North Anna Power Station Corrective Actions for Generic Letter 2004-02

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Acronym List

AECL	Atomic Energy of Canada, Limited
ASME	American Society of Mechanical Engineers
CFD	computational fluid dynamics
DFT	dry film thickness
ECCS	emergency core cooling system
FEA	Finite Element Analysis
GL	generic letter
GR	Guidance Report
GSI	Generic Safety Issue
HHSI	high head safety injection
IRS	inside recirculation spray
LHSI	low head safety injection
LOCA	loss-of-coolant accident
NEI	Nuclear Energy Institute
NAPS	North Anna Power Station
NPSH	net positive suction head
NPSHa	net positive suction head available
NPSHr	net positive suction head required
NRC	Nuclear Regulatory Commission
OBE	operating basis earthquake
ORS	outside recirculation spray
PWR	pressurized water reactor
RMI	reflective metallic insulation
RMT	recirculation mode transfer
RWST	refueling water storage tank
RS	recirculation spray
SE	Safety Evaluation
SSE	safe shutdown earthquake
ZOI	zone of influence

1.0 BACKGROUND

1.1 Introduction

The U.S. Nuclear Regulatory Commission (NRC) is auditing, on a sample basis (related to reactor type, containment type, strainer vendor, NRC regional office, and sump replacement analytical contractor), licensee corrective actions for Generic Letter (GL) 2004-02, "Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized-Water Reactors," dated September 13, 2004 [1], for approximately ten commercial pressurized water reactors (PWRs). The purpose of the audits is to verify that the implementation of Generic Safety Issue (GSI) 191, "Assessment of Debris Accumulation on PWR Sump Performance [2]" sump strainer and related modifications bring those reactor plants into full compliance with 10 CFR 50.46, "Acceptance Criteria for Emergency Core Cooling Systems for Light-water Nuclear Power Reactors," and related requirements, and to draw conclusions as to the probable overall effectiveness of GL 2004-02 corrective actions for the 69 U.S. operating PWRs.

In response to NRC GL 2004-02 [1], PWR licensees are designing and implementing new strainers in their plants in order to resolve the GSI 191 [2] sump performance issue by December 31, 2007. The North Anna Power Station (NAPS), which is operated by Dominion, proceeded to contract for design and installation of new strainers. New Atomic Energy of Canada, Limited (AECL) replacement "Finned Strainers™," with effective surface areas of 4415 ft^2 for the recirculation spray (RS) strainers and 1890 ft^2 for the low head safety injection (LHSI) strainers, have been installed in Unit 2 and are scheduled for installation in the Fall 2007 refueling outage for Unit 1. Unit 2 was selected for a focus for the audit because the strainers for that unit were installed during the Spring 2007 refueling outage.

The audit is intended to yield benefits to both the NRC and industry. For the NRC these include:

> The audit will help NRC staff determine the adequacy of the new strainer design and the contractor resources needed for future reviews, audits, and/or inspections.
>
> The NRC staff can identify generic GSI-191 issues that need to be further addressed and clarified through future interactions with strainer vendors, other licensees, and the PWR Owners Group.

Benefits envisioned for the licensee and industry include:

> Feedback from the audit will assist Dominion in resolving the GSI-191 PWR sump issue.
>
> Lessons learned from the audit will help the industry identify, focus on and prioritize the issues impacting resolution of GSI-191.

The audit commenced on July 9, 2007 when Dominion presented an overview of the GSI-191 Project to the staff audit team. Following review of the presentation materials [28] and other documents provided during the overview session, the audit continued with detailed interactions with the licensee and its contractor/vendor staff at the Innsbrook Technical Center on July 16, 2007. Two members of the NRC staff traveled to NAPS on July 18, 2007. The staff audit team and management exited with licensee personnel on July 20, 2007. Table 1 lists key

NRC staff and consultants, licensee staff and contractors, and identifies attendance during audit meetings.

Table 1 NAPS Audit Meetings

Name	Organization	Title/ Area	Project Over-view 7/9/2007	Audit Onsite Entrance 7/16/2007	Audit Onsite Exit 7/20/2007
John Lehning	NRC/SSIB	Debris Transport/ Source term/CFD Generic Comms	x	x	x
Paul Klein	NRC/DCI	Chemical Effects	participated via telephone conferences		
Ralph Architzel	NRC/SSIB	Team Leader	x	x	x
Roberto Torres	NRC/SSIB	Downstream Components	x	x	x
Steven Unikewicz	NRC/SSIB	Downstream Components	x		
Steve Smith	NRC/SSIB	Debris Characteristics/ Upstream/Screen Mod Package	x	x	x
Shanlai Lu	NRC/SSIB	Strainer Headloss/Testing	x	x	x
John Burke	NRC/DCI	Coatings	x	x	
Clint Shaffer	NRC - ARES Corp	Baseline/Break Selection/ZOI	x	x	x
Ted Ginsberg	NRC-BNL	NPSH/Latent Debris	x	x	x
Walt Jensen	NRC/DSS	Fuel/Vessel - In Office Review	x		
Richard Jervey	NRC/DDRL	NAPS Project Manager	x		
Michael Scott	NRC/SSIB	Branch Chief	x		x
Bill Ruland	NRC/DSS	Director			x

Table 1 NAPS Audit Meetings

Name	Organization	Title/ Area	Project Over-view 7/9/2007	Audit Onsite Entrance 7/16/2007	Audit Onsite Exit 7/20/2007
Chakrapani Basavaraju	NRC/DE	Structural - In Office Review	x		
Kerry Bashore	Dominion	Dir - Nuclear Eng	x		x
Harry Blake, Jr.	Dominion	Mgr - Fleet Projects		x	x
Jerry Bishoff	Dominion	VP - Nuclear Eng			x
Michael Henning	Dominion	GSI191 Project Lead	x	x	x
Addison Hall	Dominion	Head loss testing	x	x	x
Dana Knee	Dominion	Safety Analyses	x	x	x
Thomas Shaub	Dominion	Corporate Licensing	x	x	x
Jay Leberstien	Dominion	NAPS Licensing	x		x
Percy McFadden	Dominion	NTS III/Liaison		x	x
David Roth	Dominion	Eng III		x	x
Larry Kidd	Dominion	Liaison Coatings		x	
Tom Nowicky	Dominion	Mech/Liaison		x	x
Bruce DeMars	Dominion	Eng III/Liaison		x	x
E. R. Smith, Jr.	Dominion	Liaison Downstream		x	x
Michael Whalen	Dominion	NAPS Licensing		x	
Mathew McKnight	Dominion	Liaison NPSH		x	
Bob MacMeccan	Dominion	Supr, Nucl Engring			x
Michael Kai	Dominion	Princ Eng			x
Roger Cross	Dominion	Suprv EngrPrograms			x
Mike Sekulic	Dominion	Mech Eng- Insulation			x
David Sommers	Dominion	Supvr - Licensing			x

Table 1 NAPS Audit Meetings

Name	Organization	Title/ Area	Project Over-view 7/9/2007	Audit Onsite Entrance 7/16/2007	Audit Onsite Exit 7/20/2007
Gary Miller	Dominion	Licensing Engr			x
Gary Nayler	Dominion	Eng III			x
Cary LaRon	Dominion	Suprv NucSafetyAnl			x
Paul Young	JR Consulting	Project Lead -Audit			x
Thomas Bartoski	Sargent&Lundy	Project Manager	x	x	x
Larry Dewolff	Sargent&Lundy	Project Team		x	x
Vic Suchodolski	Sargent&Lundy	Project Manager		x	x
Tom Weiss	Sargent&Lundy	ME Debris Transport			x
Dean Robinson	Sargent&Lundy	ME Debris Gen			x
Greg DuBois	Sargent&Lundy	ME Downstream			x
Nigel Fisher	AECL	Testing Lead Mgr			x
Dave Rhodes	AECL	Strainer Technical Specialist			x

In addition, the NRC staff and licensee representatives conducted several telephone conference calls to discuss audit topics.

The audit provided an opportunity for the NRC to: (1) review the basis, including the detailed mechanistic analysis and design documents, for the proposed new strainer design (2) identify areas that may need clarification or generic resolution. The following technical categories related to sump performance were reviewed and discussed:

- Debris generation
- Coatings
- System head loss
- Modifications
- Debris transport
- Debris characterization
- Chemical head loss
- Upstream and downstream effects
- Net positive suction head (NPSH) for emergency core cooling system (ECCS) pumps

The staff reviewed the design documents provided by the licensee and interacted with the licensee and its vendors to develop a thorough understanding of major aspects of the design and analysis.

During the course of the audit, staff examined detailed aspects of the NAPS new strainer design noting general conformance to the approved staff guidance [6], but also identified issues related to the licensee's implementation and plans that need to be assessed as part of the licensee's completion of corrective actions for GL 2004-02 [1]. These are discussed and identified as Open Items throughout this audit report, and were communicated to the licensee during the audit meetings and telephone conferences. The licensee is expected to address and document resolution of these Open Items in conjunction with its efforts to respond to GL 2004-02 [1].

1.2 Bulletin 2003-01 Response

To reduce the risk of sump clogging and other adverse effects caused by containment debris following a loss-of-coolant accident (LOCA) during the period of continued operation until resolution of GSI-191 at operating PWRs, on June 9, 2003, the NRC issued Bulletin 2003-01, "Potential Impact of Debris Blockage on Emergency Sump Recirculation at Pressurized-Water Reactors [3]," to all PWR licensees. Bulletin 2003-01 requested that, within 60 days, PWR licensee either (1) state that the recirculation mode of the emergency core cooling and containment spray systems is in compliance with all existing applicable regulatory requirements when post-accident debris effects are considered, or (2) describe any interim compensatory measures that have been or will be implemented to reduce the risk associated with a potentially degraded or nonconforming ECCS or containment spray system until an evaluation of these systems' compliance with applicable regulations is complete. In its response to the bulletin, dated August 7, 2003, the licensee chose the second option of describing the interim compensatory measures that have been implemented to reduce the risk associated with post-LOCA debris [41].

The interim compensatory measures implemented by the licensee in response to Bulletin 2003-01 include the following [42, 41, 43, 44]:

- systematically reducing ECCS flows and realigning charging pumps from ECCS injection to the normal charging lineup for small-break LOCAs for which the pressurizer pressure remains above the shutoff head of the LHSI pumps,

- conducting two independent containment closeout inspections for cleanliness and the cleanup of foreign materials and loose debris,

- containment closeout verification that the reactor cavity transfer canal drain path is open,

- an administrative procedure concerning sub-atmospheric containment entry, which includes instructions to inspect entry and work areas for debris and administrative requirements that equipment remaining in containment must be approved by station engineering and the station nuclear safety and operating committee,

- a procedure to perform a comprehensive sump screen inspection during refueling outages to ensure that the sump screen satisfies its design requirements, including verification of no adverse gaps or breaches,

- procedural enhancements for continuous monitoring of key sump performance indicators and improved guidance for identifying debris blockage conditions and prioritizing alternate core cooling sources,

- refilling the refueling water storage tank (RWST) using borated sources following indications that sump screen blockage has occurred,

- injecting more than one RWST volume from a refilled RWST or bypassing the RWST to inject water from other sources, including the RWST for the unaffected unit via cross-ties,

- providing for an aggressive cooldown and depressurization of the reactor coolant system following a small-break LOCA,

- providing guidance to plant operators on symptoms and identification of containment sump blockage via licensed operator briefings, and

- developing contingency actions in response to containment sump blockage, loss of pump suction, and cavitation.

As described in the staff’s Bulletin 2003-01 closeout letter to the licensee dated September 19, 2005 [42], the staff evaluated the interim measures taken by the licensee to address the potential risk associated with post-LOCA debris. Based upon the information provided in the licensee’s bulletin response [41] and in the licensee’s responses to staff requests for additional information on the bulletin response [43, 44], the staff considered the actions taken by the licensee to be responsive to and to meet the intent of Bulletin 2003-01.

1.3 Generic Letter 2004-02 Responses

In response to the NRC staff's information request in Generic Letter 2004-02, the NAPS licensee submitted two correspondences:

- a 90-day response dated March 4, 2005, which discussed the planned methodology and schedule for analyzing the performance of the NAPS containment recirculation sump, as well as the methodology and schedule for conducting plant walkdowns [45], and
- a second response dated September 1, 2005, which discussed the licensee's analyses and planned modifications to ensure adequate containment recirculation sump performance [46].

Prior to the audit, the staff reviewed these correspondences from the licensee and further reviewed the GL 2004-02 request for additional information the staff sent to the licensee in a letter dated February 9, 2006 [47], to determine whether any technical issues identified in the request for additional information could be resolved through the audit review.

Through the submittals described above, the licensee provided responses to the information request in GL 2004-02 [1]. These submittals described the activities performed or planned by the licensee to ensure that the ECCS and RS system will be in regulatory compliance in light of the post-accident debris issues associated with GSI-191, including the following:

- containment walkdowns to quantify potential debris sources, verify containment drainage flowpaths, and gather data to support the design of the replacement strainers,
- debris generation and transport analyses,
- plant-specific strainer head loss testing,
- strainer structural analysis,
- upstream effects analysis,
- downstream effects analysis,
- chemical effects analysis,
- a modification to start the RS pumps based upon a low level in the RWST instead of a delay timer after the containment depressurization actuation signal,
- an increase to the containment air partial pressure operating limits in the plant technical specifications,
- revisions to the containment and dose consequence analyses to support design changes associated with the replacement strainer modification,
- a transient calculation of net positive suction head margin, and
- modifications to administrative controls for equipment insulation, housekeeping, coatings, foreign materials, and modifications inside containment.

The licensee stated that the methodology used for analyzing the performance of the containment recirculation sump was Nuclear Energy Institute (NEI) 04-07 [5], as amended by the associated staff safety evaluation (SE) [6]. A summary of the licensee's analysis was presented in the September 2005 GL 2004-02 response [46]. The September 2005 GL 2004-02 response further stated that the methodology in NEI 02-01 [19] was used for performing the containment walkdown.

The licensee's September 2005 GL 2004-02 response [46] contained the following seven commitments:

1. Upon completion of activities described in the GL 2004-02 response [46] related to modifications to the containment sump, the ECCS recirculation functions under post-accident debris loading conditions will be in compliance with the regulatory requirements listed in GL 2004-02.

2. Dominion plans to evaluate the adequacy of the strainer design and will include margin for head loss due to chemical precipitates once the test results to quantify that head loss are known.

3. Any corrective actions that are shown to be necessary for components affected by downstream effects as a result of long-term wear evaluations are planned to be completed prior to December 31, 2007.

4. Programmatic controls for containment debris sources will be put into existing procedures as necessary to ensure the potential containment debris load is adequately controlled to maintain ECCS pump NPSH margin.

5. Dominion will report the minimum NPSH margin in a license amendment request, the plans for which are described in the GL 2004-02 response.

6. Dominion will submit the GOTHIC containment analysis methodology with plant-specific analyses that support the proposed changes to the containment air partial pressure limits in the NAPS Technical Specifications.

7. The planned changes to delay the start of the RS pumps and modify the containment air partial pressure limits require a relaxation of the currently approved containment leakage assumptions for NAPS. Dominion committed to submit a revised alternate source term LOCA analysis for NAPS for NRC review in February 2006.

In addition to the licensee's two correspondences in response to GL 2004-02 that are described above, the staff expects all PWR licensees to submit a supplemental response to GL 2004-02 by December 31, 2007. The purpose of the supplemental response is for the licensee to provide remaining information to support NRC staff verification that corrective actions taken to address GL 2004-02 are adequate.

1.4 Staff Observations of Head Loss Testing for Dominion at AECL

On June 26–30, 2006, NRC staff traveled to Chalk River, Ontario, to observe head loss testing (without chemical precipitates) conducted by AECL, for three PWR units operated by Dominion (Surry Power Station, Units 1 and 2, and Millstone Power Station, Unit 2). The staff's observations from this testing are documented in a trip report dated July 31, 2006 [48].

Although the specific tests observed during the staff's visit to Chalk River were for Surry and Millstone 2, the staff's test observations provide insights into the testing conducted for NAPS because (1) the design of the strainers for NAPS is conceptually similar to that of the strainers for Surry, and (2) the test protocols used for the NAPS strainer testing (e.g., the procedures for debris preparation and addition, scaling, and termination criteria) are similar to the test protocols used for the observed testing.

On the basis of observations made during the trip, the staff concluded that AECL's test procedure and setup were generally conducive to generating conservative results. However, the staff's trip report details a number of potential head loss testing issues that licensees using AECL strainers may need to address. Among these issues, the staff noted that AECL had not completed the development of its chemical effects testing procedures at the time of the staff's visit. Additional discussion and details concerning the staff's observations of the testing conducted at AECL can be found in the staff's trip report [48]. As part of the audit, the staff has considered whether any issues identified in the trip report are still applicable and should be addressed by the licensee in its supplemental response to GL 2004-02. Any such issues are identified in the appropriate section of this audit report.

2.0 DESCRIPTION OF INSTALLED/PLANNED CHANGES

The NAPS has a subatmospheric containment design and its containment sprays systems include: (1) a containment quench spray with two pumps starting on a containment depressurization actuation signal and drawing water from the RWST until empty, and (2) the RS drawing water from the containment sump with two pumps outside containment (ORS) and two pumps inside containment (IRS). The RS pumps start on RWST low level (60%) with coincident containment depressurization actuation on a high-high containment pressure signal. The safety injection switchover over to the recirculation mode occurs at the automatic recirculation mode transfer at the 19.4% RWST level. The NAPS ECCS includes (1) the LHSI which takes suction from the RWST until the recirculation mode transfer and then switches its suction to the containment sump, and (2) the high-head safety injection which takes suction from the RWST until the recirculation mode transfer and then switches suction to the LHSI pump discharge. Thus, the recirculation systems taking suction from the containment sump include the RS and the LHSI systems [28].

New replacement strainers designed by AECL were installed in Unit 2 in April 2007 during a refueling outage and are scheduled to be installed in Unit 1 during a fall 2007 refueling outage. The RS and the LHSI each have separate strainer modules that are completely independent of the other system. The total strainer screen areas are 4,415 ft^2 and 1,890 ft^2 for the RS and LHSI systems, respectively [28].

The allowable design head loss across the new RS strainer is 5.0 feet at 180 °F and at a flow rate of 12,620 gpm corresponding to the maximum flow for all four pumps operating. The allowable design head loss across the new LHSI strainer is 8.5 feet at 113 °F and at a flow rate of 4,050 gpm, a flow corresponding to the maximum for one pump operating. For the LHSI system, the single pump operation is the most critical mode of operation from an NPSH, versus head loss, point of view [28]. For the RS strainer modules, the bottom and top edges of the fins are 6.375 inches and 21.5 inches above the sump floor, respectively. For the LHSI strainer modules, the bottom and top edges of the fins are 23.5 inches and 50.25 inches above the sump floor, respectively [73].

3.0 BASELINE EVALUATION AND ANALYTICAL REFINEMENTS

3.1 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. Sections 3.3 and 4.2.1 of NEI PWR Sump Performance Task Force Report NEI 04-07, “Pressurized Water Reactor Sump Performance Evaluation Methodology,” (the “Guidance Report”) [5] and the associated safety evaluation by the Office of Nuclear Reactor Regulation (the SE) [6], provide the NRC-approved criteria to be considered in the overall break selection process for identifying the limiting break.

The primary criterion used to define the most challenging break is the effect of generated debris on the estimated head loss across the sump strainer. Therefore, all phases of the accident scenario must be considered for each postulated break location: debris generation, debris transport, debris accumulation, and resultant sump strainer head loss. Two attributes of break selection that are emphasized in the approved evaluation methodology cited above, and which can contribute significantly to head loss are: (1) the maximum amount of debris transported to the strainer; and (2) the worst combinations of debris mixes transported to and onto the strainer surfaces. Additionally, the approved methodology states that breaks should be considered in each high-pressure system that relies on recirculation, including secondary side system piping, if applicable.

Section 3.3.5 of the staff SE describes a systematic approach to the break selection process which includes guidance for identification of break locations that rely on recirculation to mitigate the event:

- Case No. 1 - Breaks in the reactor coolant system with the largest potential for debris.
- Case No. 2 - Large breaks with two or more different types of debris.
- Case No. 3 - Breaks with the most direct path to the sump.
- Case No. 4 - Large breaks with the largest potential particulate debris to insulation weight ratio.
- Case No. 5 - Breaks that generate a “thin-bed” (high particulate with at least a 1/8" fiber bed)

The calculational report prepared by Sargent & Lundy, S&L Report No. ME-0779 [30 and 31], “Debris Generation Due to LOCA within Containment for Resolution of GSI-191,” documents the assumptions and methodology the licensee applied as part of the overall break selection process to determine the limiting break for the NAPS.

NRC Staff Audit

The NRC staff reviewed the licensee's overall break selection process and the methodology applied to identify the limiting break as presented in the licensee calculational report No. ME-0779 [30 and 31] and discussed these with the licensee's analytical contractor during the onsite audit week. The licensee identified four breaks that would encompass the worst-case situations and evaluated them in detail. The spectrum of breaks evaluated by the licensee was consistent with that recommended in the SE and consistent with regulatory position 1.3.2.3 of Regulatory Guide 1.82, Revision 3 [7]. The staff considered deviations from the staff-approved methodology to be reasonable based on the technical basis provided by the licensee, as discussed in the following paragraphs.

Rather than systematically evaluating all potential break locations by evaluating breaks incrementally along the piping as recommended in the Guidance Report, the licensee selected characteristic breaks based on piping diameters and relative locations. The largest diameter high-energy piping is the reactor coolant system cold leg piping (31 inches) with the hot leg piping (29 inches) being somewhat smaller. The largest zones of influence (ZOI) would therefore be associated with the cold leg piping. In accordance with the Guidance Report and SE, small-bore piping was not evaluated.

Dominion identified four postulated breaks for evaluation. The specific breaks are:

NAPS Break BK1:	Break BK1 was postulated in the reactor coolant system Loop B 31-inch cold leg suction piping (intermediate leg) near the steam generator at an elevation of 257 feet.
NAPS Break BK2:	Break BK2 was postulated in the reactor coolant system Loop C 31-inch cold leg suction piping (intermediate leg) near the steam generator at an elevation of 257 feet.
NAPS Break BK3:	Break BK3 was postulated in the reactor coolant system Loop A 31-inch cold leg suction piping (intermediate leg) near the steam generator at an elevation of 257 feet.
NAPS Break BK4:	Break BK4 was postulated at the connection of the 14-inch surge line to the pressurizer and is outside the steam generator compartments in the pressurizer cubicle at an elevation of 265 feet.

The selection of a cold leg break near the steam generator at the elevation of 257 feet generated the largest debris quantities, per SE Case 1. This is because the cold leg piping diameter of 31 inches is larger than the hot leg piping of 29 inches and the selected location of the cold leg breaks was about 8 inches higher in elevation than was the hot leg piping. Because the ZOIs for the dominant fibrous insulations would effectively reach to the floors of the steam generator compartments, the higher cold leg elevation along with the larger diameter ZOI means that the cold leg ZOI would impact more fibrous insulation than would occur for a hot leg break. The licensee's analysis of the three cold leg breaks, Breaks BK1, BK2, and BK3, determined the comparable debris quantities for each of the three steam generator compartments to ascertain which compartment would produce the most potential debris. These three cold leg breaks provide large breaks with variations of multiple types of debris, large breaks with the largest potential particulate debris to insulation weight ratios, and the breaks that could generate a thin-bed debris formation on the strainers, per SE Cases 2, 4, and 5, respectively.

The fourth postulated break, Break BK4, was on the 14-inch pressurizer surge line. Break BK4 along with Break BK1 satisfy the SE Case 3 criterion of evaluating breaks with the most direct path to the sump, since both breaks are near the recirculation sump. The pressurizer surge line break would produce lesser quantities of debris and most of that debris would be reflective metallic insulation (RMI) debris. Therefore, the licensee did not consider the surge line break important to the strainer blockage resolution.

The licensee determined that neither main steam nor feedwater line breaks would require the ECCS or containment sprays to operate in the recirculation mode, so that sump strainer clogging would not be an issue for these events. Because the reactor vessel is insulated entirely with RMI insulation, a reactor vessel nozzle break would not generate a worst-case debris load and also was not considered by the licensee to need further evaluation.

Dominion originally evaluated the NAPS coatings debris generation based on a 10-pipe diameter (10D) ZOI [30] that would coincide with break selections for insulations. However, when Dominion reevaluated coatings debris generation based on a 5D ZOI [31] rather than the original 10D ZOI, the 5D ZOI at the selected cold leg breaks for insulation would not impact any concrete coatings and therefore would not predict maximum coatings debris quantities. Therefore, Dominion repositioned the coatings 5D ZOI onto the hot leg piping between the reactor vessel and the steam generator to maximize the coatings debris. The licensee based the 5D ZOI on jet impingement testing conducted by Westinghouse [49]. As such, the insulation ZOIs are based on cold leg breaks, and the coatings ZOIs are based on hot leg breaks to simultaneously maximize both the insulation and coatings debris quantities.

The staff found the licensee's evaluation of break selections to be consistent with the SE-approved methodology and therefore to be acceptable.

3.2 Debris Generation/Zone of Influence

The objective of the debris generation/ZOI process is to determine, for each postulated break location: (1) the zone within which the break jet forces would be sufficient to damage materials and create debris; (2) how much debris is generated by the break jet forces; and (3) the size characteristics of the postulated debris. Sections 3.4 and 4.2.2 of the Guidance Report [5] and the NRC SE [6] provide the approved methodology to be considered in the ZOI and debris generation analytical process.

The Guidance Report baseline methodology incorporates a spherical ZOI based on material damage pressures. The size of the spherical ZOI is based, usually, on experimentally deduced destruction pressures as the pressures relate to an equivalent double-sided volume described by the ANSI/ANS 58.2 1988 standard [8]. Once the ZOI is established about a selected break location, the types and locations of all potential debris sources can be identified using plant-specific drawings, specifications, walkdown reports, or similar reference materials. The amount of debris generated is then calculated based on the amount of materials within the most limiting ZOI.

Section 4.2.2 of the SE discusses proposed refinements to the Guidance Report methodology that would allow application of debris-specific ZOIs. This refinement allows the use of a specific ZOI for each debris type identified. Using this approach, the debris generated within each ZOI is calculated, and then added to arrive at a total debris source term. The NRC staff concluded in the SE that the definition of multiple spherical ZOIs at each break location corresponding to damage pressures for potentially affected materials is an appropriate refinement for debris generation. As discussed in Section 4.2.2 of the SE, the NRC staff accepted the application of these proposed refinements for PWR sump analyses for GL 2004-02 [1] corrective actions.

NRC Staff Audit

The staff reviewed the licensee's ZOI and debris generation evaluations and the methodology application as presented in the licensee Calculational Report No. ME-0779 [30 and 31]. The staff discussed the evaluations and methodology with the licensee's analytical contractor during the onsite audit and compared them to the approved methodology documented in Sections 3.4 and 4.2.2 of the staff's SE.

The types of insulation used in the NAPS units that are within a potential ZOI include Transco RMI, Thermal-Wrap low-density fiberglass insulation, Temp-Mat high-density fiberglass insulation, and Paroc mineral wool. Dominion replaced their calcium silicate and Microtherm particulate insulations with the Paroc insulation to eliminate the high head losses associated with the particulate insulation materials. The radii assumed by the licensee for insulation ZOIs are shown in Table 2. The licensee adopted the NRC-approved ZOI radii of 2D and 11.7D directly from the SE for the Transco RMI and Temp-Mat insulations, respectively; therefore, these two ZOI radii are acceptable. Because debris generation data was not available for either the Thermal-Wrap or the Paroc mineral wool insulations, the ZOI radii were estimated by making comparison with similar materials. The 17D ZOI SE-approved for unjacketed Nukon® was adopted for the Thermal-Wrap insulation and the 5.4D ZOI SE-approved for K-Wool was adopted for the Paroc mineral wool. The licensee basis for these assumptions and the staff basis for accepting the assumptions are presented as follows.

Table 2 NAPS Insulation ZOI Radii

Insulation Type	ZOI Radius/Break Diameter
Transco RMI	2
Paroc Mineral Wool	5.4
Temp-Mat	11.7
Transco Thermal-Wrap	17

The licensee basis for adopting the Nukon® 17D ZOI for Thermal-Wrap was the similarity between the two insulation materials. The licensee further noted that a 17D ZOI was one of the larger ZOI accepted in the SE of tested insulation material. Both Nukon® and Thermal-Wrap have the same bulk density of 2.4 lb_m/ft^3 and both are manufactured from a similar fiberglass material. The principal difference between the two insulations is their fiber diameters, which are about 7.0 and 5.5 μm for Nukon® and Thermal-Wrap, respectively. In addition, the binder holding the fibers together may differ between the two insulations. The staff agreed that these two materials were quite similar and would likely have similar ZOI radii, but the staff acceptance of the 17D also considered the conservatism associated with the licensee's assumed debris size distribution for the Thermal-Wrap debris, which was presented in the licensee's transport evaluation [29].

The licensee adopted the size distribution scheme used in the NRC-sponsored volunteer plant study, which was documented in Table VI-1 of the SE, for the Thermal-Wrap insulation debris. The licensee then used guidance from Appendices II and VI of the SE developed for Nukon® debris, to arrive at a distribution of 8%, 25%, 32%, and 35% for fines, small pieces, large pieces, and intact debris, respectively. In the adoption process, the licensee combined fines and small-piece debris distribution values in Table VI-2 of the SE to arrive at a total of 33% for a combined small fines category. Of this 33%, one-quarter was assumed to be fines, which was the conservative finding from the NUREG/CR-6369 study resulting in the 8% and 25% for the fines and small pieces categories, respectively, from SE Table VI-1. This distribution is slightly more conservative than the volunteer plant distribution shown in SE Table VI-2. For comparison, another assessment for the small fines category for Nukon® with a 17D ZOI was documented in Table II-2 of the SE. That determination was 22% for the small fines category, which demonstrates the considerable conservatism of the licensee's determination of 33% with respect to Thermal-Wrap.

Given the similarities between Thermal-Wrap and Nukon® and the conservatism of the licensee size distribution with respect to that documented in the staff SE for volunteer plant Nukon®, the staff finds the combination of the licensee-assumed ZOI of 17D for Thermal-Wrap and the assumed Thermal-Wrap size distribution to be conservative and acceptable because this combination results in a bounding quantity of Thermal-Wrap fines predicted to transport to the strainers.

The licensee basis for adopting the K-Wool 5.4D ZOI for the Paroc mineral wool was the similarity between the two insulation materials and that the Paroc is stainless steel-jacketed, with stainless steel bands on 18-inch centers, whereas the K-Wool as-tested was only wire mesh lined. As further justification, the licensee noted the similarity between the Paroc jacketing and the jacketing used in the Ontario Power Generation calcium silicate debris generation testing [74] that resulted in the SE-approved calcium silicate ZOI of 5.45D.

The staff initially questioned the validity of the assumed 5.4D ZOI for Paroc because of the following:

> The licensee did not provide data that directly compared the characteristics of Paroc to K-Wool to demonstrate the stated similarity.
>
> The Ontario Power Generation test jacketing has bands on centers about 8 inches apart, compared to the NAPS Paroc bands on 18-inch centers.
>
> The Ontario Power Generation test for which the target was placed furthest from the jet nozzle, which was used to define the calcium silicate ZOI of 5.4D, resulted in 14% of its calcium silicate turned to dust debris.

Therefore, it is likely that some Paroc insulation located further away from the break than 5.4D would be damaged to the extent of forming debris.

After noting these initial staff concerns, the licensee discussed other points favorable to accepting the 5.4D ZOI for Paroc. These points included:

> The insulation damage in the Ontario Power Generation tests depended on the orientation of the jacket seam with respect to the jet and the test that defined the calcium silicate ZOI had the seam oriented for maximum damage. Within a NAPS ZOI, the Paroc jacketing seam orientations would be varied with respect to the break location. Therefore, it should be expected that some insulation blankets within the ZOI would not generate debris. This compensates for blankets outside the ZOI that could contribute to the debris load.
>
> If the NAPS Paroc ZOI was more conservatively extended to 8D, the quantity of Paroc debris would only be increased by an additional 23.7%. This illustrates that most of the Paroc located within any reasonably sized ZOI would be encompassed by the assumed 5.4D ZOI. Therefore, the bounding quantity of fibrous debris that could potentially accumulate on the NAPS replacement strainers is not very sensitive to the size of the Paroc ZOI in the range beyond 5.4D.
>
> All of the Paroc debris from the 5.4D ZOI was conservatively assumed to be destroyed into 100% transportable fine debris [29], which is highly conservative. The conservatism of this assumption would compensate for the possibility of some Paroc insulation debris being generated beyond the 5.4D ZOI boundary.

The staff accepted the licensee-assumed 5.4D ZOI for the Paroc mineral wool based on a general qualitative similarity between the Paroc and the K-Wool and that the licensee assumption that 100% of the Paroc within a 5.4D would be destroyed into fines would provide a conservative estimate for the bounding quantity of transportable Paroc debris.

The licensee's bounding debris quantity estimates are summarized in Table 3.

Table 3 Bounding LOCA-Generation Insulation Debris Quantities*

Debris Type	Break BK1	Break BK2	Break BK3	Break BK4
ZOI Generated				
Metallic (ft^2)				
Transco RMI	710.21	732.77	751.57	1306.32
Fibrous (ft^3)				
Thermal-Wrap	641.88	646.43	648.14	0
Temp-Mat	1.45	15.82	1.63	1.73
Paroc Mineral Wool	62.48	57.12	77.75	107.82
Containment Spray or Submergence Generated				
Fibrous (ft^3)				
Fiberglass	4.2	4.2	4.2	4.2
Thermal-Wrap	0	0.79	0.79	0.79
Temp-Mat	1.91	2.33	2.46	2.86
Total Fibrous Debris				
Fibrous (ft^3)	711.92	726.69	734.97	117.4

* 5% Margin was conservatively included in all debris quantities. Coatings are not included in the table.

The following observations can be made from this table:

Breaks BK1, BK2, and BK3 would generate roughly the same bounding quantities of debris. As expected, the smaller break, Break BK4, would generate substantially less debris.

The maximum quantity of fibrous debris would come from the destruction of Thermal-Wrap insulation, except for Break BK4 where the maximum would come from Paroc mineral wool.

The quantities of debris calculated to be generated by the impingement and drainage of the containment sprays and/or submergence are relatively minor when compared with the debris generated by jet impingement. This debris would only be generated from insulation whose covering would not be considered substantial enough to withstand water.

NAPS has (or will have; see section 3.3) no sources for the generation of particulate insulation debris, e.g., calcium silicate.

The original debris estimate [30] showed that Break BK2 would generate the largest quantities of fibrous debris, so the licensee selected Break BK2 to represent the debris loads for head loss testing. A subsequent revision of the debris generation calculation [31] resulted in Break BK3 generating a slightly greater total quantity of fibrous debris than would Break BK2 (about 1% greater), but Break BK2 was retained for specifying the test debris quantities. Considering the similar quantities of debris, the staff concludes that it makes little difference whether the tests are based on Break BK2 or Break BK3.

The licensee noted that fire barrier materials within containment include silicone foam, Cerafiber, and Marinite board. However, all these materials are located in cable trays in the outer annulus zones and therefore would not be impacted by a LOCA jet. The licensee also noted a small number of missile barrier wall penetrations sealed with black silicone foam material that is not be expected to contribute to the debris load on the strainers because debris from this foam would float above the strainers. The licensee also noted the presence of Thermo Lag fire barrier material, but none of this material was within a potential ZOI.

Other sources of debris at NAPS include latent debris and coatings debris, which are discussed in Sections 3.4 (page 21) and 3.8 (page 52), respectively, and chemical effects precipitants, which are not specifically addressed in this report.

The licensee presented its estimated and assumed debris size characteristics in its transport report [29]. The staff reviewed the licensee's debris size distributions with the following conclusions.

For RMI debris, the licensee adapted the Guidance Report recommendation of 75% for small fines and 25% for large piece debris. This is conservative and acceptable to the staff.

The licensee adopted the size distribution scheme used in the NRC-sponsored volunteer plant study, which was documented in SE Table VI-1 for the Thermal-Wrap insulation debris. The licensee then used guidance from SE Appendices II and VI developed for Nukon® debris, to arrive at a distribution of 8%, 25%, 32%, and 35% for fines, small pieces, large pieces, and intact debris, respectively. The staff found this size distribution to be conservative and acceptable.

For the Temp-Mat and Paroc mineral wool insulations, the licensee assumed that 100% of the debris would be fines. The key characteristic of fines is that this debris would be likely to remain suspended in water, even at relatively quiescent conditions. Because this assumption represents the extreme conservative position for debris size distribution, it is acceptable to the staff.

In conclusion, the evaluation was performed in a manner consistent with the SE-approved guidance methodology. The predicted bounding quantities of debris are conservative and acceptable.

3.3 Debris Characteristics

The staff reviewed the NAPS licensee's assumptions regarding the characteristics of post-accident debris to provide assurance that the assumed characteristics are conservative with respect to debris transport, debris bed head loss, and other areas of the sump performance analysis. The licensee's discussion of debris characteristics was primarily provided in the debris generation calculation [30, 32]. The information regarding the surrogate test material for reduced-scale testing was provided in the AECL head loss testing report [75]. Additional information concerning the post-accident debris at NAPS was provided in the licensee's slide presentation for the audit kick-off meeting [28].

The analyzed debris loading for the NAPS includes RMI, qualified coatings, unqualified coatings, latent particulate debris, latent fibrous debris, fibrous insulation debris, and foreign materials such as tape, tags, glass, and stickers. Coatings debris characteristics are discussed in section 3.8.2 of this report (page 52). Chemical effects precipitates were not included in the head loss testing completed as of the time of this audit.

The licensee referenced transport velocities from the NRC-sponsored testing [NUREG/CR-6772 - 10] for stainless steel RMI and Thermal-Wrap fibrous debris that are applicable to the NAPS transport analysis. The licensee also quoted transport velocities for stainless steel RMI from an older test report for comparison [NUREG/CR-3616 - 76]. This information was used to show that neither the large RMI debris nor the large, intact Thermal-Wrap debris could lift from the sump floor to transport onto a strainer surface. No debris characteristics for these materials were provided for application to head loss analysis.

For NAPS, the primary debris characteristics of concern relate to the assurance that the surrogate debris used in the head loss testing either prototypically or conservatively represents the NAPS plant materials.

Calcium silicate and Microtherm insulation debris was used in earlier head loss testing. The licensee stated that, due to the high head losses associated with these debris types, all of the calcium silicate and Microtherm within a potential debris zone at NAPS was or will be replaced with the Paroc mineral wool before the end of 2007. Therefore, the calcium silicate and Microtherm insulations will not be discussed further in the debris characteristics section.

The staff compared the characteristics of the surrogate test materials with the corresponding plant material to ensure either prototypicality or conservatism. The surrogate materials selected for the head loss tests are compared to the postulated plant debris in Table 4, along with the licensee justifications for the surrogate selections.

Table 4 Selection of Surrogate Test Debris

Postulated Plant Debris	Surrogate Material	Justification
Transco RMI	Transco Stainless Steel Foil	Surrogate debris manufactured from same material as plant insulation
Transco Thermal-Wrap	Thermal-Wrap Supplied Transco Products	Surrogate debris manufactured from same material as plant insulation
Temp-Mat	Temp-Mat Supplied by GLT Products	Surrogate debris manufactured from same material as plant

Postulated Plant Debris	Surrogate Material	Justification
		insulation
Paroc Mineral Wool	Paroc Mineral Wool	Surrogate debris manufactured from same material as plant insulation
Latent Fibers	Transco Thermal-Wrap	Transco Thermal-Wrap similar to Guidance Report-recommended Nukon® insulation
Qualified Coatings	Walnut Shell Flour (passed through #325 sieve)	Relatively low particle density solved transport issue with near-field debris settling that was associated with testing with heavier particulates
Unqualified Coatings		
Damaged Coatings		
Latent Particulates		

The licensee's selections for surrogate metallic and fibrous insulation debris are all valid selections since the surrogate debris was created from materials essentially the same as those installed in the plant. The use of Transco Thermal-Wrap to simulate latent fibers is acceptable since the Thermal-Wrap is low-density fiberglass insulation similar to Nukon® insulation, which the staff has accepted as a suitable surrogate for latent fibers.

3.3.1 Reflective Metallic Insulation

The licensee debris transport calculation [29] stated that the RMI installed at NAPS is Transco Mirror Insulation constructed of stainless steel foils with three layers per inch of thickness. The transport calculation stated that the size distribution assumed for the RMI debris at NAPS is 75% small fines and 25% large pieces. This distribution is consistent with the guidance in NEI 04-07 and Table 3-3 of the staff's SE on NEI 04-07 [6]. The staff considers the licensee's assumed size distribution for RMI debris to be acceptable because the assumed distribution is consistent with conservative guidance provided in NEI 04-07 and the staff's SE.

3.3.2 Fibrous Insulation

The licensee's debris transport analysis [29] stated that the fibrous insulation within the NAPS ZOIs is Transco Thermal-Wrap, Paroc, Temp Mat, and latent fibers. The Paroc is a mineral wool type insulation similar to Kaowool.

The debris characteristics the licensee assumed for the fibrous material were consistent with the NEI guidance and the NRC SE. The low-density fiberglass was assumed to fail into 8% small fines, 25% small pieces, 32% large pieces, with 35% left intact. The Paroc mineral wool insulation was assumed to fail as 100% small fines. The Temp Mat was assumed to fail as 60% small fines, with 40% left intact.

The debris transport analysis also accounts for the erosion of 90% of the larger pieces of fibrous insulation predicted to be in the sump pool, but that may not necessarily transport to the strainer as larger pieces. The fines produced by the erosion are predicted to transport to the strainer. Covered, intact, fibrous debris is not considered to erode. These assumptions are consistent with the SE on NEI 04-07 [5].

The debris transport calculation also accounts for fibrous debris generated by containment spray. In general, the amount of spray-generated debris is minor compared with the debris generated by blowdown following the postulated LOCA. All the unjacketed fiber was assumed to fail. All spray-generated debris is modeled as small fines, which is conservative.

The licensee used the original fibrous debris as surrogate debris for testing. This provides accurate prototypicality for the test debris.

3.3.3 Latent Fibrous Debris

The licensee assumed that latent fiber comprises 15% of the total latent debris loading measured in the containment. The licensee assumed that latent fibrous debris is composed of 100% small fines. Transco Thermal-Wrap fibers were used for the latent fibrous debris during testing.

The properties the licensee assumed for latent fibrous debris are consistent with NUREG/CR-6877 and the NRC SE on NEI 04-07. Therefore, the staff considers the characteristics assumed for latent fibrous debris to be acceptable.

3.3.4 Latent Particulate Debris

The licensee assumed that particulate material comprises 85% of the total latent debris loading measured in the containment. The licensee assumed that latent particulate debris is composed of 100% fine particulate. Walnut shell flour was used as the surrogate for latent particulate debris.

The walnut shell flour surrogate debris was significantly different from the corresponding plant latent and coating debris materials. The applicability of the walnut shell flour to simulate coatings debris and latent particulate was evaluated during the NRC audit for Millstone Unit 2 conducted in January 2007 [23]. Walnut shell flour was used because its material density is lighter than the plant materials being simulated. The lighter density conservatively reduces the debris settling during the testing which is a valid consideration. However, an even more important debris characteristic is the walnut shell flour's ability to simulate head loss behavior in a test bed. To justify this characteristic, the licensee provided the walnut shell flour particle size distribution because size distribution directly affects head loss characteristics.

An analysis of the walnut particle size distribution determined that (with respect to the specific surface area of the particulate) the particle size of about 32 μm corresponded to the specific surface area that was computed from the size distribution. The staff noted that the licensee quoted an average particle size of 22 μm, but this average was based on the number of particles that when recomputed to get the average size based on particle volume is about 32 μm. The head loss characteristic of particulate debris depends on the volume distribution of the particle size or specific surface area. At the very slow strainer approach velocities associated with the NAPS replacement strainers, the head loss is directly related to the square of the particulate specific surface area. The SE-approved Guidance Report recommended that the coatings particulate be assumed to have an effective spherical diameter of 10 µm and the latent particulate to be about 17.3 µm. A comparison shows that the walnut shell flour has an effective diameter that is about a factor of 3.2 and 1.8 larger than the Guidance Report recommendations for the coatings debris and latent particulate, respectively. Larger particulate surrogates would result in a lower head loss than would be expected when using prototypically sized surrogate. However, subsequent staff analysis [23 pg 46-50] found that the behavior of the walnut shell flour was similar to the behavior that would be expected for the Guidance Report recommended hypothetical 10 µm spherical particles. Therefore, the experimental evidence [23] indicates that the walnut shell flour is a reasonable surrogate for the coatings debris and an even more conservative surrogate for the latent particulate.

When scaling the surrogate quantities of particulate matter for testing, the licensee correctly maintained solid volume whenever the densities differed between the plant material and the surrogate material.

The properties the licensee assumed for latent particulate debris are consistent with NUREG/CR-6877 and the NRC SE on NEI 04-07. Therefore, the staff considers the characteristics assumed for latent particulate debris to be acceptable.

3.3.5 Fire Stop Material

The debris generation analysis considered cable tray fire stop materials as potential sources of post-accident debris in the containment. The fire stops consist of Marinite board, silicon foam, and Cerafiber. The fire stops are not within the ZOIs considered in the analysis. In addition, none of these components are considered in the containment spray-generated debris due to the specific assembly of the fire-stops. The silicone foam and Cerafiber of the fire-stops are totally enclosed in Marinite board. The debris generation calculation cites the Marinite board data sheet and NUREG 6772 testing that shows that the material remains intact even after prolonged submersion in boiling water. Based on this information, the licensee assumed that the fire stop material does not contribute to the containment spray debris generation.

The staff considers the licensee’s assumption regarding the ability of the fire stops to remain intact reasonable based on the information provided.

3.3.6 Miscellaneous Debris

The latent debris section of this report [page 23] addresses quantification and control of miscellaneous debris. This subsection of Section 3.3 assesses whether the methods used to account for the debris during testing were acceptable. The licensee’s debris transport calculation [29] states that foreign material debris sources that could result in sump strainer blockage include metal equipment tags, duct tape, vinyl stickers, plastic tags, and glass. According to the calculation, the total quantity of miscellaneous debris was approximately 240 ft^2. A 5% margin was added to this measurement. The licensee assumed that this material would fully transport to the sump strainers and would accumulate in a way that would block an area on the sump strainers equivalent to 75% of the singled-sided surface area of the miscellaneous debris.

The licensee’s methodology for characterizing nonporous latent debris by assuming it blocks an area on the sump strainer equal to 75% of the total single-sided area of miscellaneous debris is consistent with Section 3.5.2.2.2 of the staff’s SE on NEI 04-07. Therefore, the staff considers this methodology to be acceptable.

3.3.7 Debris Characteristics Conclusion

The licensee generally made conservative assumptions concerning the characteristics of debris at NAPS. A minimum 5% margin was added to each type of debris when the scaled testing loads were calculated. As described above, the staff considered the debris characteristics assumed by the licensee to be acceptable.

3.4 Latent Debris

3.4.1 Scope of Audit

Latent debris is debris present in containment before a postulated high-energy line break, which may be composed of various constituents including dirt, dust and other particulates, paint chips, fibers, pieces of paper, tags, plastic, tape, adhesive and non-adhesive labels, and fines or shards of thermal insulation or fireproof barriers. The objective of the latent debris evaluation is to provide an estimate of the types and amounts of latent debris existing in containment for assessing its impact on sump strainer head loss. The NAPS licensee evaluated the potential sources of latent debris within containment using the guidance provided in NEI 04-07 [5] and the associated NRC staff safety evaluation [6]. NEI 04-07 and the staff’s SE provide guidance for quantifying the mass and characteristics of latent debris inside containment.

The following baseline approach for evaluating latent debris is recommended in NEI 04-07 [5] and the staff's SE [12]: (1) estimate the total area available in containment for latent debris deposition, including both horizontal and vertical area contributions, (2) survey the containment to determine the mass of debris present, (3) determine the fraction of total area that is susceptible to debris buildup, (4) calculate the total quantity and composition of debris in containment, and (5) define the debris composition and physical properties. These elements of the latent debris evaluation process are addressed in the NAPS reports [33, 57, 58, 59, 60, 61, and 32].

3.4.2 Latent Debris Sampling Methodology

Dust, Particulate, Lint

The licensee's latent debris walkdown plan [57] outlines the process for evaluating the latent debris mass and the quantity of labels, stickers, etc., found in the NAPS 2 containment. A similar evaluation was done for the NAPS 1 containment. The NAPS 2 mass of latent fibrous and particulate debris was larger than the estimate for NAPS 1, and was used in the specification of the sump strainer. The NAPS 2 analysis is discussed here.

The surface areas within containment that are available for accumulation of latent debris were identified, and eight surface-area categories were defined. After accounting separately for horizontal and vertical surface configurations, a total of twelve area types were defined. The surface area of each of the twelve area types was computed with the aid of plant drawings. All of the individual area contributions were tabulated in Attachment 8.9 to the debris generation calculation [33].

To estimate the latent debris mass, including dust, particulate and lint, the licensee took a total of 48 samples. Four samples were taken for each of ten area types, seven samples were taken of horizontal piping surfaces, and one sample was taken of a horizontal ventilation duct surface. The sample locations are identified in the latent debris walkdown report [58]. At each location, a pre-weighed cloth was used to swipe or scoop debris from a surface area of between 0.38 ft^2 and 25.50 ft^2. The difference of the cloth's weight before and after the collection of the sample represents the weight of the sample. All of the measured weights were reported in grams, with a resolution of 0.1 gram. The computed weight differences for the 48 samples included one weight difference of negative value, six weight differences of zero value, and 20 weight differences of 0.1–0.3 gram. To account for the uncertainty introduced into the sample weight measurements because of the relatively large mass measurement uncertainty, NAPS added 0.1 gram to all zero values of the sample masses. The one negative value was discarded, since there were six other measurements of the same surface area type. As a result, a total of 47 samples was used to evaluate the total mass of latent debris in containment.

While the licensee made certain corrections to the latent debris data to account for measurement uncertainty, the staff questioned whether these corrections were sufficient. In particular, the staff questioned whether the relatively large measurement resolution of 0.1 gram could also affect the 20 samples for which the measured weights were of the same order of magnitude as the magnitude of the measurement resolution. The staff considered that all of the sample weight measurements suffer from the same uncertainty. Therefore, all of the weight measurements should be corrected in the same conservative manner to account for the uncertainty considering the relatively large mass measurement resolution as compared with the sample masses. The staff related this view to licensee personnel during the audit. As a result, the licensee recalculated the total mass of latent debris by adding 0.1 gram to each measured sample weight. The staff accepted this approach as a conservative estimate of the effect of the uncertainty on the computed mass of latent debris. This is discussed further in Section 3.4.3.

As discussed above, the licensee took one sample for horizontal ventilation duct surfaces. The licensee used four additional samples of horizontal piping to estimate the mean and distribution of latent debris for the horizontal ventilation surface area category. Thus, of the five sample measurements used in the calculation to represent horizontal ventilation surfaces, only one was actually taken on such a surface. This procedure may have led to an underestimation of the latent debris mass for the horizontal ventilation surface category. However, the underestimate was judged by the staff to be about 1 percent of the total estimated latent debris in the NAPS 2 containment and is not significant considering that a 5 percent margin was added to the latent debris in the sump strainer specification. This margin is discussed further in the results section below.

For each of the twelve area types, the measured sample masses and the surface area sampled were used to compute the mean sample mass per unit area, the standard deviation of this quantity, and the 90% confidence limit of the quantity. The 90% confidence limit was conservatively used as the representative latent debris sample mass per unit area for each specific area type sampled.

The total mass of latent debris present in containment in each of the twelve area types was extrapolated from the measured debris masses by multiplying the computed sample mass per unit area by the estimated surface area in containment associated with the specific area type.

The masses identified with each area type were summed to provide the total latent debris in containment.

The sampling methodology for measurement of latent debris mass and the statistical analysis performed as summarized above follow the guidance of NEI 04-07 [5] and the staff's SE [12]. In place of the sample mean, for each area type NAPS conservatively used the 90% confidence limit. The staff finds this approach to be conservative and acceptable, considering the resolution of the measured debris sample mass issue discussed subsequently in Section 3.4.3.

Tapes, Labels, Stickers and Broken Glass

The staff reviewed the licensee's walkdown plan for foreign materials, such as tags, labels and stickers [59], and the licensee's report of the quantitative results of this walkdown [60]. The methodology used is identical for NAPS 1 and NAPS 2 and is reviewed below.

The walkdowns of the NAPS 1 and NAPS 2 containments considered two categories of tags, labels and stickers: metallic and non-metallic. Metallic labels are attached to components with a stainless steel braided wire. Those metallic labels that are within the ZOI are assumed to be dislodged. However, since these labels are metallic with a significantly higher density than water, they are assumed to not readily transport to the sump and are not considered as a debris source. The staff accepts this assumption based on the significantly higher density of the metallic labels than the sump water.

Non-metallic labels consisted of stickers, placards and tape. The surface area inventory of these items was determined by a combination of identification by plant walkdown and analysis of engineering drawings. The locations of these items are identified by plant elevation and by the object on which they are mounted [60]. All stickers, placards and tape were conservatively assumed to be transportable to the containment sump. The sum of the individual areas is taken as the total area of tags, labels and stickers. One-hundred percent of the area was used as the total. The licensee's methodology is acceptable because it conservatively accounts for the inventory of stickers, placards and tape in containment.

It was assumed that all light bulbs in containment would be subject to breakage from the increased containment pressure resulting from the assumed pipe break. The light fixtures, which are predominantly glass covers that are open at the bottom [60], were assumed subject to breakage within the ZOI, and such fixtures were assumed to provide surface area to be counted in the foreign material inventory.

The staff finds that the walkdown methodology for tallying the inventory of tags, labels, and stickers is reasonable because it systematically identifies the debris as a function of location and the equipment item to which it is attached. In addition, the licensee's use of 100% of the total foreign material surface area is conservative and acceptable. The inclusion of the glass light bulb debris is also conservative, since the glass density is greater than that of the water and macroscopic pieces of glass would likely not be transportable to the containment sump. A 5 percent margin was conservatively added to both categories of tags, labels and stickers, and the glass for specification of sacrificial area for the sump strainers.

3.4.3 Latent Debris Mass and Tags and Labels Results

Latent Debris Mass

The results of the NAPS 2 analysis for latent debris mass and the quantity of tags, labels, and other such items in containment are presented in Table 5. The total quantity of latent dirt, dust and lint computed from the sample measurements and surface areas was 113 lb_m.

As discussed in Section 3.4.2, at the on-site audit NAPS recalculated the total latent debris mass, adding an additional 0.1 gram to each of the measured sample weights. The total debris load was recalculated as 123.92 lb_m. The relatively small increment associated with this uncertainty correction is because the largest contributors to the total latent debris mass are those surfaces for which the measured sample weights are the largest. For these surfaces, the addition of 0.1 gram to the sample mass is relatively small, and the effect of the uncertainty correction is not great. In the same recalculation, NAPS also re-estimated the grating areas at two elevations (291'10" and 262'10"), substituting actual beam widths and lengths for the conservative estimates that had been used to determine the originally calculated value of 113 lb_m. With these actual grating dimensions, the total debris load was recalculated as 112.43 lb_m. As a result of this recalculation, the licensee concluded that adequate conservatism was built into the calculation of the total latent debris mass to compensate for uncertainties relating to the resolution of the mass measurement apparatus.

The staff accepts that the licensee's recalculation showed that adequate conservatism was built into the original calculation to compensate for uncertainties due to mass measurement resolution. This includes a conservative estimate of containment surface areas, and also includes the use of the 90% confidence limit for latent debris mass instead of the mean value.

As discussed above, the estimate of the mean debris mass for the horizontal duct surface category uses only one measurement of that category, and supplements it with four additional measurements from the horizontal pipe category. Based upon the 90% confidence upper limit of the mean debris loading based on the five measurements, the mass of debris in this surface category is computed by the licensee as 1.83 lb_m. More conservatively, using the single representative measurement of this surface category, the mass of debris is 2.98 lb_m. Thus, the licensee result of 1.83 lb_m may be underestimated by approximately one lb_m out of a total estimate of 113 lb_m of latent debris. This is judged by the staff to be insignificant in its impact on sump strainer design, and the staff concludes that the overall estimate of 113 lb_m for the latent debris mass is justifiable as a conservative estimate of the latent debris mass in containment. In addition, the licensee included a 5% margin on latent debris in the strainer design specification, which brings the total latent debris mass specified to 118 lb_m [61].

The staff considers the licensee's assumption that latent debris consists of 15% fiber and 85% particulate to be acceptable because this assumption is consistent with the staff's SE [12].

Tags, Tapes, Labels and Glass

The licensee used the NAPS 1 foreign material estimates for the sacrificial area in the specification of the sump strainer, since the estimated foreign material surface area is greater than for NAPS 2. The total quantity of tape, tags, labels and broken glass was determined to be 240 ft^2, as shown in Table 5 [32]. This quantity was used as the sacrificial area for the sump strainer design. All stickers, placards and tape were conservatively assumed to be transportable to the containment sump. One-hundred percent of the sum of the areas of the individual debris pieces is taken as the total area of tags, labels and stickers. The staff considers this methodology to be acceptable because it conservatively accounts for the inventory of stickers, placards and tape in containment. The inclusion of the broken glass surface area in the foreign material estimate is considered conservative, since it is the staff's view that large pieces of broken glass are not likely to be transported to the sump strainer because of their specific gravity relative to water. The estimate of 240 ft^2 is, therefore, considered conservative and acceptable for application to both NAPS units.

Table 5 NAPS Latent Debris and Tags, Labels, and Other Material Results

Latent Debris and Foreign Material	Quantity	Type
[1]Dirt, Dust, and Lint	113 lb_m	Assumed 15% Fibrous and 85% Particulate
[2]Tape, Tags, and Labels	40 ft^2	Foreign Material
[2]Broken Glass (from bulbs and fixtures)	200 ft^2	
Total	240 ft^2	

[1] Estimate based on NAPS 2 measurements
[2] Estimate based on NAPS 1 measurements

3.4.4 Summary

The estimation of latent debris mass in containment follows the guidance of NEI 04-07 [5] and the staff's SE [12] and contains a number of conservatisms. As described above, based upon significant conservatisms in the latent debris mass calculation, the staff accepts the latent debris mass estimate, despite the issue raised concerning mass measurement uncertainty. Specifically, the licensee's conservative estimate of surface areas of the various area types and its use of the 90% uncertainty bound for latent mass estimation provide adequate margin to compensate for the effect of the mass measurement uncertainty. Additional conservatism is provided by the 5% margin for latent debris that was included in the strainer design specification, bringing the total latent debris mass specified for the strainer design to 118 lb_m [61].

The licensee's methodology for estimating the quantity of foreign material in containment follows the guidance of NEI 04-07 [5] and the staff's SE [12] and further contains a number of conservatisms. Therefore, the staff finds the licensee's methodology for estimating the quantity of foreign materials to be acceptable. The major contributor to the foreign material estimate is glass from light bulbs and fixtures. The staff considers the licensee's foreign material estimate to be conservative, since significant quantities of broken glass are not expected to be transportable to the sump strainer because the density and expected size of the glass pieces are likely to cause much of this debris to settle to the containment floor.

3.5 Debris Transport

Debris transport analysis estimates the fraction of debris generated by a LOCA or other high-energy line break requiring containment sump recirculation that would be transported to the sump suction strainers. Generally speaking, debris transport in the containment would occur through four major mechanisms:

- blowdown transport, which is the vertical and horizontal transport of debris throughout containment by the break jet;
- washdown transport, which is the downward transport of debris due to fluid flows from containment sprays and the pipe rupture;
- pool-fill transport, which is the horizontal transport of debris by break flow and containment spray flow to areas of the containment pool that may be active (influenced by recirculation flow through the suction strainers) or inactive (not involved in recirculation flow) during sump recirculation; and
- containment pool recirculation transport, which is the horizontal transport of debris from the active portions of the containment pool to the suction strainers through pool flows induced by the operation of the ECCS and containment spray systems in recirculation mode.

Through the blowdown mechanism, some debris would be transported throughout the lower and upper containment. Through the washdown mechanism, a fraction of the debris in the upper containment would be washed down to the containment pool. Through the pool fill-up mechanism, debris on the containment floor would be scattered to various locations, and some debris could be washed into inactive volumes which do not participate in recirculation. Any debris that enters an inactive pool would tend to stay there, rather than being transported to the suction strainers. Through the recirculation mode, a fraction of the debris in the active portions of the containment pool would be transported to the suction strainers, while the remaining fraction would settle out on the containment floor.

The staff reviewed the debris transport analysis for NAPS, which was primarily contained in the debris transport calculation [29]. The debris transport calculation stated that the transport methodology used for NAPS is based on the methodology in Nuclear Energy Institute (NEI) 04-07 [5], as modified by the associated NRC SE [6], and Regulatory Guide 1.82 [7]. In particular, the licensee's methodology for calculating debris transport fractions was modeled on the NEI 04-07 [5] baseline methodology.

The licensee did not credit a computational fluid dynamics (CFD) analysis to calculate the flow of water in the containment pool during the recirculation phase of a LOCA as an input to the determination of debris transport fractions. However, the licensee is currently developing a CFD calculation using the FLUENT code that will provide a basis for revised debris transport fractions that may be used to determine the quantities of debris for future chemical effects head loss testing. This report does not document review of the licensee’s CFD calculation because the calculation was not available during the audit. However, the staff stated during the audit that the discussion of CFD in previous audit reports [22, 23] may provide useful insights for developing the NAPS CFD model. The audit team also identified that the most recent version of the Updated Final Safety Analysis Report for NAPS available at the plant site incorrectly stated that CFD is used as a basis for computing debris transport fractions. The licensee subsequently confirmed that this statement in the recent Updated Final Safety Analysis Report update was premature and stated that an Updated Final Safety Analysis Report change request would be processed to correct the issue.

The following subsections discuss significant aspects of the licensee's transport methodology, noting any specific issues the NRC staff identified during the audit review.

3.5.1 Blowdown Transport

Because of the complexity of modeling dynamic multi-phase fluid flows in containment following a pipe rupture, the licensee used the simplified methodology for blowdown transport presented in Section 3.6.3.2 of NEI 04-07 and Appendix VI of the staff's SE on NEI 04-07 [6]. The licensee further stated that the blowdown transport analysis was also based on the methodology from NUREG/CR-6369, the Drywell Debris Transport Study performed for boiling-water reactors [34].

The licensee stated that NAPS has a mostly uncompartmentalized containment, except for the existence of a pressurizer room. Based upon the NEI methodology for this containment configuration, the licensee stated that all RMI debris (both small and large pieces) was conservatively postulated to fall directly into the containment pool rather than being blown into the upper containment [29]. Although NEI 04-07 does not specifically state that all post-accident debris should be modeled as directly falling into the containment pool, the licensee took this conservative position [29]. The licensee considered this approach reasonable based upon guidance in NEI 04-07 that large debris may be modeled as falling directly into the containment pool and the expectation that most of the small debris blown into upper containment would eventually be washed down into the containment pool [29].

The staff considered the licensee's approach for analyzing blowdown transport to be conservative for evaluating debris transport to the sump strainers. In particular, although the assumption that all post-accident debris directly enters the containment pool is not realistic, it ensures that no credit is taken for the capture and sequestration of debris at higher elevations of containment. As a result, the quantity of debris available for transport to the sump strainers is conservatively maximized. While this approach is conservative with respect to sump strainer sizing, without adequate technical justification, the staff would not consider the assumption that no debris is blown into the upper containment to be generally acceptable for other purposes, such as analyzing the susceptibility of the refueling cavity drains (or other choke points in containment) to debris blockage. This issue is further addressed in the Containment Pool Water Level Assumed for Debris Transport (page 31) and Upstream Effects (page 63) sections of this audit report.

3.5.2 Washdown Transport

Since the licensee assumed that 100% of post-LOCA debris would be deposited directly into the containment pool, a detailed washdown analysis was not done [29]. Although the licensee's discussion of washdown transport included a limited description of the potential for some small pieces of debris to adhere to wet surfaces, inertial debris capture was ultimately not credited in the analysis [29]. In general, the locations where debris is assumed to enter the recirculation pool may have a strong influence on the debris transport fractions in an analysis for which less conservative assumptions are made. However, based upon the incorporation of significant conservatism into the existing NAPS transport analysis (primarily the assumptions that 100% of the debris directly enters the containment pool and that containment pool velocities are sufficiently high to transport a large fraction of the post-accident debris, regardless of where it entered the containment pool), the staff did not consider the simplifications in the licensee's washdown analysis to be of concern.

3.5.3 Pool-Fill Transport

The licensee did not create a detailed model of debris transport resulting from shallow, high-velocity sheeting flows that may occur during the pool fill-up phase. However, the licensee stated that, for breaks within the steam generator cavities, all debris within the cavities would be assumed to transport out of the cavities during pool fill-up due to the high velocity expected at the sheeting flow wave fronts [29]. The licensee's transport analysis did not credit inactive containment pool volumes with capturing debris [29].

The staff considers the licensee's decision not to credit debris settling in inactive pool volumes within the post-LOCA containment pool to be conservative because it maximizes the quantity of debris available to transport to the sump strainers during the recirculation phase of an accident. The staff also noted that the NAPS replacement strainers are elevated 6.375 inches above the floor of containment [29]. Because of the raised configuration of the NAPS replacement strainers and conservative transport assumptions made by the licensee, the staff's review did not identify the potential for significant quantities of debris to transport to and accumulate on the sump strainers during the filling of the containment pool, which had not already been accounted for in the existing analysis as reaching the strainers during the recirculation phase of the accident. Therefore, the staff considered the licensee's treatment of pool-fill transport to be acceptable.

3.5.4 Containment Pool Recirculation Transport

The pipe breaks the licensee analyzed for debris transport during the recirculation phase of a LOCA are listed in the table below.

Table 6 Pipe Breaks Analyzed for Debris Transport [29]

Break	Description
1	A rupture of the 31-inch intermediate leg piping at the Steam Generator B nozzle
2	A rupture of the 31-inch intermediate leg piping at the Steam Generator C nozzle
3	A rupture of the 31-inch intermediate leg piping at the Steam Generator A nozzle
4	A rupture of the 14-inch pressurizer surge line inside the pressurizer room

The staff's review of the licensee's break selection criteria is provided in Section 3.1 [page 9] of this audit report. However, the staff discussed one aspect associated with the selection of pipe ruptures with the licensee related to debris transport which is described below.

The NAPS replacement strainers comprise a lower strainer module for the RS pumps designed for 100% of the total plant debris loading and an upper strainer module for the LHSI pumps designed for 50% of the total plant debris loading. The staff questioned whether more than 50% of the plant debris loading could reach the LHSI strainers because, with fewer than two RS pumps running, more than half the total sump flow could be directed through the LHSI strainers. In particular, the staff focused upon whether any postulated small-break LOCAs might result in the LHSI system operating in recirculation mode with fewer than two RS pumps operating.

The licensee responded that the containment peak pressure and depressurization analysis assumes that the quench spray system is actuated either (1) automatically at a containment pressure setpoint of 30 psia or (2) manually at a containment pressure setpoint of 20 psia [38]. The RS system is further assumed to be actuated manually when the containment pool depth reaches 2 feet, based on planned procedure changes once the replacement strainers have been installed [38]. Based upon these assumptions, the licensee determined that the RS system would be operating before the switchover of the LHSI to recirculation mode for analyzed small-break and large-break LOCAs [38, 35]. The licensee further verbally stated that emergency operating procedures will be modified following the replacement strainer installation to instruct operators to leave at least two RS pumps running following a LOCA.

Based upon the information provided by the licensee, the staff considered the licensee to have adequately justified designing the LHSI strainer for 50% of the total plant debris quantity. By ensuring that at least two of the four RS pumps are operating when the LHSI pumps are operating in recirculation mode, the staff expects that the actual flow and debris splits between the RS and LHSI strainers would be bounded by the licensee's analysis.

3.5.4.1 Debris Transport Metrics

A summary of the metrics used by the licensee to analyze debris transport during containment pool recirculation is provided in Table 7 below, which is taken from the licensee's debris transport calculation [29]. The transport metrics used by the licensee were all ultimately based on separate-effects transport testing reported in NUREG/CR-6772 [10].

Table 7 Metrics Used for Analyzing Debris Transport During Recirculation [29]

Debris Type	Size	Incipient Tumbling Velocity (ft/s)	Lift Velocity for a 6-Inch Curb (ft/s)
Fibrous	Small Pieces	0.12	0.28
	Large Pieces	0.12	0.28
	Intact Pieces	0.12	None

Debris Type	Size	Incipient Tumbling Velocity (ft/s)	Lift Velocity for a 6-Inch Curb (ft/s)
Reflective Metallic Insulation (RMI)	Large Pieces	0.28	None

The staff considered the transport metrics for RMI to be acceptable because they are based on experimental values reported in NUREG/CR-6772 [10]. The transport metrics in Table 7 that the licensee is applying to fibrous debris were derived from experiments with Transco Thermal-Wrap low-density fiberglass insulation. In addition to Transco Thermal-Wrap, the licensee is also applying the fibrous debris transport metrics to TempMat high-density fiberglass. Although two additional types of fibrous debris may be generated in the NAPS containment following a LOCA (Paroc mineral wool and small quantities of generic fiberglass), the metrics in Table 7 were not applied to these two fibrous materials because these two materials were assumed to be completely destroyed into small fines that fully transport to the sump [29].

The licensee justified the use of the above transport metrics for the fibrous debris at NAPS as follows. First, the licensee stated that these transport metrics are conservative for Thermal-Wrap debris because the metrics represent the minimum velocity values for the different sizes of Thermal-Wrap debris that were tested under quiescent conditions. The staff agrees with this statement based upon experimental data presented in NUREG/CR-6772 [10]. Second, the licensee stated that use of the metrics reported in Table 7 for TempMat is also conservative, because the higher density of TempMat would require a larger fluid velocity to induce transport. The staff considers this statement to be physically reasonable in light of the governing physical phenomena associated with debris transport and the conservatism inherent in using an incipient velocity (i.e., the velocity at which debris first begins to move) as a debris transport metric as opposed to a bulk transport velocity, at which a larger fraction of debris pieces are transported.

The staff further noted that the use of 0.12 ft/s as the metric for tumbling transport for large and intact pieces of debris will likely provide a significant overestimation of the quantity of debris expected to transport under actual plant conditions because this metric is an incipient tumbling velocity determined from testing smaller and more transportable shreds and pieces of fiberglass. The staff considered this overestimation to be conservative for sizing the sump strainers.

3.5.4.2 Fibrous Debris Erosion

The licensee's debris transport calculation [29] recognized that, while large or small pieces of exposed fibrous debris may not be transportable under low-velocity flow conditions, erosion of settled pieces of fibrous debris should be considered.

The licensee stated that Section III.3.3.3 of Appendix III to the staff's SE [6] suggests that, in lieu of specific erosion data, 90% of the small and large pieces of fibrous debris analyzed as settling in the containment pool should be considered to erode into fines over a 30-day period. The licensee stated that the SE position was based on data in NUREG/CR-6773 [37], for which one of the long-term integrated transport tests was performed at pool velocities of approximately 0.15 ft/s in the vicinity of the simulated pipe break and sump strainer. Since the licensee considered the flow velocities in the NAPS containment pool to be comparable to those in the applicable test from NUREG/CR-6773, the assumption of 90% erosion was applied for NAPS [29]. The licensee stated that large pieces of debris with intact jacketing were not considered to erode, which is consistent with the position taken in the staff's SE [6].

The staff agrees that the licensee's positions regarding fibrous debris erosion are consistent with the staff's SE and considers them to be acceptable. As noted in previous audit reports [22, 23], the staff would expect that any reductions in the quantity of fibrous debris assumed to erode in the post-LOCA containment pool be supported by a technically defensible basis, such as testing.

3.5.4.3 Containment Pool Water Level Assumed for Debris Transport

In the licensee's NPSH margin calculation [35], the licensee assumed that the 6-inch refueling canal drain would become blocked and 1850 ft^3 of water would be held up in the refueling canal. However, the debris transport calculation [29] states that the refueling canal drain should be assumed to remain unblocked based upon guidance provided in NEI 04-07 [5] that large pieces of debris should be modeled as falling directly into the containment pool. As a result, the licensee concluded that the only debris pieces capable of entering the refueling canal would be too small to block the 6-inch drain.

The staff stated a concern regarding the debris transport calculation's justification that the refueling canal drain would not become blocked to be inadequate. Specifically, as mentioned previously in Section 3.5.1 (page 27), while the assumption that large pieces of debris fall directly into the containment pool is a conservative approximation that is acceptable for sizing a sump strainer, this assumption is nonconservative with respect to analyzing the potential for debris blockage at containment choke points. The staff noted that, although the transport calculation's assumption that the refueling canal drain is not blocked did not adversely affect the debris transport fractions determined using the baseline transport methodology, this assumption could have a nonconservative effect on the CFD calculation currently being developed by the licensee. Specifically, the use of a nonconservatively high level in the containment pool would result in an underestimation of the velocities in the containment pool, which could result in reduced debris transport fractions.

In response to the staff's concern, the licensee stated that the planned CFD calculation will use the containment minimum water level calculated in the NPSH margin calculation [35], which considers the refueling canal to be filled with water. However, for the purpose of determining where drainage from the upper containment enters the containment pool, the licensee stated that the planned CFD calculation would consider the refueling canal drain to be open to flow. The licensee further stated that the assumption of the drain line being open to flow is conservative based upon its location relative to the containment sump.

The licensee's response addressed the staff's original question concerning the appropriateness of the water level in the planned CFD calculation because the licensee stated that the CFD calculation would assume a water level consistent with the plant minimum water level calculation. Since the CFD calculation was not available for review during the audit, the staff could not evaluate the conservatism associated with assuming that the refueling canal drain line is open for the purpose of assessing where refueling canal drainage enters the containment pool.

3.5.4.4 Debris Accumulation Under the Sump Strainer

In Attachment 8.3 to the debris transport calculation [29], the licensee calculated the volume of debris that could potentially accumulate beneath the replacement sump strainers. The purpose of the calculation was to provide input to the planned CFD calculation with respect to modeling the volume beneath the strainers as either blocked or allowing free flow [29].

The licensee made an unverified assumption in Attachment 8.3 that 50% of large debris pieces would not transport to the containment floor underneath the sump strainers because break flow would drive about half the large pieces of debris away from the sump region [29]. Based upon the presence of substantial conservativism in the existing transport analysis, the staff's experience with previous audits, and the staff's review of velocity contour plots from a CFD analysis for the similarly designed Surry Power Station included in the audit material for NAPS, the staff considered the licensee's assumption to be reasonable. Therefore, the staff did not consider this issue to be an open item. However, when the CFD analysis for NAPS is performed, the licensee should confirm that the fluid velocities predicted in the containment pool are consistent with the assumption that 50% of large debris pieces are not capable of reaching the containment floor underneath the strainers.

3.5.5 Approach for Calculating Debris Transport Fractions

The licensee considered it conservative to use the maximum velocity flowpath in the containment pool in determining the fraction of LOCA-generated debris that would reach the sump strainers [29]. Specifically, the licensee's methodology was to compare the maximum velocity flowpath in the containment pool to the metrics for incipient tumbling and lifting over a curb that are listed in Table 7 [29]. The staff considered the licensee's methodology to be conservative, since a significant fraction of the debris in containment would likely not be exposed to such high velocities.

Without a CFD calculation or other analysis of the flow velocities in the containment pool, the licensee assumed for all four analyzed breaks that the maximum pool flow velocity would be greater than 0.28 ft/s, which is the highest transport metric listed in Table 7. The staff considers this assumption to be conservative because it maximizes the quantity of debris transporting to the sump strainers.

The licensee further said that this conservative assumption might be revised after the CFD analysis is completed. This planned revision to the debris transport calculation was not within the scope of the audit because the licensee's CFD analysis was under development.

3.5.6 Overall Transport Results

In accordance with the methodology described by the staff above, the licensee's debris transport calculation [29] provides results for each scenario, including both debris transport fractions and total quantities of debris arriving at the containment recirculation sump. This information is reproduced in Tables 8 and 9 below. As expected based upon the discussion in Section 3.5.5 above, the transport fractions are the same for all four analyzed breaks. Therefore, differences in the total quantities of transported debris among the four breaks may be attributed to differences in how much debris generated.

Table 8 Debris Transport Fractions Calculated for Breaks 1–4 [29]

Debris Type	Transport Fraction
Transco RMI	0.75
Transco Thermal-Wrap (Within ZOI)	0.65
Transco Thermal-Wrap (Spray Generated)	1.00
TempMat (Within ZOI)	1.00
TempMat (Spray Generated)	1.00
Paroc Mineral Wool	1.00
Fiberglass (Spray Generated)	1.00
Qualified Coatings	1.00
Unqualified Coatings	1.00
Damaged Coatings	1.00
Latent Fiber	1.00
Latent Particulate	1.00
Foreign Material	1.00

Table 9 Total Quantities of Transported Debris for Breaks 1–4 [29]

Debris Type	Units	Break 1	Break 2	Break 3	Break 4
Transco RMI	ft^2	532.66	549.58	563.68	979.74
Transco Thermal-Wrap (Within ZOI)	ft^3	417.22	420.18	421.29	0.00
Transco Thermal-Wrap (Spray Generated)	ft^3	0.00	0.79	0.79	0.79
TempMat (Within ZOI)	ft^3	1.45	15.82	1.63	1.73
TempMat (Spray Generated)	ft^3	1.91	2.33	2.47	2.86
Paroc Mineral Wool	ft^3	62.48	57.12	77.75	107.82
Fiberglass (Spray Generated)	ft^3	4.20	4.20	4.20	4.20
Qualified Coatings	ft^3	5.32	5.32	5.32	0.45
Unqualified Coatings	ft^3	4.65	4.65	4.65	4.65

Debris Type	Units	Break 1	Break 2	Break 3	Break 4
Damaged Coatings	ft^3	1.72	1.72	1.72	1.72
Latent Fiber	lb_m	17.80	17.80	17.80	17.80
Latent Particulate	lb_m	100.85	100.85	100.85	100.85
Foreign Material	ft^2	252.00	252.00	252.00	252.00

Table 8 shows that the licensee assumed 100% transportability for most debris types and conservatively high transport fractions for all other types of debris. Therefore, the staff considered the licensee's existing transport analysis to be conservative overall.

3.6 Head Loss And Vortex Evaluation

3.6.1 Audit Scope

New replacement strainers designed by AECL were installed in North Anna Unit 2 in April 2007 during a refueling outage and are scheduled to be installed in Unit 1 during a fall 2007 refueling outage. The RS and the LHSI have separate strainer modules that are independent of each other. The total strainer areas are 4,415 ft^2 and 1,890 ft^2 for the RS and LHSI systems, respectively [28].

Each replacement strainer comprises a number of strainer modules attached to an interconnecting central plenum. Each module consists of 11 vertically oriented fins spaced 6 inches apart and connected with the central plenum where some fins are shortened to fit surrounding sump area structures [79]. The strainers incorporate orifices designed to force uniform flows across the various fins. For the RS strainer modules, the bottom and top edges of the fins are 6.375 inches and 21.5 inches above the containment floor, respectively. For the LHSI strainer modules, the bottom and top edges of the fins are 23.5 inches and 50.25 inches above the containment floor, respectively [73].

The allowable design head loss across the new RS strainer is 5.0 feet at 180 °F and at a flow rate of 12,620 gpm, which corresponds to the maximum flow for all four pumps operating. The allowable design head loss across the new LHSI strainer is 8.5 feet at 113 °F and at a flow rate of 4,050 gpm, which corresponds to the maximum flow for single-pump operation [78]. For the LHSI system, the licensee determined that single-pump operation is the most critical mode of operation from the NPSH margin perspective [77, 78]. AECL conducted prototypical head loss testing to qualify its design; however, these tests did not account for potential chemical effects precipitates [75]. As part of the prototypical head loss testing program, the licensee evaluated the susceptibility of the strainers to vortex formation.

The testing and analysis results of the licensee's effort were documented in eleven reports [28, 78, 73, 77, 79, 75, 30, 31, 62, 101, 80]. The NRC staff reviewed these reports and focused its audit of strainer head loss and vortexing in the areas of prototypical head loss test module design, scaling, surrogate material selection and preparation, testing procedures, results and data interpretation.

3.6.2 System Requirement

North Anna Unit 2 uses a sub-atmospheric containment designed so that the containment pressure drops below 14.7 psia one hour into a LOCA transient. Two containment spray systems depressurize and clean the containment atmosphere:

> The quench spray system has two pumps taking water from the RWST until it empties during the initial phase of a LOCA. Currently sodium hydroxide is added as a pH buffer to the quench spray pump suction five minutes after the containment depressurization signal.
>
> The RS system has two pumps inside the containment and two pumps outside the containment. All four RS pumps draw suction from the containment sump, pass heat through heat exchangers to the service water system, and spray the containment atmosphere.

The emergency core cooling system relies on the LHSI system to draw water from sump to maintain long term cooling.

Based on the revised LOCA containment analysis [62] using the GOTHIC code and approved license amendments, RS pumps switch to the containment sump on RWST level low (60 percent) with coincident containment depressurization actuation so that the containment pool water level would be sufficiently high to submerge the RS strainer. LHSI recirculation mode will start at 16 percent RWST level to gain NPSH margin and submergence. With these design changes, the most limiting NPSH margin of 1.57 feet for the LHSI pumps occurs with one pump operating at 4050 gpm after the switch-over to the containment sump. The strainer head loss due to debris needs to be less than the minimum NPSH margin.

3.6.3 Prototypical Head Loss Testing

The licensee employed Sargent & Lundy to design the initial strainer sizing design using NUREG/CR-6224 and NUREG/CR-6808 correlations. AECL, the strainer vendor, performed prototypical head loss testing based on the selected strainer surface area and the calculated debris loading. The test facility, shown in Figure 1 below, consisted of a 90-inch diameter open plastic tank with a maximum fill height of 56 inches. The fin/header test section was positioned on the floor of the tank and was attached to a piping system leading to a pump below the tank. The pump could produce a flow rate from 1 to 100 gpm. The strainer test module had one central fin and two half fins on each side with adjustable pitches (fin separation). The fins were constructed from stainless steel perforated with 1/16 inch holes and a corrugated plate bend angle of 60°. The fins were approximately dimensioned as the same size as the fins for the installed RS and LHSI strainer.

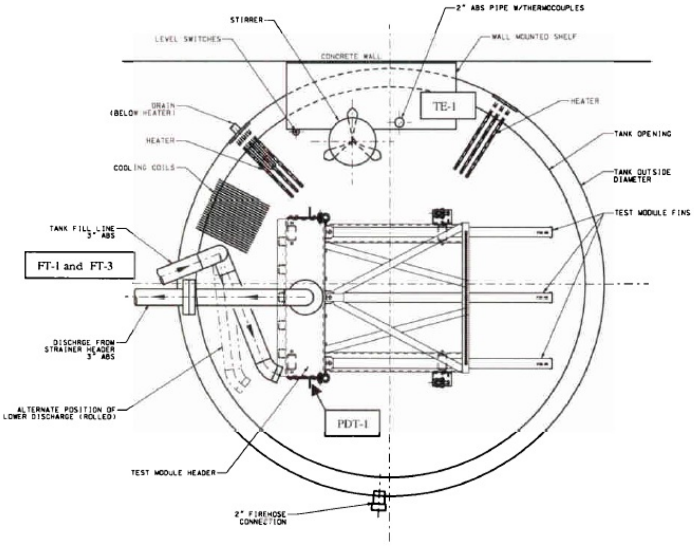

Figure 1 Head Loss Test Loop

AECL used this test loop to perform a series of tests to determine the thin bed thickness, and to optimize both the total surface area and fin pitch for normal debris. In addition, the test loop was used to conduct bypass tests. The staff reviewed the debris surrogate material selections, the testing procedures, the scaling methodology and the test results interpretation.

3.6.3.1 Debris Types, Quantities, and Characteristics

The bounding debris quantities for Break BK2 (break locations discussed in Section 3.1 page 9) were applied to the head loss testing specifications because Break BK2 was initially estimated to generate the largest quantities of debris [30]. A subsequent revision of the debris generation analysis [31] resulted in Break BK3 generating a slightly greater total quantity of fibrous debris than would Break BK2 (about 1% greater) but Break BK2 was retained for specifying the test debris quantities because of the insignificant difference in debris amounts between these two cases. The calculated foreign debris load was not added to the test debris loads; rather, the total replacement strainer area was conservatively increased by an equivalent area to simulate the accumulation of foreign debris on the replacement strainer. The bounding quantities of debris estimated for Break BK2 are compared to the full head loss test debris loads in Table 10.

Table 10 Comparison of Break BK2 and Head Loss Testing Debris Loads

Debris Type	Units	Break BK2	Full Test
Metallic Debris			
Transco RMI	ft^2	550	550
Fibrous Debris			
Transco Thermal-Wrap Fiberglass (Unspecified)*	ft^3	421 4.2	425
Temp-Mat	ft^3	18.2	18.7

Debris Type	**Units**	**Break BK2**	**Full Test**
Paroc Mineral Wool**	ft^3	57.1	57.1
Latent Fibers	lb_m	17.8	17.8
Particulate Debris			
Qualified Coatings	ft^3	5.32	6.4
Unqualified Coatings	ft^3	4.66	2.7
Damaged Coatings	ft^3	1.72	1.7
Coatings Totals	ft^3	**11.7**	**10.8**
Latent Particulate	lb_m	101.1	101
* The small quantity of unspecified fiberglass debris was subsumed into the Thermal-Wrap. ** Smaller volumes of Paroc were used for Unit 1 testing.			

The total coatings debris tested was 10.8 ft^3 compared with the total of 11.7 ft^3 coatings debris estimated to arrive at the strainers in the debris generation analysis. The debris generation and transport estimates included a 10% margin on all coatings debris that the licensee subsequently removed upon specifying the debris loads for the head loss tests. Except for coating debris, the debris generation and transport estimates compare well with the test debris loads.

Calcium silicate and Microtherm insulation debris was used in the earlier head loss testing but due to the high head losses associated with these debris types, all of the calcium silicate and Microtherm that was located within a potential debris ZOI was replaced with Paroc mineral wool. Therefore, the calcium silicate and Microtherm insulations are not discussed further in this head loss testing section.

The full debris loads were applied when the RS strainers were tested, but only half of the full debris loads were applied when testing the LHSI strainers. Because the RS pumps would take suction through the RS strainer before the LHSI switchover to recirculation, the RS strainer could be exposed to 100% of the debris load. Based on the premise that at least two RS pumps would be drawing water through the RS strainers whenever the LHSI pumps were taking suction through the LHSI strainers, the licensee determined that the LHSI strainers would not be exposed to the full debris loads. The licensee evaluated the various combinations of RS and LHSI pump flow rates and determined that no more than 46% of the total recirculation flow taking suction through either the RS or the LHSI strainer would pass through the LHSI strainers; therefore, no more than 46% of the full debris load could accumulate on the LHSI strainers. The licensee subsequently tested the LHSI strainers with 50% of the full debris load for each type of debris being introduced into the test tank.

The one surrogate debris that is dramatically different from the corresponding plant materials is the walnut shell flour that simulates the coatings debris and the latent particulates. The applicability of the walnut shell flour to simulate coatings debris and latent particulate was evaluated during the NRC audit for the Dominion operated Millstone Unit 2 plant conducted in January of 2007 [23] for which AECL also used walnut shell flour to simulate coatings debris and latent particulate. The practical reason for using the walnut shell flour was that its material density was lighter than the plant material being simulated, which would conservatively reduce the debris settling during the testing. This reason was accepted by the staff as a valid consideration. However, an important debris characteristic is the walnut shell flour's ability to simulate head loss behavior in the test bed. To justify this characteristic, the licensee provided the audit team walnut shell flour particle size distribution as evidence that demonstrates a somewhat flaky characteristic that could be responsible for its enhanced head loss behavior over the analytical expectation.

Staff Evaluation

The staff compared the characteristics of the surrogate test materials with the corresponding plant material to ensure either prototypicality or conservatism. The surrogate materials selected for the head loss are compared to the postulated plant debris in Table 11, along with the licensee's justification for the surrogate selections.

Table 11 Selection of Surrogate Test Debris

Postulated Plant Debris	Surrogate Material	Justification
Transco RMI	Transco Stainless Steel Foil	Surrogate debris manufactured from same material as plant insulation
Transco Thermal-Wrap	Thermal-Wrap Supplied Transco Products	Surrogate debris manufactured from same material as plant insulation
Temp-Mat	Temp-Mat Supplied by GLT Products	Surrogate debris manufactured from same material as plant insulation
Paroc Mineral Wool	Paroc Mineral Wool	Surrogate debris manufactured from same material as plant insulation
Latent Fibers	Transco Thermal-Wrap	Transco Thermal-Wrap similar to Guidance Report-recommended Nukon® insulation
Qualified Coatings	Walnut Shell Flour (passed through a #325 sieve)	Relatively low particle density solved transport issue with near field debris settling that was associated with testing with heavier particulates
Unqualified Coatings		
Damaged Coatings		
Latent Particulates		

The licensee's selections for surrogate metallic and fibrous insulation debris are all valid selections since the surrogate debris was created from essentially the materials as that used in the plant. The use of Transco Thermal-Wrap to simulate latent fibers is acceptable since the Thermal-Wrap is low-density fiberglass insulation similar to Nukon® insulation which the staff accepted as a suitable surrogate for latent fibers. The staff's conclusions regarding use of walnut shell flour are discussed in Section 3.3.4 (page 19) of this audit report.

3.6.3.2 Test Procedures

The key aspects of the AECL head loss testing that the staff reviewed during the onsite audit included the preparation of the surrogate debris, the introduction of the debris into the test tank, the criteria used to terminate a test, and the adequacy of the test apparatus to achieve the test objectives.

The licensee's debris generation and transport analyses for the NAPS replacement strainers clearly demonstrated that the only consequential accumulation of debris would be the very fine debris that could remain effectively suspended given sump pool turbulence conditions. Because the replacement strainer circumscribed approach velocities would be significantly slower than 0.1 ft/s, even the small fibrous shreds would be expected to remain on the sump floor rather than accumulate on the strainer vertical surfaces. Therefore, the preparation of the fibrous debris used in the NAPS head loss tests needed to generate quite fine fiber. AECL first mechanically shredded the fibrous insulations and then subjected the shreds after wetting to the agitation of a water jet from a pressure washer to separate the fibers. Photographic evidence was presented in the test report [75] to illustrate the fineness of the prepared fibrous debris. However, no data was provided whereby this fineness could be quantified and compared with the fineness of truly suspended fibrous debris. The adequacy of the preparation of the fibrous debris could only be gauged by its tendency to settle within the test tank during a test. AECL installed a mechanical stirrer that was used to reduce debris settling within the tank and occasionally used a brush to entrain settled debris. According to the post-test data for the qualifying series of thin-bed tests, 24% to 33% of the fibrous debris was recovered from the tank floor.

The audit did not identify any significant concerns with the procedures used by AECL to introduce debris into the test tank. After establishing the specified hydraulic conditions for pump flow, water temperature, and pH, the actual test was initiated with the introduction of the full load of the walnut shell flour particulate before adding the first fibrous debris. This process should have allowed the particulate to disperse uniformly within the test water before any strainer filtration. The fibrous debris was subsequently added in small batches with a volume equivalent of a 1/16-inch layer of debris on all of the strainer perforated surfaces (assuming no settling within the tank). The debris was introduced near the edge of the tank away from the test strainer module to prevent the debris from being immediately pulled to the strainer so that the debris could accumulate naturally. AECL staff stated that allowing debris to form directly on the strainer would result in less head losses due to non-uniformities. Once introduced, the debris followed the tank circulation pattern that carried debris around the outer perimeter of the tank until drawn into the strainer. The thin-bed test procedure was to continually add additional batches of fibrous debris but allow the head loss to stabilize between the additions. The idea was that the optimal fiber bed thickness for achieving the peak potential head loss would be determined once further fiber additions did not cause significantly higher head losses. The staff accepted the AECL procedures for introducing debris as adequate because each incremental fiber addition was only 1/16-inch and a relatively long testing time was used to stabilize the debris distribution on the strainer surface.

The AECL stability criterion used to terminate a test was a change of less than 5% or 0.1 psi, whichever is greater, and exhibiting no general steadily increasing trend in pressure within 1.5 hours. Since the tank turnover time for NAPS testing was typically 20 minutes, the minimum number of tank turnovers within 1.5 hours was about 4.5. In practice, a typical NAPS head loss test was conducted over a period of several days with the addition of six batches of fiber for the thin bed tests where the first two batches were introduced essentially at the beginning and the peak head losses occurring around the third or forth batch. Note that with four batches introduced and assuming 30% of that settled to the tank floor, the accumulated thickness would be about 0.18-inch thick which is consistent with NRC-sponsored closed loop head loss testing experience [81, 21]. Because the test plots covered several days' worth of head loss data within a single plot, staff review of details such as head loss increases over a 1.5 hour period to verify that the application of the AECL test termination criterion was properly applied was not possible. AECL presented photographic evidence of the test tank water visibility clearing that was associated with peak head losses and that indicates the relative completion of the debris accumulation on the test strainers. This visibility clearing is a good indicator that the tests were conducted for an adequately long time before being terminated.

Regarding the thin-bed test procedure of adding small batches until a peak head loss is obtained, in reality, the optimal bed thickness for achieving a peak head loss would be built up by a continuous addition of fiber rather than discreet batches separated by considerable times. The staff questioned what the result would be had the optimal thin-bed thickness of fibrous debris been added to the test essentially in one batch rather than the separated multiple batches. Specifically, the team questioned whether this alternative could have resulted in even higher head losses than the head losses that occurred in the tests. The licensee's response to this question was that AECL had conducted exploratory testing early on in their test program that confirmed that the NAPS thin-bed test procedure was conservative. Noting that the data from the AECL exploratory testing was not available for staff review, the staff accepted this explanation based on AECL's overall credibility in conducting head loss testing, the overall staff satisfaction with the testing performed for NAPS, and because the staff has been accepting the batch method of determining peak thin bed head losses rather than conducting multiple tests using the continuous fiber method.

The quality of several NAPS tests suffered from inadvertent pump stoppages that may have affected peak head losses in those tests. It is possible that when the pump stopped, the debris bed was disrupted and that when the pump was restarted, the renewed debris accumulation was less intact than it would have been for the original debris bed had the pump not stopped. However, only one of the final series of strainer qualification tests suffered from pump stoppage. That test (Test 15) was a thin-bed test for the LHSI strainer module. Since Test 16 was essentially a repeat test of Test 15, and the two tests had comparable results, the staff dismissed the concern about the pump stoppages.

Staff Evaluation

Regarding the fiber debris preparation, the staff found that the post-test data for the qualifying series of thin-bed tests documented that only 24% to 33% of the fibrous debris was recovered from the tank floor. Therefore, the major portion of the fibrous debris introduced into the test tank ended up the surface of the strainer. Because the approach velocity was so low around the strainer, only fine fiber could possibly be transported to the strainer surface. Based on this observation, the staff accepted this result as evidence that the AECL preparation of fibrous debris was adequate provided the testing procedure for developing a thin-bed was adequate regarding this preparation. The preparation of the particulate debris, specifically the walnut shell flour, which was simply premixed with water, was also accepted as adequate by the staff.

The staff accepted that the test apparatus is adequate to accomplish the test objectives. Heater and cooling coils adequately controlled the water temperature. Baffles and skirts protected the test strainer module from turbulent flow eddies created by the stirrer mechanism used to reduce debris settling within the tank. The flow meters were calibrated properly according to the records [75].

In terms of test termination criteria, AECL conducted the head loss testing over several days to satisfy the termination criteria. At the end of the test, the photos showed apparent visibility clearing, which is a good indicator that the tests were conducted for an adequately long time before being terminated. Therefore, the staff accepted the AECL test termination criteria as adequate for the NAPS tests.

Overall, the staff's review of the key testing procedures affecting the North Anna Unit 2 strainer head loss measurements concluded that the debris introduction procedures resulted in minimum near field settlement and resulted in conservatively measured head losses. Therefore, the North Anna Unit 2 strainer head loss testing procedures are considered acceptable.

3.6.3.3 Scaling Methodology

The AECL head loss test strainer module had one full fin and two half fins. During the test, all the debris was introduced into the flume outside of the baffles, and stirrers were used to minimize the debris settlement outside the baffle area. Therefore, debris settlement was reduced. Assuming uniform debris distribution, AECL scaled the total debris loading based on the ratio between the total testing module surface area and the actual strainer surface area. This scaling approach has been commonly used in strainer vendors' testing protocols. The strainer approach velocity was scaled one to one. The testing module had slightly different dimensions from that of actual strainers.

Staff Evaluation

The AECL head loss test was set up to reduce near-field debris settlement. The staff concludes that the settlement was minimal based on the use of a mechanical stirrer. Based on staff observations and discussions with the licensee and vendor staff, the stirrer was effective in minimizing settlement. The uniform debris distribution is used to scale the debris loading. The staff finds the assumption of uniform debris loading acceptable based on the examination of the post-test photos in reference [79]. The testing strainer surface approach velocity was kept the same as that of the actual strainer modules. Although the testing module size was slightly different from the actual strainer module size, the debris loading for the test was scaled based on the area ratio. Therefore, the area-based scaling methodology is considered acceptable.

3.6.3.4 Test Results and Interpretation

The NAPS head loss test data exhibited a decreasing head loss phenomenon that has not been seen in other test data, including in the Millstone Unit 2 data reviewed by the staff for the same type strainer as was tested for NAPS. The head loss decreased much less after reaching the peak during the strainer head loss testing for Millstone Unit 2. For NAPS, the head loss test results showed a slowly decreasing head loss once a peak head loss was reached and the rate of adding additional debris to the strainer slowed substantially. Specifically, the staff has the following observations:

1. In several key tests, substantial decreases in head losses occurred after the head losses peaked (e.g., Test NA-15 as seen in Figure B-75 in [75]) that did not occur in tests with relatively low head losses of less than 0.1 feet (e.g., Test NA-9 as seen in Figure B-52 in [75]).

2. Head loss increased followed late additions of more fiber at a rate that appeared to be faster than rates typically associated with particulate filtration. This behavior may have been due to the late fiber patching thin or sparse spots in the debris bed. Some photos of late fiber debris accumulation illustrated a patchy accumulation as this fiber apparently preferentially accumulated at the thin or sparse locations of the debris bed.

3. The test water tended to clear, which demonstrated the completeness of the particulate filtration process. Late fiber additions apparently did not acquire the brownish color of the walnut shell flour, indicating that fibrous debris added would tend to cover the penetrations along the rim of the strainer surface with a porous fluid flow path.

These observations suggest that differential pressure driven processes occurred and may have caused the observed head loss decreases.

AECL offered the theory that air dissolution within the debris bed and migration of the air through the debris bed could explain the decreasing head loss trend. With this theory, air bubbles in the debris bed decreased the available flow area, resulting in increased head losses. Then when air migration through the bed exceeded the air dissolution rate, the head loss would decrease, leading to the observed behavior. This theory was not validated or fully supported. However, if the theory were substantiated, the impact of air dissolution would have a head loss dependency, as well as a temperature dependency.

The staff speculated that the head loss decreases were due to degradation of the debris bed once additional debris accumulation effectively ceased. One possibility is that, after the peak head loss was achieved, particulate debris may have migrated from the ridges of the AECL corrugated strainer surfaces into the valleys, leaving thin or sparse spots on the ridges, which likely would have caused the head losses to decrease. Further additions of fibrous debris would preferentially seek the more open ridges, thereby reinforcing the thin or sparse ridges and perhaps causing the observed rapid head loss increases. Some test photos showed that the clean fiber added later in the testing had accumulated on top of the earlier fibrous debris (browned with walnut shell flour accumulations). Although such debris bed degradation may be a positive aspect of the AECL strainer, a question was raised regarding whether such degradation would occur to the same extent at the lower head losses associated with higher sump pool temperatures expected to occur post-LOCA in the plant.

The licensee used water viscosity for scaling test head losses to expected plant post-LOCA conditions. The ratios used were about 1.9 and 1.1 for the RS and LHSI, respectively. For the

RS, the test viscosity for the 104 °F test temperature is about 1.9 times than that of the 180 °F sump pool temperature. For the LHSI, the head loss was only scaled to the sump pool temperature of 113 °F; therefore the scaling ratio was only 1.1. For the RS strainer, the measured head losses would exceed the acceptance test criteria if the viscosity scaling were not applied. Therefore, the acceptance of the RS strainer head losses depends upon use of viscosity scaling.

The licensee's head loss scaling from the test temperature to the plant sump pool temperatures was based on the temperature-dependent viscosity of the water which has generally been accepted as conservative. That is, taking the NUREG/CR-6224 correlation [9] as a guide, when the compression of the debris bed is neglected and at low approach velocities, the head loss becomes nearly directly proportional to the viscosity, i.e., assuming that the velocity-squared term can be neglected. Neglecting the bed compression is conservative. However, the validity of the viscosity scaling methodology is based on having comparable debris beds between the test strainer and the plant replacement strainer.

Not considering potential chemical effects, AECL used a linear extrapolation scheme (pressure drop proportional to the viscosity) to predict the maximum debris bed head loss under expected post-LOCA sump temperature conditions. The sharp head loss decrease after the peak value was measured demonstrated a potential debris bed degradation mechanism. It is not clear to the staff whether the degradation mechanism had deformed the debris bed when the peak head loss was achieved. The NRC staff concluded that the licensee needs to evaluate the impact of the possible debris bed degradation mechanism on the validity of the measured peak head loss and the use of the current temperature extrapolation scheme considering the degradation mechanism and provide a summary of the results to the staff. This is **Open Item 3.6-1**.

3.6.3.5 LHSI Strainer Head Loss Assumption

The licensee reviewed LHSI one-train versus two-train operation and concluded that the limiting condition for NPSH margin occurs with one train due to the highest flow through one pump along with the highest suction piping head losses. For short-term operation, the licensee calculated a minimum LHSI NPSH margin of 1.77 feet at the time of recirculation mode transfer. This is less than the total strainer head loss. The licensee realized that the result was not acceptable. On page 6 of 8 of reference [78], the licensee assumed that the maximum "short-term" debris laden head loss would not occur at the time of recirculation mode transfer. However, the licensee assumed that it would take two pool turnovers to accumulate the needed debris on the surface of the strainer to form a thin bed.

The staff questioned this approach, noting that the SE guidance provides that a licensee evaluate the minimum NPSH margin using the maximum head loss at the beginning of recirculation. The licensee, however, deviated from the evaluation criterion of the SE to take credit for gradual debris accumulation. After the staff identified this issue, the licensee recalculated the LHSI pump NPSH time history and concluded that the NPSH margin becomes greater than the maximum head loss only a few minutes after recirculation mode transfer.

Staff Evaluation

The licensee's approach of assuming gradual debris accumulation during a period of time after recirculation mode transfer is a deviation from staff's SE. The staff agrees that the debris accumulation on the strainer surface takes time and the head loss increases over time. However, the licensee had not provided justification that demonstrated that the head loss of the debris-laden strainer is less than the NPSH margin during this period of time. The staff considers that the licensee needs to provide justification for its conclusion that the NPSH margin is greater than the maximum head loss throughout the post-LOCA period. This is **Open Item 3.6-2**.

3.6.4 Clean Strainer Head Loss

To maximize the strainer surface area in the available space of North Anna Unit 2 containment, two trains of strainer modules were connected to the pump intakes. These strainer modules were designed to be connected to a central common header. An internal orifice in the flow path of each strainer module was built to force a uniform flow through the entire array. The orifices for these modules were sized to provide appropriate resistance to balance the flow correctly. In this way, all modules from both trains are expected to experience reasonably uniform debris deposition.

The total strainer head loss is the summation of the internal (clean strainer) head loss and the debris bed head loss. AECL calculated the clean strainer head loss using standard methods for flow in pipes and ducts [13]. Since the flow inside the strainer is in the turbulent regime, the calculated total pressure drop was essentially independent of temperature.

Staff Evaluation

Because a standard flow resistance calculation method for pipes and ducts was used by AECL to calculate the strainer internal head loss, the overall analysis approach is considered acceptable. The use of the internal orifices in the flow stream inside the two strainer arrays will tend to create uniform flow across all strainer modules, reducing compaction of the debris bed to some degree on each module due to sequential deposition. This is considered by the staff to be a reasonable approach to avoid possible high head loss across the strainer arrays.

3.6.5 Head Loss Summary

The licensee tested plant-specific prototypical strainers to measure the head loss across the AECL strainer arrays with North Anna Unit 2 plant-specific debris loading. The NRC reviewed the testing matrix, the testing procedures and the system input evaluation during the audit. Because the measured maximum head loss of LHSI strainer is greater than the available LHSI pump NPSH margin available at the time of recirculation mode transfer, the licensee assumed that the strainer head loss gradually increased to the maximum thin bed head loss over time. The staff identified this as an open item as previously discussed in Section 3.6.3.5 (43) of this audit report. In addition, the observed head loss decrease during the testing is considered to be caused by debris bed degradation due to high head loss. It is not clear that this degradation mechanism would have an impact on the maximum head loss and the temperature extrapolation scheme. This is identified as an open item in Section 3.6.3.4 (page 43).

3.6.6 Vortex Evaluation

The licensee investigated the possibility of vortex formation as part of the strainer array testing program. As part of the prototypical head loss test, the licensee conducted a clean strainer head loss test and a strainer air ingestion test (Page 4 of 8 [78]). Before debris head loss testing, air ingestion was evaluated at a maximum flow rate with minimum water level. From Reference [78], Table 5.2-8, the minimum water level is 1.86 feet for the ORS pumps, which occurs at an ORS pump start time of t=1006 seconds. The minimum water level of 5 feet for LHSI pump occurs at recirculation mode transfer. The licensee tested for clean strainer head loss with the maximum flow rate through both RS and LHSI strainer modules. Neither vortex formation nor air ingestion were observed during the tests.

Staff Evaluation

The licensee tested strainer modules to evaluate possible vortex formation on top of the strainer fins. The staff concluded that the licensee's test practices were acceptable because approximately the same size strainer fins were used in the testing with a minimum submergence level determined by the LOCA analysis. Therefore, the staff agrees with the licensee that the new strainer designs are likely not subject to vortex formation.

3.7 Net Positive Suction Head

The licensee calculated NPSH margins for pumps credited with taking suction from the containment recirculation sump to provide long-term cooling to the reactor core and containment atmosphere following postulated accidents. At the NAPS, these pumps include the two LHSI pumps, the two IRS pumps and the two ORS pumps.

The staff reviewed the significant models and assumptions of the licensee's NPSH calculations and discussed these calculations with licensee personnel during the audit. The staff's review used guidance provided by NRC Regulatory Guide 1.82 [7], NRC Generic Letter 97-04 [15], the NRC Audit Plan [16], Nuclear Energy Institute (NEI) 04-07 [5], and the NRC Safety Evaluation on NEI 04-07 [12].

3.7.1 Summary of NPSH Margin Calculation Results

The NAPS NPSH margin calculation was performed using a transient methodology that takes credit for containment accident pressure (i.e., the difference between the containment atmosphere pressure and the vapor pressure of the sump water at the pump suction). Since containment parameters that influence the NPSH available (NPSHa) vary significantly during a design-basis LOCA, NAPS used the GOTHIC containment analysis code to simulate the conditions in containment following a LOCA, as well as to compute the NPSHa for the LHSI and RS pumps [39, 40].

The licensee performed an extensive series of sensitivity studies using the GOTHIC methodology, in which the accident initiator, the assumed single failure, and a number of operational parameters were varied, to arrive at the minimum NPSH margin for the LHSI, ORS and IRS pumps during the recirculation phase of a LOCA. Table 12 presents the minimum NPSHa and NPSH margin values the licensee calculated for the three pairs of pumps, showing the assumed single failures, the times at which the minimum NPSH margin occurs, the sump fluid temperatures, and pump flow rates [35].

Table 12 Worst Case Design-Basis LOCA Conditions and NPSH Margin Results for LHSI, IRS and ORS Pumps

Pumps	**Time in Transient (s)**	**Sump Suction Water Temperature (°F)**	**Pump Flow Rate (gpm)**	**NPSHa (ft)**	**NPSHr (ft)**	**NPSH Margin (ft)**
LHSI with single failure of an electrical bus	3388	173.7	4050	14.97[1]	13.4	1.57[1]
IRS with single failure of an electrical bus	2083	204.7	3400	15.12	9.6	5.52
ORS A with single failure of a casing cooling pump	1518	193.5	3750	18.73	11.3	7.43

[1] The NPSHa and NPSH margin for the LHSI pumps include a strainer head loss of 0.2 feet.

Table 12 shows that the minimum NPSH margin occurs for the LHSI pumps (two of identical design) with a single failure of one emergency electrical bus. Contributing factors to this relatively limited margin are the small height from the containment floor to the pump centerline (which is similar for all of the systems listed in Table 12), a relatively large hydraulic head loss (8.8 feet) and an NPSH required (NPSHr) which is larger than the other systems.

Based on its review of the licensee's NPSH margin calculation, the staff concluded that the licensee nonconservatively overestimated the NPSHa and NPSH margins by approximately 0.6 feet for all three sets of pumps. This issue is discussed in more detail in Open Item 3.7-1 (page 47).

The models, assumptions, and results for the licensee's NPSH calculation are discussed in further detail below.

3.7.2 Summary of NPSH Margin Calculation Methodology

NPSHa Formulation

The definition of NPSH margin from Regulatory Guide 1.82 [7] is the difference between the NPSHa and NPSHr. Regulatory Guide 1.82 defines NPSHa as the total suction head of liquid, determined at the first stage impeller of the pump, less the absolute vapor pressure of the liquid. Regulatory Guide 1.82 defines NPSHr as the amount of suction head, over vapor pressure, required to prevent more than 3% loss in total head of the first stage of the pump (due to factors such as cavitation and the release of dissolved gas) at a specific capacity. For convenience, NPSH values are generally reported as pressure heads, in units of feet of water.

The NPSHa is computed as the difference between the containment atmosphere pressure and the vapor pressure of the sump water at its assumed temperature, plus the height of water from the surface of the containment pool to the pump inlet centerline, minus the hydraulic losses for the flow path from the flow inlet at the containment floor to the pump inlet nozzle (not including the head loss contribution from the sump strainer and debris bed, which are usually accounted for separately). This formulation of NPSHa is further presented in the NAPS Updated Final Safety Analysis Report [51]. As documented in Regulatory Guide 1.82 [7], while the staff generally recommends that licensees do not credit containment accident pressure in NPSH calculations, the staff accepts this formulation for calculating the NPSHa under certain conditions as discussed further below. However, for computing NPSH, the licensee actually used a different formulation of the NPSHa equation in the GOTHIC code [39] that was more complicated than the equation in the Updated Final Safety Analysis Report.

In its review, the staff used the Updated Final Safety Analysis Report formulation for the NPSHa [51] together with the numerical values of the terms of the equation taken from the licensee's GOTHIC results to do a confirmatory calculation of the limiting NPSHa and the NPSH margin for each of the three sets of pumps. The values resulting from the staff's confirmatory calculations were compared with the licensee's values shown in Table 12, which were computed using the NPSHa formulation the licensee implemented in the GOTHIC code [39]. Through this comparison, the staff found a non-conservative bias in the values of NPSH margin the licensee computed using the GOTHIC code. Discussion with NAPS engineers during the on-site audit confirmed the staff's conclusion. The licensee attributed this non-conservative bias of approximately 0.6 feet to an inconsistency in the calculation of the static head using the GOTHIC formulation for NPSHa. The staff designated **Open Item 3.7-1** for the licensee to use a conservative or realistic formulation.

Credit for Containment Accident Pressure

In its NPSH analyses, NAPS takes credit for containment accident pressure (i.e., the difference between the containment atmosphere pressure and the vapor pressure of the sump water at the pump suction). The NAPS approach to the calculation of NPSHa for the LHSI, ORS and IRS pumps is to use the GOTHIC code to compute the NPSHa as a function of time following a postulated LOCA. For each pump and for any set of initial conditions, the calculation provides a minimum NPSHa and minimum NPSH margin for those conditions.

Based upon NRC guidance in Regulatory Guide 1.82, when calculating NPSH licensees should generally assume " . . . no increase in containment pressure from that present prior to the postulated LOCA [7]." However, Regulatory Guide 1.82 notes that this guidance does not apply for subatmospheric containments prior to the injection phase of a LOCA and further recognizes that some existing plants may not be able to conform to this guidance and still demonstrate adequate NPSHa. Under such circumstances, Regulatory Guide 1.82 recommends that licensees conservatively compute the containment pressure and sump water temperature as a function of time in determining the NPSHa [7]. The NAPS approach takes credit for the pressure terms of the NPSHa definition using a transient calculational procedure that is described in its Updated Final Safety Analysis Report [51]. This approach has also been used by NAPS in a recent license amendment request approved by the NRC staff [62, 63]. Based on this prior NRC staff review, credit for the pressure terms of the NPSHa formulation for NAPS was considered acceptable by the audit team.

GOTHIC Code Methodology

The individual terms of the NPSHa equation are either input to the GOTHIC code or calculated by the code, as described in a technical report by the licensee [40]. The difference between the containment atmosphere pressure and the vapor pressure of the sump suction water temperature is computed using the GOTHIC code. The static head of liquid is calculated using a model for the time-dependent accumulation of water on the containment floor that accounts for water holdup mechanisms including holdup of spray droplets in the containment atmosphere. The suction-side hydraulic head losses are provided as input [64] to the GOTHIC code, and are separately calculated using the Pipe 2000 hydraulic network analysis code [65]. This piping network method is similar to the industry-standard Crane methodology [14] and is considered acceptable by the staff. These contributions to the NPSHa are discussed further in Section 3.7.3 below.

The GOTHIC code contains physical models that predict the time-dependent containment atmosphere pressure, the vapor pressure of the sump fluid, and the time-dependent static head of liquid above the centerline of the pump suction. The code contains provisions for modeling the primary system, the ECCS and the containment atmosphere. Dominion has provided models of a number of design features of the NAPS ECC and spray systems that are implemented in order to achieve acceptable NPSH margins for the RS pumps. These models include quench spray water injection from the RWST to the IRS pumps and casing cooling tank water injection to the ORS pumps during the recirculation mode.

The code contains physical models of the competing processes that determine the pressurization history of containment during a LOCA. These processes include mass and energy transfer to the containment resulting from the blowdown of the reactor coolant system, steam condensation on structures and droplets, sump water volume changes, spray transport and heat transfer, holdup of liquid resulting from a number of mechanisms, and heat removal from the recirculated sump water. Containment leakage is accounted for using the Technical Specification leak rate of 0.1% per day during the first hour following the LOCA initiation [66]. The audit team did not review the GOTHIC code's models in detail, because, as described below, the staff has previously reviewed and approved the application of this code for the NAPS.

As part of a license amendment request, the licensee notified the NRC of its intention to implement the containment analyses for NAPS using the GOTHIC code, which would replace the previously used LOCTIC containment analysis code [62]. The NRC staff has previously approved a Dominion topical report (DOM-NAF-3) that presented the GOTHIC methodology [39]. In its SE corresponding to the topical report [66], the NRC staff reviewed the GOTHIC analyses that supported the changes. The staff determined that the licensee's GOTHIC analyses were consistent with the NRC staff-accepted topical report DOM-NAF-3 and were appropriate for analyzing the changes proposed in the license amendment request, including the analysis of pump NPSH margins [66].

3.7.3 Parameters Influencing NPSH Margin

The GOTHIC code contains a detailed model of the thermal hydraulics of the reactor coolant system, ECCS, spray systems, and containment. As such, it contains a number of detailed mechanistic models describing many competing rate processes. The methodology requires the input of a large number of parameters. It is beyond the scope of this audit to review the large number of model input parameters that go into each calculation done by the NAPS licensee; however, the major contributing parameters to the NPSHa calculations are discussed below. The licensee's NPSH calculations were guided by the observation that the minimum margin would likely occur for the combination of parameters that would minimize the containment pressure and maximize the sump water temperature (and, hence, the vapor pressure of this fluid), thereby minimizing the contribution of containment accident pressure to the calculated NPSH margins [51]. The staff finds this approach to be conservative and therefore acceptable.

Emergency Core Cooling System and Recirculation Spray System Configuration

The GOTHIC containment analysis encompasses both the injection and recirculation phases of a LOCA event. The conditions in containment at the startup of the RS pumps and the switch-over of the LHSI pumps are established by the events in containment during the injection phase. The lineup of selected ECCS and containment depressurization systems during the two phases of the LOCA event is briefly summarized below [51, 40].

During the injection phase of a LOCA, the ECCS system discharges water from two passive accumulators into the primary system. The high-head charging pumps are aligned with the RWST and discharge into the reactor coolant system through the boron injection tanks. Two LHSI pumps are also aligned with the RWST and discharge into the reactor coolant system when reactor coolant system pressure drops below the pumps’ shutoff head. The quench spray system provides containment spray during the injection phase of the LOCA through two quench spray pumps that are aligned to take suction from the RWST.

During the recirculation phase, the ORS and IRS pumps take suction from the containment sump, and the LHSI pumps are realigned to take suction from the containment sump and discharge to the reactor coolant system and the suction of the charging pumps. The casing cooling pumps draw water from the casing cooling tank and provide cooling water to the suction of the ORS pumps. This cooling water serves to reduce the temperature of the sump water feeding the ORS pumps, thus decreasing the water vapor pressure and increasing their NPSH margin. Similarly, the quench spray pumps provide RWST water to the suction of the IRS pumps for the same purpose.

The system parameters that actuate the RS pumps and realign the LHSI pumps to the recirculation mode have been established to provide adequate submergence of the strainers, adequate liquid level to achieve acceptable NPSH margin, and a minimum sump water temperature to achieve acceptable NPSH margin. The calculation results, presented in Table 12, are consistent with the following plant configuration [35]: the ORS pumps are started on 60% RWST level coincident with a High-High containment pressure signal; the IRS pumps are started using a 120 second delay following the same signals as the ORS pumps; and LHSI recirculation is actuated later at 16% RWST level.

Containment Pressure

The GOTHIC code is used to compute the time-dependent difference between the containment pressure and sump water vapor pressure for each case considered for NAPS [35] in the calculation of the NPSH margin for each pump. The calculation results [35] show that both the containment atmosphere pressure and the sump water temperature are rapidly decreasing with time, albeit at different rates, as the point of minimum NPSH is approached. This places a burden of accurate modeling and computation of transient containment phenomena to adequately predict the pressure difference and resulting pump NPSH margins. As discussed above the application of the GOTHIC code to NAPS [62, 63] is considered acceptable by the NRC staff.

Pump Flowrates

The pump flowrates that have been used by NAPS in its estimates of the suction head losses and NPSHr for the LHSI, ORS and IRS pumps have been computed using hydraulic models of the flow networks and the pump manufacturer's strongest pump curves. For the LHSI pumps, for example, from single-failure sensitivity studies NAPS showed that the minimum NPSH margin would occur for the failure of an emergency electrical bus, which would leave only one LHSI pump and one high-head safety injection pump operational [40]. The Pipe 2000 hydraulics code was used to model the flow from the discharge of the LHSI pump to the reactor coolant system and to the inlet of the high-head safety injection pump and then subsequently to the reactor vessel cold leg [67]. This code was used together with conservative pump characteristics to obtain the flow rate shown in Table 12. The flow rates for the ORS and IRS pumps were computed similarly.

The methodology for computing the flow rates is standard engineering practice and is acceptable. The flow rates are considered conservative since they are computed using conservative pump characteristics.

Containment Sump Pool Water Level

The inventory of water in containment is computed by GOTHIC on a transient basis. Sources of water include the accumulators, the RWST and the casing cooling tank. The associated flow rates are computed using hydraulic system analysis. The water volume released to the containment is computed from the time of the LOCA initiation during the injection phase through the recirculation phase of the event. The water inventory in containment is reduced by estimates of water holdup volumes resulting from a number of physical mechanisms. These mechanisms include condensation films on surfaces within containment, water added to spray system piping, droplets suspended in the containment atmosphere, water absorbed in insulation, and water trapped in the refueling canal and reactor cavity [40].

The sump water level is computed from the volume of liquid in containment, as reduced by the total holdup volume attributable to the various holdup mechanisms. The NAPS model contains a table of water level versus volume of water. This table was constructed using a model of the NAPS containment geometry that accounts for the slope of the containment floor and other irregularities in the containment shape [68, 69]. The net volume of water at any time, after subtracting the holdup, is used with this table to predict the containment pool water level at that time.

A detailed review of the water level computations within the GOTHIC code was beyond the scope of the audit. However, the GOTHIC methodology of calculating the sump pool water level is considered by the staff to be complete and adequate, accounting for the relevant sources of water and for the mechanisms of liquid holdup.

Suction Flow Path Hydraulic Head Loss

The suction flow hydraulic head loss reductions to the NPSHa were calculated for the LHSI, ORS and IRS pumps [64]. The suction-side hydraulic head losses are provided as input [64, 70] to the GOTHIC code, and are calculated using the Pipe 2000 hydraulic network analysis code [65]. This piping network analysis uses an industry-standard approach. Therefore, the staff considers the hydraulic head loss methodology to be acceptable.

NPSHr and the Hot Fluid Correction Factor

NPSHr values shown in Table 12 for the LHSI, ORS and IRS pumps are taken from the manufacturer's specifications. The hot fluid correction factor for NPSHr is not used [70]. The licensee's specification of NPSHr is acceptable because it is evaluated at the maximum pump flow rate and follows NRC guidance [7].

3.7.4 Net Positive Suction Head Summary

The licensee calculated the contributions to the terms of the NPSHa equation using the GOTHIC code, the Pipe 2000 hydraulics code, plant geometry, and other design inputs. The licensee computed the NPSHa on a time-dependent basis, and for given sets of initial conditions, determined the minimum pump NPSH margins for those conditions. A large number of sensitivity calculations was performed in which various single failures, operational parameters and break locations were varied for each pump. Based on these calculations, NAPS identified the worst set of parameters and identified the minimum NPSHa and NPSH margin for each set of pumps.

NAPS implemented an NPSHa formulation in the GOTHIC code to compute NPSHa [39]. This formulation of the NPSHa equation is different than the standard equation that is referenced in the licensee's Updated Final Safety Analysis Report [51]. The staff found that there is an inconsistency in the results provided by these two different formulations, and that there is a non-conservative bias in the NPSH margin values the licensee calculated using the GOTHIC code that are reported in Table 12. This issue was identified as Open Item 3.7-1.

With the exception of the issue identified in Open Item 3.7-1, the staff finds that NAPS has used acceptable methodologies for calculation of the NPSHa. The credit taken for containment accident pressure for NAPS has been reviewed and approved by NRC in the review of a license amendment request related to NPSH and containment analysis [66]. While this audit did not review the GOTHIC code modeling in detail, the use of the GOTHIC code for prediction of the containment response and pump NPSH margins was considered acceptable to the NRC staff in its review of the previous NAPS license amendment request [66].

3.8 Coatings Evaluation

3.8.1 Coatings Zone of Influence

The licensee applied a coatings ZOI with a spherical equivalent radius of 5 length/diameter (L/D). This assumption contrasts with the NRC SE [12] recommended ZOI radius of 10 L/D. The licensee references jet impingement testing conducted by Westinghouse as the basis for the application of a 5D ZOI for coatings. The test data referenced by the licensee is documented in the Westinghouse Report WCAP-16568-P, "Jet Impingement Testing to Determine the ZOI for Design Basis Accident-Qualified/Acceptable Coatings [49]." Inside the ZOI, 100% of the qualified coatings were assumed to fail as pigment sized particles (10 µm).

As stated in the NRC SE, for protective coatings, the staff position is that the licensees should use a coatings spherical equivalent ZOI determined by plant-specific analysis, based on experimental data that correlate to plant materials over the range of temperatures and pressures of concern, or 10 L/D. At the time of the audit, the NRC staff had not completed its review of WCAP-16568-P to verify whether the use of a 5 L/D coatings ZOI at NAPS was appropriate. Therefore, the coatings ZOI was designated an open item pending NRC staff review of the report. The NRC staff subsequently completed its review of the report [100]. This issue is no longer an open item.

3.8.2 Coatings Debris Characteristics

NAPS has three primary coating systems in containment. The containment liner plate is coated with Carboline CZ-11 primer with a Dupont Corlar epoxy topcoat. The total dry film thickness (DFT) for this system was specified to be less than 9 mils. The staff noted that this coating system is atypical for a design basis accident qualified system in US nuclear power plants. Dupont Corlar epoxy was qualified for the NAPS through plant-specific tests. There are no generic industry tests for this material. The test report for the CZ-11/Corlar system is contained in the NAPS Updated Final Safety Analysis Report Section 3, Appendix 3d [50].

The structural and miscellaneous steel is coated with a design basis accident-qualified Keeler & Long epoxy system with a specified DFT of less than 9 mils. The concrete surfaces are coated with a Keeler & Long system specified to be less than 6 mils DFT.

The NRC staff's SE addresses two distinct scenarios for formation of a fiber bed on the sump strainer surface. For a thin bed case, the SE states that all coatings debris should be treated as particulate and assumes 100% transport to the sump strainer. For the case in which no thin bed is formed, the staff's SE states that the coating debris should be sized based on plant-specific analyses for debris generated from within the ZOI and from outside the ZOI, or that a default chip size equivalent to the area of the sump strainer openings should be used. North Anna Unit 2 is considered a high-fiber plant due to the quantity and type of piping insulation. The licensee treated all unqualified and degraded qualified coating debris outside the ZOI as fine particulate of 10 micron size that will readily transport to the sump. As discussed above in Section 3.8.1, the licensee also treated all coating debris generated within the ZOI as fine particulate.

The replacement strainer design was tested at AECL's Chalk River Laboratory in Canada using walnut shell flour as the surrogate debris source to simulate coating debris. Portions of the model testing were witnessed by NRC staff. A trip report [48] for this visit to AECL documents the staff's observations. The 325 mesh walnut shell flour used had a size range from 2 to 60 microns with an average particle size of approximately 22 microns. The density of the walnut shell flour is somewhat lower than that of epoxy coating debris (81 lb_m/ft^3 vs. 94 lb_m/ft^3). Therefore, it will transport more readily than the epoxy coating debris. Also, the average walnut shell flour particulate size of 22 microns is within the range recommended in the NRC SE. The staff therefore believes the AECL testing using the walnut shell flour is adequately representative of coatings debris generation and transportability at North Anna Unit 2.

The staff reviewed the quantity of coating debris and methodology for determining the quantity. The staff noted that the volume of qualified coating debris within the ZOI for NAPS was considerably less than the volume determined at other GSI-191 audited sites. The licensee explained that a significant difference was the pipe break size and the coating DFT. At the NAPS the pipe break which produces the largest quantity of coating debris is 31 inches in diameter, and the concrete coating DFT is 6 mils. The design coating DFT was confirmed by reviewing the site coating specification [56]. At Waterford 3, for example, the pipe break size was 42 inches in diameter and the concrete coating was 100 mils DFT on the wall and 162 mils DFT on the floor. This difference in ZOI and paint film DFT easily explains the differences in estimated coatings debris quantity. The quantity of coating debris calculated for NAPS is therefore acceptable, with the open item on ZOI as mentioned above. As a conservatism, the licensee added 10% margin to the calculated quantities of coating debris. An additional conservatism is that Westinghouse Technical Bulletin (TB) 06-15 [54] identified that some Ameron products used on reactor coolant pump components were not design basis accident qualified. The licensee factored that into its analysis by treating it as unqualified coatings. It represents approximately 25% of the total quantity of coating debris. However, TB 06-15 was rescinded by Revision 1 dated May 03, 2007. The licensee has not updated the analysis to account for this. The staff finds that the treatment of the designated Ameron products as unqualified is a conservative and acceptable assumption for the debris generation calculation, since it results in full availability of the affected coatings for transport as particulate debris.

The containment coatings condition assessment process [53, 54] was reviewed in some detail to provide the staff with a level of confidence that the licensee's assumptions and input into the coating debris analysis are valid and there is an ongoing program in place to maintain the coatings condition. The licensee's visual condition assessment procedure was reviewed and the licensee's corporate coating specialists were interviewed about how they conduct the condition assessments. The procedures and qualifications of the personnel performing the assessments are considered adequate with one exception.

The licensee has not performed any in-situ adhesion tests themselves. The licensee stated that they will rely on the results of an ongoing test program conducted by EPRI and the Nuclear Utilities Coatings Council to validate their assessment techniques. This testing will subject visually sound and visually degraded coatings to physical testing (i.e., adhesion tests) in an attempt to show that visual assessments are capable of identifying coatings that would not remain adhered during a design basis accident. The testing has been completed; however, the report is still being prepared by the industry and therefore has not been reviewed by the NRC staff. It should be noted that the NRC staff did witness the coatings tests at three of the four plants and has no concerns with how the testing was conducted.

Assessment of qualified coatings was identified as an open item during the audit, pending industry documentation of the validation testing and NRC staff review of the report [99]. The NRC staff subsequently completed its review of the report. This issue is no longer an open item.

4.0 DESIGN AND ADMINISTRATIVE CONTROLS

4.1 Debris Source Term

Section 5.1 of NEI 04-07 [5] and the NRC staff's accompanying SE [6] discuss five categories of design and operational refinements associated with the debris source term considered in the sump performance analysis.

- housekeeping and foreign material exclusion programs
- change-out of insulation
- modification of existing insulation
- modification of other equipment or systems
- modification or improvement of coatings program

The SE states that these additional refinements should be evaluated for their potential to improve plant safety and reduce risks associated with sump strainer blockage. The staff's discussion below describes the licensee's procedures and planned or completed actions in each of these areas.

4.1.1 Housekeeping and Foreign Material Exclusion Programs

The licensee stated that the existing foreign material exclusion program has been improved because of the corrective actions taken in response to Generic Letter 2004-02. The licensee stated that a cover is installed over the strainer at the beginning of refueling outages. The licensee also stated that containment closeout inspections include a visual examination of the recirculation sump, and that the inspection procedure would be re-written to address the design of the replacement strainers.

The licensee stated that the containments are routinely washed down at NAPS at the end of each refueling outage. The licensee stated that the washdowns cover essentially all levels of containment, and that procedures instruct plant personnel to cover sensitive floor drains to prevent debris entrained in the drainage water from accumulating and causing blockage. The licensee further stated that Dominion is developing a fleet-wide latent debris program. In addition to containment washdowns, the program tentatively would include periodic walkdowns to collect latent debris samples to ensure that the latent debris analysis bounds the existing plant condition.

The licensee further stated that plans exist to create a database for the data obtained from containment debris walkdowns. The licensee planned to designate a site engineer to be responsible for GSI-191 issues, including maintaining the containment debris database.

4.1.2 Change-Out of Insulation

The licensee stated that calcium silicate and Microtherm material potentially vulnerable to becoming problematic debris following a LOCA has been removed from the Unit 2 containment and that a similar removal of these materials would be completed in the Unit 1 containment during the upcoming outage in Fall 2007.

4.1.3 Modification of Existing Insulation

The licensee stated that modification to plant insulation would be controlled through insulation change procedures or through the work order process. The licensee stated that questions in plant engineering change packages would require an engineering review if an existing insulation material is replaced by a different material. With respect to the work order process, the licensee stated that the outage planning procedure would be revised to require an engineering review of work orders, with approval from the engineering manager. The licensee stated that engineering is also present at daily outage work meetings and would be able to flag any issues associated with insulation modification resulting from emergent work orders.

4.1.4 Modification of Other Equipment or Systems

The licensee has not committed to the modification of other equipment or systems to reduce the debris source term as a corrective action in response to GL 2004-02.

4.1.5 Modification or Improvement of Coatings Program

The licensee stated that coated equipment brought into containment without Service Level 1 qualification must be reviewed by engineering. The licensee stated that non-Service-Level-1 coatings would either be remediated or would be accounted for in the sump performance analysis.

4.2 Screen Modifications

Section 5.3 of the approved Guidance Report provides guidance and considerations regarding potential sump screen designs and features to address sump blockage concerns. Specifically, the attributes of three generic design approaches are addressed. These include passive strainers, backwash of strainers, and active strainers. The staff SE does not specifically support any single design, but rather emphasizes two performance objectives that should be addressed by any sump screen design:

- The design should accommodate the maximum volume of debris predicted to arrive at the screen, fully considering debris generation, debris transport, and any mitigating factors (e.g., curbing).
- The design should address the possibility of thin bed formation.

Staff Evaluation:

The following documents were included during the staff’s review of the modifications:

- Safety and Regulatory Reviews Procedure, VPAP-3001, Revision 14
- General Nuclear Standard - Instructions for DCP Preparation, STD-GN-0001, Revision 39
- Containment Sump Strainer, DCP 05-014, Including Field Changes 1 and 2
- Incore Sump Room Drain, DCP 06-011
- RWST Level Low Function, DCP 06-013, Including Field Changes 1 and 2
- Insulation Replacement, DCP 07-004, Including Field Change 1
- Dominion Letter 06-849, License Amendment Request for GL 2004-02 Issues
- Technical Report No. NE-1472, Revision 0, Implementation of GOTHIC Containment Analyses and Revisions to the LOCA Alternate Source Term Analysis to Support Resolution of NRC GL 2004-02 for North Anna Power Station
- Draft Design Basis Document, TDBD-NAPS-GSI-191

Due to the NAPS plant design, a relatively complicated resolution to the potential for sump clogging was developed. The resolution included the need for license amendments for various aspects of plant response to a potential LOCA. The license amendments were developed to accommodate changing the logic for recirculation spray initiation. The license amendments also changed the method (computer code) that does the post-accident calculation. The license amendments had been previously reviewed by the NRC staff and found acceptable.

Dominion developed a design basis document for GSI-191 issues that includes the history of the issue, applicable references, design basis requirements, and system interfaces as they relate to the NAPS. The staff considered development of this design basis document for GSI-191 to be a good practice. The staff also noted that the standard for design change packages, STD-GN-0001, Attachment 5, had been revised to include specific review questions related to GSI-191 issues. These questions are intended to ensure that future design changes do not adversely affect the ability of the containment sump to respond, as required, during a LOCA.

Based on the review described in Section 3.0 of this audit report, the staff believes that the new sump design will be able to accommodate the maximum volume of debris. The specific design features of the strainer appear to adequately limit head loss created by the postulated amounts of insulation, coatings, foreign materials, and latent debris. However, Open Item 5.4-1 (page 75), has been identified that relates to the possibility of a thin bed when chemical precipitants are considered.

5.0 ADDITIONAL DESIGN CONSIDERATIONS

5.1 Strainer Structural Analyses

5.1.1 Structural Qualification of the Sump Strainer Assembly

The NAPS emergency core cooling and containment heat removal systems draw water from the containment sump in the basement of the containment through a set of large strainers that prevent debris from entering these systems or the reactor coolant system. The ECCS structures are passive assemblies with no moving parts. The structures are designed to prevent degraded operation of the emergency core cooling system and recirculation spray system resulting from debris accumulation on the sump strainer during accident conditions. The design and analysis of the sump strainer complies with GSI-191 guidance. There are two independent strainer systems, one for the RS system and the other for the LHSI system. LHSI strainer assemblies are stacked on top of the RS strainer assemblies and interconnected structurally by channels and angles, but the two systems are physically separate. The strainer modules are AECL Finned Strainers™ built upon passive technology.

AECL conducted dynamic and static structural analyses of the replacement strainers, using the Finite Element Analysis (FEA) method to qualify the Dominion strainer module consisting of train header modules and pump suction header modules.

The train header modules include a combined LHSI-RS header module, an RS header module, an RS header with skew-symmetric fins, and an RS transition piece. The header itself consists of a horizontal top plate and bottom plate, a horizontal baffle, two vertical baffles, and four flow deflectors; all joined by welds. The side walls are formed vertical channels that are welded to the top cover and the bottom plates of the header. There are 44 fins with perforated-corrugated sheets in a combined LHSI-RS header.

The pump suction header modules include an outside combined pump suction header and pump casing. Pump suction header modules consist of a collection header, one or two transition pieces, and reinforcing beams. AECL analyzed flanges between the pump elbow and transition piece, conducted buckling analysis of the pump housing, analyzed stress of the lugs attached to pump housing, and analyzed the piping loads for the bleed lines on top of the transition pieces for the licensee.

The strainer assembly is qualified for loadings associated with dead weight (including debris weight), seismic (including hydrodynamic mass), the differential pressure due to head loss, and thermal expansion. The load combinations are described in the design specification NAN2-34325-DS-001 [61], and the procurement specification NAP-0146 [82].

FEA, using the ANSYS computer program, was performed in the structural qualification to verify the structural integrity of all components of the strainer assembly. For the perforated plates, equivalent solid plate analysis using the FEA model was used based on the guidance of American Society of Mechanical Engineers (ASME) Section III code, appendix A-8000 [83]. The results of the stress analysis of the strainer assembly are documented in stress analysis report NAN2-34325-AR-002 [84].

A containment maximum temperature of 280 °F during a LOCA was used per the design specification.

A value of 9.0 psid differential suction pressure loading corresponding to a fully debris-loaded strainer was used in the structural design.

The structural damping is 2% for operating basis earthquake (OBE) and 3% for design basis earthquake or safe shutdown earthquake (SSE) seismic analyses.

The design conditions for the strainer modules include dead weight, live load, suction pressure, thermal loading and seismic events.

5.1.1.1 Stresses in Strainer Assembly

The strainers are designed to withstand the hydrodynamic loads and inertial effects of water in the containment basement, at full debris loading, without loss of structural integrity or strainer performance. Using a detailed FEA, the natural frequencies were calculated for the LHSI-RS header strainer module, combined LHSI-RS header with end plate strainer module, RS header module, RS header with end plate strainer module, RS header with skew-symmetric fins, and pump suction header. The criteria and allowable stresses from ASME Section III Boiler and Pressure Vessel Code were used. The membrane and membrane plus bending stresses in the top plate, bottom plate, baffle plate, deflector plates, and channels for LHSI and RS strainer components for load case LC-3 were computed and shown to be acceptable.

Staff Evaluation

Based on a review of the results, the NRC staff finds that the stress evaluations for the top plate, bottom plate, baffle plate, deflector plate, and channels for LHSI and RS strainer components for load case LC-3 are acceptable because the stresses in the strainer assembly are within allowable limits.

5.1.1.2 Fatigue Analysis of Strainer Assembly

The stress analysis report stated that in accordance with paragraph NF-3121.4 of ASME Boiler and Pressure Vessel Code, section III, an evaluation for peak stress is not required implying that explicit fatigue analysis is not needed. However, fatigue considerations were included using IEEE-344 guidelines. Conservatively, a total of 60 SSE stress cycles was considered to represent 5 OBE events of 50 OBE stress cycles and 1 SSE event of 10 SSE stress cycles. For 60 cycles, the allowable alternating stress is 320 ksi for austenitic stainless steel based on the S-N curve of Appendix I of ASME Boiler and Pressure Vessel Code, Section III. Since the strainer stresses due to an SSE are much lower than 320 ksi, the stress report concluded that the strainer meets the IEEE fatigue requirements.

Staff Evaluation

The NRC staff reviewed the fatigue evaluation stated above and found it acceptable because the seismic stresses based on 60 cycles are much lower than the applicable alternating stress amplitude provided by the S-N curve in ASME Boiler and Pressure Vessel Code, Section III .

5.1.1.3 Thermal Expansion

The stress analysis report stated that slots in the finned modules and a gap in the adjustable flange between the two pump suction headers are provided to accommodate thermal expansion. Axially slotted holes with 1.5-inch long slots are provided to accommodate an axial thermal expansion of 0.144-inch following a LOCA for a 60 inch distance between slots. The thermal expansion of the 100-inch long pump suction header following a LOCA is 0.24 inches and is less than the 0.3125-inch gap provided in the adjustable flange. As the gaps are larger than the thermal expansion during a LOCA, the licensee concluded that thermal expansion is not restricted and hence thermal stresses need not be considered in the structural analysis of the strainer assembly.

Staff Evaluation

The NRC staff reviewed the rationale provided in the stress report as stated above and found the conclusion that thermal stresses in the strainer assemblies following a LOCA need not be considered in structural analysis acceptable because the provided gaps and clearances can accommodate the thermal expansion.

5.1.1.4 Jet Impingement, Pipe Whip, and Missile Impact Considerations

The licensee was asked whether there was any package documenting the evaluations of the structural integrity of the sump strainers from any jets from potential high-energy line breaks in the vicinity of the sump strainers, any dynamic effects associated with pipe whip, and the effect of missiles. The licensee responded by providing a draft document titled "High Energy Line Break Review for the New Containment Sump Strainer - North Anna," ET-N-07-0067 [85]. The licensee also stated that evaluations have been performed by review of North Anna Units 1 and 2 piping drawings to identify piping within the LOCA boundary limit, high-energy line break piping outside the LOCA boundary limit but within the containment, and any potential missiles that could be generated within the containment. The licensee concluded that the piping within the LOCA boundary limit is protected/isolated by missile barriers and provided with whip restraints. The majority of high-energy piping within the containment is protected/isolated by missile barriers. The high-energy piping that is not isolated by a barrier meets one or more of the following conditions:

(a) is suitably separated from the containment strainers,
(b) is suitably shielded by missile barriers,
© is suitably restrained,
(d) is subject to augmented inspections,
(e) if ruptured would not require the ECCS to initiate the recirculation phase.

The next revision of reference [85] will confirm the conclusions stated in draft revision 0.

Staff Evaluation

The licensee has demonstrated that reasonable assurance exists to conclude that the RS and LHSI strainers are adequately isolated and protected from LOCA and other high energy line break piping, and missiles. The staff finds the licensee's conclusions acceptable based on review of licensee's document ET-N-07-0067 [85].

5.1.1.5 Damping (OBE, & SSE Spectra) & Seismic Analysis

The damping value used for the NAPS seismic analyses is 2% of critical for structural damping for OBE analysis, and 3% of critical for structural damping for SSE analysis. The analysis performed by AECL for the licensee is a quasi-static analysis for load case LC-3 only using an acceleration corresponding to floor response spectra peak value of SSE/design basis earthquake spectra corresponding to 3% damping. In response to a staff question about why a 1.5 multi-mode factor was not used, AECL responded by stating that since the natural frequencies of the structure were determined, a factor of 1.5 times the acceleration corresponding to first frequency can be used. AECL stated that 1.5 times the acceleration corresponding to first frequency is less than the peak acceleration. So AECL concluded that use of the peak acceleration in strainer qualification using a quasi-static method is reasonable. AECL will include the above rationale in the next revision of the strainer analysis report [84].

Staff Evaluation

The staff finds the above clarifications about seismic analysis reasonable and acceptable because the natural frequencies of the structure were determined which demonstrated that 1.5 times the spectral acceleration corresponding to the fundamental frequency is less than one times the peak spectral acceleration that was used in the seismic analysis.

5.1.1.6 Load Combinations and Acceptance Criteria

The analysis report provides the following load combinations

Table 13 Load Cases, Combinations and Service Limits

Service Limits	Load Cases	Load Combination	Category	Sump condition	Comment
Level A	LC-1	DW+LL	Normal	Dry	Material Properties at T_1
Level B	LC-2	DW+OBE	Upset	Dry	Material Properties at T_1
Level C	LC-3	DW+ SP+ SSE+Hydro-dynamics	Accident	Wet Submerged	Material Properties at T_2

Notations: DW=Deadweight; LL=Live Load
LL = 60 lbs/ft^2 for RS modules as cover plate is integral with the modules;
LL = 0 lbs/ft^2 for LHSI-RS modules as cover plate is not attached to the modules;
SP=Differential Suction Pressure= 9 psi;
Hydrodynamics=Forces from water acting on the strainer during an earthquake
T_1=Maximum air temperature under normal condition = 105 °F
T_2=Maximum sump water temperature under accident condition = 280 °F

The load case combination is based on the following observations of the free vibration analysis results.

- The fundamental frequency, be it of the RS module, the combined LHSI/RS module, or the pump suction header, is higher than 20 Hz and far to the right of the floor response spectra peak.
- The directional cross-coupling effect is small.
- The effective mass is smaller than the total mass.

Accordingly, a static analysis was carried out in which the full mass (metal plus attached water mass), using the floor response spectra peak acceleration in the x and in the z-direction, and the zero period acceleration in the y-direction. Specifically, the following conservative load case combination for stress evaluation was adopted:

Combined Response = ABS[SRSS response from (α_x = 0.6g; α_y = 0.15g; α_z = 0.6g); SP; 7/8 $(DW)_{dry}$]

The x-axis is transverse to the header, z is parallel to the header, and +y is up. $\alpha_x = \alpha_z$ = 0.6g each is a load case in which the response is to the floor response spectra peak. α_y = 0.15g is another load case in which the response is to the y axis zero period acceleration, and SP is a load case for the 9 psi suction pressure. The factor 7/8 applied on DW is to account for buoyancy.

Staff Evaluation

The staff finds the load combinations and acceptance criteria used in the structural design of the sump strainer as shown above acceptable because they meet the guidelines of Regulatory Guide 1.82 and the requirements of the design and procurement specifications for the containment passive strainer.

5.1.1.7 Perforated Sheet Analysis

The Finned Strainers™ consist of perforated sheets that have been corrugated to increase their surface area. The sheets are welded together to form hollow core fins connected to a common header. The perforated sheet is modeled as an equivalent solid sheet with an effective Young's modulus and Poisson's ratio based on ligament efficiency using guidance from Appendix A of reference [83]. Equivalent weight density is computed based on porosity. The stresses obtained from equivalent solid plate analysis are magnified by a factor based on ligament efficiency. The membrane and membrane plus bending stresses for the LC-3 load case meet the corresponding allowables for fin components (perforated sheet, inside and outside end cap, and top/bottom plate). The fundamental frequencies for RS and LHSI fins were also computed. The maximum seismic displacement of the fins was found to be 0.008inches and 0.015 inches for the RS and LHSI fins, respectively. Critical buckling loads for the RS & LHSI fins were determined and were shown to be acceptable.

Staff Evaluation

Based on a review of the perforated sheet analysis methodology, the staff agrees with the conclusion that the resulting stresses in the fins are acceptable because the stresses and the buckling loads are within the corresponding allowable limits.

5.1.1.8 Strainer Deflection

To prevent additional leakage paths from developing, the maximum deflections in the strainers and the fins are limited to very small values. The maximum seismic displacements of the fins were calculated to be 0.008 inches and 0.015 inches for RS fin and LHSI fins, respectively. These deflections are small, and AECL concluded that they are unlikely to cause any interference problem by interactions with existing equipment and structures. According to the layout, the strainers and fins are well clear of existing equipment.

Staff Evaluation

Based on a review of applicable plant and strainer drawings and the maximum seismic displacements, the staff agrees with the conclusion that the strainers and fins are clear from any interferences because the displacements do not cause any interactions with neighboring equipment or structures.

5.1.1.9 Strainer Module Base Plates

The AECL stress analysis report provided the base plate stress utilization ratios and anchor bolt utilization ratios for the various types of base plates, which were shown to be acceptable. These stresses were compared with the ASME 1989, Section III, Division 1, Subsection NF code stress allowable limits.

Staff Evaluation

Based on a review of the results of the utilization ratios for the strainer module base plates and Hilti-Kwik anchor bolts, the NRC staff finds the results acceptable because the computed utilization ratios for base plates are less than 100%, and the interaction ratios for anchor bolts are less than one.

5.1.1.10 Support Bracket Connecting Bolts

The stresses in header/frame connecting bolts, saddles and support bracket connecting bolts, and bolts in the fin tabs were computed and shown to be less than the allowables.

Staff Evaluation

Based on a review of the computed bolt stresses, the NRC staff finds that the bolt stresses and interaction ratios meet the code allowables and are therefore acceptable.

5.1.1.11 Weld Analysis

There are 20 spot welds for the large LHSI fin and 8 spot welds for the large RS fin. In FEA, the welds were modeled by coupling the nodal displacements. The maximum weld stresses meet the allowable stress limit.

Staff Evaluation

Using the criteria and allowable stresses from ASME Section III Boiler and Pressure Vessel Code, the computed weld stresses for welds were shown to be less than the corresponding allowables. The NRC staff finds that these weld stress evaluations are acceptable because they use widely accepted industry methods, codes, and standards.

5.1.1.12 Local Stress in Pump Housing

Local stresses in the pump housing, where a bracket is welded to the pipe on the opposite side, were evaluated by two methods. The first method is based on Bijlaard analysis as a first approximation by not taking into account the effect of the plenum opening. The second approach is based on FEA to assess the primary local stress between the support lugs and the large rectangular opening of the inlet plenum. The FEA method simulated the nonlinear behavior of the gap support under loading. The primary local stresses meet the allowable stress limits.

Staff Evaluation

The primary local stresses meet the 1.5 S_m allowable limit. The NRC staff finds the primary local stresses in the pump housing to be acceptable because these stresses meet the applicable allowable limits.

5.1.1.13 Hydrodynamic Mass

AECL simulated SSE hydrodynamic effects by considering the attached water mass. Added mass was determined using information from R. D. Blevins, “Formulas for Natural Frequency and Mode Shape.” Added mass in the vertical direction is zero because there is no relative motion between the strainers and pool water. In the in-plane direction of the fins (transverse header direction), the mass in front of the header is approximately equal to half the volume of a cylinder, the diameter of which is equal to the clear distance between the two fins and the length equal to the height of the header. There is an equal volume of water behind the header. In the direction normal to the fin (axial header direction), the added mass is half the entrapped water between fins plus the water mass in a half cylinder spinning about the long axis of the fin and reduced by a factor depending upon the aspect ratio as given in Blevin’s book.

Staff Evaluation

The staff finds the hydrodynamic mass calculation approach acceptable because the computations are in accordance with standard analytical methods.

5.1.1.14 Summary

The stresses in the containment sump replacement strainers, supports, anchorages, and welds were shown to meet the 1989 edition of the ASME Boiler and Pressure Vessel Code, section III, subsection NF requirements. From the buckling considerations, relevant components were shown to be stable. The calculations performed by AECL for the licensee demonstrate the structural performance of the strainer modules under the worst combination of postulated conditions. Based on these considerations, the staff finds that the design of the sump strainer assembly is structurally adequate, and that, from a structural perspective, it will perform its required safety function during a design basis accident.

5.2 Upstream Effects

The purpose of the review of upstream effects is to ensure that the licensee has appropriately accounted for potential hold up volumes, choke points, and other physical obstructions that could prevent water from draining to the sump. Any water held up by restrictions would not be available in the sump pool to provide coverage of the strainer and the required head above the strainer and would result in a reduction of NPSH margin.

To evaluate upstream effects, the staff reviewed containment drawings, discussed the subject with licensee staff, and also reviewed several other references listed at the end of this report. To verify the assumptions contained in these documents, and verify the available flow paths to the sump, the staff reviewed several containment structural drawings. The staff evaluated the licensee's treatment of potential blockage at containment drainage flow choke points and other upstream effects. No baseline document or walk down to specifically identify choke points or obstructions was provided for review. Nor did the licensee provide a description of the flowpaths, documentation which the staff considered should have been available.

The GOTHIC Analysis for NPSHa [35] makes the following corrections for holdups in the NPSH analysis: water holdup in the refueling canal, water holdup in the reactor cavity and instrument tunnel, water holdup on condensed films and heat structures, and water holdup and films on platforms and structures. The calculation also accounts for water absorption in insulation. The GOTHIC calculation realistically accounts for the holdups as part of the transient analysis. These holdups appear to be properly accounted for in the calculation.

The debris generation calculation [30] provides a calculation of the grated areas on each elevation that would allow flow from the spray system to the sump. Based on a review of the reference documents, water is discharged from the spray headers located between 85 and 100 feet above the operating deck at 291 feet, 10 inches. The water will pass through various plant elevations before ultimately draining into the containment sump formed on elevation 216 feet, 11 inches. Staff review of the provided documentation shows that at and above the operating floor elevation at 291 feet, 10 inches, the flooring is primarily grating and open area above the steam generator cavities. Around the outer edge of the containment the flooring is primarily grating or stairwells. Portions of the floor at 291 feet, 10 inch elevation are concrete. These solid portions drain to grated areas with no obstructions. Therefore, spray flow will either pass through gratings into the steam generator compartments, fall to the next lower level around the edge of the containment, or fall onto the operating floor.

At the operating floor elevation the refueling canal is also open to the spray falling from above. The GOTHIC NPSH calculation [35] assumes that the refueling canal drains become blocked and the refueling canal fills with spray water as the event progresses. By design, water can flow from the refueling cavity to the containment sump through a 6-inch drain located in the fuel transfer portion of the refueling cavity. The drain is located in the bottom of the fuel transfer canal at an elevation of 251 feet 4 in. The valves in the refueling cavity transfer canal drain lines are administratively controlled by procedure and by physically chaining and locking the valves in the open position during normal operation of the reactor. Operators are required to verify all valve positions before starting or resuming normal operation when it is known that those systems have been used during the shutdown period. The licensee assumption that the refueling canal becomes filled with water during a LOCA due to blockage of this drain line is conservative. However, the water held up in the refueling canal is not available on the containment floor to increase RS and LHSI pump NPSHa. The staff noted that installation of grating around the refueling canal drain line to minimize the chance the line could be blocked by large pieces of debris would ensure that most of the water would reach the containment sump. This relatively simple modification could enhance the safety of the plant.

Drawings show that the structure at elevation 262 feet, 10 inches is composed of grating and concrete. There are significant open areas on this elevation as well. The areas outside the refueling cavity and reactor compartments will allow water to flow through grating or drain to the grated areas to fall to the lower containment elevations. Drawings show the steam generator compartments to be open at the 262 feet, 10 inch elevation. In general, the steam generator compartments have no obstructions that would prevent the flow of water from the upper elevations to the bottom of the compartments.

The reactor cavity is a potential significant holdup volume for water in containment. In the GOTHIC NPSH calculation [35] the reactor cavity reactor cavity is assumed to fill up to the 219 foot elevation before overflowing to communicate with the recirculation sump. Spray water drains through the open annulus around the reactor vessel down into the reactor cavity and the incore instrumentation tunnel. In addition, LOCA break flow can enter the annulus. The water builds up to the 219 foot elevation and overflows to the steam generator cubicle through a 12 inch hole that has been bored in a plug in the reactor cavity wall. The hole was added by Dominion to reduce holdup of water during a LOCA.

According to the drawings, elevation 241 feet is the first major floor level above the basement elevation (216 feet, 11 inches). The flooring at this elevation is also constructed of both concrete and grating. The solid flooring at this elevation can drain to the grated area with no obstructions.

The water flows at the basement level elevation of 216 feet, 11 inches are relatively open allowing flow to the sump and strainers. Although several physical features (e.g., grating and curbs) may hold up some pieces of large debris and the floor slopes slightly away from the recirculation sump toward the center of containment, the flow of water to the sump should not be significantly impeded.

There are steam generator and pressurizer compartment blowout panels that blow out to prevent overpressurization or excessive differential pressure between these compartments during a LOCA. The panels are designed to blow out in a single piece and blow into areas where the floors are fabricated of grating. The licensee concluded that the grating areas are large enough to ensure that the blow out panels would not prevent the flow of water toward the sump.

Based upon the information reviewed and summarized above, the staff concluded that water drainage in the NAPS containment would not be susceptible to being trapped in unanalyzed hold up locations. The staff focused its review of upstream effects on the drainage flowpaths through the refueling canal and reactor cavity because of the potential for the drains to these large volumes to act as choke points for retaining substantial quantities of water if the drains were to become blocked by debris. The licensee assumed that the refueling canal becomes filled with water, which is a conservative assumption. In addition, in response to the GL 2004-02 issue, the licensee added a large drainage hole to the reactor cavity to ensure that a significant holdup volume would not occur in that location. Therefore, the staff did not identify any issues of significance with respect to the licensee's upstream effects analysis.

5.3 Downstream Effects

5.3.1 Downstream Effects - Core

The acceptance criteria for the performance of a nuclear reactor core following a LOCA are found in 10 CFR 50.46 of the Commission's regulations. The acceptance criterion dealing with the long-term cooling phase of the accident recovery is as follows:

> Long-term cooling: After any calculated successful initial operation of the ECCS, the calculated core temperature shall be maintained at an acceptably low value and decay heat shall be removed for the extended period of time required by the long-lived radioactivity remaining in the core.

At the request of the industry, the NRC staff provided additional interpretation for (1) the requirements and acceptance criteria for long-term core cooling once the core has quenched and reflooded and (2) for the mission time that should be used in evaluating debris ingestion effects on the reactor fuel [25].

Following a large break in the reactor coolant system after the core has been re-covered with water, long-term cooling at the NAPS will be accomplished by the low-pressure and high-pressure injection pumps. These pumps initially take suction from a storage tank containing borated water. When that source of water becomes depleted, the suction to the low-pressure pumps will be switched to the containment sump to recirculate water to the reactor system. At that time the containment will contain all the water spilled from the reactor system and that added by the spray systems. The core cooling mode by which water from the containment sump is continually added to the reactor system and is recirculated as it spills from the break may be required for an extended period. During this long-term cooling period, any debris that is washed into the containment pool that passes through the sump strainers will have a high probability of being pumped into the reactor coolant system.

Generic Letter 2004-02 requests that holders of operating licenses for pressurized-water reactors evaluate the ECCS and the containment spray recirculation functions. These evaluations are to include the potential for debris blockage at flow restrictions within the ECCS recirculation flow path downstream of the sump strainer. Examples of flow restrictions that should be evaluated are the fuel assembly inlet debris screens and the spacer grids within the fuel assemblies. Debris blockage at such flow restrictions could impede or prevent the recirculation of coolant to the reactor core leading to inadequate long-term core cooling.

NRC staff concerns for debris blockage of the reactor core are primarily related to the recovery following the largest postulated reactor system piping breaks. For smaller break sizes the goal of plant operators would be to fill the reactor coolant system and establish closed loop cooling using the decay heat removal system. Recirculation of sump water might not be required for small break sizes and if recirculation were needed, the requirements would be less than for large breaks. The amount of sump debris following a small break is expected to be less than that which would be generated following a large break. The audit evaluation therefore emphasized long-term cooling following large piping breaks.

Following a large-break LOCA at NAPS, the low-pressure and high-pressure ECCS pumps are aligned to inject into the reactor cold legs. If the break were in a reactor coolant system hot leg, the ECCS water would be forced through the reactor core toward the break. Core flow, including a small amount of core bypass flow, during the long-term cooling period would be equal to the total ECCS flow. If all ECCS pumps were assumed to operate, ECCS flow into the reactor coolant system through the reactor vessel and into the core would be maximized. The maximum flow condition is evaluated since it provides the greatest potential for debris transport to the reactor core and subsequent lodging within flow restrictions.

Following a large cold leg break with injection into the reactor cold legs, water will flow into the core, but the rate of core flow will be limited by the pressure needed to overcome the flow resistance of steam generated by the core in reaching the break and by the static head of the water in the core. Eventually the rate of ECCS water reaching the core will be limited to that needed to replenish what is boiled away. The excess will be spilled out of the break, including water injected into the intact cold legs that will flow around the upper elevations of the downcomer and reach the break without passing through the core. The long-term cooling period following a large cold leg break represents a minimum core flow condition. Core blockage by debris under these conditions would add to the resistance that must be overcome for the ECCS water to reach the core and lead to additional spillage from the break.

For the evaluation of potential core blockage following a hot leg or a cold leg break, the licensee stated that it is part of the PWR Owners Group, which is investigating this issue. The PWR Owners Group has developed WCAP-16406-P [18] and WCAP-16793-NP [27]. The WCAPs describe how particulate debris with a density that is heavier than water will settle in the reactor vessel lower plenum and not be passed into the core for a sufficiently low flow velocity. The WCAPs also describe how fibrous debris with a density approximately the same as water would be carried along with the recirculated sump water but would be filtered by the sump strainers and by screens at the inlet to the fuel bundles. WCAP-16406-P was submitted to the staff for review as a topical report in 2006, and WCAP-16793-NP was submitted for review in June 2007. The staff plans to complete the review of WCAP-16406-P in late 2007 and to complete the review of WCAP-16793-NP in the first quarter of 2008. Because the subject of in-vessel downstream effects is covered in much greater detail in WCAP-16793-NP than it is in WCAP-16406-P, the staff's SE of WCAP-16406-P is not expected to reach any conclusions regarding the validity of the in-vessel debris issue presented in that document. Rather, it will refer to the yet-to-be-developed SE for WCAP-16793-NP. NRC approval of a topical report is not required for a licensee to reference that report, though licensees planning to reference it should be aware of any associated issues the staff may have as its review of a given topical report proceeds.

The licensee contracted with AREVA NP to provide additional considerations by which the methodologies of WCAP-16406-P and WCAP-16793-NP can be applied to NAPS [71]. AREVA NP evaluated the amount of additional flow resistance from debris that would still allow adequate water to enter the core for core cooling. Before ECCS water can enter the core at NAPS, the water first must flow from the downcomer, turn in the lower plenum and flow upward to the core. The lower plenum provides a location of low flow velocity where heavier debris might settle without reaching the core. AREVA NP expanded on the methodology of WCAP-16406-P to provide additional equations to be used to evaluate the settling process. AREVA NP developed a methodology by which local heating might be calculated if debris lodged between the fuel bundle grid straps and the fuel rods. If debris were to be deposited behind the fuel bundle grid straps, local hot spots might be generated. The staff did not review the AREVA NP methodology in detail. However, from an abbreviated review of this material, the staff believes that the AREVA NP methodology will be beneficial in evaluating the post-LOCA consequences from debris injection into the reactor vessel at NAPS. The licensee has not yet completed evaluation of debris intrusion into the reactor vessel and long-term cooling of the core. The staff will review the licensee's application of WCAP-16406-P, WCAP-16793-NP and the AREVA NP material during the staff's review of the GL 2004-02 supplemental responses, when the licensee's evaluations of long-term core cooling have been completed.

Following a large cold leg break, continued boiling in the core will act to concentrate the debris and chemicals in the water between the core coolant channels. Chemical reaction of the debris with the pool buffering agents and boric acid from the ECCS water in the presence of the core radiation field might change the chemical and physical nature of the mixture. Heat transfer might be affected by direct plate out of debris on the fuel rods and by accumulation of material within the fuel element spacer grids. Neither WCAP-16406-P nor the AREVA NP methodology deal with the effect of chemicals in the recirculated water on core heat transfer or the possible precipitation of chemicals and debris by the boiling process. During a meeting with the PWR Owners Group on April 12, 2006, held to discuss issues associated with downstream effects on reactor fuel, the owners presented plans to develop another topical report with a more detailed fuel evaluation methodology. That report is WCAP-16793-NP. The licensee stated that they will rely on the ongoing program by the PWR Owners Group for evaluating the effects of chemicals and debris on reactor core heat transfer during the long-term cooling period.

At a meeting with the PWR Owners Group February 7, 2007, the staff gave the owners a list of considerations that should be addressed to resolve GSI-191 for the reactor core [72]:

1. Methodology should account for differences in PWR reactor coolant system and ECCS designs.

   Examples:
   - Combustion Engineering plants with smaller recirculation flows may produce extended core boiling long after hot leg recirculation begins. The extended boiling period may impact concentration of debris in a core, plate-out, etc.
   - Use of pressurizer spray nozzles for hot-leg recirculation should be evaluated for the potential of clogging with debris.
   - Upper Plenum Injection plants without cold leg recirculation flow may have no means of flushing the core following a large hot leg LOCA and may need special consideration.

2. Hot spots may be produced from debris trapped by swelled and ruptured cladding.

   - Debris may collect in the restricted channels caused by clad swelling, and at the rough edges at rupture locations.
   - FLECHT tests have shown that swelled and ruptured cladding may not detrimentally affect the cladding temperature profile. The FLECHT tests did not include post-LOCA debris.

3. Long-term core boiling effects on debris and chemical concentrations in the core should be accounted for.

   - The evaluations should be similar to post-LOCA boric acid precipitation evaluations.
   - They should account for the change in water volume available to mix with constituents concentrated by the core from debris accumulation.
   - Partial blockage of the core creates alternate circulation patterns within the reactor vessel and will affect the concentration analysis.
   - Will the solubility limits be exceeded for any of the material dissolved in the coolant that is being concentrated by boiling in the core?

4. Debris and chemicals that might be trapped behind spacer grids could potentially affect heat transfer from the fuel rods and should be evaluated.

   - Analyses show that a partially filled spacer grid produces only a moderate cladding temperature increase even if only axial conduction down the cladding is considered.
   - Similar analyses show that a completely filled spacer grid with only axial conduction will result in unacceptable temperatures.
   - A physical basis for determining to what extent the spacer grids can trap debris, and the ability for the debris to block heat transfer needs to be provided.
   - The evaluation needs to include the chemical and physical processes that may occur in the core during the long-term cooling period.

5. Consideration should be included for plating out of debris and chemicals or both on the fuel rods during long-term boiling.

   - Long-term boiling in the core following a large-break LOCA may last for several weeks for some designs depending on the ECCS flow and core inlet temperature.
   - The concentration of materials in the core, and the potential for plate out on the fuel rods (boiler scale) from this material should be determined.
   - When the composition and thickness of the boiler scale have been determined, the effect on fuel rod heat transfer should be evaluated.

6. The licensees need to address whether high concentrations of debris and chemicals in the core from long-term boiling can affect the natural circulation elevation head which causes coolant to enter the core.

   - For a large cold leg break, the density difference between the core and the downcomer determines the hydrostatic driving head, and consequently the flowrate into the core.
   - As boiling continues, a high concentration of debris and chemicals in the core may increase the core density and reduce the flow into the core.

7. If hot spots are found to occur, the licensee should address cladding embrittlement. Applicable experimental data for the calculated condition and type of cladding should be presented to demonstrate that a coolable geometry is maintained.

Staff Evaluation:

The licensee continues to evaluate the post-LOCA consequences of debris ingestion into the reactor coolant system and its effect on long-term core cooling. The licensee has stated that they will use the results from generic evaluations currently being done by the PWR Owners Group. Although downstream evaluations were in progress during the audit, the licensee has not made any final conclusions as to whether the cores at NAPS could be blocked by debris following a LOCA. This area is incomplete and is identified as **Open Item 5.3-1** for the licensee to provide a summary of the results of the in-vessel downstream effects evaluation to the staff. The staff will review the application of this methodology for the NAPS and the licensee's conclusions when they are submitted. The PWR Owners Group recently submitted WCAP-16793-NP, "Evaluation of Long-Term Cooling Considering Particulate, Fibrous and Chemical Debris in the Recirculating Fluid [27]." The staff expects to complete review of this document in early 2008.

5.3.2 Component (Ex-Vessel) Evaluation

SE Section 7.3 DOWNSTREAM EFFECTS (Audit Guidelines)

The Guidance Report provides licensees guidance on evaluating the flowpaths downstream of the containment sump for blockage from entrained debris.

The Guidance Report and associated SE identify the following aspects to be included in the downstream evaluation:

- Flow clearance through the sump strainer should be identified to determine the maximum size of particulate debris to be used in downstream component evaluations.
- An evaluation of wear and abrasion of surfaces in the emergency core cooling and containment spray systems based on flow rates to which the surfaces will be subjected and the grittiness or abrasiveness of the plant-specific ingested debris.
- A review of the effects of debris on pumps and rotating equipment, piping, valves, and heat exchangers downstream of the sump. In particular, any throttle valves installed in the ECCS for flow balancing should be evaluated for potential blockage.
- Long-term and short-term system operating lineups, conditions of operation, and mission times should be defined. For pumps and rotating equipment, the licensee should assess the condition and operability of the component during and following its required mission times.
- Component rotor dynamics changes and long-term effects on vibrations caused by potential wear should be evaluated, including the potential impact on pump internal loads to address such concerns as rotor and shaft cracking (NUREG/CP-0152 Vol. 5 , TIA 2003-04) [26].
- System piping, containment spray nozzles, and instrumentation tubing, should be evaluated for the settling of dust and fines in low-flow/low fluid velocity areas. Include such components as tubing connections for differential pressure from flow orifices,

elbow taps, and venturis and reactor vessel/reactor coolant system leg connections for reactor vessel level. Consideration should be given to any potential impact that matting may have on instrumentation necessary for continued long-term operation.

- Valve and heat exchanger wetted materials must be evaluated for susceptibility to wear, surface abrasion, and plugging that may alter the system flow distribution.
- Heat exchanger degradation resulting from plugging, blocking, plating of slurry materials must be evaluated with respect to overall system required hydraulic and heat removal capability.
- An overall system evaluation, integrating limiting conditions and including the potential for reduced pump/system capacity resulting from internal bypass leakage or through external leakage should be done.
- Leakage past seals and rings caused by wear from debris fines to areas outside containment should be evaluated with respect to fluid inventory and overall accident scenario design and license bases environmental and dose consequences.

NRC Staff Audit:

NAPS used PWR Owners Group WCAP-16406-P Evaluation of Downstream Sump Debris Effects in Support of GSI-191, Revision 0 [24] in their assessment of their ECCS and components. Revision 1 [18] to the PWR Owners Group document is currently under review as a topical report by the staff. The licensee draft evaluations of the ECCS and effects on downstream component are preliminary [87], based in part on the generic methodology of WCAP-16406-P currently under review by the NRC staff. NAPS will reassess the evaluation based on the conclusions and findings associated with the staff's review of WCAP-16406-P Revision 1. The licensee should provide the staff summary results of this evaluation. This is identified as **Open Item 5.3-2**.

The licensee evaluated the flow paths downstream of the containment sump to determine the potential for blockage due to debris passing through the sump strainer. The scope of the evaluation included components in the circulation flow path(s) including throttle valves, flow orifices, spray nozzles, pumps, heat exchangers, and valves. The staff evaluation was based on review of the recirculation flow path(s) shown on piping and instrument diagram drawings, plant procedures and UFSAR descriptions. The licensee evaluated system and component flow clearances using the following logic [46]:

- Determine the maximum characteristic dimension of the debris (clearance through the sump strainer).
- Identify the recirculation flow path(s).
- Identify the components in the recirculation flow path(s).
- Review station documents (drawings, operation & maintenance manuals, etc.) to determine flow path clearance dimensions.
- When physical drawings of the instrument connection orientation were not available, nor walkdowns to confirm location, use engineering judgement to assess acceptability.
- Determine blockage potential by comparing the component flow clearance with the flow clearance through the sump strainer.
- Based upon the previous step, identify components requiring a detailed evaluation. The evaluation should include an investigation of the effects of debris on the capability of the components to perform their intended function

Based on the flow clearance evaluations, the licensee determined that the following components required further review and investigation:

- IRS pumps
- ORS pumps
- LHSI pumps
- high-head safety injection/charging pumps
- Various ECCS and spray system instrument root isolation valves
- Various ECCS and spray system globe valves
- Various ECCS relief valves
- Various ECCS and spray system flow instruments
- RS cooler flow orifice
- ORS pump seal head tank

Based on its review of licensee-provided documentation [88, 89, 90, 91, 92, 93], the staff concluded that all system components and flow paths were appropriately listed. However, the draft evaluation provided a list of instrument connection locations and several instrument connection orientations wherein the acceptability was determined without confirmation via walkdown or review of as-built drawings. The licensee assumed that the components were acceptable by the practice of good installation and engineering judgement at the time of original construction. Additional verification and validation (walkdowns, drawing reviews, etc.) of those locations should be done to confirm physical orientation and location, and the licensee should provide a summary of the method used to accomplish this and the results to the NRC staff. This is identified as **Open Item 5.3-3**.

Following SE Section 7.3, the staff reviewed the licensee-stated design and mission times and system lineups to support mission critical systems. The mission time for the evaluation of recirculation performance was defined as 30 days. The selected time is in accordance with 10 CFR 50.46(b)(5); this regulation provides that “after any calculated successful initial operation of the ECCS, the calculated core temperature shall be maintained at an acceptably low value and decay heat shall be removed for the extended period of time required by the long-lived radioactivity remaining in the core.” Section 15.4 of the NAPS Updated Final Safety Analysis Report [52] states the duration of the LOCA is to be 30 days. Lineups, flows and pressures used to bound downstream evaluations were in all cases conservative with respect to review and evaluation of downstream components.

A detailed review of the latest revision of the high-head injection pump owners manual revealed that the licensee had modified the pump discharge orifice to reduce the probability of air entrapment due to the separation of gas and liquid caused by impeller rotation. The staff reviewed the licensee’s analysis of the extent of air entrainment (apart from vortexing), and found no significant air entrainment issues with the ECCS that would either impact ECCS pump operation or cause air pockets in ECCS piping.

The licensee did not address the potential for water hammer and slug flow in its evaluation. These areas were not reviewed by the staff during the audit.

The NAPS characterization and assumed properties of bypass debris in ECCS post-LOCA fluid (abrasiveness, solids content, and debris characterization) are ongoing and not yet complete. For the initial assessment [87] the licensee assumed 100 percent passthrough of particulate. The licensee had tested for fiber bypass testing and at the time of this audit but had yet to decide how to implement the results. The staff identified finalization of bypass testing and evaluation and reporting the summary results to the NRC staff as **Open Item 5.3-4**.

The licensee evaluation contained a list of the materials of all wetted downstream surfaces (wear rings, pump internals, bearings, throttle valve plugs, and seat materials). The staff examined this list and checked the materials of construction by reviewing design drawings and licensee technical manuals [95, 96, 97, 94, 98]. Operating and maintenance manuals correctly depict changes in the components.

For the long-term wear evaluations, the quantity and type of debris was derived from the debris transport and head loss calculations. The licensee evaluated component wear for the following components:

- Flow orifices and flow elements in the safety injection and RS systems
- Throttle valves used for flow balancing in the safety injection system
- IRS, ORS, LHSI and high-head safety injection/charging pumps
- RS heat exchangers

The SE identifies a potential vulnerability of high-pressure safety injection throttle valves to clog during ECCS operation. The licensee evaluation states that NAPS has two-inch Edward Univalves, which are stainless steel globe valves, in its high-head safety injection system [94]. The flow conditions of all the throttle valves located downstream of the high-head safety injection pumps were initially evaluated by the licensee. The staff found a documentation inconsistency in the hot leg throttle valve clogging evaluation. A 44 percent open setting was used as an input to the clearance calculation. A minimum throttle valve setting of 20 percent is maintained per Engineering Transmittal ET-CME-95-33. Licensee personnel verified that the throttle valves are locked in position and verified through performance testing. The valve position has not been changed for several years. Operating and maintenance manuals correctly depict the setting of the throttle valves as 20 percent. The downstream component evaluation did not reference operating procedures or testing history, which establish the actual position, to determine throttle valve open position during ECCS operation. The full range of possible throttle valve settings should be incorporated into the licensee revised downstream evaluations. The need to incorporate these settings and summarize the results for the staff is identified as **Open Item 5.3-5.**

The SE states that licensees should review and assess changes in system or equipment operation caused by wear (e.g., pump vibration and rotor dynamics). The ORS, IRS, LHSI and high-head safety injection pumps are exposed to debris-laden flow. The ORS and LHSI pump mechanical seals are both of a tandem design that uses primary grade and RWST water between the seal faces, respectively. These mechanical seals are not subject to wear by debris. The IRS pumps are inside containment. The environmental effects due to leakage across the throttle bushings are bounded by the post-LOCA containment environmental profile.

The licensee's draft evaluation [87] notes that there may be primary and backup seal leakage from the LHSI pumps into the Auxiliary Building. This leakage was not quantified nor was an evaluation of such leakage effects on equipment qualification, sumps and drains operation, or room habitability evaluation performed. The need to evaluate this leakage and its effects, and to summarize the results of the evaluation for the staff, is identified as **Open Item 5.3-6**.

The licensee did not fully define the range of fluid velocities within piping systems. The fluid velocities used were based on nominal system operating characteristics and did not consider the range of possible system flows. NAPS staff should reassess ECCS flow balances based on the results of system and component wear evaluations. The need to accomplish this and summarize the results for the staff is identified as **Open Item 5.3-7**.

The preliminary downstream component evaluations did not consider the use of minimum and maximum system operating points. Instead, best-efficiency performance values were used. The ECCS operating point values were not referenced back to system bases calculations. Original design flows through restricting devices were used to calculate wear. The wear evaluation(s) should be revised to reflect the full range of possible flow conditions. The need to revise the evaluation and summarize the results for the NRC staff is identified as **Open Item 5.3-8**.

The licensee used design pump curves, versus degraded, actual or modified pump curves. Values from the original design conditions were used. The effects of variances in the pump curves were not included. The pump curves used in the evaluation(s) should consider actual operating characteristics as derived from operating experience or through inservice testing. Each component should be reviewed to determine the appropriate bounding pump parameters to be used in the wear calculation and subsequent pump performance evaluations. The need for the licensee to justify the use of design curves, or to re-analyze for degraded, actual or modified pump curves, and to summarize the results of the evaluation for the NRC staff, is designated **Open Item 5.3-9**.

The licensee did not perform an overall system flow evaluation considering the results of the various component wear evaluations to prevent potential pump run-out conditions and deviation from nominal operational values for the ECCS, RS, and quench spray. The need for the licensee to integrate the wear evaluations into an overall system flow evaluation and provide summary results to the NRC staff is designated as **Open Item 5.3-10**.

5.4 Chemical Effects

The status of NAPS chemical effects evaluations was discussed during a July 19, 2007, conference call between NRC staff, the licensee, and representatives from the licensee's contractor. At the time of the call, the licensee's approach to chemical effects testing was still under development. The licensee said that the chemical source term would be calculated using two different approaches: (1) Sargent and Lundy would use the WCAP-16530-NP base chemical model and (2) independent calculations will be done by AECL. Initial bench testing and subsequent head loss testing will be done by AECL. Since the chemical testing program for the NAPS is in its preliminary stages at this time, the staff was not able to draw any conclusions regarding its adequacy. Therefore the resolution of chemical effects at NAPS and provision of results of the evaluation to the staff is designated **Open Item 5.4-1**. A similar open item has been identified for most audited plants to date.

Within this open item is the general open item across the PWR fleet associated with the potential for failed coatings debris to contribute to chemical effects through changes to the coatings debris due to the pool environment (e.g., some coating chips could turn into a product that causes high strainer head losses). This part of the chemical effects open item is being addressed by the industry generically. The staff is expecting to receive an industry report during the 4th quarter 2007 that evaluates the chemical effects of coating debris in a post-LOCA environment. If the staff determines that the report provides adequate basis to address the staff questions, then this portion of open item 5.4-1 will be closed.

Also considered within Open Item 5.4-1 is the analysis in Attachment 1 to the debris transport calculation [31], which specifies the AECL debris bed head loss testing acceptance criteria for long-term and short-term post-LOCA conditions. Since the licensee's integrated chemical effects testing plans have not been completed, the staff could not review the application of the acceptance criteria calculation. However, the staff noted that the licensee should verify that the long-term and short-term acceptance criteria are bounding with respect to all intermediate conditions once the plans for integrated chemical effects head loss testing are completed.

6.0 Conclusions

The North Anna Power Station has responded to NRC's Bulletin 2003-01 and Generic Letter GL 2004-02 according to the required schedule. New AECL RS and LHSI strainers, with effective surface areas of 4415 ft^2 and 1890 ft^2, respectively, have been installed in Unit 2 and are scheduled for installation in the Fall 2007 refueling outage for Unit 1.

An overall conclusion as to the adequacy of the licensee's corrective actions in response to Generic Letter 2004-02 will be contained in a future letter to the licensee from the NRC Office of Nuclear Reactor Regulation. This letter will consider licensee responses to GL 2004-02 requests for additional information, as well as future licensee GL 2004-02 supplemental responses reporting closure of the open items in this report and completion of GL 2004-02 corrective actions at NAPS.

Appendix I
Open Items

Open Item 3.6-1 (page 43): Temperature Scaling of Head Loss Test Data

The licensee scaled test head losses to plant sump conditions based only on temperature--driven viscosity variations. Test phenomena driven by differential pressure (e.g., opening of paths through the bed) should be considered as well. The licensee should evaluate this issue and provide a summary of the method and results to the staff in its supplemental response to GL 2004-02 due by the end of December 2007.

Open Item 3.6-2 (page 44): Justification for Time-Dependent Head Loss Assumptions

The licensee assumed that at the beginning of low head safety injection operation in the recirculation mode there would be no debris accumulation on the low head safety injection strainer, and that the strainer head loss due to debris would reach the peak thin bed head loss after a period of time. The licensee should provide the basis for these assumptions in its supplemental response to GL 2004-02.

Open Item 3.7-1 (page 47): Net Positive Suction Head Available Calculation

The calculated net positive suction head available margins for the low head safety injection, inside recirculation spray and outside recirculation spray pumps were non-conservative. The margins for these pumps were overestimated by approximately 0.6 feet of head because of an error in the calculation of the static head of liquid. The licensee should evaluate this issue and provide a summary of the method and results to the staff in its supplemental response to GL 2004-02.

Open Item 5.3-1 (page 70): Downstream Effects-Core Blockage

Although downstream evaluations were in progress during the audit, the licensee has not made any final conclusions as to whether the cores at North Anna Power Station could be blocked by debris following a LOCA, and this area is incomplete. The licensee should summarize the method and results of its evaluation of this issue in its GL 2004-02 supplemental response.

Open Item 5.3-2 (page 71): Downstream Effects Evaluations Preliminary

The licensee's evaluations of the downstream effects of debris on systems and components are preliminary, based in part on the generic methodology of WCAP-16406-P which is under review by the NRC staff. NAPS will reassess the evaluation based on the conclusions and findings associated with the staff's review of WCAP-16406-P Revision 1. The licensee should provide the staff a summary of the method and results of this evaluation.

Open Item 5.3-3 (page 72): ECCS Instrument Locations

The evaluation documented that the ECCS instrument locations are adequate because of an assumption of "good engineering practice." This assumption needs to be verified, such as by means of isometrical drawings or an ECCS survey. The licensee should provide the staff a summary of the method and results of this verification.

Open Item 5.3-4 (page 73): Debris Bypass Testing

The licensee had not made a final determination on how the bypass testing data is going to be implemented in the downstream effects evaluation for ECCS and internal vessel components. The licensee should provide the staff a summary of the method and results of its bypass testing.

Open Item 5.3-5 (page 73): Fixed Throttle Valve Setting

The downstream component evaluation did not reference operating procedures or testing history in order to demonstrate high confidence that throttle valves will remain in their fixed position during ECCS operation. Throttle valve fixed position is the basis for assuming the system's hydraulic resistance to be fixed. The licensee should address the full potential range of throttle valve positions in their revised downstream evaluation.

Open Item 5.3-6 (page 74): Quantification and Assessment of Downstream Effects That Cause Seal Leakage

The licensee did not quantify seal leakage associated with downstream effects into the Auxiliary Building, nor evaluate the effects on equipment qualification, sumps and drains operation, or on room habitability. The licensee should summarize the method and results of its evaluation of these subjects in its GL 2004-02 supplemental response.

Open Item 5.3-7 (page 74): Range of System Flows

The licensee did not fully define the range of fluid velocities within piping systems. Fluid velocities used were based on nominal system operating characteristics and did not take into account the range of possible system flows. NAPS staff should re-assess ECCS flow balances based on the results of system and component wear evaluations and should provide a summary of the method and results to the NRC staff.

Open Item 5.3-8 (page 74): ECCS Minimum and Maximum Operating Points

The preliminary downstream component evaluation did not consider the use of minimum and maximum system operating points; instead, best-efficiency performance values were used. The ECCS operating point values were not referenced back to system bases calculations. The licensee should evaluate this issue and provide a summary to the staff.

Open Item 5.3-9 (page 74): Use of Manufacturer's Pump Performance Curves

The pump performance inputs considered in the preliminary downstream components evaluation were obtained from manufacturer's pump performance curves. The evaluation should consider the use of degraded pump curves or in-service testing curves as these curves better represent actual system operating conditions. The licensee should evaluate this issue and provide a summary to the staff.

Open Item 5.3-10 (page 74): Overall Downstream ECCS Evaluation

The licensee had yet to perform an overall system evaluation that integrates the results of the downstream components evaluation. The evaluation should address compliance with 10 CFR 50.46, "Long Term Core Cooling." The licensee should evaluate this issue and provide a summary to the staff.

Open Item 5.4-1 (page 75): Evaluate Chemical Effects

The licensee's chemical effects analysis was incomplete at the time of the audit. Also, the licensee has not evaluated the contribution of coatings to chemical effects by: (1) leaching constituents that could form precipitates or affect other debris; and (2) changing form due to the pool environment. Since the licensee's integrated chemical effects testing plans have not been completed, the staff could not review the application of the debris bed head loss acceptance criteria to verify that the long-term and short-term acceptance criteria are bounding with respect to intermediate conditions. The licensee should provide the staff a summary of the method and results of its chemical effects evaluation and testing.

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