Generic Letter 2004-02

APS

Palo Verde Nuclear
Generating Station

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102-05973-JHH/RAS/DFS
March 13, 2009

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

Dear Sirs:

Subject: **Palo Verde Nuclear Generating Station (PVNGS)**
Units 1, 2, and 3
Docket Nos. STN 50-528, 50-529, and 50-530
Revision 1 to Supplemental Response to NRC Generic Letter 2004-02, "Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized-Water Reactors"

NRC Generic Letter 2004-02 requested licensees to provide information on actions taken and analyses performed to address the potential impact of debris blockage on emergency recirculation during design basis accidents. To address this issue, Arizona Public Service Company (APS) has replaced the Emergency Core Cooling System (ECCS) sump strainers in all three units of the Palo Verde Nuclear Power Station (PVNGS) with larger strainers of improved design. In addition, APS has completed all outstanding analysis and validation of the ECCS sump strainers, and is providing the updated response to GL 2004-02 in the enclosed Revision 1 to the APS Supplemental Response to NRC Generic Letter 2004-02.

By APS letter no. 102-05819, dated February 29, 2008 (Agencywide Document Access and Management System [ADAMS] Accession No. ML080710546), APS submitted to the NRC a 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." In that supplemental response, APS stated that the response contained the information requested by GL 2004-02 with the exception of information not yet available regarding completion of installation of new strainers in the Unit 2 spring 2008 refueling outage and the results of the containment sump strainer confirmatory testing, analysis and validation.

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By letter dated June 30, 2008, the NRC approved APS commitments to complete all outstanding analysis and validation of the containment sump strainers by September 30, 2008, and to submit the final response to GL 2004-02 within 45 days of completion of the analysis and validation. By APS Letter 102-05924, dated November 14, 2008, (ADAMS Accession No. ML083370162) a request was submitted for an extension for submittal of the supplemental response to GL 2004-02 to December 19, 2008. By email on November 14, 2008, (ADAMS Accession No. ML083250346) and later by letter dated December 3, 2008, (ADAMS Accession No. ML083230937) the NRC approved that request. By letter dated December 16, 2008, (ADAMS Accession No. ML083430549) the NRC requested additional information based on the APS response to the GL 2004-02, dated February 29, 2008. That letter directed APS to respond to both the RAI and provide the supplemental information within 90 days.

This submittal confirms that the actions required to ensure that PVNGS conforms to GL 2004-02 have been completed, implemented, and validated. Enclosure 1 of this revised supplemental response conforms to the NRC's revised content guide for GL 2004-02 supplemental responses as provided in the NRC letter to the Nuclear Energy Institute dated November 21, 2007 (ADAMS Accession No. ML073110389). This revised supplemental response completes submittal of information requested by GL 2004-02 by updating the supplemental response previously provided by APS's February 29, 2008, submittal. The revisions include adding the specific wording from the questions contained in the NRC content guide for GL 2004-02 submittals, updating the validation testing and testing analysis, and addressing chemical and downstream effects. In addition, Enclosure 2 provides APS's responses to the NRC's request for additional information dated December 16, 2008. As a result of the extensive revisions and additions to the February 29, 2008, GL 2004-02 supplemental response, Enclosure 1 in this submittal supersedes the previously submitted enclosure.

There are no regulatory commitments made in this submittal. If you have any questions, please contact Russell Stroud, Licensing Section Leader, at (623) 393-5111.

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

Executed on 3-13-09.
(date)

Sincerely,

JHH/SAB/RAS/gat

Enclosures:

1. Supplemental Response to NRC Generic Letter (GL) 2004-02, Revision 1
2. Response to Request for Additional Information

cc:	E. E. Collins Jr.	NRC Region IV Regional Administrator
	J. R. Hall	NRC NRR Project Manager
	R. I. Treadway	NRC Senior Resident Inspector for PVNGS

Enclosure 1

Supplemental Response to NRC Generic Letter (GL) 2004-02

Revision 1

Arizona Public Service Company

Palo Verde Nuclear Generating Station

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EXECUTIVE SUMMARY

In response to research relative to sump-strainer clogging, the U.S. Nuclear Regulatory Commission (NRC) opened Generic Safety Issue (GSI) -191, "Assessment of Debris Accumulation on Pressurized Water Reactor (PWR) Sump Performance." The objective of GSI-191 is to ensure that post-accident debris blockage does not impede or prevent operation of the Emergency Core Cooling System (ECCS) or Containment Spray System (CSS) in recirculation mode at pressurized water reactors (PWRs) during accidents for which recirculation is required.

Based on information identified during the efforts to resolve GSI-191, the NRC Staff determined that the previous guidance used to develop current licensing basis analyses did not adequately and completely model sump screen debris blockage and related effects. As a result, the NRC Staff revised the guidance for determining PWR recirculation sump screen susceptibility to the adverse effects of debris blockage and issued Generic Letter (GL) 2004-02. GL 2004-02 requests that addressees (NRC licensees that operate PWRs) perform new, more realistic analyses and submit information to the NRC confirming the functionality of the ECCS during design basis accidents that require recirculation operations.

Arizona Public Service Company (APS) Letter 102-05336, dated September 1, 2005, provided the Palo Verde Nuclear Generating Station (PVNGS) initial written response to the NRC, per GL 2004-02 Request No. 2 [Ref. 4.90]. APS submitted a Supplemental Response to GL 2004-02 on February 29, 2008 [Ref. 4.91]. However, that Supplemental Response did not address final head loss and chemical effects confirmatory testing and analysis, because that information was not available. This revised Supplemental Response provides that information.

GL 2004-02 notes that research and analysis efforts have suggested potential susceptibility of PWR recirculation sump screens to debris blockage during design basis accidents that require recirculation operation of the ECCS and CSS. The NRC requested that PWR licensees use NRC-approved methodology to evaluate the potential for adverse effects of post-accident debris blockage.

APS has completed the evaluation requested in accordance with the guidance of Nuclear Energy Institute (NEI) 04-07 [Ref. 4.30] and the associated NRC Safety Evaluation (SE) [Ref. 4.28]. As a result, APS has modified the PVNGS units to greatly increase the effective surface area of the ECCS sump screens by removing the original screens and installing strainer modules above each sump. The surface area of the new sump screens was increased from 210 ft^2 to 3,142 ft^2 per sump. In addition, the design of the new strainers has been improved by adopting strainer geometry less susceptible to blockage. This increase in effective surface area and improved design assures that ECCS and CSS will perform their intended safety functions under any blockage conditions postulated to occur after a Loss of Coolant Accident (LOCA), and includes sufficient margin for chemical effects. Other corrective actions included removal of Fiberfrax insulation in Containment and enhancements to PVNGS programs and procedures to improve control of transportable debris, thereby reducing potential blockage. Nukon insulation has been removed around letdown delay coils.

Physical modifications to Units 1 and 3 required by GL 2004-02 for the installation of larger ECCS sump strainers were completed by December 31, 2007, per the GL schedule. APS had requested and was granted an extension of the December 31, 2007, date for Unit 2 to install the larger sump strainers until the end of the spring 2008 refueling outage 2R14, based on late delivery of the strainer for installation in the fall 2006 Unit 2 Refueling Outage. The Unit 2 ECCS strainer installation was completed in 2R14 as scheduled. In addition, due to difficulties in completion of the confirmatory testing and analyses, an extension was granted to September 30, 2008. All confirmatory testing analyses were completed by September 30, 2008, as scheduled.

To further reduce potential debris loading, the Microtherm (Units 1 and 2) and Min-K (Unit 3) insulation is scheduled to be removed from the reactor head in the fall 2009 refueling outage for Unit 2, in the spring 2010 Unit 1 refueling outage, and in the fall 2010 Unit 3 refueling outage. This insulation removal will be performed in conjunction with the reactor head replacement project for each unit.

This revised supplemental response documents the completion of PVNGS commitments relative to GL 2004-02 and compliance with NRC guidance as currently formulated for determining susceptibility of PWR recirculation sump screens to the adverse effects of debris blockage during design basis accidents that require recirculation operation of the ECCS and CSS. This response does not address the pending revisions to guidance for fuel blockage evaluations. Once the new guidance is issued, this issue will be revisited on behalf of PVNGS.

APS used the NEI and NRC guidance in the evaluation of the new containment sump strainers. The guidance was used without deviations. Performance testing of the Control Components, Inc. (CCI) pocket strainers demonstrated that the maximum head loss is 4.33 ft and a minimum ECCS pump margin of 5.53 ft.

The performance testing used an initial flow rate of 11,600 gpm for the first hour of recirculation and 6,600 gpm for the remainder of the performance test. The initial flow of 11,600 gpm is based on all three ECCS pumps at maximum flow, which is not a design basis condition. The 6,600 gpm is based on the CSS and high pressure safety injection (HPSI) pumps running at maximum flow for the duration of the test. The flow rates were chosen as a bounding and conservative assumption.

Considering the overall parameters for debris generation, debris transport, material preparation, testing methodology and strainer performance testing without any deviations and the resulting head loss margin of 5.53 ft., APS has demonstrated compliance with GL 2004-02.

In the following sections of this enclosure the statements that are bold italic are the NRC's requests for information and are followed by the APS responses.

1. Overall Compliance

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

GL 2004-02 Requested Information Item 2(a)

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

This response summarizes the technical basis for the PVNGS ECCS strainer design and the associated programmatic controls that satisfy the commitments relative to GL 2004-02. The new sump strainer design complies with the revised NRC guidance for determining the susceptibility of PWR recirculation sump screens to the adverse effects of debris blockage during design basis accidents that require recirculation operation of the ECCS and CSS. The fuel blockage evaluation will be re-visited to determine necessary evaluations when pending new industry guidance on the fuel effects is issued.

The ECCS sump strainers in PVNGS Units 1, 2, and 3 have been replaced under Design Master Work Order (DMWO) 2822654, per commitments to the NRC as documented in APS Letter 102-05336 dated September 1, 2005 [Ref. 4.90]. The Unit 1 sump strainer was replaced in the spring 2007 refueling outage; the Unit 3 sump strainer was replaced in the fall 2007 refueling outage; and the Unit 2 sump strainer was replaced in the spring 2008 refueling outage. The modifications were deemed necessary based on evaluations requested by GL 2004-02 which were performed in accordance with the guidance in NEI 04-07, "Pressurized Water Reactor Sump Performance Evaluation Methodology," and the associated NRC SE [Ref. 4.28].

The new sump strainers were procured from CCI, per PVNGS Specification 13-MN-1003 [Ref. 4.31]. The new design increased the screen size from approximately 210 ft^2 to 3,142 ft^2 per sump [Ref. 4.25]. This provides sufficient area to ensure ECCS and CSS performance by accommodating any strainer blockage that is postulated to occur following a LOCA based on the results of the CCI strainer testing and strainer head loss analysis. The new strainer design includes sufficient margin for chemical effects. DMWO 2822654 also removed, from all three units, the Fiberfrax insulation from piping penetrations in the bioshield (steam generator [S/G] D-ring and pressurizer) walls, which reduced the amount of transportable debris in Containment. The Fiberfrax penetration seals were replaced with stainless steel sheet metal barriers to accomplish penetration isolation. Nukon insulation has been removed around letdown delay coils.

New sump strainers are installed in the same location as the existing strainers and located on the containment floor directly over the sump pits. The new strainers supplied by CCI incorporate diverse geometry in the design, which is less susceptible to thin-bed effects than flat screens; have modular construction, which can be enlarged if needed; and are constructed of perforated stainless steel plate. The new strainers are installed with approximately 3,142 ft^2 of strainer surface area per sump with holes having a nominal diameter of 0.083 inch. The new strainers are bolted with no gaskets or soft sealants and the screens are not welded. The combination of the CCI design, PVNGS large screen area, and minimal debris load results in open screen area and low head loss.

In each PVNGS unit, the suction supply for the ECCS and CSS pumps during recirculation following a LOCA is provided by two ECCS sumps, one for each safety-related train. The sumps are located on the lowest floor in the Containment Building and are physically separated to preclude simultaneous damage to both screens.

The strainer head loss analysis is documented in N001-1106-00228 [Ref. 4.43]. The head loss of the replacement strainers was determined to be less than the head loss across the original strainers. Calculations 13-MC-SI-0017 [Ref. 4.32] and 13-MC-SI-0018 [Ref. 4.33] verify adequate available Net Positive Suction Head (NPSH) for the ECCS and CSS pumps, respectively, based on the calculated screen head loss. These two NPSH calculations have been revised with new head loss data for the replacement ECCS sump strainers based on the chemical effects testing and strainer head loss analysis.

In support of installation of the new strainers in Unit 2, APS submitted, and the NRC in license amendment number 169 dated May 9, 2008, approved an exigent change to technical specification (TS) 3.5.5, to increase the refueling water tank (RWT) minimum water level for Unit 2 by three percent [Ref. 4.92]. For Units 1 and 3 the minimum RWT water level to meet the containment flood level analysis is the same as Unit 2 and is currently being administratively controlled. The same TS 3.5.5 changes for Units 1 and 3 were submitted to the NRC in APS Letter No. 102-05923, dated November 13, 2008 [Ref. 4.93]. The current administrative controls for Units 1 and 3 RWT level are in accordance with NRC Administrative Letter 98-10, "Dispositioning of Technical Specifications that are Insufficient to Assure Plant Safety," and will remain in effect until the Units 1 and 3 TS amendment is issued and implemented.

In an effort to further reduce potential debris loading, the Microtherm (Units 1 and 2) and Min-K (Unit 3) insulation is scheduled to be removed from the reactor head in the fall 2009 refueling outage for Unit 2, in the spring 2010 Unit 1 refueling outage, and in the fall 2010 Unit 3 refueling outage. This insulation removal will be performed in conjunction with the reactor head replacement project for each unit.

2. General Description of and Schedule for Corrective Actions

Provide a general description of actions taken or planned, and dates for each. For actions planned beyond December 31, 2007, reference approved extension requests or explain how regulatory requirements will be met as per <u>Requested Information</u> Item 2(b). (Note: All requests for extension should be submitted to the NRC as soon as the need becomes clear, preferably not later than October 1, 2007.)

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

PVNGS has installed new strainers for each ECCS sump to increase the effective screen area from 210 ft^2 to 3,142 ft^2 per sump. To accomplish this, the existing screens and steel "roof" were removed. The vertical W6x25 columns of the frame for the original strainers were shortened and circumscribing beams were removed. A new stainless steel floor was attached to the existing structural steel base frame to cover the sumps at the 80'-7" level. This floor is supported by new stainless steel floor joists. The floor has eight large-flow slots to accept flow from eight new strainer modules mounted on the new floor. Each module has flow coming from two of four sides but not from the top of the module. Both sides resemble arrays of rectangular "pigeon holes" or "mail boxes." Each rectangular pocket is approximately three inches wide by five inches high by 16 inches deep. Flow enters each three inch by five inch opening and is filtered through perforated plate on the other five sides of the pocket and the bottom of the module. The nominal diameter of the holes is 0.083 inch. Stainless steel sheet metal is used to form the modules. The flows from the two arrays of pockets meet in a plenum in the middle of the module and then move down through the slot in the floor to the sump and then to the pumps located in the Auxiliary Building.

To reduce the potential for quantities of fibrous debris in Containment, Fiberfrax was removed from the Containment. The piping penetrations in the containment bioshield walls were originally sealed with Fiberfrax. These penetrations were modified by removing the Fiberfrax and installing stainless steel sheet metal seals in the piping penetrations. In addition, Nukon insulation has been removed around letdown delay coils.

To further reduce potential debris loading, the Microtherm (Units 1 and 2) and Min-K (Unit 3) insulation is scheduled to be removed from the reactor head in the fall 2009 refueling outage for Unit 2, in the spring 2010 Unit 1 refueling outage, and in the fall 2010 Unit 3 refueling outage. This insulation removal will be performed in conjunction with the reactor head replacement project for each unit.

The existing sump temperature element was relocated to facilitate the installation of the replacement sump strainers. The relocation of the temperature element was only a physical re-location to accommodate the position of the penetration for the temperature element conduit and did not change the design requirements of the temperature element.

Programmatic controls are in place to verify containment cleanliness and ensure that no foreign material is present at the ECCS sump strainers prior to containment closure following refueling outages [Ref. 4.39]. These controls also ensure maintenance of the containment cleanliness for any entry into the containment through verification of the condition of all areas entered. Procedures are also in place to control transient materials taken into or out of containment during any entry of the containment at power [Ref. 4.40]. Programmatic controls are in place to perform periodic coatings assessment walkdowns to verify the condition of the containment coatings [Ref. 4.79].

The description of the configuration of the replacement ECCS sump strainers will be reflected in the next PVNGS Updated Final Safety Analysis Report (UFSAR).

Documents generated to support the GL 2004-02 response are listed below:

- ECCS Sump Strainer Modification Package [Ref. DMWO 2822654]
- Debris Generation Calculation [Ref. 4.4]
- Debris Transport Calculation [Ref. 4.14]
- Minimum Containment Flood Level Calculation [Ref. 4.15]
- Latent Debris Walkdown and Calculations [Refs. 4.5, 4.6, 4.7, 4.8, 4.9, 4.10, 4.11, 4.12, 4.13 and 4.41]
- Strainer Structural/ Seismic Analysis [Refs. 4.22, 4.23 and 4.24]
- Post-LOCA Chemical Effects Analysis [Ref. 4.52]
- Post-LOCA Fuel Deposition Analysis [Ref. 4.60]
- Pump Seal Evaluation [Ref. 4.45]
- Pump Seal Cyclone Separator Evaluation [Ref. 4.61]
- Downstream Effects Debris Ingestion Evaluation [Ref. 4.77]
- Downstream Effects Evaluation for ECCS Equipment [Refs. 4.37 and 4.38]

- Downstream Effects Fuel Blockage Evaluation (Fiber Bypass) [Ref. 4.83]
- Chemical Effects Head Loss Test Report [Ref. 4.42]
- Bypass and Debris Transport Test Report [Ref. 4.49]
- Strainer Head Loss Calculation (including vortex, flashing and deaeration) [Ref. 4.43]
- NPSH Calculations [Refs. 4.32 and 4.33]
- Containment Coatings Condition Assessment Procedure [Ref. 4.79]

The implementation schedule for corrective actions that were identified while responding to GL 2004-02 is summarized in Table 2-1. The corrective actions listed are more fully described in responses to items 2(c), 2(d), and 2(f).

Table 2-1: GL 2004-02 Corrective Actions Implementation Schedule

GL 2004-02 REGULATORY COMMITMENT (from APS Letter No. 102-05560 dated August 30, 2006) (Ref. 4.94)	DUE DATE	REVISED DUE DATE OR STATUS
1. Evaluate the recommendations contained in the Westinghouse downstream effects evaluation for PVNGS and establish an implementation schedule for appropriate recommendations (RCTSAI 2826236).	December 31, 2005	Completed
2. Perform confirmatory head-loss testing of new strainer with plant specific debris to ensure an adequate design (RCTSAI 2826244).	As soon in 2007 as achievable, and no later than December 31, 2007 Due date extended to September 30, 2008 in Letter 102-05861, 6/6/08	Completed
3. Verify that a capture ratio of 97 percent or higher can be achieved in the final design of the new sump screen to ensure that the fuel evaluation contained in the Westinghouse downstream effects evaluation is bounding (RCTSAI 2826247).	As soon in 2007 as achievable, and no later than December 31, 2007 Due date extended to September 30, 2008 in Letter 102-05861, 6/6/08	Completed

GL 2004-02 REGULATORY COMMITMENT (from APS Letter No. 102-05560 dated August 30, 2006) (Ref. 4.94)	DUE DATE	REVISED DUE DATE OR STATUS
4. Perform sump strainer structural evaluation to ensure seismic and operational integrity (RCTSAI 2826250).	October 31, 2006	Completed
5. Validate allocated margins for Chemical Effects in strainer head-loss to ensure an adequate design (RCTSAI 2826239).	As soon in 2007 as achievable, and no later than December 31, 2007 Due date extended to September 30, 2008 in Letter 102-05861, 6/6/08	Completed
6. Perform a confirmatory containment latent debris walkdown of PVNGS Units 1 and 3 (RCTSAI 2826259). [Note: The containment walkdown for transportable debris was completed in Unit 2 as stated in Letter No. 102-05336, 9/1/05.]	June 30, 2006	Completed
7. Perform a confirmatory containment unqualified coating walkdown of PVNGS Units 1 and 3 (RCTSAI 2826260). [Note: The containment walkdown for transportable debris was completed in Unit 2 as stated in Letter No. 102-05336, 9/1/05.]	June 30, 2006	Completed
8. Review the existing programmatic controls for containment coatings identified in the response 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," for their adequacy (RCTSAI 2826262).	November 30, 2006	Completed

GL 2004-02 REGULATORY COMMITMENT (from APS Letter No. 102-05560 dated August 30, 2006) (Ref. 4.94)	DUE DATE	REVISED DUE DATE OR STATUS
9. Review the existing programmatic and procedural controls in place to prevent potentially transportable debris (insulation, signs and foreign material) in the containment building to ensure that the bounding assumptions in the design of the new strainers will be maintained (RCTSAI 2826263).	November 30, 2006	Completed
10. Implement in Unit 1 changes to programs and procedures to ensure and/or enhance the control of transportable debris in containment (RCTSAI 2826264).	1R13 refueling outage (approximately May 31, 2007)	Completed
11. Implement in Unit 2 changes to programs and procedures to ensure and/or enhance the control of transportable debris in containment (RCTSAI 2826267).	2R13 refueling outage (approximately November 30, 2006)	Completed
12. Implement in Unit 3 changes to programs and procedures to ensure and/or enhance the control of transportable debris in containment (RCTSAI 2826269).	3R13 refueling outage (approximately December 31, 2007)	Completed
13. Install larger sump strainers in PVNGS Unit 1 (RCTSAI 2826277).	1R13 refueling outage (approximately May 31, 2007)	Completed
14. Install larger sump strainers in PVNGS Unit 2. (RCTSAI 2826278)	2R14 refueling outage (to begin no later than April 28, 2008)	Completed
15. Install larger sump strainers in PVNGS Unit 3 (RCTSAI 2826284).	3R13 refueling outage (approximately December 31, 2007)	Completed
16. Remove installed Fiberfrax insulation in PVNGS Unit 1 (RCTSAI 2826282).	1R13 refueling outage (approximately May 31, 2007)	Completed
17. Remove installed Fiberfrax insulation in PVNGS Unit 2 (RCTSAI 2826283).	2R13 refueling outage (approximately November 30, 2006)	Completed

GL 2004-02 REGULATORY COMMITMENT (from APS Letter No. 102-05560 dated August 30, 2006) (Ref. 4.94)	DUE DATE	REVISED DUE DATE OR STATUS
18. Remove installed Fiberfrax insulation in PVNGS Unit 3 (RCTSAI 2826284).	3R13 refueling outage (approximately December 31, 2007)	Completed
19. After plant specific strainer testing has been completed and the Westinghouse downstream effects evaluation for PVNGS has been evaluated, APS will submit an update to the NRC to report the validation of the allocated margins for chemical effects and identify any recommendations from the Westinghouse evaluation to be implemented (RCTSAI 2826287).	To be submitted along with the NRC RAI response as soon in 2007 as the results are available, and no later than December 31, 2007	Completed
20. Contingent on NRC approval, APS commits to complete the containment sump strainer confirmatory testing, analysis and validation for PVNGS Units 1, 2 and 3 by June 30, 2008 (RCTSAI 3106850).	New commitment in Letter No. 102-05779, 12/10/07 Due date extended to September 30, 2008 in Letter 102-05861, June 6, 2008	Completed
21. Submit the information from containment sump strainer confirmatory testing, analysis and validation for PVNGS Units 1, 2 and 3 within 90 days of their completion (this will provide information not submitted with the GL 2004-02 supplemental response due by February 29, 2008) (RCTSAI 3106852).	New commitment in Letter No. 102-05779, 12/10/07 Due date extended to November 14, 2008 in Letter 102-05861, June 6 2008	Completed

3. Specific Information Regarding Methodology for Demonstrating Compliance

a. Break Selection

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

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

1. Break Selection Criteria

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

The "limiting" break is identified as the break that results in the type, quantity, and mix of debris generation that is determined to produce the maximum head loss across the sump screen. The debris types and mix were reviewed with the possible break locations and break sizes to determine several possible limiting break locations [Ref. 4.4]. The break selection process used by APS to identify limiting breaks at PVNGS is described in the methodology in Section 3.3.4 of NEI 04-07 [Ref. 4.30] and the associated NRC SE [Ref. 4.28].

The largest lines in descending order in the Containment are as follows: hot leg (42-inch ID), cold leg suction (30-inch ID), cold leg discharge (30-inch ID), main steam (28-inch), feedwater (24-inch), shutdown cooling (SDC) suction line from reactor coolant system (RCS) (16-inch ID), safety injection (SI) and SDC injection lines to RCS (14-inch), pressurizer surge line (12-inch), and the pressurizer spray line (4-inch).

Feedwater or main steam line breaks do not result in recirculation through the ECCS recirculation sumps and are not required to be analyzed for limiting breaks. Within the S/G D-ring walls, the SI and SDC injection and SDC suction lines are of smaller diameter than the hot and cold leg RCS piping. As a result, any breaks in these lines would be bounded and were not specifically analyzed. Any breaks in the pressurizer spray lines located within the S/G D-ring and pressurizer enclosure are also bounded by breaks in the larger lines in these areas and would not be required to be analyzed for debris generation. However, breaks in the pressurizer enclosure have the potential for creating a greater quantity of fiber insulation debris than the other analyzed breaks since the pressurizer enclosure includes Nukon and Temp-Mat insulation that could become debris. As a result, these breaks were specifically analyzed for debris generation.

Although there are some high energy lines existing outside the S/G D-ring and pressurizer enclosure their effects are considered bounded by the conservative debris generation assumptions used for analysis of the breaks within the S/G D-ring and pressurizer enclosure discussed below.

Section 3.3.5.2 of the SE [Ref. 4.28] describes a systematic approach to break selection along individual piping runs that starts at an initial location along a pipe, generally a terminal end, and steps along in equal (five-foot) increments, placing breaks at each sequential location. The NRC staff notes in the SE that the concept of equal increments is only a reminder to be systematic and thorough. Section 3.3.5.2 of the SE further states that the key difference between many breaks (especially large breaks) is not the exact location along the pipe, but rather the envelope of Containment material targets that is affected.

At PVNGS the exact break location along the pipe is not considered critical. To ensure a conservative assumption for maximum debris development, APS considered that any break within the S/G D-ring or pressurizer enclosure will result in a ZOI that will affect the entire S/G D-ring or pressurizer enclosure. Therefore the envelope of affected containment material targets is defined by the S/G or pressurizer enclosure and all piping reflective metal insulation (RMI)(Transco and Diamond Power Mirror) in the S/G D-ring and pressurizer enclosure is considered within the Zone of Influence (ZOI) for analyzed breaks. This is based on the large ZOI radius for Mirror insulation [Ref. 4.30].

RMI and Min-K or Microtherm insulation is installed on the reactor head. The insulation on the reactor head could be dislodged by a Control Element Drive Mechanism (CEDM) ejection event and therefore, was evaluated as break S5.

Section 3.a.3 below provides the basis for limiting break size. As provided in the general guidance of NEI 04-07, break exclusion zones were disregarded and all piping locations were considered. NRC Branch Technical Position (BTP) MEB 3-1 was not used as a basis for determining potential LOCA break locations.

2. <u>Secondary Line Breaks</u>

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

Feedwater or main steam line breaks do not result in recirculation through the ECCS sumps and therefore, are not required to be analyzed for limiting breaks [Ref. 4.4]. Within the S/G D-ring walls, the SI and SDC injection and SDC suction lines are of smaller diameter than the hot and cold leg RCS piping. As a result, any breaks in these lines would be bounded by a hot leg break and were not specifically analyzed.

3. Basis for Limiting Break Size and Location

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

The hot leg is the largest line (42-inch ID) within the S/G cavity and produces the largest ZOI. A break (S1) on the hot leg at the S/G nozzle captures the most insulation debris. A break at this location also affects coating on sections of all S/G cavity walls, and captures the largest quantity of particulate debris. Since the south S/G D-ring is closest to the recirculation sumps and would potentially transport the most debris to the sump, the S1 break was analyzed for the S/G #2 hot leg nozzle. The cold legs have a smaller diameter (30-inch ID) than the hot legs and produce a smaller ZOI. However, because of the location of the cold leg suction lines relative to the S/G pedestal and the S/G D-ring entrance/exit path at Elevation (El) 80'-0", water and debris from a break in the line from S/G #2 to RCP 2A (S2) or to 2B (S3) flows only to the east side (from S2) or the west side (from S3) of Containment. The flow path from each of these locations to the recirculation sump is slightly different in terms of obstructions on El. 80'-0". Therefore, both of these break locations were analyzed.

The reactor head insulation is a hybrid design, consisting both of metal and non-metallic insulation. RMI and Min-K or Microtherm insulation is installed on the reactor head. The reactor head insulation is shielded from breaks (S1, S2 and S3) in the main RCS loop piping by the reactor cavity concrete. However, insulation on the reactor head could be dislodged by a control element drive mechanism (CEDM) ejection event and was evaluated as break S5. A CEDM ejection is assumed to result in a break diameter of nominally 4 inches. Based on its size the CEDM ejection S5 break would generate less fibrous debris and particulate debris than a large break in the primary loop (S1, S2, and S3). In addition, the S5 break would have a reduced ECCS recirculation flow rate as compared with the hot leg or cold leg breaks (S1, S2, and S3).

The hot and cold leg breaks (S1, S2, and S3) are also considered bounding for a reactor head vent line break which could result in a ¾-inch break and generate a minimal amount of debris. In addition, the SI injection and the SDC injection and suction lines located within the S/G D-ring are smaller diameter than the RCS piping and any breaks are considered bounded by the hot leg S1 break.

For breaks S4 and S6 there is the potential for a greater quantity of fiber insulation debris then from S1, S2 and S3 since the pressurizer enclosure includes Nukon and Temp-Mat insulation that could become debris. Based on this, the breaks (S4 and S6) in the pressurizer enclosure were also analyzed.

Figure 3-1 shows the locations of the postulated breaks and Table 3-1 provides the details on the locations for these breaks [Ref. 4.4].

Figure 3-1: Break Locations

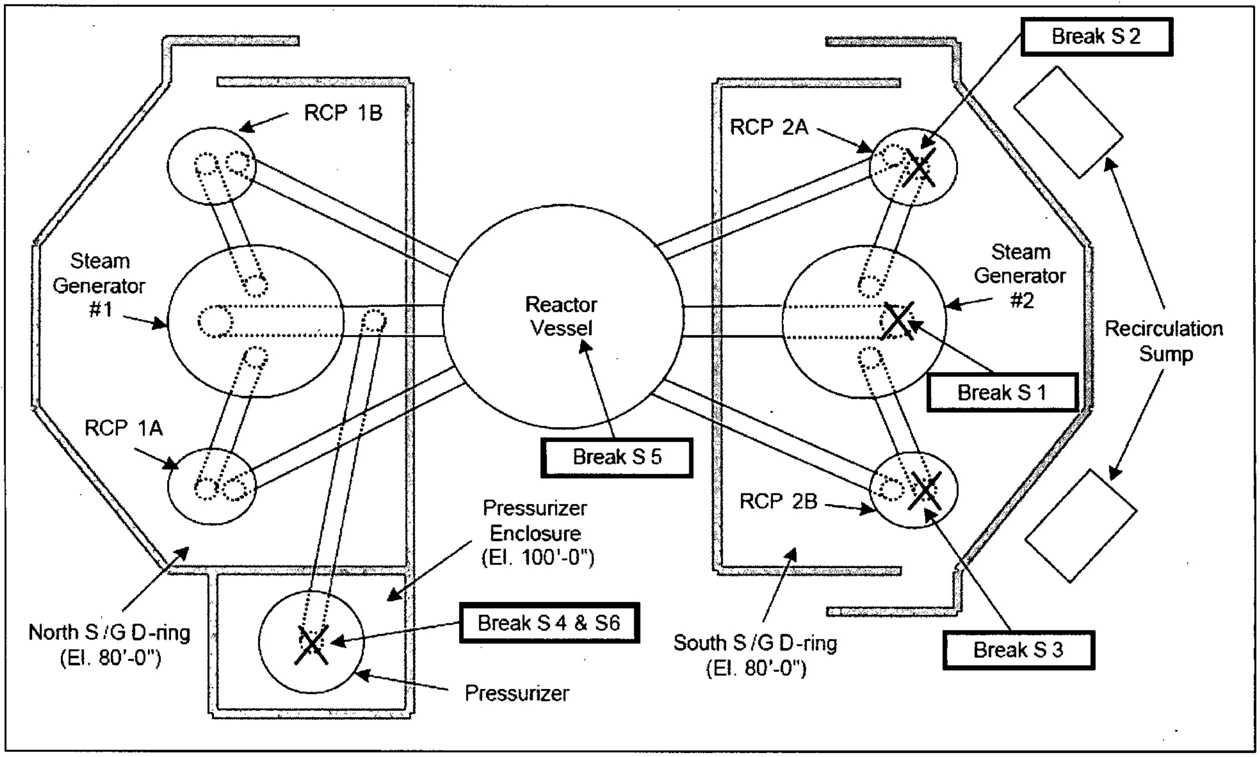


Table 3-1: Postulated Break Locations

Break Name	Location	Break ID (In)[2]	Elevation (Ft)	North-South Location (Ft) [1]	East-West Location (Ft) [1]	Enclosure
S1	S/G 2 hot leg (E-063-42") piping at the S/G nozzle	42	101.33	28.5 south	1 east	South S/G D-Ring
S2	Loop 2A cold leg suction (E-073-30") piping at the Reactor Coolant Pump (RCP) nozzle	30	92.61	28.5 south	18.36 east	South S/G D-Ring
S3	Loop 2B cold leg suction (E-084-30") piping at the RCP nozzle	30	92.61	28.5 south	16.36 west	South S/G D-Ring
S4	Surge line (E-028-BCAA-12") piping at the Pressurizer nozzle	12	110.42	26.3 north	40.21 west	Pressurizer
S5	CEDM ejection at Reactor Head	4	~122.5	0.0 north	1 east [3]	Reactor Head
S6	Pressurizer spray line piping at Pressurizer nozzle	4	152.47	26.3 north	40.21 west	Pressurizer

(1) North-south and east-west locations are in reference to center of the containment building.
(2) Nominal pipe diameter.
(3) Break location is conservatively at the reactor vessel centerline to maximize the amount of debris generated.

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

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

- ***Describe the methodology used to determine the ZOIs for generating debris. Identify which debris analyses used approved methodology default values. For debris with ZOIs not defined in the guidance report/SE, or if using other than default values, discuss method(s) used to determine ZOI and the basis for each.***
- ***Provide destruction ZOIs and the basis for the ZOIs for each applicable debris constituent.***
- ***Identify if destruction testing was conducted to determine ZOIs. If such testing has not been previously submitted to the NRC for review or information, describe the test procedure and results with reference to the test report(s).***
- ***Provide the quantity of each debris type generated for each break location evaluated. If more than four break locations were evaluated, provide data only for the four most limiting locations.***
- ***Provide total surface area of all signs, placards, tags, tape, and similar miscellaneous materials in containment.***

1. Methodology for Determination of ZOIs

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 (GR)/safety evaluation (SE), or if using other than default values, discuss method(s) used to determine ZOI and the basis for each.

The evaluation performed for PVNGS to determine the amount of debris adhered to the guidance provided in NEI 04-07, Baseline Methodology, and the associated SE, as well as WCAP-16568-P for qualified coatings [Refs. 4.30, 4.28 and 4.54, respectively]. The NEI Methodology was developed with the intent that all PWR owners would perform the evaluations in a consistent manner.

There are three basic steps in determining the debris generated as defined by the NEI Methodology and the SE:

- Select break
- Identify the ZOI for the break
- Quantify (by type) the debris that would be generated by the break

Debris generation was postulated at six different break locations (see Table 3-1), which bound all other locations for debris generation coupled with readiness of transport.

The amount of debris generation was evaluated based on the ZOI method, whereby, the radius (r) of this ZOI was based on multiples of the diameter (D) of the pipe where the break occurs (r/D). These r/D values comply with NEI 04-07 and its associated SE for the various types of insulation, etc., in the vicinity of the break.

Coatings on steel, concrete, and equipment in Containment are also evaluated. All qualified coatings at PVNGS for concrete are epoxy which are evaluated for a 4 r/D ZOI based on the results of testing presented in WCAP-16568-P [Ref. 4.54]. All qualified coatings for steel are inorganic zinc (IOZ), which are evaluated for a 5 r/D ZOI [Ref. 4.54], also based on results of testing. All unqualified and damaged qualified coatings are considered to be debris consistent with NEI 04-07 and its associated SE. Further discussion of coatings is contained in Section 3.h of this response submittal.

In accordance with NEI 04-07, all insulation material and coatings within the ZOI were considered to be generated as debris.

The cleanliness of Containment and presence of foreign material and latent material that could dislodge and become debris under LOCA conditions were considered in the debris generation evaluation. Minimizing such material is controlled by PVNGS procedures [Refs. 4.39 and 4.78].

Debris generation modes other than jet impingement, such as containment spray and submergence, were also considered, e.g., all unqualified and damaged qualified coatings in Containment are assumed to fail and become debris. In addition, turbulence-induced debris generation phenomenon caused by cascading water was considered, but generally is not applicable because practically all insulation is jacketed in Containment. The velocities and location of this cascading water are not sufficient to cause debris generation.

2. Zone of Influence

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

Table 3-2 lists ZOI r/Ds for qualified coatings and insulation materials (from NEI 04-07, Table 3-2 and Section 3.4.2.2).

Table 3-2: NEI 04-07 Zone of Influence

Insulation/Coating	ZOI Radius/ Break Diameter (r/D)
Protective coatings (Qualified)	10
Transco RMI	2.0
Min-K and Mirror RMI with standard bands	28.6
Temp-Mat with stainless steel wire retainer	11.7
Unjacketed Nukon	17.0

Table 3-3 lists ZOI r/Ds for qualified coatings and insulation materials found in the PVNGS Units 1, 2, and 3 containments. These ZOIs were used in the debris generation analysis [Ref. 4.4]. Table 3-3 also includes the assumption applied relative to unqualified and damaged qualified coatings:

Table 3-3: PVNGS Zone of Influence

Insulation/Coating	ZOI Radius/ Break Diameter (r/D)
Piping (Transco RMI or Mirror RMI)	28.6
Equipment RMI (Transco RMI)	2.0
Min-K/Microtherm	28.6 (2)
Nukon (All)	17.0
Temp-Mat (All)	11.7
Thermo-Lag	28.6 (1)
Qualified Coatings - Epoxy	4.0
Qualified Coatings – Inorganic Zinc (IOZ)	5.0
Unqualified Coatings and Damaged Qualified Coatings	All assumed to fail

(1) There is no information in the NEI or NRC documents [Refs. 4.28 and 4.30] regarding the ZOI for Thermo-Lag 330. Analysis assumed that the ZOI for this material was equal to the largest ZOI recommended by the NEI and NRC guidance documents (28.6 r/D). This is conservative and requires no further justification.

(2) It is assumed that Microtherm insulation installed on the reactor head in Units 1 and 2 has the same ZOI as Min-K insulation. Both insulations are microporous and Min-K has a ZOI of 28.6 r/D [Refs. 4.28 and 4.30], which is the largest of any insulation type. This is therefore considered a conservative assumption which requires no further justification.

The Transco RMI insulation on the pressurizer contains three layers of foil per inch of insulation [Ref. 4.4].

Transco RMI is essentially the same as Diamond Power Mirror RMI except that Transco RMI has more robust securing bands, giving it a smaller ZOI (2 r/D from NEI 04-07, Table 3-2). However, for the PVNGS evaluation, all Transco RMI on piping was conservatively modeled as Diamond Power Mirror RMI (28.6 r/D).

For Transco RMI installed on equipment, a 2.0 r/D ZOI was used, consistent with NEI 04-07, Table 3-2.

The ZOI for Thermo-Lag is unknown; therefore, the maximum ZOI of 28.6 r/D that is recommended for any insulation type by both the NEI and NRC Guidance documents [Refs. 4.28 and 4.30] is used.

There are various types of coatings documented within Containment [Ref. 4.4]. Coatings are classified as qualified, damaged qualified or unqualified. Qualified coatings are defined as coatings that will remain in place under Design Basis Accident (DBA) conditions. These coatings, if in good condition, were considered to become debris only in the ZOI. ZOI Radius/Break Diameters of 4 r/D for qualified epoxy coatings and 5 r/D for qualified inorganic zinc (IOZ) coatings are used. These values are based on jet impingement testing to determine ZOI for qualified coatings, per WCAP-16568-P [Ref. 4.54]. WCAP-16568-P is valid for PVNGS DBA Qualified/Acceptable untopcoated inorganic zinc coatings and DBA Qualified/Acceptable epoxy coating systems [Ref. 4.4, Attachment 8.15].

Table 3-4 lists the types of insulation located within S/G D-ring and pressurizer enclosures and above the reactor head, which is where the analyzed breaks are postulated to occur [Ref. 4.4].

Table 3-4: Insulation Type and Location

Insulation Type	Equipment/Location
Stainless Steel Reflective Metal Insulation (RMI) – Transco RMI	steam generators (S/G), primary and secondary piping connections to S/Gs, pressurizer, reactor head, reactor coolant pumps (RCP), RCS piping
Diamond Power Stainless Steel Mirror Insulation	SI, SDC, and chemical & volume control (CH) system piping at RCS; pressurizer spray and surge line piping; main steam, feedwater, auxiliary feedwater, and S/G blowdown piping at S/G; instrument and sample lines at RCS and S/G
Microtherm / Min-K (encapsulated)	located on reactor vessel head
Transco Temp-Mat with SS inner and outer skin	pressurizer (at keyway locations)
Nukon (under RMI)	Top of pressurizer
Unjacketed Nukon	pressurizer spray, feedwater, and S/G blowdown lines at piping supports
Temp-Mat	pressurizer ("field packed" at isolated locations)
Thermo-Lag	electrical raceways and equipment
Alpha-cloth	instrumentation penetrations in north S/G D-ring

3. Destruction Testing for Determination of ZOIs

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).

WCAP-16568-P [Ref. 4.54], which documented the destruction testing, was used for identifying ZOIs for qualified coatings.

4. Debris Generation

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.

The total quantity of debris generated for the six postulated LOCA Breaks (S1 through S6) is given in Section 6.2.1 of Calculation 2005-06160 [Ref. 4.4] and is repeated in Table 3-5. These debris quantities are applicable to PVNGS Units 1, 2, and 3.

Table 3-5: Total Debris Generated

Debris Type	**Units** (volume, area or weight)	**Break S1**	**Break S2**	**Break S3**	**Break S4**	**Break S5**	**Break S6**
INSULATION							
Diamond Power Mirror Foil – Within ZOI	[ft^2]	23,827	23,827	23,827	11,337	0	5,669
Transco RMI Foil – Within ZOI	[ft^2]	30,338	23,464	23,464	432	25	25
Nukon – Within ZOI	[ft^3]	9.82	9.82	9.82	9.16	0	3.33
Temp-Mat – Within ZOI	[ft^3]	0	0	0	0.15	0	0
Fiberfrax – Within ZOI(2)	[ft^3]	0	0	0	0	0	0
Thermo-Lag 330 – Within ZOI	[ft^3]	3.53	3.53	3.53	0	0	2.39
Alpha-cloth – CSS Generated	[ft^3]	0.1	0.1	0.1	0	0	0

Debris Type	**Units** (volume, area or weight)	**Break S1**	**Break S2**	**Break S3**	**Break S4**	**Break S5**	**Break S6**
Min-K/Microtherm (5)	[ft^3]	0	0	0	0	5.3	0
QUALIFIED COATINGS(1) (3)							
Steel Coatings (IOZ)	[ft^3]	2.2	2.2	2.2	0.1	0.1	0.2
Concrete Wall Coatings (Epoxy)	[ft^3]	0.1	0.1	0.1	0.1	0	0
Concrete Floor Coatings (Epoxy)	[ft^3]	1.8	1.8	1.8	0	0	0
DAMAGED COATINGS(1)							
Containment Liner (IOZ)	[ft^3]	0.01	0.01	0.01	0.01	0.01	0.01
Floor & Touchup (Epoxy)	[ft^3]	2.03	2.03	2.03	2.03	2.03	2.03
Log Totals After May 1997 – Epoxy	[ft^3]	0.32	0.32	0.32	0.32	0.32	0.32
Indeterminate Coatings (Epoxy)	[ft^3]	0.55	0.55	0.55	0.55	0.55	0.55
UNQUALIFIED COATINGS(1)							
From Entry in Coatings Log - (Failure Mode Eliminates Blockage Concern – This material is organic and inorganic zinc.)	[ft^3]	0.36	0.36	0.36	0.36	0.36	0.36
"R" Class Inorganic Zinc (IOZ)	[ft^3]	0.12	0.12	0.12	0.12	0.12	0.12
Totals After May 1997 – Zinc	[ft^3]	0.67	0.67	0.67	0.67	0.67	0.67

Debris Type	**Units** (volume, area or weight)	**Break S1**	**Break S2**	**Break S3**	**Break S4**	**Break S5**	**Break S6**
Zinc Primer/Cold Galvanizing	[ft^3]	0.13	0.13	0.13	0.13	0.13	0.13
Alkyd Enamel	[ft^3]	0.25	0.25	0.25	0.25	0.25	0.25
LATENT DEBRIS	[lb$_m$]	119.21	119.21	119.21	119.21	119.21	119.21
FOREIGN MATERIALS							
Duct Tape	[ft^2]	0.56	0.56	0.56	0.56	0.56	0.56
Glass Lighting	[ft^2]	139.2	139.2	139.2	139.2	139.2	139.2
Ty-Wraps	[ft^2]	0.45	0.45	0.45	0.45	0.45	0.45
Foil Labels	[ft^2]	2.24	2.24	2.24	2.24	2.24	2.24
Metal Labels	[ft^2]	41.63	41.63	41.63	41.63	41.63	41.63
Paper Labels	[ft^2]	17.78	17.78	17.78	17.78	17.78	17.78
Plastic Labels	[ft^2]	181.14	181.14	181.14	181.14	181.14	181.14
Velcro Labels	[ft^2]	0.55	0.55	0.55	0.55	0.55	0.55
Transient Material (4)	[ft^2]	66.0	66.0	66.0	66.0	66.0	66.0

(1) The volume of coating was determined as the product of component surface area and coating thickness. Conservative assumptions were made where details were not readily available. The coating thickness was conservatively taken as the maximum of the possible coating systems used.

(2) DMWO 2822654 removed the Fiberfrax from the PVNGS Unit 1, 2, and 3 Containments.

(3) Based on break ZOI of 5.0 r/D for steel coatings and 4.0 r/D for concrete coatings, design basis case, consistent with WCAP-16568-P [Ref. 4.54] recommendations. Break S1 is the bounding case for qualified coatings debris. Break S1 is the bounding case for qualified coatings debris and is also applied to breaks S2 and S3.

(4) This is the quantity of transient materials allowed per procedure [Ref. 4.39].

(5) PVNGS will eliminate the Min-K/Microtherm from the reactor head in each unit. This modification will be implemented when the reactor heads are replaced [Ref. 4.14, Attachment 5]. The new heads will be insulated with RMI, which will not adversely impact head loss test results.

5. Total Surface Area of All Signs, Placards, Tags, Tape, and Similar Miscellaneous Material

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

The total surface area of foreign material such as signs, labels, tags, tape, etc., is based on a walkdown of the Unit 2 Containment. Unit 2 is representative of Units 1 and 3 based on the design similarities between PVNGS Containments. In addition, the plant labeling procedures are the same for all PVNGS units. Table 3-6 lists the total quantity of foreign material based on the walkdown [Ref. 4.4].

Table 3-6: Foreign Materials

FOREIGN MATERIALS	Units	Quantity
Duct Tape	[ft^2]	0.56
Glass Lighting	[ft^2]	139.2 (1)
Ty-Wraps	[ft^2]	0.45
Foil Labels	[ft^2]	2.24
Metal Labels	[ft^2]	41.63 (1)
Paper Labels	[ft^2]	17.78
Plastic Labels	[ft^2]	181.14 (1)
Velcro Labels	[ft^2]	0.55
Transient Materials	[ft^2]	66.0
Total Foreign Materials	[ft^2]	449.55

(1) The glass lighting, metal labels and plastic labels do not transport..

The 66.0 ft^2 of transient materials is the maximum quantity of transient materials allowed per procedure [Ref. 4.39].

c. Debris Characteristics

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

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

1. Debris Size Categorization

Provide the assumed size distribution for each type of debris.

Section 3.4.3.2 of NEI 04-07 suggests a two-category size distribution for material inside the ZOI of a postulated break: small fines and large pieces. The NRC staff evaluation for this section in the SE states that the two-category size distribution is adequate, but can be problematic for debris transport refinements (e.g., computational fluid dynamics [CFD] analysis) that more realistically treat the transport process [Ref. 4.28, pg. 36). Therefore, the debris size categorization for Diamond Power Mirror RMI and Transco RMI foil debris outlined below breaks down the two categories into three sizes (fines, small pieces and large pieces). Two size categories are used for the low-density fiberglass (LDFG) and the high-density fiberglass (HDFG) debris. Based on these categories, values of debris size distribution from Calculation 2005-09080 [Ref. 4.14] are provided below.

Diamond Power Mirror RMI and Transco RMI Debris Size Categorization

The debris size distribution for RMI foil debris endorsed by the SE [Ref. 4.28] is divided into two categories: small fines and large pieces. Small fines are defined as debris capable of passing through openings in gratings, trash racks, and radiological fences less than a nominal 4-inch square [Ref. 4.28]. In this evaluation, within the small fines category, there are two sizes assumed (fines and small pieces).

The NEI-proposed distribution [Ref. 4.30] for RMI foil debris is 75 percent small fines (less than 4-inch square nominal) and 25 percent large pieces greater than or equal to 4-inch square nominal). Table 3-3 of the SE [Ref. 4.28] confirms this distribution. Further support for this distribution can be found in Appendix VI to the SE, which explains that the classification comes from the testing of a Diamond Power Specialty Company (DPSC) Mirror RMI cassette as reported in NUREG/CR-6808 [Ref. 4.71].

Section 3.2.2.4 of NUREG/CR-6808 [Ref. 4.71] discusses the details of the Siemens Metallic Jet Impact Tests (MJIT), which were conducted between October 1994 and February 1995, and are the basis for the NEI-and SE-endorsed size distribution for all RMI. Figure 3-7 of NUREG/CR-6808 [Ref. 4.71] refines this distribution (figure also contained in Appendix VI of the SE [Ref. 4.28] as Figure VI-2) as follows: five percent are fines (¼-inch square and smaller), 70 percent are small pieces (larger than ¼-inch square and smaller than 4-inch square) and 25 percent are large pieces (4-inch square and larger). Table 3-7 provides the PVNGS assumed debris size distribution percentages.

Table 3-7: RMI Debris Size Distribution

Size	Size Percentage
Fines (≤¼ inch)	5
Small pieces (> ¼ inch but < 4 inch)	70
Large pieces (≥4 inch)	25

Low Density Fiberglass (LDFG) (Nukon) Insulation Debris Size Categorization

LDFG debris such as Nukon can be divided into four sizes to permit transport analysis refinement according to the NRC's SE [Ref. 4.28]. The four sizes include fines and small pieces which are divisions of the small fines category, and large and intact pieces which are divisions of the large pieces category of the two-category size distribution suggested in NEI 04-07.

Table 3-8 summarizes the fibrous debris characteristics for those four sizes (from Safety Evaluation, Appendix VI, Table VI-1).

Table 3-8: Fibrous Debris Sizes

Size	Description	Airborne Behavior	Waterborne Behavior
Fines	Individual fibers or small groups of fibers	Readily moves with airflows and slow to settle out of air, even after completion of blowdown	Easily remains suspended in water– even relatively quiescent water
Small Pieces	Pieces of debris that easily pass through gratings	Readily moves with depressurization air flows and tends to settle out when airflows slow	Readily sinks in hot water and transports along the floor when flow velocities and pool turbulence are sufficient. Subject to subsequent erosion.
Large Pieces	Pieces of debris that do not easily pass through gratings	Transports with dynamic depressurization flows but generally is stopped by gratings	Readily sinks in hot water, and can transport along the floor when flow velocities and pool turbulence are sufficient. Subject to subsequent erosion.
Intact Pieces	Damaged but relatively intact pillows	Transports with dynamic depressurization flows but is stopped by gratings; may remain attached to piping	Readily sinks in hot water, and can transport along the floor when flow velocities and pool turbulence are sufficient. Still encased in its cover, thereby not subject to subsequent erosion.

For LDFG debris, Sections 3.4.3.2 and 3.4.3.3.1 of NEI 04-07 [Ref. 4.30] propose that 60 percent of all fibrous material within the ZOI becomes small fines. This position, accepted as conservative (although not realistic) in the NRC Staff evaluation of GR Section 3.4.3.2 in the SE [Ref. 4.28, p. 36], is based on a single LDFG debris generation test performed by Ontario Power Generation (OPG). In this test, 52 percent of the debris generated was small fines (see Table 3-7 of NUREG/CR-6808, [Ref. 4.71]). The use of 60 percent is also confirmed in Appendix II to the SE. Therefore, the fibrous debris size distribution is as listed in Table 3-9 and was utilized by PVNGS.

Table 3-9: LDFG (Nukon) Debris Size Distribution

Size	Size Percentage
Fines & Small Pieces	60
Large & Intact Pieces	40

Nukon debris is not subject to additional erosion when this NRC-approved size distribution is utilized [Refs. 4.28 and 4.30].

High-Density Fiberglass (HDFG) (Temp-Mat) Insulation Debris Size Categorization

In addition to Nukon, Temp-Mat HDFG insulation debris can be generated at PVNGS. Section 3.4.3.3.1 of NEI 04-07 [Ref. 4.30] proposes that 60 percent of all Nukon fibrous material within the ZOI becomes small fines. Since Temp-Mat has a higher destruction pressure than Nukon, the use of 60 percent fines for Temp-Mat is more conservative than the size distribution presented (and considered conservative) in Section II.3.1.2 of Appendix II to the SE. Table 3-10 summarizes the two fibrous debris size categories used by PVNGS.

Table 3-10: HDFG (Temp-Mat) Debris Size Distribution

Size	Size Percentage
Small Fines	60
Large Pieces	40

Temp-Mat debris is not subject to additional erosion when this NRC-approved size distribution is utilized [Refs. 4.28 and 4.30].

Debris Size Categorization for Thermo-Lag 330

Thermo-Lag 330 is a fire-barrier installed primarily on cable trays. The debris generation calculation indicates that the Thermo-Lag 330 is not installed within a ZOI of 4.0 r/D [Ref. 4.4] of any potential primary piping break. However, industry information regarding the destruction properties of Thermo-Lag 330 was not identified; therefore, a size distribution is not provided for Thermo-Lag 330. Rather the evaluation for PVNGS assumes all Thermo-Lag 330 generated will transport uninhibited to the sump strainers.

The Thermo-Lag as tested for PVNGS was a combination of 1-inch by 1-inch, 2-inch by 2-inch, and 3-inch by 3-inch pieces, fines from the cutting of the various sample sizes, and fines eroded by high pressure water jet. Section 3.f.4 provides preparation process for Thermo-Lag 330 used in the testing.

Debris Size Categorization for Coatings Debris

NEI 04-07 and the SE [Ref. 4.28, pg. 21-23] guidance indicate the following effects for coatings:

- All coatings in the ZOI will fail.
- All qualified coatings outside the ZOI remain intact unless damaged or degraded.
- All unqualified coatings in containment will fail.

Per Section 3.4.3.3.3 of NEI 04-07, all qualified coatings within the ZOI are considered small fines. This size is also conservatively applied to all unqualified coatings per the SE [Ref. 4.28, pg. 21], which states the following in its interpretation of NEI 04-07:

> *"... the coating debris size within the ZOI is applicable to all 'unqualified' indeterminate, and 'unacceptable' coatings that fail outside the ZOI."*

Damaged qualified epoxy coatings may be treated "as chips no smaller than 1/32 inch" [Ref. 4.4, Attachment 3]. Additionally, Item #4 of the "NRC Staff Review Guidance Regarding Generic Letter 2004-02 Closure in the Area of Coatings Evaluation," which is Enclosure 2 of the "Revised Guidance for Review of Final Licensee Responses to Generic Letter 2004-02," [Ref. 4.86], states that licensees may treat damaged qualified epoxy coatings that fail outside the break ZOI as chips and use available transport data to reduce their overall transport fraction. Therefore, qualified epoxy coatings deemed damaged or degraded are assumed to fail as chips no smaller than 1/32 inch at PVNGS.

Debris Size Categorization for Latent Debris

Guidance pertaining to the size of latent debris is provided in the Staff evaluation of GR Section 3.6.3 in the SE [Ref. 4.28, p. 60], which states that all debris generated outside the ZOI is small fine debris. This position, which was utilized by PVNGS, is consistent with the concept that latent debris consists of loose fibers and dirt/dust particles.

Min-K and Microtherm Debris Size Categorization

The guidance in the SE related to the size categorization of Min-K and Microtherm [Ref. 4.28] states that it should be considered 100 percent small fines debris. In addition, the Min-K and Microtherm generated by Break S5 is located in proximity to the break and would, therefore, likely be small fines debris. As a result, all generated Min-K and Microtherm debris at PVNGS is assumed to be small fines.

Alpha-cloth Debris Size Categorization

The Alpha cloth is a high density woven fiberglass material similar to Nukon cloth. The Nukon cloth does not transport as demonstrated in the transport test [Ref. 4.49].

2. Density of Debris

Provide bulk densities (i.e., including voids between the fibers/particles) and material densities (i.e., the density of the microscopic fibers/particles themselves) for fibrous and particulate debris.

The bulk densities and material densities for fibrous and particulate debris are provided below. Bulk densities are expressed as as-fabricated (theoretical packing) density (c_o) for fibrous debris. Material densities are expressed as fiber density (μ_f) for fibrous debris and as particle density (μ_p) for particulate debris.

Thermo-Lag 330

Thermo-Lag 330 properties for PVNGS are provided in Table 3-11 [Ref. 4.81].

Table 3-11: Thermo-Lag 330 Insulation Properties

Parameter	Value
As-Fabricated (theoretical packing) Density	73.8 lbm/ft^3
Fiber Density (μ_f)	Not available

Nukon Properties

Nukon properties for PVNGS are provided in Table 3-2 of NEI 04-07 and are repeated in Table 3-12.

Table 3-12: Nukon Insulation Properties

Parameter	Value
As-Fabricated (theoretical packing) Density (c_o)	2.4 lbm/ft^3
Fiber Density (μ_f)	159 lbm/ft^3

Temp-Mat Properties

Temp-Mat properties for PVNGS are provided in Table 3-2 of NEI 04-07 and are repeated in Table 3-13.

Table 3-13: Temp-Mat Insulation Properties

Parameter	Value
As-Fabricated (theoretical packing) Density (c_o)	11.8 lbm/ft^3
Fiber Density (μ_f)	162 lbm/ft^3

Inorganic Zinc (IOZ) Coatings Density

IOZ coatings density for PVNGS are taken from Table 3-3 of NEI 04-07 and repeated in Table 3-14.

Table 3-14: Inorganic Zinc Coatings Density

Parameter	Value
Particle Density (μ_p)	457 lbm/ft^3

Epoxy/Epoxy Phenolic Coatings Density

Epoxy/epoxy phenolic coatings density for PVNGS are taken from Table 3-3 of NEI 04-07 and repeated in Table 3-15.

Table 3-15: Epoxy/Epoxy Phenolic Coatings Density

Parameter	Value
Particle Density (μ_p)	94 lbm/ft^3

Alkyd Coatings Density

Alkyd coatings density for PVNGS are taken from Table 3-3 of NEI 04-07 and repeated in Table 3-16.

Table 3-16: Alkyd Coatings Density

Parameter	Value
Particle Density (μ_p)	98 lbm/ft^3

Latent Debris Properties

Latent debris properties for PVNGS are provided in the Staff evaluation of GR Section 3.5.2.3 in the SE [Ref. 4.28, pp. 50-53) and are repeated in Table 3-17 below. The properties are based on the "Method 2" debris characteristic definitions.

Table 3-17: Latent Debris Properties

Parameter	Value
Latent Particulate	
Percentage by mass of latent debris inventory	85
Particle Density (μ_p)	2.7 g/cm^3 (168.6 lbm/ft^3)
Latent Fiber	
Percentage by mass of latent debris inventory	15
As-Fabricated (theoretical packing) Density (c_o)	2.4 lbm/ft^3
Fiber Density (μ_f)	1.5 g/cm^3 (93.6 lbm/ft^3)

3. Assumed Specific Surface Areas for Fibrous and Particulate Debris

Provide assumed specific surface areas for fibrous and particulate debris.

The specific surface area (S_v) was used for preliminary analytically determined head loss values across a debris-laden sump screen using the correlation given in NUREG/CR-6224 [Ref. 4.66]. However, since the PVNGS head loss across the installed sump screens was determined via testing, the S_v values are not used in the design basis for PVNGS. Therefore, these values are not provided as part of this response.

4. Technical Basis for Debris Characterization Assumptions

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

Debris characterization properties of Nukon, Temp-mat, epoxy coatings, IOZ coatings, and alkyd coatings are as provided in NEI 04-07. The latent debris head loss properties are based on the “Method 2” debris characteristic definitions of NEI 04-07 SE.

d. Latent Debris

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

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

1. Methodology for Latent Debris Evaluation

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

Latent debris includes dirt, dust, lint, fibers, etc. and is a contributor to head loss across the sump screen. In accordance with recommendations in NEI 02-01 [Ref. 4.95], actual samples of discreet locations were collected as documented in detailed Walkdown Reports for Units 1, 2 and 3, [Refs. 4.10, 4.11, and 4.12, respectively]. These walkdowns inventoried the amount and types of latent debris materials that could become transportable and could contribute to the sump blockage or cause detrimental effects if allowed to pass the sump strainer.

The latent debris samples were collected using masolin cloth. Each masolin cloth was stored in a plastic bag. Each sample bag with masolin cloth was weighed before and after the sample was taken. The accuracy of the scale was to the 1/1000th gram, the weights were recorded to the 1/10th gram. The sampling area size identified in the walkdown plan was between five and 100 square feet. However, several of the actual samples acquired were less than five square feet due to the surface availability of the particular sample. [Refs. 4.10, 4.11 and 4.12]

Calculation 2005-06305 [Ref. 4.13] determined the total latent debris in Containment based on the sample measurements and containment surface areas. In that calculation the total latent debris in PVNGS Units 1, 2, and 3 Containments was calculated using statistical analysis (Student t distribution) from the sample collection measurements and the containment surface areas. A 90 percent confidence was selected (there will be a 90 percent probability that the actual mean loading will be less than or equal to the calculated upper limit on the mean debris loading). Typically four, but a minimum of three, samples of each surface type were collected.

The containment surface areas included the containment liner, equipment and component surface areas determined using arithmetic and trigonometric formulas for basic geometric shapes. Surface areas for horizontal surfaces of round pipes, ducts, tanks, etc. considered only the top hemisphere surface. Surface areas for vertical surfaces of round pipes, ducts, tanks, etc. considered the entire circumferential surface area. Dimensions were taken from scaled drawings and reference documents. The reactor cavity was not included because any debris washed down would drain to the reactor cavity sump and not transport to the recirculation sump. The refueling pool and transfer pool areas were not included because these areas are steel lined concrete and are subject to water fill/drain activity each refueling outage, which would wash away the latent debris. In addition, the containment dome liner surface was not considered in the calculated containment liner surface area for latent debris because it is inverted or tangent to the vertical plane.

Several methodologies were used in determining surface areas of piping, each based on specific piping characteristics within Containment. Piping insulation within Containment is predominately Mirror RMI installed by Diamond Power or RMI installed by Transco, Inc., for which detailed fabrication drawings were used in totaling pipe footage and insulation diameters. Uninsulated stainless steel piping surface areas were calculated based on pipe footage and diameters taken directly from the PVNGS piping isometric drawings. Uninsulated carbon steel piping and 10-inch diameter CS (uninsulated stainless steel) piping surface areas were obtained from APS calculations 13-NC-ZC-0208, Appendix A, Table A, page 43 [Ref. 4.46] and 13-NC-ZC-0237, Table 2.1, page 3 [Ref. 4.47]. Separation of vertical and horizontal surface areas for this piping was determined based on a calculated ratio of vertical to horizontal surface areas on included pipe from detailed piping insulation drawings.

Surface areas of steel beams and shapes supporting grating within Containment were based on the top horizontal surface of the beam or shape. Identification and lengths of the steel beams or shapes were determined from direct take-off from the steel framing drawings. Widths of the steel beams or shapes were determined from the Manual of Steel Construction [Ref. 4.96].

2. Assumptions Used in Latent Debris Evaluation

Provide the basis for assumptions used in the evaluation.

In Calculation 2005-06305 [Ref. 4.13], the following assumptions are made:

a) It is assumed that the debris loading is a normal distribution for a given sample type. This assumption is supported by the walkdown observations which showed that debris distribution appeared uniform for a given surface type.

b) The total surface area quantity of uninsulated carbon steel and 10-inch CS piping were taken from APS calculations [Refs. 4.46 and 4.47] (quantities are identical in both calculations). To determine the horizontal and vertical quantities, multipliers of 0.721 (horizontal) and 0.279 (vertical) are assumed. These multipliers represent the ratio of horizontal to vertical insulated piping within Containment as identified in Appendix A of the calculation [Ref. 4.13].

c) Conservative assumptions were used to determine basic geometric shapes to represent the building, equipment and components in the calculation of containment surface area.

d) Containment surface areas (HVAC duct, equipment and pipe) were calculated based on Unit 2 specific documents. It was assumed that these values are representative of all three PVNGS units for the purposes of containment surface area calculation. While it is recognized there may be unit-unique variances to equipment locations and/or HVAC duct and pipe routings, these unit-unique differences are not considered to be significant enough to affect the calculated containment surface areas for each of the three PVNGS units due to the conservatism employed by the calculation.

3. Results of Latent Debris Evaluation

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.

Walkdowns were performed in all three PVNGS units to determine the latent debris quantity using the sampling methods described in NEI 02-01 [Ref. 4.95]. As shown below the Unit 2 latent debris quantity was determined to be the largest at 119.21 lb. and is considered bounding for all three units. See Sections 3.c.1 and 3.c.2 above for latent debris size categorization and properties.

The total latent debris quantity determined in each Containment [Ref. 4.13] is as follows:

Unit 1 – The total weight of latent debris in Containment is 101.17 lb.
Unit 2 – The total weight of latent debris in Containment is 119.21 lb.
Unit 3 – The total weight of latent debris in Containment is 105.82 lb.

A conservative value of 200 lb. of latent debris was used in the strainer head loss testing [Ref. 4.81].

4. Sacrificial Strainer Surface Area

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

The PVNGS strainer surface area is 3,142 ft^2. Of that surface area, a sacrificial surface area of 400 ft^2 was conservatively excluded from use for chemical effects head loss testing. This sacrificial surface area was not provided to offset the 119.21 lb of latent debris identified above. This latent debris load was increased to 200 lbs. and added to the overall debris load for head loss testing.

The sacrificial area is excluded to conservatively offset the effects of labels, tags, stickers, placards and other miscellaneous or foreign materials. The sacrificial strainer surface area of 400 ft^2 is greater than the recommended 75 percent of the total foreign material debris area as described in NEI 04-07. The maximum quantity of foreign material determined to be transportable for PVNGS is 88 ft^2 (66 ft^2 with overlap [0.75*88 ft^2]). This value is rounded to 100 ft^2 for conservatism in the PVNGS evaluation.

e. Debris Transport

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

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

1. Methodology Used to Analyze Debris Transport

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

As part of the response to GL 2004-02, an evaluation for PVNGS was performed in accordance with the methodology outlined in the NEI 04-07 Guidance Report (GR) and its associated SE to determine the debris loading that would result in the maximum head loss across the ECCS sump screens. Additional guidance on debris transport was taken from Regulatory Guide 1.82 [Ref. 4.34]. The evaluation quantifies the high energy line break (HELB) generated debris that would be transport to the ECCS sump strainers. The amount of debris generation and characteristics of debris transport are used to determine debris loading. The debris loading is maximized to conservatively evaluate the blockage of the strainers and its effect on NPSH of the pumps. As an additional conservatism the time dependent rate of debris loading (accumulation) on the strainers is not credited to reduce the effect of any strainer blockage.

Debris transport was considered during PVNGS containment pool fill-up prior to recirculation and during actual recirculation. The containment pool is defined as the water that accumulates on the floor of the Containment. The containment pool has active areas whose contained debris and water volumes may transport to the ECCS sump strainers. The containment pool also has inactive areas, although they were not credited in the transport analysis [Ref. 4.14]. In determining debris transport, computational fluid dynamics (CFD) was used to chart flow velocities in a three dimensional (3-D) model. CFD analysis considered bulk flow velocity and turbulence in detail and is evaluated in a 3-D model of the containment pool. The debris that is sufficiently fine to remain in suspension due to turbulence is considered to transport to the strainers.

In the PVNGS evaluation each type of debris was considered as to its size distribution. It is conservatively assumed that the debris breaks down to its minimum size during debris generation; thus no further particle size reduction would occur during transport.

NRC sponsored experimental transport data was used in conjunction with CFD to predict debris transport. The CFD modeling techniques are consistent with NUREG/CR-6773 [Ref. 4.72]. For PVNGS all debris generated within ZOIs inside the S/G D-rings is assumed to be transported to the active area of the containment pool at the bottom of the S/G D-rings. For this active area there are no significant debris blockage points upstream of the strainers (See Section 3.I). The water holdups in Containment amount to a small percentage of the total water inventory and are conservatively accounted for in the minimum flood level calculation [Ref. 4.15].

The strainers are submerged by more than two inches at the minimum flood level during recirculation; therefore, blockage from floating debris is not credible. Additionally, the top of the strainers are not perforated but are solid plate [Ref. 4.25], which reduces the potential for any floating debris to be drawn down onto the strainer surfaces.

The strainers are completely submerged at recirculation actuation signal (RAS). The PVNGS CSS, low pressure safety injection (LPSI) and high pressure safety injection (HPSI) pump suctions are piped together so RAS switchover is simultaneous for all pumps.

Transport Modes

Debris transport is the estimation of the fraction of debris that is transported from debris sources to the ECCS sump strainers. In accordance with the guidance provided in Section 3.6.1 of NEI 04-07, four major debris transport modes were considered.

- Blowdown Transport – The horizontal and vertical transport of debris by the break jet. For PVNGS all fiber, particulate, and RMI-type debris is conservatively transported to the containment floor and no debris is transported upwards to the containment dome.

- Washdown (containment spray) Transport – The vertical transport of debris by the containment sprays/break flow. Since all fiber, particulate, and RMI debris for PVNGS is modeled as transporting to the containment floor during blowdown, there is no washdown transport.

- Pool Fill-Up Transport – The horizontal transport of the debris by break and containment spray flows to active and inactive areas of containment pool. For PVNGS all fiber, particulate, and RMI debris is conservatively transported out of the S/G D-rings to the containment pool and no transport to inactive areas is modeled.

- Recirculation Transport – The horizontal transport of the debris in the active areas of the containment pool by the recirculation flow through the ECCS/CSS. For PVNGS the velocity contours provided in the CFD analysis [Ref. 4.14, Attachment 1] are used to determine whether each debris type will stall or transport to the ECCS sump strainers.

2. Debris Transport Assumptions

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

Certain assumptions are inherent in the PWR sump evaluation methodology presented in NEI 04-07, the SE, and various NUREGs and were used by PVNGS in their evaluation. Additional assumptions for the PVNGS evaluation [Ref. 4.14] include:

- In the absence of specific coatings information, coatings are assumed to be epoxies

- All latent fiber is assumed to have the same characteristics as Nukon insulation.

- Thermo-Lag 330 debris is generated, but no debris information is provided in NEI 04-07 for Thermo-Lag. Therefore, all Thermo-Lag 330 debris generated is assumed to transport uninhibited to the sump strainers.

For PVNGS debris transport, it was conservatively assumed that the maximum flow from each train of the CSS, LPSI, and HPSI pumps is exiting from each train's respective ECCS recirculation sump. This was done to maximize debris transport to the sump and thus provide a conservative head loss evaluation.

3. Debris Transport Evaluation - CFD

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

The PVNGS debris transport evaluation was performed in conformity with the guidance provided in the SE in addition to portions of the methodology presented in Section 3.6 of NEI 04-07. The blowdown and washdown transport analyses were performed consistent with Section 3.6 of NEI 04-07 and Appendix VI of the SE. Containment pool fill-up transport analysis was performed consistent with Appendix III of the SE; however, no volumes in inactive areas were modeled. An analytically refined recirculation transport analysis was performed using a CFD model of the post-LOCA recirculation flow patterns in Containment. Guidance for the recirculation transport analysis is provided in Appendix III of the SE.

a) Computational Fluid Dynamics: Methodology

CFD models a fluid as it behaves in a complex geometry with various fluid inlet sites and outlets. It can predict fluid velocities at many points in a 3-D fluid field. For PVNGS, a steady state CFD analysis was performed using FLUENT Version 6.1.22 software on the available volume of water in the bottom of the Containment during a LOCA [Ref. 4.14]. The flow patterns and velocities attained are used as inputs to the debris transport analysis. The CFD modeling techniques used are consistent with the SE, NEI 04-07 [Ref. 4.30] and NUREG/CR-6773 [Ref. 4.72].

CFD model development involves the creation of a three dimensional computer model of the system geometry using a computer aided drawing (CAD) package. During the model geometry creation process, some conservative assumptions were made for simplification. These assumptions are based on experience and an understanding of the flow details of interest. Initially as part of the evaluation process the model is divided into thousands of three dimensional cells within which flow equations are solved. Afterwards the areas of special interest and of high velocity gradients are adapted to increase the number of cells being evaluated. Factors influencing the flow conditions, boundary conditions, are then assigned to the model. These include inlet flows, properties of the water, and pressure loss through the sump screens. Then the simulation processing is performed, which consists of the computer solving a complex and coupled set of numerical equations for each of the cells within the modeled space. The results are most effectively communicated through the creation of graphical plots and animation.

Scenarios

The LOCA scenarios that were simulated using the CFD model [Ref. 4.14] are listed in Table 3-18.

Table 3-18: LOCA Scenarios Simulated

Scenario #	Break Flow Rate (gpm)	Break Entry Point	Sump(s) Operating	Containment Spray Flow (gpm)
1	1,400	Southeast stairwell	Southeast	4,885
2	2,800	Southeast stairwell	Southeast & Southwest	9,770
3	1,400	Southwest S/G D-ring opening	Southwest	4,885
4	1,400	Northwest S/G D-ring opening	Southwest	4,885
5	12,800	Northwest S/G D-ring opening	Southeast & Southwest	10,400

Scenario #5 assumes both trains of the LPSI pumps operating. This is conservative because during a RAS, both LPSI trains are not operating. However, failure of a single LPSI train to shutoff for one hour after RAS is considered.

b) Modeling Assumptions

The walls and floor of Containment were assumed smooth, i.e., the roughness height is zero. This results in a conservatively higher velocity near the floor and walls of the containment pool.

The top surface of the containment pool was modeled as a rigid frictionless lid. This results in a CFD model of the containment pool that has a constant elevation.

Figure A1 of "Post LOCA Debris Transport for Resolution of GSI-191," Rev. 2 [Ref. 4.14] provides the geometry and inlet flow conditions used for

Scenarios 1 through 5. That figure shows the location and flow rate of each of the spray flows as well as the location of the assumed breaks. Drawings listed in Section 6 of "Post LOCA Debris Transport for Resolution of GSI-191." Rev. 2 [Ref. 4.14] were used to create the model. Also the detailed geometry near the sump pit and the surrounding inner mesh screens is provided in Figure A2 of "Post LOCA Debris Transport for Resolution of GSI-191," Rev. 2 [Ref. 4.14]. The grating and screens that surround the sump pit were combined into a single surface. The water level is 4.5 ft above the floor for all the scenarios. Obstructions such as columns, tanks, equipment, etc., are noted. There are two sumps located in the Containment, one on the southeast side and one on the southwest side.

The CFD model is considered to be acceptable and representative of the flows in Containment after the replacement of the pre-GSI-191 sump screens, because the replacement sump screens are located on a sub-floor over the sump pit; hence they occupy the same footprint. Therefore, a significant difference in the containment pool flows is not anticipated. Additionally the outlet piping was not considered due to its minimal impact on velocity distribution.

The hallway area north of the primary shield wall within the S/G D-ring will divert a fraction of the flow. However, for conservatism, this hallway area was modeled as inactive for all breaks. All Tri-Sodium Phosphate (TSP) baskets were conservatively modeled as solid boxes.

Break flow from HPSI will enter the containment pool through several of the four containment stairwells. However, conservatively, the break flow was modeled as flowing through the closest stairwell to the break. The containment spray flow rates emerging from each of the four access doors to the SG Bays are assumed equal.

The water properties for density and viscosity were assumed at a temperature of 252°F [Ref. 4.31] for modeling because water has a lower viscosity at a higher temperature. A lower viscosity conservatively results in a smaller boundary layer and a higher velocity near the floor.

The containment spray flow is distributed into twelve areas of the Containment and the flow is commensurate with the percentage of containment spray that gets funneled into each area.

c) Results

The CFD analysis is used to determine the transport fractions for the non-small fines of Mirror and Transco RMI, Nukon, Temp-Mat, plastic and metallic equipment labels, light bulb glass and damaged qualified epoxy coating debris only. Detailed recirculation transport analyses are not performed for small fines of these debris types as they are 100 percent transportable. A detailed recirculation transport analysis is not performed for Thermo-Lag 330 either, as all Thermo-Lag 330 is considered to transport to the sump screens.

Debris that is dislodged from the piping or equipment will transport to the sump screen only if the flow velocities generated from the postulated line break exceed the minimum transport velocity for the entire path from the area where the debris enters the pool to the sump screen perimeter. The strainers construction results in the bottom of the strainer being 9 inches above the containment floor. Once at the perimeter of the sump screen, the velocity must exceed the lift velocity to transport debris to the strainer.

No detailed recirculation transport evaluations are performed for small fines debris. Rather, all small fines debris is treated as transporting to the sump screens.

The transport properties used herein are the velocity at which incipient tumbling occurs (transport threshold velocity) and the lift over curb velocity. Each type of debris has distinct transport properties.

Incipient Tumbling Velocity

The incipient tumbling velocity used for the recirculation transport analysis for RMI, Nukon, Temp-Mat and coating chip debris generated is presented below.

Stainless Steel RMI Foil – Mirror and Transco

Per Tables 4-1 and 4-2 of NUREG/CR-3616 [Ref. 4.64], the minimum flow velocity associated with incipient tumbling (velocity required to initiate motion) for pieces of stainless steel RMI foil is 0.20 ft/s. Therefore, the minimum flow velocity associated with incipient tumbling for all non-fines RMI foil sizes is taken as 0.20 ft/s. It is noted that the NUREG/CR-3616 tests used Mirror RMI foil. However, the tests are considered applicable to Transco RMI as well since the foil inside the RMI cassettes is similar.

Stainless Steel Covers/Lagging – General

Per Table 4-1 of NUREG/CR-3616 [Ref. 4.64], the minimum flow velocity associated with incipient tumbling (velocity required to initiate motion) for RMI covers is 0.7 ft/s. Therefore, the minimum flow velocity associated with incipient tumbling for all RMI lagging is taken as 0.7 ft/s. This transport velocity is also considered acceptable for lagging on any other type of insulation (e.g. fiber).

Nukon (LDFG) and Temp-Mat (HDFG)

For large Nukon insulation debris, Table 5-3 of NUREG/CR-6808 [Ref. 4.71] reports various transport velocities for pieces of Nukon debris; the lowest reported velocity is for a 1-inch by 3-inch by 2-inch piece and the corresponding incipient tumbling velocity is 0.26 ft/s. This velocity is used for large Nukon debris herein.

The Nukon transport velocity is also used for Temp-Mat. This is considered acceptable since the as-fabricated density of Temp-Mat is greater than the as-fabricated density of Nukon; therefore, Temp-Mat is more likely to settle and not transport than Nukon.

Epoxy Paint Chips

Per Table 4-3 of NUREG/CR-6916 [Ref. 4.97], the minimum incipient tumbling velocity for the "E3C" coating system (which most closely resembles the coatings at Palo Verde [Ref. 4.14, Attachment 4]) is 0.34 ft/s. This incipient velocity is for one to two inch coating chips. The bulk tumbling velocity for this range of coating chips sizes is 1.01 ft/s. For a continuous distribution of chips ranging in size from 1/64-inch to two inches the incipient tumbling velocity is 0.79 ft/s (the bulk tumbling velocity is 1.42 ft/s). While the velocity associated with the continuous size distribution is likely more appropriate, for conservatism the minimum incipient tumbling velocity of 0.34 ft/s is used herein.

Lift Over Curb Velocity

The curb at the edge of the sump is multi-staged [Ref. 4.25]. Based on the curb configuration, the bottom of the lowest pocket in the sump screen begins approximately nine inches above the containment floor. Therefore, debris must lift off the floor to transport to the strainer pockets.

Lift over curb data for a 2-inch, 6-inch and 9-inch curb is used in the transport analysis. Data for 2-inch and 6-inch curbs is from NUREG/CR-6772 [Ref. 4.65] and data for 9-inch curbs is from CCI Test Report 680/41401 [Ref. 4.49]. Plant specific transport data was obtained from flume tests performed by CCI [Ref. 4.49]. The plant specific tests [Ref. 4.49] included a 9-inch curb and a maximum velocity of 0.66 ft/s and are therefore the most appropriate data to use. However, of the debris types which are subjected to a detailed recirculation transport evaluation, only equipment labels, light bulb glass and damaged qualified epoxy coating chips were evaluated by the 9-inch curb test. Therefore, transport of other debris is evaluated based on data for either a 2-inch or 6-inch curb.

The lift over curb velocity for RMI, fibrous debris, coating chips, and foreign material generated is presented below.

Stainless Steel RMI Foil – Mirror and Transco

Per Table 3.5 of NUREG/CR-6772 [Ref. 4.65], the lift over curb velocity for a 2-inch curb for both 1/2-inch by 1/2-inch and 2-inch by 2-inch RMI foil is 0.84 ft/s for Configuration A. Specific data is not available for a 6-inch curb although Table C.17 of NUREG/CR-6772 indicates that the RMI tested did not lift at velocities up to 0.99 ft/s for Configuration A. Therefore, the lift over curb velocity for all non-fines RMI sizes is taken as 0.99 ft/s.

Nukon (LDFG) and Temp-Mat (HDFG)

Per Table 3.1 of NUREG/CR-6772 [Ref. 4.65], the lift over curb velocities for size Classes 3 and 4 Nukon debris are 0.25 ft/s for 2-inch curbs and 0.34 ft/s for 6-inch curbs for Configuration A. Due to the curb configuration at Palo Verde, the lift over curb velocity for a 6-inch curb (0.34 ft/s) is considered appropriate and is used for large Nukon insulation debris.

The Nukon transport velocity is also used for Temp-Mat. This is considered acceptable since the as-fabricated density of Temp-Mat is greater than the as-fabricated density of Nukon; therefore, Temp-Mat is more likely to settle and not transport than Nukon.

Covers/Lagging and Intact Debris

Lift over curb velocities for insulation lagging and intact debris are not provided in the available literature; however, they are expected to be significantly greater than the velocities experienced in the post-LOCA sump pool. Thus, lagging and intact debris (RMI or fiber) will not lift over a curb due to their size and density.

Epoxy Paint Chips

The PVNGS transport tests [Ref. 4.49] indicate that epoxy coating chips (up to ¼-inch in size) did not lift over a 9-inch curb in the test loop at upstream velocities up to 0.66 ft/s (0.20 m/s). Therefore, the minimum lift over curb velocity for epoxy paint chip debris is greater than 0.66 ft/s, but is conservatively taken as 0.66 ft/s. Also, typically the lift over curb velocity is greater than the bulk tumbling velocity for a debris type [Ref. 4.65] and the most conservative (smallest) bulk tumbling velocity for damaged qualified epoxy coating chips larger than 1/32-inch is 1.01 ft/s, making 0.66 ft/s a conservative lift over curb value.

Foreign Materials (Resin Labels and Light Bulb Glass)

Transport of resin (plastic) equipment labels and light bulb glass is documented in the CCI transport, bypass and head loss test report [Ref. 4.49]. Plastic labels and light bulb glass will not transport to the sump screen since their lift over curb velocity is greater than 0.66 ft/s. The same test apparatus used to investigate epoxy coating chips transport was used to investigate transport of these debris types. Based on the information in the test report, plastic labels have a transport fraction of zero. Additionally, since metallic equipment labels will be heavier and denser than plastic labels, it is considered conservative to apply the results of the plastic label transport test to metallic equipment labels also. Therefore, metallic equipment labels also have a transport fraction of zero. Finally, based on the information in the test report, light bulb glass has a transport fraction of zero.

Debris Transport Analysis Results

Flow patterns were derived for the five LOCA scenarios determined for PVNGS [Ref. 4.14]. Table 3-19 provides the highest continuous velocities used in the debris transport calculation to define the amount of debris in the water flow path before it reaches the applicable ECCS sump strainer.

Table 3-19: Highest Continuous Velocity Connecting Break to Sump Region

	Scenairo				
	1	2	3	4	5
Highest continuous velocity zone connecting the break to the sump region (ft./sec.)	0.13	0.21	0.17	0.10	0.64

A summary of the blowdown, washdown, pool fill-up, and recirculation debris transport modes and the manner in which they are modeled is provided in Table 3-20. Debris transport logic trees were used to determine transport fractions for non-fines debris (whose transport fraction is 1.0), which are reported in Section 3.e.6.

Table 3-20: Summary of Debris Transport Analysis

Transport Mode	Details
Blowdown	All fiber, particulate, and RMI debris is transported to the containment floor. No debris is transported upwards to the containment dome.
Washdown	Since all fiber, particulate, and RMI debris is modeled as transporting to the containment floor during blowdown, there is no washdown transport.
Pool Fill-up	All fiber, particulate, and RMI debris is transported out of the D-rings to the sump pool. No transport to inactive volumes is modeled.
Recirculation	The velocity contours provided in the CFD analysis [Attachment 1 of Ref. 4.14] are used to determine whether each debris type will stall or transport to the sump. Large RMI, fibrous debris, equipment labels and damaged qualified epoxy coating chips do not transport to the sump for CFD scenarios 1 through 4. For CFD scenario 5, large RMI, equipment labels, light bulb glass and damaged qualified epoxy coating chips do not transport to the sump, but large piece fibrous debris does transport to the sump. Accordingly, the scenario 5 results are used to determine the bounding debris load at the strainer.

4. <u>Debris Interceptors</u>

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

No debris interceptors are installed or credited. However, there is a curb around the perimeter of each ECCS sump strainer. The PVNGS chemical effects head loss testing was performed with an arrangement to represent the curb [Ref. 4.81].

5. <u>Fine Debris Settlement versus Transport</u>

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

Per the Staff evaluation for GR Section 3.6.3 in the SE to NEI 04-07, for the PVNGS evaluation all small fines debris, regardless of type, was modeled as transporting to the ECCS sump strainer. The transport fraction to the sump screen is equal to 1.0 (i.e., no credit was taken for settling of small fines).

6. Debris Transported to Sump Strainer

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

The PVNGS calculated debris transport fractions and the total quantities of each type of debris transported to the strainers were determined [Ref. 4.14] and are summarized in Table 3-21 and Table 3-22 for the bounding breaks.

Debris transport fractions are provided in Table 3-21. A portion of RMI foil debris and fiber debris transports to the sump while all qualified and unqualified coatings debris (except for damaged qualified epoxy coating chips), Alpha-cloth, Min-K/Microtherm, Thermo-Lag, latent debris, and foreign material (except for plastic and metallic labels and light bulb glass) transports to the sump for all break scenarios. Insulation jacketing/lagging does not transport. The transport fractions for fibrous insulation, damaged qualified epoxy coating chips, plastic and metallic equipment labels, light bulb glass and RMI debris are taken from CFD Scenario 5 since this scenario results in the most Nukon at the sump screen.

It is unclear what constitutes the bounding break from a head loss perspective. Break S1 generates the same debris types as Breaks S2, S3 and S6, except for resulting in more Transco RMI than either Break S2 or S3 and more of all types of debris than S6. Break S1 also generates considerably more debris than Break S4 (especially coating debris), except for fibrous debris. Break S1 generates slightly more Nukon debris than S4 (9.82 – 9.16 = 0.66 ft^3). However, Break S4 generates a small amount (0.15 ft^3) of Temp-Mat. Considering that Temp-Mat is approximately five times as dense as Nukon (11.8 pcf vs 2.4 pcf) [Ref. 4.30, Table 3-2], this small amount of Temp-Mat is equivalent to approximately 0.75 ft^3 (0.15 x 11.8/2.4) of Nukon. Therefore, the amounts of fibrous debris generated by Breaks S1 and S4 are approximately equal and the Break S1 fibrous debris total is utilized in the transport evaluation. Finally, Break S5 generates a debris type which Break S1 does not. Break S5 results in 5.3 ft^3 of Min-K/Microtherm. Since no Min-K/Microtherm is generated by other breaks, the transport of debris from Break S5 is also evaluated. The final tabulation of debris at the sump screen is shown in Tables 3-21 and 3-22.

Foreign materials inside containment may become debris during a LOCA or during containment spray and may add to the debris loading of the ECCS sump screen. Examples of foreign materials are valve tags, cable tray and conduit tags, etc. The type, size, and quantity of foreign materials are provided in the Walkdown Report for Unit 2 [Ref. 4.2]. For the PVNGS all foreign materials except for resin labels secured with metal wire or screws were presumed to be a debris source regardless of location. Resin labels secured with metal wire or screws were only presumed to be a debris source if within the ZOI for the postulated breaks [Ref. 4.2]. The strainer vendor's testing documents that resin (plastic) labels and light bulb glass will not transport [Ref. 4.49]. Since metallic equipment labels are heavier and denser that plastic labels, it is considered conservative to also apply the results of the plastic labels to the metallic labels. All other foreign materials were modeled with 100 percent transport to the sump screen.

Foreign materials can either disintegrate in transport or be transported to the sump screen intact. Since no disintegration data is available for the foreign materials at PVNGS, they are modeled as remaining intact. In this case, the wetted sump screen area was reduced by an area equivalent to 75 percent of the original single sided surface area of the foreign materials transported to the sump screen per the SER [Ref. 4.28, pg. 49-50].

Table 3-21: Bounding Debris Quantity at Sump for Primary Loop Break S1

Debris Type	Units (volume, area or weight)	Fraction of Debris at Sump Screen	Debris Generated	Debris Quantity at Sump
Insulation within Break ZOI				
Diamond Power Mirror RMI Foil	[ft²]	0.050	23,827	1,191
Transco RMI Foil	[ft²]	0.050	30,338	1,517
Nukon	[ft³]	1.00	9.82	9.82
Nukon (fines/small pieces) (3),(4)	[ft³]	*1.00*	*5.89*	*5.89*
Nukon (large pieces) (3),(4)	[ft³]	*1.00*	*3.93*	*3.93*
Temp-Mat	[ft³]	Not generated for Primary Loop Breaks		
Thermo-Lag 330	[ft³]	1.00	3.53	3.53
Min-K/Microtherm (6)	[ft³]	1.00	0	0
Alpha-cloth	[ft³]	1.00	0.1	0.1
Coatings				
Qualified IOZ	[ft³]	1.00	2.2	2.2
Qualified Epoxy	[ft³]	1.00	1.9	1.9
Unqualified IOZ	[ft³]	1.00	1.28	1.28
Unqualified Alkyds	[ft³]	1.00	0.25	0.25
Damaged Qualified IOZ	[ft³]	1.00	0.01	0.01
Damaged Qualified Epoxy	[ft³]	0	2.9	0
Foreign Materials				
Total Foreign Materials	[ft²]	0.195(5)	449.55	87.58(7)
Plastic Labels(3)	[ft²]	*0*	*181.14*	*0*
Metallic Labels(3)	[ft²]	*0*	*41.63*	*0*
Light Bulb Glass(3)	[ft²]	*0*	*139.2*	*0*
Other Foreign Materials(3)	[ft²]	*1.00*	*87.58*(7)	*87.58*(7)
Latent Debris				
Latent Debris (Particulates)(1),(2)	[lbm]	1.00	170	170
Latent Debris (Fiber)(1),(2)	[lbm]	1.00	30	30

(1) The total latent debris is conservatively increased to 200 lbm.

(2) Per the Staff Evaluation of Section 3.5.2.3 of NEI 04-07, 85 percent of the latent debris is particulate and 15 percent is fiber [Ref. 4.30].

(3) Italics denote subtotals.

(4) Nukon is 60 percent small fines and 40 percent large pieces per Table 3-9.

(5) The fraction of debris at the sump screen for "Total Foreign Materials" is not a transport fraction of a particular material but rather a calculated ratio of the total transported foreign material to the total generated foreign material.

(6) PVNGS will eliminate the Min-K/Microtherm from the reactor head in each unit when the reactor heads are replaced. The new heads will be insulated with RMI.

(7) Overlap is not accounted for in this value.

Table 3-22: Bounding Debris Quantity at Sump for Break S5

Debris Type	Units (volume, area or weight)	Fraction of Debris at Sump Screen	Debris Generated	Debris Quantity at Sump
Insulation within Break ZOI				
Diamond Power Mirror RMI Foil	[ft^2]	Not generated for Break S5		
Transco RMI Foil	[ft^2]	0.050	25	1.25
Nukon	[ft^3]	Not generated for Break S5		
Nukon (fines/small pieces) (3),(4)	[ft^3]	Not generated for Break S5		
Nukon (large pieces) (3),(4)	[ft^3]	Not generated for Break S5		
Temp-Mat	[ft^3]	Not generated for Break S5		
Thermo-Lag 330	[ft^3]	Not generated for Break S5		
Min-K/Microtherm (6)	[ft^3]	1.00	5.3	5.3
Alpha-cloth	[ft^3]	Not generated for Break S5		
Coatings				
Qualified IOZ	[ft^3]	1.00	0.1	0.1
Qualified Epoxy	[ft^3]	1.00	0	0
Unqualified IOZ	[ft^3]	1.00	1.28	1.28
Unqualified Alkyds	[ft^3]	1.00	0.25	0.25
Damaged Qualified IOZ	[ft^3]	1.00	0.01	0.01
Damaged Qualified Epoxy	[ft^3]	0	2.9	0
Foreign Materials				
Total Foreign Materials	[ft^2]	0.195(5)	449.55	87.58(7)
Plastic Labels(3)	[ft^2]	*0*	*181.14*	*0*
Metallic Labels(3)	[ft^2]	*0*	*41.63*	*0*
Light Bulb Glass(3)	[ft^2]	*0*	*139.2*	*0*
Other Foreign Materials(3)	[ft^2]	*1.00*	*87.58*(7)	*87.58*(7)
Latent Debris				
Latent Debris (Particulates)(1),(2)	[lbm]	1.00	170	170
Latent Debris (Fiber)(1),(2)	[lbm]	1.00	30	30

(1) The total latent debris is conservatively increased to 200 lbm.

(2) Per the Staff Evaluation of Section 3.5.2.3 of NEI 04-07, 85 percent of the latent debris is particulate and 15 percent is fiber [Ref. 4.30].

(3) Italics denote subtotals.
(4) Nukon is 60 percent small fines and 40 percent large pieces per Table 3-9.
(5) The fraction of debris at the sump screen for "Total Foreign Materials" is not a transport fraction of a particular material but rather a calculated ratio of the total transported foreign material to the total generated foreign material.
(6) PVNGS will eliminate the Min-K/Microtherm from the reactor head in each unit when the reactor heads are replaced. The new heads will be insulated with RMI.
(7) Overlap is not accounted for in this value.

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).***

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

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

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.***

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

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

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

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

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

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

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.

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.***

13. ***State whether temperature/viscosity was used to scale the results of the head loss tests to actual plant conditions. If scaling was used, provide the basis for concluding that boreholes or other differential-pressure induced effects did not affect the morphology of the test debris bed.***

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.***

1. <u>Schematic Diagrams</u>

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

Figure 3-2. Simplified Diagram of ECCS and CSS Systems During Recirculation

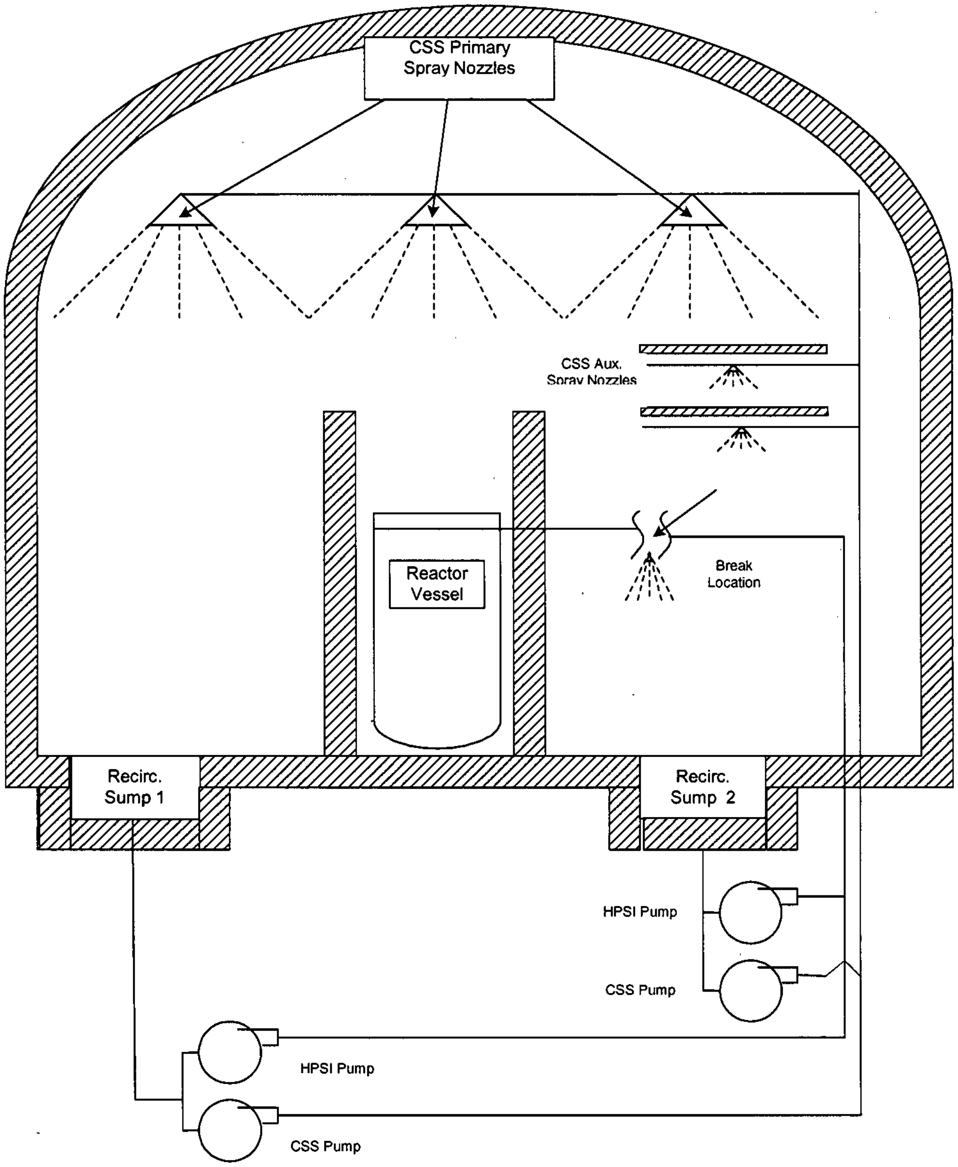


Figure 3-3: Hot Leg Injection

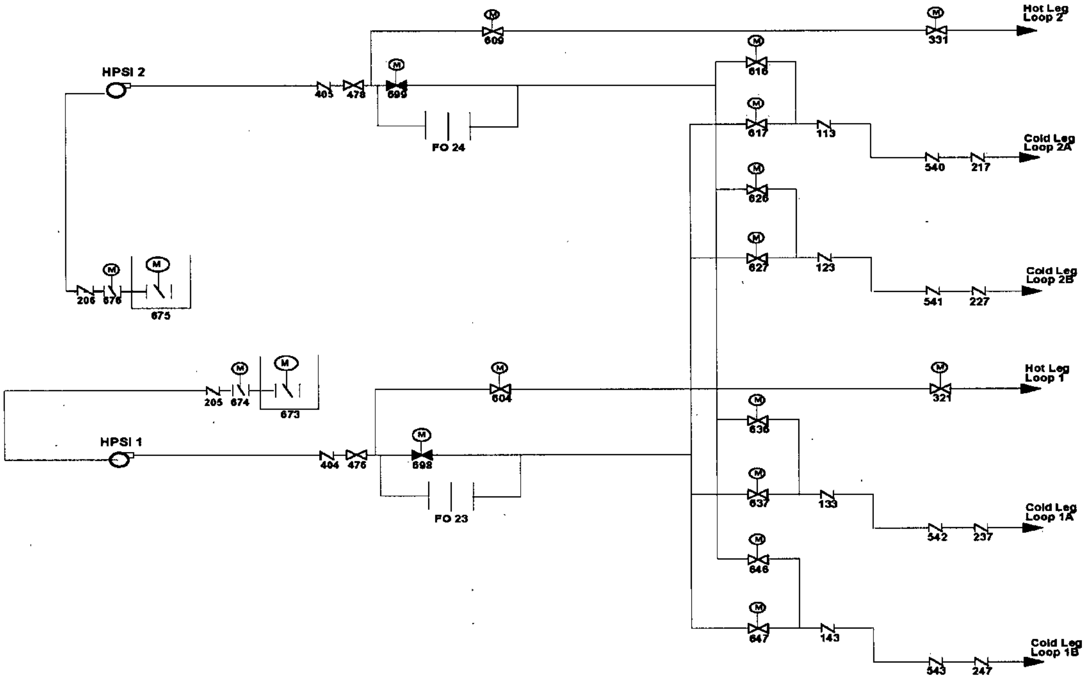


Figure 3-4. Recirculation LOCA, HPSI

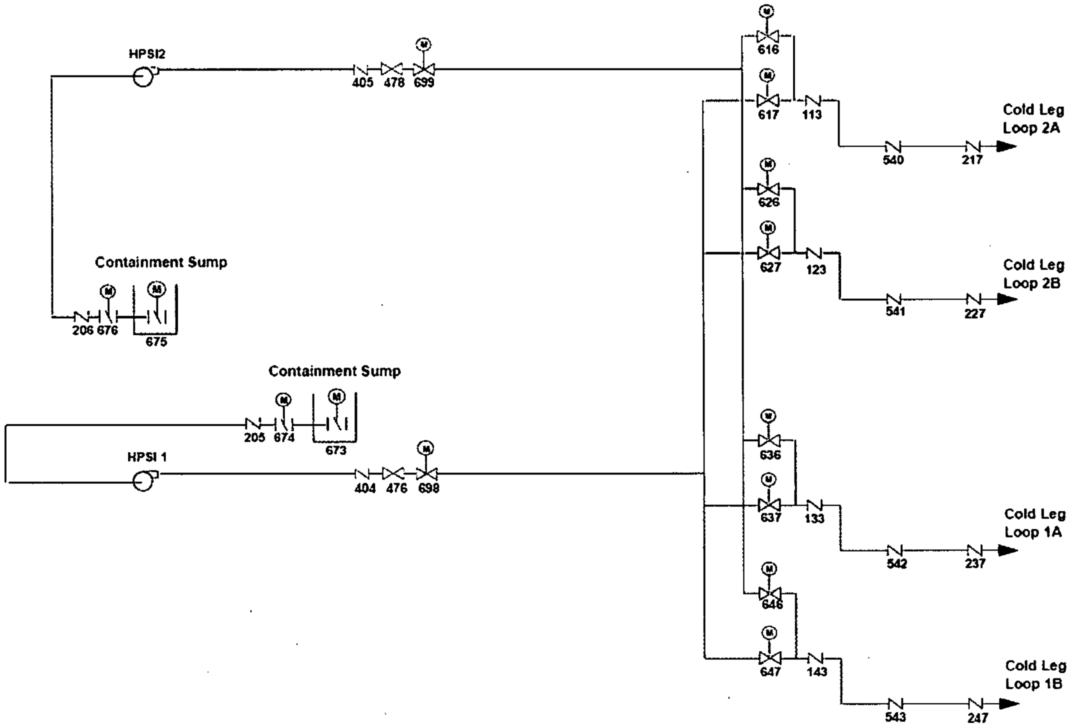
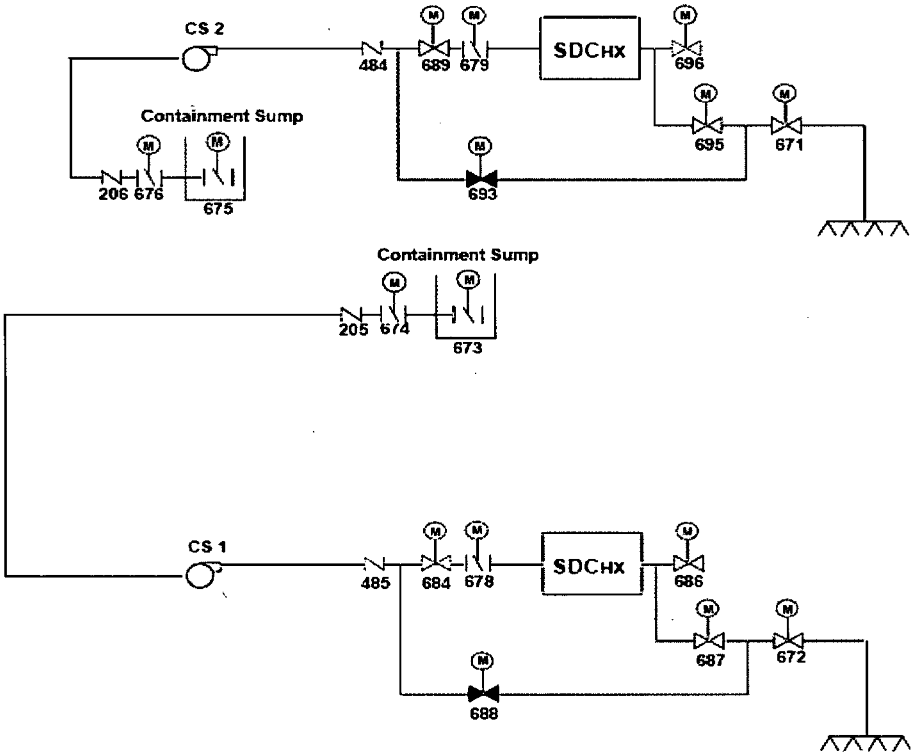


Figure 3-5. Recirculation LOCA, Containment Spray



2. Minimum Submergence

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

The minimum containment flood water level is elevation 84.5 ft following a small or large break LOCA [Ref. 4.15]. The minimum submergence is approximately 2.1 inches above the top of the strainers [Ref. 4.43]. The vortex analysis for the strainers was performed using this submergence and the elevation of the top of the strainer.

To ensure maintenance of this minimum containment flood level and in support of installation of the strainers in Unit 2, APS submitted, and the NRC in License Amendment 169, dated May 9, 2008, approved an exigent change to TS 3.5.5, to increase the RWT minimum water level for Unit 2 by three percent [Ref. 4.92]. For Units 1 and 3, the minimum RWT level to meet the containment flood level analysis is the same as Unit 2 and is currently being administratively controlled. The same TS 3.5.5 changes for Units 1 and 3 were submitted to the NRC in APS Letter No. 102-05923, dated November 13, 2008 [Ref. 4.93]. The current administrative controls for Units 1 and 3 RWT level provided in accordance with NRC Administrative Letter 98-10, "Dispositioning of Technical Specifications that are Insufficient to Assure Plant Safety," will remain in effect until the Units 1 and 3 TS amendments are approved and implemented.

3. Proof of Absence of Vortices

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

The vortex analysis is split into two parts. The first part determines if a clean strainer is susceptible to vortex formation [Ref. 4.42]. The other part determines if debris laden strainers are susceptible to vortex formation following a pump stop and restart since small openings may form in the debris bed due to air coming out of solution within the strainer when the pump stops [Ref. 4.43].

The discussion below shows that the Palo Verde strainers are not susceptible to vortex formation under either of the conditions outlined above.

The clean strainer head loss test (Test 1) performed in April 2008, in the CCI Multi Functional Test Loop (MFTL) [Ref. 4.42] shows that there were no vortices formed at a flow rate of 196.2 m^3/h and a submergence of one (1) cm. Considering the scale factor of 56.9 (see Section 3.o.2.s of this response), this flow rate corresponds to a plant flow rate of 49,150 gpm which is much greater than the maximum recirculation flow rate of 11,600 gpm (see Section 3.f.10.a).

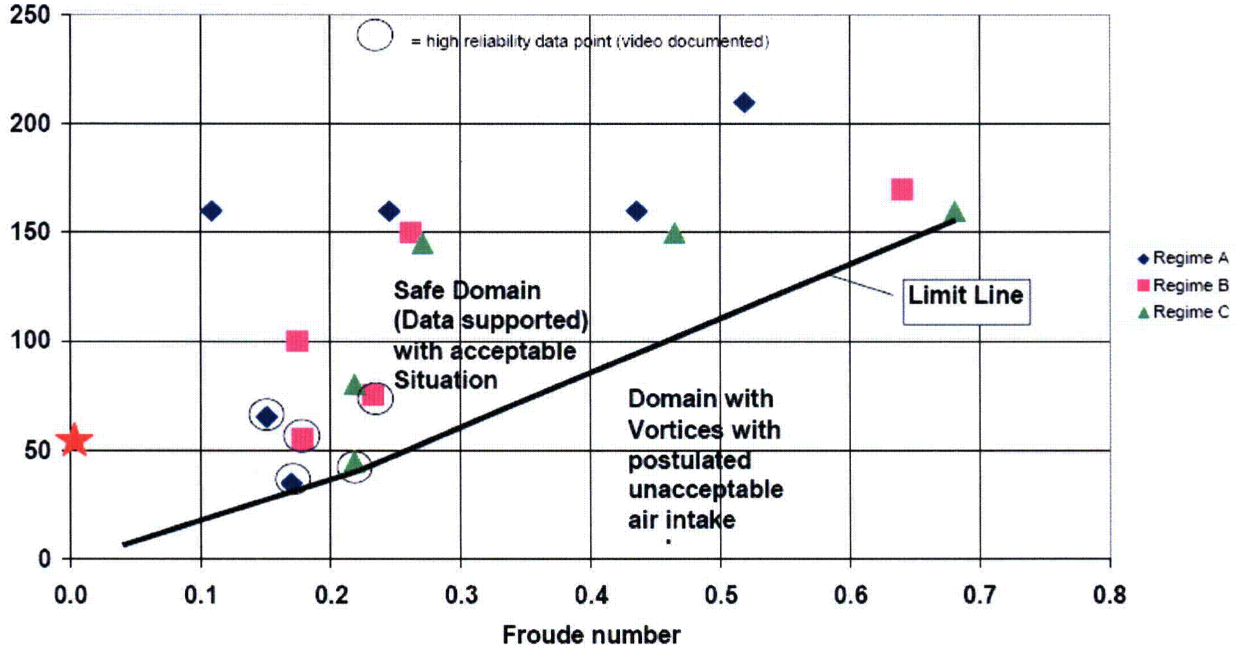
Also, the one (1) cm tested submergence is much lower than the minimum Palo Verde strainer submergence of 5.33 cm at the minimum flood level [Ref. 4.43].

This test confirms that vortices will not form at Palo Verde under clean strainer conditions. Further proof is obtained from generic vortex tests for clean strainers which were performed by CCI and are documented in the following subsection.

Generic Clean Strainer Vortex Testing [Ref. 4.82]

Generic tests have also been performed to explore the ranges of allowable flow and submergence parameters which do not show significant vortices for clean strainers [Ref. 4.82]. The results of these tests are displayed in Figure 3-6, which form the basis of the assessment in this subsection.

Figure 3-6: Minimum Submergence Level (mm) as a Function of Froude Number



The different regimes of vortexing in the legend are defined as follows:

A. more or less stationary limited vortex cones at surface with no air intake into pockets

B. infrequent instationary vortices which cause singular air bubble intake at frequencies of one to five short-duration vortices within five minutes

C. frequent instationary vortices with two to five vortices within one minute, however no air intake that would come close to one percent volume flow.

In order to apply the results of the generic tests to Palo Verde, the velocity into the installed modules was determined. For the modules situated directly above the sump cavity, the following pocket entry surface data was obtained [Ref. 4.43]. The elevation of the cartridges is nine pocket rows tall by 0.12 m per row = 1.08 m [Ref. 4.101]. The number of cartridges facing the flow is 16 cartridges by seven modules plus 10 cartridges by one module = 122 cartridges [Ref. 4.25]. Each cartridge has a width of 168 mm [Ref. 4.101]. Therefore, the pocket approach area for these modules is 1.08 m by 122 by 0.168 m = 22.14 m^2 (conservatively neglecting the flow through the bottom plates).

With the maximum flow rate of 0.732 m^3/s (11,600 gpm) [Ref. 4.43], the approach velocity (v) is:

$0.732\ m^3/s\ /\ 22.14\ m^2 = 0.033\ m/s$

The PVNGS minimum water submergence (h) is the minimum water level [Ref. 4.15] minus the height of the top of the strainers [Ref. 4.25].

(84'-6" – 84'-3.9") = 0.175 ft = 0.0533 m [Ref. 4.43].

The Froude number definition is $Fr = v^2 / g / h$. Thus,

$Fr = (0.033\ m/s)^2 / 9.81\ m/s^2 / 0.0533\ m = 0.0021$

The resulting data point is shown as a star in the figure above.

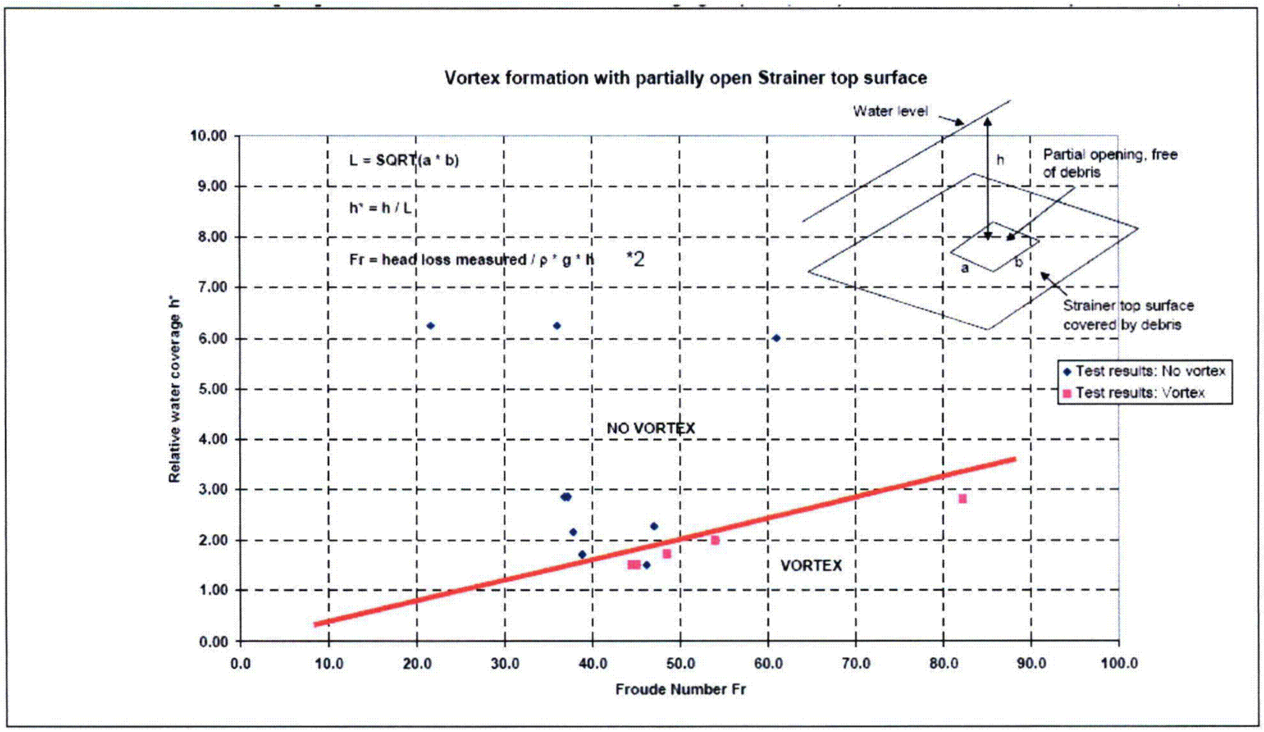
It can be seen that this data point is within the range of acceptable conditions, which, combined with the clean strainer test [Ref. 4.42] which showed no vortex formation with flow conditions that bound those at Palo Verde, guarantees that no vortexing will occur for the clean strainer condition.

Proof of Absence of Vortices for Pump Stopping and Restarting [Ref. 4.43]

For continuous pump suction, there is a fairly uniform distribution of velocity through the strainer screen and this velocity is sufficiently low to preclude any vortex formation, as discussed above. However, if the pump suction is stopped, air bubbles (trapped in the internal cavities of the strainer) either escape through the top cover plates for strainers that have perforated top cover plates, or through the top pockets for strainers that have unperforated cover plates such as Palo Verde. These air bubbles have been observed to create localized "clean screen windows" in the debris on the cover plates. A limited amount of entrapped air bubbles always forms during the suction due to the head loss across the screen and the reduced solubility of air in water at the lower pressure inside the strainer. This deaeration has always been observed and cannot be prevented for any kind of strainer due to this physical process.

CCI observed that after restarting the pump, these "clean screen windows" can experience localized high velocities. At these locations, vortices were indeed observed taking air into the strainer cavities through the top cover plates. CCI has performed systematic tests to gain understanding of this phenomenon [Ref. 4.43] for strainer applications in France. The results from these tests are shown in the graph in Figure 3-7 for perforated cover plates.

Figure 3-7: Vortex Formation with Partially Open Strainer Top Surface (Strainer with Perforated Cover Plates)



The Froude number, as defined here, is two times the measured head loss divided by the submergence h.

The dimensionless submergence level (h*) is obtained by dividing by a reasonable observed "clean screen window" dimension (L) of 0.05 m.

The regimes between vortex and no-vortex can be separated by a straight line which is proportional to the Froude number (shown in Figure 3-7 above).

The PVNGS strainers have unperforated cover plates, and CCI has also performed some testing of that configuration [Ref. 4.43]. The testing was an attempt to evaluate the same limit for vortices entering the top row of pockets instead of through the perforated cover plates. For the configuration with unperforated cover plates, CCI was not able to produce any vortexing. The sequence of events and the range of parameters of the CCI tests for unperforated cover plates are shown in Table 3-23.

Table 3-23: Vortex Test Data for Unperforated Cover Plates

Pump Status	Time History	Flow Rate	Delta P	Temperature	Water Cover	Comments Observations
	hr: min	gpm (m^3/hr)	In WC (cm WC)	°F (°C)	In (cm)	
Pump is Running	during 48 hours	275.2 (62.5)			3.94 (10)	
Shut Down	09:19			85.1 (29.5)	3.94 (10)	Clean water, escaping air bubbles from two upper pockets during 66 sec after shut down
Restarting	09:34	275.2 (62.5)	38.9 (99)	85.1 (29.5)	3.94 (10)	No vortex
	09:44	275.2 (62.5)	41.3 (105)		3.94 (10)	No vortex
	09:47	308.2 (70)	45.9 (116.5)		3.94 (10)	No vortex
	09:49	352.2 (80)	50 (127)		3.94 (10)	No vortex
	09:51	396.3 (90)	55.1 (140)		3.94 (10)	No vortex
	09:56	418.3 (95)	68.9 (175)	85.1 (29.5)	3.94 (10)	No vortex
	10:03	418.3 (95)	70.5 (179)		3.15 (8)	No vortex
Shut Down	10:07					A few single air bubbles
Restarting	10:09	275.2 (62.5)	40.1 (102)		3.15 (8)	No vortex

Pump Status	Time History	Flow Rate	Delta P	Temperature	Water Cover	Comments Observations
	hr: min	gpm (m^3/hr)	In WC (cm WC)	°F (°C)	In (cm)	
	10:12	398.5 (90.5)	56.3 (143)		3.15 (8)	No vortex
	10:19	398.5 (90.5)	59.8 (152)		1.38 (3.5)	No vortex
	10:25	275.2 (62.5)	40.6 (103)		3.94 (10)	No vortex
	10:30	275.2 (62.5)	41.3 (105)		3.94 (10)	No vortex

It is apparent from the data above that the most severe condition that still produced no vortices was the case with a head loss of 152 cm WC and a water submergence of 3.5 cm. It is assumed, since no data with lower water submergence was available, that this data point represents the vortexing limit for unperforated cover plates, and that the limit is a linear function of the Froude number similar to the above case with perforated cover plates.

The critical test Froude number is:

Fr = 2 * 152 cm / 3.5 cm = 86.9

The dimensionless submergence is (by using L as the pocket width of 8.4 cm):

h* = h/L = 3.5 cm / 8.4 cm = 0.417

The proportionality factor for the vortex limit with non-perforated plates therefore is:

f = 0.417 / 86.9 = 0.00480

For PVNGS the maximum structurally allowable head loss at 25°C is 10.4 ft WC = 124.8 inches [Ref. 4.44]. This head loss is assumed for this vortex analysis.

The PVNGS minimum submergence h* is 0.0533 m = 2.1 inches

The PVNGS-specific Froude number therefore becomes:

Fr = 2 * 124.8 in / 2.1 in = 119

The maximum limit Froude number for PVNGS is:

Fr (limit) = h* / 0.0048 = (0.0533 m / 0.084 m) / 0.0048 = 132

The limit of 132 is larger than the (very conservative structural limit-based) value of 119.

Therefore, it is determined that air vortexing is not a concern for the case of a pump stop and restart after a "clean screen window" has formed due to air coming out of solution within the strainer.

4. Performance Tests

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.

CCI performed testing to determine the head loss characteristics across the sump strainer.

Descriptions of small scale filter tests, large scale filter tests, and the multi-functional test loop (MFTL) are provided in the following subsections. Small scale and large scale filter tests were performed to develop strainer sizing requirements for PVNGS, while the results of the chemical effects head loss tests performed on the MFTL validated the sizing of the strainers.

The results which are used in the determination of the design basis strainer head loss as documented herein are based on the April 2008 strainer testing in the MFTL as discussed in Section 3.f.4.d below. Therefore, only this testing is described in detail herein. Short summaries are provided for the other strainer testing that was performed.

a) Small-Scale Filter Testing (October 2005)

CCI "Small Filter Performance Test Specification" [Ref. 4.18] defines the test requirements to determine head losses across a representative strainer module with six pockets installed in a vertical flow test loop.

For the small scale tests, a representative strainer specimen with six pockets was fabricated and installed in the CCI test loop in vertical flow orientation. This orientation allows very little sedimentation effects and forms a fairly uniform debris bed, which is more easily adaptable to theoretical modeling with head loss equations. Chemical effects were not considered in the small scale tests.

The results of the small scale tests are provided in the CCI test report [Ref. 4.29].

b) Large-Scale Filter Testing (December 2005)

CCI "Large-Scale Filter Performance Test Specification" [Ref. 4.19] defines the test requirements to determine head losses across the sump strainer.

For the general "large scale" test, a complete strainer module consisting of 120 pockets was installed and fully submerged in the CCI large test loop with a horizontal flow orientation into the pockets. Due to the limiting capacity of the test loop pump, only 44 pockets of the module were actually used for the testing; the other remaining pockets were covered up. The flow into the pockets closely correlates with the actual installation at PVNGS and simulates the flow conditions into the pockets more realistically than the small-scale testing. The horizontal orientation allows development of a non-uniform debris bed as would be expected in the case of a LOCA in the plant. Chemical effects were not considered in the large scale tests.

The results of the large scale tests are provided in the CCI large-scale test report [Ref. 4.21].

c) Multi-Functional Test Loop Testing (February-March 2007)

Two sets of head loss tests were performed in the MFTL. The first set was performed in February-March, 2007, and the second set was performed in April 2008 (see sub-section d below). The 2007 testing included foreign materials and epoxy chip transport tests, bypass tests and head loss tests. General conclusions regarding the head loss behavior of epoxy chips relative to particulates are obtained from the 2007 testing. The 2007 head loss testing was superseded by the April 2008 head loss testing since the 2007 head loss testing did not include chemical effects. In addition, the April 2007 testing used more surrogates for the debris than did the April 2008 testing. Therefore, the 2007 head loss testing is not described in detail herein.

These tests are documented in the CCI transport, bypass and head lost test report [Ref. 4.49].

d) Multi-Functional Test Loop Testing (April 2008) [Refs. 4.42, 4.81]

The April 2008 chemical effects head loss testing constitutes the design basis head loss testing for the Palo Verde strainers installed in Units 1, 2 and 3. This testing was witnessed by the NRC Staff on April 20-25, 2008, and the NRC observations are documented in a trip report dated July 16, 2008 (ADAMS Accession No. ML081640193) [Ref. 4.99]. In this report, the NRC concluded that the test methods being employed by CCI were generally prototypical or conservative.

The design basis head loss is based on the following three tests.

- Test 1: Clean Head Loss Test
- Test 2: Full Debris Load Chemical Effects Head Loss Test
- Test 3: Full Debris Load Chemical Effects Head loss Test (same as Test 2)

The chemical effects head loss tests were run using the full load of non-chemical debris and the 30-day chemical precipitate quantity. Thin bed tests were not included in this test series due to Palo Verde's limited fiber quantities. The fiber fines present in the plant are adequate to create an approximately 1/11-inch thick theoretical debris bed. Because this bed thickness is less than the generally accepted required bed thickness to experience a thin bed effect, the full debris loading is expected to be bounding.

This testing was performed using CCI Test Specification Q.003.84 810 [Ref. 4.81] and the results are documented in CCI Test Report 680/41437 [Ref. 4.42]. Deviations from the test specification are documented in the test report. The deviations did not impact the validity of the test results.

Test Loop Configuration [Ref. 4.81]

The MFTL testing was performed in an open channel flume approximately 3 m long and 0.4 m wide which can accommodate a maximum water depth of 1.4 m. A 40 pocket strainer test module (four pockets wide by 10 pockets tall) was placed at one end of the test flume. The flow into the test module was horizontal and continuously recirculated during the course of each test. The differential pressure, flow rate, water temperature, and water level were all measured with calibrated instruments. Figures 3-8 and 3-9 show the test flume as it was configured for the chemical effects head loss tests, except that in the sketch the bottom row of pockets is not blocked (see following discussion).

Figure 3-8: Picture of CCI MFTL

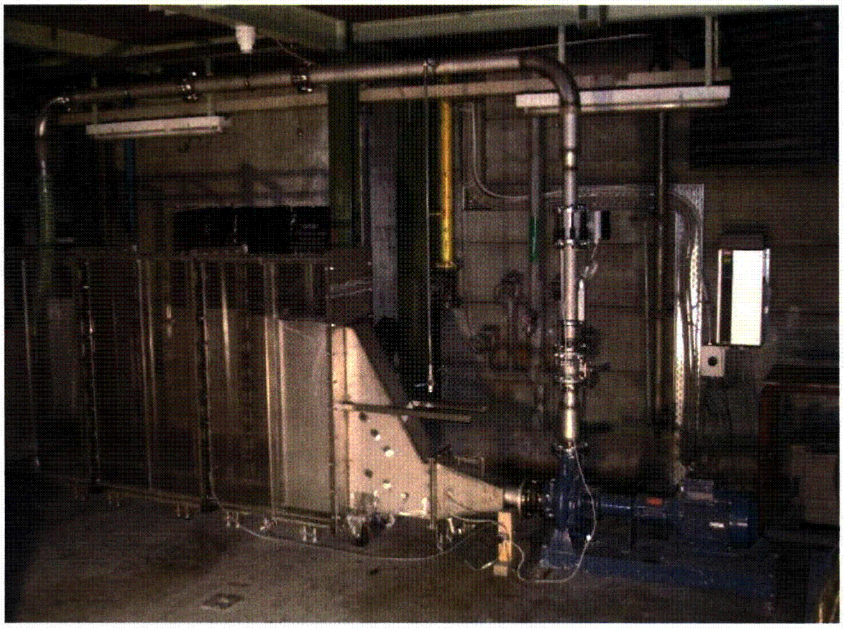
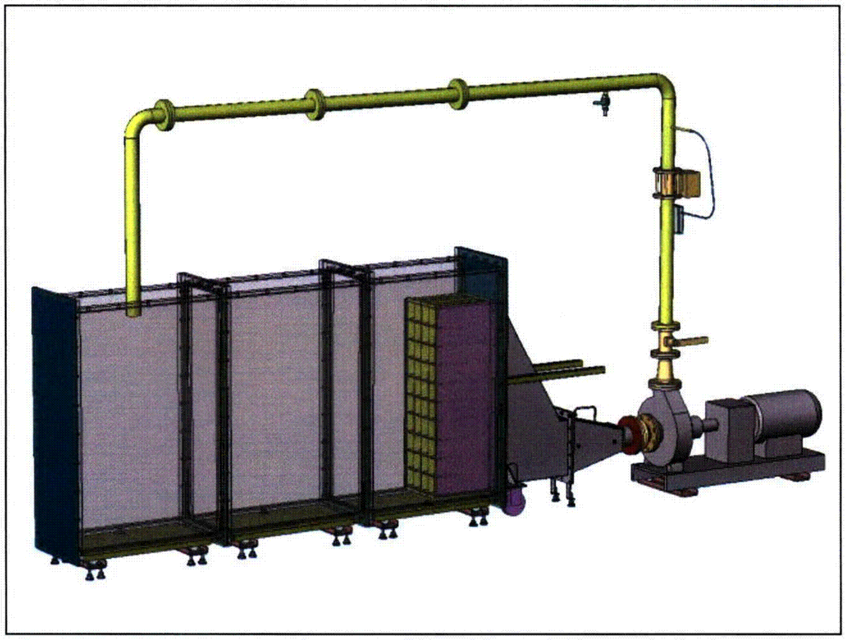
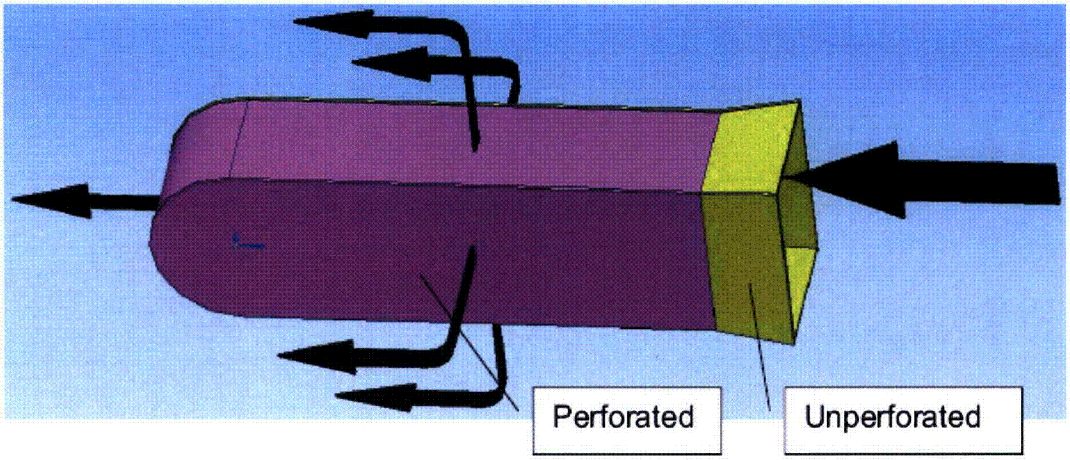


Figure 3-9: Sketch of the CCI MFTL



The pockets were each 120 mm tall, 84 mm wide, and 400 mm deep, which is the same size pocket in the same orientation as installed at Palo Verde [Ref. 4.101]. The basic geometry and dimensions of a typical strainer pocket are shown in Figure 3-10. An array of these pockets forms a strainer cartridge.

Figure 3-10: CCI Strainer Pocket



In the plant, the bottom of the lowest strainer pocket sits 9.8 inches above the containment floor due to a concrete curb (3- inch), a sub-floor (4-inch), and the height of the pockets off the sub-floor (2.8" or 71 mm) [Refs. 4.25 and 4.42]. In order to simulate this configuration in the test loop, the bottom row of pockets was blocked off. The blockage of the bottom pockets combined with the test module being 30 mm off the flume floor resulted in the bottom of the lowest pockets in the tests being 150 mm (approximately six inches) off the floor, which is conservative relative to the plant configuration. Also, by blocking the bottom row of pockets in the test loop, the test module was effectively nine pocket rows tall, which is the same height of pocket rows in the modules installed in the plant.

In the test loop, the top plate and side plates of the strainer module were unperforated while the bottom plate was perforated but sealed during the test. The top and sides were the same as in the plant while the bottom is perforated (and not sealed) in the plant. The larger gap between the floor and the pockets in the plant (71 mm in plant vs. 30 mm in test) along with the perforated bottom plates would allow more debris to become "trapped" below the level of the installed strainer modules than in the tests. Thus, more debris transports to the strainer pockets in the tests than in the plant.

The test strainer module configuration is considered geometrically similar, although not the same, as the installed configuration at Palo Verde. Thus, the tested configuration is considered prototypical for Palo Verde.

Test Water Level & Submergence

The minimum submergence in the plant is 5.33 cm (2.1 inches) [Ref. 4.43]. The clean strainer head loss tests were performed with a strainer submergence of one cm [Ref. 4.42]. The chemical effects head loss tests were begun with a submergence of one to 1.5 cm but the water level increased when non-chemical debris and chemical precipitates were added to the test loop. However, the test loop water level was lowered such that the strainer submergence was 2.5 cm or less after the addition of both the non-chemical debris and the chemical precipitates [Ref. 4.42].

Debris which was drained from the test loop was filtered and returned to the test loop at the sparger location [Ref. 4.81].

Test Loop Water Temperature

The chemical effects head loss tests were run with room temperature water. During the course of the chemical effects head loss tests, the water temperature ranged from 13 to 28°C (55 to 82°F) [Ref. 4.42].

Test Scale Factor

The test scale factor is 56.9 and is described in detail in Section 3.o.2.s.

Test Flow Rates

As stated in Section 3.f.10 of this response [Attachment 8.11 of Ref. 4.4], the flow rate through the strainer is 11,600 gpm at the onset of recirculation and 6600 gpm after one hour. These flow rates were scaled using the scale factor of 56.9 and the results provided in Table 3.24 [Ref. 4.81]:

Table 3-24: Test Flow Rates

Plant Flow Rate (gpm)	Plant Flow Rate (m^3/h)	Test Loop Flow Rate (m^3/h)
11,600	2635	46.33
6600	1499	26.36

The clean screen head loss tests were performed using flume flow rates from zero to 196.2 m^3/h, which corresponds to plant flow rates of zero to approximately 49,150 gpm.

At flow rates of 11,600 and 6600 gpm, the complete turnover of the test loop was approximately shown in Table 3-25 [Ref. 4.81]:

Table 3-25: Test Loop Turnover Times

Turnover Water Level @ 1.25 m	Water Filling Test Loop	Time for 1 Turnover	Time for 15 Turnovers
Test loop 3 m by 0.4 m - 11600 gpm in plant	1500 L	1.9 min	29.1 min
Test loop 3 m by 0.4 m - 6600 gpm in plant	1500 L	3.4 min	51.2 min

The chemical effects head loss tests were performed using a flume flow rate of 26.3 to 26.4 m^3/h, which corresponds to a plant flow rate of 6600 gpm. After all non-chemical debris and chemical precipitates were added to the test loop, a flow sweep was performed to determine the head loss at different flow rates. The order of the flow rates tested during the flow sweep was: 100, 80, 90, 100, 110, 120, 176 percent, and 100 percent of the nominal scaled 6600 gpm flow rate. The 176 percent data point corresponds to a plant flow rate of 11,600 gpm. These flow rates are summarized in Table 3-26 [Ref. 4.81].

Table 3-26: Test Loop Flow Rates During Flow Sweep for Tests 2 and 3

		Flow Rate (m^3/h)						
Plant Flow Rate	Test Loop Flow Rate	80%	90%	100%	110%	120%	176%	100%
6600 gpm	26.36 m^3/h	21.09	23.72	26.36	29.00	31.63	46.39	26.36

Non-Chemical Debris Load Quantity

The non-chemical debris load used for Tests 2 and 3 is presented in Table 3-27 [Ref. 4.81].

Table 3-27: Basis for Tested Debris Quantities

Type of Debris	Volume (ft^3)	Density (lbm/ft^3)	Mass (lbm)
Insulation			
Nukon fiber fines	8.31	2.4	19.94
Nukon fiber < 3" x 3"	5.54	2.4	13.30
Thermolag 330	3.88	73.8	286.34
Coatings			
Qualified IOZ	2.42	443.6	1073.51
Unqualified IOZ	1.41	443.6	625.48
Qualified Epoxy	2.09	98.5	205.87
Unqualified Alkyd(1)	0.28	98.5	27.58
Unqualified Aluminum(1)	0.20	98.5	19.70
Damaged IOZ	0.01	442.9	4.43
Latent Debris			
Latent fiber(2)	12.5	2.4	30.0
Latent particulate(3)	1.01	167.4	168.74

Notes Regarding Debris Surrogates (see subsequent section)

1) Unqualified alkyd and aluminum coatings are modeled as epoxy fines.
2) Latent fiber is modeled as Nukon fines.
3) Latent particulate is modeled as a mixture of stone flour and sand.

The debris quantities added to the test loop are computed based on the debris quantities in the plant, the surrogate types (where applicable), and the scale factor of 56.9. The total tested debris quantities are given in Table 3-28 [Ref. 4.81].

Table 3-28: Tested Debris Quantities

Type of Debris	Mass (kg)
Insulation Debris	
Nukon fiber fines	0.398
Nukon fiber < 3" x 3"	0.106
Thermo-Lag 330	2.284
Particulate Debris	
Coating IOZ	13.586
Pulverized Epoxy Coating	2.019
Sand 0.5<x<2.0 mm	0.377
Sand 0.075<x<0.5 mm	0.471

Type of Debris	Mass (kg)
Stone Flour	0.498

The debris quantities above were then split into portions which were added during the test since the entire quantity was not added at once. The portion masses are given in Table 3-29 [Ref. 4.81].

Table 3-29: Debris Portions for Head Loss Tests

Debris Name	Units	Portion 1	Portion 2	Portion 3	Portion 4
Insulation Debris					
Nukon fines	(kg)	0.133	0.133	0.133	
Nukon < 3"x3"	(kg)			0.053	0.053
Thermo-Lag 330	(kg)			1.142	1.142
Particulate Debris					
Coating IOZ	(kg)	4.529	4.529	4.529	
Pulverized Epoxy Coating	(kg)	0.673	0.673	0.673	
Sand 0.5<x<2.0mm	(kg)	0.126	0.126	0.126	
Sand 0.075<x<0.5 mm	(kg)	0.157	0.157	0.157	
Stone Flour	(kg)	0.166	0.166	0.166	

Non-Chemical Debris Preparation and Surrogates [Ref. 4.81]

Nukon and Latent Fiber

In the head loss tests, both Nukon insulation and latent fiber were tested as Nukon; thus a surrogate was not used for Nukon insulation debris. The preparation of the Nukon fiber debris followed the steps below [Ref. 4.81]:

- The fibers were freed from the jacketing (if jacketed). Then the fibers were baked by placing them in an oven with a regulated temperature of 250°C for 24 hours. The baking was meant to simulate the exposure of fiber insulation in the plant to hot surfaces such as the steam generator, pressurizer, and piping.
- Several batches can be mixed together to a main batch (portion) according to the test description.

Fiber (fines)

- The fibers were hand cut in pieces of approximately 50 by 50 mm.
- The dry material was weighed
- The fibers were split in batches of 3 to 4 dm^3 (0.1 to 0.14 ft^3)

- Each batch was soaked in approximately two liters of water (1/2 gal) until the fiber appeared saturated.
- The fiber pieces were decomposed by a high pressure water jet with a capacity of 100 bar and with the jet a distance of plus or minus 0.05 m to the water surface. Each fiber batch was blasted for approximately four minutes.
- Water added during fiber deposition was not drained as the fiber fines would also be drained.
- It was verified by visual means that the insulation was decomposed in the water into fine pieces with no clumps of fibers remaining intact and individual fiber pieces smaller than 8 mm.

Figure 3-11 shows a photograph of the prepared Nukon fines.

Figure 3-11: Prepared Nukon Fines Slurry

CCI measured the size distribution of Nukon fines prepared for Test 2 and Table 3-30 provides the results [Ref. 4.42].

Table 3-30: Nukon Fines Size Distribution

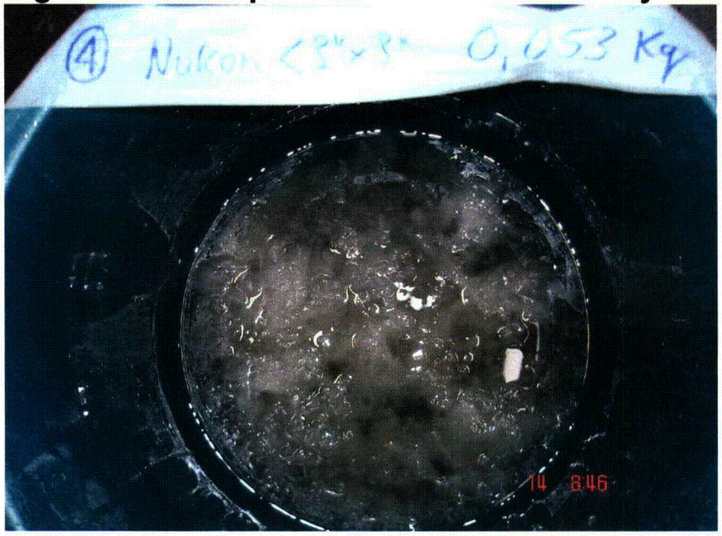
Size Class	1	2	3	4
Fiber length	< 0.5 mm	0.5 – 2 mm	2 – 5 mm	> 5 mm
Fraction	41%	48%	10%	~1%

<u>Nukon Fiber Pieces (less than 3-inch by 3-inch)</u>

- The fibers were hand cut in pieces of approx. 76 by 76 mm.
- The dry material was weighed
- The fiber pieces were soaked in a bucket

Figure 3-12 shows a photograph of the prepared Nukon pieces.

Figure 3-12: Prepared Nukon Pieces Slurry



The Nukon size distribution in Section 3.c.1 of this response is 60 percent fines and small pieces and 40 percent large and intact pieces. In the testing, all "fines and small pieces" were considered fines and all "large and intact pieces" were considered pieces less than 3-inch by 3-inch. Modeling of latent fiber as fines is consistent with the latent debris size distribution in Section 3.c.1.

Thermo-Lag 330

Similarly, a surrogate was not used for Thermo-Lag 330. APS provided CCI with prototypical Thermo-Lag 330 for the head loss tests. The preparation of the Thermo-Lag 330 debris followed the steps below:

- The wire backing was removed.
- The boards were cut into equal areas of 1-inch by 1-inch, 2-inch by 2-inch, and 3-inch by 3-inch pieces.
- The dust from the cuttings was saved and added to the particulate debris additions.
- The pieces were placed in a debris bucket and pressure blasted by a high pressure water jet with a capacity of 100 bar and with the jet a distance of plus or minus 0.05 m to the Thermo-Lag 330 surface for approximately four minutes for each batch.
- Water used during deposition was not discarded as it contained Thermo-Lag 330 particulate which was used during the test.
- The Thermo-Lag 330 pieces were soaked for a minimum of 24 hours.

The Thermo-Lag 330 remained largely undamaged following pressure blasting and remained largely in chunk form, [Ref. 4.99].

Inorganic Zinc Coatings

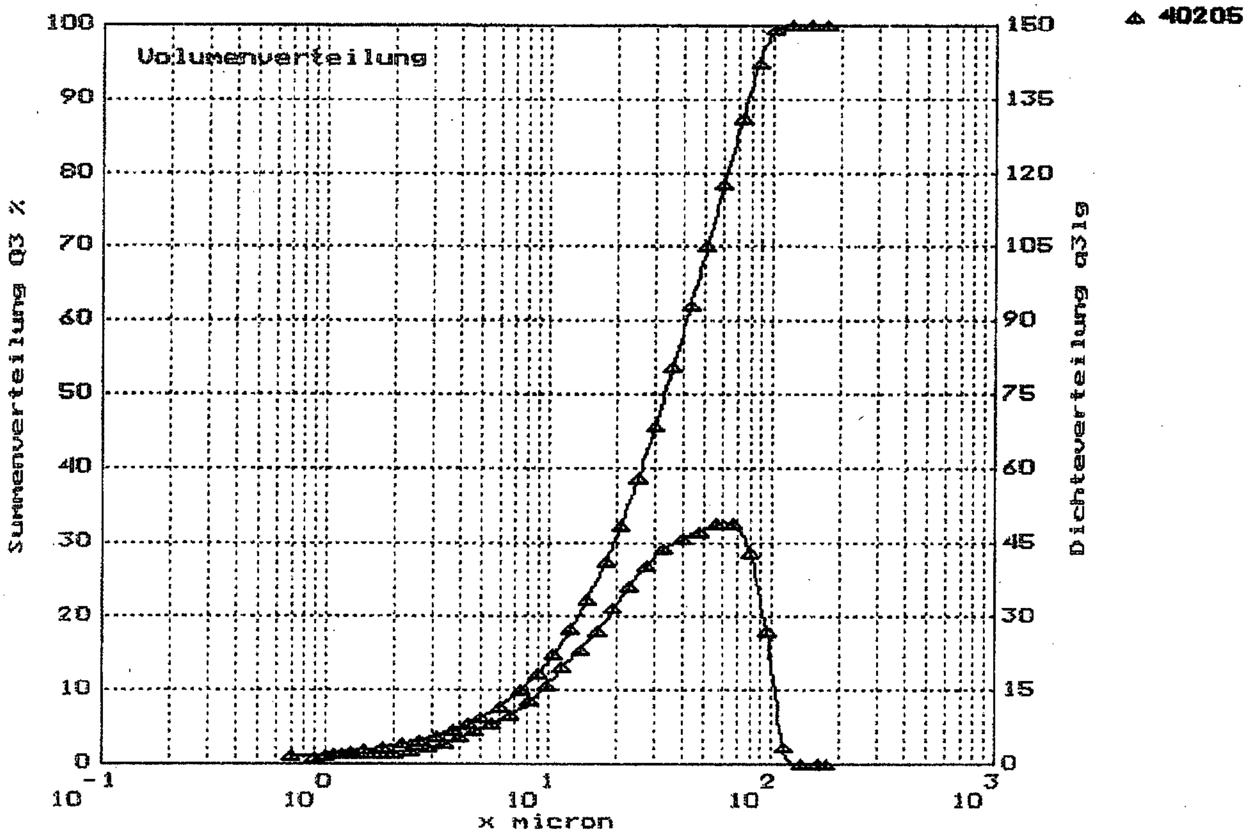
Qualified, unqualified, and damaged inorganic zinc (IOZ) coatings were all tested using Carboline "Special Zinc Filler" as a surrogate. Carboline "Special Zinc Filler" is the primary component in Carbozinc 11 which is an inorganic zinc coating. The zinc filler was prepared by saturating it in water along with the other particulate. The particle size for the zinc filler is in the range of five to nine microns. Thus, the zinc particulate tested was fines, which is consistent with the size distribution for coatings provided in Section 3.c.1.

Epoxy and Alkyd Coatings

Qualified epoxy and unqualified alkyd coatings were tested as pulverized Amerlock 400 epoxy coating. The alkyd coatings were modeled as such because according to Table 3-3 of NEI 04-07 Vol. 1 [Ref. 4.30], the density of alkyd (98 lbm/ft^3) coatings is approximately equal to the epoxy coatings (98.5 lbm/ft^3) which were used.

The epoxy coatings fines for this test were created using Amerlock 400 produced by Ameron. The referenced Amerlock 400 material was reduced in size to very fine particles by the Jet Pulverizer Company. The average size of the fine material was approximately 10 microns (see Figure 3-13) with a Sv value of approximately 0.414 to 0.453 m^2/cm^3. Thus, the epoxy particulate tested was fines, which is consistent with the size distribution for coatings provided in Section 3.c.1.

Figure 3-13: Size Distribution for Epoxy Fines



The epoxy material was reduced in a 12-inch mill by use of air jets to impact the epoxy material against itself. A description of the process may be found at www.jetpul.com [Ref. 4.102].

Some of the epoxy could not be economically reduced and was segregated from the fine material during processing. The experienced staff at Jet Pulverizer Company commented that the epoxy was extremely durable and significantly harder to process than "paint chips" processed by another customer.

Latent Particulate

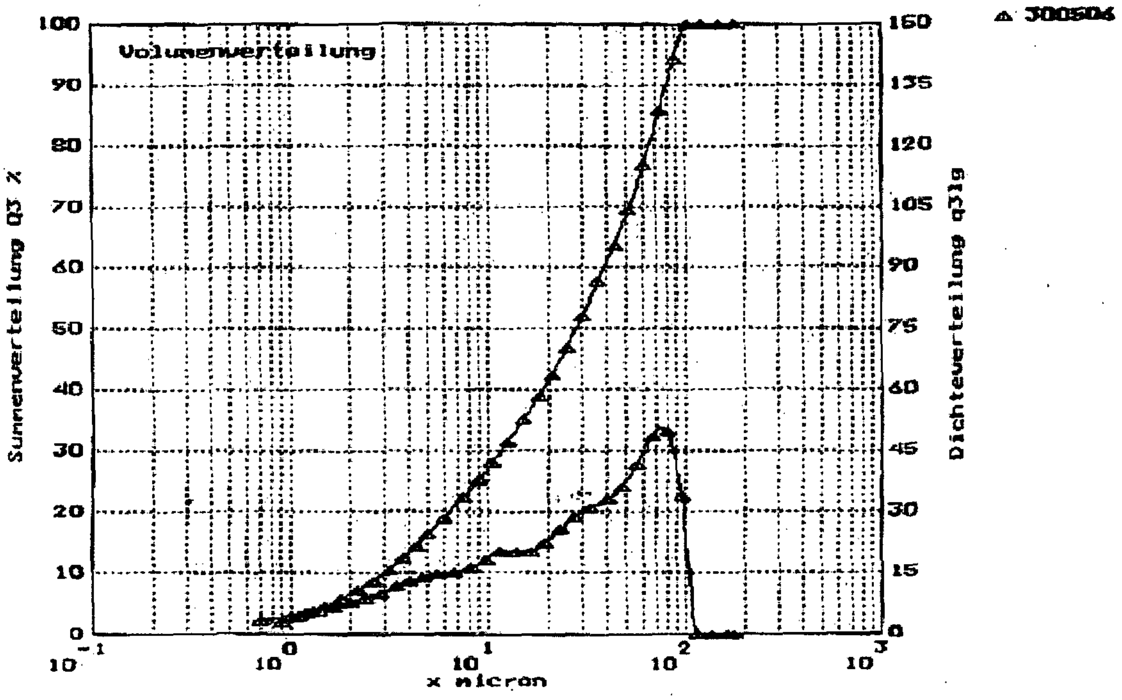
Latent particulate was tested as a 37 percent stone flour (size less than 10 μm), 35 percent sand between 0.075 and 0.5 mm, and 28 percent sand between 0.5 and 2.0 mm. The use of sand and stone flour was based on the description of latent particulate debris in Appendix VII to the SE for NEI 04-07 [Ref. 4.28]. All components of latent debris are fines, which is consistent with the latent debris size categorization in Section 3.c.1 of this response.

The sand was purchased by CCI and sieved to the appropriate size distribution. The sand was sieved according to the following:

- The sand was first sieved using a 2.0 mm or #9 mesh (Tyler mesh size) to remove the less than 2.0 mm size particles. All sand that did not pass through the 2.0 mm mesh was discarded.
- The sand which passed through the #9 mesh was then passed through a 0.5 mm or #32 mesh. All sand which did not pass through the 0.5 mm mesh represented the greater than 0.5 mm and less than 2.0 mm size distribution.
- The sand which passed through the 0.5 mm mesh was then sieved through a 0.075 mm mesh. All sand which did not pass through the 0.075 mm mesh sieve was used for the greater than 0.075 and less than 0.5 mm size particles.
- Sand which passed through the 0.075 mm sieve was used in the stone flour portion.

For the stone flour portion, CCI has used a COOP product (COOP is a Swiss brand) in the past for strainer performance testing which comes very close to fine particulate debris. The size spectrum analysis measured its Sv value as 0.776 m^2/cm^3, corresponding to a sphere diameter of 7.7 μm (see Figure 3-14). This is a measured value which is bounded by the 10 μm size assumed for coatings particulate [Ref. 4.28].

Figure 3-14: Size Distribution for Stone Flour



The quantity of particulates is defined by volume. However, the particulate quantity for the tests is measured by weight. For the head loss, besides the above value of Sv, the representative volume quantity is important. Therefore, the volume quantity was converted to weight by the density of the surrogate particulates.

The stone flour density was measured to be 2680 kg/m^3 (167.4 lb/ft^3). According to the Staff Evaluation of GR Section 3.5.2.3 in the SE for NEI 04-07 [Ref. 4.28], latent particulate has a density of 168.6 lb/ft^3 - very similar to that of stone flour. The sand was assumed to have the same density as the stone flour.

Tested Debris Compared to Analytically Determined Debris at Strainer

The tested debris quantity at the sump strainer for Tests 2 and 3 is compared to the quantity analytically determined by the debris generation and transport analysis [Refs. 4.4 and 4.14] in Table 3-31. The margin between the tested quantity and the analytically determined quantity is provided below.

Table 3-31: Comparison of Analytically Determined Debris Quantity to Tested Debris Quantity for Test 2 and 3

Debris Type	Units	Quantity at Sump Tested by CCI[1]	Break S1 Quantity at Sump	Margin
Insulation/Fiber				
Mirror RMI	ft^2	0	1,191	Note 3
Transco RMI	ft^2	0	1,517	Note 3
Nukon – Fines / Small Pieces	ft^3	8.31	5.89	2.42
Nukon – Large Pieces	ft^3	5.54	3.93	1.61
Temp-Mat	ft^3	0	0	Note 5
Thermo Lag 330	ft^3	3.88	3.53	0.35
Min-K/Microtherm	ft^3	0	0	Note 3
Alpha Cloth	ft^3	0	0.1	Note 3
Coatings				
Qualified IOZ	ft^3	2.42	2.2	0.22
Qualified Epoxy	ft^3	2.09	1.9	0.19
Unqualified IOZ	ft^3	1.41	1.28	0.13
Unqualified Alkyd	ft^3	0.28	0.25	0.03
Damaged Qualified IOZ	ft^3	0.01	0.01	0
Unqualified Aluminum	ft^3	0.20	0	0.20
Latent				
Fiber	lbm	30[2]	30	0
Particulate	lbm	170[2]	170	0
Sacrificial Area	ft^2	400[4]	100	300

1. See non-chemical debris subsection f.4.d [Ref. 4.81, Table 6]
2. Values are presented as volumes, but are converted from mass [Ref. 4.81, per Note 3 to Table 6].
3. See subsequent section entitled "Untested Debris Types."
4. Sacrificial area was considered in the determination of the scale factor for the head loss testing, see Section 3.o.2.s of this response regarding scaling.
5. Temp-Mat is generated by a break which generates a less bounding quantity of debris than Break S1 [Ref. 4.14].

Untested Debris Types

Reflective Metal Insulation (RMI)

RMI did not transport to the strainer face in the transport testing at the highest flow velocity which corresponded to 0.2 m/s (0.66 ft/s) upstream of the curb and 0.32 m/s (1.5 ft/s) over the curb [Ref. 4.49]. Therefore RMI is not used for chemical effects head loss testing [Ref. 4.81].

Epoxy Coatings as Chips (Instead of as Particulate)

CCI has performed tests for various nuclear plants that consistently show that head losses are smaller when using paint chips instead of corresponding amounts of coating particles. This is partly due to lower transportability and the stronger tendency for the paint chips to settle out. Moreover, the crucial head loss parameter Sv of paint chips is much lower than the one for fine particles [Ref. 4.43].

For plants that cannot substantiate formation of a thin fiber bed, the NRC position is that assumptions related to coatings characterization be realistically-conservative based upon the plant-specific susceptibilities and data identified by the licensee, or that a default area equivalent to the area of the sump-screen openings be used for coatings size [Ref. 4.28]. As documented in the introduction to Section 3.f.4.d of this response, the PVNGS fiber bed thickness was approximately 1/11-inch, which is less than the typical thin bed thickness of 1/8-inch. To address this issue, PVNGS performed head loss testing in 2007, both with coatings modeled as particulates and paint chips [Ref. 4.49].

The respective test comparisons demonstrate that the assumption of the coatings being decomposed into fine particles versus paint chips is conservative. The 2007 PVNGS head loss tests [Ref. 4.49] with paint chips demonstrated that the head loss with paint chips was lower than the use of a surrogate of fine particles, such as stone flour. Also, the epoxy coating chips would not transport over the curb near the sump in the plant [Ref. 4.14].

Therefore, the use of particulates in the tests [Ref. 4.42] is conservative for epoxy coatings [Ref. 4.43].

Alpha Cloth

The material properties of Alfa cloth and Nukon cloth are very similar [Ref. 4.109]; therefore, the transport properties of both materials would be similar. Nukon cloth was tested and found not to transport [Ref. 4.49]. Based on the similar properties, Alfa cloth was not considered to transport and was not specifically tested.

Min-K / Microtherm

The CEA ejection, break S5 was not physically tested for head loss. The decision not to test is based on a qualitative assessment. It is also noted that the debris generated directly by the CEA ejection break S5 will be removed during the scheduled reactor head replacement projects for each PVNGS unit.

A qualitative assessment [Ref. 4.100] was completed and assumed that the microporous insulation debris generated by break S5 behaves as either all fiber or as all particulate. The debris generated in the CEA ejection was then compared to the larger total debris generated by the large break LOCA break S1. The result of the qualitative assessment, in conjunction with available margins for uncertainties, was that the CEA ejection break S5 is bounded by the as-tested large break LOCA break S1 debris loadings.

The following margins are available for uncertainties:

- Clean screen area existed during the large beak LOCA break S1 as-tested condition, which bounds break S5.
- Industry test results are available to reduce the ZOI and debris generated for encapsulated microporous insulation. However, the PVNGS qualitative assessment assumed the insulation was not encapsulated. If the industry data was used it would significantly reduce the encapsulated microporous debris generated and debris loading at the strainers.
- The head loss from the bounding large break LOCA is 4.33 ft with a margin of 5.53 ft or greater at the ECCS pumps

Chemical Precipitate Debris Load

The tested chemical precipitate is described in detail in Section 3.o.2.u. This section also includes a comparison to the analytically determined chemical precipitate quantities and shows margin between the tested and analytical quantities.

Chemical precipitate preparation is described in detail in Section 3.o.2.j. The WCAP-16530-NP precipitate generator method is used [Ref. 4.70]. For this method, the precipitates are generated outside the test loop prior to being added to the test loop.

Section 3.o.2.o provides the results of the one-hour settled volume tests. All precipitates used in the testing met their one-hour settled volume criteria.

Debris Addition [Refs. 4.42 and 4.81]

The debris was prepared as described in a previous subsection and Table 3-31 (above), was split into portions in preparation for addition to the testing loop.

Debris was added to the test loop beginning with debris Portion 1. All debris was introduced at the sparger approximately two meters from the strainer [Ref. 4.81]. Additions were alternated between fiber and particulate. For example, one dip bucket (approximately five liters) from the particulate slurry was added and then one dip bucket from the fiber slurry was added to the loop. All debris was added very slowly into the loop at the water surface. During the addition, water from the loop was used to help dilute/agitate the debris in the addition bucket. This was done by dipping the addition bucket into the loop and then slowly raising it while tilted allowing the fines to release into the flume. This was done slowly to prevent waves or turbulence in the loop. After each fiber addition, the loop was checked for sedimentation and was agitated as necessary. The slow addition of debris in this manner at two meters from the strainer face along with agitation ensured that non-prototypical sedimentation, agglomeration and deposition of debris did not occur.

The process was repeated for Portions 2, 3 and 4 until all fiber fines and particulate were emptied into the flume. Once all fiber and particulate debris was added, the water level was adjusted to the appropriate submergence level.

During these tests, the Nukon fiber fines were prepared per typical CCI practice. The individual portions of 0.133 kg of Nukon fiber were prepared using a high pressure water jet until between 30 to 40 liters of water were in each bucket. This resulted in a maximum concentration of approximately 3.3 to 4.4 grams per liter Nukon fines. As the water and fiber slurry was added to the loop in individual dip buckets its concentration was further diluted with water in the loop. Additionally, as the water fiber slurry was transferred from the preparation bucket to the loop, filtered water collected near the sparger was taken from the loop and added to the preparation bucket. This practice further reduced the Nukon concentration in the preparation buckets [Ref. 4.42].

Similar to the Nukon fiber preparation, the particulate debris was first mixed into a water and particulate slurry. Just as with the Nukon fiber slurry, the particulate was diluted further within the individual dip buckets as the particulate was added to the loop. Also, filtered water collected near the sparger was taken from the loop and added to the preparation bucket to continually reduce particulate concentration [Ref. 4.42].

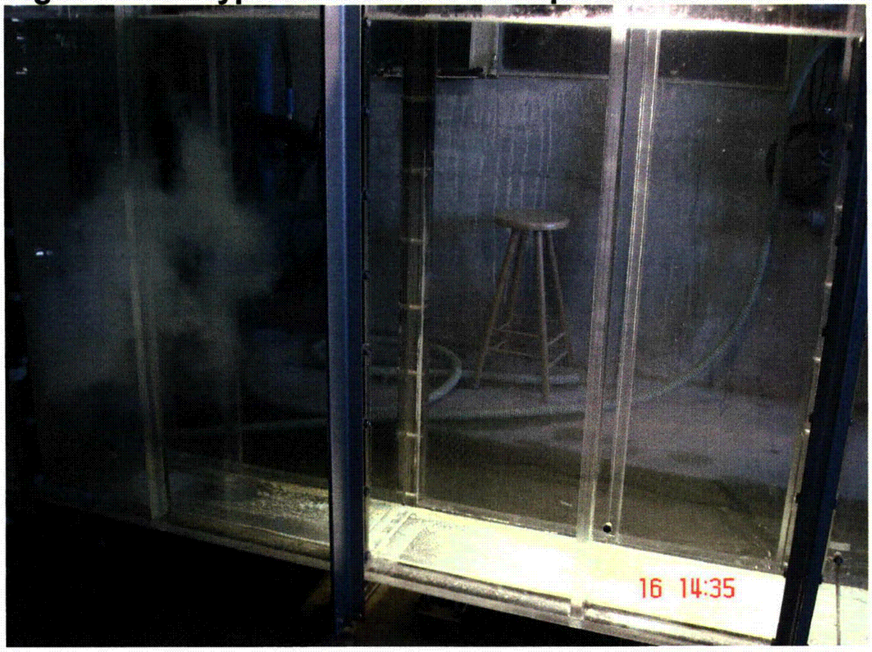
After the stability criterion was reached with all non-chemical debris in the test loop, the chemical precipitate was added [Ref. 4.81]. The chemical precipitates were added to the test loop using a transfer pump. Each precipitate type constituted one portion and each portion was added in 20 minutes or less. However, a minimum of four hours elapsed between chemical additions to the test loop. After all chemical portions were added to the test loop, the water level was adjusted to the appropriate submergence.

Figures 3-15, 3-16, and 3-17 show typical fiber, particulate, and chemical precipitate additions, respectively.

Figure 3-15: Typical Fiber Addition

Figure 3-16: Typical Particulate Addition

Figure 3-17: Typical Chemical Precipitate Addition



Debris Agitation [Refs. 4.42 and 4.81]

During and after each fiber addition, the loop was checked for sedimentation. Per the CCI Test Engineer's judgment, sedimentation on the loop floor was agitated and re-suspended using two methods: 1) a short burst from propeller style drill bit in the sedimentation area or 2) a squeegee approximately the width of the flume was used to move fiber and particulate away from the strainer to allow agitation with the drill bit or a squeegee was used to "lift" the debris off the floor. Using either method, the debris bed was not disrupted.

During debris introduction for Portions 1 and 2 during Tests 2 and 3, a squeegee was used to slowly and gently move fiber fines and particulate debris which had accumulated on the flume floor further than approximately 10 cm from the front of the strainer. Once moved approximately 40 to 60 cm away from the strainer face, the propeller drill bit was used to re-suspend and redistribute the fiber and particulate fines as evenly as possible within the flume.

After Portion 3 began, which included some larger pieces of Nukon and Thermo-Lag 330, the squeegee was no longer used and only the propeller style drill bit was used to agitate debris which had accumulated on the flume floor greater than 30 cm from the strainer face. It was noted after four drill agitation attempts that some of the larger sand particulate could not be re-suspended and would not transport to the strainer. Final debris sedimentation immediately in front of the strainer was approximately 10 to 20 percent.

During or after debris agitations there were no visual or pressure drop indicators that the debris bed was adversely or non-conservatively affected. Each agitation re-suspended the targeted fiber fines and particulate evenly throughout the height and width of the test flume. Agitating the flume resulted in a conservatively even debris distribution as it provided more opportunity for fiber fines to remain as single fibers and maximize the potential to distribute along the clean pocket surface area.

Stability Criteria / Test Termination Criteria

Test stability and termination criteria are discussed in detail in Section 3.o.2.p. The stability criterion following non-chemical and chemical debris addition was plus or minus one percent change for 60 continuous minutes while the stability criterion during the flow sweep was plus or minus two percent change for 30 continuous minutes.

The strainer head loss data collected during the flow sweep included the total amount of generated debris and the 30-day chemical precipitate quantity. Therefore, stable head loss measurements during the flow sweep are indicative of the head loss which would be experienced after 30 days. Therefore, extrapolation of the test data to 30 days is not required.

Debris Sedimentation

The amount of settled debris in the loop was gathered and an estimation of percentage of debris per location determined and recorded. The debris settled in the following locations was collected and placed in separate individual marked containers. The containers were placed side by side and the percentage of debris which deposited in the strainer pockets and on the floor was estimated and recorded.

Test Performance – Complete Test Procedure

The following steps are taken from the CCI test specification [Ref. 4.81] used to perform the chemical effects head loss tests (Tests 2 and 3). These test steps contain much of the information presented in the subsections above, but present the information in the sequence in which it was used during the tests. For the chemical tests, preparatory work and clean head loss testing occurred prior to performance of the main test steps. During chemical testing a chemist could be consulted for unexpected issues or behavior.

1. For the first test only, take a sample of the prepared fines of Nukon for size distribution analysis.

2. After filling the pool to approximately one cm water level above the top of the strainer start the recirculation pump.

3. Flush the pressure taps feeding the pressure transducer to ensure that there is no particulate debris build-up/blockage and/or air bubbles inside.

4. The clean head loss measurement should be done once for all tests. A clean head loss reading will also be specifically taken at 26.36 m^3/hr and 46.33 m^3/hr flow rates.

5. The flow rate should be adjusted to 26.36 m^3/hr for Tests 2 and 3.

6. Photographs of the dry prepared debris and photographs of the dry mixed debris will be made.

7. Next prepare the particulate and fine and/or chunks of fiber debris water slurries as outlined in the debris preparation subsection. The fiber and particulate should be weighed into portions (See Table 3-29).

8. The fiber fines (Nukon) should be broken down into single fibers in separate water/Nukon slurry in the preparation buckets using the high pressure water jet method. The water/Nukon slurry cannot be drained during preparation as fiber fines would also be lost.

9. Photographs of the fiber debris slurries should be made. Obtain some prepared debris from the water slurry and take photographs of the removed debris to show preparation quality.

10. The particulate debris (Zinc filler, Epoxy dust and stone flour) should be mixed in one preparation bucket per portion in a water/particulate slurry.

11. Debris Portion 1 should then be added to the loop. All debris is to be introduced at the sparger approximately two meters from the strainer. Alternate the additions between fiber and particulate. For example, add one dip bucket (approximately five liters) from the particulate slurry and then one dip bucket from the fiber slurry to the loop. All debris should be added very slowly into the loop at the water surface. During the addition, water from the loop should be used to help dilute/agitate the debris in the addition bucket. Do this by dipping the addition bucket into the loop and then slowly raising it while tilted allowing the fines to release into the flume. The process is repeated for Portions 2 and 3 until all fiber fines and particulate have been emptied into the flume. This must be done slowly to prevent waves or turbulence in the loop.

NOTE: Movies of the fiber and debris additions should be taken to demonstrate the debris is not settling in significant quantities.

12. If the loop water is clear, drain the loop during and after each debris addition. The loop should be drained to a level of approximately 2.1 cm above the strainer. If the loop becomes too full to add more debris water, wait for the debris to deposit and then reduce the water level. Although some particulate may be lost, debris which can be filtered out of the drained water will be returned to the loop at the sparger location.

13. Record the water level before and after each draining sequence by measuring at the side of the strainer and on top of the strainer.

14. During and after each fiber addition check the loop for sedimentation. Per the Test Engineer's judgment, sedimentation on the loop floor should be agitated and re-suspended using one of two methods: 1) a short burst from propeller style drill bit in the sedimentation area or 2) a squeegee approximately the width of the flume used to move fiber and particulate away from the strainer to allow agitation with the drill bit or a squeegee used to "lift" the debris off the floor. For method 1, the bit cannot be used less than 30 cm from the front of the strainer and will only be directed toward the loop floor during operation (never directed or even angled toward the strainer during operation). Using both methods extreme attention to not disrupting the debris bed will be taken. Other debris agitation methods may be used at the Test Engineer's discretion (if another agitation method is used record and describe it in the test protocol).

15. Repeat Steps 11 through 14 for Portions 2, 3 and 4. The Thermo-Lag and Nukon pieces in Portions 3 and 4 should be slowly released into the water at the sparger, approximately two meters from the strainer, at water level. Record the time that each portion of Thermo-Lag and Nukon piece addition is initiated.

16. Once the debris bed has been formed and the particulate has filtered sufficiently, the bed should be photographed using an underwater camera. Photographs should be checked to ensure they are of usable quality (correctly aimed, in focus, etc.) prior to proceeding with the test. The following sections of the strainer should be photographed:

    a. Front Top
    b. Front Middle
    c. Front Bottom
    d. Movie of entire Front

17. Once all fiber and particulate debris has been added the head loss will be measured until a range of between minus one percent and one percent change for 60 continuous minutes or the test engineer states to continue. If the test engineer states to continue testing without reaching the stabilization criteria the reasoning should be clearly recorded in the test protocol. Once the stability criterion is met, continue to next step.

18. Prepare chemical precipitate quantities described in Figure 3-34 using the procedures outlined in Section 3.o.2.j.

19. Adjust the water level in the flume to a range of one cm to 2.1 cm above the top of the strainer.

20. Add the chemical portion to the loop using the transfer pump. This should be performed in 20 minutes or less.

21. Once all precipitate is completely added, measure and record the pH in the test loop.

22. Agitate any settled precipitate as necessary.

23. After a minimum of four hours have passed since completing each portion of precipitate introduction and most recent agitation, confirm the loop water is clear (visually verify no precipitate remains suspended). Once confirmed, repeat Steps 18 through 23 until all three precipitate portions have been added. If the loop will not clear consult the CCI test engineer for next steps. Record any deviation from the test specification.

24. If head loss reaches a level that pump cavitation occurs consult the CCI test engineer.

25. Measure the head loss after the complete chemical addition until stabilization of a range of between minus one percent and plus one percent head loss change in 60 continuous minutes is observed or the CCI test engineer states to continue. The values will be recorded and the test is complete.

26. Once the debris bed has been formed and the particulate has filtered sufficiently, the bed should be photographed using an underwater camera. Photographs should be checked to ensure they are of usable quality (correctly aimed, in focus, etc.) prior to proceeding with the test. The following sections of the strainer should be photographed:

   a. Front Top
   b. Front Middle
   c. Front Bottom
   d. Movie of entire Front

27. Visually inspect the debris bed using the photos and video from the underwater camera for signs of channeling (bore holes). If bore holes are observed record their presence.

28. Next, perform a "Flow Sweep". Start by SLOWLY reducing flow to 80 percent per Table 3-26, allow to stabilize to within a range of between minus and plus two percent change for 30 continuous minutes unless the CCI test engineer states to continue. If the CCI test engineer states to continue the test prior to meeting the stability criteria the reason should be recorded. Record the head loss reading.

29. Repeat Step 28 by increasing to 90, 100, 110, 120 and 176 percent and then reducing back to 100 percent.

    NOTE: If any air ingestion is observed increase water level to 5.33 cm above strainer.

30. After final stabilization has occurred the pump should be stopped for 10 minutes and then be restarted at 100 percent flow rate. If no vortexing is observed increase the flow rate to 176 percent. Any vortexing or air ingestion witnessed should be recorded.

31. Adjust flow rate to 100 percent. Begin slowly reducing water level until the point that air ingestion is observed, or the top holes on the return sparger become unsubmerged, whichever occurs first. Record water level and the test results.

32. The amount of total debris which is added for each test will be recorded. Also, the amount of settled debris in the loop will be gathered and an estimation of percentage of debris per location determined and recorded. The debris settled in the following locations will all be collected and placed in separate individual marked containers. The containers will be placed side by side and an estimate generated on the percentage of debris which deposited in each of the following locations made and recorded.

    a. On the flume floor
    b. In the strainer pockets

e) MFTL Test Results for April 2008 Testing [Ref. 4.42]

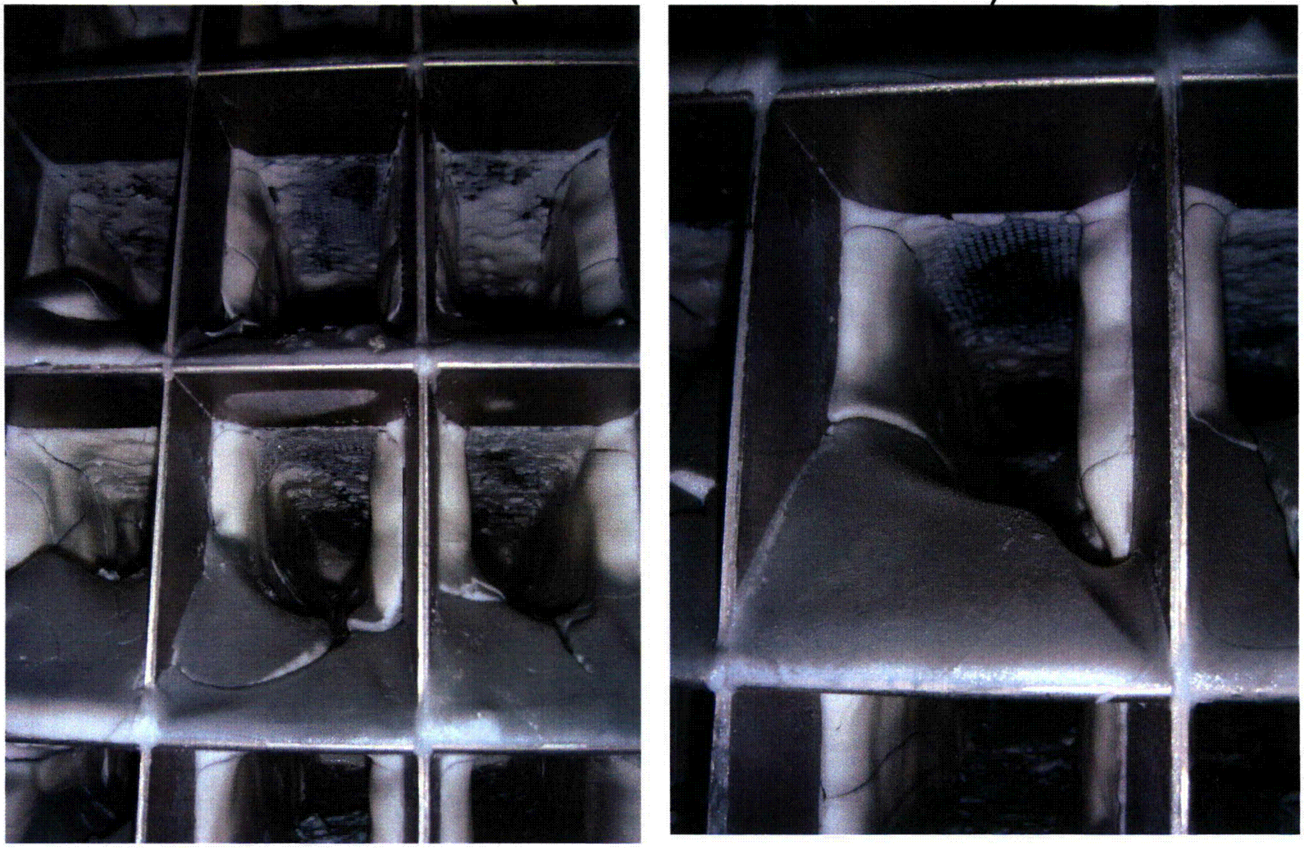
The clean strainer test (Test 1) resulted in a head loss of 0.1 mbar at a nominal flow of 6600 gpm equivalent and 0.4 mbar at a nominal flow rate 11,600 gpm equivalent. Also, no vortices were observed at flow rates up to 196.2 m^3/h (49,150 gpm equivalent) with one cm submergence, which is less than the PVNGS submergence of 5.3 cm (2.1 inches) at the minimum Containment flood level [Ref. 4.43].

The results of chemical effects head loss Tests 2 and 3 are provided below and in Sections 3.o.2.p and 3.o.2.q of this response. Tests 2 and 3 were identical in procedure and amount of debris with some difference in the time taken for debris addition. The tests show similar results:

- Test 02: No thin bed effect was observed and open strainer surface area was visible after the introduction of the non-chemical debris (Figure 3-18). Clean screen area following chemical addition was also visually observed at the top of several pockets (Figure 3-19). The maximum head loss reached at 6600 gpm equivalent flow was 42.6 mbar and for the 11,600 gpm equivalent it was 90.0 mbar. There was a pressure spike to 159.5 mbar at 11,600 gpm, but the spike was most likely the result of air ingestion through the top of the strainer cartridges. The water level was increased to 5.3 cm above the strainer (the Palo Verde minimum submergence) from approximately one cm and both the air ingestion and head loss spikes stopped and the head loss returned to its previous level. Bore holes were not visibly observed in this test.

Figure 3-18: Test 2 Open Area with 100% Non-Chemical Debris (Underwater Photo Taken During Test)

Figure 3-19: Test 2 Open Area with 100% Non-Chemical & Chemical Debris (Photos Taken After Draindown)



- Test 3: No thin bed effect was observed and, as in Test 2, open strainer surface area was visible after the non-chemical debris was added (Figure 3-20). Clean screen area following chemical addition was also visually observed at the top of several pockets (Figure 3-21). The head loss increased while adding the chemical debris continuously. The maximum head loss reached at 6600 gpm equivalent flow was 92.6 mbar and for the 11,600 gpm equivalent it was 160.7 mbar. Bore holes were not visibly observed in this test.

Figure 3-20: Test 3 Open Area with 100% Non-Chemical Debris (Underwater Photo Taken During Test)

Figure 3-21: Test 3 Open Area with 100% Non-Chemical and Chemical Debris (Photo Taken After Draindown)

26 13:37

Because the Palo Verde debris configuration has a layer thickness less than what is typically considered the minimum for a thin bed condition (1/10-inch to 1/8-inch), a small difference in the debris layer can have a large influence on the head loss. The thin debris bed causes repeatability of the chemical head loss tests to be very difficult. In addition, Test 2 exhibited a steady upward head loss trend while Test 3 exhibited an upward trend. The difference in behavior can be attributed to the unpredictable nature of strainers with open surface area [Ref. 4.42].

A 10-minute pump stop was made after each test's flow sweep. A small decrease in head loss occurred after restart; however, the head loss increased back nearly to the value before the stop. Additionally, no vortexing was observed after pump restart [Ref. 4.42].

Any debris which settled away from the test was agitated to assist in transport to the strainer. Final debris sedimentation in front of the strainer was 11 percent (Test 3) to 19 percent (Test 2).

The stability criteria which were met in Tests 2 and 3 are provided in Section 3.o.2.p.

Plots of the pressure drop, flow rate, and water temperature throughout Tests 2 and 3 are provided in Section 3.o.2.q.

Plotting the flow sweep data demonstrates a quadratic tendency indicative of open screen area in the post-chemical precipitate addition test loop (see Figures 3-22 and 3-23 in Section 3.f.10). Additionally, when the flow rate was reduced from 176 percent to 100 percent, the head loss decreased from its level prior to the flow sweep meaning more screen area opened during the sweep. This indicates that during the higher flow portion of the flow sweep, the bed shifted slightly to expose more open screen area.

5. <u>Ability to Accommodate the Maximum Volume of Debris</u>

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

In each PVNGS unit there are two fully redundant ECCS sumps, each servicing one train of ECCS and CSS. The sizing and adequacy of the PVNGS strainers are based on all the transportable debris within the entire Containment arriving at a single sump strainer. The strainer head loss testing was also based on this maximum Containment debris loading arriving at a single sump strainer.

6. <u>Ability of the Screen to Resist the Formation of a "Thin Bed"</u>

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

As stated in Section 3.f.4 above, tests did not show the formation of a thin bed, and there were areas of clean strainer.

7. <u>Basis for the Strainer Design Maximum Head Loss</u>

Provide the basis for the strainer design maximum head loss.

The PVNGS specified maximum strainer head loss including chemical effects is 5.0 ft at the maximum sump flow rate for the post-LOCA recirculation phase [Ref. 4.31]. The head loss criteria for strainer sizing are based on 11,600 gpm for the first hour of RAS and then 6,600 gpm for the remaining duration of the ECCS mission time. These head loss criteria retain a minimum of 5.53 ft of margin between required and available NPSH as discussed in Section 3.o.1. The head loss analysis is discussed in Sections 3.f.9 and 3.f.10.

8. Strainer Maximum Design Head Loss

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

The PVNGS head loss analysis [Ref. 4.43] determined that the strainer head loss is 4.33 ft at the sump temperature with the least margin (193.8°F). This head loss is less than the 5.0 ft allowable head loss in the strainer specification [Ref. 4.31]. The head loss criteria retain a minimum of 5.53 ft of margin between the required and available NPSH as discussed in Section 3.o.1. The PVNGS conservatisms used in the head loss and vortexing calculations are included in Sections 3.f.3, 3.f.9, and 3.f.10.

9. Strainer Clean Head Loss Calculation [Ref. 4.43]

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

The head loss in the strainer internal structures is determined using test data [Test 1 in Ref. 4.42] and the theory described below. Based on very similar geometric conditions, equal flow rates are assumed for all pockets in all cartridges for the clean strainer head loss calculation.

The chemical effects test report [Ref. 4.42] documents the clean strainer head loss. For a flow rate of 46.3 m^3/h (plant flow rate equivalent of 11,600 gpm), the head loss is 0.4 mbar or 0.013 ft WC.

For the installed strainer structures, two additional head loss contributions need to be considered (in addition to the screen perforated plate):

a. The redirection head loss from the horizontal flow out of the cartridges into the vertical down flow in the strainer cavities between the cartridges; and

b. The constriction head loss through the openings of the lower duct plates.

These contributions are further discussed in the following subsections.

Redirection Head Loss:

Using the straight passage [Ref. 4.84, Diagram 7.4] to determine the redirection head loss in the vertical flow channel between the cartridges, the formula is:

$\text{Zeta}(c,st) = 1.55 * (Qs/Qc) - (Qs/Qc)^2$

Qs = flow rate from the side
Qc = flow rate vertically in the central duct

This applies to the velocity head in the main channel w(c).

For a single cartridge and half the channel width (symmetry):

Q(tot) = 0.732 m^3/s

There are seven modules with 16 cartridges and one module with 10 cartridges. The flow per cartridge then becomes:

Q(cart) = 0.732 /(7*16 + 1*10) = 0.006 m^3/s.

The spreadsheet in Table 3-32 shows the computation for each influx from a pair of pockets and the integration of the head loss vertically in the channel width of 250 mm and the cartridge width of 168 mm. There are nine vertical pockets in a cartridge.

Table 3-32: Re-direction Head Loss (Part a) Calculation Spreadsheet

Flow rate per cartridge	(m^3/s)	0.006
Number of pockets vertically		9
Flow rate per pocket row (Qs)	(m^3/s)	0.00066667
Cartridge width	(m)	0.168
Half channel width	(m)	0.125
Water density	(kg/m^3)	1000

row number	flow rate Qc m^3/s	Qs/Qc	zeta(c,st)	w(c) m/s	head loss Pa	accumul. HL Pa
1	0.00066667	1	0.55	0.03174603	0.2771479	0.2771479
2	0.00133333	0.5	0.525	0.06349206	1.05820106	1.33534895
3	0.002	0.33333333	0.40555556	0.0952381	1.83925422	3.17460317
4	0.00266667	0.25	0.325	0.12698413	2.62030738	5.79491056
5	0.00333333	0.2	0.27	0.15873016	3.40136054	9.1962711
6	0.004	0.16666667	0.23055556	0.19047619	4.18241371	13.3786848
7	0.00466667	0.14285714	0.20102041	0.22222222	4.96346687	18.3421517
8	0.00533333	0.125	0.178125	0.25396825	5.74452003	24.0866717
9	0.006	0.11111111	0.15987654	0.28571429	6.52557319	**30.6122449**

The overall redirection head loss (HL) is 30.6 Pa or 0.0102 ft WC.

Constriction Head Loss in Lower Duct Plate:

Conservatively a head loss coefficient for the constriction of 1.5 was used.

For the lower duct plate, there is an open flow area in this plate for a large module of A= 3 * 0.364 * 0.184 = 0.20 m^2

The flow rate for a large module is: Q = 16 * 0.006 = 0.096 m^3/s

The velocity through the plate is therefore: w = Q/A = 0.48 m/s

The constriction head losses: HL = 1.5 * 1000 / 2 * 0.48^2 = 173 Pa = 0.058 ft WC

Overall Clean Head Loss:

As a result of the two contributions the overall clean head loss at a flow rate of 11,600 gpm = HL measured + HL redirected + HL constricted:

HL(clean) = 40 + 30.6 + 173 = 243.6 Pa = 2.436 mbar = 0.081 ft WC

For the flow rate of 6600 gpm, the square dependency for turbulent flow is:

HL(clean) = 0.081 * (6600/11600)^2 = 0.026 ft WC

10. Debris Head Loss Analysis

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

This section is split into three parts. The first part (a) explains the flow rates at which the strainer head loss is determined. The second part (b) explains how the allowable head loss for the sump strainer is determined. The third part (c) explains how the strainer head loss as a function of sump temperature is determined.

a) Flow Rates Used in Strainer Head Loss Calculation

The procurement specification for the PVNGS ECCS sump strainers [Ref. 4.31] requires a maximum head loss across the strainers of 5.0 ft at a sump discharge flow rate of 11,600 gpm when considering the maximum applicable debris loads. This flow is based on one LPSI pump (5,000 gpm), one CSS pump (5,200 gpm) and one HPSI pump (1,400 gpm) operating at maximum flow. This is conservative as only the HPSI and CSS pumps are actually credited for design basis accident mitigation in the PVNGS UFSAR Chapters 6 and 15 analyses. Normally the LPSI pump is shut off at the start of recirculation. However, if the CSS pump is inoperable, the LPSI pump can be used. Thus, all three pumps would not operate concurrently during the recirculation mode. Either the HPSI and CSS pumps or the HPSI and LPSI pumps will operate. Of these two scenarios, the combination of the HPSI and CSS pumps operating results in the higher recirculation flow rate. See Figures 3-2 through 3-5 (above) for schematic diagrams of the ECCS and CSS. For the PVNGS evaluation, the maximum assumed flow rate is 11,600 gpm for the first hour of the recirculation mode and then 6,600 gpm for the remainder of the recirculation mode [Ref. 4.4, Attachment 8.11]. This sequence is based on a failure of one LPSI pump to automatically shut off following start of recirculation and the operators taking action within one hour to manually shut off the LPSI pump.

b) Allowable Head Loss

There are two basic limitations to head losses:

- Hydraulic limit for ensuring that the NPSH requirements of the pumps are met.
- Structural limit for ensuring that the strainer structures withstand pressure loads.

Hydraulic Limits on Head Loss

The maximum allowable head loss per the PVNGS strainer specification is 5.0 ft of water [Ref. 4.31]. The corresponding design temperature above which this head loss cannot be exceeded is the threshold temperature of 193.8°F, derived below.

The initial air inventory in containment was applied to the total containment pressure for water temperatures below the corresponding vapor temperature (threshold). For temperatures above this threshold temperature, no credit for air contribution was taken and the containment pressure corresponding to the vapor pressure was assumed.

The threshold temperature which corresponds to the vapor pressure at the lowest initial containment air pressure was calculated as follows:

The minimum initial air pressure in the Containment [Ref. 4.80] is:

P(air) = 10.12 psi = 0.69775 bar = 69,775 Pa

This corresponds to a water vapor threshold temperature of 89.9°C (193.8°F).

Below 193.8°F, the allowable head loss credits the difference between the initial air pressure and the water vapor pressure at a given sump temperature, resulting in a larger allowable head loss. This is pertinent when considering that chemical precipitates might only start forming at temperatures lower than 193.8°F. Table 3-33 illustrates this benefit as an allowable head loss versus temperature.

Table 3-33: Allowable Head Loss Versus Temperature (Hydraulic)

Temperature	°C	25	30	40	50	60	70	80	89.9
	°F	77	86	104	122	140	158	176	193.8
Vapor pressure	Pa	3166	4241	7375	12335	19920	31160	47360	69775
Difference to vapor pressure at 193.8°F	Pa	66609	65534	62400	57440	49855	38615	22415	0
Difference to vapor pressure at 193.8°F	ft WC	22.27	21.91	20.86	19.21	16.67	12.91	7.49	0.00
Allowable head loss (+5.0 ft)	ft WC	27.27	26.91	25.86	24.21	21.67	17.91	12.49	5.00

Above the threshold temperature of 193.8°F, the allowable head loss is assumed constant at 5.0 ft water column (WC), due to the containment pressure increasing with vapor pressure without crediting the initial air contribution [Ref. 4.43].

Structural Limits on Head Loss

The maximum allowable pressure difference for the strainer structures and their supports [Ref. 4.44] was determined to be 31,000 Pa = 10.4 ft WC at a temperature of 70°F or 21.1°C. This limit is governed by the capacity of the frame structure [Ref. 4.44, Section 7.1.3.4].

This limiting pressure difference was determined by the stress allowable according to the formula Sm+Sb = Sy * 0.66 * 1.7 (AISC Code). The temperature dependence of the yield strength (Sy) was obtained by linear interpolation of the values determined [Ref. 4.44, Table 4-2]. Since the allowable pressure difference is proportional to Sy, the structural limits shown in Table 3-34 are derived:

Table 3-34: Allowable Head Loss Versus Temperature (Structural)

Temperature	°C	25	30	40	50	60	70	80	89.9	122.2
	°F	77	86	104	122	140	158	176	193.8	252.0
Yield Strength Sy (304L)	MPa	172.4	172.4	171.1	165.5	161.4	157.2	153	148.9	139
Allowable head loss	ft WC	10.40	10.40	10.32	9.98	9.74	9.48	9.23	8.98	8.39

c) Strainer Head Loss

The strainer head loss calculation was finalized based on the updated test debris and flow rate requirements from the latest MFTL test results. The test results [Ref. 4.43] are based on the chemical test specification [Ref. 4.81] and the MFTL test report and the corresponding test protocols [Ref. 4.42].

The PVNGS head loss analysis [Ref. 4.43] considers the time dependent recirculation flow rate (11,600 gpm up to one hour, 6,600 gpm after one hour) and sump fluid temperature.

The temperature range in the head loss analysis was from the lowest test temperature of 56.8 °F up to the maximum sump fluid temperature of 252 °F [Refs. 4.31 and 4.43]. The minimum initial containment air pressure was credited at sump temperatures less than the saturation temperature corresponding to the minimum initial air pressure in the head loss analysis as described in Section 3.f.10.b. The limitation to the hydraulic allowable head loss ensures that the NPSH requirements of the pumps are met. The structural limit ensures that the strainer structures sustain the pressure loads.

Three tests were run as follows:

- Test 1: Clean strainer (without debris, without chemicals)
- Tests 2 and 3: Strainer with debris and chemicals

The clean strainer head loss though the test module for the 100 percent (11,600 gpm) flow rate is 0.4 mbar.

<u>Flow Sweep Data Evaluation</u>

It was observed in the tests that the screen area was not completely covered with debris, and that open screen areas were distinctly visible (see Section 3.f.4.e) and by the quadratic tendency which indicates open screen area. The quadratic tendency is discussed later in this section. This fact demonstrated that the scalability of the test results to higher temperatures could not be performed considering viscosity alone, but required an in-depth evaluation, taking both turbulent (clean screen areas) and laminar (debris-laden areas) regimes into account. In order to scale the test results to higher temperatures, the flow sweep data was evaluated to identify the head loss behavior based on these two concurrently present regimes.

The graphs in Figures 3-22 and 3-23 show the expanded test data for Tests 2 and 3 for the time ranges of the flow sweeps.

Note, the head loss was recorded every minute, flow rate every 15 minutes, and temperature every 30 minutes and therefore the head loss and flow rate plots do not always correlate as expected in the figures below (e.g. sometimes there is a drastic increase or decrease in head loss while it appears as though the flow rate increased or decreased gradually).

Figure 3-22: Test 2 Flow Sweep Test Trend

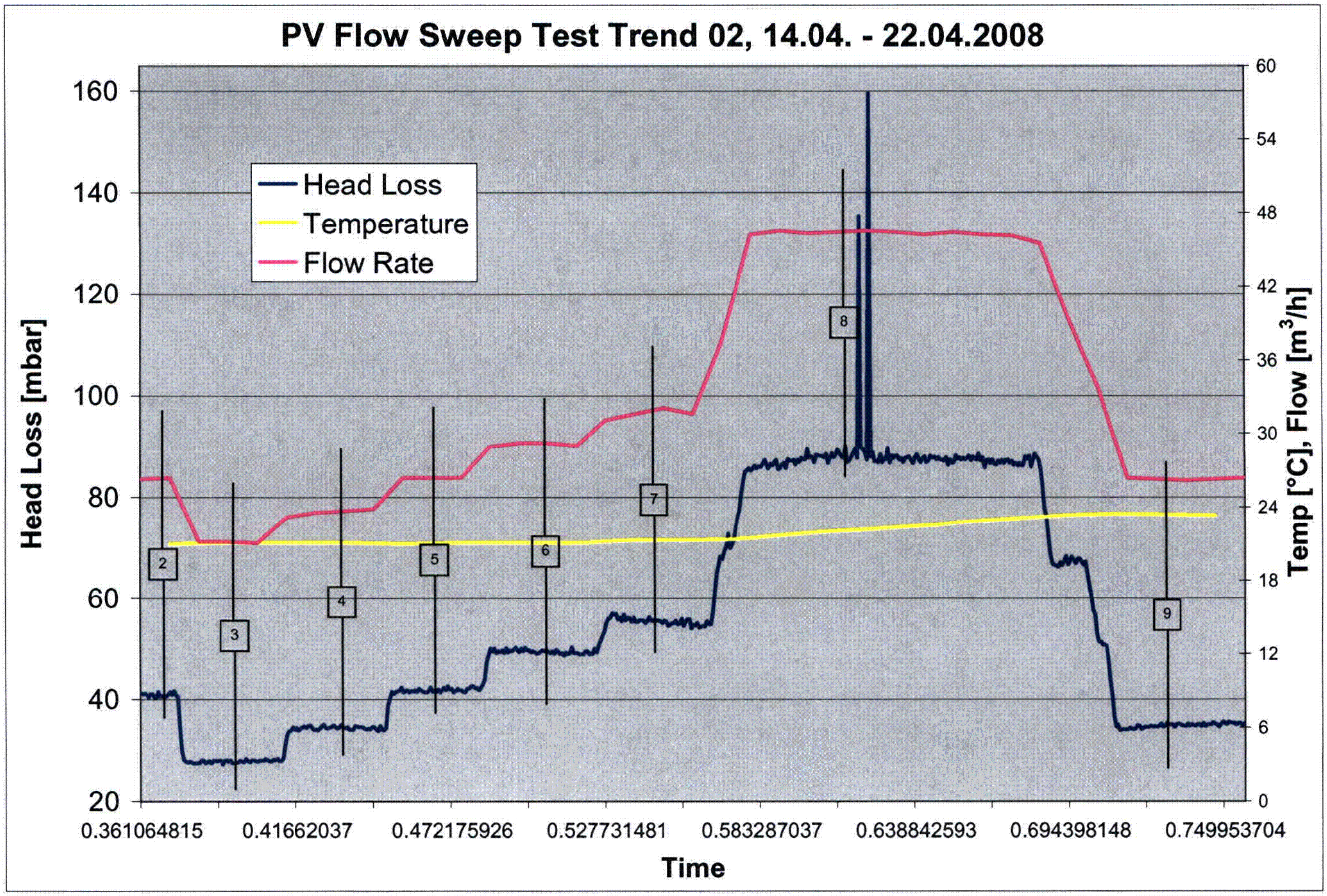
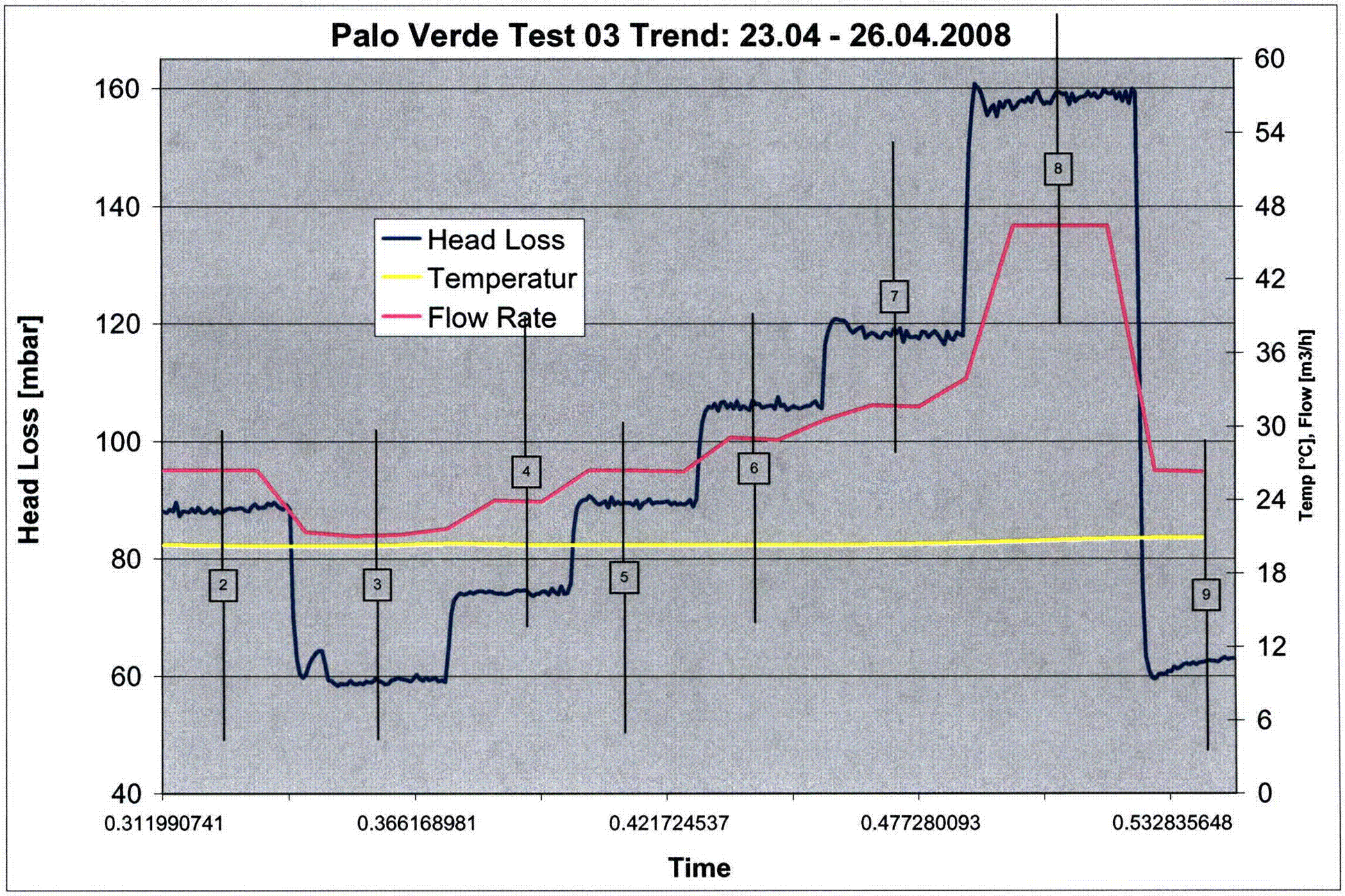


Figure 3-23: Test 3 Flow Sweep Test Trend



From the plateaus shown in the graphs above (numerically identified as 2 through 9 on the figures) for the distinct head losses at distinct flow rates, the flow sweep test data in Figures 3-24 and 3-25 below can be derived for the dependence of head loss versus flow rate. The flow sweep test data are plotted in Figures 3-24 and 3-25 with linear and square fits of all points (these fits are for information only and not in relation to the theory discussed in the next section):

Figure 3-24: Test 2 Flow Sweep Data

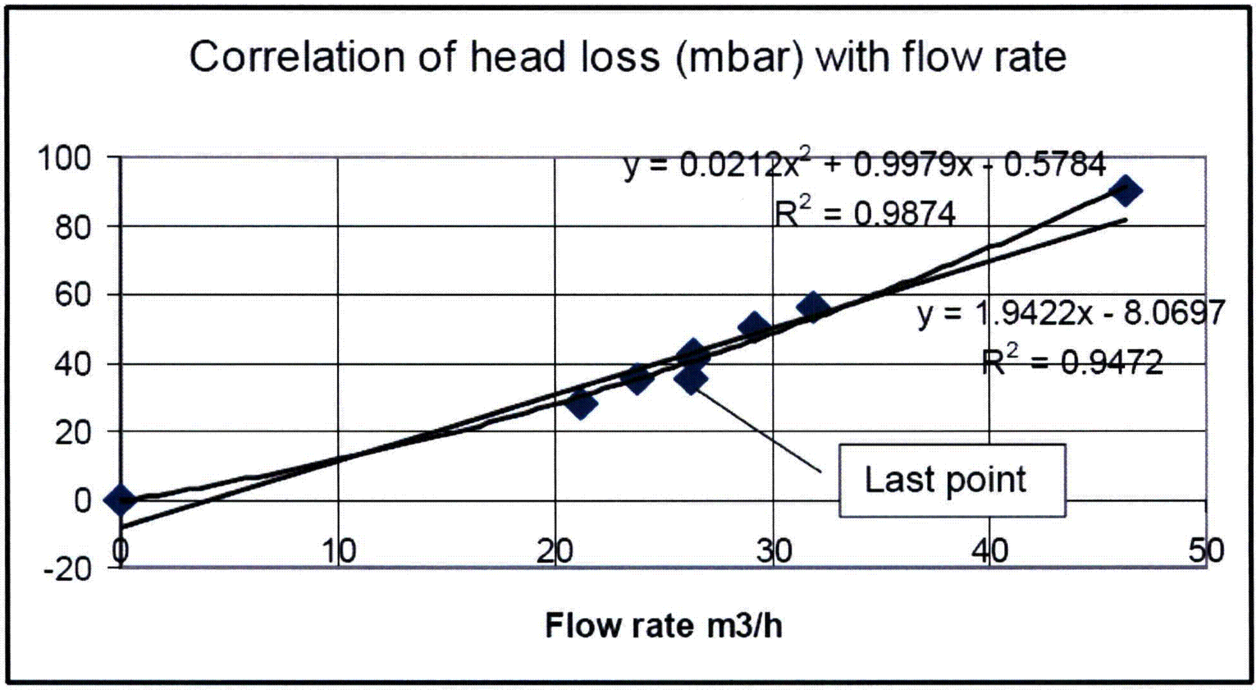
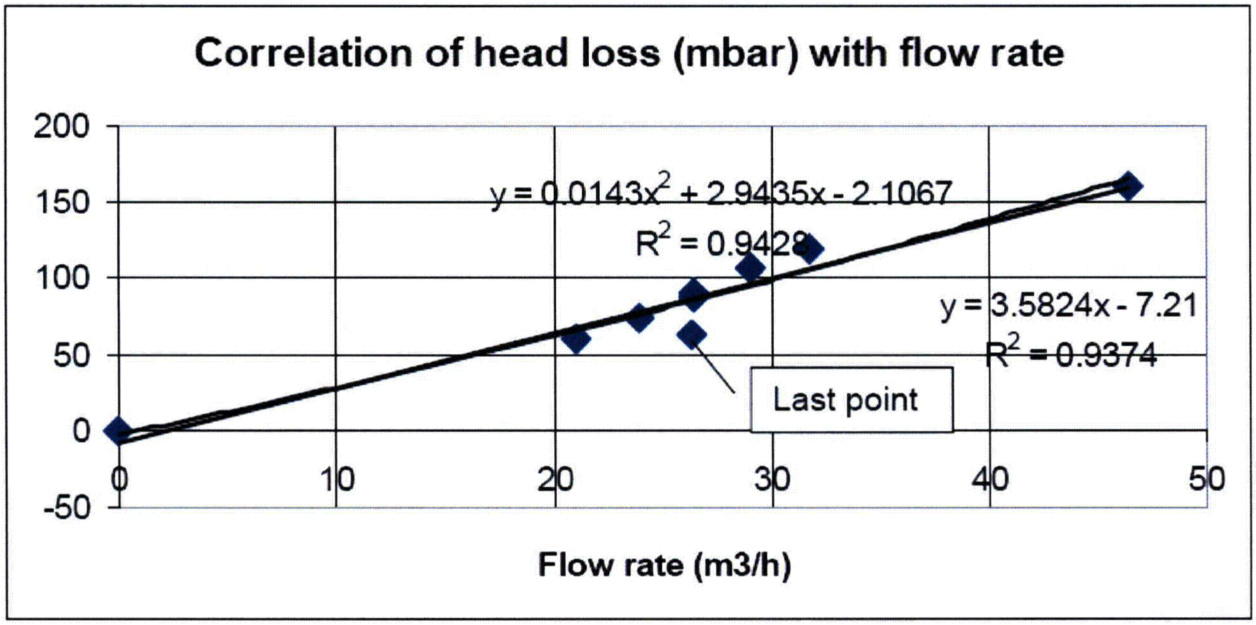


Figure 3-25: Test 3 Flow Sweep Data



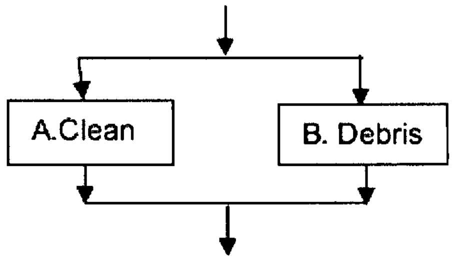
The following interpretation applies to both tests:

- Up to the second highest flow rate, neglecting the highest data point and the last point, there is a slightly increased tendency above linear, and the tendency to a square dependence indicates existence of clean screen.
- The highest data point is lower than expected from the tendency of the previous data points. This suggests additionally created open areas or clean screen at the highest flow rate.
- The last data points (at 100 percent flow) after the highest flow rate do not reproduce the initial data points at 100 percent flow. This is a confirmation of a bed change at the highest flow rate.
- The data supports two distinct bed configurations, one for up to the second highest flow rate, referred to as configuration "a," and the other for the highest flow rate data point and the last data point (at 100 percent flow), referred to as configuration "b."

Theory for Separated Parallel Flows for a Partially Open Screen

Figure 3-26 depicts the model used for a flow rate sweep with constant clean and debris laden screen areas:

Figure 3-26: Parallel Flow Through a Strainer with Debris Laden and Open Areas



The screen is separated into a parallel path flow pattern with a clean screen portion A (turbulent, square dependency on flow rate) and a debris laden screen portion B (laminar, linear dependency on flow rate).

The total head loss HL (in mbar) is equal for both paths, and is postulated to be related to the flow rates for portion A (FRA) and portion B (FRB) in m^3/h as follows (Moreover, the debris laden laminar portion is made proportional to the water viscosity μ as well):

HL = CA * FRA ^ 2 (1)

HL = CB * FRB * µ (2)

CA = Coefficient for clean screen

CB = Coefficient for debris laden screen

Moreover, for the total flow rate:

FRtot = FRA + FRB (3)

From (1) and (2) solved for flow rates and substituted into (3):

FRtot = SQRT(HL/ CA) + HL/ CB / µ

Or, by separating and squaring:

(FRtot - HL/ CB / µ)^2 = HL/ CA

Or, by expanding:

FRtot^2 – 2*FRtot * HL/ CB / µ + (HL/ CB / µ)^2 = HL/ CA

Or, by separating for HL:

HL^2 * (1/ CB / µ)^2 + HL * (- 1/ CA - 2 * FRtot / CB / µ) + FRtot^2 = 0

The simplified equation is as follows:

HL^2 * a + HL * b + c = 0

where

a = (1/ CB / µ)^2
b = (- 1/ CA - 2 * FRtot / CB / µ)
c = FRtot^2

This quadratic equation has the following solution for HL:

HL = (-b -SQRT(b^2-4*a*c))/(2a) (4)

From the test data of the flow sweep, a curve fit can be developed for the head loss data points as a function of the total flow rate. The values of CA and CB are determined by iteration, whereby the sum of the squared deviations between measured head losses and theoretical head losses is minimized.

With the values of CA and CB known, the bed configuration, and the HL function are defined by equation (4) above.

Since there are two distinct screen configurations identified for both tests, it was decided to fit the theoretical equation in two ways for both tests:

- configuration "a" to the first six flow sweep data points plus origin (origin, 100, 80, 90, 100, 110, and 120 percent) and
- configuration "b" to the last two flow sweep data points plus origin (origin, 176 percent, and 100 percent).

Fitting of Flow Sweep Test Data

Spreadsheets documenting the determination of CA and CB for configurations "a" and "b" for both Tests 2 and 3 are provided in Tables 3-35 and 3-36.

Table 3-35: Determination of CA and CB for Test 2

Test #2 14.4.-22.4.2008												
Configuration a												
Flow coefficients	CA	0.091005	CB	8377.222								
	Flow rate m3/h	Head Loss mbar	Temperat. °C	Viscosity kg/sm	coeff.a	coeff.b	coeff.c	HL(theory) mbar	HL deviation^2 mbar	FRA m3/h	FRB m3/h	FRB/FRtot %
	0	0	21	0.000981	0.014797	-1.0988E+01	0	0	0	0	0	
	21.2	28	21.1	0.000979	0.014874	-1.6159E+01	449.44	28.56380421	0.317875182	17.7163706	3.48362943	16.43%
	23.8	35	21.1	0.000979	0.014874	-1.6794E+01	566.44	34.80216621	0.039138209	19.5555426	4.24445741	17.83%
	26.4	42	21	0.000981	0.014797	-1.7411E+01	696.96	41.49255763	0.257497757	21.3526526	5.04734737	19.12%
	26.4	41	21	0.000981	0.014797	-1.7411E+01	696.96	41.49255763	0.24261302	21.3526526	5.04734737	19.12%
	29.2	50	21.1	0.000979	0.014874	-1.8111E+01	852.64	49.05542288	0.892225937	23.2172215	5.98277854	20.49%
	31.9	56	21.3	0.000974	0.015028	-1.8810E+01	1017.61	56.66592352	0.443454132	24.9532845	6.94671553	21.78%
								Sum	2.192804237			

Test #2 14.4.-22.4.2008												
Configuration b												
Flow coefficients	CA	0.075238	CB	8012.981								
	Flow rate m3/h	Head Loss mbar	Temperat. °C	Viscosity kg/sm	coeff.a	coeff.b	coeff.c	HL(theory) mbar	HL deviation^2 mbar	FRA m3/h	FRB m3/h	FRB/FRtot %
	0	0	21	0.000981	0.016173	-1.3291E+01	0	0	0	0	0	
	26.3	35	23.4	0.000923	0.018277	-2.0402E+01	691.69	34.99987546	1.55107E-08	21.5682507	4.73174933	17.99%
	46.3	90	21.9	0.000959	0.01694	-2.5343E+01	2143.69	90.00004105	1.68501E-09	34.5862142	11.7137858	25.30%
								Sum	1.71957E-08			

Table 3-36: Determination of CA and CB for Test 3

Test #3 23.4.-26.4.2008												
Configuration a												
Flow coefficients	CA	0.193477	CB	18062.53								
	Flow rate m3/h	Head Loss mbar	Temperat. °C	Viscosity kg/sm	coeff.a	coeff.b	coeff.c	HL(theory) mbar	HL deviation^2 mbar	FRA m3/h	FRB m3/h	FRB/FRtot %
	0	0	20.2	0.001002	0.003053	-5.1686E+00	0	0	0	0	0	
	21	60	20.2	0.001002	0.003053	-7.4893E+00	441	60.36953166	0.136553648	17.6642056	3.33579437	15.88%
	23.9	74	20.3	0.000999	0.003069	-7.8167E+00	571.21	75.3018379	1.694781916	19.7282243	4.17177572	17.46%
	26.4	88	20.2	0.001002	0.003053	-8.0861E+00	696.96	89.19648254	1.431570474	21.4713362	4.92866378	18.67%
	26.4	91	20.3	0.000999	0.003069	-8.0937E+00	696.96	89.12318173	3.52244681	21.4625119	4.93748806	18.70%
	29	107	20.3	0.000999	0.003069	-8.3818E+00	841	104.321408	7.174855072	23.2205193	5.77948067	19.93%
	31.7	119	20.4	0.000997	0.003085	-8.6901E+00	1004.89	120.8179662	3.305001266	24.9891204	6.71087964	21.17%
								Sum	17.26520919			

Test #3 23.4.-26.4.2008												
Configuration b												
Flow coefficients	CA	0.134393	CB	13774.19								
	Flow rate m3/h	Head Loss mbar	Temperat. °C	Viscosity kg/sm	coeff.a	coeff.b	coeff.c	HL(theory) mbar	HL deviation^2 mbar	FRA m3/h	FRB m3/h	FRB/FRtot %
	0	0	20.2	0.001002	0.00525	-7.4408E+00	0	0	0	0	0	
	26.3	63	20.9	0.000984	0.005445	-1.1322E+01	691.69	62.99998227	3.14313E-10	21.6511756	4.64882441	17.68%
	46.4	161	20.6	0.000992	0.005361	-1.4236E+01	2152.96	161.0000082	6.65727E-11	34.6118026	11.7881974	25.41%
								Sum	3.80886E-10			

The resulting values are summarized in Table 3-37:

Table 3-37: Summary of CA and CB Values

Fitted Coefficients	Test 2		Test 3	
	Config. a	Config. b	Config. a	Config. B
CA	0.091005	0.075238	0.193477	0.134393
CB	8377.222	8012.981	18062.53	13774.19

For all test data, the flow rate through the debris laden part of the screen lies in the range from 15 to 28 percent of the total flow rate, with the remaining majority of the flow rate passing through the clean screen areas. The results show that Test 3 has higher resistance coefficients, and therefore is bounding for Test 2. This is consistent with the peak head losses observed in Tests 2 and 3 as discussed in Section 3.f.4.e. Moreover, configuration "a" of Test 3 is bounding for all bed configurations.

The correlation between the theoretical head loss predicted by the curve fits and the head loss measurements can be seen in Figures 3-27 and 3-28 for Test 3:

Figure 3-27: Comparison of Predicted Head Loss to Measured Head Loss for Bed Configuration a of Test 3

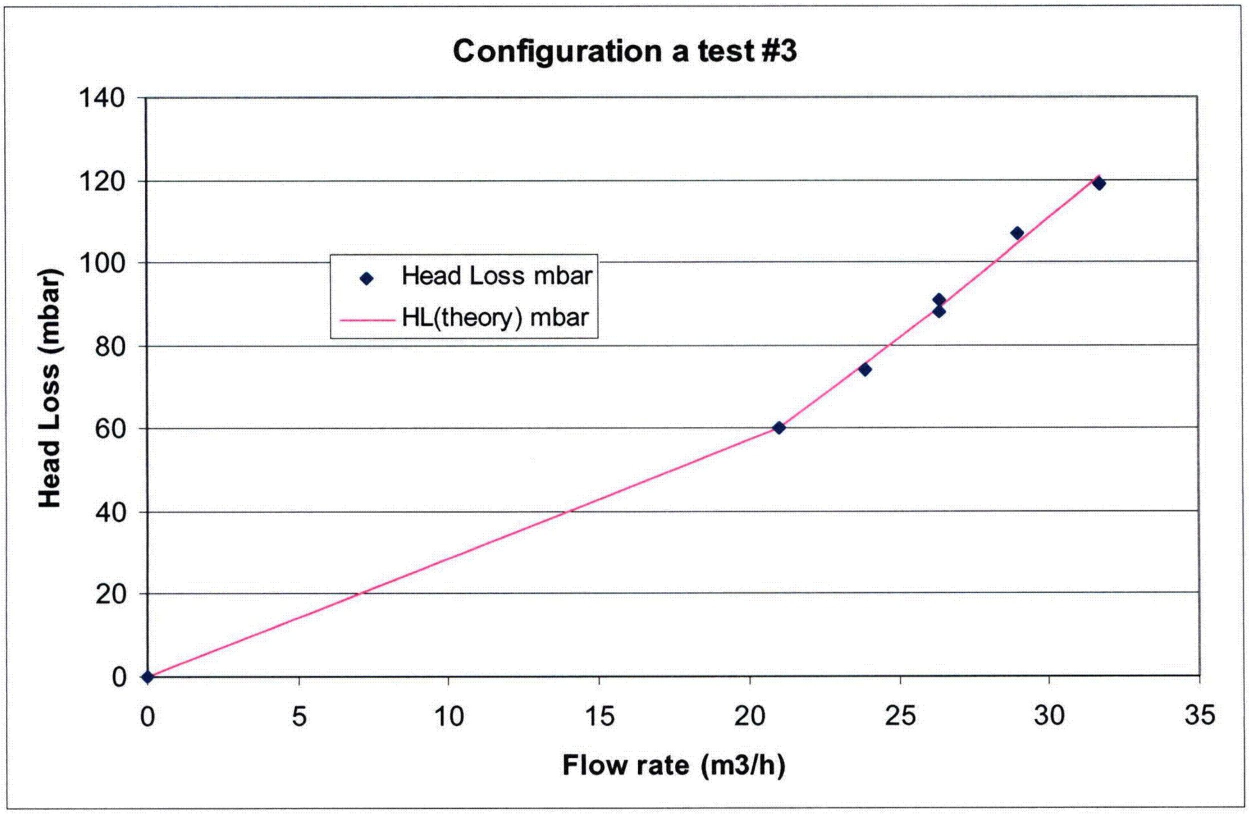
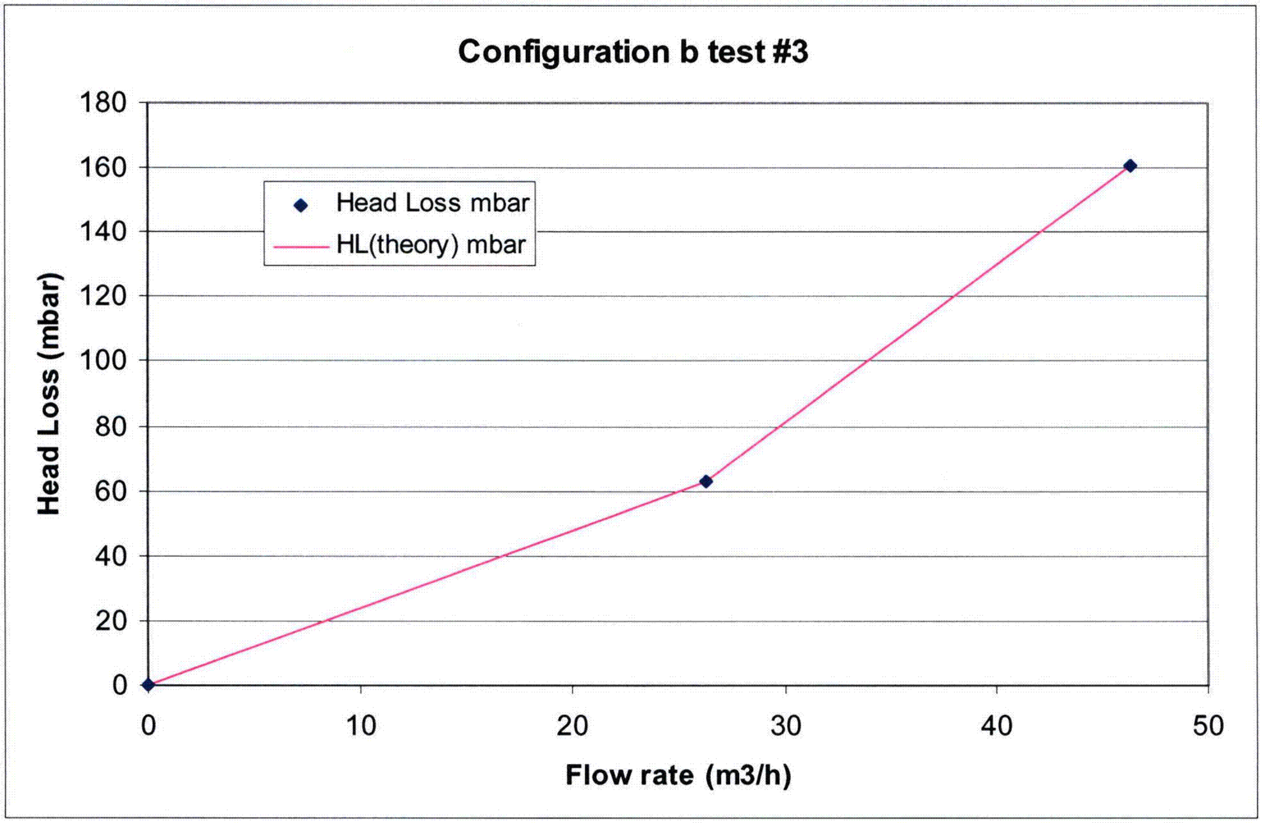


Figure 3-28: Comparison of Predicted Head Loss to Measured Head Loss for Bed Configuration b of Test 3



The Test 3 coefficients for configuration "a" are used conservatively for all cases of flow rates and temperatures in the next subsection.

Detailed Head Losses for Installed Strainers

For the PVNGS installed strainer, somewhat different conditions exist than in the test facilities (e.g. temperature), and the measured head losses are adjusted based on analytical considerations. This is accomplished as discussed below.

Head Loss Due to Debris

The most conservative debris based head loss is provided by use of the coefficients CA = 0.193477 and CB =18062.5 for Test 3, bed configuration "a." Conservatively these values are used for the PVNGS head loss evaluation. Temperature (through viscosity) and flow rate changes are incorporated in theory, and can be readily applied.

Viscosity Adjustment

The viscosity for pure water is known as a function of temperature. However, the presence of chemical effects may influence the viscosity in the post-LOCA containment pool. There is data on viscosity from the Los Alamos ICET Test 2 [Ref. 4.89], which was used as a basis in the PVNGS analysis because of the combination of TSP buffer with Nukon insulation in the post-LOCA containment pool.

NUREG/CR-6914, Volume 3 [Ref. 4.89, Figure 4.72] shows that neither temperature nor time has a significant influence on the viscosity of the ICET Test 2 solution, as can be seen in the following kinematic viscosities:

25°C:
pure water: 0.9025E-6 m^2/s
ICET Test 2 : 0.94E-6 m^2/s
chem. factor = 0.94E-6 m^2/s / 0.9025E-6 m^2/s = 1.04

60°C:
pure water: 0.4745E-6 m^2/s
ICET Test 2: 0.50E-6 m^2/s
chem. factor = 0.50E-6 m^2/s / 0.4745E-6 m^2/s = 1.05

As a result, assuming a five percent increase to the viscosity of pure water would bound the viscosity increase due to chemical effects.

However, NUREG/CR-6914, Volume 3 [Ref. 4.89, Figure 4.73] shows dynamic viscosities with higher factors compared to pure water for ICET Test 2. This data is at 25°C and the maximum value shown is 0.001275 Pa*s, which is larger than the value for pure water by a factor of 0.001275 Pa*s / 0.0008999 Pa*s = 1.42. The more conservative factor at 25°C was used in the PVNGS evaluation.

Since the ICET Test 2 report does not contain corresponding dynamic viscosity values at 60°C, a comparison was made of the viscosities with those of ICET Test 1 [Ref. 4.85]:

The viscosity of pure water at 23°C is 0.000941 Pa*s. The viscosity from ICET Test 1 [Ref. 4.85, Chapter 4.5.5, Figure 36] is 1.745E-6 m^2/s * 998 kg/m^3 = 0.001742 Pa*s. The kinematic viscosity ratio becomes 0.001742 Pa* s / 0.000941 Pa*s = 1.851.

This indicates that the chemical effect on viscosity is substantially larger for ICET Test 1 than for ICET Test 2 (with a value of 1.42).

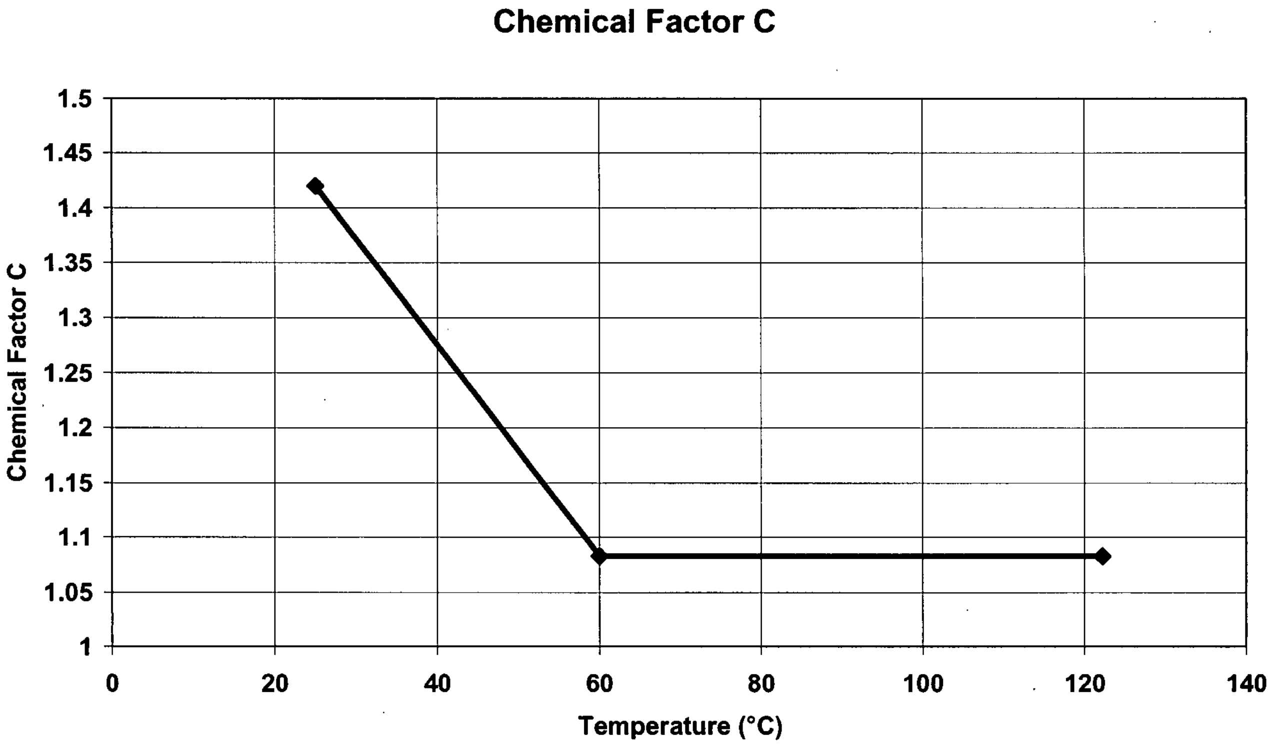
From this data for room temperature, it can be concluded that using the factor from ICET Test 1 at 60°C for kinematic viscosity, instead of the unavailable data of ICET Test 2, is conservative. The factor used in the PVNGS evaluation was the average viscosity from NUREG/CR-6914, Volume 2 [Ref. 4.85, Chapter 4.5.5, Figure 35], $0.514E\text{-}6\ m^2/s * 983\ kg/m^3 = 0.000505\ Pa*s$. Since the viscosity of pure water is 0.0004665 Pa*s [$0.4745E\text{-}6\ m^2/s * 983\ kg/m^3$], the ratio (referred to as the chemical factor C) becomes:

0.000505 Pa*s / 0.0004665 Pa*s = 1.083 for $T_{sump} > 60°C$

For the temperatures in between 25°C and 60°C, linear interpolation is used. For temperatures above 60°C, the factor will be conservatively kept constant.

This results in the correlation provided in Figure 3-29 for the chemical factor C defined above:

Figure 3-29: Chemical Factor C



This chemical factor C is used to increase the pure water viscosities for the head loss calculations for the screen according to the theory of separated parallel flows for a partially open screen since the head loss through the debris laden portions of the strainer are proportional to viscosity.

Total Strainer Head Loss and Comparison with Allowables

Given the strainer debris bed/open area head loss correlation described above and the clean strainer head loss determined in Section 3.f.9, the overall head loss of the strainer assembly was computed for all temperatures.

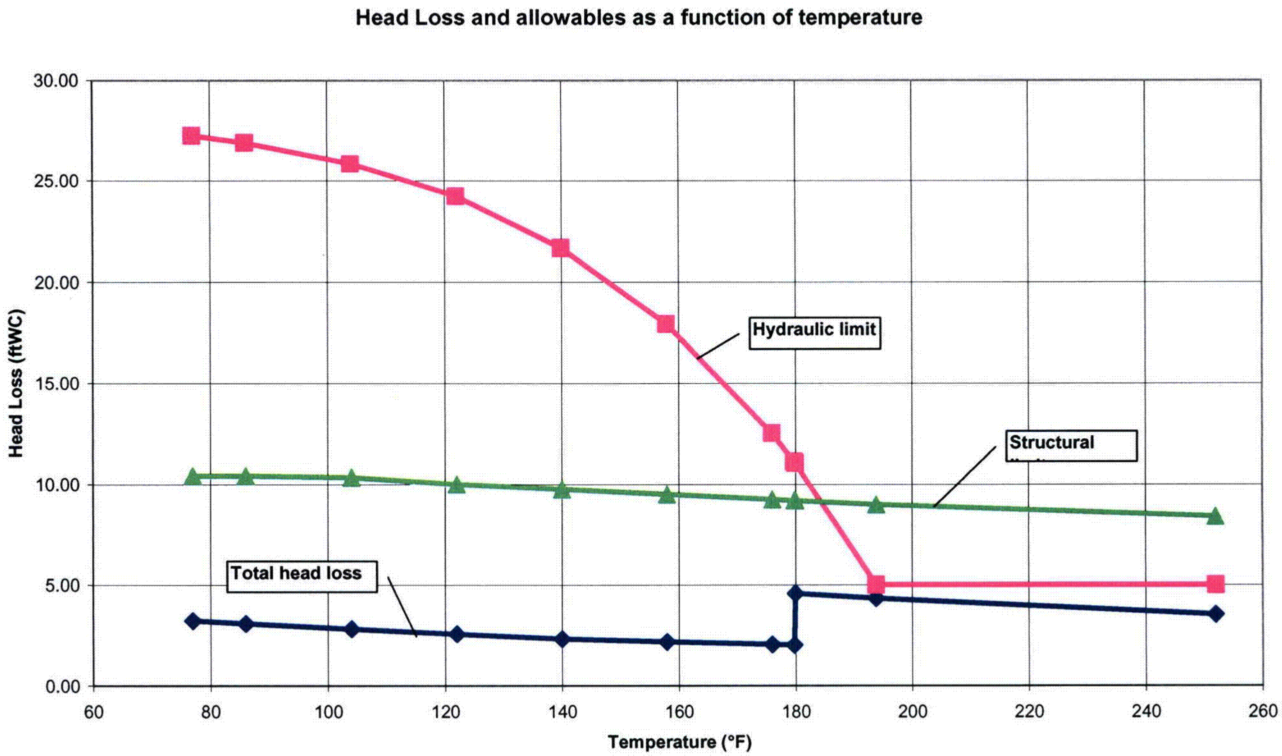
The scaling on a reduced flow rate of 6600 gpm at a time 5003 seconds after the LOCA event is interpreted to occur between 25°C and a certain maximum temperature, while the higher flow rate of 11,600 gpm occurs at higher temperatures earlier in the event. Two sump temperature response curves were defined in the ECCS strainer specification [Ref. 4.31]. In the time range of the high flow rate (from 1403 to 5003 seconds), the minimum sump temperature from both sump temperature response curves is 180°F = 82.2°C. This supports taking credit for the reduced flow rate below this temperature. At higher temperatures lower flow could be possible; however at the higher temperatures the higher flow rate is conservative. The computation for the entire temperature range is provided in Table 3-38 and Figure 3-30.

Table 3-38: Overall Head Loss Calculation

Flow rate (plant)	gpm	6600	11600
	m^3/h	1498.86	2634.36
Test scaling factor		56.9	56.9
Test flow rate	m^3/h	26.34	46.30
Flow Coefficients			
CA		0.19347711	0.19347711
CB		18062.5292	18062.5292
Temperature	°C	25	60
Chemical Factor C		1.42	1.083

Temperature	°C	25	30	40	50	60	70	80	82.1	82.2	89.9	122.2
Temperature	°F	77	86	104	122	140	158	176	179.8	180.0	193.8	252.0
Flow Rate	gpm	6,600	6,600	6,600	6,600	6,600	6,600	6,600	6,600	11,600	11,600	11,600
	m^3/h	26.3420035	26.3420035	26.3420035	26.3420035	26.3420035	26.3420035	26.3420035	26.3420035	46.2980668	46.2980668	46.2980668
Clean head loss (internal)	ft WC	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.081	0.081	0.081
Dynamic viscosity	Kg/sm	0.0008999	0.0007977	0.0006532	0.000547	0.0004665	0.000404	0.0003544	0.000346	0.0003456	0.0003148	0.0002278
Chemical factor		1.42	1.37185714	1.27557143	1.17928571	1.083	1.083	1.083	1.083	1.083	1.083	1.083
Dynamic viscosity (+chem)	Kg/sm	0.00127786	0.00109433	0.0008332	0.00064507	0.00050522	0.00043753	0.00038382	0.00037472	0.00037428	0.00034093	0.00024671
Calculation two-flow theory												
coeff. a		0.00187706	0.00255945	0.0044151	0.00736597	0.01200833	0.01601118	0.02080648	0.021829	0.02187956	0.02637039	0.05035917
coeff. b		-7.45110619	-7.83390488	-8.66922489	-9.6901882	-10.9418171	-11.8349555	-12.7679485	-12.9524421	-18.8651489	-20.2052208	-25.9479276
coeff. c		693.901149	693.901149	693.901149	693.901149	693.901149	693.901149	693.901149	693.901149	2143.51099	2143.51099	2143.51099
Head loss (theory)	mbar	95.4210101	91.3000515	83.6013788	75.9991492	68.578829	64.2091327	60.2656973	59.5493493	134.650666	127.205598	103.330059
	ft WC	3.19042725	3.05264188	2.79523468	2.54105208	2.29295167	2.1468497	2.01499987	1.99104858	4.5020814	4.25315353	3.45486843
Total Head Loss	ft WC	3.22	3.08	2.82	2.57	2.32	2.17	2.04	2.02	4.58	4.33	3.54
Hydraulic limit	ft WC	27.27	26.91	25.86	24.21	21.67	17.91	12.49	11.10	11.03	5.00	5.00
Structural limit	ft WC	10.40	10.40	10.32	9.98	9.74	9.48	9.23	9.18	9.18	8.98	8.39
Margin to hydraulic limit	ft WC	24.05	23.83	23.04	21.64	19.35	15.74	10.45	9.08	6.45	0.67	1.46
Margin to structural limit	ft WC	7.18	7.32	7.50	7.41	7.42	7.31	7.19	7.16	4.60	4.65	4.85

Figure 3-30: Head Loss and Allowables as a Function of Temperature



The total calculated head loss is 4.33 ft WC for the design temperature of 193.8°F (the margin is lowest at 193.8°F), which is below the allowable limit of 5.0 ft provided in the sump strainer specification [Ref. 4.31]. The strainer head loss is less than both the structural and hydraulic allowable limits over the full range of temperatures.

11. <u>Complete Water Seal</u>

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.

The top of the PVNGS strainer is completely submerged a minimum of 2.1 inches below the minimum containment flood level. There are no vents above that water level and there are no failure criteria required to be applied.

There are two pipes and a conduit that penetrate the strainer floor plates and extend above the containment flood water level. The conduit is for the sump temperature element and is sealed below the strainer floor. The two pipes include the low temperature overpressure (LTOP) relief line and a pipe that serves as a valve stem extension protector for the sump suction line isolation valve. The LTOP line is isolated by its relief valve and the stem extension pipe is sealed at the valve actuator. As a result, there are no additional sources of air ingestion which could affect the ability to pass the required flow through the strainers. Appendix B of this document provides additional details of the pipes and conduit.

12. Near Field Settling

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.

As discussed in Section 3.f.4.e, only limited sedimentation (11 percent) was observed during the critical Test 3 of the MFTL testing. The test report [Ref. 4.42] states that agitation was used to ensure a maximum amount of debris flowing into the pockets. This agitation counterweighs any possible effects from any slight difference in plant specific approach velocity fields [Ref. 4.43]. Therefore, for PVNGS strainer head loss testing no credit was taken for near field settling.

13. Temperature/Viscosity Scaling of Head Loss Tests

State whether temperature/viscosity was used to scale the results of the head loss tests to actual plant conditions. If scaling was used, provide the basis for concluding that boreholes or other differential-pressure induced effects did not affect the morphology of the test debris bed.

The head loss values through the debris laden portion of the strainer are linearly scaled with respect to viscosity to determine the strainer head loss at temperatures other than those which were tested. The justification for the linearity between head loss and viscosity is given in NUREG/CR-6224 [Ref. 4.66]. As discussed in Section 3.f.4.d, bore holes were not observed during the chemical effects head loss testing, although open area was observed. Temperature and viscosity scaling is not applied to head loss through open areas. More detail regarding the use of viscosity scaling through only the debris laden portion of the screen is provided in Section 3.f.10.

14. Credit for Containment Accident Pressure in Flashing Evaluation

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.

The flashing evaluation [Ref. 4.43], which is repeated below, was performed using post-LOCA containment pressure and sump water temperature response curves for a double ended discharge leg slot break (DEDLSB) LOCA scenario with maximum safety injection. The analysis which developed these response curves was performed using assumptions which maximize the global containment pressure and temperature response due to design basis mass and energy release events. However, sufficient margin is available such that flashing is not expected to occur under any circumstance.

The flashing evaluation (shown below) [Ref. 4.43] determines that a strainer head loss of approximately 32 ft is required for the postulated occurrence of flashing. This is much larger than the allowable strainer head loss at high sump temperatures where flashing is most likely. The maximum allowable strainer head loss at sump temperatures greater than 193.8°F is 5.0 ft [Ref. 4.31; also see Section 3.f.10 of this response for the allowable head loss as a function of temperature].

Therefore, it is concluded that flashing will not occur, even if a more conservative LOCA pressure response were used.

Flashing Analysis [Ref. 4.43]

To ensure that no flashing occurs downstream of the sump screen, the absolute pressure after the screen must be higher than the vapor pressure based on the sump water temperature. Table 3-39 provides calculated data for the two cases of transients after a LOCA [Ref. 4.31, Attachment 5]. The table provides the pressure difference between the containment pressure at various time points after 1403 sec and the vapor pressure of the sump water [Ref. 4.43]:

Table 3-39: Flashing Investigation

First scenario	Pressure		Temperature		Saturation Pressure	Pressure Difference
Time (sec)	psia	bar(abs)	°F	°C	bar(abs)	bar
1,403	67	4.62	180	82.2	0.52	4.10
5,000	58	4.00	215	101.7	1.08	2.92
10,000	52	3.59	240	115.6	1.72	1.87
50,000	41	2.83	230	110.0	1.43	1.40
100,000	32	2.21	210	98.9	0.97	1.24
Second scenario						
1,403	62	4.27	180	82.2	0.52	3.75
5,000	52	3.59	215	101.7	1.08	2.51
10,000	43	2.96	230	110.0	1.43	1.53
50,000	33	2.28	220	104.4	1.18	1.10
100,000	26	1.79	195	90.6	0.71	1.08
1,000,000	21	1.45	171. 7	77.6	0.43	1.02
2,000,000	18	1.24	155	68.3	0.29	0.95

The minimum pressure difference of both scenarios is 0.95 bar = 31.8 ft WC.

This pressure difference is substantially more than all the calculated debris head loss values and the structural limit. Therefore, no flashing resulting in two phase flow occurs within the debris bed and behind the screen.

The elevation difference between the sump outlet and the pump inlet (minimum difference of 26.8 ft as documented below) is larger than the maximum suction line head loss. Therefore, flashing will also not be a concern at the pump inlet. This corresponds to a void fraction of zero at the pump inlet due to flashing.

<u>Analysis of Air Ingestion Due to Deaeration [Ref. 4.43]</u>

One phenomenon which cannot be prevented is a small amount of deaeration due to the difference in solubility of air in water resulting from the pressure difference across the screen. In the following discussion, a conservative assessment is made of the maximum air ingestion rate, which is expected to be minimal.

Table 3-40 shows the basic behavior of the solubility of air in water.

Table 3-40: Dissolved Air in Water at Various Pressures

Dissolved Air in Water (25°C)						
Gauge Pressure (atm)	**0**	**1**	**2**	**3**	**4**	**5**
Dissolved Air (g/kg)	**0.023**	**0.045**	**0.068**	**0.091**	**0.114**	**0.136**

The solubility of air in water is a maximum at the lowest temperature of interest, i.e. here about 25°C = 77°F. The table of dissolved air in water at 25°C clearly shows that the solubility is proportional to absolute pressure. The difference of solubility is 0.023 g Air / kg Water per one atm. A bounding pressure difference across the strainer is conservatively picked as the allowable structural head loss (10.4 feet = 3.17 m = 0.307 atm).

Assuming conservatively that the water entering the strainer is fully saturated with air, the bounding difference of solubility of air in water is:

0.307 * 0.023 = 0.00706 g Air / kg Water or 7.06E-6 kg Air / kg Water.

The densities are:

- for air 1.169 kg/m^3 at 25°C and one atm

- for water 997 kg/m^3 at 25°C

The volume ratio therefore becomes:

(7.06E-6 kg Air/kg Water) / 1.169 kg/m^3 * 997 kg/m^3 = 0.00602 or 0.60 %

This value is applicable at the top elevation of the strainer (strictly speaking at the upper water surface which touches the air). At the pump suction from the sump pit, the water experiences a pressure increase again due to the static water head. The minimum containment water level is 84.5 ft [Ref. 4.31]. The suction pipe elevation in the sump pit is 73'-7". The elevation difference between the minimum water level and suction pipe elevation is 10'-11", which is more than the above postulated maximum head loss.

Therefore, any deaeration that could occur in the strainer cavities is reversed again before the water reaches the sump outlet. The net air production therefore is zero. Therefore, deaeration of the water is not a problem for any temperatures and pressures from the strainer to the sump outlet.

The following assesses deaeration from the sump outlet to the pump inlets by demonstrating that the elevation difference between the sump outlet and the pump inlets is larger than the respective piping head loss.

The suction line head losses and static heads are contained in Table 3-41 [Refs. 4.32 and 4.33]:

Table 3-41: Suction Head losses and Static Heads

Suction Line	Head Losses (ft)	Static Head Losses (ft)
HPSI A	11.2	40.0
HPSI B	10.8	40.0
LPSI A	11.6	37.7
LPSI B	11.4	37.7
CS A	12.9	38.8
CS B	12.61	38.8

The elevation difference between the sump outlet and the pump inlets is a minimum of 37.7ft – 10'-11" (from above) = 26.8 ft. This is substantially more than the maximum suction line head loss of 12.9 ft (which conservatively includes 6.06 ft of head loss due to the pre-GSI-191 strainer). Therefore, reinitiating deaeration downstream of the sump outlet can be excluded. This corresponds to a void fraction of zero at the pump inlets due to deaeration.

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.

- ***Provide applicable pump flow rates, the total recirculation sump flow rate, sump temperature(s), and minimum containment water level.***
- ***Describe the assumptions used in the calculations for the above parameters and the sources/bases of the assumptions.***

- ***Provide the basis for the required NPSH values, e.g., three percent head drop or other criterion.***
- ***Describe how friction and other flow losses are accounted for.***
- ***Describe the system response scenarios for LBLOCA and SBLOCAs.***
- ***Describe the operational status for each ECCS and CSS pump before and after the initiation of recirculation.***
- ***Describe the single failure assumptions relevant to pump operation and sump performance.***
- ***Describe how the containment sump water level is determined.***
- ***Provide assumptions that are included in the analysis to ensure a minimum (conservative) water level is used in determining NPSH margin.***
- ***Describe whether and how the following volumes have been accounted for in pool level calculations: empty spray pipe, water droplets, condensation and holdup on horizontal and vertical surfaces. If any are not accounted for, explain why.***
- ***Provide assumptions (and their bases) as to what equipment will displace water resulting in higher pool level.***
- ***Provide assumptions (and their bases) as to what water sources provide pool volume and how much volume is from each source.***
- ***If credit is taken for containment accident pressure in determining available NPSH, provide description of the calculation of containment accident pressure used in determining the available NPSH.***
- ***Provide assumptions made which minimize the containment accident pressure and maximize the sump water temperature.***
- ***Specify whether the containment accident pressure is set at the vapor pressure corresponding to the sump liquid temperature.***
- ***Provide the NPSH margin results for pumps taking suction from the sump in recirculation mode.***

The PVNGS NPSH requirements for the LPSI and HPSI pumps are taken from Calculation 13-MC-SI-0017 [Ref. 4.32] and the NPSH requirements for the CSS pumps are taken from Calculation 13-MC-SI-0018 [Ref. 4.33]. The NPSH requirements for the

LPSI, HPSI and CSS pumps are based on maximum pump flow rates during recirculation. The procurement specification for the strainers allows a maximum head loss of 5.0 ft for the strainers with the applicable debris loading. The NPSH calculations assume a head loss of 6.06 ft (which is the head loss of the original strainers) for conservatism.

1. Flow Rates, Sump Temperature, and Minimum Containment Water Level

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

The PVNGS maximum ECCS (recirculation) sump flow rate of 11,600 gpm (per sump) is based on HPSI, LPSI, and CSS pumps operating at pump maximum flow. The maximum flows for the HPSI, LPSI, and CSS pumps are 1400 gpm, 5000 gpm, and 5200 gpm respectively. The assumption of the LPSI pump operating is conservative since the LPSI pumps receive an automatic signal to stop upon initiation of RAS. The head loss including chemical effects uses the maximum flow rate of three pumps operating (HPSI, LPSI, and CSS) for the first one hour following a RAS and then the maximum flow rate of the HPSI and CS pumps for the remainder of the ECCS mission time. One hour is used as a conservative time delay for the operators to stop the LPSI pump in the event the LPSI pump fails to automatically stop upon a RAS. The ECCS sump water temperature profile [Ref. 4.50] provides a peak temperature of 242.5°F. The NPSH calculation was performed at 300°F for conservatism to minimize NPSHa [Refs. 4.32 and 4.33]. At initiation of RAS the minimum containment water level is at elevation 84'-6" [Ref. 4.15], which ensures that the strainers are fully submerged by approximately 2.1 inches [Ref. 4.43].

2. NPSH Evaluation Assumptions

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

The determination of the recirculation flow rate assumes maximum flow of the operating pumps.

The Containment response for determination of maximum sump temperature assumes loss of offsite power coincident with a LOCA and the most severe single active failure is hypothesized as loss of a CSS pump with no failure in the DG system.

For determining a minimum containment water level, the assumptions were selected to minimize available water to the sump via various hold up mechanisms and limiting break locations (see Sections 3.g.9 and 3.g.10).

3. Net Positive Suction Head Required (NPSHR)

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

The flow rate for the HPSI, LPSI, and CSS recirculation are conservatively assumed to be equal to the pump maximum flow rate specified by the pump vendor. The vendor specified pump maximum flow rate in Table 3-42 represents the maximum service flow rate that the pump will satisfactorily perform provided sufficient NPSH is available.

Table 3-42: NPSH Requirements

Pump	**Mode**	**Flow Rate (GPM)**	**NPSHR (ft)**	**Basis**
CSS	Recirc - Spray	5200	22	NPSHR as prescribed by vendor.
HPSI	Recirculation	1400	25	HPSI injection assumes maximum flow rate and corresponding NPSHR as prescribed by vendor.
LPSI	Recirculation	5000	20	LPSI recirculation mode conservatively assumes 5000 gpm. Original design interface requirements evaluate ECCS NPSH @ 3500 gpm. NPSHR as prescribed by vendor.

4. Describe How Friction and Other Flow Losses are Accounted

Describe how friction and other flow losses are accounted for.

The PVNGS pump suction line losses based on the viscosity of water were increased to account for the sump water viscosity due to post-LOCA chemical effects. This correction factor for viscosity affects the piping friction coefficient. The increase in sump water viscosity does not affect the hydraulic resistance for valves and fittings since those are primarily due to form losses and not friction. The ECCS and CSS piping friction coefficients and resistance factors for pipe fittings in the PVNGS NPSH calculations are obtained from Crane Technical Paper 410.

5. System Response Scenario for LBLOCA and SBLOCAs

Describe the system response scenarios for LBLOCA and SBLOCAs.

When a LOCA occurs, the Safety Injection System (SIS) and the CSS are actuated. The total time delay is assumed to be 30 seconds from when the pressurizer pressure reaches the Safety Injection Actuation Signal (SIAS) setpoint to when the SI flow is delivered to the RCS.

The CSS is automatically actuated by a Containment Spray Actuation Signal (CSAS) from the Engineered Safety Features Actuation System (ESFAS). The CSAS is initiated by a coincidence of two-out-of-four high-high containment pressure signals, or by two remote manual signals from the control room, or by loss of power to two-out of-four actuation logic channels. The CSAS may also be initiated manually in the control room.

The supportive systems of the CSS are automatically actuated by a SIAS from the ESFAS. The SIAS is generated prior to or coincidentally with the CSAS by a two-out-of-four high containment pressure signals, or by two remote manual signals from the control room, or by the loss of power for two-out-of-four actuation logic channels. The SIAS is also actuated by lower pressurizer pressure signals. CSS suction is automatically changed from the RWT to the ECCS Sump by a RAS from the ESFAS.

The CSAS starts the CSS pumps and opens the containment spray header isolation valves. The specific sequence of pump and valve actuation depends on which power source is available. If offsite power is available, all equipment can receive power simultaneously. If offsite power is not available, the safeguards loads are divided between the two unit specific DGs and are sequentially started after the DGs are running. During the injection mode, the minimum flow lines just downstream of each CSS pump are kept open to prevent deadheaded operation. Water that passes through the minimum flow lines is returned to the RWT.

Once the CSS pumps are started and the valves are opened, water flows into the containment spray headers. These headers contain spray nozzles which break the flow into small droplets, thus enhancing the water's cooling effect on the containment atmosphere. As these droplets fall to the containment floor they absorb heat until reaching thermal equilibrium within the Containment. When reaching the containment floor the water drains to the ECCS sump where it remains until the recirculation mode begins.

When RWT inventory is reduced to a level of approximately 10 percent, a two-out-of-four low RWT level signal initiates a RAS. The RAS closes the minimum flow line isolation valves (SI-664 and 665) and opens the ECCS sump isolation valves (SI-673, 674, 675, and 676). Upon indication that transfer to recirculation has occurred, the operator verifies that the appropriate amount of water has been discharged into the Containment, and the flow path from the sump to the suction of the SI pumps is open. The operator also verifies the mini-flow isolation valves are closed to prevent depletion of ECCS sump inventory. Following this, the operator closes the RWT isolation valves (CH-530 and 531). The RAS may also be manually initiated at the component level.

For a large-break LOCA, the time until recirculation is taken for the limiting case for containment peak pressure, which is the double ended discharge leg slot break with maximum SI flow rate [Ref. 4.62]. This analysis assumes a loss of off-site power and one train of containment spray. For this case, recirculation occurs at 1403 seconds. At 1403 seconds after LOCA, the sump temperature is 178.7°F at 66.7 psia. A small break LOCA may not lead to a RAS. In the event that sump recirculation is required to mitigate the small-break LOCA, the quantity of debris at the ECCS sump will be less than the bounding debris transport case for the large-break LOCA. Also the flow rate requirements for the ECCS pumps are less than that for a large-break LOCA. The limiting case for the minimum containment flood level is the small-break LOCA; however, it is also conservatively applied as the minimum flood level for a large-break LOCA. Based on these reasons, the limiting case for NPSH is the large-break LOCA.

6. Operational Status of ECCS and CSS Pump

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

Following a large-break LOCA, the SIAS initiates operation of the LPSI, HPSI, and the CSS pumps. Initially, the suction water inventory for these pumps is the RWT. Upon reaching the low level setpoint for the RWT, the RAS actuates and the suction source for the pumps is switched from the RWT to the ECCS sump. Upon initiation of RAS, the LPSI pumps are shutdown and the HPSI and CSS pumps continue to operate (See Section 3.g.1).

7. ECCS Single Failure Assumptions

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

Emergency core cooling is provided by the ECCS. The ECCS is designed to provide abundant cooling water to the RCS to remove heat at a rate sufficient to maintain the fuel in a coolable geometry and to ensure that zirconium-water reaction is limited to a negligible amount (less than one percent).

The ECCS design ensures that required safety functions are accomplished with either onsite or offsite electrical power system operation, assuming a single failure (qualified as follows) of any component. The single failure may be an active failure during the initial period following an accident (coolant injection phase of emergency core cooling) or an active or limited leakage passive failure during the long term cooling (coolant recirculation) phase of emergency core cooling. Although the ECCS is designed to accommodate a limited leakage passive failure during the recirculation phase, it is not designed to accommodate arbitrary large leakage passive failures such as the complete double-ended severance of piping, which are extremely low probability events.

The limiting single failure used in the head loss evaluation includes the maximum flow rate of three pumps operating (HPSI, LPSI, and CSS) for the first one hour following a RAS and then the maximum flow rate of the HPSI and CS pumps for the remainder of the ECCS mission time. One hour is used as a conservative time delay for the operators to stop the LPSI pump in the event the LPSI pump fails to automatically stop upon a RAS.

8. Determination of ECCS Sump Water Level

Describe how the containment sump water level is determined.

The minimum water level in the post-LOCA containment pool during the recirculation mode is at elevation 84'-6" (54 inches above the containment floor which is at elevation 80'-0") as documented in calculation 13-MC-SI-0804 [Ref. 4.15]. That calculation considers that a volume of RWT water is diverted to the volume control tank (VCT) via the boric acid makeup (BAM) pumps. It also considers a portion of the RWT injection volume fills the CSS supply piping and is not available to the ECCS sump.

The calculation also considers water volume held up in the containment atmosphere and on surfaces, along with water diverted to the reactor cavity, depending on break location. The calculation assumed the reactor cavity completely fills [Ref. 4.15].

9. Assumptions in Determination of Minimum Water Level for NPSH Margin

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

The following assumptions are made in calculation 13-MC-SI-0804 [Ref. 4.15] for minimum containment flood level conservatism:

- The large-break LOCA results in debris that may block the reactor cavity drain line. Therefore, water from the break may not exit the reactor cavity until it reaches an elevation of 96.8 ft which is the top of the reactor cavity cooling fans.
- For the large-break LOCA the reactor cavity completely fills.
- For the small-break LOCA the volume inside and outside the reactor cavity fills at the same rate.
- The surge line break occurs at the surge line's highest elevation, which is the bottom of the Pressurizer.
- A portion of the containment spray is held up in the Containment Building. The maximum containment spray flow rate for two train operation is assumed to conservatively maximize the containment spray hold-up.
- The additional amount of water needed to fill the CSS is the volume of CSS piping above the minimum technical specification (TS) surveillance requirement (SR) 3.6.6.2 CSS fill level of 113 ft. in the containment spray header.
- The containment atmospheric conditions at RAS for each scenario are selected to maximize water that would be held up in the atmosphere.
- Calculation of the water held up on the containment surfaces considers a film thickness applied over containment vertical and horizontal surfaces. The film thickness is conservatively based on the temperature difference between the maximum saturated post-LOCA temperature and the maximum normal containment temperature. The total surface area for containment walls, structures, and equipment is consistent with that used for the latent debris evaluations.
- RCS volume shrinkage is considered for the evaluated breaks.
- The minimum TS level RWT volume is assumed to minimize water transferred to the containment floor during injection.

- For the large break and surge line breaks, the minimum TS Safety Injection Tank (SIT) volume is assumed to minimize water transferred to the containment floor during injection.
- The small-break LOCA assumes the pressurizer is completely filled.
- For the small-break LOCA, no RCS spillage or SIT volumes are credited.

10. Empty Spray Pipe, Water Droplets, Condensation and Holdup on Horizontal and Vertical Surfaces

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.

The empty CSS piping is the volume of CSS piping above the minimum TS SR 3.6.6.2 CSS fill level of 113 ft. in the containment spray header. This volume of water is not included in the containment pool volume.

Containment spray water may be held up in the containment atmosphere, containment spray droplets, containment spray header piping, condensation on horizontal and vertical surfaces, and in the reactor cavity. The following discusses the volume of water held up in these items [Ref. 4.15].

A fraction of the total water delivered to Containment flashes in the containment atmosphere. The quantity that flashes was calculated for the large break and surge line breaks based on the steam mass and pressure conditions at RAS as determined in the associated analyses [Ref. 4.62]. For the small break, the water volume held up as vapor was determined assuming a vapor pressure equal to the maximum CSS actuation pressure. Assuming the vapor pressure is equal to the containment pressure is conservative since this neglects the heat up of the containment air and its contribution to containment pressurization, which maximizes the amount of steam in the atmosphere (i.e., all of the containment pressurization comes from steam being added to the air).

Containment spray volume holdup was determined by calculating the fall time at terminal velocity for water droplets from the main spray header median height and the average drop diameter, and the fall time at terminal velocity for droplets from the auxiliary spray header median height and average drop diameter. The held up volume is the product of the fall time and the maximum spray flow rate for each system.

Condensation holdup on horizontal and vertical surfaces was determined by calculating the total surface area and then applying a uniform water film thickness. The total surface area for containment walls, structures, and equipment is consistent with the surface area used for the latent debris evaluations. This value is considered conservative as no distinction was made for surface area orientation; the water film is assumed uniform over all horizontal and vertical surfaces.

11. Assumptions for Equipment that Displace Water in Minimum Water Level Determination

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

The determination of the equipment that will displace water in the Containment below the containment flood water level was based on PVNGS unit drawings. The following are assumptions used in the determination of the equipment volume [Ref. 4.107].

- The volume of containment piping with a diameter less than 3 inches is not credited. In addition for simplification, the reactor vessel lower head was considered a 10 ft diameter, three ft high cylinder existing between elevations 65'-0" and 78'-3", and a 14 ft diameter, 1.7 ft high cylinder between elevations 78'-3" and 80'-0" (based on inspection of reactor vessel drawings.)
- The volume of major equipment was calculated based on simple geometric figures. The maximum dimensions from the geometric figures were obtained from the Containment Building drawings.
- The miscellaneous structural steel was assumed to be evenly distributed throughout the Containment. Stairs were assumed to be uniformly designed. Ladders were assumed to be 90 degree vertical stairs for purposes of volume displacement.
- It was assumed that the reactor cavity sumps MRDNP01A/B at elevation 55'-0" and the radioactive waste sumps MRDNP02/03 at elevation 76'–0" have pumps with a 4.0 ft^3 displacement based on geometry of pumps shown in the pump vendor drawing.
- The surface area of the concrete was estimated using simple geometric figures. The calculated displaced volume of the concrete includes the concrete slab floors, unlined concrete and supports, the reactor cavity and concrete walls at the examined elevation.
- The reactor cavity is surrounded by a reinforced concrete wall (primary shield wall) and is included as part of the concrete volume when calculating the free volume of Containment outside the reactor cavity above elevation 80'–0".

- The steel volume of the TSP baskets is approximately one percent of the volume of the TSP chemical based on estimation using the TSP basket drawing.

- The guide tubes for incore detector cable are 2-inch pipe (2.38" O.D.) based on a coil outer diameter of 1.75 inches and for the volume of supports for these guide tubes another 100 percent was added. All such volume is distributed below the 65'–0" elevation. Based on inspection of the vendor drawing each guide tube has an average length of 40.0 ft.

- Duct near the reactor cavity HVAC normal cooling fans are considered 48-inch ID up to the 92'-0" level. Above 92'-0" the duct and fan interior is considered 30-inch ID to account for the fan motor, blades, etc.

- Since the centerline of reactor drain tank (RDT) is at elevation 85'-0" and has a radius of 3.0 ft, 45 percent of tank volume was modeled below elevation 84'-6". Since the top of the RDT is at elevation 88'-0", 10 percent was assumed above elevation 87'-0". The RCP Lube Oil Tank has a centerline elevation of 82'-10" with radius of approximately 1.9 ft. Since the top of the tank is at approximately 84.7 ft, it was therefore assumed 100 percent of the displaced volume is between elevations 80'-0" to 84'-6".

- The installed ECCS sump strainer has a total volume of 97.4 ft^3 and the removed strainer had a total volume of 23.5 ft^3. In order to take a conservative approach to the minimum flood level, a volume of 23.5 ft^3 was used below an elevation of 86'-0" and the difference of the two volumes was added once above 86.13 ft.

- Monorail – A monorail (M-ZCN-G03) exists in the east area of the Containment, outside the S/G D-ring at an approximate elevation of 85'-0". The I-Beam is shown as a W8 on the containment drawing and was assumed to be an 8.12-inch flange or a W8 x 35 which would be a cross sectional area of 10.3 in^2. It also shows an overall length of approximately 16.5 ft. The hoist itself was estimated to have a volume of 2.0 ft^3.

- Wet Layup Pumps – Two (2) wet layup pumps (M-SGN-PO1A and M-SGN-PO1B) are located in the east part of the Containment at floor elevation 80'-0". From the pedestal details, an estimated volume of 4 ft^3 was used for both pedestals. Treating the pumps as a cylinder with a radius of 4.5 inches and a length of 44 inches results in a total volume of 3.24 ft^3.

12. Assumptions for Water Sources to Minimum Water Level Determination

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

- Water sources available to provide flood water volume are the RWT volume (72,620 ft^3), the RCS volume spill (3364 ft^3 for a large break LOCA only), and the four SITs (1750 ft^3 per SIT) (for all assumed breaks except small break) [Ref. 4.15]. The specified volumes are minimum values.
- The minimum water transferred from the RWT during injection is ensured by RWT volume controls. The net minimum volume that will be transferred is 543,200 gallons or 72,620 ft^3 [Ref. 4.15].
- Except for the small break, conservative RCS and SIT volumes are added to the RWT inventory to establish the total volume of water available for flooding. For the small break, no RCS spillage or SIT volumes are credited. For the small break, the strainers would remain fully submerged using the minimum RWT volume specified in TS 3.5.5 for Unit 2 and are administratively controlled in Units 1 and 3. In support of installation of the new strainers in Unit 2, APS submitted, and the NRC in license amendment 169 dated May 9, 2008, approved an exigent change to TS 3.5.5, to increase the RWT minimum water level for Unit 2 by three percent [Ref. 4.92]. For Units 1 and 3 the minimum RWT water level to meet the containment flood level analysis is the same as Unit 2 and is currently being administratively controlled. The same TS 3.5.5 changes for Units 1 and 3 were submitted to the NRC in APS Letter No. 102-05923, dated November 13, 2008 [Ref. 4.93]. The current administrative controls for Units 1 and 3 RWT level provided in accordance with NRC Administrative Letter 98-10, "Dispositioning of Technical Specifications that are Insufficient to Assure Plant Safety," will remain in effect until the Units 1 and 3 TS amendment is issued and implemented.

13. Containment Pressure for Determination of NPSH

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.

Credit is not taken for containment accident pressure in determining available NPSH; however, minimum partial pressure of air in Containment prior to the accident is considered. This minimum initial partial pressure is only used for sump water temperature where vapor pressure of water is less than the initial partial pressure of air. Otherwise, the partial pressure is not used.

It is assumed that water vapor and air are the only significant components of the atmosphere inside the Containment during normal operation.

To minimize the initial partial pressure of air in Containment prior to a LOCA, the total initial pressure in the Containment is minimized and the initial partial pressure of water vapor is maximized. To minimize the initial partial pressure of air, the Containment is assumed to cool to 50°F from the maximum normal temperature.

The maximum containment temperature during normal operation (120°F) is used to determine the maximum saturation pressure of water. This maximum saturation pressure of water maximizes the initial partial pressure of water in the Containment, thereby minimizing the initial partial pressure of air.

14. Assumptions to Minimize Containment Accident Pressure and Maximize Sump Water Temperature

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

Credit is not taken for containment accident pressure in determining available NPSH; however, minimum partial pressure of air in Containment prior to the accident is considered as discussed in 3.g.13.

The following assumptions are made for conservatism in the analyses of maximum sump water temperature [Refs. 4.50 and 4.62].

- The containment response assumes a loss of offsite power coincident with a LOCA and a single active failure of one containment spray pump.
- The minimum containment spray flow rate is assumed for the operating containment spray pump.
- The RWT usable water volume is conservatively assumed as 400,000 gallons at 120°F. The minimum volume available from the RWT is 543,200 gallons at 120°F.

15. Containment Accident Pressure at Vapor Pressure Corresponding to the Sump Liquid Temperature

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

For sump temperatures below the saturation temperature corresponding to the minimum initial partial pressure of air in containment, credit was taken for the minimum initial partial pressure of air. For sump temperatures above the saturation temperature corresponding to the minimum initial partial pressure of air in containment, the containment accident pressure was assumed to be at the vapor pressure corresponding to the sump liquid temperature.

16. NPSH Margin

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

The specified maximum allowable strainer head loss including chemical effects is 5.0 ft at the maximum sump flow rate for the post-LOCA recirculation phase. The head loss criteria for strainer sizing is based on 11,600 gpm for the first hour of RAS and then 6,600 gpm for the remaining duration of the ECCS mission time. This head loss criteria retains approximately 4.86 ft of margin between required and available NPSH. This is based on 3.8 ft of margin in the NPSH calculations [Refs. 4.32 and 4.33] plus the difference between the pre-GSI-191 strainer HL of 6.06 ft. and the new strainer maximum allowable HL of 5.0 ft.

The PVNGS head loss analysis [Ref. 4.43] determined the strainer head loss to be 4.33 ft. The NPSH calculations for the SIS and CSS pumps [Refs. 4.32 and 4.33] conservatively retain the use of head loss across the original sump strainers of 6.06 ft. The calculations have been updated to document the conservatism in the assumed strainer head loss.

As outlined above, this result in a minimum NPSH margin of 5.53 ft (5.0 ft – 4.33 ft + 4.86 ft).

h. Coatings Evaluation

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

- ***Provide a summary of type(s) of coating systems used in containment, e.g., Carboline CZ 11 Inorganic Zinc primer, Ameron 90 epoxy finish coat.***
- ***Describe and provide bases for assumptions made in post-LOCA paint debris transport analysis.***
- ***Discuss suction strainer head loss testing performed as it relates to both qualified and unqualified coatings and what surrogate material was used to simulate coatings debris.***

- ***Provide bases for the choice of surrogates.***
- ***Describe and provide bases for coatings debris generation assumptions. For example, describe how the quantity of paint debris was determined based on ZOI size for qualified and unqualified coatings.***
- ***Describe what debris characteristics were assumed, i.e., chips, particulate, size distribution and provide bases for the assumptions.***
- ***Describe any ongoing containment coating condition assessment program.***

1. Coatings Systems

Provide a summary of type(s) of coating systems used in containment, e.g., Carboline CZ 11 Inorganic Zinc primer, Ameron 90 epoxy finish coat.

The original construction coating systems and corresponding maximum coating thicknesses are summarized in Table 3-43 [Ref. 4.44, Attachment 8.7].

Table 3-43: Original Construction Coatings

Coating Description	**Coating System**	**Maximum Thickness**
Concrete and Masonry (Epoxy)		
Sealer	Valspar Keeler & Long E1	1.5 mils (1)
Topcoat	Valspar	17.5 mils (2)
Carbon Steel (Inorganic Zinc-, IOZ)		
Prime Coat	Mobil Valspar Carboline	5 mils

(1) Represents primer/sealer only, which is applicable to concrete walls without wainscoat applied

(2) Represents primer and topcoat(s), which is applicable to floors and concrete walls with wainscoat applied

Table 3-44 provides the materials approved for containment DBA qualified coatings for current and future installations [Ref. 4.57].

Table 3-44: Current Approved Coatings

SUBSTRATE	MCS	COATING SYSTEMS	DRY FILM THICKNESS, DFT
Steel	302	CarboZinc 11SG/none	2 to 3 mils DFT
Steel	202	Carboguard 890N*/none	4 to 6 mils DFT
Steel	202	Keeler & Long 6548 7107/E Series	4.5 to 12 mils DFT
Steel	302	Keeler & Long 6548 7107/E Series	4.5 to 12 mils DFT
Concrete	205	Keeler & Long 6129/5000	35.5 to 126 mils DFT
Concrete	205	Keeler & Long 4129/6548S/E Series	2.5 to 54 mils DFT
Concrete	N/A	Ameron Amerlock Sealer/ Amerlock 400NT	The coating system has not been used at PVNGS

Maintenance Coating System (MCS)
*Carboguard 890 changed to Carboguard 890N. DBA testing performed for 890 is applicable to 890N.

2. Assumptions in Post-LOCA Paint Debris Transport Analysis

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

All coatings within the ZOI are considered particulate and are assumed to transport to the sump, per the Staff evaluation for GR Section 3.6.3 in the SE to NEI 04-07, (transport fraction to sump screen = 1.0). This size is conservatively applied to all unqualified coatings outside the ZOI per the SE. The only coating debris that is not considered to fail as particulate debris is damaged qualified epoxy coatings. The NRC revised guidance pertaining to GL 2004-02 [Ref. 4.86] affirms this approach.

Based on guidance provided [Ref. 4.4, Attachment 3], damaged qualified epoxy coatings may be treated “as chips no smaller than 1/32 inch. Additionally, Item #4 of the “NRC Staff Review Guidance Regarding Generic Letter 2004-02 Closure in the Area of Coatings Evaluation,” which is Enclosure 2 to the “Revised Guidance 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’” issued on March 28, 2008 [Ref. 4.86], states that licensees may treat damaged qualified epoxy coatings that fail outside the break ZOI as chips and use available transport data to reduce their overall transport fraction. Therefore for PVNGS, qualified epoxy coatings considered damaged or degraded are considered to fail as chips.

The results of the coating chip transport analysis are documented in Section 3.e.3.c. The transport analysis determined that the coating chips do not transport to the strainer based on the coating chip transport data in NUREG/CR-6772 [Ref. 4.65], NUREG/CR-6916 [Ref. 4.97], and PVNGS specific transport testing performed by CCI [Ref. 4.49].

The Palo Verde specific transport testing was performed using the flume described in Section 3.f.4.d, but with a different configuration. The flume was modified such that it was eight meters long (vs. three meters) and the bottom row of pockets was not blocked. In addition, a 9-inch curb was installed in the flume upstream of the strainer module. To perform the tests, debris was placed on the flume floor far away from the curb in a quiescent test loop with a water height of 60 cm. Once the debris was added to the test loop, flow was initiated such that the flow velocity in the flume increased to 0.2 m/s (0.66 ft/s), which resulted in a flow velocity over the curb of 0.32 m/s (1.0 ft/s).

The following sizes of epoxy coating chips were tested in the plant specific transport tests: less than 0.6 mm, 0.6 to 2.0 mm, and 2.36 to 6.35 mm. The largest of these sizes is larger than the sump screen openings which are 2.1 mm [Ref. 4.25]. The tests documented that none of these epoxy chips transported over the nine inch curb in the flume.

3. Head Loss Testing for Coatings Debris

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.

A discussion of the strainer head loss testing as it relates to both qualified and unqualified coatings is located in Section 3.f.4.d under subsection "Non-chemical debris and surrogates". A discussion of the treatment of epoxy chips is located in Section 3.f.4.d under subsection "Epoxy coatings as chips". A discussion of surrogate materials used to simulate coating debris is located in Section 3.f.4.d under subsections "Inorganic zinc coatings" and "Epoxy and alkyd coatings".

4. Basis for Surrogate Materials in Head Loss Tests

Provide bases for the choice of surrogates.

A discussion of surrogate materials used in head loss testing is located in Section 3.f.4.d under subsection "Non-chemical debris preparation and surrogates

5. Coatings Debris Generation

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.

In the PVNGS evaluation for equipment and platform support steel, the length (scaled from drawings) and designation of each member within the 5.0 r/D ZOI [Ref. 4.54] were calculated for each break. The length was then multiplied by the cross-sectional perimeter of the member and the coating thickness to obtain the volume of coating debris generated. Conservative assumptions were made where details were not readily available. An additional 10 percent was added to the equipment/support steel coating debris volume for each break to account for any miscellaneous coated metal surfaces not tabulated.

For coated, uninsulated carbon steel piping within the 5.0 r/D ZOI [Ref. 4.54] at PVNGS, the volume of coating debris generated was determined by multiplying the outside perimeter of the piping by the piping length and coating thickness. To determine what coated piping was located within the S/G D-ring and pressurizer enclosure, piping isometrics for piping within Containment were reviewed. The uninsulated carbon steel piping was assumed to be coated.

For floor and wall coatings, the 4.0 r/D ZOI [Ref. 4.54] was truncated at the intersection with the floor or wall. The width of the ZOI projection was taken as the entire wall segment width. The minimum and maximum wall elevations were calculated based on the break elevation and the distance from the break to the wall.

To calculate the volume of coating debris, all coatings within the applicable break ZOI and all damaged coatings was assumed to have the maximum thickness values of the coatings systems used in Containment. This conservatively results in the maximum coating debris being transported to the sumps.

6. Coatings Debris Characteristics

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

Per Section 3.4.3.2 of NEI 04-07, all qualified coatings within the ZOI are considered small fines. This size (10μm in diameter, spherical particle) is also conservatively applied to all unqualified coatings outside the ZOI per the SE [Ref. 4.28, pg. 21].

Based on guidance provided [Ref. 4.14, Attachment 8.12] damaged qualified epoxy coatings may be treated "as chips no smaller than 1/32-inch." Additionally, Item #4 of the "NRC Staff Review Guidance Regarding Generic Letter 2004-02 Closure in the Area of Coatings Evaluation," which is Enclosure 2 to the "Revised Guidance 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,'" issued on March 28, 2008 [Ref. 4.86], states that licensees may treat damaged qualified epoxy coatings that fail outside the break ZOI as chips and use available transport data to reduce their overall transport fraction. Therefore, for the PVNGS evaluation, the qualified epoxy coatings considered damaged or degraded are considered to fail as chips.

7. Coatings Condition Assessment Program

Describe any ongoing containment coating condition assessment program.

PVNGS procedure 81DP-0AP05 [Ref. 4.79] defines the containment coatings monitoring program. The coatings assessment walkdowns are performed in accordance with this procedure and qualification requirements of the personnel performing the assessment. These inspections are conducted every operating cycle.

PVNGS procedure 81DP-0AP02 [Ref. 4.36] provides the overall guidelines and conditions for the "PVNGS Coatings Program." The procedures define the criteria to ensure that coating systems are properly supplied and maintained to perform their intended function. The Civil Engineering organization is responsible for the PVNGS Coatings Program. Their responsibilities include specifying and approving coatings materials, and selecting appropriate color codes, performance monitoring of coatings in Containment and maintaining the unqualified coatings log. The implementation of specifications, procedures, and inspections are coordinated through Civil Engineering. The PVNGS Coatings Program specifies control measures to ensure that inspections and verifications are adequate to achieve the required quality. The PVNGS Quality Assurance (QA) program allows for inspections (verifications) to be performed through worker verification, second party verifications, independent verification, and/or independent inspection. Coating activity inspections at PVNGS are performed primarily by second party verifications.

i. Debris Source Term

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

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

  <u>GL 2004-02 Requested Information Item 2(f)</u>
  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 GL 2004 Requested Information Item 2(f), provide the following.

- ***A summary of the containment housekeeping programmatic controls in place to control or reduce the latent debris burden. Specifically for RMI/low-fiber plants, provide a description of programmatic controls to maintain the latent debris fiber source term into the future to ensure assumptions and conclusions regarding inability to form a thin bed of fibrous debris remain valid.***
- ***A summary of the foreign material exclusion programmatic controls in place to control the introduction of foreign material into the containment.***
- ***A description of how permanent plant changes inside containment are programmatically controlled so as to not change the analytical assumptions and numerical inputs of the licensee analyses supporting the conclusion that the reactor plant remains in compliance with 10 CFR 50.46 and related regulatory requirements.***

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

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

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

1. Programmatic Controls to Limit Debris Sources in Containment

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

GL 2004-02 Requested Information Item 2(f)

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

Specification 13-AN-0448 [Ref. 4.63] identifies the technical requirements to control the temporary installation of maintenance and monitoring equipment in Seismic Category I Buildings to ensure the safe and continued operation of PVNGS. Transient materials are considered unattended/uncontrolled temporary equipment and/or material in areas containing systems, structures, or components (SSCs) that are safety-related whenever they are required to be operable or available for safe shutdown and/or continued safe shutdown.

Transient materials and equipment include nylon or tefzel wrap, cable wraps (e.g., blue tefzel cable wraps), weld attachments, anchor bolts, chain, cable wraps, nylon rope, wire rope, scaffolding, tie wire, and snow fencing in temporary bull pens. Operations tracks and monitors the acceptable placement and restraint of transient material. All short term transient material that has safety-related SSCs within two times its ZOI is required to be restrained per the specification. Transient material is required to be removed as soon as the work or activity is complete.

A maximum of 66 ft^2 of transient materials is permitted in Containment provided the area (square footage) is quantified and tracked [Ref. 4.39]. This same amount allowed by procedure is considered in the debris generation calculation [Ref. 4.4] and the debris transport calculation [Ref. 4.14].

PVNGS procedure 40ST-9ZZ09 [Ref. 4.39] requires a surveillance to verify cleanliness of the Containment prior to establishing containment integrity. The purpose of the procedure is to perform a visual inspection to verify that no loose debris other than latent debris is present in the Containment that could be transported to the ECCS sump and cause restriction of the pump suctions during LOCA conditions. Visual inspections are performed in all accessible areas of the Containment, at least once daily in affected areas of containment entry, and all affected areas during final entry when containment integrity is established.

The two main goals of the procedure are to ensure that no loose materials are transported to the ECCS sump under LOCA conditions; and that any loose materials that may be transported to the sump screens cannot cause damage ECCS related components, e.g., erode ECCS and CS pumps, clog valves, etc.

Thermo-Lag fireproofing is controlled in Containment and requires that none be added or modified in Containment without engineering analysis and approval with respect to debris generation [Ref. 4.69].

2. Housekeeping Programmatic Controls

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.

The latent debris was determined by sampling and statistical analysis in all three units. The maximum quantity of latent debris was determined to be 119 lbs (Section 2.5 Calculation 2005-06160 Debris Generation Due to LOCA within Containment for Resolution of GSI-191). All latent debris is assumed to transport. As a conservative measure, the strainer design specification and related head loss testing used an assumed latent debris quantity of 200 lbs to ensure margin and conservatism. The latent debris margin is available for areas/components that are normally inaccessible or not normally cleaned (containment crane rails, cable trays, main steam/feedwater piping, tops of SGs, etc.).

A containment cleanliness inspection is performed as a prerequisite prior to entering Mode 4 after all refueling outages. The requirements for the inspection are documented in procedure 40ST-9ZZ09 "Containment Cleanliness Inspection" [Ref. 4.39]

PVNGS is performing pre-Mode 4 inspections for latent debris during the refueling outage. This process divides the containment building into approximately 21 areas and each area is assigned to a member of the management team. All visually assessable areas regardless of location are monitored. The assigned person will assess and initiate actions to maintain containment cleanliness. These actions may include the use of ladders, scaffolding, and other means for debris removal. The assigned personnel are briefed on GL 2004-02, transient combustibles per procedure 14DP-0FP33, "Control of Transient Combustible" [Ref. 4.111], housekeeping expectations per procedure 30DP-0WM012, "Housekeeping" [Ref. 4.78], installation specification for the control of transient material [Ref. 4.63], and related operating experience.

The Containment is monitored with the exception of locked high radiation areas that are not entered. The process was initiated in spring 2008 refueling outage 2R14. Due to the success of the pre-Mode 4 inspection, the process is being formalized and the policy guide will be issued prior to next refueling outage.

3. Foreign Material Programmatic Controls – Zone III Exclusion Area

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

Walkdowns were performed in all three PVNGS units to quantify the latent debris [Refs. 4.10, 4.11 and 4.12]. The Unit 2 latent debris quantity of approximately 119 lbs is the largest and bounding for the three units. The debris transport calculation conservatively assumes 200 lbs of latent debris [Ref. 4.19]. Transient materials in Containment are controlled by procedure, and visual inspection for loose debris is performed prior to establishing containment integrity (see Sections 3.i.1 and 3.i.2).

4. Programmatically Control of Permanent Plant Changes Inside Containment

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.

The design inputs requirements checklist (DIRC) of the PVNGS design change procedure 81TD-0EE10 [Ref. 4.104] establishes controls such that no large volumetric items are added or deleted in Containment that could affect the water level to free volume relationship (tank curve) of Containment or LOCA flood level. DIRC Topical Question 8 requires the identification of any material that might affect the amount of aluminum in Containment, or changes to type or quantity of protective coatings. DIRC Topical Question 11 requires the identification of any proposed change that would adversely affect the ECCS and CSS pump NPSH as a result of a change in the amounts of fibrous materials and/or unqualified coatings or as a result of a change in the amounts generated and transported to the ECCS sump strainers. DIRC Topical Question 36 specifically addresses impact to the ECCS sump strainer sizing. This section of the DIRC requires review of design modifications for impact due to:

- Any change to the flow paths of water to the ECCS sump strainers that would alter the flow velocities to the sump strainers or create traps for debris to collect and block flow paths to the ECCS sump strainers.

- Any changes to the internals of ECCS components (pumps, valves, heat exchangers, seals, etc.) in the recirculation mode flow path or nuclear fuel assembly design that would affect component resistance to blockage or erosion by debris-laden fluid.

- Any addition of materials to the Containment that has the potential to become ECCS sump strainer debris upon a LOCA, such as fibrous materials including insulation, particulate-based insulation, coatings on surface areas not previously coated or on new equipment and materials, plastic film, nonmetallic labels or tags, ty-wraps, tape, etc. Other materials that may be transportable to the sump are also required to be evaluated. This includes material that could break down to particulate when exposed to jet impingement, heat, containment spray or other LOCA conditions.

- Any addition of materials to the Containment that may affect the ECCS sump post-LOCA recirculation fluid chemistry. Chemical effects on the recirculation fluid following a LOCA on sump strainer sizing is a concern and the addition of materials that would result in precipitate formation such as silicon, aluminum, calcium in the ECCS sump recirculation fluid, or that would affect minimum mass of TSP, maximum RCS and ECCS injection fluid volume, or boron concentration, need to be evaluated. Any aluminum that is added to Containment is categorized as either submerged in the containment recirculation fluid, or non-submerged but exposed to the containment environment. The mass and surface area of the submerged or exposed aluminum is factored into the chemical effects analysis.

- Any changes to the containment free volume that reduces the minimum containment flooding level.
- Any change or addition to high-energy piping in the vicinity of the ECCS sump strainers so as to cause a HELB jet impingement or pipe whip concern.
- Any addition of high energy piping outside the bioshield wall that would require evaluation of a new postulated break for sump strainer debris generation.

5. Maintenance Activities Managed in Accordance with Maintenance Rule, 10 CFR 50.65

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

Transient materials that are unattended/uncontrolled in Containment during Operating Modes 1-4 with RCS pressure equal to or greater than 385 psia are controlled during containment entry per the transient material control procedure 13-AN-0448 [Ref. 4.63]. This procedure limits allowable transient materials to 66 ft^2. Temporary modifications are controlled by the design change process as defined in 81DP-0EE10 and 81TD-0EE10 [Refs. 4.104 and 4.20]. The design change process requires review of materials added to containment for impact to sump debris load and chemical effects.

6. Insulation Change-Out

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

PVNGS design change (DMWO 2822654 Revision 0) removed Fiberfrax insulation from the containment building secondary shield wall pipe penetrations in Units 1, 2 and 3. This change was performed to reduce the potential debris thickness at the strainers, which decreases the expected head loss across the sump strainer screens. In addition, some Nukon insulation was removed from around the letdown delay coils which were previously installed after original plant design and construction.

In an effort to further reduce potential debris loading, the Microtherm (Units 1 and 2) and Min-K (Unit 3) insulation is scheduled to be removed from the reactor head in the fall 2009 refueling outage for Unit 2, in the spring 2010 Unit 1 refueling outage, and in the fall 2010 Unit 3 refueling outage. This insulation removal will be performed in conjunction with the reactor head replacement project for each unit. The Min-K and Microtherm insulation is located at CEDM nozzle locations on the reactor head. The new reactor heads will be insulated with RMI.

7. Modifications to Reduce Debris

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

Per DMWO 2822654 Revision 0, the removal of Fiberfrax and Nukon insulation as described in Section 3.i.6 reduces the debris burden at the sump strainer during DBAs requiring recirculation operation of the ECCS and CSS. Additionally Min-K and Microtherm insulation will be removed as described in Section 3.i.6.

8. Modifications to Equipment or Systems to Reduce Debris

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

PVNGS has not modified any equipment or systems to reduce the potential debris burden at the sump strainers.

9. Coatings Program Modifications or Improvements

Actions taken to modify or improve the containment coatings program.

The current PVNGS Coating Program and specification [Refs. 4.36 and 4.57] cover specifications of materials, protection of plant equipment, surface preparation, application, and inspection procedures. The purpose of the coatings program for painting and coatings is to provide controls for these activities. The PVNGS Maintenance Coatings Program outlines the requirements for the painting and coatings program, and the implementation of engineering requirements established in procedure 81DP-0AP02 [Ref. 4.36] and specification A0-AN-0449 [Ref. 4.57].

The PVNGS Civil Engineering organization is responsible for implementing the coatings program including specifications, procedures, and inspections. Specific responsibilities include specifying and approving coatings and materials; and selecting appropriate color codes; performance monitoring of coatings in containment; and maintaining the unqualified coatings log. Coatings work performed on structures and components for Containment are classified at Q-Class. All materials used for this application are also Q-Class.

Safety-related coatings are those that are applied inside of Containment [Ref. 4.35]. Detached coatings can affect the safety function of a safety-related SSC. Coatings are classified as DBA Qualified Coating Systems, or DBA Unqualified Coating Systems. Coating materials procured for safety-related applications for Containment are required to meet 10CFR50 Appendix B and PVNGS UFSAR requirements for coating applications. These materials are a DBA Qualified Coating System in accordance with PVNGS requirements. DBA Qualified Coating Systems are single or multiple coatings applied in accordance with the tested configuration that complies with ANSI N101.2 or ASTM D3911 for testing, and ANSI N101.4 or ASTM D3843 for application documentation requirements. The DBA Unqualified Coating Systems are coating applications that deviate from the original DBA tested configuration or have not been DBA tested.

Inspections are integral to a coatings application project. The PVNGS Coating Program specifies control measures to ensure that inspections and verifications are adequate to achieve the required quality. The PVNGS QA program allows performance of inspections and verifications through worker verification, second party verifications, independent verification, and/or independent inspection. Coating activity inspections at PVNGS are performed primarily by second party verifications. Coating applicators are required to complete the appropriate Coatings Inspection training and possess the Qualification Card for Coating applications.

Qualified and unqualified coatings are controlled in Containment requiring that none are added or modified in Containment without engineering analysis and approval with respect to debris generation. PVNGS specification A0-AN-0449 [Ref. 4.57] and the coatings program procedure 81DP-0AP02 [Ref. 4.36] govern any such application of coatings.

PVNGS procedure 81DP-0AP05 [Ref. 4.79] controls the monitoring program for the containment coatings. The coatings assessment walkdowns are performed in accordance with this procedure and it provides the qualification requirements of the personnel performing the assessment. The frequency of inspections is every operating cycle. The first assessment under this containment coatings monitoring program was performed in the Unit 1 fall 2008 refueling outage.

j. Screen Modification Package

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

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

1. Description of Sump Screen Design Modifications

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

Two ECCS sumps are installed, each serving one train of ECCS and CS pumps. These sumps are installed in separate depressions at the lowest practical elevation in Containment, below the floor at elevation 80'-0". There is a curb to impede heavy debris being swept along the floor from clogging the sump strainers. The bottom of the lowest strainer pockets is approximately nine inches above the Containment 80' elevation floor [Ref. 4.25]. This height consists of a 3-inch curb around the perimeter of the containment sump strainer assembly, 4-inch height of the strainer subfloor above the top of the 3-inch curb, and a 2.8-inch gap between the top of the strainer subfloor and the lowest strainer pockets. The edge of the strainer assembly subfloor is inset horizontally 6-1/8 inches from the outer edge of the curb [Ref. 4.59].

The curb also provides protection from surface drain. No drains from upper regions of Containment impinge on the screen assemblies of the strainers. There is no significant physical barrier between the two sump strainers above the floor, but the distance between them is 26 ft. Physically separated sumps preclude simultaneous damage to both strainers and the associated ECCS and CSS trains. Main Steam line breaks or Feedwater line breaks do not require the function of the ECCS sumps. There are no high-energy pipe lines in the vicinity of the sumps or strainers. Therefore, pipe whip and jet impingement are not concerns for the sumps and strainers.

The ECCS sump strainer screen is fabricated from austenitic stainless steel and zinc-coated carbon steel. Both materials have a low sensitivity to spray-induced corrosion and are not adversely affected by periods of inactivity.

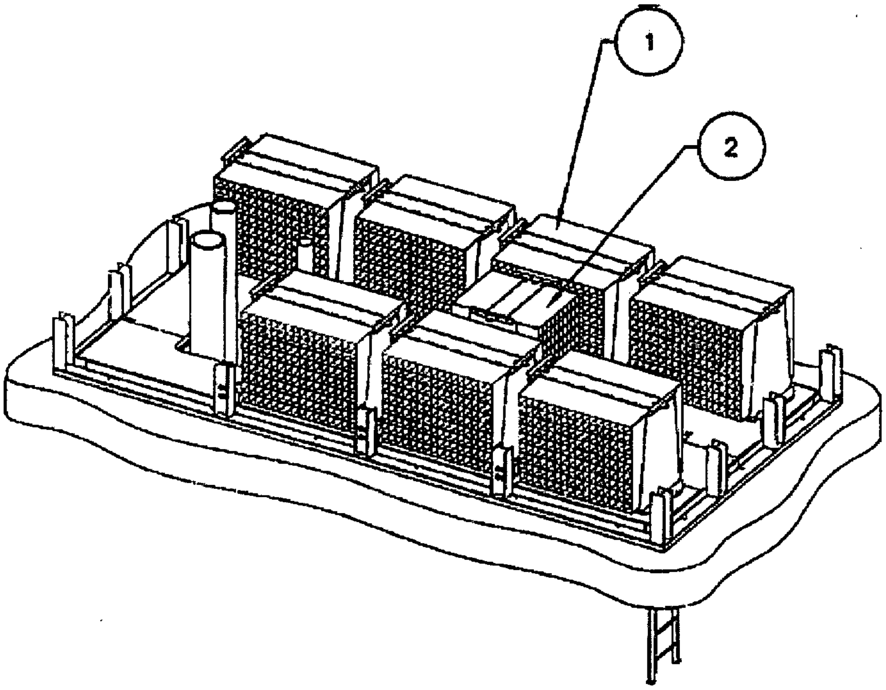
The strainers are designed to be completely submerged below the minimum calculated flood water level at the onset of recirculation. The strainers are of robust design and can easily withstand the modest pressure differential loads even considering debris build-up. There is a top cover on each of the strainer modules, but the manner of construction and fit up of the cover is such that the sheet metal will not be seal-tight. As a result, any air that would initially be inside the strainer modules would self-vent.

The strainer configuration is designed with an access manhole in the stainless steel floor that supports the strainer modules. This allows personnel access to inspect the valves, piping, and vortex eliminators previously installed in the sump. The inservice inspection program specifies the frequency and details of these inspections.

The strainers are of advanced passive design using a convoluted structure. The strainer modules consist of horizontal cassette pockets made of perforated plate that provide the screen area (see Figure 3-31). The strainer modules resemble "pigeon holes" or rectangular pockets, a design which greatly increases effective area on a limited floor footprint. Each pocket is approximately three inches wide by five inches high, and the leading edge is solid plate, which acts as an integral trash rack to protect the perforated portion of the pocket from debris. With the horizontal cassette pocket (specialty) design, the strainers consist of both vertical and horizontal flow paths through the screening elements. All pockets are submerged at the minimum post-LOCA flood level. Since the strainers are approximately 3,142 ft^2 vs. the original 210 ft^2 screens, design liquid flow velocity at the strainer is less than that for the original screens.

Figure 3-31: West Sump Screen Arrangement

(east sump is similar in arrangement)



(1)	seven modules with16 Cartridge Units	2875 ft^2
(2)	one module with 10 Cartridge Units	266 ft^2
	10-inch Pipe Vent	1 ft^2
	TOTAL FLOW AREA APPROX	3142 ft^2

Size of Screen Perforations: 0.083 in

The sumps are designed to preclude air ingestion because of the low velocity through the strainers and the previously existing vortex interrupters on the ECCS pump suction pipe in the sumps are retained. No other detrimental hydraulic effects will occur at the sump or at the suction to the pumps.

2. Other Modifications by the Strainer Replacement

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.

To install the sump strainer floor and strainer modules, the ECCS sump temperature element, associated conduit, and the sump access ladder were relocated.

k. Sump Structural Analysis

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

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

GL 2004-02 Requested 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.

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

1. Sump Strainer Structural Analysis

Provide the information requested in GL 2004-02 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.

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

The strainers are installed in locations that are remote to high-energy line breaks and are located outside of the bio-shield wall. The strainers consist of pocket cartridges, which are assembled together into strainer modules. These modules are tied together using a module support structure and are supported at the base by a sub-floor that covers and seals the entire sump. The sub-floor is attached to the base of the columns of a modified version of the previous sump screen frame.

CCI analyzed the imposed stresses on the ECCS sump strainer standard pocket cartridge [Ref. 4.22], the strainer module and support structure [Ref. 4.24], and the supporting sub-floor [Ref. 4.23]. Also these components were further assessed for a larger differential pressure by CCI [Ref. 4.67].

In the strainer component and supporting structure final stress evaluation, the limits of the American Institute of Steel Construction (AISC) Manual of Steel Construction, 9th Edition and the limits of the ASME B&PV Code, Subsection NF are both satisfied. The requirements of the AISI manual were also considered for the perforated plates used in the strainer.

As the strainer is not a pressure-retaining part, it is not subjected to any pressure transients or hydrostatic pressure during normal operation of the unit. As shown through testing, with the strainer areas covered with debris and the pumps in operation, there will still be some flow through the strainer. Hence, the critical components with respect to loads caused by the pressure drop are the perforated plates that are part of the strainer modules.

The strainer components and supporting structures were evaluated for the load combinations in the PVNGS UFSAR. The analysis determined that the governing load combination was $1.7\ S > D + P + Ta + E'$ where S is the AISC normal allowable stress, D is dead load, P is the stresses caused by differential pressure across the strainer during flooded condition, E' is SSE earthquake-induced stresses, and Ta is accident thermal stresses. As the LOCA condition governs, the earthquake-induced stresses include the effects of sloshing and consideration of the hydrodynamic masses. The amounts of debris considered for the calculation of the equivalent pressure which acts over the two strainer modules (large and small modules) were 520 lbs and 325 lbs, which corresponds to 32.5 lbs/cartridge since there are 16 or 10 cartridges in the two strainer modules.

The cartridge analysis was performed using ANSYS, version 10.0. Stresses were calculated for both the perforated and unperforated plates. For the AISC evaluation, an allowable stress increase factor of 1.7 for SSE was used in accordance with the load combinations. For the ASME evaluation, an allowable stress increase factor of 1.5 was used. For both the perforated and unperforated plates, the maximum membrane stress, σ_m, was calculated to be less than 1.7 times 0.6 times the yield stress (AISC) and less than 1.5 times the calculated allowable stress (ASME). The maximum membrane stress plus bearing stress, $\sigma_m + \sigma_b$, was calculated to be is less than 1.7 times 0.66 times the yield stress (AISC) and less than 1.5 times the calculated allowable stress (ASME). Thus, all stresses are below the stress limits for load combinations for SSE accelerations.

The analysis of the modules was also performed using ANSYS, Version 10.0. Since standard modules consist of the support, the duct, and either 10 or 16 cartridges, a module with 16 cartridges is conservatively considered in the analysis. The maximum membrane stress, σ_m, was calculated to be less than 1.7 times 0.6 times the yield stress (AISC) and less than 1.5 times the calculated allowable stress (ASME). The maximum membrane plus bearing stress, $\sigma_m + \sigma_b$, was calculated to be less than 1.7 times 0.66 times the yield stress (AISC) and less than 1.5 times the calculated allowable stress (ASME). Thus, all stresses are below the stress limits for load combinations for SSE accelerations.

For the various component parts of the strainer module, e.g., duct lower plate, duct upper plate, duct side panel, etc., the maximum membrane stress, σ_m, was calculated to be less than the material yield strength. Further, the maximum membrane plus bending stress, $\sigma_m + \sigma_b$, was calculated to be less than the cumulative maximum stress plus bending stress.

In the sub-floor calculation, AISC Manual of Steel Construction, 9th Edition limits are satisfied. The strainer modules are included with a beam and spring model representing its real center of gravity, mass, and stiffness. The springs were defined so that the beam model and the structural model have the same fundamental natural frequencies in all coordinate planes.

The ANSYS computer program was used to calculate the plate stress at the strainer opening. The maximum membrane plus bending stress was calculated to be less than the allowable membrane stress limit. The computer program also calculated the bending stresses for quadratic and rectangular plate geometries. The maximum bending stresses were below the allowable stress limit. Also, the maximum bending stresses for the sump access base plate and access cover are also calculated to be below the allowable stress limit.

The CCI calculation 3SA-096.043 [Ref. 4.67] structurally evaluates the maximum allowable stress difference for the three major strainer components consisting of the cartridge, module, and sub-floor. The CCI calculation uses the same geometry and calculation models to find the maximum allowable pressure difference. The calculations [Refs. 4.22, 4.23, and 4.24].show that the maximum allowable stress difference over each of these three major strainer components as follows:

- Cartridge: 6,527 psi (0.045 MPa)
- Module: 4,496 psi (0.031 MPa)
- Sub-floor: 6,527 psi (0.045 MPa)

The weakest component, which is also the limiting condition, was found to be the module (frame structure).

Maximum Allowable Pressure Difference

The original analyses performed [Refs. 4.22, 4.23, and 4.24] were based on a maximum allowable pressure difference of 5.0 ft WC. An additional analysis [Ref. 4.67] was performed to determine the maximum allowable pressure difference. The maximum allowable pressure difference for the strainer structure and the sub-floor was determined to be 10.4 ft WC at the material temperature of 70°F [Ref. 4.44]. The yield strength (Sy) of 304 L stainless steel is temperature-dependent. Since the allowable pressure difference is proportional to this Sy, the maximum allowable head loss for the strainer structure at 193.8°F was computed to be 8.98 ft. WC.

Design Codes and Engineering Handbooks

The following Design Codes and Engineering Handbooks were used in the analysis of the sump strainer structural analysis:

- 2004 Edition ASME Boiler and Pressure Vessel Code, Section II: Part D-Properties
- AISC, Manual of Steel Construction, 9th Edition
- AISI, North American Specification for the Design of Cold-Formed Steel Structural Members, 2001 Edition
- T. Kirk Patton, Tables for Hydrodynamic Mass Factors for Translational Motion
- Hurty, W. and Rubinstein, M., Dynamics of Structures, Prentice Hall Inc., Englewood Cliffs, New Jersey
- Roarks' Handbook of Formulas for Stress & Strain, Sixth Edition, Warren C. Young
- PVNGS Design Basis Manual C6, Revision 6, Category I Building Topical

2. Frame Structural and Strainer Seismic Analysis

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

Frame Structural Analysis

The frame for the original sump strainers was modified and supports the strainer sub-floor. The design of the modified sump frame for the attachment of the replacement sump strainers was modeled in GTStrudl with the actual horizontal forces acting at the center column members on the two longer sides of the frame. This is consistent with the CCI structure load transfer (connection) points to the original PVNGS strainer frame [Ref. 4.3]. The equivalent static seismic loads, hydrodynamic loads, and sloshing loads were also applied to the model. GTStrudl was used to check the Interaction Coefficients (IC) for W6 column members. The GTStrudl model was used to determine the plate stresses and anchor forces under the applied loads. The plate stresses were shown to be less than the allowable plate stresses determined using AISC, times an allowable stress increase factor of 1.7. The anchor bolt forces (tension and shear) were shown to be less than the allowable tension and shear loads for cast-in-place anchors.

The hydrodynamic mass was calculated in the two horizontal orthogonal directions according to the column orientation and the loading direction; the sloshing loads were conservatively calculated for the loads parallel to the flanges and perpendicular to the flanges.

The frame design calculations were performed according to the 9th Edition of the AISC manual. Based on no differential pressure or thermal loads, the following load combination governs:

1.7 S > D + E' (SSE)

where E' is SSE induced stresses which includes hydrodynamic and sloshing effects during flooding conditions. S is the AISC normal allowable stress and D is dead load.

The calculation [Ref. 4.3] has evaluated the frame design per the applicable specifications and standards and these are the maximum interaction coefficients:

IC_maxCol = 0.285 < 1.7, maximum IC value for W6 column members

IC_weld = 0.403 < 1.7, maximum IC value for the weld between the column members and the baseplate

IC_plate = 1.567 < 1.7, IC value for the base plate

IC_anchor = 0.862 < 1.0, IC value for anchors on the baseplate

IC_stfplate = 0.786 < 1.0, maximum IC value of the stiffener plate

IC_stfweld = 0.646 < 1.0, maximum IC value of the stiffener weld

Evaluation of the original frame design of the ECCS sump screens for the attachment of the replacement ECCS sump strainers demonstrates that the member stresses, the member connections, the base plates and the anchors are qualified according to the PVNGS specifications for the revised strainer configuration.

Seismic Analysis

CCI analyzed the imposed stresses for the strainer support structure beam connections to the sump beams [Ref. 4.23]. The sub-floor consists of the support structure with seven large strainer modules plus one small strainer module and the connections beams. Sliding joints are provided between sub-floor and supports so that different expansion of steel structure and concrete floor is compensated. Therefore, there are no significant temperature stresses if the strainers are exposed to air or fully submerged.

The strainers are Seismic Class 1 structures. The natural frequencies are calculated for the strainer sub-floor for submerged strainers. For the containment pool filled condition, the hydrodynamic water masses are considered in addition to the steel mass.

CCI calculated the loads due to sloshing of water subjected to horizontal acceleration [Ref. 4.23, Attachment A]. The maximum sloshing load per module is 578 lb_f while the incidence load height is 2.258 ft. The conservatively calculated hydrodynamic water mass covers the influence of the sloshing effect in the y-direction of the large strainer module and in the x-direction of the small strainer module.

The ANSYS model calculated the dominant mode frequencies in the x, y, and z-direction as 11.50 Hz, 11.06 Hz, and 14.46 Hz, respectively [Ref. 4.23, Attachment B]. The seismic response spectra are given in Tables 3-45 and 3-46, and Figure 3-32. The damping (D) values of five percent for horizontal and seven percent for vertical accelerations of the critical damping are used for SSE. The square root sum squared (SRSS) combination method was used to combine the results for the x, y, and z-directions.

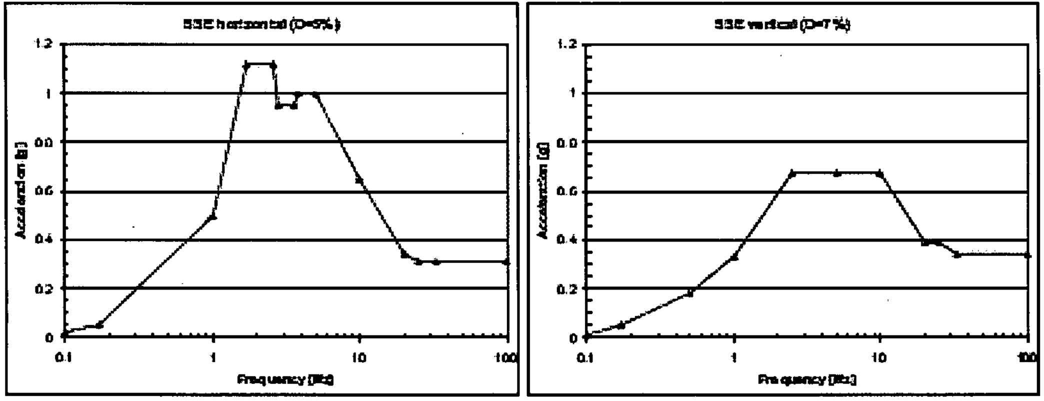
Table 3-45: Seismic Accelerations, g Levels

Freq.	0.1	0.17	1	1.7	2.6	2.8	3.6	3.8	5	10	20	25	33	100
SSE Horiz. (D=5%)	0.02	0.05	0.5	1.12	1.12	0.95	0.95	1.00	1.00	0.65	0.34	0.31	0.31	0.31

Table 3-46: Seismic Accelerations, g Levels

Freq.	0.1	0.17	0.5	1	2.5	5	10	20	25	33	100
SSE Vert. (D=7%)	0.01	0.05	0.18	0.33	0.67	0.67	0.39	0.39	0.39	0.34	0.34

Figure 3-32: Seismic Accelerations SSE



3. <u>Evaluations Performed for Dynamic Effects such as Pipe Whip</u>

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

The sump strainer modules are located between the bioshield wall (outside the S/G D-Ring) and the containment liner. There are no high-energy lines in the vicinity of the ECCS sump strainers. Therefore, the strainer design is not exposed to dynamic effects such as pipe whip, jet impingement, and missiles associated with high-energy line breaks [Ref. 4.110].

4 <u>Credit for Backflushing Strategy</u>

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

The PVNGS sump strainer does not have backflushing capability.

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).

> ***<u>GL 2004-02 Requested Information Item 2(d)(iv).</u>***
> ***The basis for concluding that the water inventory required to ensure adequate ECCS or CSS recirculation would not be held up or diverted by debris blockage at choke-points in containment recirculation sump return flowpaths.***

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

1. <u>Summary of Upstream Effects Evaluation</u>

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

> ***<u>GL 2004-02 Requested Information Item 2(d)(iv)</u>***
>
> ***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.***

The water flow path through the Containment upstream of the ECCS sumps during a LOCA could be affected by debris collecting at possible restrictions. Water could be retained at possible pockets or holdups that would effectively reduce the amount of water available for recirculation. To address these potentials, equipment location drawings were reviewed to determine likely flow paths and possible choke points. A walkdown of the flow paths for all floor elevations was conducted inside and outside the S/G D-rings in PVNGS Unit 2.

This walkdown was performed following guidance from NEI 02-01, and the results are documented in PVNGS Document N001-1106-00007 [Ref. 4.2]. Based on design similarities between PVNGS Units 1, 2, and 3, the Unit 2 walkdown results are applicable to all PVNGS Units.

The containment structure outside of the S/G D-Rings consists of four distinct floor elevations excluding the fuel pool and reactor cavity area. These floor elevations are 80'-0", 100'-0", 120'-0" and 140'-0". Above floor elevation 140'-0" there are miscellaneous partial equipment/personnel platforms that do not obstruct water flow to the sumps. The Unit 2 walkdown verified that clear flow paths exist to the sumps such that injected water would not be held up and could freely flow back to the sumps. During the walkdown, no choke points were identified [Ref. 4.2].

2. Evaluation of Flow Paths from Postulated Breaks and Containment Spray Washdown

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

Upper Elevations

Floor elevations 100'-0", 120'-0" and 140'-0" consist of concrete slabs and industrial grating. There are no gross openings through these floor elevations other than penetrations for pipe, duct, electrical tray/conduit and equipment. Stairways accessing each floor elevation are made of grating. Typical attributes of each floor elevation include the following (floor elevation 80'-0" is discussed separately):

- There is a level transition where the concrete floor slab meets floor grating.
- There is a 3-inch gap between the concrete floor slab and containment liner and at all of these junctures there is a 4-inch high steel toe-plate on the concrete floor slab.
- There is no gap between floor grating and the containment liner.
- There are 3-1/2-inch to 4-inch high toe-plates at all penetrations through both the concrete floor slabs and floor gratings.

Flow paths through floor elevations 100'-0", 120'-0" and 140'-0" appear unobstructed. Water from containment spray will typically rain through the grating and flow from the concrete floor slabs and through the grating. Debris would typically need to fit through grating slots to pass below. There is a sufficient open concrete/grating interface to mitigate forming of choke points for the water/debris mix flow from concrete floor slabs onto the grating.

On floor elevation 100'-0", there are labyrinth-type openings to each RCP bay. These openings were discounted as flow paths into or out of the S/G D-Ring by the walkdown team. This is because each opening opens to a small triangular shaped concrete slab inside the S/G D-Ring before transitioning to grating or open space. Due to the S/G D-Ring structural geometry, it was assumed that all water flowing into or originating from inside the S/G D-Ring will flow down to the 87'-0"/80'-0" elevation and exit the elevation 80'-0" labyrinth-type openings on its way to the sumps. Refer to the elevation 80'-0" floor discussion for details on the labyrinth-type openings.

Storage containers/racks for lead shielding blankets and scaffolding were observed on floor elevations 100'-0", 120'-0" and 140'-0" are not in a location that would impact water/debris flow.

The reactor head inspection stand has adequate drainage and would not impede flow from containment spray. A small amount of water will puddle in slight variations of the solid floors and other horizontal surfaces and water drops will cling to the vertical surfaces. However, no other obstructions will significantly impede water flow from the upper elevations of Containment to the 80'-0" elevation.

Doors to S/G Bays at Elevation 80'-0"

Each S/G D-Ring has one door at the 100'-0" elevation and two doors at the 80'-0" elevation. The doors at the 100'-0" elevation probably will not pass any water in that they are above the maximum water flood level and water will collect at the lower elevations. During normal operation, each opening has a closed steel framed door with "pressure-relief" panels. The elevation 80'-0' door pressure relief panels are held in place by clips. The panels will release during a LOCA at various pressure differentials [Ref. 4.4]. The highest such differential inside over outside is 1.0 psi which is approximately a 2.3 ft WC difference. This ensures that the doors' panels will open and stay open for a LOCA and will not impede flow.

For smaller breaks outside the S/G D-Rings, compartment pressurization to provide the differential pressure across the "pressure-relief" panels may not occur. Only CS flow from the spray headers above the S/G D-Ring walls will enter the compartments. There is limited free volume in the S/G D-Rings below the containment minimum flooding level of 84.5' relative to the Containment free volume outside the S/G D-Rings. The static head from the differential flood height across the doors will open the door panels and allow water to flow from the S/G D-Rings to the Containment general area and the ECCS sumps [Ref. 4.15].

The tops of the S/G D-Ring walls are at elevation 155'-0" and the S/G D-Ring is open down to the floor at elevation 87'-0". The floor at elevation 87'-0" transitions to the containment basement elevation 80'-0" are by way of a vertical 7-foot precipice bounded by a handrail and 4-inch toe-plate. This edge is unobstructed at the metal stairs down to elevation 80'-0". Water from a LOCA and containment spray would flow out from the S/G D-Rings to the basement of Containment via these labyrinth-type openings. Each S/G D-Ring space from elevation 155'-0" to elevation 87'-0" is occupied by the S/G, two RCPs, miscellaneous catwalks and platforms at elevations 100'-7", 107/108'-0", 117'-9 1/8", 128'-0", 136'-1 1/4", and 148'-9", and stairs down from elevation 157'-6".

The southwest and southeast labyrinths open into the containment basement approximately 25 ft from the west side of the southwest sump and from the east side of the southeast sump, respectively. Obstacles in the flow path primarily consist of platform support steel columns, platform access stairs, miscellaneous pumps and TSP baskets. None of these would create a significant flow obstruction.

Water flowing outside the S/G D-Rings on the Containment floor at elevation 80'-0" from the north side to the south side would encounter a very open floor plan as it approaches the ECCS sumps.

Other Upstream Effects

The bottom of the pressurizer compartment is at elevation 100'-0". However, at this elevation there is a 2'-0" by 16'-6" opening to elevation 80'-0" below. Water from a LOCA inside the pressurizer compartment would pour through this opening (which is above the northwest labyrinth-type opening to the S/G D-Ring) and flow to the sump via the west side of Containment at elevation 80'-0".

The following upstream effects are already appropriately considered in the calculation of LOCA minimum water level [Ref. 4.15]:

- Water will be retained in the containment spray droplets as they fall.
- Water that fills the containment spray headers also reduces the depth of water at the straplers.
- Water inventory at the sumps is also reduced by the large amount of water vapor in the LOCA containment environment.

3. Measures Taken to Mitigate Potential Choke Points

Summarize measures taken to mitigate potential choke points.

Walkdowns performed to verify flow paths in Containment to the ECCS sumps identified no potential choke points. No measures to mitigate choke points were required. Additionally, design change procedure 81TD-0EE10 [Ref. 4.104] established controls to review design changes for the potential to adversely alter the flow paths or velocity of water to the ECCS sump strainers or to create choke points.

4. Evaluation of Water Holdup at Installed Curbs or Debris Interceptors

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

There is an equivalent 9-inch curb at the base of the ECCS sump strainer. The water below this curb is considered in the determination of minimum flood level in the Containment, total water volume in Containment, and minimum submergence level above the strainers. .

Debris interceptors have not been installed at PVNGS.

5. Potential Blockage of Reactor Cavity and Refueling Cavity Drain

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

The refueling cavity surrounds the upper part of the reactor and extends from the operating floor at elevation 140'-0" down to the reactor head flange at the elevation 114'-0". The western part of the cavity encompasses the fuel upender which extends down to the elevation 98'-.6". This cavity will collect approximately 11 percent of the containment spray flow and would fill up except for the two floor drains. Both are 10-inch diameter drain pipes in the floor of the refueling cavity liner. One drain is west of the reactor and the other is east of the reactor and both drain to the elevation 80'-0" area.

A concern with the refueling cavity is the potential for pieces of debris (e.g., a 10-inch by 10-inch piece of sheet metal insulation jacket) to migrate to one or both drains and greatly restricting the flow such that the refueling cavity would fill. The east part of the refueling cavity is at elevation 114'-0", the same elevation as the reactor flange. Blockage of the east 10-inch drain opening would not result in an appreciable water hold up. The lower west part of the refueling cavity is deeper with greater floor area to gather containment spray flow which could hypothetically hold thousands of cubic feet of water if its drain were blocked.

This scenario is deemed not credible. No high-energy pipes are in the near vicinity of the 10-inch openings that drain the refueling cavity. The 10-inch drains are open with no covers, grates or screens, so the minimum flow restriction in the cavity drain line flowpath is the inner diameter of the 10-inch drain line. Debris would need to be at least 10 inches wide to bridge the opening and cause blockage. Smaller debris would just pass straight through. Debris would also need to be planar in order to adequately seal the opening. A crumpled piece of sheet metal would not seal the opening.

Postulated high-energy line break locations for debris generation are in the hot leg piping at the S/G nozzle, cold leg suction piping below the RCP, pressurizer surge line piping, CEDM nozzle at reactor head, and pressurizer spray line at pressurizer nozzle. The postulated breaks in the three areas or compartments within the Containment are discussed in the following paragraphs regarding the potential of debris to enter the refueling cavity.

The cold leg and hot leg breaks are in the S/G D-rings. The hot leg piping at the S/G nozzle is at centerline elevation 101.33 ft. and the cold leg suction piping is at centerline elevation 92.61 ft. The debris generated from the cold leg and hot leg breaks would need to be forced around the equipment in the S/G D-rings and ejected above the top of the concrete wall of the S/G D-ring wall at the 155'-0" elevation to enter the refueling cavity. Between the hot leg and cold leg break locations there are structural members, other piping, and several levels of catwalk grating that surround the equipment. This would deflect or restrict in size the debris from a hot leg or cold leg break that has a possibility of entering the refueling cavity. Based on the location of the breaks in the S/G D-rings, it is not considered credible that these breaks will generate debris that will result in blockage of the refueling cavity drain lines.

The top of the pressurizer compartment is a concrete slab and there is not a feasible path for debris from postulated breaks in the pressurizer compartment to the refueling cavity.

The reactor vessel head insulation is a hybrid design consisting of both metal and non-metallic insulation. The area directly above the upper-most section of the head contains a layer of Microtherm (Units 1 and 2) or Min-K (Unit 3) insulating material encapsulated in stainless steel. The total volume of fiber insulation is 10 ft^3 maximum per PVNGS DMWO 2513158 [Ref. 4.108]. The reactor vessel head insulation is shielded from breaks in the main RCS loop piping by the reactor pressure vessel cavity concrete. This insulation could be dislodged by a CEDM ejection or vent line break and transported to the recirculation sump via the 10-inch refueling cavity drains. A CEDM ejection from the reactor head is investigated as break S5. The debris generated from this break is determined to be 5.3 ft^3 [Ref. 4.4]. A CEDM ejection results in a break diameter of nominally 4 inches, while a reactor head vent line break results in only a ¾-inch break [Ref. 4.4]. Based on the small break sizes in this area, the debris will not be large enough to block the refueling cavity drain lines.

It is assumed that the debris generated due to the LOCA would block the reactor cavity drain line and completely fill the reactor cavity. This assumption is conservative as it minimizes the containment water level.

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 screens 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 susceptable to plugging or excessive wear due to extended post-accident operation with debris-laden fluids.

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

The downstream effects reports discussed here were prepared based on guidance in WCAP-16406, Revision 1 [Ref. 4.38].

1. Components

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.

<u>GL 2004-02 Requested Information Item 2(d)(v)</u>
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.

Westinghouse performed a generic evaluation of the downstream impact of sump debris on the performance of the ECCS and CSS following a LOCA. This evaluation was performed in accordance with the methodology presented in WCAP-16406-P [Ref. 4.38], without deviations.

An additional evaluation of the downstream impact of sump debris on the performance of the ECCS and CSS following a LOCA was performed in order to support PVNGS's compliance to NRC GL 2004-02. The evaluation considered the effect of debris ingested through the ECCS sump strainer on the following operable components:

- ECCS and CSS Valves
- ECCS and CSS Pumps
- ECCS and CSS Heat Exchangers
- ECCS Orifices
- CSS Nozzles
- Piping and Instrument Tubing
- Reactor Vessel Water Level System (RVWLS)
- Reactor Vessel Internals
- Nuclear Fuel

Debris concentrations were determined for fibrous, particulate, and coatings debris. Fiber bypass tests were performed with Nukon fibers to determine fiber bypass fraction. The fibers which passed through the strainer module surfaces with a hole size of 0.083 inches was captured by a much finer screen with a 0.012 inch stainless steel mesh. Two bypass tests were performed, identified as Test 02 and Test 03. In Test 02, fibers were added all at once, whereas for Test

03, batches of one quarter of the full amount were added at intervals of one hour. The bypass fraction for Test 02 was 8.1 percent and for Test 03 was 12.3 percent [Ref. 4.49]. The fibrous debris bypass fraction of 12.3 percent is used for the determination of the fibrous debris concentration for downstream effects evaluations [Ref. 4.77]. For particulate and coatings debris, a 100 percent bypass fraction is used in the determination of debris concentrations [Ref. 4.77]. Additionally 5 percent of the RMI debris is assumed to be destroyed and bypass the screen as particulate debris [Ref. 4.77].

The PVNGS evaluation used a conservative evaluation approach that considered debris passing through the sump screen that was larger than the actual size of the holes in the sump screen. This was done to maximize the adverse affects of debris-laden fluid on ECCS and CSS components downstream of the sump. Based on the sizing assumptions provided in WCAP-16406-P [Ref. 4.38], deformable objects of up to two times a sump screen hole size of 0.09 inches are assumed to pass through the sump screen, and are further assumed to deform to pass through any downstream clearance equal to or larger than the sump screen hole size. The ECCS sump strainer design has a nominal hole diameter of 0.083 inches. The acceptance criteria for gaps in the PVNGS strainer installation were determined [Ref. 4.103]. This criteria ensures that the debris bypass due to the gaps does not exceed the debris bypass based on the strainer perforation size.

The basis for concluding that inadequate core or containment cooling would not result from the debris-laden fluid effects is that the acceptance criteria of WCAP-16406-P are met by evaluation or by plant modifications.

The PVNGS downstream effects evaluation supports the following conclusions for the components identified in response above.

2. Verification that Components are not Susceptible to Plugging

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.

a) Valves

The valves were evaluated for plugging, erosion and sedimentation. These issues are not a concern with ECCS and CSS valves. The downstream evaluation contained a recommendation regarding potential emergency operating procedure changes. PVNGS has evaluated the recommendation and determined that no change is required.

b) Pumps

For pumps, three aspects of operability are potentially affected by debris ingestion through the sump screen during recirculation. These aspects are hydraulic performance, mechanical shaft seal assembly performance, and mechanical performance (vibration) of the pump. These operability aspects are summarized as follows:

- For hydraulic performance, as long as the increase in the wear ring gap due to the wear by the sump debris does not affect the pump discharge flow, the pump will maintain positive flow margin, i.e. have sufficient flow to cool the core. The wear ring gap may increase to two times the design clearance without affecting the hydraulic performance of the pump [Ref. 4.38, Section 8.1.2].
- For the mechanical shaft seal assembly performance, the concern is failure of the backup seal bushing due to wear from the sump debris. The majority of the plants reviewed have seal bushings made of carbon/graphite [Ref. 4.38]. Based on the review, it is recommended that if the disaster bushing is a carbon (graphite) material, the bushing should be replaced with a more wear resistant material, such as bronze [Ref. 4.38, Section 8.1.2].
- For multi-stage pumps, vibration may occur due to the increase in the wear ring gap. For symmetric wear of JHF model pumps and RL-IJ model pumps, the wear ring gap may increase to 2.8 times the design clearance without adversely affecting the pump dynamic performance [Ref. 4.38]. For other models of multi-stage pumps, vibration is not a concern for symmetric wear increases of up to 2.0 times the wear ring gap design clearance [Ref. 4.38, Section 8.1.5]. Also experimental data indicates a packing-type wear on the discharge side wear rings, and a free-flowing abrasive-type wear on the suction side wear rings of multi-stage pumps. This results in asymmetric wear of the pumps. Referenced material [Ref. 4.38, Appendix R] identifies the method by which the acceptable amounts of asymmetric wear for multi-stage pumps can be defined. WCAP-16406-P states that for pumps other than the RL-IJ pump specifically analyzed, an acceptable wear limit in the case of symmetric wear is 2 times the design clearance of the pump being analyzed. The basis for this assumption was that of all the pump user manuals were consulted in the development of WCAP-16406-P. These manuals suggest replacement of the wear rings once worn to the point where the design clearance has been increased by 2 times. This symmetric wear limit was used along with the actual pump design clearances and the methodology provided in Appendix R of WCAP-16406-P to develop pump

specific asymmetric wear acceptance criteria for the Palo Verde Downstream Effects Evaluation on multi-stage pumps [Ref. 4.112]. Therefore, a pump specific wear evaluation was completed, satisfying limitation #30 of the NRC's SER.

The hydraulic performance of the pumps is evaluated by comparing the impact of wear of the pump internals on head and flow to the pump performance curve. The increased internal-to-external leakage of the pump fluid due to wear does not impact the required NPSH, so only the impact on the flow must be evaluated [Ref. 4.38]. All pumps must undergo this hydraulic evaluation, which is based on the minimum pump performance curve [Ref. 4.38, Figure 8.1.8]. If a pump meets the following criteria, no further hydraulic evaluation is required:

- Hydraulic flow margin positive at beginning of containment recirculation
- Wear ring material 400 BHN
- Impeller hub material 400 BHN

If any of the above criteria are not satisfied, the change in the pump wear ring gap due to abrasive wear must be calculated and the resulting reduction in the pump discharge flow evaluated. However, if positive flow margin exists, no further evaluation is required. The wear rate of wear rings does not impact the positive flow margin of a pump. The amount of wear does impact the flow margin of a pump. In the downstream effects evaluation of the Palo Verde pumps, the maximum wear over the 30-day mission time was calculated [Ref. 4.112]. It was determined that the amount of wear experienced by all of the Palo Verde pumps was insufficient to significantly impact the positive flow margin.

Positive flow margin exists when the pumps are able to provide more flow than that required to cool the core. Because a potential flow loss from the ECCS pumps over a 30-day mission time is more than compensated for by the reduction in coolant demand (about 88 percent) resulting from the reduction in decay heat over the same period, no loss of positive flow margin is expected during the assumed 30-day mission time [Ref. 4.38, Section 8.1.2].

For the PVNGS pumps shown in Table 3-47, the hydraulic flow margin is assumed to be positive at the start of containment recirculation, as the pumps are designed to provide sufficient flow for core cooling. These pumps do not meet the criteria for wear ring and impeller hub materials hardness greater than 400 BHN, so a wear evaluation was completed for these pumps.

Table 3-47: Hydraulic Performance Evaluation

Pump	Hydraulic Flow Margin	Wear Ring Material	Impeller Hub Material	Evaluation Required
LPSI pumps	positive	208 BHN	300 BHN	yes
HPSI pumps	positive	381 BHN	300 BHN	yes
CS pumps	positive	208 BHN	300 BHN	yes

For single-stage pumps (LPSI and CS), the free-flowing abrasive wear model [Ref. 4.38, Appendix F] was used to calculate the amount of wear (mils) on the impeller hub and on the pump wear ring, thus determining the increase in the diametric clearance between the two components [Ref. 4.56, Appendix B, Section B.1]. The increase in this clearance will affect the hydraulic efficiency of the pump since it results in increased internal-to-external leakage of the pump fluid.

For the multi-stage pumps (HPSI), the suction side is subjected to a lower debris concentration than the discharge side, since the debris particles are centrifuged out of the fluid that enters the impeller shroud volume and leaks back to the impeller suction. Therefore, separate evaluations were done for the suction and discharge side wear ring clearances. The packing-type wear model [Ref. 4.2, Appendix O] was used to calculate the amount of wear (mils) on the pump discharge side impeller hub and wear ring [Ref. 4.56, Appendix B, Section B.2]. The free-flowing abrasive wear model was used to calculate the amount of wear (mils) on the pump suction side impeller hub and wear ring in conjunction with a suction side multiplier.

The wear rates of all affected pumps were calculated [Ref. 4.56, Appendix B]. As long as the resulting wear gap clearance, including the effects of both normal and abrasive wear, is within the replacement range of two times the initial design clearance, no further evaluation is required [Ref. 4.38, Figure 8.1.8]. The change in the wear ring gap due to normal wear is assumed to not exceed three mils based on industry and PVNGS operating experience [Ref. 4.112]. Test data of pump performance with various amounts of wear ring gaps (percent of design gap) [Ref. 4.38, Figure 8.1.3]. For 400 percent gap, the data indicate zero percent impact on delivered flow, approximately 1.5 percent on hydraulic efficiency, and approximately two percent on total dynamic head (TDH). For a pump operating on a constant system curve, a loss of two percent of TDH would reduce flow by one percent. Based on data [Ref. 4.38, Figure 8.1.3], the measured impact is less than the expected one percent value. Therefore, the impact on hydraulic performance due to wear ring gap increases of up to four times the design clearance is insignificant.

As shown in Table 3-48 the increased clearance for the pumps above is within the four times the design clearance criteria, therefore no effect on their hydraulic performance are expected.

Table 3-48: Hydraulic Performance Evaluation

Pump	Erosive Wear (mils)	Abrasive Wear (mils)	Total Wear (mils)	Design Clearance (mils)	Increased Clearance (mils)	4X Design Clearance (mils)
LPSI	3.0E-3	17.1	20.1	31	51.1	124
HPSI	3.0E-3	2.9 suction 39.7 discharge	2.9 suction 39.7 discharge	23	25.9 suction 62.7 discharge	92
CS	3.0E-3	17.1	17.1	25	42.1	100

The PVNGS CS, LPSI, and HPSI pumps utilize external seal flush taken from the pump discharge and passed through a cyclone separator. Particles passing through the cyclone separator will be carried into the seal chamber. It is expected that there would be a reduction of 70:1 or better in particles larger than 10 microns in the fluid routed to the pump seal [Ref. 4.45]. This reduction in debris coupled with an initial debris concentration of 2,000 part per million (ppm) means that the flushing connection would initially be delivering fluid on the order of 30 ppm. With a debris depletion constant of 0.07 per hour, within 26 hours the debris level would be comparable to the five nephelolometric turbidity units (NTU) (~ppm) of solids allowed in drinking water by the Environmental Protection Agency (EPA) drinking water standards. The use of cyclone separators on the flushing water categorizes the PVNGS pumps as not having debris-laden flushing water pumped into the pump seals.

As discussed in the PVNGS evaluation of the debris effects on the ECCS pump seal cyclone separators [Ref. 4.61], testing at Exelon-owned plants shows that the PVNGS installed cyclone separators will not plug when exposed to the level of debris expected to occur during a postulated LOCA . The part numbers of the cyclone separators tested by Exelon , are the sameas those on the cyclone separators installed at PVNGS. The fiber concentration of the recirculated fluid during a postulated LOCA at PVNGS compares to the fiber concentration used in testing of other cyclone separators. The test report indicates that the cyclone separator was tested with more than 6.0 ppm of fiberglass in addition to other particulate debris constituents. The fiber concentration is three times more concentrated than the 2.0 ppm concentration documented in SDOC N001-1106-00011 [Ref. 4.77] for the PVNGS cyclone separators. The Exelon cyclone separators were tested with more than 60 lbs of particulate debris in 600 gallons. The equivalent mass of debris at PVNGS's concentration would be less than 3.5 lbs.

As discussed in the PVNGS evaluation of the debris effects on the ECCS pump seal cyclone separators [Ref. 4.61] the Exelon results are applicable to the PVNGS separators and shows that the PVNGS cyclone separators are qualified to perform their design function when exposed to the debris that would be expected during a postulated LOCA. Hence, the cyclone separators installed at PVNGS will perform their intended design function while passing three times the expected concentration of fibrous debris and seventeen times the particulate debris than expected during a postulated LOCA at PVNGS.

c) Heat Exchangers

The PVNGS SDC heat exchanger tube plugging evaluation demonstrated that the tube ID (0.652 inch) is larger than the largest anticipated debris particle size (0. 1875 inch). Consequently, tube plugging will not occur. The heat exchanger wear evaluation demonstrated that erosion due to the debris ingested through sump screen is very minimal, less than 0.6 percent of the actual tube wall thickness. The remaining wall thickness was determined to be greater than the thickness required to retain pressure and the erosion effect is not a concern [Ref. 4.56].

d) Nozzles and Orifices

The PVNGS containment spray nozzle plugging evaluation demonstrated that the nozzle orifice diameter (0.375 inches for the CSS primary spray headers and 0.1875 inches for the CSS auxiliary spray headers) are larger than the anticipated debris particle size. Consequently, plugging will not occur. Also, for the spray nozzle wear evaluation, the nozzles will perform their design basis functions. Failure of spray nozzles due to erosive wear occurs when the flow from the nozzle is increased by 10 percent due to the increase in nozzle inner diameter. The flow increase due to erosive wear was determined to be 1.5 percent for the CSS primary spray headers and 0.8 percent for the CSS auxiliary spray headers [Ref. 4.56].

The orifice plugging evaluation demonstrated that no orifice bore size is smaller than the largest particle that could pass through the sump strainer, therefore plugging is not a concern. The findings of the orifice wear evaluation concluded that the orifices will perform their design basis functions [Ref. 4.56].

e) Instrument Lines

The PVNGS instrumentation tubing evaluation demonstrated that the transverse ECCS recirculation flow velocity meets the WCAP-16406-P acceptance criteria to prevent debris settlement in the instrument lines. Consequently, debris settlement does not occur and the instrumentation will perform its design basis functions.

3. NRC Approved Methods Used

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

The downstream effects evaluation of debris ingestion on the auxiliary equipment at PVNGS, including the pumps, heat exchangers, orifices, spray nozzles, and instrumentation tubing, follow the methodology in WCAP-16406-P [Ref. 4.38]. No exceptions or deviations were taken to this methodology.

4. Summary and Conclusions of Downstream Evaluations

Provide a summary and conclusions of downstream evaluations.

The downstream impact of sump debris on the performance of the ECCS and CSS following a LOCA at PVNGS was evaluated [Ref. 4.56]. The effects of debris ingested through the ECCS sump screen during the recirculation mode of the ECCS and CSS include erosive wear, abrasion, and potential blockage of flow paths. The smallest clearance found for the heat exchangers, orifices, and spray nozzles in the recirculation flow path is 0.1875 inches for the auxiliary header containment spray nozzles; therefore no blockage of the ECCS flow path is expected with the current sump screen hole size of 0.083 inches.

The instrumentation tubing was also evaluated for potential blockage of the sensing lines. The transverse velocity past this tubing was found sufficient to prevent debris settlement into these lines; therefore, no blockage will occur.

The heat exchangers, orifices, and spray nozzles were evaluated for the effects of erosive wear for an initial total debris concentration of 684 ppm over the 30-day mission time. The erosive wear on these components was determined to be insufficient to affect the system performance.

For pumps, the effect of debris ingestion through the sump screen on three aspects of operability; hydraulic performance, mechanical shaft seal assembly performance, and mechanical performance (vibration) of the pumps was evaluated. The hydraulic and mechanical performances of the pump and shaft seals were determined to be acceptable. There will be no blockage of the cyclone separators for this debris concentration.

5. Summary of Design and/or Operational Changes

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

No design or operational changes to systems or components has been implemented at PVNGS based on the results and conclusions from the downstream effects study.

n. Downstream Effects – Fuel and Vessel

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

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

1. Reactor Vessel Internals

The smallest flow clearance found in the reactor vessel internals evaluation is 0.75 inches, which means that any sump screen hole diameter smaller than 0.37 inches will not result in plugging by either deformable or non-deformable debris [Ref. 4.83]. The diameter of holes in the PVNGS sump strainers is designed to be less than 0.09 inches.

The fuel design currently employed at PVNGS Units 1, 2 and 3 incorporates a protective grid at the bottom nozzle. An evaluation of the protective grid was performed in which fibrous debris was assumed to collect on the first grid in a manner similar to the collection of hair in a sink drain. Test data obtained from the replacement sump screen designed for the PVNGS units and the PVNGS-specific fibrous debris loading were used to support a refined evaluation of fibrous debris collection on the protective grid fuel design employed. This was performed by providing information on the size, size distribution and amount of fibrous debris that would be expected to pass through the replacement sump screens for the PVNGS units [Ref. 4.83].

The acceptance criterion for this evaluation is the demonstration of less than complete blockage of the core flow area. The core flow area for the PVNGS units is 112 ft^2. The application of the refined downstream effects fuel evaluation approach to evaluate the collection of fibrous debris on a protective fuel grid for the PVNGS units, coupled with the use of PVNGS-specific ECCS sump screen by-pass data, resulted in a calculated blocked flow area at the core of 24.78 ft^2 or about 22 percent of the available core flow area. Applying a factor of 1.2 to the blockage calculations to address uncertainties results a calculated total blocked area of 29.74 ft^2 or about 27 percent of the available core flow area [Ref. 4.83].

For PVNGS, based on the 7.30 lb (or 3.04 ft^3) of fibrous debris ingested into the core, the resultant total core flow area blockage is 27 percent. Therefore complete core flow area blockage is not reached [Ref. 4.83].

The PWR Owners Group (PWROG) is currently undertaking a program under Project Authorization PA-SEE-0312 that may provide additional information regarding the limits of fibrous debris that can be passed to and through the core and still provide for successful long-term core cooling [Ref. 4.83]. The PWROG program results will be compared against this evaluation to assess what, if any, impact the program has on the conclusions drawn from this evaluation.

2. Nuclear Fuel

Calculation 2007-19863 [Ref. 4.60] evaluates the deposition of debris material on the fuel rods, which may potentially interfere with the transfer of heat to the coolantand result in excessive fuel cladding temperatures. The calculation uses plant specific conditions and methodology recommended in WCAP-16793-NP [Ref. 4.58], OG-07-534 [Ref. 4.58.1], and OG-08-64 [Ref. 4.58.2]. The primary mode of deposition is by boiling in the core. The plate-out of the chemicals that are introduced into the ECCS sump as a result of a LOCA in the Containment was analyzed. These chemicals are from materials present in the reactor coolant (boric acid and lithium hydroxide), that dissolve in the Containment (e.g., aluminum, insulation, and concrete), and that are added to the recirculating water in the sump (i.e., boric acid and TSP).

The maximum fuel cladding temperature and deposit thickness determined from the analysis were compared to the maximum acceptable temperature of 800°F and the conservative maximum deposition thickness of 50 mils (1,270 microns) as indicated in WCAP-16793-NP, Section 2.4.2 and Appendix A, page A-5 [Ref. 4.58]. The final calculated deposition thickness is 5.4 mils (136 microns), which is less than the recommended upper limit of 50 mils. The calculated maximum temperature of the fuel cladding over the 30 days following the LOCA is less than 352°F which is less than the recommended maximum cladding temperature of 800°F. Based on the results of Calculation 2007-19863 [Ref. 4.60], the effect of the dissolved chemicals plating out on the fuel cladding is acceptable.

o. Chemical Effects

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

- ***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.***
- ***Content guidance for chemical effects is provided in Enclosure 3 to a letter from the NRC to NEI dated March 278, 20078 (ADAMS Accession No. ML080230112).***

1. Head Loss Results

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.

In April of 2008, a strainer module representative of the strainer modules at Palo Verde was tested by CCI under flow, debris, and chemical effects conditions that were scaled to the conditions at Palo Verde [Ref. 4.42]. The results of these tests were used to determine the maximum expected strainer head loss as a function of containment sump temperature [Ref. 4.43]. The testing and the head loss calculation are described in detail in Sections 3.f.4.d and 3.f.10 of this response.

The maximum allowable strainer head loss as a function of sump temperature was determined based on structural and hydraulic considerations [Ref. 4.43]. For all sump temperatures, it is shown that the expected strainer head loss is less than the allowable strainer head loss [Ref. 4.43].

The structural head loss limit is based on the maximum allowable pressure differential of 10.4 ft at a material temperature of 70 °F [Ref. 4.67]. The hydraulic head loss limit is based on the specified maximum allowable head loss of 5.0 ft. At the limiting temperature of 193.8 °F, the calculated strainer head loss including debris and chemical effects is 4.33 ft.

In the NPSH calculations for the ECCS and CSS pumps [Refs. 4.32 and 4.33] the original screen head loss value of 6.06 ft is used. The conclusions of these pre-GL 2004-02 NPSH calculations for the ECCS and CSS pumps [Refs. 4.32

and 4.33] show an NPSH margin of at least 3.8 ft for all pumps. The current NPSH margin is therefore the pre-GL 2004-02 margin (3.8 ft) plus the difference between the pre-GL 2004-02 screen head loss (6.06 ft) and the current strainer head loss (4.33 ft) which equals (3.8 + 6.06 - 4.33 = 5.53) 5.53 ft. This is the minimum margin that occurs at a sump water temperature of 193.8 °F. Greater margin exists at other sump water temperatures.

The in-vessel chemical effects analysis is described in the response to Section 3.n.

2. Content Guide for Chemical Effects

Content guidance for chemical effects is provided in Enclosure 3 to a letter from the NRC to NEI dated March 28, 2008, "Revised Guidance 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,'" (ADAMS No. ML080230112).

Responses to the content guidance in Enclosure 3 to a letter from the NRC to NEI dated March 28, 2008 [Ref. 4.86], are provided in the following subsections.

a) Simplified Chemical Effects Analysis

Sufficient 'Clean' Strainer Area: Those licensees performing a simplified chemical effects analysis should justify the use of this simplified approach by providing the amount of debris determined to reach the strainer, the amount of bare strainer area and how it was determined, and any additional information that is needed to show why a more detailed chemical effects analysis is not needed.

PVNGS did not perform a simplified chemical effects analysis. The quantity of chemicals (aluminum, calcium, and silicon) dissolved in the post-LOCA containment pool was determined using WCAP-16530-NP [Ref. 4.70] and its associated letters and SE [Ref. 4.87]. The precipitate quantities were provided to the screen vendor, CCI, so that prototypical chemical effects head loss tests could be performed. The precipitates were generated outside the test loop using a precipitate generator [Ref. 4.81].

b) Debris Bed Formation

Debris Bed Formation: Licensees should discuss why the debris from the break location selected for plant-specific head loss testing with chemical precipitate yields the maximum head loss. For example, plant X has break location 1 that would produce maximum head loss without consideration of chemical effects. However, break

location 2, with chemical effects considered, produces greater head loss than break location 1. Therefore, the debris for head loss testing with chemical effects was based on break location 2.

The debris quantities used by tthe screen vendor in the head loss tests [Refs. 4.81 and 4.42] are shown to be greater than the maximum debris quantities that transport to the strainer modules [Ref. 4.14, Section 6.2]. The use of the maximum debris load ensures the maximum head loss in the tests. Break selection criteria are discussed in detail in Section 3.a. Debris transport is discussed in detail in Section 3.e.

The chemical precipitate quantities used by the screen vendor in the head loss tests [Refs. 4.81 and 4.42] are shown to be greater than the maximum 30-day precipitate chemical quantities for PVNGS Units 1, 2 and 3 in Section 6.2 of the chemical effects analysis [Ref. 4.52], which uses the WCAP-16530-NP [Ref. 4.70] methodology. This comparison is repeated in Section 3.o.2.u. Inputs to the chemical effects analysis are described in more detail in the response to Section 3.o.2.c.

c) Plant-Specific Materials and Buffers

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

The PVNGS Units 1, 2 and 3 chemical effects analysis is documented in Calculation 2006-05860 [Ref. 4.52]. This calculation determines both the quantity of chemicals that would be dissolved in the post-LOCA containment pool as well as the predicted quantity of precipitate present in the post-LOCA containment pool using the methodology (and spreadsheet) outlined in WCAP-16530-NP [Ref. 4.70]. Descriptions of the primary inputs to the chemical effects analysis are provided in the following paragraphs. PVNGS Units 1, 2 and 3 are similar, and therefore all inputs apply to all three units unless otherwise specified. References for all inputs, if not provided, can be found in Calculation 2006-05860 [Ref. 4.52].

The materials in Containment that are exposed to the containment flood sump water or containment spray in the post-LOCA environment and potentially dissolve and may precipitates in the post-LOCA containment pool. The materials considered in the Palo Verde chemical effects analysis are: Nukon, Min-K/Microtherm, Alpha cloth, latent debris, exposed aluminum metal, and exposed concrete. Some LOCA generated debris (e.g. stainless steel RMI, Thermo-Lag, and epoxy and inorganic zinc coatings) does not contribute to the quantity of dissolved chemicals in the post-LOCA containment pool since these debris types are not soluble. This is consistent with the guidance in WCAP-16530-NP [Ref. 4.70].

All soluble LOCA generated debris (Nukon, Alpha cloth, Min-K / Microtherm, and latent debris) was modeled as being submerged in the containment pool. Nukon and Alpha cloth debris were as modeled as E-glass and they release primarily calcium and silicon, and a smaller amount of aluminum. Min-K / Microtherm was modeled as silica powder and releases silicon. Latent debris was modeled as 85 percent particulate concrete and 15 percent fiberglass (E-glass), and it releases calcium, silicon, and aluminum. The debris quantities are based on the PVNGS debris generation calculation [Ref. 4.4]. For Nukon insulation, 20 percent margin was added, and for Min-K/Microtherm, 10 percent margin was added. This results in the most conservative calcium, silicon, and aluminum releases in the post-LOCA containment pool and, hence, the most conservative precipitate production.

The following equipment in Containment contains exposed aluminum metal: reactor coolant pumps, refueling equipment, movable incore detector drives, aluminum terminators, temperature switches, excore system, equipment hatch hoist assembly, Rosemount transmitters, four miscellaneous instruments, Dwyer Series 1800/2000 devices, four Limitorque motor operators, Fisher pressure regulators, Keene stair nosings, and the fuel transfer tube quick closure unit, four PDTrac enclosures, and the upgraded refueling machine [Ref. 4.26]. The aluminum quantity is the same for all three units.

In the PVNGS chemical effects analysis, aluminum metal was modeled as submerged or non-submerged. The submerged aluminum metal in Containment has a surface area of 41.9 ft^2 and a mass of 171.4 lbm (values include 20 percent margin) for the chemical effects analysis. The non-submerged aluminum metal in Containment has a surface area of 824.2 ft^2 and a mass of 2,225.3 lbm (values include 20 percent margin) for the chemical effects analysis.

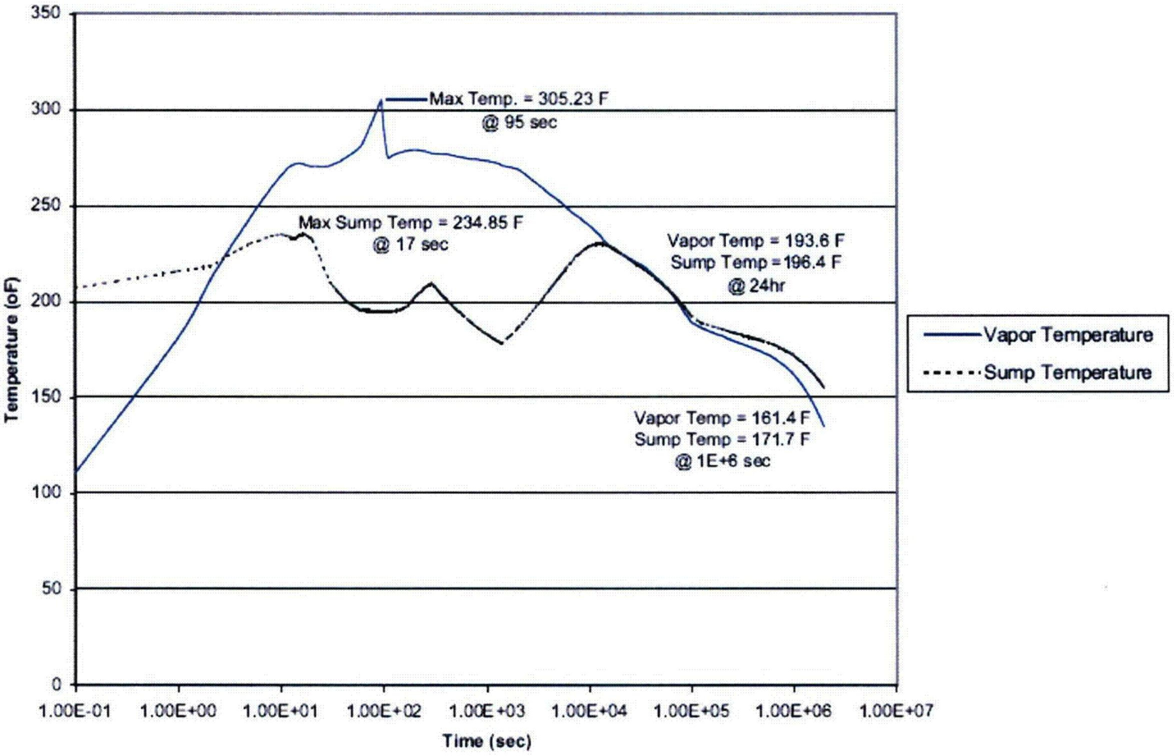
For the PVNGS evaluation, the quantity of exposed concrete was defined as either concrete coated with unqualified coatings, or concrete coated with qualified coatings within the break ZOI. This concrete is subject to dissolution in the post-LOCA environment. The submerged exposed concrete has a surface area of 6,269 ft^2 (value includes 10 percent margin) and the non-submerged exposed concrete has a surface area of 8,479 ft^2 (value includes 10 percent margin).

The quantity of debris, aluminum, and concrete that dissolves is dependent on the characteristics of both the post-LOCA containment pool and the containment spray. The containment pool properties are used to determine dissolution of submerged materials and the spray properties are used to determine dissolution of non-submerged materials. The most important properties of the containment pool and spray are: the containment pool volume, the ECCS sump water and containment atmosphere temperature profiles, the sump and spray pH profiles, and the spray duration during the injection phase.

The maximum available containment pool volume was conservatively used in the chemical effects analysis. This results in the greatest quantity of dissolved material since the material dissolution rate is dependent on the concentration of material already dissolved in the containment pool per the WCAP-16530-NP [Ref. 4.70] methodology; i.e., the lower material concentration in the containment pool, the higher the dissolution rate, the more material dissolves. The maximum containment pool mass is determined in Calculation 13-MC-SI-0804 [Ref. 4.15].

The ECCS sump water and the containment atmosphere temperature profiles are taken from Calculation 13-NC-ZC-0238 [Ref. 4.50]. This analysis determines the long-term equipment qualification (EQ) temperature (containment atmosphere and ECCS sump) and pressure profiles in Containment using realistic assumptions that maximize the temperature response to design-basis mass and energy release events. The containment atmosphere and ECCS sump water temperature profiles are repeated in Figure 3-33.

Figure 3-33: Containment Steam and ECCS Sump Water Temperatures



The containment pool and spray pH profiles used in the chemical effects analysis are based on the pH of the water in RWT and on the pH of the containment pool water as determined in Calculation 13-MC-SI-0016 [Ref. 4.27]. All pH values were selected to maximize the amount of material dissolution. Material dissolution is minimized at neutral pH values (approximately 7.0) and maximized with more acidic (less than 7.0) or more basic (greater than 7.0) solutions. During the injection phase, the containment spray draws water from the RWT. The RWT maximum boron concentration of 4,400 ppm corresponds to a minimum acidic pH of 4.3 [Ref. 4.52]. Therefore, during the injection phase, the containment spray pH is modeled as 4.3 from 92 seconds (when spray is initiated) to 1,438 seconds (when recirculation begins. The initial containment pool pH is 4.4 based on the initial containment pool water boron concentration of 4,241 ppm. Therefore, the containment pool pH is modeled as 4.4 from time zero until the time at which containment spray starts (92 seconds), at which point the containment pool pH was conservatively modeled as 4.3 (the spray pH) until recirculation begins at 1,438 seconds. The maximum pH in the containment pool during recirculation is 8.1. This pH value applies to both the containment pool and spray during the recirculation phase once the TSP buffer is dissolved in the sump pool.

The event mission time also has an impact on the quantity of dissolved materials. The chemical effects analysis was performed using a post-LOCA mission time of 30 days in accordance with Section 2.0 of the NRC SE on GR NEI 04-07 [Ref. 4.30]. Therefore, the chemical quantities dissolved in the sump and the predicted precipitate quantities are based on a 30-day event duration. Containment spray is conservatively modeled as remaining on for the entire 30-day event, which maximizes dissolution of non-submerged materials.

d) Chemical Effects Testing

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

PVNGS chemical effects testing was performed by CCI with chemical precipitates generated in a separate tank and injected into the test loop [Refs. 4.81 and 4.42].

e) Method of Addressing Plant-Specific Chemical Effects

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

The methodology in WCAP-16530-NP [Ref. 4.70] was used to determine the quantity of chemicals which dissolve and precipitate in the post-LOCA containment pool for PVNGS.

f) AECL Model

AECL Model: Since the NRC staff is not currently aware of the testing approach, the NRC staff expects licensees using it to provide a detailed discussion of the chemical effects evaluation process along with head loss test results.

AECL Model: Licensees should provide the chemical identities and amounts of predicted plant-specific precipitates.

The AECL method is not used by PVNGS.

g) WCAP Base Model

1) Deviations from WCAP Base Model

WCAP Base Model: For licensees proceeding from block 7 to diamond 10 in the Figure 1 flow chart [in Enclosure 3 to a letter from the NRC to NEI dated March 28, 2008 (ADAMS Accession No. ML*080230112), 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.*

The WCAP-16530-NP base model spreadsheet was originally issued in February 2006, along with the WCAP document [Ref. 4.70]. Following the original issue, errors were discovered in the spreadsheet as described in Letter WOG-06-102 [Ref. 4.70.1] and a revised spreadsheet was issued on March 17, 2006, via Letter WOG-06-103 [Ref. 4.70.2]. Additional errors in the spreadsheet were discovered and were described in Letter OG-06-232 [Ref. 4.70.3]. These errors were corrected, and a revised spreadsheet was issued on August 7, 2006, via Letter OG-06-255 [Ref. 4.70.4]. Following this issuance of the spreadsheet, one additional error in the spreadsheet was discovered as described in Letter OG-06-273 [Ref. 4.70.5], dated August 28, 2006. However, no revision to the WCAP spreadsheet was issued following the issuance of Letter OG-06-273.

The spreadsheet used in Calculation 2006-05860 [Ref. 4.52] was based on the spreadsheet issued via Letter OG-06-255; however, the spreadsheet was modified to address the error described in Letter OG-06-273. The error correction involved changing a cell reference in several worksheets as is described in Letter OG-06-273. Letter OG-06-273 states that this error only impacts plants such as PVNGS that use TSP for a buffer.

In addition, sheets were added to the WCAP-16530-NP base model spreadsheet to explicitly address particulate concrete separately from exposed concrete. These sheets were added since the WCAP-16530-NP spreadsheet modeled the dissolution of exposed concrete as a function of surface area, not thickness. Hence, dissolution of exposed concrete continues throughout the duration of the event based on the implicit assumption that there is an unlimited quantity of concrete. Given the limited mass of particulate concrete, the assumption of indefinite dissolution was not appropriate. Therefore, separate sheets were added such that dissolution of particulate concrete continued only to the point at which all particulate concrete was dissolved.

Other than the modifications mentioned above, no other changes were made to the WCAP base model spreadsheet used in the PVNGS chemical effects analysis. Also, none of the refinements presented in WCAP-16785-NP [Ref. 4.53] were incorporated into the WCAP-16530-NP base model spreadsheet.

The PWROG responses to the relevant NRC RAI's [Refs. 4.70.6, 4.70.7, and 4.70.8] and the NRC SE [Ref. 4.87] were considered in the PVNGS chemical effects analysis and were found to not affect the results.

OG-06-387 [Ref. 4.70.6] (RAI #24) discusses the aluminum corrosion rate from ICET Test #1 and OG-07-129 [Ref. 4.70.7] (RAI #6) includes a set of correlation coefficients that was developed by the NRC based on ICET Test #1 data (which has a relatively high initial dissolution rate). The NRC correlation coefficients result in a higher mass of precipitate. OG-07-408 [Ref. 4.70.8, top of page 6] and the NRC SE [Ref. 4.87, pg 14] note that the aluminum corrosion rates are not conservative over the first 15 days but the cumulative 30-day integrated aluminum corrosion product release rate is appropriate. This information along with some editorial changes was included in the approved version of the chemical model documentation, WCAP-16530-NP-A [Ref. 4.88]. Based on this, the release rates and integrated aluminum corrosion products for intermediate times (i.e., less than 30 days) found in the spreadsheets in Calculation 2006-05860 [Ref. 4.52, Attachment 1] are not considered conservative and should not be used. As a result, only the 30-day precipitate masses were considered appropriate and were used in the CCI chemical effects head loss tests [Ref. 4.52].

2) Precipitate Quantities

<u>WCAP Base Model</u>: List the type (e.g., AlOOH) and amount of predicted plant-specific precipitates.

The maximum quantities of precipitates in the PVNGS containment pool due to material dissolution over 30 days following a LOCA were determined in Calculation 2006-05860 [Ref. 4.52].

The results of the chemical effects calculation [Ref. 4.52] are summarized in Tables 3-49 and 3-50 below:

Table 3-49: Dissolved Chemical and Precipitate Quantities (Breaks S1, S2, and/or S3)

Palo Verde Generating Station	Dissolved Chemicals (g)			
	Ca	Si	Al	Total
Units 1, 2, and 3	9,942	10,618	24,593	45,154

Palo Verde Generating Station	Precipitates (g)			
	NaAlSi3O8	AlOOH	Ca3(PO4)2	Total
Units 1, 2, and 3	33,023	47,053	25,652	105,728

Table 3-50: Dissolved Chemical and Precipitate Quantities (Break S5)

Palo Verde Generating Station	Dissolved Chemicals (g)			
	Ca	Si	Al	Total
Units 1, 2, and 3	9,650	15,975	24,551	50,175

Palo Verde Generating Station	Precipitates (g)			
	NaAlSi3O8	AlOOH	Ca3(PO4)2	Total
Units 1, 2, and 3	49,681	43,154	24,896	117,731

h) WCAP-16530-NP Refinements

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

The PVNGS chemical effects analysis, Calculation 2006-05860 [Ref. 4.52], does not utilize any of the refinements described in WCAP-16785-NP [Ref. 4.53]. Specifically, the analysis does not model aluminum passivation, or credit solubility of phosphates, silicates, or aluminum alloys.

i) Solubility of Phosphates, Silicates and Al Alloys

1) Refinements (plant-specific inputs) to the base WCAP-16530 Model

***Solubility of Phosphates, Silicates and Al Alloys**: Licensees should clearly identify any refinements (plant-specific inputs) to the base WCAP-16530 model and justify why the plant-specific refinement is valid.*

The PVNGS chemical effects analysis, Calculation 2006-05860 [Ref. 4.52], does not utilize any of the refinements described in WCAP-16785-NP [Ref. 4.53].

2) Inhibition of Aluminum that is not Submerged

Solubility of Phosphates, Silicates and Al Alloys**: 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 aluminium passivation, and (3) the amount of containment spray time (following the achieved threshold of chemicals) before aluminium that is sprayed is assumed to be passivated.**

The PVNGS chemical effects analysis, Calculation 2006-05860 [Ref. 4.52], does not utilize any of the refinements described in WCAP-16785-NP [Ref. 4.53]. Specifically, the analysis does not model aluminum passivation.

3) Solubility of Phosphates, Silicates and Al Alloys

Solubility of Phosphates, Silicates and Al Alloys**: 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.**

The PVNGS chemical effects analysis, Calculation 2006-05860 [Ref. 4.52], does not utilize any of the refinements described in WCAP-16785-NP [Ref. 4.53]. Specifically, the analysis does not credit solubility of phosphates, silicates, or aluminum alloys.

4) Type and Quantity of Precipitates

Solubility of Phosphates, Silicates and Al Alloys**: Licensees should list the type (e.g., AlOOH) and amount of predicted plant specific precipitates.**

The PVNGS chemical effects analysis, Calculation 2006-05860 [Ref. 4.52], does not utilize any of the refinements described in WCAP-16785-NP [Ref. 4.53]. The type and amount of predicted plant precipitates based on WCAP-16530-NP analysis are provided in the Section 3.o.2.g.2 of this response.

j) Precipitate Generation

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

For the chemical effects head loss testing, the precipitates were formed in a separate mixing tank [Ref. 4.81]. The procedure recommended for preparing precipitates is based on the PWR Owner's Group chemical effects evaluation, Document No. WCAP-16530-NP, Revision 0 methodology [Ref. 4.70]. The precipitates used were sodium aluminum silicate ($NaAlSi_3O_8$) and aluminum oxyhydroxide (AlOOH). In addition, as some calcium will dissolve in the post-LOCA containment pool per the WCAP and PVNGS utilizes TSP for a buffer, some calcium precipitates would form and were represented as calcium phosphate ($Ca_3(PO_4)_2$).

All chemical precipitates were prepared as slurries in water in a separate mixing tank for subsequent use in screen prototype testing. The surrogate precipitates were prepared in accordance with the guidance provided in WCAP-16530-NP, Revision 0. The amount of precipitate that was prepared was based on the predicted precipitate loading reduced by the scaling factor [Ref. 4.81].

The quantity of chemicals used to generate the precipitates added to the test loop is provided in Figure 3-34 [Ref. 4.81].

Figure 3-34: Quantity of Chemicals Used to Generate Precipitates

Portion 1	Units	
Mass NAS Desired	kg	1.138
Initial Vol. of Water	L	99
$Al(NO_3)_3 \cdot 9H_2O$	kg	1.628
40% Na4SiO4 Solution	kg	8.047
Min. Final Vol. Water	L	105

Portion 2		
Mass AlOOH Desired	kg	0.566
Initial Vol. of Water	L	47
$Al(NO_3)_3 \cdot 9H_2O$	kg	3.54
30% NaOH Solution	kg	3.78
Min. Final Vol. Water	L	52

Portion 3		
Mass $Ca_3(PO_4)_2$ Desired	kg	0.477
Initial Volume of Water	L	97
$Ca(CH_3CO_2)_2 \cdot H_2O$	kg	0.811
$Na_3PO_4 \cdot 12\ H_2O$ (TSP)	kg	1.168
Min. Final Vol. Water	L	97

The following is a description of the precipitate generation process [Ref. 4.81].

Preparation of Sodium Aluminum Silicate (NAS)

- Verify the mixing tank has been rinsed with water and is visibly clean of particulate matter.
- Add the required volume of potable water to the tank.
- Initiate mixing.
- Slowly add the required quantity of aluminum nitrate nonahydrate ($Al(NO_3)_3 \cdot 9H_2O$) and allow to dissolve.

- After aluminum nitrate dissolution is complete (allowing at least 15 minutes), slowly add the required quantity of sodium silicate solution ($Na_20*3SiO_2$). Precipitate slurry will form on addition of sodium silicate.

- Continue mixing for a minimum of 60 minutes and then secure mixing.

- Verify that the pH is greater than 6.5 to show that the reaction is complete. Use a 100 mL sample of the precipitate slurry for the one--hour settling volume determination. Dilute the sample to obtain a concentration of 9.6 to 9.8 grams per liter.

- Obtain and dilute the sample directly after mixing is secured. Mix the sample following dilution in order to homogenize the solution.

- Once the settling criterion is met (see Section 3.o.2.o), transfer the contents of the mixing tank to suitably sized storage container(s) or directly to the strainer test loop.

- Re-suspend solids via mixing before transfer to the test loop. If the mixture is stored for greater than 24 hours before introduction into the test loop, remix to homogenize and re-verify the settling criterion is met.

<u>Preparation of Aluminum Oxyhydroxide (AlOOH)</u>

- Verify mixing tank has been rinsed with water and is visibly clean of particulate matter.

- Add the required volume of potable water to the tank.

- Initiate mixing.

- Slowly add the required quantity of aluminum nitrate nonahydrate ($Al(NO_3)_3 \cdot 9H_2O$) and allow to dissolve.

- After aluminum nitrate dissolution is complete (allow at least 15 minutes), slowly add the required quantity of sodium hydroxide solution (NaOH). Precipitate slurry will form on addition of sodium hydroxide.

- Continue mixing for a minimum of 60 minutes, then secure mixing.

- Verify that the pH is greater than 6.5 to show that the reaction is complete. Use a 100 mL sample of the precipitate slurry for one-hour settling volume determination. Dilute the sample to obtain an AlOOH concentration of 2.1 to 2.3 grams per liter.

- Obtain and dilute the sample directly after mixing is secured. Mix the sample following dilution in order to homogenize the solution.
- Once the settling criterion is met (see Section 3.o.2.o), transfer the contents to a storage container or directly to the strainer test loop.
- Re-suspend the solids via mixing before transfer to the test loop. If the mixture is stored for greater than 24 hours before introduction into the test loop, remix to homogenize and re-verify the settling criteria.

Preparation of Calcium Phosphate (Ca3(PO4)2)

- Verify mixing tank has been rinsed with water and is visibly clean of particulate matter.
- Add the required volume of potable water to the tank.
- Initiate mixing.
- Slowly add the required quantity of calcium acetate monohydrate ($Ca(CH_3CO_2)_2{\bullet}H_2O$) and allow to dissolve.
- After calcium acetate dissolution is complete (allow at least 15 minutes), slowly add the required quantity of TSP dodecahydrate. Precipitate slurry will form on addition of TSP.
- Perform mixing for a minimum of 60 minutes, then secure mixing.
- Measure and record the pH in the mixing tank.
- Use a 100 mL sample of the precipitate slurry for one-hour settling volume determination. Dilute the sample to obtain a $Ca_3(PO_4)_2$ concentration of 0.9 to 1.1 grams per liter.
- Obtain and dilute the sample directly after mixing is secured.
- Remix sample following dilution in order to homogenize the solution.
- Once the settling criterion is met (see Section 3.o.2.o), transfer contents of the mixing tank to a storage container or directly to the strainer test loop.

- Re-suspend the solids via mixing before transfer to the test loop. If the mixture is stored for greater than 24 hours before introduction into the test loop, remix to homogenize and re-verify the settling criteria.

k) Chemical Injection into the Loop

<u>Chemical Injection into the Loop</u>: 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.

The PVNGS chemical effects testing, injects precipitate prepared in a separate mixing tank consistent with WCAP-16530-NP [Ref. 4.70].

<u>Chemical Injection into the Loop</u>: 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.

The PVNGS chemical effects testing, injects precipitate prepared in a separate mixing tank consistent with WCAP-16530-NP [Ref. 4.70].

<u>Chemical Injection into the Loop</u>: 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).

The PVNGS chemical effects testing, injects precipitate prepared in a separate mixing tank consistent with WCAP-16530-NP [Ref. 4.70]. The mass of precipitates added to the test loop is equivalent to 100 percent of the calculated 30-day precipitates mass in the post-LOCA environment.

l) Pre-Mix in Tank

<u>Pre-Mix in Tank</u>: Licensees should discuss any exceptions taken to the procedure recommended for surrogate precipitate formation in WCAP-16530.

The guidance of WCAP-16530-NP was used for preparing the precipitates. This includes the use by CCI of the updated one hour settled volumes (6.0 ml for Aluminum Oxyhydroxide and Sodium Aluminum Silicate, 5.0 ml for Calcium Phosphate) found in WCAP-16530-NP-A [Ref. 4.88].

The sodium silicate used by CCI was manufactured by Chemira GmbH while the sodium silicate used in the development of the WCAP-16530-NP methodology was manufactured by EMD Chemicals Inc. Westinghouse verified that the two products were equivalent for the purposes of preparing the sodium aluminum silicate precipitates.

m) Technical Approach to Debris Transport

<u>Technical Approach to Debris Transport (Decision Point)</u>: State whether near-field settlement is credited or not.

Near-field settlement is not credited for PVNGS. Debris was agitated in the flow loop [Ref. 4.42].

n) Integrated Head Loss Test with Near-Field Settlement Credit

<u>Integrated Head Loss Test with Near-Field Settlement Credit</u>: Licensees should provide the one-hour or two-hour precipitate settlement values measured within 24 hours of head loss testing.

Near-field settlement is not credited for PVNGS. Debris was agitated in the flow loop [Ref. 4.42]. See Section 3.o.2.o for precipitate settlement values. A more in depth discussion of debris agitation and settling is also provided in Sections 3.f.4.d and 3.f.4.e.

<u>Integrated Head Loss Test with Near-Field Settlement Credit</u>: Licensees should provide a best estimate of the amount of surrogate chemical debris that settles away from the strainer during the test.

Near-field settlement is not credited for PVNGS. Debris was agitated in the flow loop [Ref. 4.42]. See Section 3.o.2.o for the settlement fractions from the head loss tests. A more in depth discussion of debris agitation and settling is also provided in Sections 3.f.4.d and 3.f.4.e.

o) Head Loss Test without Near Field Settlement Credit

<u>Head Loss Testing Without Near Field Settlement Credit</u>: 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.

A more in depth discussion of debris agitation and settling is also provided in Sections 3.f.4.d and 3.f.4.e.

<u>Test #2: Chemical Effects Test – April 14 through 22, 2008:</u>

- Non-chemical debris addition time = one hour
- Sedimentation in front of the strainer test module = 19.1 percent
- Debris in the pockets = 80.9 percent

The majority of the sedimentation in front of the strainer consisted of Nukon fines and pieces as well as Thermo-Lag. While most of the Thermo-Lag settled immediately in front of the strainer, two or three pieces did settle inside the strainer pockets. Any debris which settled away from the test strainer module was agitated to assist in transport to the strainer [Ref. 4.42].

Test #2 ended during an NRC staff visit to CCI. At the end of the test, the flume was drained. In the NRC trip report [Ref. 4.99], the representatives of the NRC staff noted that "There was very little settlement of debris on the bottom of the flume. There was some small amount of debris piled against the bottom of the strainer."

Test #3: Chemical Effects Test – April 23 through 26, 2008

Non-chemical debris addition time = 2.4 hours

Sedimentation in front of the strainer test module = 11 percent,

Debris in the pockets = 89 percent

The majority of the sedimentation in front of the strainer consisted of Nukon fines and pieces as well as Thermo-Lag. While most of the Thermo-Lag settled immediately in front of the strainer, two or three pieces did settle inside the strainer pockets. Any debris which settled away from the test strainer module was agitated to assist in transport to the strainer [Ref. 4.42].

***Head Loss Testing Without Near Field Settlement Credit*: 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).**

For preparation of the precipitates, the measurement of the one hour settling volume was performed using the time criterion of one hour (60 +5/-0 minutes) after mixing is stopped. If the mixture is stored for greater than 24 hours before introduction into the test loop, then the solution is remixed to homogenize and the settling criterion re-verified.

The procedure followed to measure the one hour settled volumes was as follows [Ref. 4.81]:

- Transfer a 10.0 milliliter aliquot of the diluted sample to a graduated 15 milliliter centrifuge tube (or other suitable graduated measuring vessel). Make sure that the solids are suspended in solution prior to transferring to the centrifuge tube. Stir the sample prior to transferring to the tube if necessary.

- Set the centrifuge tube (or other suitable graduated measuring vessel) in a stable vertical position.
- After one hour (60 +5/-0 minutes), measure and record the precipitate volume.
    - For NAS and AlOOH, the settling volume should be 6.0 milliliters or greater for a 10.0 milliliter sample of freshly prepared surrogate. If more than 24 hours have elapsed since initial preparation of the surrogate, the settling volume should be 6.0 milliliters or greater and within 1.5 milliliters of the freshly prepared surrogate measured settling volume.
    - For $Ca_3(PO_4)_2$, the settling volume should be 5.0 milliliters or greater for a 10.0 milliliter sample of freshly prepared surrogate. If more than 24 hours have elapsed since initial preparation of the surrogate, the settling volume should be 5.0 milliliters or greater and within 1.5 milliliters of the freshly prepared surrogate measured settling volume.
- If the settling criterion is not met, obtain and dilute another sample from the mixing tank and repeat the settled volume test. Consult a Manager or Chemistry Lead if the settling criterion is not met after re-sampling.
- Return the contents of the settling criterion test sample(s) to the mixing chamber.

The one-hour settled volume results are [Ref. 4.42]:

Test #2: Chemical Effects Test: – April 14 through 22, 2008

- pH from mixing tank of $NaAlSi_3O_8$ = 10.2
- pH from mixing tank of AlOOH = 11.0
- pH from mixing tank of $Ca_3 (PO_4)_2$ = 10.4
- Settled volume after one hour of $NaAlSi_3O_8$ = 9.6 mL
- Settled volume after one hour of AlOOH = 6.5 mL
- Settled volume after one hour of $Ca_3 (PO_4)_2$ = 8.0 mL

Test #3: Chemical Effects Test – April 23 through 26, 2008

- pH from mixing tank of $NaAlSi_3O_8$ = 10.2

- pH from mixing tank of AlOOH = 11.0
- pH from mixing tank of $Ca_3(PO_4)_2$ = 10.4
- Settled volume after one hour of $NaAlSi_3O_8$ = 9.1 mL
- Settled volume after one hour of AlOOH = 6.5 mL
- Settled volume after one hour of $Ca_3(PO_4)_2$ = 8.0 mL

The settled volume for $NaAlSi_3O_8$ and AlOOH must be greater than 6.0 mL when near field settlement is not credited. Also, the settled volume for $Ca_3(PO_4)_2$ must be greater than 5.0 mL when near field settlement is not credited [Ref. 4.88]. These criteria have been met in Test #2 and Test #3.

Although near field settlement is not credited, a comparison of the one-hour settled volume values for NAS and AlOOH to the one-hour settled volume values for the 2.2 g/l concentration line on Figure 7.6-1 [Ref. 4.70] was performed. This comparison is requested [Ref. 4.87] for plants which do credit near field settlement. The one- hour settled volume measurement for the 2.2 g/l concentration line in Figure 7.6-1 is 9.1 ml. Based on this, the NAS for Tests #2 and #3 would meet this criterion while the AlOOH would not meet this criterion for either test. However, as discussed above, near field settlement is not credited since debris was agitated to ensure maximum transport to the strainer. The total quantity of settled debris was 19 percent for Test #2 and 11 percent for Test #3, as documented above.

p) Test Termination Criteria

<u>Test Termination Criteria</u>: Provide the test termination criteria.

The head loss is measured after the chemical addition until stabilization of a range plus or minus one percent head loss change in 60 continuous minutes is observed.

During the flow sweep in which the flow is varied in steps between 80 percent and 176 percent of the design flow, the stability criterion is between plus or minus two percent change for 30 continuous minutes.

Test #2: Chemical Effects Test – April 14 through 22, 2008

The plus or minus one percent change for 60 continuous minutes stability criterion was not met for following the addition of 100 percent of the non-chemical debris because the head loss was so low, the stability criterion could not be reached. The most stable head loss observed was

1.2 percent on April 15, 2008, at nine time points between 22:34 and 22:57.

The plus or minus one percent change for 60 continuous minutes stability criterion was not met following the addition of a combination of 100 percent of the non-chemical and chemical debris. This was because the head loss was so low, the stability criterion could not be reached even after about 88 hours of run time. The most stable head loss observed was 1.3 percent.

The flow sweep stability criterion (between plus and minus two percent change for 30 continuous minutes) was met for each flow tested.

Test #3: Chemical Effects Test – April 23 through 26, 2008

The plus and minus one percent change for 60 continuous minutes stability criterion was not met following the addition of 100 percent of the non-chemical debris. The most stable head loss observed was 1.2 percent. Because open screen conditions were visible after 100 percent of the non-chemical debris had been added, it was determined that after 23 hours of continuous operation the test should be continued with the addition of the chemical debris.

The stability criterion of plus or minus one percent change in 60 continuous minutes was met following the addition of the combination of 100 percent of the non-chemical and chemical debris.

The flow sweep stability criterion (between plus and minus two percent change for 30 continuous minutes) was met for each flow tested.

q) Data Analysis

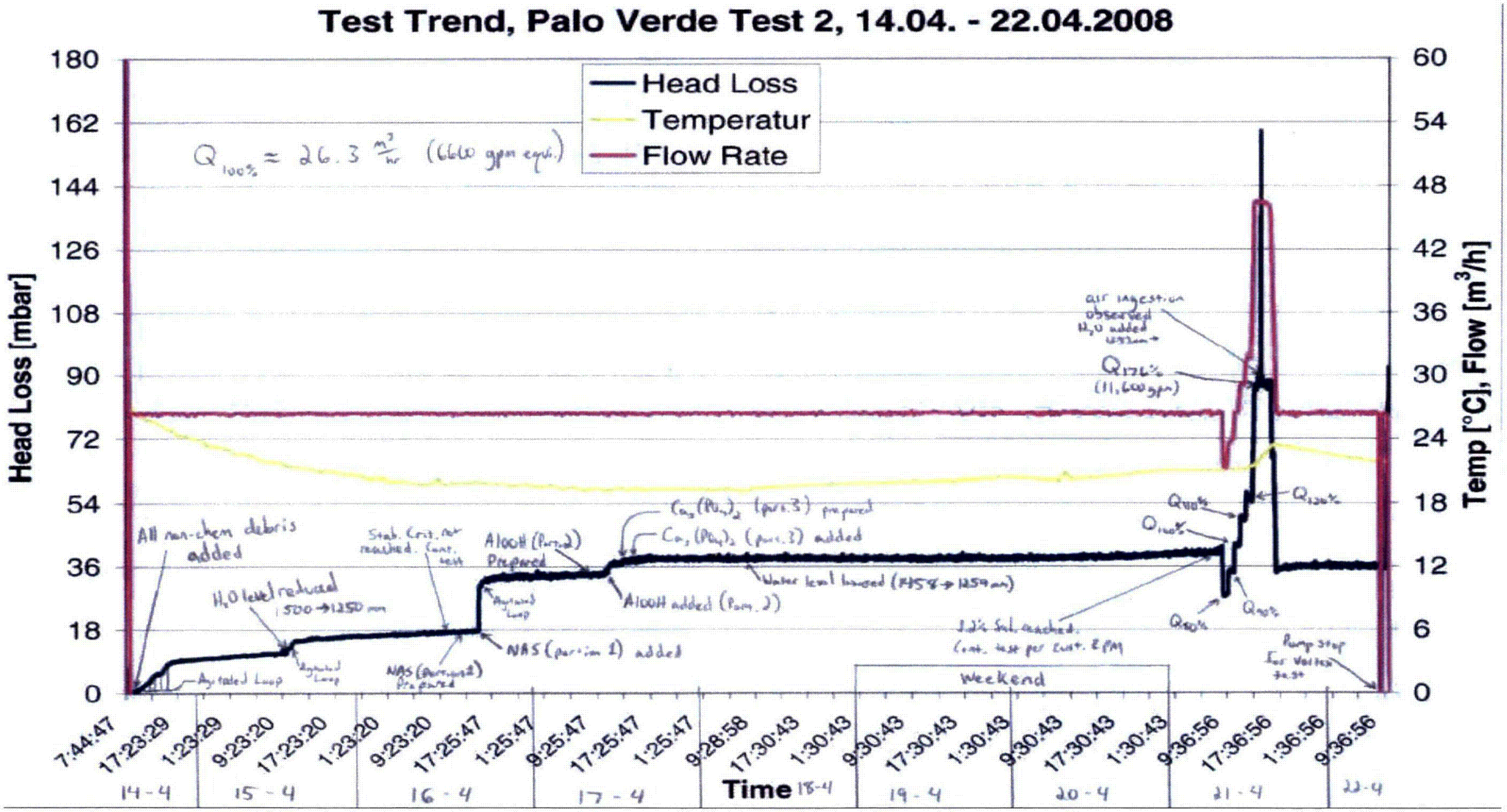
***Data Analysis*: Licensees should provide a copy of the pressure drop curve(s) as a function of time for the testing of record.**

Test #2: Chemical Effect Test

This chemical test was performed between April 14, and April 22, 2008, with the full amount of fiber, particulate and chemicals. See Figure 3-35 below [Ref. 4.42]

In the early part of the test, the head loss increased in a stair step fashion as the debris and precipitates were added in batches over time. This was followed by a multi-day period in which the full debris and precipitate load was on the strainer. The final portion of the timeline shows the head loss variations through the flow sweep. Magnifications of the pressure traces during the flow sweeps are provided in Section 3.f.10 of this response.

Figure 3-35: Test #2 Chemical Effects Test Plot

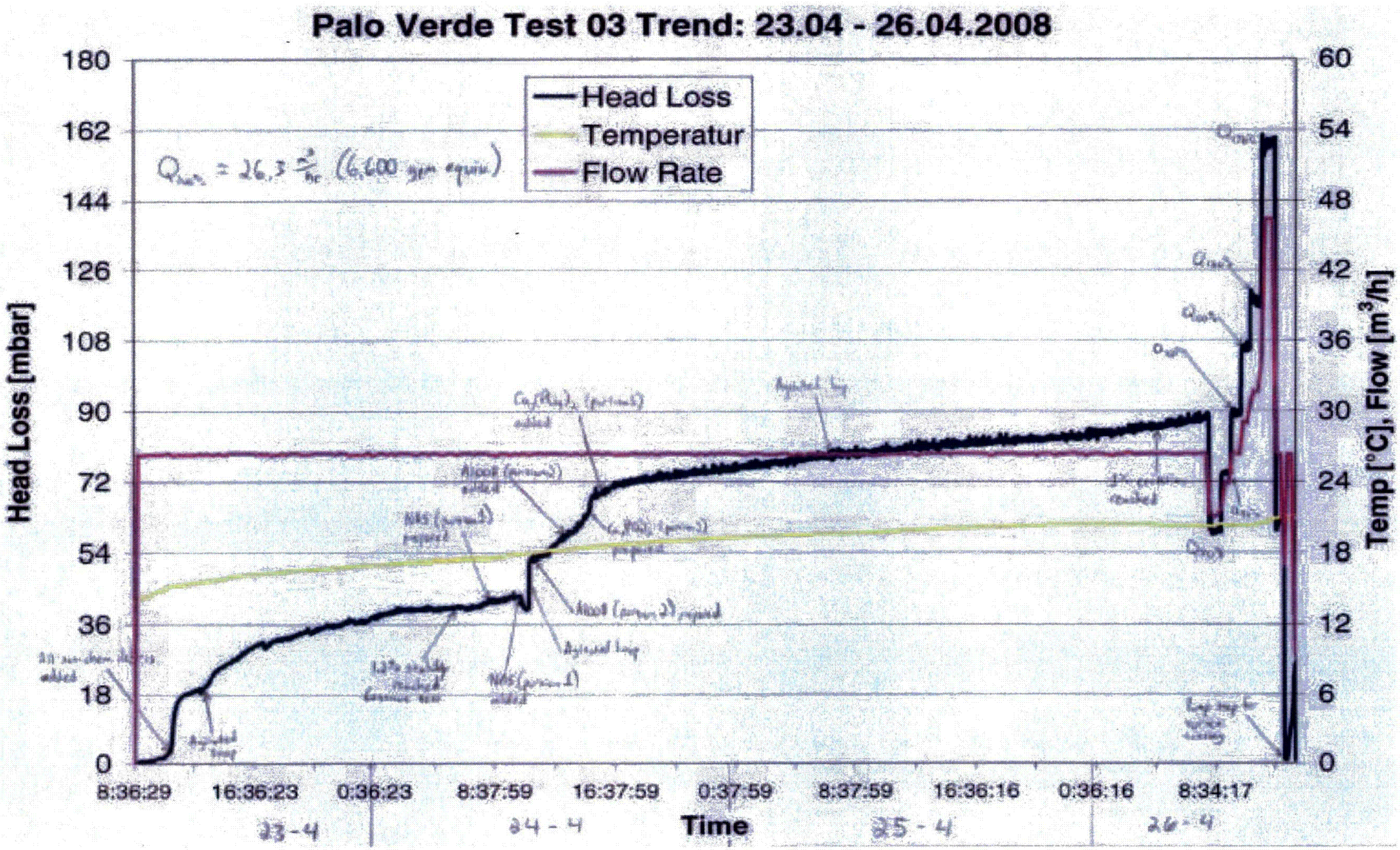


Test #3: Chemical Effect Test

This chemical test, a repetition of previous Test #2, was performed between April 23, and April 26, 2008, with the full amount of fiber, particulate and chemicals. See Figures 3-36 below [Ref. 4.42].

In the early part of the test, the head loss increased in a stair step fashion as the debris and precipitates were added in batches over time. This was followed by a multi-day period in which the full debris and precipitate load was on the strainer. The final portion of the timeline shows the head loss variations through the flow sweep.

Figure 3-36: Test #3 Chemical Effects Test Plot



***Data Analysis*: Licensees should explain any extrapolation methods used for data analysis.**

Extrapolation was neither used nor required for the PVNGS data analysis. Further details are provided in the "Stability Criteria / Test Termination Criteria" subsection in Section 3.f.4.d [Ref. 4.43].

r) Integral Generation

Integral Generation (Alion):

The chemical effects tests were performed by CCI. The Alion test approach is not applicable for PVNGS.

s) Tank Scaling / Bed Formation

***Tank Scaling*: Explain how scaling factors for the test facilities are representative or conservative relative to plant-specific values.**

Calculation of Scaling Factor

Table 3-51 shows the screen area of the ECCS sump strainer and the screen area of the test module used in the test loop [Ref. 4.8]. The filtering surface of the actual strainer effective surface area is conservatively reduced by the sacrificial area to offset any potential foreign material debris. The scaling factor is the result of the division of the two areas.

Table 3-51: ECCS Strainer and Test Model Screen Areas

Screen Area Plant	Net Screen Area Plant	Screen Area Test Loop	Scaling Factor
3142 ft2 (-400 ft^2)	254.7 m^2	4.5 m^2	56.9

The amount of fiber, particulate, and chemical precipitate as well as the flow rate were recalculated from the plant condition to the test condition by the scaling factor.

The sacrificial area of 400 ft^2 offsets any potential blockage due to such items as labels and placards [Ref. 4.43]. Whole pockets can only be blocked at their entrance, if the labels are larger than a pocket opening and sufficiently stiff to prevent being drawn into the pocket by flow head loss. Tape and stickers do not meet these conditions. This potential behavior would be limited to metal or very stiff plastic labels which have been shown not to transport to the strainer screen [Ref. 4.49].

<u>Bed Formation</u>: Explain how bed formation is representative of that expected for the size of materials and debris that is formed in the plant specific evaluation.

As discussed in the "Test Loop Configuration" subsection of Section 3.f.4, the test loop set-up is geometrically similar to the installed strainer cartridge modules.

Given the geometric similarities between the test strainer modules and the installed strainer modules, the scaled debris and precipitate load used in the test, and the scaled flow rate used in the test, a debris bed representative of the expected post-LOCA debris bed was formed in the chemical effects head loss testing. Section 3.f.4.d contains a detailed comparison of tested parameters to plant parameters.

t) Tank Transport

<u>Tank Transport</u>: 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.

The amount of fiber, particulate, and chemical precipitate, as well as the flow rate, was calculated based on the plant expected conditions for flow rate, chemical precipitate, and debris load using a scaling factor. Any debris that settled away from the test strainer module was agitated to assist in transport to the strainer [Ref. 4.81].

A comparison of the analytically determined transported non-chemical debris to the quantity of tested non-chemical debris is provided in Section 3.f.4.d.

u) 30-Day Integrated Head Loss Test

<u>30-Day Integrated Head Loss Test</u>: 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.

The masses of the three precipitates used by CCI in the chemical effects head loss tests are shown in Table 3-52 [Refs. 4.52 and 4.81]. By multiplying the tested masses by the test scaling factor, the plant equivalent masses can be determined.

Table 3-52: Mass of Chemical Precipitate in CCI Tests

	Precipitates used in CCI Tests (kg)			
	$NaAlSi_3O_8$	AlOOH	$Ca_3(PO_4)_2$	Total
Mass in Test Loop	1.138	0.566	0.477	
Scaling Factor	56.9	56.9	56.9	
Equivalent Mass in Test Loop	64.7	32.2	27.1	124.0

The total equivalent precipitate load used in the CCI tests is greater than the total 30-day precipitate load calculated for all PVNGS breaks as shown in Table 3-53. Using a greater precipitate load in the tests, results in a conservative chemical effects evaluation. While the individual precipitate loads used in the CCI test are greater than the calculated loads for both $NaAlSi_3O_8$ and $Ca_3(PO_4)_2$ in all breaks, the calculated AlOOH mass for all breaks is higher than the mass used in the CCI test. However, the sum of the masses of $NaAlSi_3O_8$ and AlOOH used in the CCI test is greater than the sum of the masses of $NaAlSi_3O_8$ and AlOOH calculated for all breaks. This is acceptable since the settling rate and filtration characteristics of these two precipitates are sufficiently similar as to be interchangeable in the head loss test [Ref. 4.70, Section 7.3.2].

Table 3-53: Comparison of Tested and Calculated Precipitate Masses

		Mass of Precipitate (kg)				
		$NaAlSi_3O_8$	AlOOH	$Ca_3(PO_4)_2$	Sum of $NaAlSi_3O_8$ and AlOOH	Total
Equivalent Mass in Test Loop		64.7	32.2	27.1	96.9	124.0
Break S1, S2, S3	Mass	33.0	47.1	25.7	80.1	105.8
	Test Minus Break	31.7	-14.9	1.4	16.8	18.2
Break S5	Mass	49.7	43.2	24.9	92.9	117.8
	Test Minus Break	15.0	-11.0	2.2	4.0	6.2

<u>30-Day Integrated Head Loss Test</u>: Licensees should provide a copy of the pressure drop curve(s) as a function of time for the testing of record.

The pressure drop curves as a function of time for the testing of record is provided in Section 3.o.2.q.

v) Data Analysis Bump Up Factor

<u>Data Analysis Bump Up Factor</u>: 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.

PVNGS does not use a bump up factor to determine head loss.

p. Licensing Basis

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

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

<u>GL 2004-02 Requested Information Item 2(e)</u>
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 generic letter. Any licensing actions or exemption requests needed to support changes to the plant licensing basis should be included.

Activities have been completed to ensure that ECCS and CSS recirculation functions under debris loading conditions at PVNGS Units 1, 2, and 3, are in compliance with the regulatory requirements listed in the Applicable Regulatory Requirements section of GL 2004-02. Compliance has been achieved through analysis, mechanistic evaluations, modifications to increase the available sump screen area, changes to the plant to reduce the potential debris loading for the ECCS sump strainers, and programmatic and process controls to ensure continued compliance. The previously installed Fiberfrax insulation has been removed from PVNGS Units 1, 2, and 3. Nukon insulation has been removed around letdown coils. Larger ECCS sump strainers have been installed in all three units. The installed strainers increase the available screen area from the original 210 ft^2 to 3,142 ft^2 in each of the two ECCS sumps. The installed strainers occupy the same footprint as the original strainers.

In support of installation of the new strainers in Unit 2, APS submitted, and the NRC in license amendment number 169 dated May 9, 2008, approved an exigent change to technical specification (TS) 3.5.5, to increase the refueling water tank (RWT) minimum water level for Unit 2 by three percent [Ref. 4.92]. For Units 1 and 3 the minimum RWT water level to meet the containment flood level analysis is the same as Unit 2 and is currently being administratively controlled. The same TS 3.5.5 changes for Units 1 and 3 were submitted to the NRC in APS Letter No. 102-05923, dated November 13, 2008 [Ref. 4.93]. The current administrative controls for Units 1 and 3 RWT level provided in accordance with NRC Administrative Letter 98-10, "Dispositioning of Technical Specifications that are Insufficient to Assure Plant Safety," will remain in effect until the Units 1 and 3 TS amendment is issued and implemented.

The UFSAR will be updated with changes in accordance with 10 CFR 50.71(e).

4. REFERENCES

These reference documents were used in the development of Enclosure 1:

4.1 SDOC MN725-A00153, Revision 0, "Turbine-Generator Final Report 105% Core Thermal Uprate Study"

4.2 SDOC N001-1106-00007, Revision 0, "Unit 2 Debris Walkdown Report"

4.3 Calculation 13-CC-ZC-0197, Revision 6, "Containment Bldg. Misc. Structures Part 2"

4.4 SDOC N001-1106-00002 Revision 3, "Debris Generation Due to LOCA within Containment for Resolution of GSI-191"

4.5 SDOC N001-1106-00022, Revision 0, "Walkdown Report for Evaluating Fibrous Sources Inside PVNGS-1 Containment," Revision 1

4.6 SDOC N001-1106-00024, Revision 0, "Walkdown Report for Evaluating Fibrous Sources Inside PVNGS-3 Containment," Revision 0

4.7 SDOC AN449-A00090, Revision 1, "Unit 1 Unqualified Coatings Walkdown Report"

4.8 SDOC AN449-A00086, Revision 1, "Unit 2 Unqualified Coatings Walkdown Report"

4.9 SDOC AN449-A00091, Revision 1, "Unit 3 Unqualified Coatings Walkdown Report"

4.10 SDOC N001-1106-00021, Revision 0, "Walkdown Report for Evaluating Latent Debris inside PVNGS Unit 1 Containment for Resolution of GSI-191," Revision 1

4.11 SDOC N001-1106-00008, Revision 0, "Walkdown Report for Evaluating Latent Debris inside PVNGS Unit 2 Containment for Resolution of GSI-191," Revision 0

4.12 SDOC N001-1106-00023, Revision 0, "Walkdown Report for Evaluating Latent Debris inside PVNGS Unit 3 Containment for Resolution of GSI-191," Revision 1

4.13 SDOC N001-1106-00001, Revision 1, Calculation 2005-06305, "Latent Debris Generation due to LOCA within Containment for Resolution of GSI-191," Revision 1

4.14 SDOC N001-1106-00003 Revision 2, Calculation 2005-09080, "Post LOCA Debris Transport for Resolution of GSI-191"

4.15 Calculation 13-MC-SI-0804, Revision 6, “Containment Building Water Level During LOCA”

4.16 SDOC N001-1106-00004, Revision 0, "GSI-191 Chemical Effects and Margin Evaluation," Revision 0

4.17 NRC letter dated 12/13/2006, “PVNGS Unit 2 – Approval of GL 2004-02 Extension Request”

4.18 SDOC N001-1106-00027, Revision 0, (Q00384747), “CCI Small-Filter Performance Test Specification, Revision 3”

4.19 SDOC N001-1106-00028, Revision 0, (Q00384751), "CCI Large-Filter Performance Test Specification," Revision 3

4.20 Technical Document 81TD-0EE10 Rev 18, Design Change Process

4.21 SDOC N001-1106-00220, Revision 0, (68041213), "CCI Large-Scale Strainer Performance Test," Revision 4

4.22 SDOC N001-1106-00032, Revision 0, (3SA096025), "Structural Analysis of a ECCS Strainer Standard Module Cartridge," Revision 4

4.23 SDOC N001-1106-00038, Revision 0, (3SA096034), "Seismic Analysis Report Strainer Subfloor," Revision 1

4.24 SDOC N001-1106-00037, Revision 0, (3SA096033), "Structural Analysis of Strainer Module and Support Structure," Revision 2

4.25 SDOC N001-1106-00033, Revision 5, (9002291CH), “CCI Fabrication Drawing – Strainer,” Revision F

4.26 Calculation 13-NC-ZC-0202, Revision 11, “Post-LOCA Hydrogen Generation”

4.27 Calculation 13-MC-SI-0016, Revision 5, “Tri-Sodium Phosphate Basis Calculation”

4.28 Safety Evaluation by the Office of Nuclear of Reactor Regulation Related to NRC Generic Letter 2004-02, Nuclear Energy Institute GR (Proposed Document Number NEI 04-07), “Pressurized Water Reactor Sump Performance Evaluation Methodology,” issued December 6, 2004

4.29 SDOC N001-1106-00029, Revision 0, (68041129), “CCI Small Filter Performance Test Report”

4.30 Nuclear Energy Institute (NEI) Document Number NEI 04-07, Revision 0, "Pressurized Water Reactor Sump Performance Evaluation Methodology," dated December 2004.

4.31 Specification 13-MN-1003, Revision 2, “Emergency Recirculation Sump Strainers”

4.32 Calculation 13-MC-SI-0017, Revision 6, “Safety Injection System Interface Requirements Calculation”

4.33 Calculation 13-MC-SI-0018, Revision 7, “Safety Injection System Interface Requirements Calculation”

4.34 NRC Regulatory Guide 1.82 “Water Sources for Long-Term Recirculation Cooling Following a Loss-of-Coolant Accident,” Revision 3

4.35 Procedure 38DP-0MI01, Revision 9, “Control of Painting and Coating Operations”

4.36 Procedure 81DP-0AP02, Revision 2, “PVNGS Coatings Program”

4.37 Westinghouse LTR (CSA-05-21), “Downstream Effects Evaluation to Support the Resolution of GSI-191 for Palo Verde Nuclear Generating Station,” August 30, 2005

4.38 Westinghouse Document WCAP-16406-P, Revision 1, “Evaluation of Downstream Sump Debris Effects in Support of GSI-191, August, 2007

4.39 Procedure 40ST-9ZZ09, Revision 19, “Containment Cleanliness Inspection”

4.40 Procedure 30DP-9MP03, Revision 13, “System Cleanliness and Foreign Material Exclusion Controls”

4.41 SDOC N001-1106-00219, Revision 0, “Unit 2 Fiber Walkdown Report,”

4.42 SDOC N001-1106-00227 Revision 4, (68041437), “Chemical Effect Test,”

4.43 SDOC N001-1106-00228 Revision 4, (3SA096079), “Head Loss Calculation Based on Test April 2008”

4.44 SDOC N001-1106-00176, Revision 0, (3SA096043), “Evaluation of the Maximum Allowable Pressure Difference,”

4.45 SDOC N001-1106-00226, Revision 0, Calculation 2007-22843, (200722843), “Evaluation of Palo Verde ECCS Pump Seal Based on WCAP-16406-P,”

4.46 Calculation 13-NC-ZC-0208, Revision 10, “Passive Heat Sinks for Containment P/T Analysis”

4.47 Calculation 13-NC-ZC-0237, Revision 5, “Maximum Passive Heat Sink for Hydrogen Generation & ECCS Evaluation”

4.48 NUREG/CR-6874, “GSI-191: Experimental Studies of Loss-of-Coolant-Accident-Generated Debris Accumulation and Head Loss with Emphasis on the Effects of Calcium Silicate Insulation,” April 2004

4.49 SDOC N001-1106-00030, Revision 0, (68041401), “CCI Test Report 680/41401, Transport, Bypass, and Head Loss Tests”

4.50 Calculation 13-NC-ZC-0238, Revision 5, “System Design LOCA Analysis”

4.51 SDOC N001-1106-00033, Revision 5, (9002291CH), CCI Calculation 3SA-096043, “CCI Fabrication Drawing–Strainer,” Revision F

4.52 SDOC N001-1106-00231 Revision 1, “Post-LOCA Chemical Effects Analysis in Support of GSI-191”

4.53 Westinghouse Calculation WCAP-16785-NP, “Evaluation of Additional Inputs to the WCAP-16530-NP Chemical Model,” Revision 0, May 2007

4.54 Westinghouse Calculation WCAP-16568-P, “Jet Impingement Testing to Determine the Zone of Influence (ZOI) for DBA-Qualified/Acceptable Coatings,” Revision 0

4.55 Procedure 40EP-9EO03, Revision 26, “Loss of Coolant Accident”

4.56 N001-1106-00012, Revision 2, (CNCSA0547), “Palo Verde Sump Debris Downstream Effects Evaluation for ECCS Equipment”

4.57 A0-AN-0449, Revision 4, “Specification for Coating Activities at Palo Verde Nuclear Generating Station”

4.58 Westinghouse Calculation WCAP-16793-NP, “Evaluation of Long-Term Cooling Considering Particulate, Fibrous, and Chemical Debris in the Recirculating Fluid,” May, 2007

4.58.1 OG-07-534, “Transmittal of Additional Guidance for Modeling Post-LOCA Core Deposition with LOCADM Document for WCAP-16793-NP (PA-SEE-0312),” December 14, 2007

4.58.2 OG-08-64, Transmittal of LTR-SEE-I-08-30, “Additional Guidance for LOCADM for Modification to Aluminum Release” for Westinghouse Topical Report WCAP-16793-NP, “Evaluation of Long-Term Cooling Considering Particulate, Fibrous and Chemical Debris in the Recirculating Fluid (PA-SEE-0312),” February 28, 2008

4.59 Drawing 13-C-ZCS-0669 Rev 7, Containment Internals Emergency Recirculation Sump Screen Plans, Sections and Details

4.60 SDOC N001-1106-00223, Revision 1, Calculation 2007-19863, “Post-LOCA Fuel Deposition Analysis in Support of GSI-191”

4.61 SDOC N001-1106-00225, Revision 1, Calculation 2008-00603, “Evaluation of Effects of Debris on the Palo Verde ECCS Pump Seal Cyclone Separators”

4.62 Calculation 13-NC-ZC-0232, Revision 10, “Loss of Coolant Accident Pressure and Temperature Containment Analysis for Limiting Case”

4.63 Specification 13-AN-0448, Revision 1, “Installation Specification for the Control of Transient Material”

4.64 NUREG/CR-3616, "Transport and Screen Blockage Characteristics of Reflective Metallic Insulation Materials"

4.65 NUREG/CR-6772, "GSI-191: Separate-Effects Characterization of Debris Transport in Water"

4.66 NUREG/CR-6224, "Parametric Study of the Potential for BWR ECCS Strainer Blockage Due to LOCA Generated Debris"

4.67 SDOC N001-1106-00176, Revision 0, (3SA096043), Calculation 3SA-096.043, "Evaluation of the Maximum Allowable Pressure Difference," Revision 1

4.68 81DP-0ZZ01, Revision 15, "Civil System, Structure, and Component Monitoring Program"

4.69 EDC 2006-00486 to Specification 13-MN-0169, Revision 9

4.70 WCAP-16530-NP, "Evaluation of Post-Accident Chemical Effects in Containment Sump Fluids to Support GSI-191," Revision 0, dated February 2006, supplemented by the following letters:

4.70.1 Letter WOG-06-102, "Distribution of Errata to WCAP-16530-NP, "Method for Evaluating Post-Accident Chemical Effects in Containment Sump Fluids" (PA-SEE-0275)," dated March 17, 2006.

4.70.2 Letter WOG-06-103, "Distribution of WCAP-16530-NP," Method for Evaluating Post-Accident Chemical Effects in Containment Sump Fluids" (PA-SEE-0275)," dated March 17, 2006.

4.70.3 Letter OG-06-232, "PWR Owners Group Letter Regarding Additional Error Corrections to WCAP-16530-NP (PA-SEE-0275)," dated June 17, 2006

4.70.4 Letter OG-06-255, "PWR Owners Group Letter Releasing Revised Chemical Model Spreadsheet From WCAP-16530-NP (PA-SEE-0275)," dated August 7, 2006

4.70.5 Letter OG-06-273, "PWR Owners Group Method Description of Error Discovered August 16, 2006 in Revised Chemical Model Spreadsheet (PA-SEE-0275)," dated August 28, 2006

4.70.6 Letter OG-06-387, Letter from PWR Owners Group "Responses to the NRC Request for Additional Information (RAI) on WCAP-16530, 'Evaluation of Chemical Effects in Containment Sump Fluids to Support GSI-191,' " November 21, 2006

4.70.7 Letter OG-07-129, Letter from PWR Owners Group "Responses to the NRC Second Set of Requests for Additional Information (RAI's) on WCAP-16530, 'Evaluation of Chemical Effects in Containment Sump Fluids to Support GSI-191,' " April 3, 2007

4.70.8 Letter OG-07-408, Letter from PWR Owners Group "Responses to the NRC Requests for Clarification Regarding WCAP-16530, 'Evaluation of Chemical Effects in Containment Sump Fluids to Support GSI-191' (PA-SEE-0275)," September 12, 2007

4.71 NUREG/CR-6808, "Knowledge Base for the Effect of Debris on Pressurized Water Reactor Emergency Core Cooling Sump Performance"

4.72 NUREG/CR-6773, "GSI-191: Integrated Debris-Transport Tests in Water Using Simulated Containment Floor Geometries"

4.73 Continuum Dynamics, Inc. (C.D.I.) Report No. 96-06, Revision A, "Air Jet Impact Testing of Fibrous and Reflective Metallic Insulation." (Included in Volume 3 of BWR URG, NEDO-32686-A, Ref. 4.76)

4.74 Continuum Dynamics, Inc. (C.D.I.) Report No. 95-09, Revision 4, "Testing of Alternate Strainers with Insulation Fiber and Other Debris." (Included in Volume 2 of BWR URG, NEDO-32686-A, Ref. 4.76)

4.75 NUREG/CR-2982, "Buoyancy, Transport, and Head Loss of Fibrous Reactor Insulation"

4.76 GE Document NEDO-32686-A, DRF A74-00004, Class I, Volume 1, "Utility Resolution Guide for ECCS Suction Strainer Blockage," dated October 1998

4.77 N001-1106-00011, Revision 2, "Palo Verde Units 1, 2, 3, GSI-191 Downstream Effects Debris Ingestion"

4.78 30DP-0WM12, Revision 18, Housekeeping

4.79 81DP-0AP05, Revision 0, Containment Coatings Condition Assessment

4.80 N001-1106-00224 Revision 0, Minimum Containment Air Pressure Prior to a Loss of Coolant Accident

4.81 N001-1106-00229 Revision 2, (Q00384810), Chemical Effect Head Loss Test Specification

4.82 N001-1106-00230 Revision 0, (68041434), Vortexing Test Report for Clean Strainers

4.83 N001-1106-00232 Revision 0, (LTRSEEI08136) Transmittal of Summary GSI-191 Fuel Evaluation for Palo Verde Units 1, 2, and 3

4.84 E. Fried, I.E. Idelchik, Flow Resistance , a Design Guide for Engineers, 1989, Hemisphere Publishing Corporation

4.85 NUREG/CR-6914, Vol. 2, Integrated Chemical Effects Test, Test #1 Data Report, December 2006

4.86 Letter from William H Ruland of the NRC to Anthony R. Pietrangelo of the NEI, dated March 28, 2008, "Revised Guidance 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,'" (ADAMS Accession No ML080230112).

4.87 Final Safety Evaluation By the Office of Nuclear Reactor Regulation Topical Report WCAP-16530-NP, "Evaluation of Post-Accident Chemical Effects in Containment Sump Fluids to Support GSI-191" Pressurized Water Reactor Owners Group Project No. 694, December 21, 2007

4.88 WCAP-16530-NP-A, "Evaluation of Post-Accident Chemical Effects in Containment Sump Fluids to Support GSI-191," March 2008. (NRC approved version of Ref. 4.70 which includes Ref. 4.87).

4.89 NUREG/CR-6914, Vol. 3, Integrated Chemical Effects Test, Test #2 Data Report.

4.90 Arizona Public Service Company Letter 102-05336, dated September 1, 2005, Response to Request No. 2 in NRC Generic Letter 2004-02, "Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized-Water Reactors" (ADAMS Accession No. ML052500306).

4.91 Arizona Public Service Company Letter 102-05819, dated February 29, 2008, Supplemental Response to NRC Generic Letter 2004-02, "Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized-Water Reactors" (ADAMS Accession No. ML080710546).

4.92 NRC Letter dated May 9, 2008, Palo Verde Nuclear Generating Station, Unit 2 - Issuance Of Exigent Amendment Re: Revised Minimum Water Level For Technical Specification 3.5.5, Refueling Water Tank (ADAMS Accession No. ML081270305).

4.93 Arizona Public Service Company Letter 102-05923, dated November 13, 2008, Request for Amendments to Technical Specification (TS) 3.5.5, Refueling Water Tank (RWT), to Increase the RWT Minimum Water Level for Units 1 and 3 and Incorporate Editorial Changes for Units 1, 2, and 3 (ADAMS Accession No. ML083370161).

4.94 Arizona Public Service Company Letter No. 102-05560, dated August 30, 2006, Revision to Commitment Date Associated with NRC Generic Letter 2004-02, "Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized-Water Reactors" (ADAMS Accession No. ML052500489)

4.95 NEI 02-01, "Walkdowns"

4.96 Manual of Steel Construction, 9th edition, July 1989

4.97 NUREG/CR-6916, “Hydraulic Transport of Coating Debris,” December 2006

4.98 Westinghouse Document LTR-CDME-08-58, “Evaluation of Sodium Silicate Solution Procured by CCI for Use in the Preparation of Chemical Surrogates for Salem Units 1 and 2,” Rev. 0, dated 12-March-2008

4.99 NRC Staff Memorandum, “Foreign Travel Trip Report – NRC Staff Visit to Winterthur, Switzerland, to Observe Sump Strainer Testing Performed by Control Components, Incorporated – Detailed Technical Description”, (ADAMS Accession No. ML081640193), dated July 16, 2008

4.100 PVAR 3292078 (ENG 3293757) – Qualitative Evaluation for Not Performing Head Loss Testing for Microporous Insulation for the CEA Ejection Break S5

4.101 SDOC N001-1106-00168, Revision 1, (938200002), CCI Dwg. 938200002-CCI Fabrication Drawing Standard Cartridge 9 Pocket

4.102 http://www.jetpul.com, website for The Jet Pulverizer Company

4.103 N001-1106-00042, Revision 1, (68041254), “Acceptance Criteria for Holes Sizes and Gaps”

4.104 Procedure 81DP-0EE10 Revision 17, Design Change Process

4.105 Procedure 81DP-0AP02, Revision 2, PVNGS Coatings Program

4.106 Specification A0-AN-0449, Coating Activities

4.107 Calculation 13-MC-ZC-0801, Revision 2, “Containment Free Volume for Flood Level Determination”

4.108 DMWO 2513158 Reactor Head Insulation Modification, dated 05/07/2002

4.109 PVAR 3292081 (ENG 3293759) – Comparison of Nukon Cloth and Alfa Cloth used for Removal Insulation

4.110 13-AN-0448, Revision 1, Installation Specification for the Control of transient Material

4.111 Procedure 14DP-0FP33, Control of Transient Combustible

4.112 SDOC N001-1106-00244, Revision 0, (LTR-SEE-IV-09-17), “Westinghouse Response to Palo Verde Generic Letter 2004-02 Response Comments”

5. APPENDICES

Appendix A - Index of RAI Responses

Appendix B - Evaluation of “Straw Effect” at ECCS Sump

APPENDIX A
INDEX OF RAI RESPONSES

Appendix A identifies the location of information provided in the enclosure that addresses the issues identified in the NRC letter to APS, dated February 9, 2006, "Request for Additional Information Re: Response to Generic Letter 2004-02, Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized-Water Reactors" (ADAMS Accession No. ML060390350).

GL Response	Subsections	RAI Questions
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2. General Description of and Schedule for Corrective Actions		
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	m. Downstream Effects – Components and Systems	14, 35
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	o. Chemical Effects	5, 7, 8, 10, 11, 12, 14
	p. Licensing Basis	

RAI Questions 2, 3, 4, and 6

The ICET tests are not specifically used by PVNGS for the analyses to evaluate the chemical effects to validate sump strainer sizing. Description of the debris types and debris quantities generated is provided in the response to Section 3.b and the description of the chemical effects evaluations are provided in the response to Section 3.o.

RAI Question 9

PVNGS uses TSP to buffer the containment sump pool pH following a LOCA. There are no plans to change to a different chemical as the buffering agent.

APPENDIX B
EVALUATION OF "STRAW EFFECT" AT ECCS SUMP

Background

Discussions at the CCI User's Group meeting held June 28 and 29, 2007, included discussion of an effect of potential air drawn into the suction pipe from pipes that are submerged in the sump pit on one end and are open to the containment air environment on the other end. If the pressure required to drain the water in such a line is less than the differential pressure across the sump strainer, then air will be ingested in the suction pipe via the partially submerged pipe. This issue needed to be reviewed for applicability to PVNGS.

Evaluation

Based on review of the PVNGS ECCS sump configuration, there are: (a) two pipes-14-inch LTOP sparger lines, (b) two valve stem extension pipes-sump containment isolation valve stem extension protector pipes, and (c) one conduit (with one end submerged in the sump pit and the other end above the minimum containment flood level) – 3/4-inch conduit for the sump temperature element.

(a) The 14-inch low temperature over-pressure (LTOP) relief sparger line is open to the sump pit via holes in the wall of the pipe to distribute the force of the discharge fluid. This line is closed above the flood water level as this line is the discharge line from the SDC relief valve [Appendix B, Refs. 1, 2, 3, 4, 5, 6, and 7]. This sparger line has been further evaluated for air entrainment [Appendix B, Ref. 16] and determined that the potential effect of air entrainment on required pump NPSH is negligible.

(b) The valve stem extension cover is open at the bottom in the sump pit. This pipe is bolted to the valve body bracket. At the top, this pipe is bolted to the valve actuator. The actuator gear box compartment is a bolted enclosure that is well sealed with gaskets and o-rings. Since the top of the stem extension cover is enclosed and sealed using gaskets and o-rings, the draw down concern is not applicable [Appendix B, Refs. 8, 9, 10, 11, and 15].

(c) The 3/4-inch conduit for the sump pit temperature element (TE) is routed through the strainer sub-floor. The TEs use a conduit seal below the containment flood level that is qualified for the ECCS sump environment. The TEs are procured and installed as Q Class instruments and qualified for the sump environment. Therefore, the conduit does not need to be considered as a potential air entrainment source [Appendix B, Refs. 12, 13, and 14].

Conclusion

The review of the pipes and conduit that penetrate the strainer sub-floor has determined these components to be adequately closed or sealed, and any potential air ingestion via these pipes and conduit has negligible impact on required pump NPSH.

References

1. 01-M-SIP-0002 Rev 33, P & I Diagram Safety Injection and Shutdown Cooling System
2. 02-M-SIP-0002 Rev 28, P & I Diagram Safety Injection and Shutdown Cooling System
3. 03-M-SIP-0002 Rev 31, P & I Diagram Safety Injection and Shutdown Cooling System
4. 01-P-SIF-0151 Rev 2, Ctmt Bldg Iso Sfty Inj Sys Shtdwn Clg Overpress Relief
5. 02-P-SIF-0151 Rev 1, Ctmt Bldg Iso Sfty Inj Sys Shtdwn Clg Overpress Relief
6. 03-P-SIF-0151 Rev 1, Ctmt Bldg Iso Sfty Inj Sys Shtdwn Clg Overpress Relief
7. N001-1106-00033 Rev 5, CCI Fabrication Drawing-Strainer
8. N001-1104-00282 Rev 10, 24" Class 150 Wafer Valve Assy SI-673,675 V-CE-16690 30JN82
9. N001-1104-00274 Rev 8, 24" Class 150 Wafer Vlv Assy SI-UV-673 & 675
10. N001-1104-00275 Rev. 8, 24" Class 150 Wafer Vlv Assy SI-UV-673,675
11. 13-P-ZCG-112 Rev 15, Containment Building Misc Embedded Pipe Details Below EL. 80'-0"
12. 13-E-ZCC-0074 Rev 25, Containment and MSSS Bldg. Post LOCA Devices Conduit Seal Requirement.
13. 13-Q-ZZP-0017 Rev. 0, EQ Configuration Drawing Weed RTDs and Thermocouples
14. J556-00086 Rev. 3, General Purpose Head / Hex Nipple / Sensor / Mounting Bracket
15. VTD-L200-00006 Rev 3, Instruction and Maintenance Manual for Limitorque Type HBC (PUB. #HBCI-90)
16. PVAR 3269697 (ENG 3270085) – Air Entrainment from containment Sump PSV Sparger

ENCLOSURE 2

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

The NRC issued a letter dated December 16, 2008, titled: "Palo Verde Nuclear Generating Station, Units 1, 2, and 3 Request for Additional Information Re: Generic Letter 2004-02, "Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized Water Reactors," (Agencywide Documents Access and Management System (ADAMS) Accession No. ML083430549). That letter requested additional information to supplemental the Arizona Public Service Company (APS) submitted supplemental response to Generic Letter (GL) 2004-02 for Palo Verde Nuclear Generating Station, Units 1, 2, and 3, dated February 29, 2008 (ADAMS Accession No. ML080710546). The following provides the additional requested information or provides the location of that information within Enclosure 1.

1 NRC Request - Describe in detail the basis for the assumed zone of influence (ZOI) of 17.0 D (break diameter) for Thermo-lag. If all the Thermo-lag in a steam generator (SG) compartment or the pressurizer compartment were within the ZOI, how much would the debris totals increase?

APS Response - Thermo-Lag is no longer considered subject to a 17.0D ZOI; rather, it is now considered debris if located within 28.6D of a given break [Enclosure 2, Ref. 1]. No ZOI for Thermo-Lag is provided in any of the guidance documents; therefore the maximum ZOI of 28.6D that is recommended for any insulation type by either NEI 04-07 or the associated NRC SER [Enclosure 2, Refs. 2 and 3] is used in the debris generation calculation [Enclosure 2, Ref. 1].

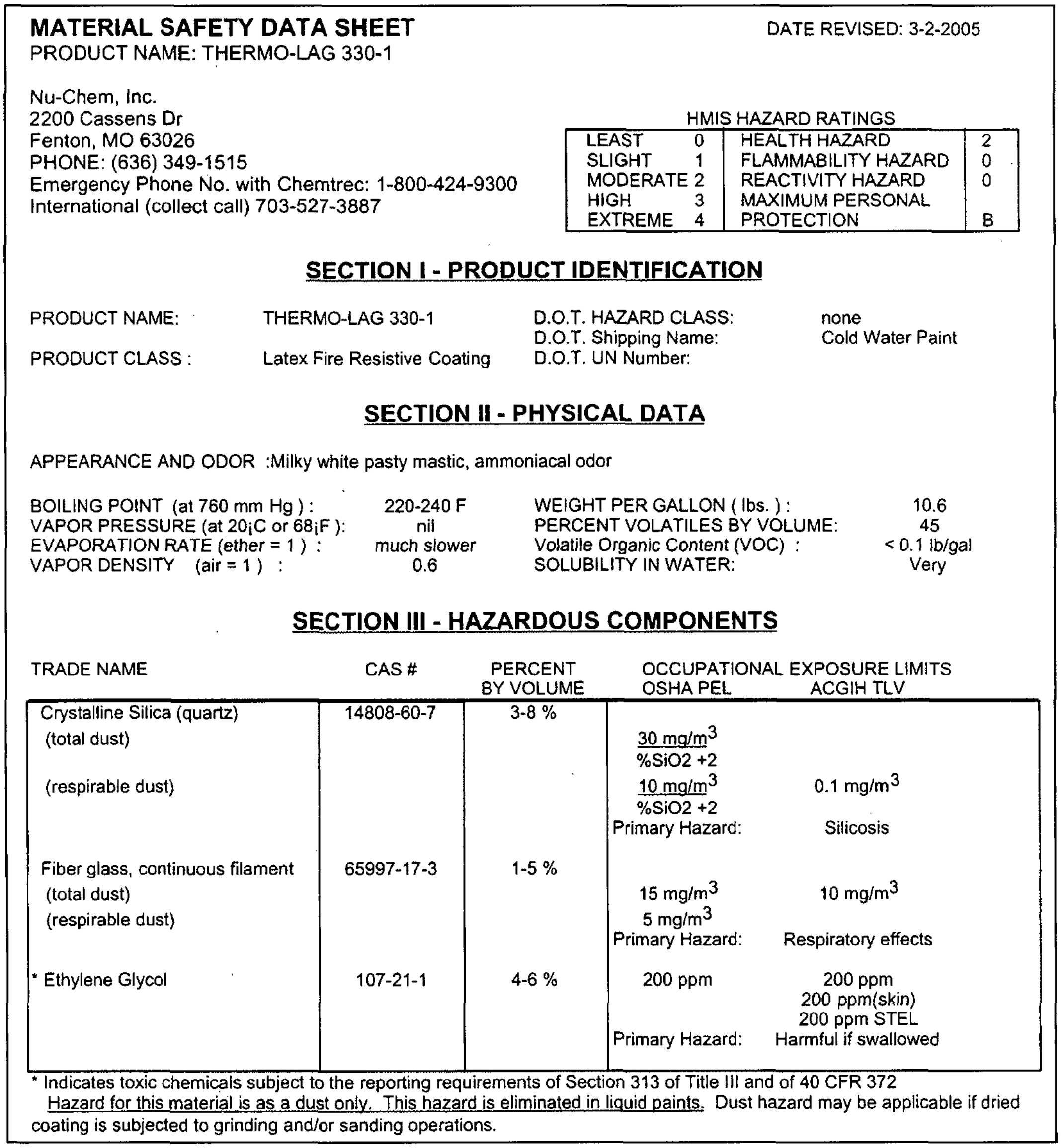
If all the Thermo-lag in a SG compartment or the pressurizer compartment were utilized in the calculation of Thermo-Lag debris, the maximum amount of Thermo-Lag generated would not increase as the total volume of Thermo-Lag is contained within the 28.6D ZOI.

2 NRC Request - Provide a complete listing of the constituent materials that make up Thermo-lag 330, as well as the bulk and material densities of Thermo-lag 330 in its installed condition. In addition, please justify the similarity of any surrogate materials used to represent Thermo-Lag 330 for head-loss testing with the properties of the actual material. Please provide a justification that any surrogate materials used would provide a prototypical or conservative head loss during testing.

APS Response - Hazardous components of the trowelable mastic used to make Thermo-Lag 330 panels are listed in the product MSDS (page 1 of MSDS included as Figure 1 to this enclosure). Additional information regarding the composition of Thermo-Lag 330 is provided in Table 3.2-1 of WCAP-16530-NP [Enclosure 2, Ref. 4], which lists silicon dioxide, E-glass and epoxides as the main constituents. The density of Thermo-Lag 330 panels is approximately

73.8 lbs/ft^3; the density of trowelable wet mastic is listed as 10.6 lbs/gal by the MSDS (Figure 1).

Figure 1: Page 1 of Thermo-Lag 330-1 MSDS



MATERIAL SAFETY DATA SHEET DATE REVISED: 3-2-2005
PRODUCT NAME: THERMO-LAG 330-1

Nu-Chem, Inc.
2200 Cassens Dr
Fenton, MO 63026
PHONE: (636) 349-1515
Emergency Phone No. with Chemtrec: 1-800-424-9300
International (collect call) 703-527-3887

HMIS HAZARD RATINGS

LEAST	0	HEALTH HAZARD	2
SLIGHT	1	FLAMMABILITY HAZARD	0
MODERATE	2	REACTIVITY HAZARD	0
HIGH	3	MAXIMUM PERSONAL PROTECTION	B
EXTREME	4		

SECTION I - PRODUCT IDENTIFICATION

PRODUCT NAME:	THERMO-LAG 330-1	D.O.T. HAZARD CLASS:	none
		D.O.T. Shipping Name:	Cold Water Paint
PRODUCT CLASS :	Latex Fire Resistive Coating	D.O.T. UN Number:	

SECTION II - PHYSICAL DATA

APPEARANCE AND ODOR :Milky white pasty mastic, ammoniacal odor

BOILING POINT (at 760 mm Hg) :	220-240 F	WEIGHT PER GALLON (lbs.) :	10.6
VAPOR PRESSURE (at 20¡C or 68¡F):	nil	PERCENT VOLATILES BY VOLUME:	45
EVAPORATION RATE (ether = 1) :	*much slower*	Volatile Organic Content (VOC) :	< 0.1 lb/gal
VAPOR DENSITY (air = 1) :	0.6	SOLUBILITY IN WATER:	Very

SECTION III - HAZARDOUS COMPONENTS

TRADE NAME	CAS #	PERCENT BY VOLUME	OCCUPATIONAL EXPOSURE LIMITS OSHA PEL	ACGIH TLV
Crystalline Silica (quartz)	14808-60-7	3-8 %		
(total dust)			$\frac{30\ mg/m^3}{\%SiO_2 + 2}$	
(respirable dust)			$\frac{10\ mg/m^3}{\%SiO_2 + 2}$	0.1 mg/m^3
			Primary Hazard:	Silicosis
Fiber glass, continuous filament	65997-17-3	1-5 %		
(total dust)			15 mg/m^3	10 mg/m^3
(respirable dust)			5 mg/m^3	
			Primary Hazard:	Respiratory effects
* Ethylene Glycol	107-21-1	4-6 %	200 ppm	200 ppm 200 ppm(skin) 200 ppm STEL
			Primary Hazard:	Harmful if swallowed

* Indicates toxic chemicals subject to the reporting requirements of Section 313 of Title III and of 40 CFR 372
Hazard for this material is as a dust only. This hazard is eliminated in liquid paints. Dust hazard may be applicable if dried coating is subjected to grinding and/or sanding operations.

Palo Verde supplied the same Thermo-Lag material that is installed in the plant to CCI for use in the plant specific head loss testing. Therefore, no surrogate material was used for head loss testing [Enclosure 2, Ref. 5].

3 NRC Request -The staff is uncertain that the 10-inch diameter refueling cavity drains would not be blocked during a loss-of-coolant accident (LOCA). Please justify that pieces of insulation or debris foreign material would not be ejected up and into the refueling canal, partially or completely block the drains, and create a hold-up volume affecting containment sump level. The response should address the potential for certain types of debris to float temporarily following a LOCA, transport toward the canal drain due to surface currents, and later sink on top of

the canal drain. Also, please also identify the minimum flow restriction in the cavity drain line flowpaths.

APS Response – The discussion on the potential blockage of the 10-inch refueling cavity drains is provided in Section 3.I.5 of Enclosure 1. As stated in that section this scenario is not credible.

4. NRC Request - Considering that the PVNGS units have relatively low amounts of fibrous insulation, please describe how your containment cleanliness and foreign material exclusion programs assure that latent debris in containment will be controlled and monitored to be maintained below the amounts and characterization assumed in the emergency core cooling system (ECCS) strainer design. In particular, what is planned for areas/components that are normally inaccessible or not normally cleaned (containment crane rails, cable trays, main steam/feedwater piping, tops of SGs, etc.)?

APS Response - The discussion on containment cleanliness is provided in Section 3.i.2 of Enclosure 1.

5 NRC Request - Identify and describe any programmatic procedures for the control of tags and labels inside containment.

APS Response – Labeling at PVNGS is controlled by procedure 40DP-0OP08 "Plant Labeling." The procedure includes the placement and removal of labels in the containment building. Past practices for labeling inside Containment included the use of metal and resin/plastic labels. In the resolution of issues related to GL-2004-02, transport testing was performed for resin/plastic labels. The labels were found not to transport onto the strainer surface. However, the use of new resin/plastic labels in containment was discontinued. Beginning in the fall of 2007 refueling outage (3R13), only stainless steel labels were used for new label installation. In addition many of the existing resin/plastic labels have been replaced with metal. The PVNGS intent is to replace as many Containment resin/plastic labels with stainless steel labels during future refueling outages as practical.

The plant labeling procedure is being updated to reflect the practice of only using stainless steel labels for equipment in Containment.

PVNGS continues to use plastic/paper tags for work permits in Containment. The majority of the plastic/paper work permits are used during plant outages. A majority of the work permit tags in Containment are removed prior to the containment cleanliness inspection that is performed as a priority to entering Mode 4.

Procedure 40OP-9ZZ11, "Mode Change Checklist, Appendix C," requires that prior to Mode 4 entry, the permit tags that are to remain in the Containment are either specifically evaluated by engineering or are logged and the quantity bounded in an approved engineering evaluation.

6 NRC Request - Provide verification that the fibrous size distribution used during testing was prototypical or conservative compared to the size distribution predicted by the transport evaluation.

APS Response – The fiber size distribution utilized in the transport analysis is given in Section 3.c.1 of Enclosure 1.

The fiber size distribution utilized during testing is given in the sub-section titled "Non-Chemical Debris Preparation and Surrogates" in Section 3.f.4.d of Enclosure 1. This section verifies that the tested fibrous size distribution is either prototypical or conservative.

7 NRC Request - Provide details of the debris addition procedures used. Please include a description of fibrous concentration during debris addition, the debris addition location, and the method of adding fibrous debris to the test tank. Please provide verification that the debris introduction processes did not result in non-prototypical settling, agglomeration, or deposition of debris.

APS Response – The details of the debris addition procedure used during testing are given in the sub-sections entitled "Debris Addition" and "Test Performance – Complete Test Procedure" in Section 3.f.4.d of Enclosure 1.

8 NRC Request - Provide the amount of various debris types added during each test, or list each surrogate and verify that the amounts added to the test were scaled properly. Please provide scaling values used for testing.

APS Response – The quantity of debris used during testing is given in the sub-section entitled "Non-Chemical Debris Load Quantity" in Section 3.f.4.d of Enclosure 1. Surrogates used are described in the sub-section entitled "Non-Chemical Debris Preparation and Surrogates."

Test scaling is described in Section 3.o.2.s of Enclosure 1.

9 NRC Request - Provide the flume flow values used during testing or verify that the flows were scaled properly based on plant design flow rates. Please provide the flow rate through the strainer during the boron precipitation/hot leg injection mode of operation (if applicable).

APS Response – The strainer design specification utilized a design flow rate of 11,600 gpm. The flow rate is the maximum possible flow based on the containment spray (CS) pump at 5,200 gpm, the low pressure safety injection (LPSI) pump at 5,000 gpm, and the high pressure injection (HPSI) pump at 1,400 gpm, all running together during the recirculation mode. The strainer testing flow rate (scaled to the size of the test loop) bounds all design conditions, including simultaneous boron precipitation/hot leg injection mode of the HPSI pump at 1,200 gpm with the CS pump at 5,200 gpm, or 6,400 gpm total flows. See discussion in Sections 3.f.4.d and 3.o.2.s of Enclosure 1 for flume flow rates and scaling verification.

10 NRC Request - If agitation was utilized to prevent debris settling, please verify that the debris bed was not non-conservatively disturbed by the agitation and that non-prototypical transport did not result.

APS Response – Debris agitation methods used during testing are described in the sub-sections entitled "Debris Agitation" and "Test Performance – Complete Test Procedure" in Section 3.f.4.d of Enclosure 1.

11 NRC Request - Provide an overview of the test procedures used during testing for all thin-bed, chemical effects and full-fiber load tests.

APS Response – An overview of the test procedures used during head loss testing is provided in Section 3.f.4 of Enclosure 1.

12 NRC Request - Provide any extrapolation or scaling performed on the test data to account for flow rates or temperatures different from those present during testing. If temperature scaling was used, please discuss consideration made for bore holes or channeling that may have occurred during testing or how it was verified that these phenomena did not occur (e.g., conducting flow sweeps).

APS Response – Flow rate and temperature/viscosity scaling of the strainer head loss are discussed in Sections 3.f.10 and 3.f.13 of Enclosure 1.

Verification that bore holes did not form in the debris bed is provided in Section 3.f.4.e of Enclosure 1. This section also documents that open area was observed during both head loss tests.

13 NRC Request - Provide the test termination criteria and the methodology by which the final head-loss values were extrapolated to the ECCS mission time or some predicted steady state value. Please include enough test data so that the extrapolation results can be verified by the staff.

APS Response – The test termination criteria used during testing are given in the sub-section entitled "Stability Criteria / Test Termination Criteria" in Section 3.f.4.d of Enclosure 1.

Extrapolation of test data was neither required nor performed as documented in Sections 3.f.4.d and 3.f.10 of Enclosure 1.

The complete pressure trace for the head loss tests is provided in Section 3.o.2.q of Enclosure 1. In addition, a magnified view of the flow sweep data is provided in Section 3.f.10.

14 NRC Request - Provide the methodology used for calculation of clean strainer head loss (CSHL).

APS Response – The methodology used for the calculation of the clean strainer head loss is presented in Section 3.f.9 of Enclosure 1.

15 NRC Request - Provide the calculated CSHL value.

APS Response – The clean strainer head loss value is presented in Section 3.f.9 of Enclosure 1.

16 NRC Request - Provide the chemical effects information requested by the NRC content guide for chemical effects as provided in Enclosure 3 of a letter from the NRC to Nuclear Energy Institute (NEI) dated March 28, 2008 (ADAMS Accession No. ML080380214). The head-loss review requires (at least) a graph of head loss over time, test termination criteria, and any extrapolation that was performed using the test data.

APS Response – The requested information is provided in Section 3.o of Enclosure 1.

17 NRC Request - Provide the calculated void fraction downstream of the strainer.

APS Response – The void fraction due to vortexing, flashing, and deaeration is zero at the ECCS and CS pump inlets as documented in Sections 3.f.3 and 3.f.14 of Enclosure 1.

18 NRC Request - Provide an evaluation of the potential for flashing within the debris bed or internal to the strainer based on the head-loss values obtained during final head-loss testing. In this evaluation, please consider containment sump pool levels and the possible range of flow rates through the strainer.

APS Response – The flashing analysis is described in detail in Section 3.f.14 of Enclosure 1.

19 NRC Request - Considering that Tests 2 and 3 were run identically, please provide an evaluation of the differences in test results. [The licensee pointed out that the two tests were performed with identical conditions but resulted in markedly different behavior. One test seemed to be affected by boreholes, similar to what was observed at Control Components, Incorporated (CCI) testing for Salem Nuclear Generating Station. The other test was stated to have formed a thin bed more gradually and resulted in an eventual head loss that was over twice as great.]

APS Response – The differences between Tests 2 and 3 are assessed and explained in Section 3.f.4.e of Enclosure 1.

20 NRC Request - Provide information that establishes that the strainer is fully submerged during all accident conditions including small-break LOCAs (SBLOCAs). Otherwise, provide evaluations for head loss and air entrainment considering that the strainer is not fully submerged. Please note that strainer failure criteria from NRC Regulatory Guide 1.82, Revision 3, "Water Sources for Long-Term Recirculation Cooling Following a Loss-of-Coolant Accident," may be more restrictive than existing PVNGS net positive suction head (NPSH) margin calculation procedures.

APS Response – The Containment water level calculation 13-MC-SI-0804 provides the analyses of the post-LOCA containment water level. The calculation evaluates large break as well as small break LOCAs. The results of the analyses determine that the minimum water level for the limiting case which is a small break LOCA at the top of the pressurizer is 84'-6". This provides water coverage of approximately 2.1 inches above the top of the strainer modules; thus the strainers are fully submerged during all accident conditions.

21 NRC Request - The supplemental response discussed a "straw effect" at the containment sump considering a 14-inch low temperature over-pressure (LTOP) sparger line that enters the sump pit. This line is a shutdown cooling relief valve discharge line. This line is not open to the containment atmosphere above the minimum water level. The NRC staff questioned whether air could enter the sump from this line through the following process: rapidly following a LOCA, air

and steam would pressurize the sparger line up to the first closed valve up to a value near the peak containment pressure. Soon afterward, water would flood the containment and cover the holes on the sparger line. Later, as the containment is gradually depressurized, the pressurized gases in the LTOP line could depress the column of water in the LTOP sparger line and potentially escape into the sump. Please discuss whether the pressurized gases in the LTOP line are forced out of the sparger holes and into the sump, and whether the resultant potential effect of air ingestion by ECCS and Containment Spray System pumps has been evaluated.

APS Response – The effects of accumulated and pressurized gas (air and steam) in the LTOP discharge sparger line have been evaluated [Enclosure 2, Ref. 6]. The evaluation assumes that the maximum volume of gas confined above the top ring of sparger holes is initially pressurized at maximum post-LOCA containment pressure. Subsequent depressurization of containment following transfer of the emergency core cooling system (ECCS) and the containment spray system (CSS) pump suctions to the containment sump causes expansion of the gases and eventual bubble formation. The rate of bubble formation at the sparger is proportional to the rate of depressurization of the containment building. The resultant rate of bubble formation has been demonstrated to be small, and entrainment of all of the gas into the ECCS and CSS pump suction conservatively results in a maximum void fraction well below the established threshold for pump operation [Enclosure 2, Ref. 6]. As a result, the potential air and steam initially trapped will have no adverse impact on ECCS or CSS pump operation.

22 NRC Request - Provide a description of any changes made to the NPSH calculation and minimum NPSH margins as a result of completion of strainer head-loss testing.

APS Response –The NPSH calculations were updated to account for the sump water viscosity due to post-LOCA chemical effects. The head loss margins in the ECCS and CSS pump NPSH calculations for the configuration prior to the strainer replacement bound the NPSH available following implementation of the strainer replacement modification with consideration of the chemical effects.

23 NRC Request - Provide the information requested under item (m) in the Revised Content Guide for Generic Letter 2004-02 Supplemental Response dated November 21, 2007 (ADAMS Package Accession No. ML07311 0389).

APS Response – The responses are provided in Section 3.m of Enclosure 1.

24 NRC Request - The NRC staff considers in-vessel downstream effects to not be fully addressed at PVNGS as well as at other pressurized-water reactors. The supplemental response refers to draft WCAP-16793-NP, "Evaluation of Long-Term Cooling Considering Particulate, Fibrous, and Chemical Debris in the Recirculating Fluid." The NRC staff has not issued a final safety evaluation (SE) for WCAP-16793-NP. The licensee may demonstrate that in-vessel downstream effects issues are resolved for PVNGS by showing that the PVNGS plant conditions are bounded by the final WCAP-16793-NP and the corresponding final

NRC staff SE, and by addressing the conditions and limitations in the final SE. The licensee may alternatively resolve this issue by demonstrating without reference to WCAP-16793-NP or the staff SE that in-vessel downstream effects have been addressed at PVNGS. In any event, the licensee should report how it has addressed the in-vessel downstream effects issue within 90 days of issuance of the final NRC staff SE on WCAP-16793-NP. The NRC staff is developing a Regulatory Issue Summary to inform the industry of the staff's expectations and plans regarding resolution of this remaining aspect of Generic Safety Issue (GSI)-191.

APS Response – APS, in accordance with the NRC staff's expectations when issued, will provide information on how it has addressed the in-vessel downstream effects issue.

Response References

1. PVNGS Calculation 2005-06160, "Debris Generation Due to LOCA Within Containment for Resolution of GSI-191," Revision 3, 9/29/2008.
2. Nuclear Energy Institute (NEI) document NEI 04-07 Rev. 0, December 2004, "Pressurized Water Reactor Sump Performance Evaluation Methodology"
3. Safety Evaluation by the Office of Nuclear Reactor Regulation Related to NRC Generic Letter 2004-02, Nuclear Energy Institute Guidance Report (Proposed Document Number NEI 04-07), "Pressurized Water Reactor Sump Performance Evaluation Methodology," Issued 12/06/2004.
4. WCAP-16530-NP, "Evaluation of Post-Accident Chemical Effects in Containment Sump Fluids to Support GSI-191," Revision A, March 2008.
5. CCI Report No. Q.003.84 810, "Chemical Effect Head Loss Test Specification," Revision 2, 4/22/08.
6. PVAR 3269697 (ENG 3270085) – Air Entrainment from containment Sump PSV Sparger.