stream (Reference 27 p. Section 8.6.6)[JT581]. 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. It was found that all instruments identified as required post-LOCA are located either on the top or side of the applicable headers. This also 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.[JT582] An evaluation of the effects of debris laden recirculation fluid on the reactor vessel level monitoring system (RVLMS) was also performed, and it was determined that RVLMS is acceptable.[JT583]

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

Response to 3.m.3:

The only plant design change made in response to the downstream effects evaluations was the redesigning of the CS pump seals for PSL2 and the HPSI pump seals for both PSL1 and PSL2.[JT584] The previous seal cooling systems relying on process water with a cyclone separator were replaced with a closed-cycle seal systems that utilize recirculated seal cavity fluid.[JT585]

The only operational change made related to downstream effects was that inspection requirements were updated for the new strainer system. Inspection of the strainer system requires verification of maximum strainer equipment gaps to meet new specifications to maintain debris bypass size limits, and inspection now includes new strainer system piping and manifolds in addition to the strainer filtration surface.[JT586]

3.n. Downstream Effects – Fuel and Vessel

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

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

Response to 3.n.1:

In-vessel downstream effects for PSL1 and PSL2 were evaluated per the methodology and acceptance criteria in WCAP-16793-NP, the associated NRC SE, WCAP-17788-P, and WCAP-17788-NP. The evaluation included the following:

1. PCT due to deposition of debris on fuel rods (WCAP-16793-NP).
2. 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).

For both units, 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 for each unit as it was used to inform the WCAP evaluations.

PSL Fiber Penetration Testing

PSL1 and PSL2 both conducted fiber penetration testing in 2015.[JT587] The purpose of the testing was to collect time-dependent fiber penetration data of the prototypical strainers for each unit. For each unit, at least one large-scale test was conducted with test parameters selected to be representative of the most conservative conditions (temperature, flow rate, and water chemistry). The test results were used to derive a model to quantify fiber penetration for the PSL1 and PSL2 strainers at their respective plant conditions. The penetration test is described for each unit in the sections below.[JT588]

PSL1 Test Loop Design

The test loop used for penetration testing was the same loop used for head loss testing (described in the Response to 3.f.4), except for one difference in configuration: in penetration testing, one of two available in-line filters was always online. The loop included a metal test tank that housed a test strainer. Water was circulated by a pump through the test strainer, a fiber filtering system, and various piping components. The test tank was rectangular, as shown in Figure 3.n.1-1. Debris was introduced in the high-agitation regions on both sides of the strainer in order to model both the front and rear debris approach paths to the strainer. These regions were equipped with 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 and the surrounding acrylic boxes imitated the gaps between the PSL1 strainer modules and the keyway walls that surround them. Additionally, the obstructing pipe modeled one of the three plant strainer suction pipes that can pass in front of the plant strainer modules. Both the size of the obstructing pipe and its position relative to the test module were modeled prototypically.[JT589]

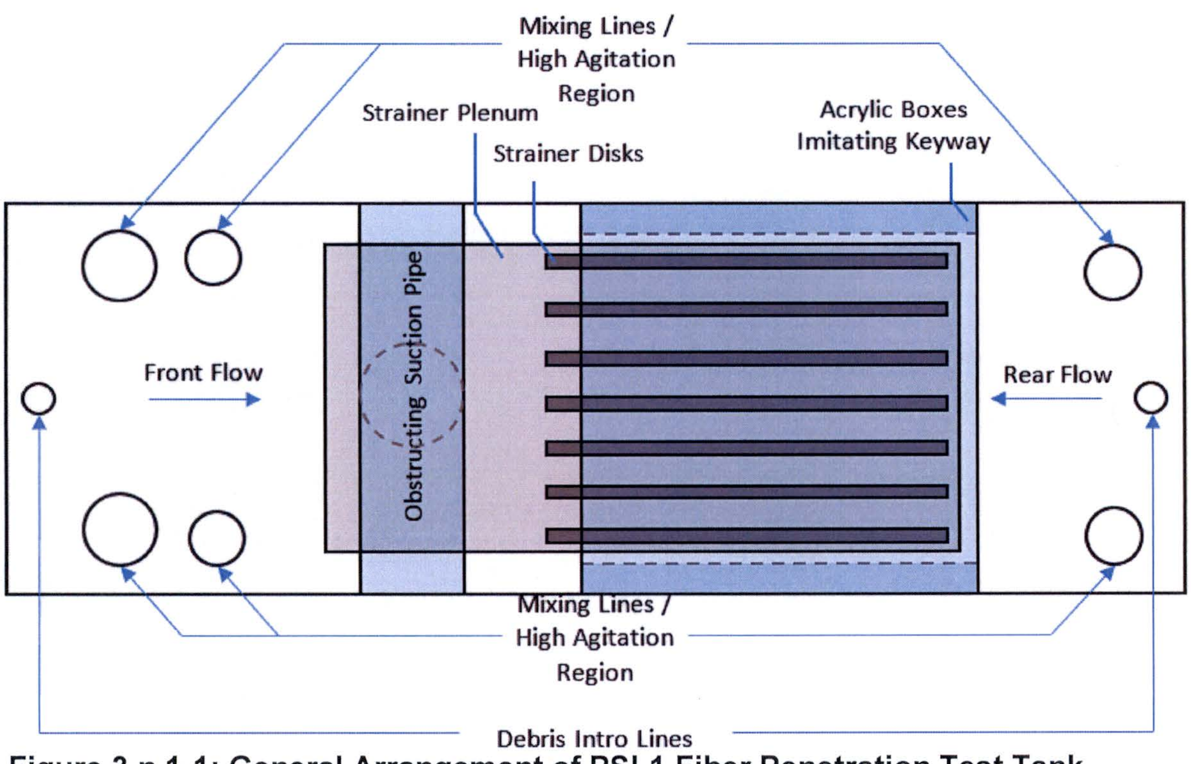

Figure 3.n.1-1: General Arrangement of PSL1 Fiber Penetration Test Tank

The effectiveness of the agitation regions is displayed 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 PSL1 Fiber Transport[JT590]

Test[1]	Fiber Size	Gross Fiber Added (g)	Non-Transported Fiber (g)	Net Fiber Added (g)	% of Fiber Transport
Low Flow	Fines	7,287.70	3.05	7,284.65	99.96%
High Flow	Fines	7,287.44	0.84	7,286.60	99.99%

[1] The test shown corresponds to the name assigned to each test in the PSL1 fiber penetration test report.

PSL1 Test Strainer

The test strainer for penetration testing was a prototypical strainer module [JT591]that matched the key design parameters of the most common plant strainer modules (as described in the Response to 3.f.4). The test strainer was similar to that used in head loss testing with the only difference that every other disk of the module was removed for penetration testing, such that only 7 of the 13 disks were installed on the module.[JT592] This modification more than doubled the gap between adjacent disks to prevent a fiber bridge from developing across adjacent disks. This promoted fiber penetration by preserving penetrable strainer area. The plenum slots corresponding to the removed disks were capped to prevent a path for flow to bypass the remaining perforated strainer disks. [JT593]

PSL1 Debris Types and Preparation

Nukon and Temp-Mat were both used in testing.[JT594] This is appropriate because the only other types of fibrous debris in containment are LDFG, Thermal Wrap, and latent fiber, which all have similar characteristics to Nukon.[JT595]

All fiber fines were prepared according to the NEI protocol (Reference 8)[JT596] following the same procedures used for the head loss tests. Preparation of Nukon and Temp-Mat debris was performed separately. Nukon sheets, with an overall thickness of 2 inches, were baked single-sided until the binder burnout reached into approximately half the thickness. The heat-treated sheets were then cut up into approximately 2"x2" cubes and weighed out according to batch size. Nukon was then pressure-washed with test water following the NEI protocol. Temp-Mat was pre-shredded by the debris vendor and heat treated at the test vendor's facility.[JT597] Temp-Mat batches were prepared with equal parts of heat-treated and un-treated Temp-Mat. Temp-Mat was then pressure-washed in the same manner as the Nukon debris. Figure 3.n.1-2 shows the prepared Nukon and Temp-Mat fines after pressure washing.

Figure 3.n.1-2: Nukon Fines (Left) and Temp-Mat Fines (Right) Prepared for PSL1 Penetration Testing [JT598]

After each debris type was separately pressure-washed, the Nukon and Temp-Mat prepared for each batch were combined and stirred to form a homogeneous mixture before introduction.

PSL1 Debris Introduction

Fine debris was introduced in four separate batches of increasing batch size for each test.[JT599] The maximum fiber fines debris load of a 10.126", 30", and 42" break was bounded by the cumulative fiber load of the first, third, and fourth batch, respectively, where the 30" and 42" break loads were bounded with a 10% margin .[JT600]

The first and fourth batches resulted in theoretical uniform bed thicknesses of 0.067" and 0.386", respectively. The first batch consisted only of Nukon.[JT601] Since Nukon penetrates more readily than Temp-Mat or a mixture of the two,[JT602] this was more conservative than using the debris composition representative of the maximum 42" break (approximately 10% Temp-Mat). Further, the effect of this conservatism was maximized since Nukon was introduced at the clean strainer condition, when penetration is the highest. Temp-Mat was added in the remaining batches [JT603]to achieve a final fine fiber composition that was representative of the maximum 42" break.[JT604]

Fine fiber debris was introduced to the front and rear sides of the test tank via a front and rear debris hopper,[JT605] respectively. Each batch was split evenly between the two sides of the strainer.[JT606]

Debris was added to the hopper by using 5 gallon buckets to transfer the debris slurry from the barrel to the debris hopper. During this process, the debris slurry was stirred to promote a homogeneous mixture in the barrel. Additionally, the debris added to the hopper and transported into the tank was stirred, as necessary to break up any agglomeration of fibers that formed.[JT607]

For each batch, the debris introduction rate was controlled to maintain a prototypical debris concentration in the test tank.[JT608]

PSL1 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.[JT609]

Fibers that passed through the strainer were collected by the in-line filters downstream of the test strainer and upstream of the pump.[JT610] All of the flow downstream of the strainer travelled through the 5-micron filter bags before returning to the test tank.[JT611] The capture efficiency of the filter bags was verified to be above 97 percent.[JT612] The filtering system allowed the installation of 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.[JT613]

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.[JT614] When processing the filter bags, in either a 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.[JT615] This process was repeated for each bag until two consecutive bag weights were within 0.05 g of each other.[JT616]

A clean set of filter bags were placed online before a debris batch was introduced to the test tank, and were left online for a minimum of three pool turnovers (PTOs) to capture the prompt fiber penetration.[JT617] For each batch, at least one additional filter bag set was used to capture the fiber penetration due to shedding. For Batches 3 and 4, an additional filter bag was used to capture long-term shedding data.[JT618] At the time that the final Batch 4 shedding filter bag was taken offline, the test duration exceeded the minimum amount of time required after an accident for operators to switch to simultaneous cold and hot leg recirculation injection in the plant.[JT619] 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.[JT620]

PSL1 Test Parameters

The test water used for fiber penetration testing had a chemical composition prototypical to PSL1. The plant condition selected for testing was that of the minimum boron concentration of 0.1424 mol/l and the corresponding buffer (NaOH) concentration of 0.0830 mol/l.[JT621] This water chemistry corresponds to the maximum pH condition at the sump [JT622]and was chosen based on small scale testing results that showed more bypass at a higher pH.[JT623] Test water was prepared by adding pre-weighed chemicals to DI water per the prescribed concentrations.[JT624]

Two different strainer approach velocities, 0.0024 ft/s and 0.0096 ft/s, were determined from plant operating conditions and used for the PSL1 fiber penetration testing.[JT625] The PSL1 strainer modules are spread out around almost the entire circumference of the containment building, resulting in a significant variance in distance to the suction plenum, and causing a non-uniform flow distribution among the various modules at clean strainer conditions. This non-uniform flow distribution was evaluated and the resulting average approach velocities of the modules ranged from 0.00018 ft/s to 0.0096 ft/s. The maximum module approach velocity (0.0096 ft/s) and the 8th highest module approach velocity (0.0024 ft/s), which coincides with the 65th percentile velocity among all of the modules, were selected as test velocities.[JT626]

Each of the two approach velocities was used for the entire duration of a single test. All other test parameters were constant between the two tests.[JT627]

PSL1 Strainer Penetration Model Development

Data gathered from the PSL1 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 individual test results.[JT628]
- The results for each test 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.[JT629] Figure 3.n.1-3 compares the fiber penetration results of the high flow test (shown as circles) with the fiber penetration quantities determined by applying the high flow model to the test conditions (shown as blue solid line). As Figure 3.n.1-3 shows, the model results adequately represent the test data.[JT630] A model of similar quality was achieved for the low flow test.

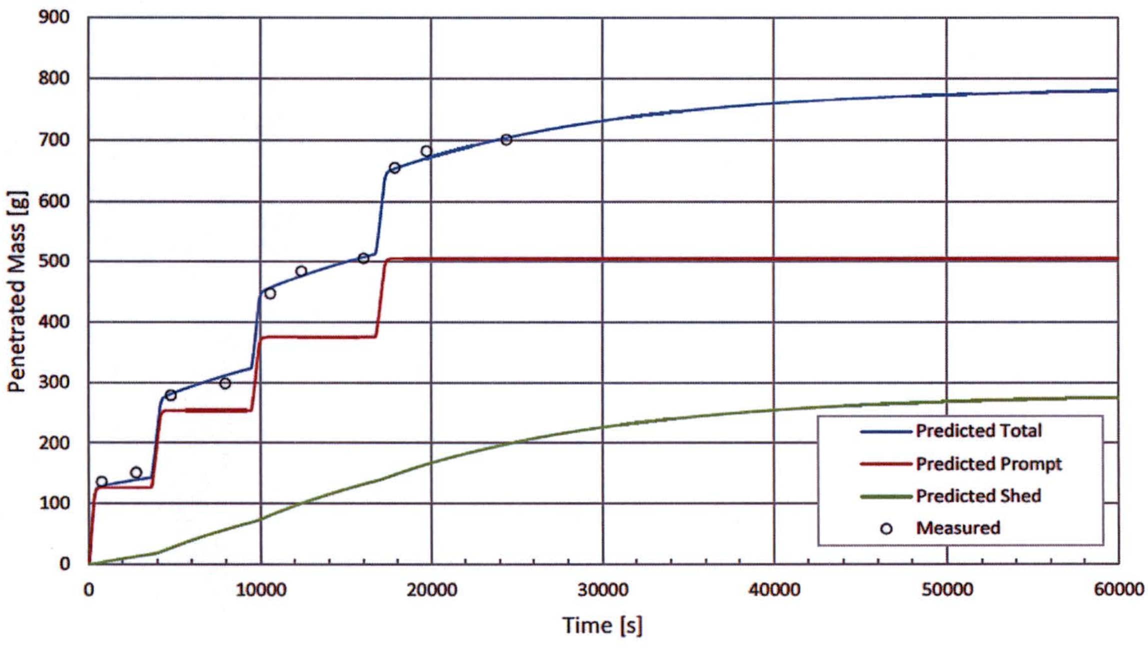

Figure 3.n.1-3: PSL1 High Flow Test Penetration Model Fit[JT631]

The penetration models from the previous step were then 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 was performed to quantify the total amount of fiber that could pass through the strainer under certain plant conditions. Example applications of the low-flow and high-flow models are shown below.[JT632] 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.1-4 and Figure 3.n.1-5 show the resulting cumulative fiber penetration through the strainer over time at plant conditions.

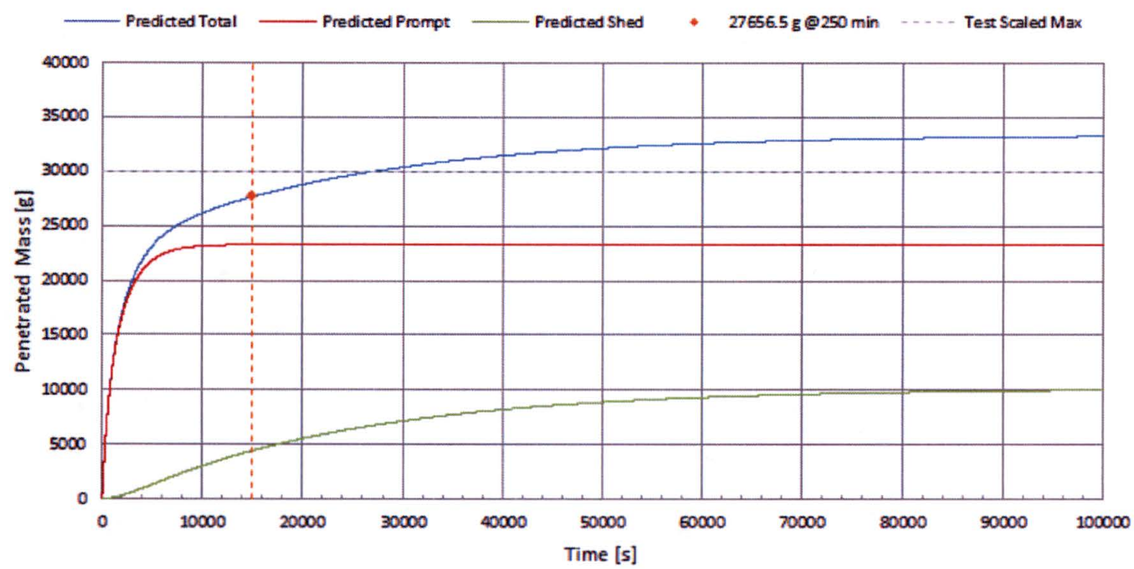

Figure 3.n.1-4: PSL1 Low Flow Penetration Model at Plant Scale[JT633]

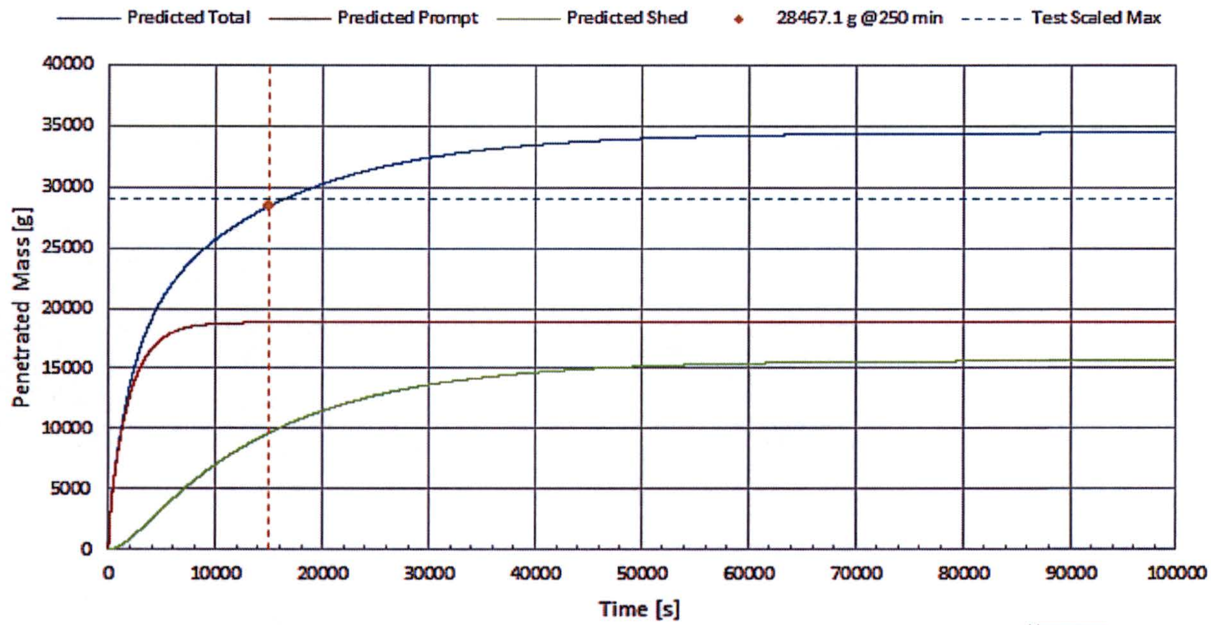

Figure 3.n.1-5: PSL1 High Flow Penetration Model at Plant Scale [JT634]

As the figures show, the high-flow model shows slightly higher penetration than the low-flow model when applied to plant conditions. Therefore, the high-flow model was used to determine the total fiber penetration quantity for resolution of in-vessel effects.

Figure 3.n.1-6 shows the prompt fiber penetration fraction as a function of fiber quantity on the strainer derived using the high flow fiber penetration model. As expected, the prompt penetration fraction decreases as a fiber debris bed forms on the strainer.

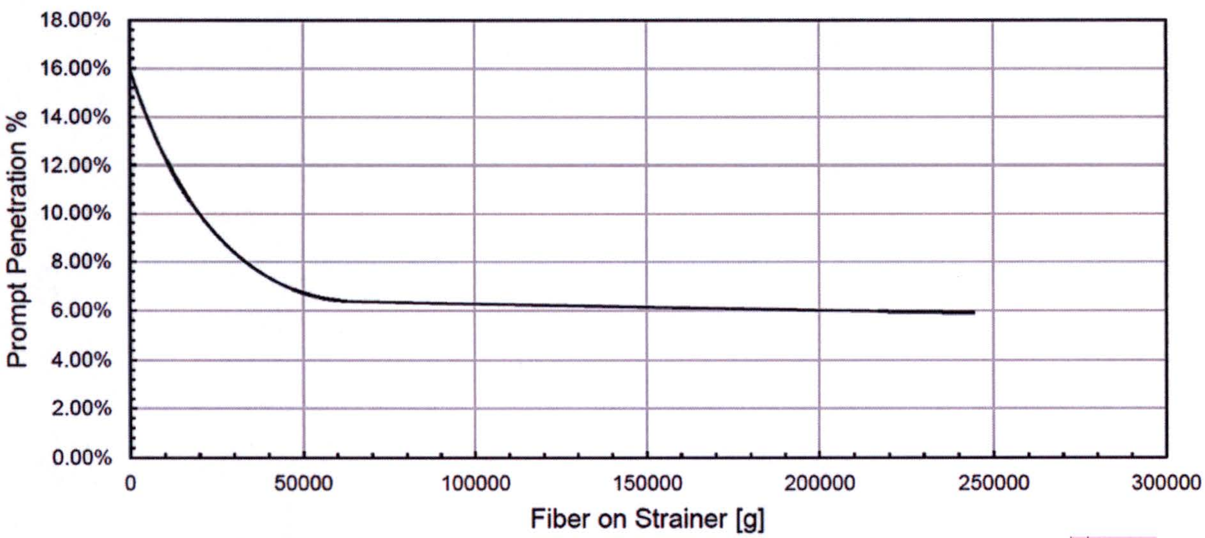

Figure 3.n.1-6: PSL1 Prompt Fiber Penetration Fraction Strainer Model [JT635]

Figure 3.n.1-7 shows the shedding rate calculated from the high flow model as a function of time. 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.

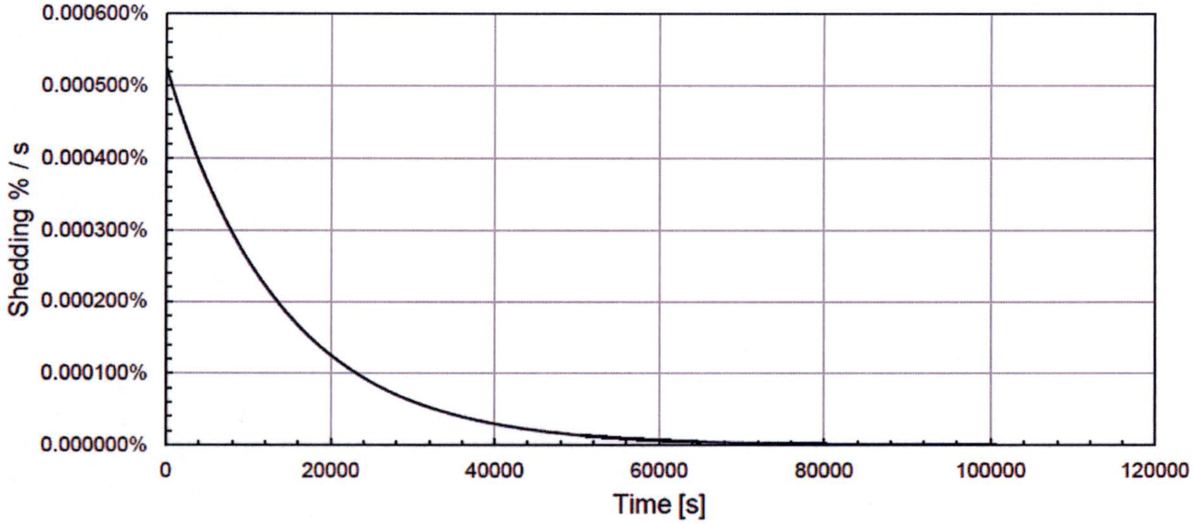

Figure 3.n.1-7: PSL1 Shedding Rate Calculated from High Flow Correlation [JT636]

PSL2 Test Loop Design

The test loop used for penetration testing was the same loop as used for head loss testing (described in the Response to 3.f.4), with a couple differences: in penetration testing, one of two available in-line filters was always online, and the transition tank and related piping were not used. The test loop consisted of a metal test tank that housed a test strainer. Water was circulated by a pump through the test strainer, in-line filtering housings, and various piping components. The test tank had a flume geometry, as shown in Figure 3.n.1-8. Debris was introduced in the high-agitation region, which was equipped with 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 and tank walls imitated the gaps between adjacent strainer stacks and the wall behind them at the plant.[JT637]

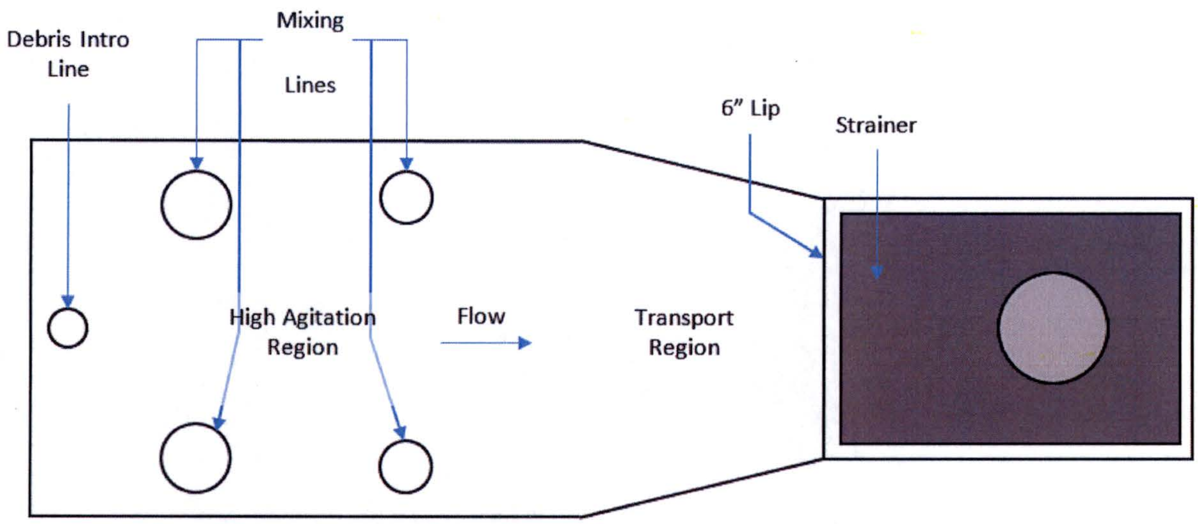

Figure 3.n.1-8: PSL2 General Arrangement of Test Tank

The effectiveness of the agitation regions is displayed in Table 3.n.1-2, 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.1-2: Summary of PSL2 Fiber Transport[JT638]

Gross Fiber Added (g)	Non-Transported Fiber (g)	Net Fiber Added (g)	% of Fiber Transport
9,834.62	200.45	9,634.17	97.96%

PSL2 Test Strainer

The test strainer was composed of two prototypical strainer modules assembled on top of each other.[JT639] The test strainer matched the key design parameters of the plant strainer modules (as described in the Response to 3.f.4). The only difference from the test strainer used in head loss testing was that every other disk of the module was removed, such that only 14 of the 30 disks were installed on the modules for penetration testing.[JT640] Removing every other disk more than doubled the gaps between adjacent disks to prevent a fiber bridge from developing across adjacent disks. This promoted fiber penetration by preserving penetrable strainer area.[JT641] 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.[JT642]

PSL2 Debris Types and Preparation

Nukon was the only debris type used in testing,[JT643] which is appropriate because LDFG and latent fiber are the only other types of fibrous debris in containment, and they have similar characteristics to Nukon.

All fiber fines were prepared according to the NEI protocol (Reference 8) [JT644]following the same procedures as were used for head loss testing. Nukon sheets, with an overall thickness of 2 inches, were baked single-sided until the binder burnout reached into approximately half the thickness. The heat-treated sheets were then cut up into approximately 2"x2" cubes and weighed out according to batch size. Batches were then pressure-washed with test water following the NEI protocol.[JT645] The prepared fiber is shown in Figure 3.n.1-9.

Figure 3.n.1-9: Nukon Fine Fiber Prepared for PSL2 Penetration Testing[JT646]

PSL2 Debris Introduction

Debris was introduced in six separate batches. The debris quantity for each of the first two batches equated approximately to a 1/16" theoretical uniform bed thickness. The third through sixth batch loads each equated to approximately a 1/8" bed thickness. This resulted in a cumulative bed thickness of approximately 5/8".[JT647] This total test fiber load bounded the maximum fiber fines load for a 42" break with 10% margin.

Debris was introduced via a debris hopper. Debris was added to the hopper by using 5 gallon buckets to transfer the debris slurry from the barrel to the debris hopper. During this process, the debris slurry was stirred to promote a homogeneous mixture in the barrel.[JT648] Additionally, the debris added to the hopper and transported into the tank was stirred, as necessary 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.[JT649]

PSL2 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.[JT650]

Fibers that passed through the strainer were collected by the in-line filter downstream of the test strainer and upstream of the pump.[JT651] All of the flow downstream of the strainer travelled through the 5-micron filter bags before returning to the test tank.[JT652] The capture efficiency of the filter bags was verified to be above 97 percent.[JT653] The filtering system allowed the installation of 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.[JT654]

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 DI water to remove residual chemicals before being dried and weighed.[JT655] When processing the filter bags, in either clean or debris laden state, the filter bags were dried in an oven for at least an hour before being cooled and weighed inside a humidity-controlled chamber.[JT656] This process was repeated for each bag until two consecutive bag weights were within 0.05 g of each other.[JT657]

A clean set of filter bags were placed online before a debris batch was introduced to the test tank, and were left online for a minimum of three PTOs to capture the prompt fiber penetration. For each batch, at least one additional filter bag set was used to capture the fiber penetration due to shedding. For Batches 2 and 6, an additional filter bag set was used to capture long-term shedding data. The final filter bag set for Batch 6 was left in to collect fiber beyond the latest time at which simultaneous cold and hot leg recirculation injection would begin in the plant.[JT658] Before further debris addition, a visual check was required to verify that all introduced debris had transported to the strainer.[JT659] 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.

PSL2 Test Parameters

The test water used for fiber penetration testing had a chemical composition prototypical to PSL2. The plant condition selected for testing was that of the minimum boron concentration of 0.1617 mol/l and the corresponding buffer (TSP) concentration of 0.006569 mol/l.[JT660] The test water chemistry corresponds to the maximum pH condition at the plant[JT661]and was chosen based on small scale testing results which showed more bypass at a higher pH.[JT662] Test water was prepared by adding pre-weighed chemicals to DI water per the prescribed concentrations.[JT663]

A strainer approach velocity of 0.00342 ft/s was determined from plant operating conditions and used for the PSL2 fiber penetration testing.[JT664] This approach velocity was calculated by dividing a total strainer flow rate of 8,600 gpm by the strainer surface area of 5,607 ft^2. This is appropriate because the PSL2 strainer is flow-controlled and the flow velocity through the various strainer stacks is uniform.

PSL2 Strainer Penetration Model Development

Data gathered from the PSL2 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 based on the test results.[JT665]
- 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 the PSL2 test. Figure 3.n.1-10 compares fiber penetration test results (shown as circles) with the fiber penetration quantities determined by applying the model to the test conditions (shown as blue solid line). As Figure 3.n.1-10 shows, the model results adequately represent the test data.

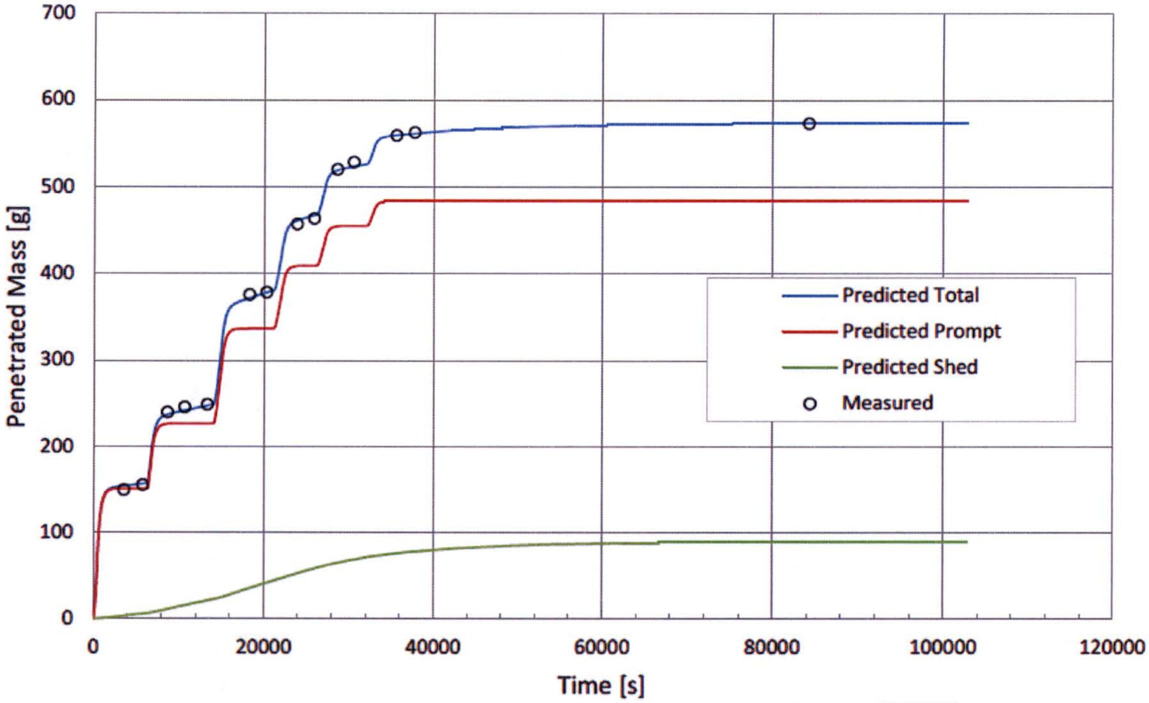

Figure 3.n.1-10: PSL2 Test Penetration Model Fit [JT666]

The penetration model from the previous step was then used to determine the prompt fiber penetration fraction and shedding fraction for a given amount of fiber accumulated on the strainer. Coupled with a fiber transport model, a time-dependent evaluation was performed to quantify the total amount of fiber that could pass through the strainer under certain plant conditions. An example application of the penetration model is shown below.[JT667] The model was used to determine the total fiber penetration quantity. 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.1-11 shows the resulting cumulative fiber penetration through the strainer over time.

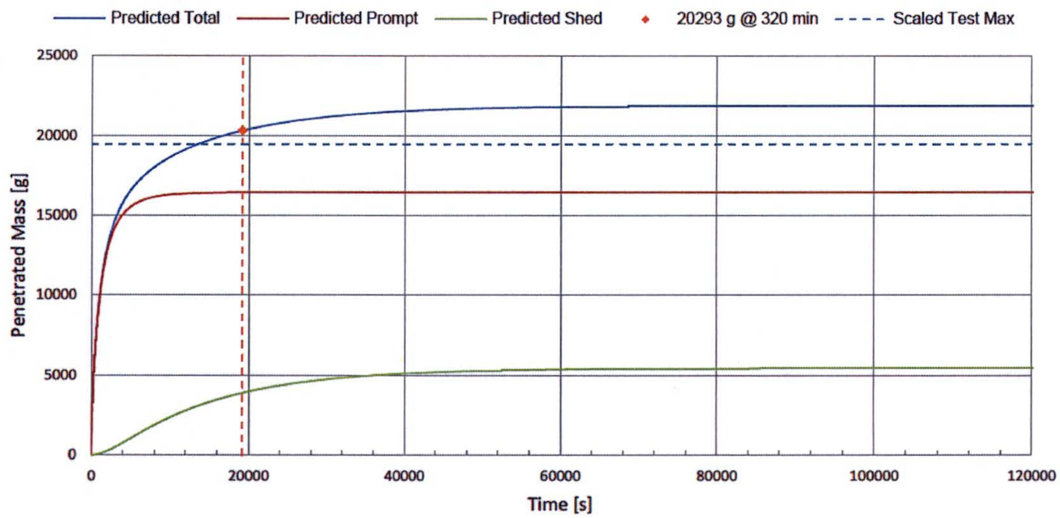

Figure 3.n.1-11: PSL2 Penetration Model at Plant Scale [JT668]

Figure 3.n.1-12 shows the prompt fiber penetration fraction as a function of fiber quantity on the strainer derived using the penetration model. As expected, the prompt penetration fraction decreases as a fiber debris bed forms on the strainer.

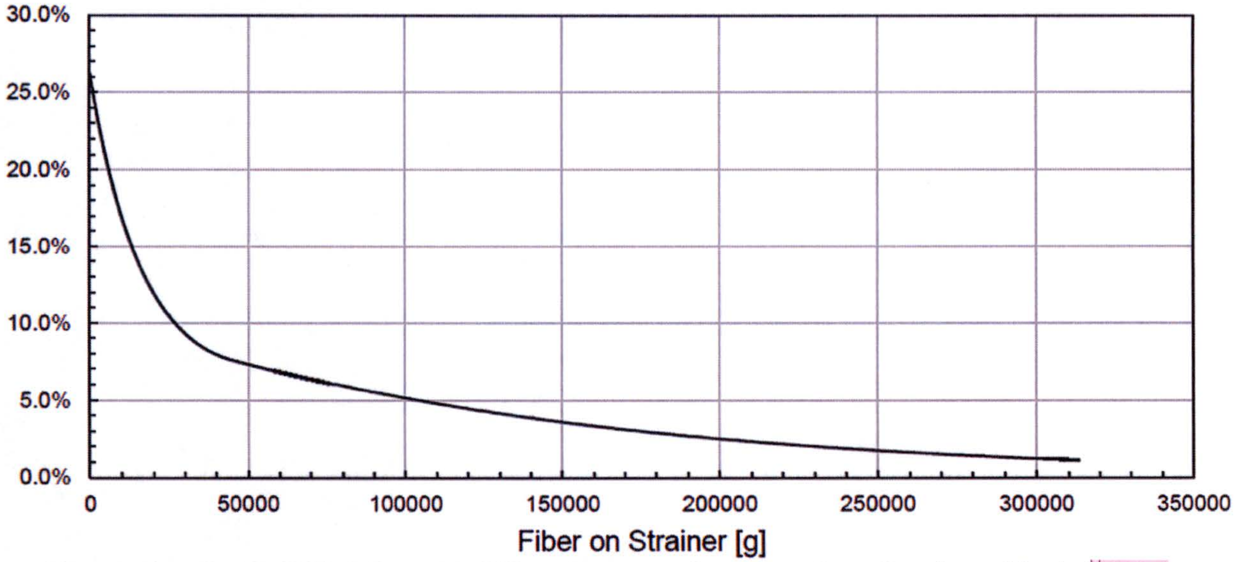

Figure 3.n.1-12: PSL2 Prompt Fiber Penetration Fraction Strainer Model [JT669]

Figure 3.n.1-13 shows the shedding rate calculated from the penetration model as a function of time. 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.

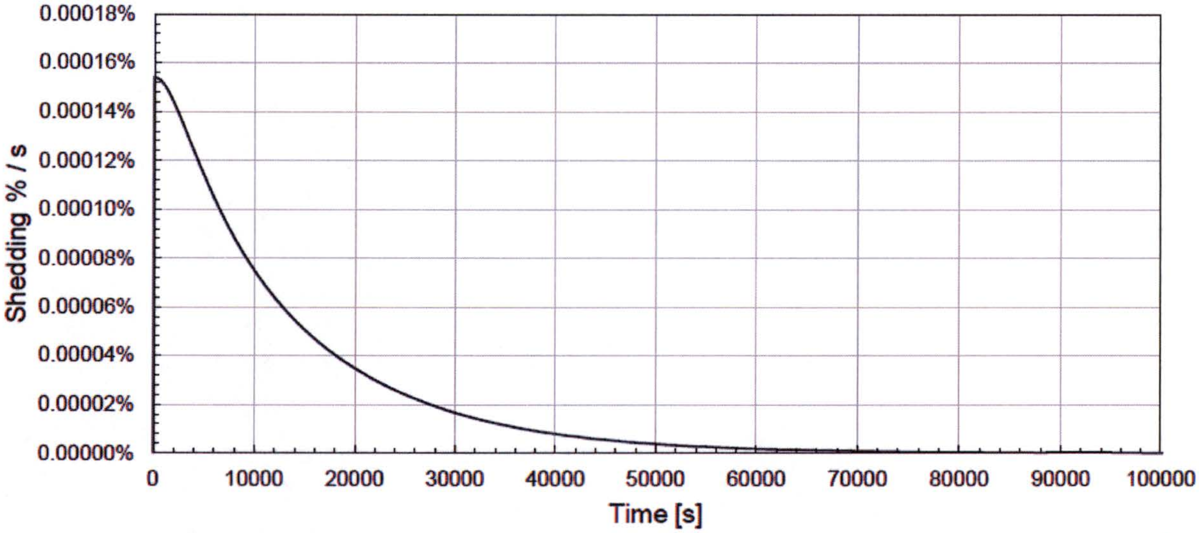

Figure 3.n.1-13: Shedding Rate Calculated from PSL2 Penetration Correlation

[JT670]

Peak Cladding Temperature (PCT) and Deposition Thickness (DT)

For both PSL1 and PSL2, the LOCADM spreadsheet, which is contained as part of WCAP-16793-NP Revision 2 (Reference 28)[JT671], 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 PCT. The calculated scale thickness was then combined with the thickness of existing fuel cladding oxidation and crud build-up to determine the total DT. The calculated total DT and PCT were compared with the acceptance criteria provided in WCAP-16793-NP. Note that the evaluation also considered the applicable requirements and recommendations from the following Pressurized Water Reactor Owners Group (PWROG) letters: OG-07-419, OG-07-534, OG-08-64, and OG-10-253. The limitations and conditions (LACs) identified in the NRC's SE (Reference 29)[JT672] of this WCAP were also addressed.

The inputs (such as pH values, temperature profiles, debris quantities, etc.) used in the PSL LOCADM analyses conservatively bound all potential breaks at the plant, and thus, the results are applicable for all breaks at PSL1 and PSL2. Table 3.n.1-3 summarizes the PCT and DT for both PSL1 and PSL2.[JT673]

Table 3.n.1-3: Summary of PCT and DT for PSL1 and PSL2

Unit	PCT (°F)		DT (mils)	
	Results	Acceptance Criteria	Results	Acceptance Criteria
PSL1	392.7	< 800	18.65	< 50
PSL2	386.9		14.34	

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 28 pp. 10-3)[JT674] was not used. Instead, accumulation of fiber on the reactor core inlet and inside the reactor vessel was determined using the WCAP-17788-P methodology, as discussed later in this 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 (LACs) that must be addressed. The responses to these LACs 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 LAC is associated with the 15 g/FA limit established in WCAP-16793-NP, and is not being used for PSL1 or PSL2. Therefore, this LAC is not applicable.

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, and is not being used for PSL1 or PSL2. Therefore, this LAC is not applicable.

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, and is not being used for PSL1 or PSL2. Therefore, this LAC is not applicable.
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 PSL1 and PSL2. Therefore, this LAC is not applicable.

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, and is not being used for PSL1 or PSL2. Therefore, this LAC is not applicable.

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, and is not being used for PSL1 or PSL2. Therefore, this LAC is not applicable.

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 PCTs are well within the acceptance criterion of 800 °F.[JT675]

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 doubling 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 PSL1 and PSL2 do not employ any conservatism-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 (Reference 28 pp. E-16)[JT676], the recommended thermal conductivity of 0.11 BTU/(h-ft-°F) can be converted to 0.2 W/m-K, which is used in the evaluation for PSL1 and PSL2.

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, and is not being used for PSL1 or PSL2. Therefore, this LAC is not applicable.

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, and is not being used for PSL1 or PSL2. Therefore, this LAC is not applicable.

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, and is not being used for PSL1 or PSL2. Therefore, this LAC is not applicable.

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 PSL1 and PSL2 does not use the "Margin Calculator".

In summary, the evaluation showed that the PCT and total DT due to accumulation of debris on the fuel rods met the acceptance criteria and will not challenge the LTCC.

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 is evaluated for both hot leg break (HLB) and cold leg break (CLB) scenarios using the methodology of WCAP-17788-P (Reference 9)[JT677]. The evaluation used time-dependent fiber penetration fractions obtained from PSL 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 package [JT678]for both units. The NARWHAL model used the methodology from WCAP-17788-P and evaluated every break in a self-consistent and time-dependent manner. Impact on the results due to variabilities in the inputs was evaluated by sensitivity analyses. These evaluations are summarized below.

Hot Leg Breaks

A base case was first run for both PSL1 and PSL2. This case used design bases inputs and conditions to determine expected in-vessel debris loads. The largest core inlet and total reactor vessel fiber loads for the base case were 21.2 and 25.4 g/FA, respectively, for PSL1[JT679], and 18.6 and 19.7 g/FA, respectively, for PSL2.[JT680] These results were compared to the limits contained in the version of WCAP-17788, which is currently in NRC review, and were found to be acceptable. It should be noted that, the core inlet and total reactor vessel fiber loads presented here are total 30-day values.

The base case evaluation was followed up with a sensitivity run that biased the inputs, per the direction of WCAP-17788-P Volume 1, to maximize the core inlet fiber loads.[JT681] The major changes in the sensitivity case are summarized below.

1. The operation of containment spray was minimized by assuming a single CS pump failure and minimum operation time. This change caused more fiber that passed through the strainers to flow into the reactor.
2. The time at which simultaneous hot and cold leg injection occurs was extended to the latest time. This maximizes the time during which debris can accumulate at the core inlet.

The largest 30-day core inlet and total reactor vessel fiber loads for the sensitivity case were 24.6 and 59.3 g/FA, respectively, for PSL1,[JT682] and 24.3 and 39.7 g/FA, respectively, for PSL2.[JT683] These results were compared to the limits contained in the version of WCAP-17788, which is currently in NRC review, and were found to be acceptable. Similar to the base case, the total core inlet fiber loads are conservative because they were calculated for the entire 30-day mission time.

<u>Cold Leg Breaks</u>

The same base case and sensitivity case inputs and conditions were used for CLB analysis with NARWHAL. As seen with the HLB evaluations, the sensitivity case, resulted in more debris to the core inlet than the base case. The largest 30-day core inlet fiber loads for PSL1 and PSL2 are 7.5 and 6.9 g/FA, respectively.[JT684] These results were compared to the limits contained in the version of WCAP-17788, which is currently in NRC review, and were found to be acceptable.

3.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 PSL1 and PSL2 includes:

- Quantification of chemical precipitates using the WCAP-16530-NP-A methodology (Reference 16)[JT685].
- 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.

The amount/mass of chemical precipitates for each unit was quantified assuming a bounding amount of LOCA generated debris. 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 used in the prototypical strainer tests to determine the resulting head loss across the strainers. Before the tests were conducted, the SAS, AlOOH, and calcium phosphate (note, PSL2 only) were prepared according to the WCAP-16530-NP-A recipes and were verified to meet the settling criteria within 24 hours of the test.[JT686] 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.[JT687] 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 (Reference 5)*[JT688].

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)[JT689]. PSL1 and PSL2 responses to the GL supplement 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 p. 8)[JT690]. Figure 3.o.2.22-1 (provided at the end of the Response to 3.o) highlights the PSL chemical effects evaluation process using the flow chart in Figure 1 of the March 2008 guidance (Reference 5 p. 8)[JT691].

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

   Neither PSL1 nor PSL2 are 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

   Three head loss tests were completed for PSL1: two full load tests and one thin bed test.[JT692] Two head loss tests were completed for PSL2: one full load test and one thin bed test.[JT693] These tests were utilized to develop the contributions from conventional debris, calcium phosphate, and aluminum precipitates. Full debris load test loads were organized to bound all prototypical debris loads.[JT694] For the thin-bed test, a debris bed that was saturated with particulate debris was formed.[JT695] Chemical precipitate was added to these tests as described in the Response to 3.f.4. See the Response to 3.f.7 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

Response for PSL1

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.

PSL1 uses NaOH to buffer the post-LOCA containment sump pool to a final pH between 8.14 and 9.66.[JT696] The injection sprays deliver the NaOH to the containment sump pool and are buffered to a pH of 9.49.[JT697] 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. The pH values are summarized in Table 3.o.2.3-1.

Table 3.o.2.3-1: PSL1 pH Values[JT698]

Design Input	pH
Sump and Recirculation Spray pH Used to Determine Chemical Release Rates	9.66
Injection Spray pH Used to Determine Chemical Release Rates	9.49
Sump pH Used to Determine Aluminum Solubility	8.14

A 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: PSL1 Temperature Profiles used to Determine Chemical Release Rates [JT699]

Time (s)	Post-LOCA Sump Temperature (°F)	Post-LOCA Containment Temperature (°F)
0	120	120
0.01667	139	188
0.03333	155	-
0.1667	195	264
0.3333	200	264
1.667	205	260
3.333	-	256
4.583	210	-
5.00	-	255
6.67	205	-

Time (s)	Post-LOCA Sump Temperature (°F)	Post-LOCA Containment Temperature (°F)
11.67	218	-
16.67	215	252
66.67	181	222
166.67	189	210
1666.67	160	165
16666.67	125	128
20000	123	125
28000	122	122
36000	121	121
43200	120	120

The total surface area of aluminum within PSL1 containment is 63.42 ft^2 (3.67 ft^2 submerged + 59.75 ft^2 unsubmerged) which was identified by recent walkdowns.[JT700] The mass of these aluminum metals was assumed to be 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.[JT701]

The total amount of concrete assumed to be exposed and submerged in the containment sump pool was 10,000 ft^2.[JT702] 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 PSL1 post-LOCA containment sump pool and is not tracked for this purpose.

Injection sprays were assumed to begin 1.34 minutes post-LOCA.[JT703] Recirculation was assumed to start at 4,571 seconds or 76.2 minutes after LOCA initiation, which is based on the minimum ECCS containment analysis case.[JT704] Containment spray was assumed to run for 30 days,[JT705] which maximized the release of aluminum.

The debris quantities used to calculate the amount of chemical products were 23 ft^3 of Nukon, 11 ft^3 of Temp-Mat, and 1,073 ft^3 of Thermal-Wrap. The amount of latent fiberglass insulation in containment is 15 lbm. Additionally, a 150 lbm contingency of E-Glass was added for chemical product generation purposes.[JT706] Note, the debris quantities utilized in the chemical effects analysis bound the quantities shown in Table 3.b.4-1.

Both AlOOH and SAS are acceptable surrogates for aluminum precipitates and may be converted to either aluminum surrogate stoichiometrically relative to aluminum for head loss testing. In the case of PSL1, calcium silicate debris only served to determine which type of surrogate the aluminum release precipitates as; therefore, no attempt was made to maximize or minimize silicon sources independent of aluminum release.[JT707]

Response for PSL2

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.

PSL2 uses TSP to buffer the post-LOCA containment sump pool to a final pH between 7.081 and 8.102.[JT708] The injection sprays were assumed to be the same pH as the sump. 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. The pH values are summarized in Table 3.o.2.3-3.

Table 3.o.2.3-3: PSL2 pH Values[JT709]

Design Input	pH
Sump and Recirculation Spray pH Used to Determine Chemical Release Rates	8.102
Injection Spray pH Used to Determine Chemical Release Rates	8.102
Sump pH Used to Determine Aluminum Solubility	7.081

Bounding containment sump pool and containment temperature profiles were used to maximize chemical release rates. The temperature profiles are shown in Table 3.o.2.3-4 and Table 3.o.2.3-5.

Table 3.o.2.3-4: PSL2 Containment Temperature Profiles used to Determine Chemical Release Rates[JT710]

Time (s)	Post-LOCA Containment Temperature (°F)	Time (s)	Post-LOCA Containment Temperature (°F)
0.00	120.00	32.28	229.04
0.07	242.15	33.12	228.49
0.16	263.38	40.03	224.09
0.32	266.65	73.37	215.20
0.49	265.48	106.70	208.20
0.66	264.46	140.70	203.30
0.74	263.99	157.37	201.37
0.99	262.70	190.70	198.45
1.32	260.88	224.03	196.54
1.66	259.19	257.37	194.53
1.99	257.80	290.70	192.55
2.32	256.63	324.03	190.66
2.66	255.65	416.67	185.96
2.99	255.11	583.33	178.97
3.32	254.57	750.00	173.47
3.66	254.00	916.67	169.09

Time (s)	Post-LOCA Containment Temperature (°F)
3.99	253.24
4.32	252.37
4.66	251.10
4.99	250.16
5.32	249.56
5.99	248.55
6.66	247.74
7.32	247.09
7.99	246.59
8.32	246.38
8.95	246.06
9.78	245.75
10.62	245.55
11.45	245.45
12.28	244.96
13.95	242.85
14.78	241.93
15.62	241.08
16.45	240.28
17.28	239.54
18.95	238.17
19.78	237.53
20.62	236.92
21.45	236.33
22.28	235.76
23.95	234.61
24.78	234.04
25.62	233.48
26.45	232.92
27.28	232.35
28.95	231.24
29.78	230.69
30.62	230.13
31.45	229.58

Time (s)	Post-LOCA Containment Temperature (°F)
1,083.33	165.49
1,250.00	162.47
1,416.67	159.92
1,583.33	158.37
1,750.00	157.92
2,083.33	154.95
2,416.67	152.42
2,750.00	150.31
3,083.33	148.11
3,250.00	147.13
3,333.33	146.66
3,416.67	146.23
3,500.00	145.83
3,583.33	145.43
3,666.67	145.04
3,833.33	144.28
3,916.67	143.91
4,000.00	143.53
4,083.33	143.16
4,166.67	142.80
4,333.33	142.14
4,416.67	141.83
4,500.00	141.52
4,583.33	141.21
4,666.67	140.91
4,833.33	140.30
4,916.67	140.01
6,458.33	136.96
8,125.00	133.81
9,791.67	131.32
13,125.00	127.40
14,791.67	125.81
16,458.33	124.98
43,200.00	124.98

Table 3.o.2.3-5: PSL2 Containment Sump Temperature Profile used to Determine Chemical Release Rates [JT711]

Time (s)	Post-LOCA Containment Sump Temperature (°F)
0.00	215.00
10.00	215.00
40.70	168.92
57.37	173.66
74.03	177.32
90.03	180.14
106.70	182.20
123.37	183.64
140.03	184.62
157.37	185.24
190.70	185.76
207.37	185.79
240.70	185.52
257.37	185.26
274.03	184.91
290.70	184.50
324.03	183.53
333.33	183.22
416.67	180.18
500.00	176.89
583.33	173.66
666.67	170.64
750.00	167.87
833.33	165.36
916.67	163.09
1,000.00	161.06
1,083.33	159.21
1,166.67	157.54
1,250.00	156.02
1,333.33	154.63
1,416.67	153.36
1,500.00	152.19
1,583.33	151.23
1,666.67	150.64
1,750.00	150.25
1,833.33	149.77
1,916.67	149.22
2,000.00	148.61
2,083.33	147.97
2,166.67	147.36
2,250.00	146.76
2,333.33	146.17
2,416.67	145.61
2,500.00	145.09
2,583.33	144.59
2,666.67	144.11
2,750.00	143.64
2,833.33	143.17
2,916.67	142.69
3,083.33	141.71
3,166.67	141.25
3,333.33	140.37
3,416.67	139.95
3,500.00	139.56
3,583.33	139.19
3,750.00	138.48
3,833.33	138.14
3,916.67	137.80
4,000.00	137.47
4,083.33	137.14
4,166.67	136.82
4,250.00	136.50
4,333.33	136.20
4,416.67	135.91
4,500.00	135.63
4,583.33	135.35
4,666.67	135.08
4,750.00	134.81
4,833.33	134.55
4,916.67	134.28
6,458.33	131.37
8,125.00	128.66
9,791.67	126.45
11,458.33	124.60
13,125.00	123.01
14,791.67	121.60
16,458.33	120.82
43,200.00	120.82

The total surface area of aluminum within PSL2 containment was assumed to be identical to the PSL1 value of 63.42 ft^2 (3.67 ft^2 submerged + 59.75 ft^2 unsubmerged) identified by recent walkdowns.[JT712] The mass of these aluminum metals was assumed to be 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.[JT713]

The total amount of concrete assumed to be exposed and submerged in the containment sump pool was 50,000 ft^2.[JT714] 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 PSL2 post-LOCA containment sump pool and is not tracked for this purpose.

Injection sprays were assumed to begin immediately post-LOCA and were assumed to be equivalent to the maximum sump pH. Containment spray was assumed to run for 30 days, which maximized the release of aluminum.[JT715]

The debris quantities used to calculate the chemical products were 1,398 ft^3 of Nukon and 12.2 ft^3 of fiberglass. The amount of latent fiberglass insulation in containment is 15 lbm. Additionally, a 170 lbm contingency of E-Glass was added for chemical product generation purposes.[JT716] Note, the debris quantities utilized in the chemical effects analysis bound the quantities shown in Table 3.b.4-2 and Table 3.b.4-3.

The quantity of Cal-Sil insulation used to calculate the chemical products was 108.1 lbm. Additionally, a 5.4 lbm contingency of Cal-Sil was added for chemical product generation purposes.[JT717] Note, the debris quantities utilized in the chemical effects analysis bound the quantities shown in Table 3.b.4-2 and Table 3.b.4-3.

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

PSL1 and PSL2 are 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. *<u>Separate Effects Decision (Decision Point)</u>: 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

PSL1 and PSL2 are 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. *<u>AECL Model:</u>*

   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 3.o.2.6.i

   This question is not applicable because PSL1 and PSL2 are 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 3.o.2.6.ii

   This question is not applicable because PSL1 and PSL2 are 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 (Reference 5 p. 8)*[JT718] *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 3.o.2.7.i

The PSL1 and PSL2 chemical model quantifies chemical precipitates using the WCAP-16530-NP-A (Reference 16)[JT719] 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 (Reference 16)[JT720] to double the aluminum release rate from aluminum metal over the initial 15 days. The spreadsheets also allow for separate accounting of "thick" aluminum (not mass limited) and "thin" aluminum (mass limited). 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. The equations and methodology used for "thin" metallic aluminum and "thick" metallic aluminum are identical.[JT721] As shown in Figure 3.o.2.7.i-1 and Figure 3.o.2.7.i-2, the ICET 1 and 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.

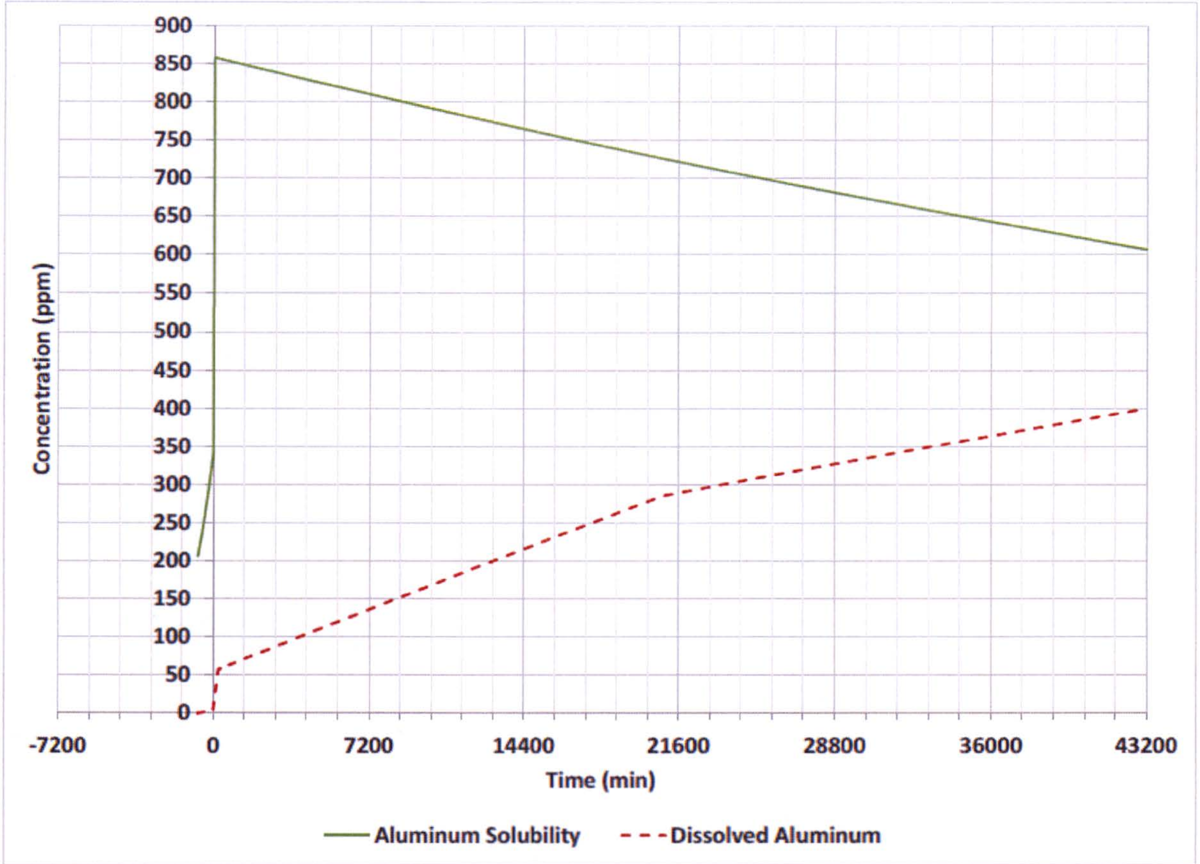

Figure 3.o.2.7.i-1: Simulation of ICET 1 Al Concentration and Solubility [JT722]

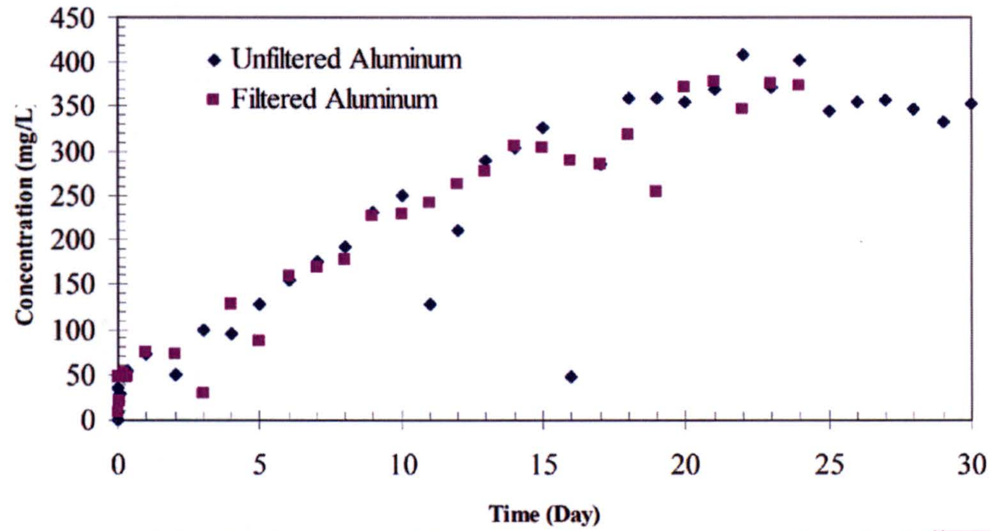

Figure 3.o.2.7.i-2: Measured Aluminum Concentrations in ICET 1 [JT723]

ii. *Licensees should list the type (e.g., AlOOH) and amount of predicted plant-specific precipitates.*

Response 3.o.2.7.ii

Response for PSL1

The aluminum precipitate mass that would be generated in the PSL1 containment sump pool crediting the aluminum values determined by walkdowns is 7 kg.[JT724] Note that this value is provided in terms of elemental aluminum. The evaluation also showed that aluminum precipitation will not occur until the sump temperature drops to below 98.2 °F.[JT725] See the Response to 3.f.4 for details on the amount of AlOOH and SAS precipitate surrogate added to the head loss test.

For input into testing, the bounding precipitate surrogate masses that were calculated to be generated without crediting the aluminum values determined by walkdowns in the PSL1 containment sump pool were 1,050.2 kg SAS and 794.8 kg AlOOH.[JT726] This input determined the ratio of aluminum surrogates used in head loss testing. Note that, per the WCAP-16530-NP-A Safety Evaluation, both aluminum precipitates are acceptable surrogates for aluminum precipitate in head loss testing. Therefore, AlOOH and SAS surrogates may be substituted for each other stoichiometrically relative to aluminum. See the Response to 3.f.4 for details on the amount of precipitate surrogate added to the head loss test.

Response for PSL2

The aluminum precipitate mass that would be generated in the PSL2 containment sump pool crediting the aluminum values determined by walkdowns is 2.1 kg .[JT727] Note that this value is provided in terms of elemental aluminum. The evaluation also showed that aluminum precipitation will not occur until the sump temperature drops to below 120.8 °F.[JT728] See the Response to 3.f.4 for details on the amount of AlOOH and SAS precipitate surrogate added to the head loss test. The calcium phosphate precipitate mass that would be generated in the PSL2 containment sump pool is 91.3 kg.[JT729] Calcium phosphate precipitate was assumed to form in the sump pool before initiation of sump recirculation.

For input into testing, the bounding precipitate surrogate masses that were calculated to be generated without crediting the aluminum values determined by walkdowns in the PSL2 containment sump pool were 244.5 kg SAS, 201.6 kg AlOOH, and 91.3 kg calcium phosphate.[JT730] This input determined the ratio of aluminum surrogates used in head loss testing. Note that, per the WCAP-16530-NP-A Safety Evaluation, both aluminum precipitates are acceptable surrogates for aluminum precipitate in head loss testing.

Therefore, AlOOH and SAS surrogates may be substituted for each other stoichiometrically relative to aluminum. See the Response to 3.f.4 for details on the amount of precipitate surrogate added to the head loss test.

8. <u>*WCAP Refinements*</u>*: State whether refinements to WCAP-16530-NP-A were utilized in the chemical effects analysis.*

Response to 3.o.2.8

Refinements 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 PSL1 and PSL2 chemical models include the following application of an aluminum solubility correlation to determine formation temperature and timing.

The aluminum solubility limit was determined using the equation below, developed by Argonne National Laboratory (ANL).[JT731]

$$C_{Al,sol} = \begin{cases} 26980 \cdot 10^{(pH+\Delta pH)-14.4+0.0243T}, & \text{if } T \le 175\ °F \\ 26980 \cdot 10^{(pH+\Delta pH)-10.41+0.00148T}, & \text{if } T > 175\ °F \end{cases}$$

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

Reduction 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. *<u>Precipitate Generation (Decision Point)</u>: 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, PSL1 and PSL2 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. *<u>Chemical Injection into the Loop</u>:*

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 either PSL1 or PSL2. 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 either PSL1 or PSL2. 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 either PSL1 or PSL2.

12. *<u>Pre-Mix in Tank</u>: 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, AlOOH, and calcium phosphate (PSL2 only) was followed with no exceptions.

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

Response to 3.o.2.13

PSL1 and PSL2 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. PSL did not credit any near field settlement in head loss testing.[JT732] Also refer 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

   Neither PSL1 nor PSL2 credited 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.i

   Neither PSL1 nor PSL2 credited 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

   Response for PSL1

   When fines and particulates were observed settling on the tank floor, manual mixing was applied to re-suspend the settled debris.[JT733] Small pieces of fiber settled on the obstruction pipe, the plenum, and against the plenum extending back to the tank floor [JT734]because the strainer became circumscribed with fibrous debris. There was some entrapment of chemical precipitate in this fiber with little to no settling of precipitate away from the strainer.[JT735]

Response for PSL2

Testing photos show that small pieces transported to the immediate vicinity of the strainer and that little other debris is settled in this area.[JT736] Additionally, when fines and particulates were observed to settle on the tank floor, manual mixing was applied to re-suspend the settled debris when possible.[JT737] There was some entrapment of chemical precipitate in this fiber with little to no settling of precipitate away from the strainer.[JT738]

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 1-hour settling volume for each batch of chemical precipitates was determined at the time that the batch was produced and was required to be 6 ml (SAS and AlOOH) / 5 ml (calcium phosphate – PSL2 only) or greater. The chemical precipitate settling was also required to be measured within 24 hours of the time the surrogate was to be used and the 1-hour settled volume was required to be 6 ml or greater and within 1.5 ml of the freshly prepared surrogate. Chemical precipitates that failed the 6 ml or greater (initial test or re-test) and within 1.5 ml of the freshly prepared surrogate criteria were not used in testing.[JT739]

16. *Test Termination Criteria: Licensees should provide the test termination criteria.*

Response to 3.o.2.16

Response for PSL1

The head-loss test was terminated once the last chemical debris addition did not produce a new head-loss peak.[JT740] The debris bed in this state was characterized using both a temperature and a flow sweep. See the Response to 3.f.4 for details on test termination.

Response for PSL2

The head-loss test was terminated once the last chemical debris addition did not produce a new head-loss peak.[JT741] The debris bed in this state was characterized using both a temperature and a flow sweep. See the Response to 3.f.4 for details on test termination.

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.f.4.

ii. *Licensees should explain any extrapolation methods used for data analysis.*

Response to 3.o.2.17.ii

No extrapolation methods were necessary since the last chemical debris addition in each test did not produce a new head-loss peak.[JT742]

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

PSL1 and PSL2 are using the separate chemical effects approach to determine the chemical source term. This section is not applicable to the PSL1 or PSL2 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

PSL1 and PSL2 are using the separate chemical effects approach to determine the chemical source term. This section is not applicable to the PSL1 or PSL2 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

PSL1 and PSL2 are using the separate chemical effects approach to determine the chemical source term. This section is not applicable to the PSL1 or PSL2 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

PSL1 and PSL2 are using the separate chemical effects approach to determine the chemical source term. This section is not applicable to the PSL1 or PSL2 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

PSL1 and PSL2 are using the separate chemical effects approach to determine the chemical source term. This section is not applicable to the PSL1 or PSL2 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

PSL1 and PSL2 are using the separate chemical effects approach to determine the chemical source term. This section is not applicable to the PSL1 or PSL2 chemical effects analysis. See Figure 3.o.2.22-1.

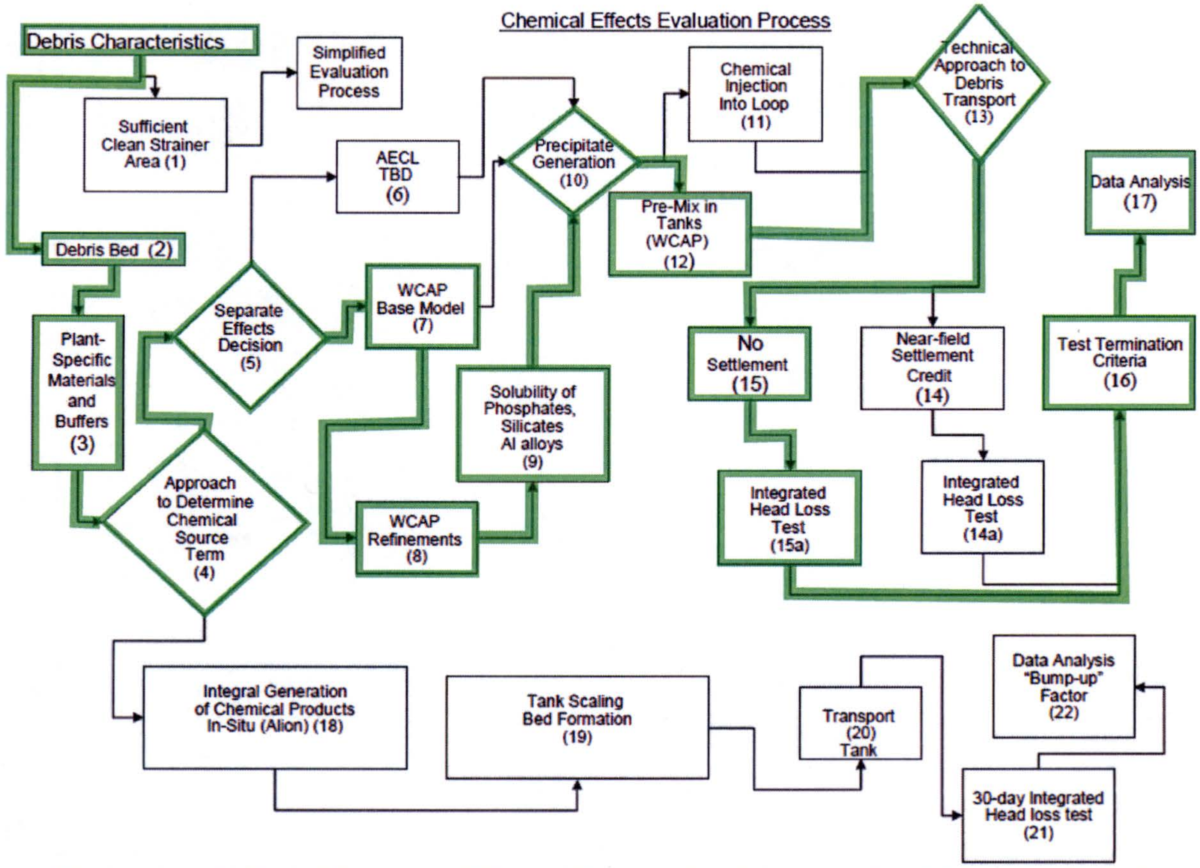

Figure 3.o.2.22-1: Chemical Effects Evaluation Process for PSL1 and PSL2 (Reference 5 p. 8)[JT743]

3.p. Licensing Basis

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

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:

As discussed in other sections of this response, physical plant changes and procedural changes have been made to PSL1 and PSL2 to resolve GL 2004-02 and GSI-191 concerns.

The PSL1 and PSL2 UFSARs have previously been updated to incorporate the effects of plant modifications and evaluations performed in accordance with the requirements of 10 CFR 50.59. The UFSARs will be reviewed after NRC acceptance of information presented in this submittal to determine if any further changes are determined to be necessary. If changes are determined to be necessary, then the UFSAR updates will occur after receipt of the final closeout letter from the NRC.

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.
4. **NRC Staff Review Guidance (ML080230462).** NRC Staff Review Guidance Regarding Generic Letter 2004-02 Closure in the Area of Coatings Evaluation. March 2008.
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.
6. **NEI Guidance Report NEI 04-07 Volume 2.** Pressurized Water Reactor Sump Performance Evaluation Methodology 'Volume 2 - Safety Evaluation by the Office of Nuclear Reactor Regulation Related to NRC Generic Letter 2004-02'. December 2004. Revision 0.
7. **NRC Revised Guidance Regarding Coatings Zone of Influence for Review of Final Licensee Responses to Generic Letter 2004-02 (ML100960495).** NRC Revised Guidance Regarding Coatings Zone of Influence for Review of Final Licensee Responses to Generic Letter 2004-02, "Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized-Water Reactors". April 6, 2010.
8. **NEI Guidance Report on Fibrous Debris Preparation (ML120481057).** Generic Procedure - ZOI Fibrous Debris Preparation: Processing, Storage, and Handling. January 24, 2012. Revision 1.
9. **Westinghouse WCAP-17788-NP Volume 1.** Comprehensive Analysis and Test Program for GSI-191 Closure (PA-SEE-1090). July 2015. Revision 0.
10. **NRC Issuance of Amendment (ML16063A121).** St. Lucie Plant, Unit No. 2 - Issuance of Amendment Regarding Transitioning to Areva Fuel (CAC NO. MF5495). April 19, 2016.
11. **License Amendment Request, L-2008-125.** Increase in Refueling Water Tank Level. June 30, 2008.
12. **NEI Guidance Report NEI 04-07 Volume 1.** Pressurized Water Reactor Sump Performance Evaluation Methodology 'Volume 1 - Pressurized Water Reactor Sump Performance Evaluation Methodology'. December 2004. Revision 0.
13. **NUREG/CR-6772.** GSI-191: Separate Effects Characterization of Debris Transport in Water. August 2002.
14. **NUREG/CR-6808.** Knowledge Base for the Effect of Debris on Pressurized Water Reactor Emergency Core Cooling Sump Performance. February 2003.
15. **NUREG/CR-6224.** Parametric Study of the Potential for BWR ECCS Strainer Blockage Due to LOCA Generated Debris. October, 1995.

16. **Westinghouse WCAP-16530-NP-A.** Evaluation of Post-Accident Chemical Effects in Containment Sump Fluids to Support GSI-191. March 2008.
17. **NEI Guidance Report NEI 09-10.** Guidelines for Effective Prevention and Management of System Gas Accumulation. April 2013. Revision 1a-A.
18. **Crane Technical Paper 410.** Flow of Fluids Through Valves, Fittings, and Pipe. 1988.
19. **ASME PTC8.2-1990.** Centrifugal Pumps. 1990.
20. **ASME Steam Tables.** ASME Steam Tables. January 1, 1979. 4th Edition.
21. **NRC Audit Report (ML070950240).** San Onofre Nuclear Generating Station Unit 2 and Unit 3 GSI-191 Generic Letter 2004-02 Corrective Actions Audit Report. May 2007.
22. **NRC Audit Report (ML082050433).** Indian Point Energy Center Corrective Actions for Generic Letter 2004-02. July 2008.
23. **AEP-NRC-2010-39 (ML101540527).** Donald C. Cook Nuclear Power Plant Units 1 and 2 Updated Final Response to Nuclear Regulatory Commission Generic Letter 2004-02. May 26, 2010.
24. **Peter S. Tam (ML101960128).** Donald C. Cook Nuclear Plant, Units 1 and 2 (DCCNP 1&2) -NRC Staff Comments on Licensee's Supplemental Responses to Generic Letter 2004-02 (TAC NOS. MC4679 and MC4680). July 2010.
25. **Nuclear Industry Procedure IP-ENG-001.** Standard Design Process. *September 8, 2016.* Revision C.
26. **AISC Manual of Steel Construction.** AISC Manual of Steel Construction: Allowable Stress Design. July 2006. 13th Edition.
27. **Westinghouse WCAP-16406-P-A.** Evaluation of Downstream Sump Debris Effects in Support of GSI-191. March 2008. Revision 1.
28. **Westinghouse WCAP-16793-NP.** Evaluation of Long-Term Cooling Considering Particulate, Fibrous and Chemical Debris in the Recirculating Fluid. October 2011. Revision 2.
29. **NRC Safety Evaluation.** Final Safety Evaluation by the Office of Nuclear Reactor Regulation, Topical Report WCAP-16793-NP, Revision 2, "Evaluation of Long-Term Cooling Considering Particulate, Fibrous and Chemical Debris in the Recirculating Fluid", PWROG Project No. 694. April 2013.