Indian Point Energy Center Corrective Actions for Generic Letter 2004-02

Enclosure

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Acronym List

Alion	Alion Science and Technology
CFD	computational fluid dynamics
D	break diameters
DDTS	drywell debris transport study
DSS	Division of Safety Systems
ECCS	emergency core cooling system
GL	generic letter
GSI	Generic Safety Issue
IPEC	Indian Point Energy Center
IP2 (3)	Indian Point Nuclear Generating Unit No. 2 (3)
IR	internal recirculation
LOCA	loss-of-coolant accident
NEI	Nuclear Energy Institute
NPSH	net positive suction head
NPSHa	net positive suction head available
NPSHr	net positive suction head required
NRC	Nuclear Regulatory Commission
PWR	pressurized water reactor
RCS	reactor coolant system
RHR	residual heat removal
RMI	reflective metallic insulation
RPV	reactor pressure vessel
RWST	refueling water storage tank
SE	safety evaluation
VC	vapor containment
ZOI	zone of influence

1 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 nine commercial pressurized water reactors (PWRs). The purpose of the audits is to help verify that the implementation of Generic Safety Issue (GSI) 191, "Assessment of Debris Accumulation on PWR Sump Performance [2]" sump strainer and related modifications will 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 emergency core cooling system (ECCS) strainers in their plants in order to resolve the GSI 191 [2] sump performance issue, originally scheduled to be resolved by December 31, 2007. The Indian Point Energy Center (IPEC), which is operated by Entergy Nuclear Operations, Inc. (Entergy or the licensee), contracted for design and installation of new strainers. Unit 3 was selected for focus for the audit because the strainers for that unit were installed during the 3R14 refueling outage in spring 2007, in advance of the final installation of Unit 2 strainers, which was eventually completed in April 2008. New Enercon replacement basket ("Top Hat") strainers with effective surface areas of 3156 ft^2 for the internal recirculation strainer and 1058 ft^2 for the containment strainer were installed in Unit 3. Additionally flow channeling barriers were designed and installed to route the post-LOCA water into the reactor sump and then up through the incore instrumentation tunnel to the vapor containment (VC) annulus through openings in the crane wall before entering the internal recirculation (IR) sump or the VC sump. This flow path is designed to cause a large quantity of the LOCA-generated debris to settle in the reactor sump or elsewhere in the VC before reaching the IR or VC sump strainers.

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 Entergy 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.

On May 12, 2006, three NRC staff members traveled to the IPEC to observe installation of new sump strainers at Indian Point Nuclear Generating Unit No. 2 (IP2) [35]. This pre-audit visit is discussed in more detail in Section 1.5, Staff Observation of IP2 Containment Sump Strainer Installation. The licensee had previously presented its plans for addressing GSI-191 in a February 9, 2007 meeting in Rockville, MD [37]. The audit commenced on November 20, 2007 when Entergy provided audit review documentation to the staff audit team. Following review of the presentation materials and other documents provided in advance, the audit continued with detailed interactions with the licensee and its contractor/vendor staff at the IPEC beginning December 3, 2007. The staff audit team and management exited with licensee personnel on December 6, 2007. In addition to the meetings on site, the NRC staff and licensee representatives conducted telephone conference calls following the audit to discuss audit topics. On January 7, 2008, the staff and licensee discussed questions regarding differential pressure across newly installed flow barriers. On February 6, 2008, the licensee and staff discussed proposed extension of completion dates for GL 2002-04 corrective actions. On March 5, 2008, a final teleconference was held to discuss audit topics, including identification of Open Item 3.5-5 related to time dependent analyses of transport (page 47). Table 1.1-1 lists key NRC staff and consultants, licensee staff and contractors, and identifies attendance during audit meetings.

Table 1.1-1 IPEC Audit Meetings and Contacts

Name	Organization	Title/ Area	Audit Onsite Entrance 12/3/2007	Audit Onsite Exit 12/6/2007
John Lehning	NRC/DSS	Debris Transport/CFD/ Alternate Methodology	x	x
Ralph Architzel	NRC/DSS	Team Leader	x	x
Matt Yoder	NRC/Division of Component Integrity	Chemical Effects		x
Erv Geiger	NRC/DSS	Downstream Components	x	x
Steve Smith	NRC/DSS	Head loss, Vortexing and Testing/Upstream	x	x
John Burke	NRC/Division of Component Integrity	Coatings	x	x
Kevin Mangan	NRC/Region I	Generic Comms/Screen Mod Package	x	x

Name	Organization	Title/ Area	Audit Onsite Entrance 12/3/2007	Audit Onsite Exit 12/6/2007
Clint Shaffer	NRC – ARES Corp	Baseline/ Break Selection/ ZOI/Debris Characteristics	x	x
Ted Ginsberg	NRC-Brookhaven National Laboratory	NPSH/Latent Debris	x	x
Ralph Landry	NRC/DSS	Fuel/Vessel-In Office Review		
Brett Titus	NRC/Division of Engineering	Strainer Structural Design-In Office Review		
Michael Scott	NRC/DSS	Branch Chief		x
Larry Doerflein	NRC/Region I	Branch Chief		x
Paul Cataldo	NRC/Region I	Sr. Resident Inspector	x	
John Boska	NRC/Division of Operating Reactor Licensing	IPEC Project Manager		
Roger Waters	Licensing	IPEC	x	x
Bob Walpole	Manager, Licensing	IPEC		x
Pat Conroy	Director, Nuclear Safety Assurance	IPEC	x	x
Tony Vitale	GMPO	IPEC		X
Joe Pollock	SVP	IPEC		X
Tom McCaffery	Manager, Design Engineering	IPEC	x	X
Valerie Cambigianis	Supervisor, Design Engineering	IPEC	x	X
Paul Studley	Operations Manager	IPEC		X
Steven Verrochi	Manager, System Engineering	IPEC	x	X

Name	Organization	Title/ Area	Audit Onsite Entrance 12/3/2007	Audit Onsite Exit 12/6/2007
Tom Orlando	Director, Engineering	IPEC	x	
Leland Cerra	Design Engineering	IPEC	x	x
Frank Inzirillo	Manager, Quality Assurance	IPEC		x
Don Mayer	Director Unit 1	IPEC		x
Steve Munoz	Project Management	IPEC		x
Jeff Gehrlein	Project Management	IPEC	x	x
Jay Basken	Enercon		x	x
David Dijak	Enercon		x	x
Atul Patel	Enercon		x	x
Aaron Smith	Enercon		x	x
Gilbert Zigler	Alion			x

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 and (2) identify areas that may need clarification or generic resolution. The following technical categories related to sump performance were reviewed and discussed:

debris generation
debris transport
coatings
debris characterization
system head loss
chemical head loss
modifications
upstream and downstream effects
net positive suction head (NPSH) for 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 IPEC new strainer design noting general conformance to the approved staff guidance [5], 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. The staff communicated the open items to the licensee during the audit meetings and telephone conferences. The licensee is expected to address these open items and document their resolution in conjunction with its final submittal to the NRC addressing GL 2004-02 [1].

1.2 Bulletin 2003-01 Responses

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 licensees 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 for IPEC, dated August 7, 2003 [26], Entergy chose the second option of describing the interim compensatory measures that have been implemented to reduce the risk associated with post-LOCA debris.

The interim compensatory measures implemented by the licensee documented in response to Bulletin 2003-01 [26] and in its reply to requests for additional information regarding Bulletin 2003-01 [27] include the following:

- Operator training to monitor operating recirculation and/or residual heat removal (RHR) pumps for erratic flow,
- Procedures which call, in the event of inadequate core cooling using IR pumps, for shifting to the independent alternate VC sump drawn upon by the RHR pumps,
- In the event of a loss of recirculation capability from both the IR and VC sumps, delaying depletion of the RWST (refueling water storage tank) by minimizing flow and depressurizing the reactor coolant system (RCS) to reduce break flow,
- An operator training plan to present the mechanisms and potential consequences of sump clogging,
- In the event of the inability to establish or maintain recirculation flow, the securing of all containment spray flow depending on containment conditions,
- Addition of water to the RWST from the primary water system upon loss of recirculation flow, a beyond-design basis circumstance,

- Foreign material control programs to ensure that inappropriate materials are not left in containment and that the containment sumps are free of debris,

- Plant startup containment walkdowns and inspection activities,

- Removal of the blind flange on the 4-inch refueling cavity drain line prior to startup, and

- Inspection of the sump screens each outage to verify the as-left condition is consistent with design requirements.

As described in the staff's Bulletin 2003-01 closeout letter to the licensee dated August 22, 2005 [28], the staff evaluated the interim measures taken by the licensee to address the potential risk associated with post-LOCA debris. Based on the information provided in the licensee's bulletin response and in the licensee's responses to staff requests for additional information on the bulletin response, 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 licensee submitted two correspondences before the audit that were reviewed by NRC staff auditors. These included a 90-day response dated February 28, 2005 [29], which discussed the planned methodology and schedule for analyzing the performance of the containment recirculation sump, as well as the methodology and schedule for conducting plant walkdowns, and a second response dated September 1, 2005 [30], which discussed the licensee's analyses and planned modifications to ensure adequate containment recirculation sump performance.

A third response dated December 15, 2005 provided a supplemental response and gave an update on progress [105]. Following the audit a fourth response dated February 28, 2008 [106], responded to the NRC staff's request for additional information dated February 9, 2006 as well as supplementing the responses following content guidance provided by the NRC.

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

- containment walkdowns and surveillances completed with the exception of latent debris sampling for Unit 2,
- vendor debris generation analyses completed,
- vendor post-accident containment water level calculations completed,
- plant-specific strainer head loss testing,
- formal acceptance of completed vendor calculations,
- available NPSH analysis,
- Entergy review of vendor debris transport analysis,
- Entergy review of vendor downstream effects evaluation,
- Development of conceptual design options,

- Entergy review of vendor debris head evaluations (sump screen surface area determination),
- Selection of final design,
- Selection of sump screen hardware vendor,
- Assessment of margin to address chemical effects,
- Programmatic and procedural changes, and
- Confirmatory latent debris sampling for Unit 2

Entergy stated that the methodology used for analyzing the performance of the containment recirculation sump would be Nuclear Energy Institute (NEI) 04-07 [4], as amended by the associated NRC staff safety evaluation (SE) [5]. A summary of the licensee's analysis was presented in the September 2005 GL 2004-02 response [30]. The September 2005 GL 2004-02 response further stated that the licensee used the methodology in NEI 02-01 [13] for performing the containment walkdown.

The licensee's September 2005 GL 2004-02 response [30] contained the following two commitments:

- Complete IP3 containment walkdowns to support the analysis of susceptibility of the ECCS and containment spray system recirculation functions to the adverse effects of debris blockage identified in Generic Letter 2004-02, and

- Complete the analyses of the susceptibility of the ECCS and containment spray system recirculation functions for IP2 and IP3 to the adverse effects of post-accident debris blockage and operation with debris-laden fluids identified in Generic Letter 2004-02.

The NRC staff reviewed this response letter and requested additional information in a February 9, 2006 letter [31]. Entergy's response came in a letter dated February 28, 2008, as noted above. In addition to the licensee's two correspondences in response to GL 2004-02 that are described above, the staff expected 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, including addressing the requested additional information. In a letter dated December 3, 2007 [32], the licensee requested an extension to the date for a supplemental response to GL 2004-02 until February 29, 2008. Additional correspondence was received from the licensee pertaining to extensions to the NRC's original due date of December 31, 2007, for completion of corrective actions for GL 2004-02. On September 17, 2007, the licensee submitted an extension request for IP2 to the end of the IP2 spring 2008 refueling outage [93], in order to complete plant modifications scheduled for that outage. On October 24, 2007, the licensee submitted an extension request for IP3 to the end of the IP3 spring 2009 refueling outage for a similar reason [94]. By letters dated November 20, 2007, the NRC approved the IP2 extension request [95] and denied the IP3 extension request [96]. On December 3, 2007, the licensee submitted a revised extension request for IP3 to complete the plant modifications by June 30, 2008 [32]. By letter dated December 20, 2007, the NRC approved the IP3 extension request [97]. On April 8, 2008, the licensee requested an additional extension for IP2 and IP3 to October 31, 2008, to complete analysis and licensing activities [98]. By letter dated April 10, 2008, the NRC approved the extension request for IP2 and IP3 [99]. The licensee therefore has until October 31, 2008 to complete all corrective actions to address GL 2004-02.

The discussions in the licensee's GL 2004-02 responses are generally based on underlying analyses and calculations that the staff reviewed in detail during the audit review. As a result, this report defers discussion on the technical issues addressed in the GL 2004-02 responses to the appropriate audit report sections that address the licensee's underlying analyses.

1.4 Staff Observations of Head Loss Testing for IP2 at Alion/Warrenville, Illinois

On February 24, 2006, NRC staff traveled to the Alion Science and Technology (Alion) Hydraulics Laboratory in Warrenville, Illinois, to observe head loss testing (without chemical precipitates) conducted by Alion for the IR sump strainer design intended for IP2. The staff's observations from this testing are documented in a trip report dated April 17, 2006 [34].

Although the specific tests observed during the staff's visit were for IP2 rather than IP3, the staff's test observations provide insights into the testing conducted for IP3 because (1) the design of the strainers for IP3 is very similar to that of the strainers for IP2, and (2) the test protocols used for the IP3 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.

The test observed by the staff was for a thin-bed condition without chemical precipitates. The test strainer was a 3×3 array of full-size double-top-hat modules. Particulate debris was added first, and fibrous debris was subsequently batched into the tank in increments of ⅛-inch or 1/4-inch theoretical bed thickness. The maximum head loss measured in the test was approximately 0.42 ft, at a fluid temperature of approximately 57 °F. After the test tank was drained, it was clear that the debris had accumulated non-uniformly over the test strainer array, with the strainer modules nearest the pump suction receiving the largest accumulations of debris. Minimal debris settling was observed during the test. The trip report also discusses subsequent visual examination of non-uniformities along the thickness of the debris bed (i.e., higher concentrations of particulate debris in the layers of the bed nearest the strainer surface) and visual observations made following the removal of the downstream filters (referred to as debris bypass eliminators) from one strainer module.

The staff noted several potential issues associated with the test, which included the termination criterion (less than a 1% increase in head loss in a 10-minute period and at least 5 pool turnovers) and the apparent use of low-density fiberglass as a surrogate for high-density fiberglass. However, as noted in the trip report, the staff could not fully follow through with these issues at the test site, since interfacing calculations such as the debris transport and debris bed head loss calculation were not reviewed as part of the trip to observe testing. Additional discussion and details concerning the staff's observations of the testing for IP2 conducted at Alion/Warrenville can be found in the staff's trip report [34].

1.5 Staff Observation of IP2 Containment Sump Strainer Installation

On May 12, 2006, three NRC staff members traveled to the Indian Point Energy Center to observe installation of new sump strainers at IP2 [35]. As discussed above, although the focus of the audit was IP3, the IP2 and IP3 replacement strainers are similar. This trip was a pre-audit visit, although commencement of the audit was delayed considering the completion status of the analyses and facility changes at IPEC.

During the staff's visit, IP2 was refueling, and installation of the new, larger IR and VC sump strainers was in progress. Structural supports were being installed in the sumps, and double top hat modules were being moved into containment and installed onto the supports. Unlike IP3, for which all of the strainer modules were installed within the IR and VC sump pits, some of the IR strainer modules at IP2 were to be installed above the containment floor in an area that that was marked off with tape during the staff's visit. The licensee stated that downstream filters had been installed in all the double top hat modules.

The staff also observed modifications made to the containment to enhance debris settlement in the containment pool and to prevent larger pieces of debris from reaching the containment sumps. The modifications would accomplish this objective by channeling flow in the post-accident containment pool down through the reactor cavity using perforated flow barriers (that are assumed to become blocked with debris during an accident). The flow would be returned to the floor level by flowing up through the in-core instrumentation tunnel and would subsequently travel to the containment sumps through two 20-inch holes cut through the crane wall. Based on the staff's visual observation, the in-core instrumentation tunnel appeared to be approximately 20 ft below the floor level, which would provide significant opportunity for many types of debris to settle out.

Although the main focus of the staff's visit was to observe the installation of the replacement strainers, the staff briefly observed the material condition of other equipment of concern to sump performance, including the trisodium phosphate buffer baskets, the thermal insulation on various components and piping in containment, the refueling canal drainage path, containment coatings, and general containment cleanliness with respect to latent debris.

No specific concerns were identified based on the staff's brief observation of the installation of the new sump strainers. The observations made by the staff during this visit served as an input to the staff's audit review.

1.6 Information Notice 2005-26

NRC and the nuclear industry jointly sponsored Integrated Chemical Effects Tests to investigate potential chemical effects in representative post-LOCA containment environments. The Integrated Chemical Effects Test series was conducted by Los Alamos National Laboratory, at the University of New Mexico. Integrated Chemical Effects Test #3 showed that the presence of calcium silicate insulation and trisodium phosphate in a simulated post-LOCA containment pool rapidly formed a calcium phosphate precipitate. Information Notice 2005-26, "Results of Chemical Effects Head Loss Tests in a Simulated PWR Sump Pool Environment," along with Information Notice 2005-26, Supplement 1, "Additional Results of Chemical Effects Tests in a Simulated PWR Sump Pool Environment," discussed results from NRC-sponsored head loss testing at Argonne National Laboratory. The Argonne National Laboratory test results showed that substantial head loss can occur if sufficient calcium phosphate is produced in a simulated post-LOCA containment pool and is transported to a pre-existing bed on the containment sump screen.

Calcium silicate insulation is installed in the IP2 containment. IP3 currently uses NaOH for buffering such that IN 2005-06 is not applicable. To reduce the potential for formation of calcium phosphate at IP2, the licensee submitted a license amendment request on October 24, 2007 [36], to replace the existing trisodium phosphate buffer with sodium tetraborate. The licensee's evaluation determined that sodium tetraborate is an acceptable alternative to trisodium phosphate based on industry testing of buffers outlined in WCAP-16596-NP, "Evaluation of Alternative Emergency Core Cooling System Buffering Agents," and through plant-specific application of the chemical model developed in WCAP-16530-NP, "Evaluation of Post-Accident Chemical Effects in Containment Sump Fluids to Support Generic Safety Issue 191 [14]." Under the existing trisodium phosphate conditions, the model predicts 738 lbs of chemical precipitates. For the proposed sodium tetraborate condition using conservative values for pH, temperature, and quantities of contributing materials, the model predicts 65 lbs of chemical precipitates. Based on the WCAP-16530-NP model, the switch from trisodium phosphate to sodium tetraborate results in a reduction in the mass of predicted chemical precipitates of 673 lbs. The NRC approved the amendment request on February 7, 2008, and installation was completed in the spring 2008 refueling outage at IP2 [90]. A similar amendment request was submitted to the NRC for IP3 on February 28, 2008 [91], and it was issued on June 9, 2008.

2 DESCRIPTION OF INSTALLED/PLANNED CHANGES

The below text is excerpted/paraphrased from Engineering Request ER-06-3-005 [33]. Figure 1; IR Sump Strainer, Figure 2; VC Sump Strainer Framing, and Figure 3, IP3 Flow Channeling Design (all below) are extracted from the licensee's February 9, 2007 presentation to the NRC [37] to aid the reader in visualizing the modifications.

> ....
> This modification replaces the existing grating and fine screen in the IR and VC sumps with flow barriers and top hat type strainers designed to accommodate the increased post accident debris loads. The new strainers are sized to limit the head loss across the strainers to ensure positive NPSH margin for the IR and RHR pumps. The flow channeling barriers are designed to route the post-LOCA sump recirculation flow into the reactor sump and up through the incore instrumentation tunnel to flow into the containment annulus through openings in the crane wall before flowing to either the recirculation sump or the containment sump. This flow path is credited so that a large quantity of the LOCA generated debris will settle in the reactor sump or elsewhere in the containment before reaching the recirculation sump or the containment sump.
>
> <u>Structures, Systems or Components Description</u>
>
> The internal recirculation (IR) portion of the ECCS is placed in service after the contents of the RWST are injected into the Reactor Coolant System and the water level in containment is adequate for starting one IR pump. The system is arranged so that the IR pumps take suction from the IR sump in the containment floor and deliver spilled reactor coolant and borated refueling water tank to the core through the RHR heat exchangers. The IR pumps can also supply the Containment Spray headers at the same time they are recirculating cooled water through the core. The ECCS is also arranged to allow

either of the RHR pumps to take over the recirculation function. The RHR pumps would only be used to provide containment and core cooling if the capability for internal recirculation was lost for some reason. Water is delivered from the containment to the RHR pumps from the separate vapor containment (VC) sump.

As described in the Updated Final Safety Analysis Report, the IR sump [previous condition] contains two screens through which the recirculated water must flow before entering the pumps. The first screen consists of approximately 48 ft^2 of 1×4" floor grating which covers the sump at elevation 46'. The purpose of the grating is to prevent large particles from entering the sump. The second screen is located in the sump and has the capability to exclude particles greater than ⅛ inch in diameter from the recirculation pump suction….

As described in the Updated Final Safety Analysis Report, the VC sump [previous condition] contains two screens through which the recirculated water must flow before entering the RHR pump suction. The first screen consists of approximately 41 ft^2 of 1×4" floor grating which covers the sump at elevation 46'. The purpose of the grating is to prevent large particles from entering the sump. The second screen is located in the sump and has the capability to exclude particles greater than ⅛ inch in diameter from the RHR pump suction….

Reason For Change

The IR and VC sumps at IP3 are impacted by NRC Generic Letter (GL) 2004-02. Following a LOCA event, thermal insulation, coatings and other materials in the vapor containment may be dislodged by the impingement of a high-energy steam/water jet emanating from the pipe break. Harsh environmental conditions and Containment Spray System operation may result in dislocation and transport of additional debris, Some of the debris will be transported to the sump screens, where it may accumulate, resulting in a pressure drop (head loss) across the sump screens. As a result, post-LOCA debris blockage of the sump screens and operation with debris-laden fluids could challenge the plant's ability to provide adequate long-term cooling (recirculation function) to the core/fuel via the Safety Injection System, RHR system and to the Vapor Containment via containment spray system (recirculation spray). The current design of the Sumps and Containment Building structures has been determined to be inadequate to ensure post-accident long-term containment and core cooling with the postulated debris generation and sump screen deposition (i.e., current design cannot comply with GL 2004-02 requirements). A design change is required to reduce debris transport to the sumps and to increase strainer surface area so that IR and RHR pump NPSH margins are maintained.

Design Objective To Resolve Problem

The design objective of this modification is to install the necessary strainer hardware and flow channeling barriers to address the concerns in NRC GL 2004-02. This modification will replace the existing grating and fine screen in the IR and VC sumps with flow barriers and top hat type strainers designed to accommodate the increased post accident debris loads. The new strainers are sized to limit the head loss across the strainers to ensure positive NPSH margin for the IR and RHR pumps. The flow channeling barriers are designed to route the post-LOCA sump recirculation flow into the reactor sump and up through the incore instrumentation tunnel where it will flow into the containment annulus through openings in the crane wall and labyrinth wall before flowing to either the recirculation sump or the containment sump. This flow path is credited so that a large quantity of the LOCA generated debris will settle in the reactor sump or elsewhere in containment before reaching the recirculation sump or the containment sump.

Implementation of this modification is based on existing design parameters of 50% strainer area blockage and RWST water level at transfer to recirculation. Implementation of GSI-191 will address the requirements to satisfy higher debris loads and chemical effects and may require a change in RWST level at switchover to recirculation and associated Emergency Operating Procedure setpoint.

Relationship With Other Modifications

This modification interfaces with the IR pump replacement modification ER-04-3-066. This will impact installation of the IR pumps and affect the IR pump NPSH calculation… The NPSH calculation will be revised under the scope of this modification using the NPSH data for the replacement pumps and the screen head loss…..

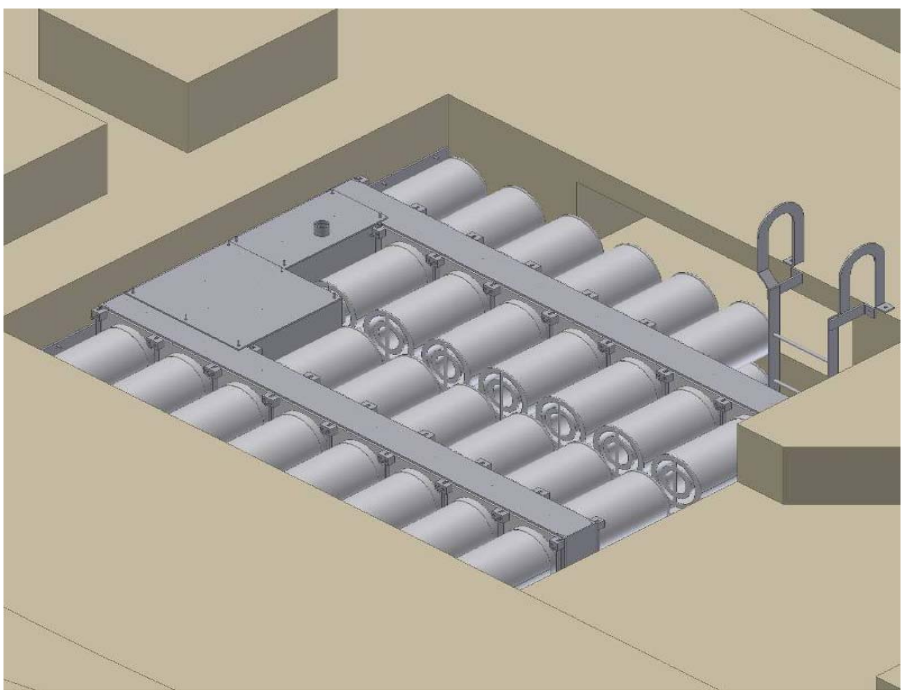


Figure 1 IR Sump Strainer

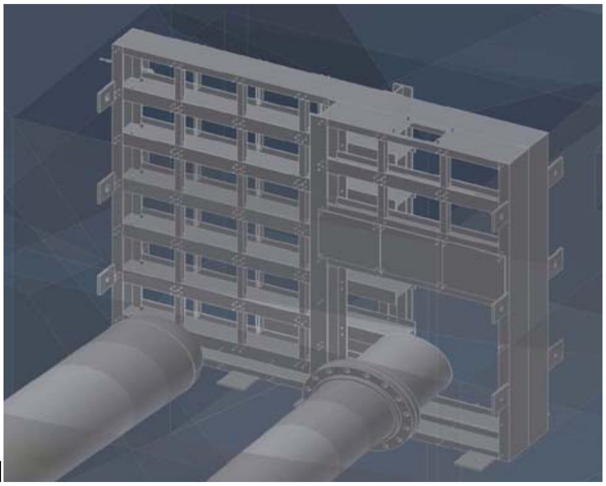


Figure 2 VC Sump Strainer Framing

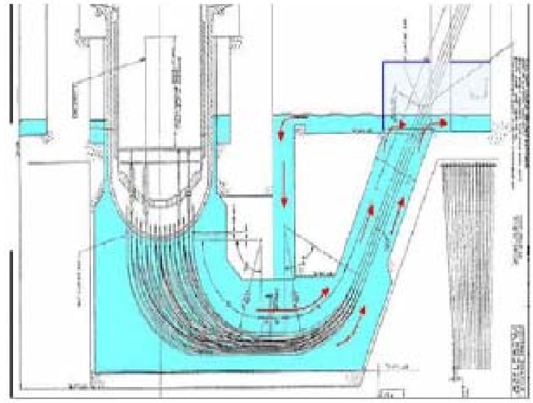


Figure 3 IP3 Flow Channeling Design

3 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 the NEI guidance report [4] and the associated NRC SE [5] 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.

The report prepared by Enercon Services Inc., entitled, “IP3 Reactor Building GSI-191 Debris Generation Calculation” [25], documents the assumptions and methodology the licensee applied as part of the overall break selection process to determine the limiting breaks for IP3. Enercon systematically evaluated postulated breaks at about 1-ft intervals along the applicable piping to determine the maximum potential debris for each type of insulation. This process identified 13 postulated breaks that would encompass the worst-case scenarios. Four breaks were identified for each of three break size scenarios. These break size scenarios included the large-break LOCA, alternate-break LOCA, and small-break LOCA. The thirteenth break was a break at the reactor pressure vessel (RPV) nozzle. The alternate break scenario (based on guidance in the NEI GR as approved by the staff SE) limited the break size to be a maximum of the inner diameter associated with a 14-inch Schedule 160 pipe. ECCS recirculation was determined not necessary for either a main steam line break or a feedwater line break.

For the four large-break LOCA cases, the break location was systematically moved along the piping until the largest fiber debris quantity was determined for the South Side Compartment. This location was designated Design Case 1. A second application of the systematic approach was used to determine the largest quantity of particulate insulation debris for the South Side Compartment, which became Design Case 2. A similar evaluation for the North Side Compartment determined the break locations designated as Design Cases 3 and 4 for fibrous and particulate debris, respectively. The same evaluation procedure was applied for the alternate methodology breaks, except that the break size for any pipe was limited to 11.5 inches, corresponding to the inside diameter of the IP3 pressurizer surge line. Note that the inside diameter associated with a 14-inch Schedule 160 pipe is about 11.2 inches, so use of 11.5 inches in the evaluation is conservative. The third application of the break selection procedure was for a 3-inch small-break LOCA.

Design Case 13, a break at the reactor vessel nozzle, could produce a modest quantity of fibrous debris in addition to a large quantity of reflective metallic insulation (RMI) debris, but this break could also produce the largest quantity of qualified coatings debris due to the break effluents being shunted into the reactor cavity. The maximum predicted quantity of postulated qualified coatings debris was associated with the reactor vessel nozzle break.

The specific large-break LOCA breaks selected by the licensee were:

<u>Design Case 1</u>: The 31-inch crossover leg pipe at the bottom of the steam generator in RCS Loop #32 in the South Side Compartment.
<u>Design Case 2</u>: The 27.5-inch cold leg pipe in RCS Loop #31 between the reactor coolant pump and the penetration to the RPV in the South Side Compartment.
<u>Design Case 3</u>: The 31-inch crossover leg pipe at the bottom of the steam generator in RCS Loop #34 in the North Side Compartment.
<u>Design Case 4</u>: The 27.5-inch cold leg pipe in RCS Loop #33 between the reactor coolant pump and the penetration to the RPV in the North Side Compartment.

The specific alternate-break LOCA breaks selected by the licensee were:

<u>Design Case 5</u>: The cold leg pipe in RCS Loop #32 at the bottom of the reactor coolant pump in the South Side Compartment with a break diameter of 11.5 inches.
<u>Design Case 6</u>: The cold leg pipe in RCS Loop #31 between the reactor coolant pump and the penetration to the RPV in the South Side Compartment with a break diameter of 11.5 inches.
<u>Design Case 7</u>: The cold leg pipe in RCS Loop #34 at the reactor coolant pump in the North Side Compartment with a break diameter of 11.5 inches.
<u>Design Case 8</u>: The cold leg pipe in RCS Loop #33 between the reactor coolant pump and the penetration to the RPV in the North Side Compartment with a break diameter of 11.5 inches.

The specific small-break LOCA breaks selected by the licensee were:

Design Case 9: The cold leg pipe in RCS Loop #32 at the reactor coolant pump in the South Side Compartment with a break diameter of 3 inches.
Design Case 10: The cold leg pipe in RCS Loop #32 at the reactor coolant pump in the South Side Compartment with a break diameter of 3 inches.
Design Case 11: The cold leg pipe in RCS Loop #34 at the reactor coolant pump in the North Side Compartment with a break diameter of 3 inches.
Design Case 12: Line No. 61 in the North Side Compartment with a break diameter of 3 inches.

Design Cases 1, 3, 5, 7, 9, and 11 were selected to maximize the fibrous debris in their respective compartments. Design Cases 2, 4, 6, 8, 10, and 12 were selected to maximize the particulate debris in their respective compartments.

The single RPV nozzle break was:

Design Case 13: An RPV nozzle break contained within the primary shield wall.

NRC Staff Audit

The NRC staff reviewed the licensee's overall break selection process and the methodology applied to identify the limiting breaks as presented in the licensee's Report No. CON033-CALC-004 [25] and discussed the selection process and methodology with the licensee's analytical contractor during the onsite audit week. The staff noted the following specific aspects of the licensee break selection analyses:

- A systematic approach was used to incrementally evaluate potential breaks along all applicable piping.

- The potential breaks were evaluated for both the North and South Side Compartments.

- The worst-case breaks were independently evaluated for fibrous insulation, particulate insulation, and coatings debris.

- For the alternate break scenarios, the licensee used an inner pipe diameter of 11.5 inches, which is conservative with respect to the inner diameter of 11.2 inches corresponding to 14-inch Schedule 160 pipe.

- The licensee determined that neither main steam line breaks nor feedwater line breaks would require containment sump recirculation; therefore, such breaks were not evaluated.

- In accordance with the Guidance Report [4] and SE, small-bore piping was not evaluated.

The licensee's break selection methodology considered breaks in the RCS with the largest potential for generating debris. Because the licensee subsequently combined the largest quantity fibrous debris with the largest quantity of particulate debris, although the quantities came from different breaks, the licensee effectively considered breaks that could generate multiple types of debris; breaks with the largest potential particulate debris to insulation ratio by weight; and breaks that could generate a thin bed of debris on the strainer. The licensee's flow channeling through the in-core instrumentation tunnel means that the flow path is long enough such that no break would have significantly greater transport than another would. Therefore, in the worst-case threat of strainer blockage, all breaks are effectively equal distance from the strainers, therefore breaks with the most direct path to the sump were considered, as well.

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

3.2 Debris Generation/Zone of Influence

The objective of the debris generation/ zone of influence (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 the break jet forces generate; and (3) the size characteristics of the postulated debris. Sections 3.4 and 4.2.2 of the Guidance Report [4] and the NRC SE [5] 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 on experimentally determined destruction pressures that were determined by applying ANSI/ANS 58.2 1988 standard jet expansion models [7] to testing of various types of insulation. The pressure gradients were used to correlate the damage to insulation blankets or cassettes by air and steam jets during debris generation testing to an equivalent spherical model of destruction. The relationship between the ANSI/ANS 58.2 1988 standard and the NRC SE [5] approved ZOIs was assessed in Appendix I of the SE. Once the ZOI is established for a selected break location, the types and locations of all potential debris sources within the ZOI can be identified using plant-specific drawings, specifications, walkdown reports, or other 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 amount of debris generated within each material-specific ZOI is calculated, and then these material-specific debris amounts are added to arrive at a total debris source term. The NRC staff concluded in its 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.
Section 4.2.2 of the SE documents the staff acceptance of these proposed refinements for these analyses.

The report prepared by Enercon Services Inc., entitled, "IP3 Reactor Building GSI-191 Debris Generation Calculation" [25], documents the assumptions and methodology the licensee applied to estimate bounding LOCA-generated debris quantities for IP3. The types of insulations within the IP3 containment include Nukon® fiberglass, Temp-Mat™, mineral wool, unspecified fiberglass, calcium silicate, and RMI. Some of the calcium silicate insulation was manufactured using asbestos fibers. The manufacturer of the insulation designated as 'calcium silicate' was not specified. The manufacturer and specific characteristics for the insulation listed as unspecified fiberglass were not identified, but a walkdown determined the fiberglass is a low-density fiberglass similar in composition and structure to Nukon® insulation [25]. In addition, the unspecified fiberglass is present in containment in significantly lesser quantities than either the Nukon® or the Temp-Mat™ insulation. The licensee assumed the following radii for its ZOIs for its insulation and thermal barrier material:

- The licensee adopted the SE-recommended ZOI radii of 17 break diameters (D) for Nukon® and 11.7D for Temp-Mat™.
- The licensee assumed a 17D ZOI for mineral wool based on the argument that the mineral wool is denser than Nukon®; therefore, less likely to be damaged.
- The licensee assumed a 17D ZOI for the unspecified fiberglass based on the argument that the unspecified fiberglass would not be less dense than the Nukon®; therefore, no more likely to be damaged than Nukon.
- The licensee assumed a 6.4D ZOI for the jacketed calcium silicate insulation, including that containing asbestos, primarily based on the SE-accepted recommendation of 5.45D for jacketed calcium silicate, but with a conservative enhancement to 6.4D to adopt the knowledge base-recommended destruction pressure of 20 psi [23] rather than the SE-accepted 24 psi.
- The licensee assumed a 6.4D ZOI for the Marinite boards based on the material's high resistance to damage, corrosion, and water.
- The licensee similarly assumed a 6.4D ZOI for the Transite boards based on its high-strength properties.
- The licensee adopted the SE-recommended ZOI radius of 28.6D for the Diamond Power Specialty Company Mirror® RMI with standard bands.
- The licensee assumed a large 28.6D ZOI for cloth-bound calcium silicate insulation.

The radii assumed by the licensee for insulation ZOIs are summarized in Table 3.2-1.

Table 3.2-1 IP3 Insulation ZOI Radii

Insulation Type	ZOI Radius / Break Diameter
Jacketed Calcium Silicate	6.4
Marinite	
Transite	
Temp-Mat™	11.7
Mineral Wool	17.0
Nukon®	
Unspecified Fiberglass	
Reflective Metallic Insulation	28.6
Cloth Bound Calcium Silicate	

<u>NRC Staff Audit</u>

The staff reviewed the licensee's ZOI and debris generation evaluations and the methodology applied presented in licensee Report No. CON033-CALC-004 [25] and discussed it with the licensee's contractor during the onsite audit. The approved methodology documented in Sections 3.4 and 4.2.2 of the staff's SE was used as an acceptance guide.

The staff acceptance of the licensee assumed ZOI radii follows:

- Because the ZOI radii for the Nukon®, Temp-Mat™, jacketed calcium silicate, and the Diamond Power Specialty Company Mirror® RMI with standard bands were adopted from the SE-accepted guidance report recommendations, these ZOIs are all acceptable.

- Mineral wool is 2 to 4 times as dense as Nukon®. The comparison of debris damage for three insulations with differing densities shown in SE Figure II-8 supports the assumption of less damage for a higher density material. Therefore, the staff accepts a 17D ZOI for mineral wool based on the argument that the mineral wool is denser than Nukon®; therefore, less likely to be damaged. This ZOI is considered to be conservative.

- Because Nukon® has low density relative to the majority of fiberglass insulations, it is unlikely that the unspecified fiberglass insulation is less dense than Nukon® and therefore the ZOIs for these materials should be similar. The staff accepts the 17D ZOI as acceptable for the unspecified fiberglass.

- For Marinite, an Ontario Power Generation test [39] mounted a Marinite board 5D in front of a two-phase jet and barely pitted the surface. The test found that it is difficult to generate substantial quantities of fine particulate from this material. Therefore, a 6.4D ZOI is acceptable for Marinite.

- There are no available data for the Transite board, but its strength properties are similar to that of Marinite, and the Transite is nominally twice as dense as the Marinite. The staff accepts the licensee-assumed 6.4D ZOI based on its similarity to Marinite and higher density.

- The cloth binding the IP3 cloth-bound calcium silicate was described as resembling a plaster cast, rather than being a simple layer of cloth. As such, the cloth binding would be expected to provide significant protection to the calcium silicate, at least at greater distances from the break. The staff therefore accepts the licensee-assumed 28.6D ZOI, which is the largest ZOI for any material listed in the Table 3.2 of the SE [5], as conservative.

In summary, all the licensee-assumed ZOI radii for their containment insulations are acceptable and conservatively or realistically predict bounding insulation debris quantities.

The licensee's bounding debris quantity estimates are summarized in Table 3.2-2 below. Note that this table was compiled by taking the largest quantity for each debris type from the applicable Design Case results. For example, for a large-break LOCA, the largest quantity of Nukon® comes from Design Case 3 but the largest quantity of unspecified fiberglass comes from Design Case 1 (as designated by the numbers in parentheses).

Table 3.2-2 Bounding LOCA-Generation Insulation Debris Quantities (Less Coatings)

Debris Type	Large-break LOCA	Alternate-break LOCA	Small-break LOCA	RPV Nozzle
Metallic (ft^2)				
RMI	0	0	0	22,324(13)
Fibrous (lb_m)				
Nukon®	1996.7(3)*	604.0(7)	24.4(11)	0
Temp-Mat™	3058.7(3)	1391.7(5)	724.4(9)	336.5(13)
Mineral Wool	75.4(3)	21.0(7)	0	0
Unspecified Fiberglass	124.2(1)	60.5(5)	8.2(11)	0
Particulate (lb_m)				
Asbestos	468.3(2)	410.0(6)	105.7(10)	0
Calcium Silicate	311.9(3)	8.4(5)	425.9(12)	0
* The number parentheses indicate the design case break scenario associated with quantity.				

The following observations can be made from this table:

- The only source of RMI debris is the RPV insulation, and that insulation would only be damaged by an RPV nozzle break.

- The largest source of fibrous debris comes from Temp-Mat™ insulation, followed by Nukon®. Contributions from mineral wool and the unspecified fiberglass are much less.

- The use of the alternate break methodology significantly reduces the potential debris loads, but these debris loads are still substantial.

- Even the small-break LOCA can generate substantial quantities of fiber and calcium silicate.

- Both asbestos-bearing calcium silicate and non-asbestos-bearing calcium silicate insulations are present in containment in relatively large quantities.

- A relatively large quantity of calcium silicate debris could be generated for small-break LOCA Design Case 12, which involved Line No. 61, which is not large enough to be considered either a large-break LOCA or an alternate-break LOCA.

The licensee generally based its LOCA-generated insulation debris size distributions on a generic ALION debris generation report [40] that the staff reviewed onsite. The generic size distributions are based on the SE-recommended distribution of the four debris size categories designated as fines, small pieces, large pieces, and intact pieces. The radial location of a specific insulation target was used to look up the size distribution for that type of insulation at that location within the ZOI. When the quantities of debris are summed by size for all insulation targets within the ZOI for each debris type, the size distributions for a specific break scenario are obtained. The size distributions assumed by the licensee are summarized in Table 3.2-3, LOCA-Generation Insulation Debris Size Distributions.

Table 3.2-3 Licensee-Assumed LOCA-Generation Insulation Debris Size Distributions

Debris Type & ZOI Application Range	Fines	Small Pieces	Large Pieces	Intact Pieces
Nukon®, Mineral Wool, and Unspecified Fiberglass				
Up to 7D	20%	80%	0	0
7D to 11.9D	13%	54%	16%	17%
11.9D to 17D	8%	7%	41%	41%
Temp-Mat™				
Up to 3.7D	20%	80%	0	0
3.7D to 11.7D	7%	27%	32%	34%
Calcium Silicate				
Up to 2.7D	50%	50%	0	
2.7D to 28.6D	23%	15%	62%	
Marinite				
Up to 2.7D	50%	50%	0	
2.7D to 6.4D	23%	15%	62%	
Transite				
Up to 6.4D	100%	0	0	
Diamond Power Specialty Company Mirror® RMI				
Up to 28.6D	0	75%	25%	0

The ALION size distributions for Nukon® and Temp-Mat™ are analytical enhancements to the approach recommended in SE Appendix II. In this approach, the small fines debris (i.e., the fines and small-piece debris grouped together) were first plotted as a function of jet stagnation pressure. Then, with the spherical ZOI radius versus jet pressure determined using the ANSI/ANS Standard 58.2 [7], an integration was performed over the ZOI to determine the fraction of small fines versus large pieces that would be generated within the ZOI. The subsequent split of the small fines into fines and small pieces and the large debris into large pieces and intact pieces was based on the overall debris assessment obtained in the Drywell Debris Transport Study (DDTS) [20]. The ALION enhancement was to further subdivide the ZOI into zones and integrate the debris size distribution within each specific zone to determine a size distribution for each zone. The staff found this approach for Nukon® and Temp-Mat™ to be acceptable because it is consistent with or more precise than the DDTS evaluations.

The licensee assumed the Nukon® size distribution was conservatively applicable to both the mineral wool and the unspecified fiberglass. For the mineral wool, this assumption was based on the fact that mineral wool is 2 to 4 times as dense as Nukon® and therefore less prone to creating finer debris. Similarly, the unspecified fiberglass is likely to be at least as dense as Nukon®. The comparison of debris damage for three insulation types with differing densities shown in SE Figure II-8 supports the assumption of less damage for a higher density material. The staff noted that since there are substantially lesser quantities of both mineral wool and unspecified fiberglass than Nukon® and Temp-Mat™ in IP3, the accurate prediction of the size distributions for mineral wool and the unspecified fiberglass is not nearly as important as it is for the Nukon® and Temp-Mat™. The staff accepted the licensee assumption of equating the size distributions for mineral wool and the unspecified fiberglass to that of Nukon® because the assumption is consistent with the information in the SE with respect to the effect of density on material damage.

In a similar manner, the licensee applied the SE Appendix II recommendation to obtain a size distribution for the jacketed calcium silicate to the portion of the ZOI where size distribution data was available, i.e., between 2.7D and 5.45D. This size distribution was extended inward by adopting a SE-recommendation that all insulation within the 2.7D would be destroyed into small fines debris. However, the licensee further assumed that 50% of debris within 2.7D would be fine dust and 50% would be small pieces, which is an important assumption in light of a subsequent transport assumption that the small pieces would not further erode when subjected to water. The staff accepted this 50% assumption within 2.7D because most of the volume within a 2.7D is nearer the outside diameter, where the data indicates that only about half of the insulation is damaged sufficiently to form either small or fine debris. The licensee conservatively extended the size distribution outward from 5.45D to 6.4D for jacketed calcium silicate and then to 28.6D for cloth-bound calcium silicate by maintaining the 5.45D size distribution beyond 5.45D. The staff accepted the licensee's calcium silicate size distribution as being conservative with respect to generating fine calcium silicate debris because it resulted in the generation of a larger quantity of fine particulate debris than the guidance presented in the SE-approved GR calls for.

There are little or no data available for the Marinite and Transite thermal barrier materials. Results of a test performed by Ontario Power Generation [39] that were made available to the NRC demonstrated how difficult it is to damage Marinite board. Based on this test, the staff accepted the licensee size distribution for Marinite, shown in Table 4, as acceptable. Further, the licensee assumption that 100% of the Transite debris would be fines is acceptable because fine debris results in higher transport and higher head loss and the assumption is therefore conservative.

The debris generation process was satisfactory because it generally followed the approved guidance methodology, provided adequate justifications for other approaches taken for specific insulation types, and therefore predicted conservative bounding quantities of debris.

3.3 Debris Characteristics

The staff reviewed the Indian Point 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 [25] and the debris transport calculation [41]. The ALION head loss testing reports [43, 44, and 45] provided the information regarding the surrogate test material chosen for head loss testing.

The analyzed debris loading for IP3 includes RMI debris, fibrous insulation debris, particulate insulation debris, qualified coatings, unqualified coatings, latent particulate debris, latent fibrous debris, and foreign materials such as tape, tags, glass, and stickers. Coatings debris characteristics are discussed in a separate section of this report (3.8.2). Chemical effects precipitates were not included in the head loss testing that had been completed at the time of the audit. The most important characteristics related to debris are the transport velocities used in the computational fluid dynamics (CFD) analysis, the debris erosion properties also used in the debris transport analyses, and the characteristics of the surrogate debris used in the head loss testing.

3.3.1 Reflective Metallic Insulation

The licensee debris generation calculation [25] stated that the RMI installed at IP3 is Diamond Power Specialty Company Mirror® with standard bands constructed of 0.0025-inch-thick stainless steel foils with 0.25-inch separation. The 3.5-inch-thick cassettes installed on the RPV have 13 foils. Because the RMI is installed only on the RPV, and the RPV would be shielded by structural materials (e.g., walls) from breaks at locations other than RPV nozzles, the only break scenario that would produce significant RMI debris would be an RPV nozzle break. The size distribution for the RMI debris was assumed to be 75% small pieces and 25% large pieces, which is consistent with the guidance in NEI 04-07 and Table 3-3 of the staff's SE on NEI 04-07 [5]. Therefore, the staff considers the licensee's assumed size distribution for RMI debris to be acceptable. The licensee debris transport analysis [41] did not predict the transport of RMI debris to the strainers, and no RMI debris was simulated in the head loss testing [43, 44, and 45]. The only break location that is predicted to produce RMI is a reactor cavity break. The transport analysis shows that RMI should not transport to the strainer from this location based on CFD analysis.

Based on the debris generation and transport analyses, the licensee judged that it would be very unlikely that significant RMI debris would transport to the recirculation strainers. The licensee's analysis determined that the debris interceptors would stop all but the smallest pieces, and RMI debris channeled into the in-core instrumentation tunnel would remain in the tunnel. NRC-sponsored testing [9] has shown that it takes flow velocities greater than about 1 ft/s to lift a small piece of stainless steel debris over a 6-inch curb. The licensee's transport analyses have demonstrated that tunnel flow velocities are much less than 1 ft/s. Only RMI debris initially blown into the upper containment and washed down to the annulus near the strainers or blown through the in-core instrument tunnel directly into the outer annulus would have a chance to approach the strainers. Only an RPV nozzle break would generate significant quantities of RMI debris, but because that break would not generate any calcium silicate debris, the resultant head losses would be substantially less than the other break scenarios, even if the RMI was to accumulate in the strainer pits in significant quantities. The staff therefore accepts the licensee's approach of screening RMI debris from further consideration.

3.3.2 Fibrous Insulation

The licensee's debris generation analysis shows that the types of fibrous insulation available in containment that could potentially become debris include: Nukon®, Temp-Mat™, mineral wool, and some fiberglass for which the manufacturer could not be determined. The most important characteristic of the fibrous debris is the debris size distribution, which was addressed in Section 3.2 (see page 20) of this report. The licensee's transport analysis [41] demonstrates that most of the debris accumulation would be due to transport of suspended fine fibers. The exception is small-piece debris washing down from the upper containment into the outer annulus and near enough to the strainers to slide or tumble into a strainer pit.

The exposed small and large-piece fibrous debris that settled to the sump pool floor would undergo some erosion and thereby give up fibers that would be subject to suspended transport to the strainers. The licensee assumed that 10% of small and large-piece debris would subsequently erode into fine fibrous debris; however, this percentage was not adequately supported in the licensee's analysis provided to the staff. This issue is important because the eroded fibers would transport as suspended debris and contribute to the accumulation on the strainers. The covered, intact, fibrous debris was considered to not erode, consistent with the SE on NEI 04-07. The licensee assumption of 10% erosion of exposed pieces of fibrous insulation was based on the application of an erosion rate documented in the SE Appendix III.3.3.3. This rate was based on NRC-sponsored testing [21], and an assumption that the erosion process would effectively cease within 24 hours [41]. The licensee did not compare relative turbulence levels for the IP3 active sump pool with the NRC-sponsored testing to assess the applicability of the test data documented in the SE. The erosion process depends strongly upon the water turbulence and/or the shearing velocity of flow moving past the piece of debris. Note that one of the tests documented in NUREG/CR-6773 [21] had an erosion rate of 2% per hour at 4 hours. This rate would extrapolate into 38% erosion in 24 hours assuming a constant rate. Also, the cessation of erosion within 24 hours would depend upon the relative turbulence and shearing velocity that the debris is exposed to. With turbulence and velocity high enough, erosion has been observed to continue at a slow rate for an extended period of time, greater than 24 hours. The inadequate justification for the 10% erosion fraction is further addressed in Section 3.5.4.4 below and associated Open Item 3.5-2 **(**page 43**)**.

The debris transport characteristics used in the licensee's CFD analysis for fibrous insulation were based primarily on Nukon®, which has been more thoroughly studied than other types of fibrous debris. The justification for applying Nukon® characteristics to other debris types, e.g., the Temp-Mat™, is that denser debris would transport less easily than would the Nukon®, which is the lightest of the IP3 fibrous insulations. The Nukon® transport velocities adopted by the licensee were taken from NRC references [23 and 9]. The transport velocities needed to lift small- and large-piece Nukon® debris over a 6-inch curb are larger than CFD-calculated flow velocities along the bottom of the in-core instrumentation tunnel. This supports the licensee's assumption that such debris will not transit the tunnel. In the outer annulus, the small- and large-piece debris would move along the floor only if the flow velocity exceeded 0.12 and 0.37 ft/s for small and large pieces, respectively. The CFD-calculated flow velocities in the outer annulus vary between 0 and about 0.5 feet per second. Therefore, there are significant areas in the pool capable of transporting small pieces of fibrous insulation. The areas where large pieces of fiber could transport are somewhat smaller. Figures 5.9.5, 5.9.7, and 5.9.9 of [41] show the areas of the outer annulus where transport of small and large pieces is predicted to occur.

The surrogate materials used by the licensee in head loss testing for the fibrous debris were either the same as the plant material or similar to the plant insulation. Nukon® and Temp-Mat™ were both used as direct replacements in the testing. Mineral wool with a density of 8-lb_m/ft^3 was used in the prototype head loss tests [42] as a surrogate for the plant mineral wool, for which the actual density was unknown. Typical mineral wool densities range between about 4 and 10 lb_m/ft^3. The licensee conservatively assumed 10 lb_m/ft^3 for the plant mineral wool density to maximize the debris mass used in the head loss testing. The licensee used Nukon® as a surrogate material for the unspecified fiberglass insulation debris. This is acceptable because both materials are low-density fiberglass of similar construction [25]. The staff accepts the licensee surrogate fibrous insulation materials used in the head loss testing as either prototypical or conservative with respect to the actual IP3 materials.

The debris characteristics assumed by the licensee for the fibrous material were consistent with the NEI guidance and the NRC SE, though, as noted above, the staff found the licensee's justification for application of the 10% erosion limit in the SE to be inadequate.

3.3.3 Particulate Insulation

The IP3 containment contains substantial quantities of calcium silicate of at least two types. Some of the calcium silicate insulation was manufactured using asbestos fibers. The other type of calcium silicate used some other form of fiber. With respect to debris generation, the two types of calcium silicate insulation are treated identically in the debris generation calculation [25]. The only debris generation variation for calcium silicate is whether or not the insulation is jacketed with stainless steel, which reduces the assumed ZOI radius. The size distributions for calcium silicate were addressed in Section 3.2 of this report and accepted by the staff.

The transport analysis assumed that both types of calcium silicate fines transport completely to the strainer. However, the analysis demonstrated that the small and large pieces of calcium silicate will not transport to the strainers. Because the calcium silicate pieces have a density of 14.5 lb_m/ft^3, the pieces would readily settle in the sump pool at a rate of about 1 ft/s [41]. The velocities required to transport calcium silicate were not provided, but the staff accepts that a piece of calcium silicate would require a substantially larger flow velocity to move or lift it than would a piece of Nukon® of similar size, because of the calcium silicate's greater density. Therefore, where Nukon® pieces will not transport, neither will calcium silicate pieces.

The important remaining characteristic of the calcium silicate is its dissolution properties. Pieces of calcium silicate debris located in the sump pool could potentially further erode, giving up very fine, highly transportable particles. The licensee assumed that all such pieces of calcium silicate debris, including the calcium silicate with asbestos fibers, would not further erode; therefore, not transport to the strainers. The basis for this assumption was licensee-sponsored dissolution testing of two pieces of calcium silicate removed from the IP2 containment that were identified as asbestos bearing, based on the white coloring. These two pieces were tested in 200 °F water for 2 hours with stirring added for 30 minutes [45]. The data indicated that any erosion was very minor. However, the staff concluded that the testing duration was too short to ascertain whether dissolution that occurred over a 30-day mission time could be significant (e.g., 0.05% for 2 hours extrapolates to 18% in 30 days). Discussions with the licensee vendor resulted in the acknowledgement that a slight rate of erosion likely occurred. The vendor also noted another vendor dissolution test where about 5% erosion occurred in 2 weeks for a type of calcium silicate similar to that located in the Indian Point containments. This information suggests that some erosion will likely occur in 30 days. As such, the licensee assumption of no erosion was not adequately justified as conservative and was identified as Open Item 3.5-3, which is further discussed in the Debris Transport Section (see page 44).

The calcium silicate dissolution testing sponsored by the licensee was based on only one type of calcium silicate (i.e., asbestos fiber bearing), but the IP3 containment has calcium silicate both with and without asbestos. NRC-sponsored dissolution testing [9] found that testing calcium silicate in 176 °F water for 20 minutes with occasional stirring resulted in about 75% of the calcium silicate pieces eroding. The NRC-sponsored test result is significantly different from the Indian Point vendor testing. To understand the different test results, a calcium silicate insulation expert was consulted during the onsite audit. The primary reason for the behavior difference is the manufacturing process of the calcium silicate insulation; i.e., either a press shaping process or a molding shaping process. The Indian Point asbestos insulation was manufactured using the press shaping process, which is resistant to water erosion. The calcium silicate used in the NRC-sponsored testing was manufactured using the molding process, which is apparently susceptible to water erosion. The licensee was unable to verify that all potential IP3 calcium silicate debris was manufactured using the water-resistant press process. Therefore, the erosion fractions determined by the licensee could be non-conservative. This is further addressed in Open Item 3.5-4 (page 44).

The staff finds the calcium silicate characteristics assumed by the licensee to be acceptable, with the exception of the assumption that it will not dissolve or erode in the post-LOCA pool. A reevaluation of the calcium silicate dissolution potential could significantly increase the calcium silicate debris loads predicted to accumulate on the strainers.

Thermo-12™ Gold IIG calcium silicate insulation manufactured by Industrial Insulation Group, LLC was obtained in a powder form for use as a surrogate for the IP3 head loss testing. The licensee's vendor performed microscopic comparisons among a sample of IP3 calcium silicate, a sample of Thermo-12™ Gold IIG calcium silicate, and a sample of Performance Contracting, Inc. calcium silicate [46]. ALION concluded that the IP3 calcium silicate sample is comparable to the Thermo-12™ Gold IIG sample based on microscopic, elemental, and macroscopic assessments. The assessment showed that basic size information is similar. The macroscopic assessment showed that the IP3 and Thermo-12™ Gold IIG samples morphology were both hard packed. However, the Performance Contracting, Inc. sample was fragile and friable in handling, while the Thermo-12™ Gold was less likely to break. This finding supports the previous assessment that resistance of calcium silicate to dissolution in water varies significantly. The Thermo-12™ Gold IIG and IP3 calcium silicates should have similar dissolution characteristics. Although this ALION sample comparison is qualitative in nature, the staff accepts that the Thermo-12™ Gold IIG calcium silicate powder is a reasonable head loss test surrogate for the IP3 calcium silicate because it exhibited reasonably similar characteristics when compared to the PCI calcium silicate during both microscopic and macroscopic examinations.

3.3.4 Latent Fibrous Debris

The licensee assumed that latent fibers comprise 15% of the total latent debris mass measured in the containment and that the latent fibrous debris is composed of 100% small fines. Nukon® 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.

3.3.5 Latent Particulate Debris

The licensee assumed that particulate material comprises 85% of the total latent debris mass measured in the containment and that the latent particulate debris is composed of 100% fine particulate. Silica sand was used as a surrogate material for latent dirt and dust debris in the head loss testing. The size distribution of the surrogate sand mixture was prepared to be consistent with the latent dirt/dust size distribution provided in the SE [5]. 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.

3.3.6 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 and Transite board. The fire stops are not within the ZOIs considered in the analysis; therefore, the analysis did not predict debris generation from these materials. The debris generation calculation cites the NUREG/CR-6772 [9] testing that shows that the Marinite material remains intact even after prolonged submersion in boiling water. Transite is a high-temperature structural material similar to Marinite. The Material Safety Data Sheets (www.bnzmaterials.com) for both Marinite and Transite state that these materials are water insoluble. Therefore, significant debris would not be generated due to exposure to either the containment sprays or submersion within the sump pool. The staff considers the licensee’s assumption regarding the ability of the fire stops to remain intact reasonable based on the information provided.

3.3.7 Miscellaneous Debris

A walkdown assessment of the miscellaneous debris provided estimates of areas for tape, equipment labels, and tags, and the number of tie wraps. The licensee conservatively assumed that this material would fully transport to and accumulate on the sump strainers. Rather than introduce surrogate miscellaneous debris into the head loss testing, the licensee planned to extrapolate head loss testing results from the reduced gross screen area due to the miscellaneous debris. The staff considers this type of extrapolation to be potentially non-conservative. (See Open Item 3.6.1, page 58) The accepted methodology for characterizing miscellaneous debris is to assume that it blocks an area on the sump strainer and to subtract this area from the total strainer area prior to scaling debris amounts and flow velocities. This methodology is presented in Section 3.5.2.2.2 of the staff’s SE on NEI 04-07.

3.3.8 Debris Characteristics Conclusion

The staff reviewed the IP3 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 debris characteristics used in the debris CFD transport analysis were acceptable but there are three open items associated with the erosion of debris within the sump pool. These are:

> The licensee did not provide adequate technical basis for its assumed 10% erosion fraction for the small and large pieces of fibrous debris settled in the sump pool. The licensee's assumption of zero erosion of calcium silicate debris in the sump pool was not technically justified.
>
> The licensee had not verified that all of its potential calcium silicate debris was manufactured by the water-resistant press-shaping process. If any of the Indian Point calcium silicate insulation that could form debris was manufactured by the molding process, that debris should be considered to erode more completely into fines and be available to transport to the strainers, resulting in substantially larger calcium silicate debris loads.
>
> In addition, the extrapolation of test results to account for blockage of the strainer from miscellaneous debris is potentially non-conservative. The licensee planned to use this extrapolation method for other conditions as discussed in Open Item 3.6-1 (page 58).

The debris characteristics associated with the fire stop materials, the latent debris, and the miscellaneous materials are all acceptable as discussed above. The surrogate materials used by the licensee in head loss testing were all acceptable. With the exception of the issues noted 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 unintended debris present in containment prior to a postulated high-energy line break, which may be composed of various constituents including dirt, dust and other particulate, paint chips, fiber, 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 IP3 licensee evaluated the potential sources of latent debris within containment using the guidance provided in NEI 04-07 [4] and the associated NRC staff SE [5].

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 performing a latent debris evaluation is recommended in NEI 04-07 [4] and the staff's SE [5]: (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. IP3 reports associated with latent debris and the supporting containment walkdowns [47, 50] address these elements of the latent debris evaluation process.

3.4.2 Latent Debris Sampling Methodology

The licensee's latent debris walkdown plan [47] outlines the process for evaluating the mass of dust, dirt and lint and the quantity of foreign materials (labels, stickers, etc.) found in the IP3 containment. The licensee's methods for evaluating the masses of these two types of latent debris are described separately below.

Dust, Dirt, Lint

The surface areas within containment that are available for accumulation of dust, dirt and lint were identified and eight surface-area categories were defined, accounting separately for horizontal and vertical surface configurations. The surface area of each of the eight area types was computed with the aid of plant drawings. The containment latent debris walkdown report [50] tabulated all of the individual area contributions.

The sampling of the IP3 containment for latent debris took place at the end of an outage before clean up work was performed. IP3 observed that samples taken at this time would provide a conservative estimate of the latent debris mass. This judgment is reasonable to the staff, since debris generated by work performed during the outage was not yet collected and removed.

The latent debris walkdown report [50] identifies sample locations. At each of 45 locations, a pre-weighed tack cloth was used to collect debris from a surface area of between 0.1 ft^2 and 52 ft^2. The difference of the cloth's weight before and after the collection of the sample represents the weight of the sample. All the measured sample weights were reported in grams, with an accuracy of 0.1 gram.

The measurement variation introduces an uncertainty of ± 0.1 gram to the estimation of each of the sample masses. The uncertainty of the mass measurement was substantial for 10 of the 45 latent debris samples whose masses were 0.5 grams or less. This issue was discussed with the licensee during the audit. A conservative approach to address the 0.1-gram measurement uncertainty would have been for the licensee to add the uncertainty of the measurement to the measured mass of each latent debris sample. The staff estimated that accounting for the measurement uncertainty in this way would add approximately 7% to the total mass of latent debris determined by the licensee. The licensee responded that they sampled latent debris at the end of an outage before conducting the containment cleanup prior to restart [50]. The licensee further noted that one sample collection area appeared to be the site of a work area that had not been cleaned [50]. Based on the information provided by the licensee, the staff considered the conservatism associated with performing the latent debris sample collection prior to conducting the containment cleanup to bound the uncertainty associated with the measurement of latent debris sample masses for IP3.

For each area type except one, a minimum of three samples was collected, as the SE guidance recommends. For gratings, only two samples were taken. However, based on the staff's review of the latent debris calculation [50], these samples, appear to represent areas which are among the dirtiest sampled, and provide conservative upper bounds for the mass of debris per unit area. Therefore, the staff judged two samples adequate.

The licensee used the mean value of the latent debris sample masses collected for each area type to represent the mass loading of debris for that area type. Alternately, the licensee's analysis could have provided a more conservative statistical bound (e.g., mean plus standard deviations) for the latent debris mass loading. While the SE [5] recommends that "[s]tatistical sample mass collection is an acceptable method for quantifying latent debris inventories [5, p. 48]," it does not specify detailed criteria for computing the mass loading of debris. The staff accepts the mean value of the samples for use in computing the total mass loading of debris in the IP3 containment because the samples were conservatively collected at the end of an outage at which time cleanup had not yet been performed.

The total mass of latent debris present in containment in each of the eight area types was extrapolated from the measured debris masses by multiplying the computed sample mass per unit area sampled by the estimated surface area of 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 generally follows the guidance of NEI 04-07 [4] and the staff's SE [5]. Any deviations were found to be acceptable based on collection of samples before containment cleanup. Therefore, the staff finds this approach to be acceptable.

Tags, Tapes, Labels, Stickers and Other

The staff reviewed the licensee's walkdown procedure for foreign materials, such as tags, labels and stickers [47, 50], and the licensee's report of the quantitative results of this walkdown [50]. The walkdown of the IP3 containment catalogued the inventory of tags, labels, stickers and tie wraps. Additionally, fiberboard associated with the cable trays was also included in the walkdown. Tag material included metal, plastic, paper and fiberboard. Vinyl stickers were also inventoried. Despite the fact that the metallic and plastic tags are attached with metal wire and would likely not be transportable to the sump screen, their area was conservatively included in the inventory of foreign material.

Tag, label and sticker types were identified and characterized by area. During the walkdown, the area of each observed tag or label was estimated and conservatively counted as one or more of the standard area types. For the RCS compartment, the procedure was for samples to be collected from one of four reactor coolant pump platforms, and the resulting count to be multiplied by four. This procedure provided an estimate of the foreign material surface area for each area type. The total area was obtained by summation of the areas of each area type. This methodology conservatively accounts for the area of tags, and is acceptable.

The number of plastic tie wraps, most of which are used on cable trays, was computed by estimation of the number of tie wraps per unit area of cable tray and multiplication by the estimated total area of cable trays. While the tie wrap inventory was computed, the tie wraps were not included in the foreign material area count since they were not expected to transport to the sump and collect on the sump screen. The staff accepts this assumption because of the significantly higher density of the tie wraps compared with the sump water.

Of the other material in containment that was inventoried, the fiberboard material is accounted for as a debris source as part of the plant fiber inventory and is therefore not accounted for as part of the latent debris inventory.

3.4.3 Dirt, Dust and Lint Mass, and Tags and Labels Results

The results of the IP3 analysis for dirt, dust and lint mass and the quantity of tags and labels in containment, are presented in Table 3.4-1; IP3 Latent Debris and Tags, Labels, and Other Material Results. These debris types are discussed separately below.

Dirt, Dust and Lint

Using the methodology described above, the total quantity of latent dirt, dust and lint in containment computed from the sample measurements and surface areas was 250 lb_m. As discussed in Section 3.4.2, the licensee's calculation of the total mass of latent debris contains an uncertainty due to the mass measurement instrument uncertainty of ± 0.1 gram. However, the staff considered the uncertainty addressed through conservatisms in the latent debris sampling process and noted that the importance of the uncertainty is small compared to the total mass of fibrous and particulate debris generated by other sources during the most limiting LOCA event.

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 [5].

Tags, Tapes, Labels and Stickers

Based on the methodology described above, the licensee calculated the total area of tags, labels, tape and stickers to be 45.8 ft^2. This is the surface area intended for use as the sacrificial area for the sump strainer design. All of these materials were conservatively assumed transportable to the containment sump.

Table 3.4-1 IP3 Latent Debris and Tags, Labels, and Other Material Results

Latent Debris and Foreign Material	Quantity	Type
Dirt, Dust, and Lint	250 lb_m	Assumed 15% Fibrous and 85% Particulate
Tape, Tags, Stickers and Labels	45.8 ft^2	Foreign Material

3.4.4 Latent Debris Summary

The estimation of latent debris mass in containment generally follows the guidance of NEI 04-07 [4] and the staff's SE [5] and contains a number of conservatisms. The licensee sampled the containment for dirt, dust and lint at the end of an outage and before cleanup. The staff expects that sampling during this time would yield a conservative measure of latent debris and concluded that this conservatism bounds uncertainties associated with the measurement of the latent debris samples.

The licensee’s methodology for estimating the quantity of foreign material in containment follows the guidance of NEI 04-07 [4] and the staff’s SE [5] 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.

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. Debris transport in the containment can be considered to occur through four primary 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 the containment spray 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 (hold-up or settling volumes for fluid not involved in recirculation flow) during recirculation flow; 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 system in recirculation mode.

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

The staff reviewed the debris transport analysis for IP3, which was primarily contained in the debris transport calculation [41]. The debris transport calculation stated that the transport methodology used for IP3 is based on the methodology in NEI 04-07 [4], as modified by the associated NRC SE [5]. In accordance with this guidance, logic trees were used to analyze transport for each type of generated debris.

The licensee's debris transport methodology used assumptions from both the NEI 04-07 [4] baseline methodology as well as analytical refinements from Section 4 of the NEI guidance document. In particular, the licensee used Flow-3D, a CFD code, to model the flow of water in the containment pool during the recirculation phase of a LOCA. The following subsections discuss the licensee's overall transport methodology, noting specific issues the NRC staff identified during the audit review.

3.5.1 Blowdown Transport

The licensee considered blowdown from a LOCA to be omni-directional. Based on the assumption that debris would be carried along with blowdown flow and a calculation of the relative volumes of the upper and lower containment, the licensee estimated that 79% of fine debris would be blown to upper containment and 21% would be blown to lower containment [41].

The licensee estimated that, while 79% of small fibrous debris pieces would be blown toward the upper containment, only 51% of small fibrous debris pieces would reach the upper containment due to attenuation on structures, grating, and the need for some pieces of debris to make sharp changes of direction [41]. No large fibrous pieces were assumed to be blown into the upper containment because such debris would not be capable of passing through grating. All small and large fibrous debris pieces not assumed to be blown into the upper containment were assumed to fall (or be washed down) to the containment floor.

The licensee assumed that 100% of small pieces of calcium silicate debris would be blown down directly to the containment pool inside the annulus crane wall [41]. The staff considered this assumption unrealistic, since small pieces of debris are considered to be of a size range that would be capable of passing up through the floor grating above the break level. Once through the grating, the staff expected that some fraction of the small pieces of calcium silicate debris would wash down to the containment pool outside the crane wall. Based on the licensee’s assumption that all calcium silicate debris is blown down directly to the containment pool inside the crane wall, a transport percentage of 0% was assumed for chunks of calcium silicate since analysis indicated that they cannot be transported up through the incore instrumentation tunnel during recirculation. If the blowdown and washdown of calcium silicate chunks were treated more representatively, based on the licensee’s CFD analysis, the staff considered it likely that a non-negligible fraction of calcium silicate chunks would be washed down into the outer annulus outside the crane wall and could subsequently transport to the containment sumps during recirculation without having to transport up through the incore instrumentation tunnel. The staff does not typically expect small pieces of calcium silicate to be a significant contributor to strainer blockage because they would have difficulty adhering to most strainer surfaces and would be too large to fill small voids in a compact fibrous debris bed. However, in addressing Open Item 3.5-3 regarding the erosion of calcium silicate debris, the licensee should consider the potential for some fraction of the small pieces of calcium silicate debris to be washed down in the containment pool outside the crane wall. Specifically, the calcium silicate pieces in the containment pool outside the crane wall may be exposed to different flow conditions (e.g., velocity and turbulence) than those inside the crane wall, which could lead to differences in the quantity of fine, eroded material generated.

The licensee analyzed direct blowdown transport to the IR and VC sumps [41]. For the IR sump, the licensee stated that debris interceptor barriers would not be installed above the IR sump gates due to the presence of a number of obstructions. This configuration presents openings that small pieces of debris could potentially pass through during the blowdown phase of a LOCA. However, the licensee stated that the percentage of debris blown directly into the IR sump room would be conservatively limited to a value of 1% of small pieces based on several factors: (1) the location of the primary system piping with respect to the openings leading to the IR sump room requires debris to make a significant direction change, (2) there are a number of physical obstructions in the openings above the IR sump gates, and (3) the volume of the IR sump room represents only 0.3% of the total containment volume. For the VC sump, the licensee provided a similar basis, but stated that the quantity of debris directly blown to the VC sump would be negligible because the VC sump room is smaller than the IR sump room and its openings are also smaller.

With the exception of the issue discussed above concerning the washdown of small pieces of calcium silicate, the staff considered the licensee's assessment of blowdown and washdown transport to be reasonable overall based on the information provided by the licensee concerning the physical geometry and layout of the containment. The staff noted that the fraction of debris assumed to be blown into the upper containment for IP3 was significantly higher than the NEI 04-07 baseline guidance [4]; however, this difference was assessed by the staff as being addressed through both the licensee's assumption that most of the debris subsequently was washed down into the containment pool and through identification of Open Item 3.5-1,below, which requests that the licensee provide adequate justification for assuming that 40% of the small pieces of fibrous debris blown into upper containment would be captured there.

The staff agrees that the licensee's approach of assuming that no large debris pieces reach the upper containment is conservative with respect to sump strainer sizing, However, without adequate technical justification, the staff would not consider the assumption that no large (or small) debris is captured in the upper containment to be generally acceptable for other purposes, such as analyzing the susceptibility of the refueling canal drain (or other choke points in containment) to debris blockage. Blockage of drainage flowpaths in containment and other upstream effects are addressed in Section 5.2 (page 85) of this audit report.

Finally, the staff did not perform a detailed review of the physical layout of the IP3 containment in the vicinity of the IR sump and VC sump rooms and further noted that the LOCA-jet model and blowdown transport methodology approved in the SE were not sufficiently detailed to be applied for calculating blowdown transport into particular containment compartments. Particularly for plants like IP3, with a sump pit configuration, it is critical that pieces of debris large enough to cause blockage at the entrance to the pit (where the fluid velocity tends to be relatively high) be prevented from accumulating there. Based on the licensee's assessment that few small pieces and no large pieces of debris can reach the IR and VC sump rooms due to the tortuous containment geometry and physical obstructions, the staff concluded that the licensee's results appear reasonable for computing blowdown transport percentages to the IR sump and the VC sump without prior IR sump operation. For these two cases, relatively high debris transport percentages were calculated during the recirculation phase. Based on this fact and the information summarized above from the licensee indicating that little or no debris is expected to be blown down to the IR and VC sump rooms, there is reasonable assurance that uncertainties associated with the licensee's blowdown model are bounded. However, the calculated transport percentages for the case of VC sump operation after 24 hours of IR sump operation are small, and there was not sufficient information for the staff to conclude that blowdown transport to the VC sump was conservatively addressed for this case. This issue is discussed in more detail in Section 3.5.4.6, on page 45.

3.5.2 Washdown Transport

The licensee stated that, since it assumed the debris blown into the upper containment consisted of fines and small pieces, most of this debris would be washed back down to the lower containment [41]. The analysis further assumed a fraction of the small pieces of debris blown into upper containment would be held up on gratings at the 95' and 68' elevations of containment. The licensee assumed that failed coatings in the upper containment would be washed down by containment spray flows [41].

As discussed in more detail below, the licensee developed a model to determine the distribution of containment spray drainage [41]. Based on the assumption that debris would be scattered relatively uniformly upon the operating deck and in the refueling canal, the licensee considered that washdown transport along various pathways to the containment pool would be in proportion to the distribution of containment spray drainage flow. The licensee stated that, although there are openings in the operating deck above the IR sump, debris barrier interceptor material installed in the RHR heat exchanger room above the IR sump and above the incore instrumentation tunnel prevent small or large pieces of debris from being washed directly to the IR sump.

The licensee's transport calculation credited floor grating at the 95' and 68' elevations of containment with capturing small pieces of fibrous debris during washdown. The licensee stated that this credit was based on testing performed for the DDTS [20, Volume 2], which showed that 40–50% of small fiberglass debris would be washed through grating due to spray flows [20, Volume 2]. The licensee considered this testing from the DDTS, which was performed to simulate debris transport in the drywell portion of a boiling-water reactor containment, to be applicable to IP3 based on an analysis of the containment spray flow rates considered in the study compared to the spray flow rates applicable to IP3. Using the results of the DDTS, the licensee assumed that 40% of the small pieces of debris blown into upper containment would be retained there [41].

The staff considered the licensee's interpretation and application of the DDTS results to IP3 to be not adequately justified. Although the tests in the DDTS did generally result in 40–50% of the debris being washed through the gratings, the duration of these tests was only 30 minutes. Based on these results for a 30-minute period, the conclusion stated in the DDTS was that no capture should be assumed for debris fragments that are smaller than the openings in the floor grating. Therefore, the staff considered the licensee's assumption of 40% retention of debris in upper containment to be contrary to the DDTS results and to have an inadequate technical basis. The staff further noted that a substantial fraction of the debris held up on gratings could be exposed to concentrated streams of run-off flow (as opposed to fine spray droplets), which could further increase the tendency for small pieces of debris to be washed through floor grating as compared to the results from the DDTS experiments. Therefore, the staff designated as **Open Item 3.5-1** that the licensee adequately justify its assumption of 40% retention of the small fibrous debris pieces blown into upper containment.

3.5.3 Pool-Fill Transport

The licensee stated that, since the debris interceptor barriers installed on the containment floor elevation would interdict all debris except for fines, no significant quantities of debris would transport to the strainers as the containment pool fills following a LOCA [41]. The licensee assumed that debris transport to inactive hold up volumes in containment was negligible during pool fill up, and this phenomenon was not credited in the transport calculation.

The staff considered the licensee's neglect of debris transport to the IR sump and to the VC sump (without prior operation of the IR sump) during the pool-fill-up phase to be appropriate. The debris interceptor barriers installed in containment are designed to prevent small and large pieces of debris from transporting to the sumps, and all fine debris was conservatively assumed to transport via recirculation flows. The staff guidance predicts that most of the fine debris in containment would accumulate on the strainers during the recirculation phase. Furthermore, the difference in timing for debris transporting during pool fill up as compared to recirculation is not significant for the IP3 analysis because all of the transporting non-chemical debris was assumed to be present on the sump strainers at the initiation of recirculation for the purpose of performing head loss testing. However, this conclusion does not apply for the special case of the time-dependent evaluation of transport to the VC sump after 24 hours of IR sump operation. In this case, neglecting pool-fill transport directly to the VC sump lacks the conservatism of the previous two cases, since the licensee calculated that the majority of the suspended fines would tend to be drawn onto the IR sump during its assumed 24-hour period of operation. The staff's review of the licensee's time-dependent modeling of VC sump transport is addressed separately in Section 3.5.4.6 below.

The licensee's neglect of debris transport to inactive containment pool volumes during the pool-fill-up phase is conservative with respect to maximizing the quantity of debris assumed to reach the strainers. Based on the discussion above, the staff generally considered the licensee's treatment of pool-fill transport to be appropriate.

3.5.4 Containment Pool Recirculation Transport

The licensee performed significant modifications in containment to prevent most small and large pieces of debris from reaching the containment sumps. By installing debris interceptor barriers at various locations in containment (e.g., at the doors between the steam generator compartments and the annulus) and creating holes in the crane wall near the opening for the incore instrumentation tunnel, the licensee ensured that small or large pieces of debris in the containment pool inside the crane wall at the start of recirculation would have to transport down into the reactor cavity and then be lifted up by the flow through the incore instrumentation tunnel to pass through the crane wall openings and reach the IR or VC sump. As the reactor cavity provides a large, relatively quiescent volume approximately 25–30 ft below the containment floor elevation, small and large pieces of debris that enter the cavity would generally be incapable of transporting up through the incore instrumentation tunnel and to the containment sumps. The staff considered the licensee's modifications to channel flow through the reactor cavity and incore instrumentation tunnel to be an innovative approach for reducing the quantity of debris at the containment sumps.

3.5.4.1 Initial Distribution of Debris at Switchover

The initial distribution of debris at switchover to recirculation could vary widely, depending upon the break location and chaotic phenomena during the blowdown, washdown, and pool-fill phases of the LOCA. Based on an assessment that the containment pool does not have a preferential direction of flow once the reactor cavity, incore instrumentation tunnel, and sump cavities have been filled, the licensee assumed that debris washed down into the containment pool by containment spray drainage would remain in the general vicinity of the washdown location prior to switchover.

All latent debris in containment was assumed to be uniformly distributed on the containment floor at the beginning of recirculation. Unqualified coatings and fine debris in lower containment were assumed to be uniformly distributed in the outer annulus or inside the crane wall, depending upon their location. Unqualified coatings, fine debris, and small pieces of debris in the upper containment were assumed to be distributed in accordance with the expected distribution of containment spray drainage. Large and small pieces of insulation in the lower containment were assumed to be located between the places they were assumed to be destroyed and the entrance to the reactor cavity.

The staff considered the licensee's assumed initial debris distributions in containment to be appropriate because they representatively or conservatively model expected conditions during a LOCA for the purpose of predicting debris transport for IP3. In actuality, the distribution of post-LOCA debris through the blowdown, washdown and pool-fill processes is a random process. In other words, a single debris distribution at switchover cannot be specified for all postulated LOCAs. Therefore, the staff expects that postulated variations in the initial debris distribution should not result in a non-conservative impact on the calculated debris transport fractions. The staff concluded that postulated variations in the initial debris distribution assumed by IP3 would not result in a non-conservative impact on the calculated debris transport fractions based upon two primary reasons:

- The licensee assumed 100% transport for fine debris (including fines from the erosion of large and small pieces of debris), regardless of its starting location.
- The licensee's transport calculation indicated that small and large pieces of debris in the containment pool inside the crane wall cannot exit the incore instrumentation tunnel, regardless of precisely where they are located when switchover begins.

These two factors, which are independent or only weakly linked to the initial debris distribution at switchover, determine the transport behavior of much of the post-LOCA debris for IP3. The staff also considered it reasonable to assume that washed-down debris would generally begin recirculation near the location where it washed down from upper containment, since the majority of the washed-down debris would enter the containment pool after the filling of inactive containment pool volumes and the buildup of an initial layer of water along the entire containment pool floor level, which are two events that would reduce the magnitude of high-velocity, preferentially directed containment pool flows prior to the switchover to recirculation. Therefore, the staff concluded that the IP3 transport results are not very sensitive to the initial debris distribution at switchover and considered the licensee's assumptions in this area to be appropriate in the context of the IP3 transport calculation.

3.5.4.2 Computational Fluid Dynamics Analysis

The licensee computed flow velocity and turbulence fields in the containment pool during the recirculation phase of a LOCA with the aid of the Flow-3D CFD code [41]. As described in more detail below, the licensee compared the flow velocities resulting from the CFD simulations to experimentally generated debris transport thresholds to determine percentages of transported debris. IP3 has two containment recirculation sumps, the IR sump, which is the preferred means of recirculation, and the VC sump, which provides back-up capability.

The licensee performed CFD simulations to compute the flow field in the containment pool when each of the two sumps is placed into operation [41]. The licensee stated that station procedures do not permit both the IR sump and VC sump to in operation simultaneously. Using the CFD simulations performed for the IR sump and the VC sump, the licensee computed debris quantities and transport fractions for (1) the IR sump, (2) the VC sump without initial IR sump operation, and (3) the VC sump after operation of the IR sump for 24 hours. The staff's discussion below evaluates the licensee's assumptions, analytical models, and calculations associated with determining the containment pool recirculation debris transport percentages.

The licensee stated that the CFD simulation was performed using a rectangular mesh [41]. For the main part of the containment pool model, the mesh spacing was 4 inches in both horizontal directions and 3 inches in the vertical direction. To model the incore instrumentation tunnel, the licensee used a 6-inch square mesh. The licensee stated that the total number of cells used for the IP3 CFD model was 1,767,204. The licensee used the renormalized group theory model to simulate the effect of turbulence in the containment pool.

Modeling of Containment Spray Drainage

The licensee assumed that containment spray droplets are initially distributed uniformly across horizontal cross-sections of upper containment [41]. Based on this assumption, the licensee calculated the quantity of spray droplets landing on any given area in containment using a ratio of that area to the total cross-sectional area in containment. For spray droplets landing on a solid surface, such as the operating deck, the licensee approximated the runoff of spray drainage by considering ratios of open perimeters where water was expected to drain.

In accordance with the above model, the licensee used containment drawings to calculate the fraction of spray drainage that would reach the containment pool through various pathways [41]. Table 3.5-1 below summarizes the results of this calculation.

Table 3.5-1 Licensee's Calculated Distribution of Spray Drainage Flow

Spray Drainage Pathway	Percentage of Total Spray Drainage
Through the Steam Generator Compartments	11.0%
Through the Refueling Canal	21.3%
Through Miscellaneous Grated Areas in the Steam Generator Compartments	29.4%
Through Both the 95' and 68' Elevation Gratings in the Annulus	26.0%
Through the 95' Elevation Gratings and Openings Around Support Beams	12.3%

The licensee attempted to model the kinetic energy of the containment spray drainage entering the containment pool [41]. The kinetic energy of the spray drainage was calculated using a model for droplets in freefall. The licensee stated that a terminal velocity of 29 ft/s for spray droplets is appropriate since this value is the terminal velocity for large raindrops, and smaller droplets have a lower terminal velocity.

The staff considered the licensee's modeling of the kinetic energy of containment spray drainage to be appropriate for droplets falling through the containment atmosphere and directly impacting the containment pool. However, the licensee also applied this model to streams of spray drainage running off surfaces, which the staff considered non-representative. Since the terminal velocity of a stream of water may be well in excess of the terminal velocity of a large raindrop, the licensee's approach had the potential to underestimate the kinetic energy introduced into the containment pool by spray drainage runoff. As the licensee's transport calculation shows, the majority of the spray drainage entering the pool is in the form of runoff, rather than droplets formed by the containment spray nozzles. Another non-representative aspect of the licensee's modeling was that the kinetic energy of spray drainage entering the containment pool from the refueling canal drain line was assumed equal to the potential energy between the elevation of the outlet of the drain line (52.67') and the containment pool minimum water elevation (47.19'). This assumption neglected any kinetic energy the drainage may have acquired from its transit from the refueling canal to the outlet of the refueling canal drain line. A final non-representative aspect of the assumption that spray drainage is in the form of droplets is that droplets are unable to penetrate through the containment pool to influence the turbulence and velocity near the containment pool floor, as could streams of spray drainage. Modeling all containment spray as droplets neglects the potential for streams of containment spray drainage to influence the transport of debris along the containment floor in localized areas in containment where spray drainage is concentrated. This statement is particularly applicable to IP3, given its relatively shallow minimum containment pool depth of 1.19 ft (following what at the time of the audit was a planned modification to the refueling water storage tank lower-level set point).

Despite these non-representative aspects of the licensee's modeling of containment spray drainage, based on the licensee's conservative assumption of 100% transport of fine debris and the installation of debris interceptor barriers designed to prevent the transport of large and small pieces of debris in the containment pool, the staff concluded that modeling containment spray drainage in a representative manner would not have had a significant impact on the debris transport fractions for IP3. Therefore, the staff did not consider the licensee's spray drainage model to be an open item.

Modeling of Break Flow

The licensee defined a region in the CFD model corresponding to the break location, placing it slightly below the surface of the containment pool to avoid drastic increases in computational time associated with predicting splashing behavior [41]. The velocity of the flow exiting the break source was computed in a manner similar to that described above for containment spray drainage, with the exception that a terminal velocity for the break flow was not specified.

The staff considered the licensee's model of break flow to be appropriate. Although the horizontal pipe exit velocity was neglected by the licensee, this value is expected to be small relative to the vertical velocity of the break flow entering the containment pool that was calculated by the licensee (30.9 ft/s) [41] for the purpose of computing the kinetic energy imparted into the containment pool. This conclusion is based upon the staff's review of similar vendor calculations for a different licensee [89]. Furthermore, by conservatively locating the break source beneath the surface of the containment pool, none of the kinetic energy in the break model was dissipated via splashing. The staff also expected that the effects of the horizontal velocity component from the break flow on the directionality of the containment pool velocity field would not significantly alter the licensee's debris transport results. This conclusion is based on the facts that (1) the licensee did not credit debris settling in the containment pool within the crane wall and (2) perturbations to the containment pool flow pattern within the crane wall would not be expected to affect the licensee's conclusions with respect to the types and sizes of debris that would be capable of transporting up through the incore instrumentation tunnel.

Modeling of Blockage at Debris Interceptor Barriers

The licensee assumed that the debris interceptor barriers installed in the crane wall doorways, in crane wall penetrations, and around the IR and VC sumps would be blocked with debris during a LOCA, which would force all flow (and debris) from inside the crane wall to pass through the incore instrumentation tunnel in order to reach the containment sumps [41]. The licensee stated that this assumption is conservative because it results in the velocity in the incore tunnel being maximized, thereby providing a bounding estimate of transport through the incore tunnel.

The staff partially agreed with the licensee's statement, but noted that certain types of debris that were assumed to settle in the incore instrumentation tunnel could be capable of passing through the ½-inch holes in the debris interceptor barriers, particularly paint chips. The staff noted during the audit that assuming that paint chips are incapable of transporting through the debris interceptor barriers could be non-conservative. In response, the licensee stated that the failure of unqualified coatings would be expected to occur gradually following a LOCA. By the time significant quantities of paint chips could reach the debris interceptor barriers, the licensee stated that it is likely that the barriers would be blocked by debris generated by the LOCA and/or foreign materials. Although complete blockage of the debris barriers will not occur for all postulated LOCAs, significant blockage of the debris barriers would be likely for the limiting debris loadings with respect to sump performance. The staff also noted that paint chips are not considered a significant challenge with respect to strainer performance under typical post-LOCA conditions that are applicable to IP3. Finally, the staff noted that the conservatism associated with not crediting the debris barriers as intercepting any fine debris would be expected to bound any nonconservatism associated with the assumption that paint chips cannot pass through the barriers. Therefore, the staff did not consider the licensee's assumption that paint chips cannot pass through the debris interceptors to be an open item.

The staff also discussed with the licensee the structural loading analysis performed for the debris interceptor barriers. The staff questioned whether spillage from the break entering the containment pool near the barriers could result in unacceptable structural loadings on the barriers. The staff noted that the conversion of the potential energy associated with the elevation difference between the break location and the containment pool surface to kinetic energy could result in relatively fast-moving water flowing directly at the debris barriers. The licensee responded that the structural loading associated with this phenomenon would be bounded by the structural loading from jet impingement for which the barriers had been analyzed. Based on the staff's assessment of the analyzed impingement loadings relative to the potential fluid momentum associated with break spillage, the staff considered the licensee's response to be reasonable.

<u>Modeling of the Containment Sumps</u>

The IR and VC sumps were modeled in the CFD input deck by locating mass sinks at the openings of the sump pits [41]. Detailed modeling of the top hat strainer modules was not attempted. As a result, the licensee noted that there is the potential for inaccuracy in the predicted flow pattern in the vicinity of the sump pit.

The staff recognized the limitations associated with the licensee's modeling of the area directly in the vicinity of the sumps, but considered them to be insignificant for the IP3 debris transport calculation. For IP3 the flow pattern around the sumps is determined largely by surrounding walls and other upstream flow obstacles to the extent that a detailed model of the strainer surface would not be expected to significantly affect the overall flow characteristics in the containment pool. Furthermore, because of the licensee's conservative assumptions regarding the transport of fine debris and the flow channeling modifications to address the transport of small and large pieces of debris, no significant changes would be expected to occur to the calculated debris transport percentages for a more accurate modeling of the sump strainers. Therefore, the staff considered the licensee's modeling of the containment sumps to be acceptable for the IP3 CFD simulation.

<u>Convergence of the Steady-State Solution</u>

The licensee stated that the determination that a converged steady-state solution had been reached by the CFD code was made by monitoring the estimated mean kinetic energy as a function of time and by checking velocity and turbulent kinetic energy patterns in the containment pool versus time [41]. Although the licensee did not provide specific details of how these determinations were made, the licensee stated verbally during the audit that the velocity and turbulence patterns were checked at 30-second intervals near the end of a simulation.

The IR and VC sump simulations were each run for a total of 600 seconds of simulated time, with several restarts occurring for each to implement corrections and modifications to the CFD model. The licensee stated that, because the solution was allowed to reach steady state after the final changes, the earlier model configurations did not have an adverse impact on the final CFD results.

Based on an examination of graphs of mean kinetic energy versus time and contour plots of velocity and turbulence, the staff considered the CFD simulations for IP3 to have adequately converged to a steady-state solution. However, the staff noted that specific criteria for evaluating the steadiness of the mean kinetic energy and velocity and turbulence patterns did not appear to have been established. The staff believes that establishing criteria for evaluating the convergence of a CFD simulation would provide increased confidence in the determination that a steady-state solution has been achieved.

3.5.4.3 Debris Transport Metrics

The metrics used by the licensee to analyze the tumbling transport of small and large pieces of Nukon® and generic fiberglass, stainless steel RMI debris, 1-inch chunks of calcium silicate, and epoxy paint chips during containment pool recirculation are provided in Table 3.5-2 Tumbling Velocity Metrics for Debris Transport During Recirculation below. The licensee's debris transport calculation also included transport metrics for curb lift velocity. The staff did not review these metrics in detail because, although curbs were included in the CFD model of the IP3 containment, the curbs were ultimately not credited with retaining debris following a LOCA.

Table 3.5-2 Tumbling Velocity Metrics for Debris Transport During Recirculation

Debris Type	Size	Tumbling Velocity Metric(ft/s)
Nukon® and Generic Fiberglass	Small Pieces (< 6 inch)	0.12
	Large Pieces (> 6 inch)	0.37
RMI	All	0.28
Calcium Silicate	1-inch Chunks	0.25
Unqualified Paint	Epoxy Paint Chips	0.27

The tumbling velocity transport metrics in Table 3.5-2 were taken from NUREG/CR-6772 [9], NUREG/CR-6808 [23], and NUREG/CR-6916 [51]. The staff generally considered the application of these test values to be appropriate because the debris used in the velocity metric tests was representatively or conservatively sized with respect to the IP3 plant debris. The staff noted a potential non-conservatism in that the tumbling velocity metric for unqualified epoxy paint chips was based on a bulk tumbling velocity value at which 80% of the debris began transporting (as opposed to a more conservative incipient tumbling velocity value at which initial motion of debris occurs). However, based on a subsequent review of NUREG/CR-6916 [51], the staff concluded that the licensee's tumbling velocity metric for epoxy paint chips is reasonable. The staff's conclusion is based on the facts that (1) there is significant scatter in the incipient tumbling transport data for various sizes and configuration of epoxy chips, (2) the licensee chose the most conservative bulk tumbling velocity among the different chip sizes and configurations for two-coat epoxy paint, a velocity which was in the range of the incipient tumbling velocity for many other sizes of failed epoxy coatings, (3) in actuality, the distribution of paint chip debris will likely span a range of different sizes and configurations, and (4) paint chips are not considered to be a significant contributor to measured head loss under typical post-LOCA conditions that are applicable to IP3 because they have difficulty climbing onto and adhering to most strainer surfaces, are unable to fill small voids in a compact fibrous debris bed, and tend to form porous accumulations.

The licensee's transport calculation also included metrics for the turbulent kinetic energy required to suspend debris particles and fibers [41]. These suspension metrics were calculated based on the application of Stokes' Law. In discussions with the licensee during the audit, the staff noted that application of Stokes' Law for determining suspension metrics lacked adequate benchmarking for typical post-LOCA debris and that Alion's application of this law assumed without justification that all debris particles were perfectly spherical, all debris particles were of a size equal to the nominal debris size for a given type of debris, and that the flow in the containment pool could be considered quiescent. The staff stated that these concerns with Alion's application of Stokes' Law to the settling of fine debris in a containment pool had been discussed in a number of previous audits [15, 100, 101], but that open items had not been designated because the affected licensees had not ultimately credited the settling of fine debris. The licensee replied that the use of Stokes' Law was actually supported by considerable test data. However, such data were not provided during the audit, and the issue was not pursued further as IP3 did not ultimately use Stokes' Law to credit the settling of fine debris.

The licensee performed a stand-alone Flow-3D simulation to determine the terminal settling velocity of a 1-inch chunk of calcium silicate [41]. The simulation was based on the assumption that the calcium silicate chunk was completely saturated with water. Based on the Flow-3D simulation, the licensee calculated a terminal velocity of 1.03 ft/s for a 1-inch chunk of calcium silicate. The staff questioned the accuracy of the licensee's calculation and noted that it is not clear that calcium silicate chunks would be fully saturated while they are sinking in the containment pool. As a result, the licensee's predicted terminal settling velocity is likely to be somewhat non-conservative. In addition, the staff noted other considerations associated with differences in the shape of calcium silicate chunks and the lack of benchmarking of this analytical result with test data. The licensee acknowledged these issues, but stated that they were not significant because the terminal settling calculation was only used to determine whether calcium silicate chunks would be capable of transporting upward out of the incore instrumentation tunnel. Based on this statement and the fact that velocities in the incore instrumentation tunnel were significantly less than 1.03 ft/s, the staff did not consider issues associated with the calculated terminal settling velocity for calcium silicate chunks to be significant with respect to the calculated debris transport fractions and did not designate an open item.

3.5.4.4 Debris Erosion

The licensee's transport calculation considered the erosion of small and large pieces of fibrous debris (including Nukon, Temp-Mat™, and mineral wool) as well as chunks of calcium silicate and asbestos debris in the post-LOCA containment pool over a 30-day mission time [41].

Fibrous Debris Erosion

The licensee assumed that 1% of small and large pieces of fibrous debris retained in the upper containment would be eroded by containment sprays [41]. The licensee stated that this assumption was based on testing performed as part of the DDTS [20 Volume 2]. The licensee stated that the assumption of 1% erosion for small and large pieces of debris in upper containment is consistent with the approach taken for the pilot plant in Appendix VI to the staff's SE on NEI 04-07 [5].

To compute erosion of fibrous debris in the post-LOCA containment pool, the licensee used the methodology and erosion rate in Appendix III to the staff's SE [5]. However, unlike the calculation in Appendix III to the SE, which assumed that erosion would continue for 30 days, the licensee's calculation for IP3 assumed that fibrous debris erosion would end after 24 hours. The licensee stated that this assumption was based on the theory that erosion results primarily from small, loosely attached pieces of fiber breaking off larger pieces. As a result, the licensee calculated an erosion percentage of 7%, which the licensee rounded up to 10% in an attempt to add conservatism [41].

The staff identified several issues associated with the licensee's analysis of fibrous debris erosion. Regarding the erosion of fibrous debris retained on gratings in upper containment, the staff noted that the testing performed for the DDTS was based on spray droplets and did not fully consider the effects of runoff in concentrated flow streams. In addition, the DDTS testing showed that erosion from break flow was significantly higher than for containment spray flow. In Appendix VI to the SE, erosion from break flow was conservatively addressed through the assumption of 90% erosion for debris in the containment pool. Given the licensee's assumption that erosion in the containment pool would be limited to 10%, it is not clear that there is sufficient conservatism in the IP3 transport calculation to account for erosion from break flow.

The staff concluded that adequate justification was not provided for the licensee's assumption of 10% erosion for small and large pieces of fibrous debris in the containment pool. Although the licensee stated that one plant has performed testing that reportedly demonstrates less than 10% erosion in the containment pool over a 30-day period, these test results were not provided to the staff during the audit. Therefore, the staff could not determine whether these test results were valid and applicable to IP3. Furthermore, the staff has seen other plant-specific erosion test data demonstrating continuation of fibrous debris erosion longer than 24 hours that led to a 30-day debris erosion percentage substantially higher than 10%. Therefore, the staff does not have confidence in the licensee's assumptions that erosion in the containment pool will (1) cease after 24 hours and (2) be limited to 10%. In addition, the staff has seen erosion test data and other evidence indicating that different types of fibrous debris may experience substantially different erosion rates. Depending on the binder or stitching used to construct a particular type of fibrous debris, its erosion rate may be higher or lower than that of Nukon® low-density fiberglass, for which most erosion testing has been done. For example, the staff noted during a previous audit of San Onofre Nuclear Generating Station that certain types of fibrous debris might be notably more fragile than Nukon, such as aged mineral wool [15], which could result in increased erosion rates as compared to Nukon.

In light of the concerns discussed above, the staff designated as **Open Item 3.5-2** that the licensee provide adequate justification demonstrating that the assumed 30-day erosion percentages for small and large pieces of fibrous debris retained in the upper containment and settled in the post-LOCA containment pool are conservative for all types of fibrous debris at IP3 for the post-LOCA mission time of the IP3 containment sump. In light of the licensee's intention to credit analysis of time-dependent debris transport behavior (see discussion in Section 3.5.4.6 below), the licensee's response to Open Item 3.5-2 should also provide adequate justification for using a 24-hour period to determine the erosion of fibrous debris.

<u>Calcium Silicate and Asbestos Debris Erosion</u>

Based on testing described in a report provided during the onsite portion of the audit [45], the licensee's debris generation and transport calculations [25, 41] concluded that chunks of calcium silicate and asbestos would not erode in the post-LOCA containment pool over the 30-day sump mission time.

The staff performed a limited review of the licensee's calcium silicate erosion testing. Based on this review, the staff determined that the licensee's conclusion that none of the calcium silicate and asbestos debris would experience erosion over 30 days did not have an adequate technical basis. As discussed in further detail below, the staff's determination was based on two primary observations: (1) the erosion testing procedure was not adequate to conclude that the calcium silicate erosion percentage was zero, and (2) the calcium silicate at IP3 may have been formed by a different process (molding) than the process used to form the material that was tested by the licensee (hydraulic pressing) that came from IP2.

A staff concern with the licensee's calcium silicate erosion test procedure is that the tests were not conducted for a sufficiently long period of time (only 2.5 hours) to distinguish between an erosion rate of zero and a small erosion rate that could lead to a substantive erosion percentage over the long-term post-LOCA mission time of the containment sump. Additional uncertainty is added by the fact that all measurements of the sample masses taken after the start of the erosion testing were done without drying the samples. Since the measured mass differences during the testing ranged from hundredths to tenths of a gram, small variations in the quantity of water adhering to the samples at the time of weighing could easily have influenced these measurements. Measurements of the concentration of cationic or anionic species, which could have provided an accurate estimate of dissolved material (i.e., calcium or silicates), were not performed. Finally, the staff noted that the erosion samples were only stirred for the final half hour of testing, and that the amount of turbulent kinetic energy induced in the test fluid was not compared to the value expected in the plant containment pool. As a result, it was not clear to the staff that the test flow conditions were representative of the actual plant. The erosion test report itself accurately reflects that the purpose of the tests was to determine if wholesale dissolution of calcium silicate would occur [45]. However, the debris generation and transport calculations [25, 41] subsequently overextended the results of the testing in referencing the test report as a basis to assume zero erosion of calcium silicate over the entire post-LOCA mission time of the containment sump.

As a result of the staff's concerns with the licensee's erosion and dissolution testing for calcium silicate that are discussed above, the staff designated as **Open Item 3.5-3** for the licensee to adequately justify that there is zero erosion of calcium silicate and asbestos debris over a 30-day period in the containment pool during the post-LOCA mission time of the containment sump. The licensee's resolution of this open item should consider the staff's discussion of calcium silicate transport during the blowdown phase of a LOCA in Section 3.5.1, above.

The staff was also concerned that the calcium silicate at IP3 may have been formed by a different process than the calcium silicate from IP2 that had been tested by the licensee for dissolution. In order to address staff questions, the licensee arranged a teleconference with two representatives from the insulation industry who had extensive experience with calcium silicate manufacturing. The insulation-manufacturing representatives outlined the three major processes that have been used by domestic manufactures to produce calcium silicate insulation. Among the distinctions made between the three processes that are pertinent to sump performance, the staff noted that whether the calcium silicate was molded or hydraulically pressed appeared to have the potential to influence the resilience of the material to erosion in a containment pool (as well as to LOCA jets and for other aspects of the sump performance analysis). Based on the discussion during the phone call, the staff concluded that, unless the licensee could determine that the calcium silicate at IP3 was formed by the same manufacturing process as the calcium silicate from IP2, the dissolution tests results for the IP2 material would probably not be applicable to the IP3 material. The staff identified **Open Item 3.5-4** for the licensee to justify application of this testing to IP3.

3.5.4.5 Debris Flotation

Based on concerns that Temp-Mat™ and mineral wool debris may float for a period of time following a LOCA, the licensee considered the phenomenon of Temp-Mat™ and mineral wool flotation through the incore instrumentation tunnel during the filling of the containment pool. These insulation materials were analyzed for flotation due to evidence that they would saturate with water more slowly than low-density fiberglass insulation (e.g., Nukon®) as the result of having a higher as-fabricated density.

The licensee's analysis of flotation considered large pieces of Temp-Mat™ and mineral wool debris that would be scattered around inside the crane wall. As the containment pool starts to fill following a LOCA, the licensee stated that some of these large pieces of debris would be washed into the incore instrumentation tunnel. The licensee stated that, at this time, the tunnel would also be filled from the annulus side with containment drainage that had passed through debris interceptor barriers. The licensee stated that the streams of water falling into the incore instrumentation tunnel would establish a flow pattern in the tunnel that would tend to draw floating debris toward the falling streams of water. Once the height of water in the instrument tunnel exceeded the height of a dividing wall in the tunnel, the licensee stated that floating debris would be prevented from leaving the incore tunnel. Based on this analysis, the licensee stated that transport of Temp-Mat™ and mineral wool debris by flotation would be negligible.

Based on the information provided by the licensee, the staff considered the licensee's analysis regarding the lack of flotation of Temp-Mat™ and mineral wool debris through the incore instrumentation tunnel to be reasonable. In addition to the considerations discussed by the licensee, the staff also expected that the impact of streams of falling water entering the incore tunnel on pieces of floating insulation would speed the process of saturating these pieces of insulation with water, which would enhance their settling.

3.5.4.6 Time-Dependent Debris Transport Model

The licensee's debris transport calculation included time-dependent modeling of debris transport [41]. The purpose of the time-dependent model was to determine the debris loading the VC sump strainer would need to be capable of tolerating after the IR sump has operated for a given period of time (i.e., 24 hours). The licensee stated during the audit that the time-dependent transport model was for information only, and that the preferred objective was to demonstrate through testing (that was ongoing at the time of the audit) that the IR sump could tolerate the entire plant debris load, including chemical precipitates, or, if necessary, use the alternate methodology accepted in Section 6 of the staff's SE [5] on NEI 04-07 [4].

The licensee modeled the quantity of debris in the containment pool as a function of time using a simple exponential decay function. The licensee's model was based on a number of simplifying approximations, including the following: (1) all debris except unqualified coatings outside the ZOI is generated prior to the switchover to recirculation, (2) all debris is in the containment pool at the start of recirculation, and (3) no debris passes through the strainer and subsequently returns to the containment pool. Based on these simplifications, the licensee calculated that less than 1% of the total debris loading would be available for transport to the VC sump after 24 hours of IR sump operation. Increasing the conservatism of the calculation to account for uncertainties in the analysis, the licensee raised the assumed percentage of the total debris loading available for transport to the VC sump after 24 hours of IR sump operation to 5%.

Although several staff concerns with the approach were noted in discussions during the audit, based on the licensee's verbal indication that the time-dependent transport model was for information only, the staff's review was limited. The staff learned subsequent to the on-site portion of the audit that the licensee planned to credit time-dependent debris transport in lieu of the Section 6 alternate methodology. Because of this new information, the staff followed up with a more detailed review of the licensee's time-dependent debris transport methodology.

Overall, the staff concluded that the licensee had not provided adequate technical justification to demonstrate that simplifications and significant uncertainties associated with the time-dependent model had been conservatively addressed. Among the most significant approximations made by the licensee that are either inadequately justified or non-conservative with respect to the design of the VC sump are the following:

- **Washdown of debris into the containment pool would be completed prior to the switchover to containment sump recirculation.** While it seems reasonable that the majority of debris would be washed down prior to switchover, the licensee did not provide adequate technical basis to support the assumption that all washdown would be completed prior to switchover. The staff expects that a non-negligible fraction of washdown is expected to would occur after switchover because the washdown of debris in the containment building is a time-dependent process that may involve some debris passing through more than one level of gratings.
- **Essentially all erosion of fibrous debris in containment would cease after 24 hours, and the vast majority of the eroded fines would erode and transport very quickly.** While erosion rates have been demonstrated to decrease with time, the staff has not seen evidence that they reach or closely approach zero after 24 hours. In addition, gradual blockage at debris interceptor barriers in containment and the assumed transfer from the IR sump to the VC sump after 24 hours may cause changes in the containment pool flow pattern. As a result of the changing flow pattern in the pool, some debris formerly exposed to low velocities may be exposed to increased velocities, which could temporarily increase local erosion rates.
- **The IR sump strainer has a capture efficiency of 100% for fine debris.** Although, based on the design of the downstream filters, a high capture efficiency is expected for all fibrous debris other than fine, short strands, prior to the formation of a contiguous debris bed on the IR sump strainer, the filtration efficiency for fine particulate debris would be expected to be significantly less than 100% because achieving efficient filtration of fine particulate debris much smaller than the strainer perforation diameter requires the prior accumulation of fibrous debris and coarser particulate debris. Depending upon the plant-specific debris mixture, achieving efficient filtration of fine particulate debris could require a number of containment pool turnovers.
- **Securing the IR pumps after 24 hours of IR sump operation would not temporarily result in reverse flow through the strainer or the release of trapped gas that could cause some of the debris accumulated on the strainers to be resuspended in the containment pool.** Although, because of its location in a pit, it is unlikely that reverse flow or trapped air could cause major quantities of debris to be resuspended in the containment pool, it is not clear that this effect is negligible.
- **Flotation would not significantly delay the progress of debris sinking in the containment pool.** Any debris that is floating will be delayed in transporting to the sump strainers or being eroded. Such delays would increase the quantity of debris remaining in the containment pool after 24 hours of IR sump operation, which would subsequently be available for transport to the VC sump.
- **Pool-fill and blowdown transport would not result in any debris being transported directly to the VC sump.** As discussed above in Sections 3.5.1 and 3.5.3, transport to the VC sump through these two mechanisms was neglected for cases that did not

include time-dependent modeling, which the staff considered acceptable based in part on other conservatisms associated with those cases. However, those conservatisms do not apply to the time-dependent modeling of the VC sump. Although pool-fill and blowdown transport percentages to the VC sump are not expected to be large, the licensee did not provide an adequate technical basis in the debris transport calculation to justify its assumption of zero transport to the VC sump due to pool fill and blowdown.

- **No chemical precipitates would accumulate on the debris bed covering the IR sump strainers within 24 hours of the LOCA.** The licensee's analysis did not include any discussion of the formation and accumulation of chemical precipitates in the debris bed.

Although the licensee increased the calculated debris transport percentage for the VC sump after 24 hours of IR sump operation from 1% to 5% in an attempt to account for potential non-conservatisms associated with some of the approximations listed above, the staff concluded that the licensee had not provided sufficient technical basis to conclude that there is reasonable assurance that the potentially non-conservative approximations listed above have been bounded. The staff designated as **Open Item 3.5-5** that the licensee provide adequate justification demonstrating that the quantities of debris assumed to transport to the VC sump after 24 hours of IR sump operation are conservative. The justification should address, but not be limited to addressing, the issues raised in this section of the audit report.

3.5.4.7 Flow Channels through Crane Wall Openings

The licensee stated that, because of the flow channeling modifications performed in containment, a non-negligible difference in the water levels inside and outside the crane wall appeared possible [41]. Based on the free surface model in the Flow-3D code that was used for the IP3 CFD simulations, the licensee calculated this water level difference to be minor (approximately 0.1 ft). The licensee stated that the two openings made in the crane wall measured 24 inches by 24 inches and 48 inches by 24 inches. Based on the information provided by the licensee concerning the sizes of the crane wall openings and that approaching flow must pass through either debris interceptor barrier material or the incore instrumentation tunnel, the staff considered it reasonable to expect that these openings in the IP3 crane wall would not become blocked with debris following a LOCA. Therefore, the staff concluded that the licensee's calculation showing minimal water level differences inside and outside the crane wall was reasonable.

3.5.5 Calculation of Debris Transport Percentages

The licensee calculated debris transport percentages by overlaying plots of velocity and turbulent kinetic energy contours in the containment pool on top of plots of the distribution of each type of post-accident debris at the beginning of the recirculation phase of a LOCA. The licensee then highlighted the overlapping regions where debris was initially distributed and where flow in the containment pool exceeded the applicable metrics necessary for transport along a flow path to the sump strainers. A transport fraction was then derived for each type of debris by dividing the highlighted overlapping areas by the total area over which the debris was initially distributed.

The staff considered the licensee's methodology to be reasonable because it is a means of comparing the expected containment pool flow conditions at a given location along a flow path to the sump strainers to the transport metric for a given type of debris predicted to be present at that location at the start of containment sump recirculation. The intent of the licensee's methodology is to represent the physical debris transport process during sump recirculation by coupling these inputs. The staff observed that there are a number of similarities between the methodology used by the licensee and the methodology used for the volunteer plant CFD analysis in Appendix III to the staff's SE [5]. When taken in conjunction with the conservatisms associated with the licensee's assumed initial debris distributions at switchover to recirculation (see Section 3.5.4.1 above) and debris transport metrics (see Section 3.5.4.3 above), the staff considered the licensee's methodology for calculating debris transport percentages to be appropriate, based on the staff's acceptance of these aspects of the methodology, as discussed above.

3.5.6 Overall Transport Results

In accordance with the methodology described above, the licensee's debris transport calculation [41] provides transport percentages for post-LOCA debris for three cases: (1) for the IR sump, (2) for the VC sump without prior operation of the IR sump, and (3) for the VC sump following 24 hours of IR sump operation. Note that the transport percentages to the VC sump calculated for the third case are significantly lower than those for the other cases because the majority of the debris was calculated to have accumulated on the IR sump strainer during its assumed operation for the first 24 hours of the LOCA.

As shown in Table 3.5-3 Summary of Debris Transport Results, the licensee conservatively did not credit the retention or settling of fine debris in the containment. The very small transport fractions for larger sizes of debris in Table 3.5-3 show the effectiveness of the licensee's approach of channeling flow through the reactor cavity and incore instrumentation tunnel. The small percentage of transporting small and large pieces of fibrous debris is mainly through erosion, with a minor fraction of the small pieces assumed to transport during blowdown and recirculation.

Table 3.5-3 Summary of Debris Transport Results

Debris Type	Debris Size	Debris Transport Percentage		
		IR Sump	VC Sump (Without IR Sump Operation)	VC Sump (After 24 hours of IR Sump Operation)
Nukon® / Generic Fiberglass	Fines	100%	100%	5%
	Small Pieces	13%	8%	1%
	Large Pieces	10%	10%	1%
	Intact Blankets	0%	0%	0%
Temp-Mat™	Fines	100%	100%	5%
	Small Pieces	15%	14%	1%
	Large Pieces	10%	10%	1%
	Intact Blankets	0%	0%	0%
Mineral Wool	Fines	100%	100%	5%
	Small Pieces	15%	14%	1%
	Large Pieces	10%	10%	1%
	Intact Blankets	0%	0%	0%
Calcium Silicate / Asbestos	Fines	100%	100%	5%
	Chunks	0%	0%	0%
Kaowool	Fines	100%	100%	5%
Fiberboard (Marinite)	Fines	100%	100%	5%
Qualified Coatings	Fines	100%	100%	5%
Unqualified Coatings (Inside ZOI)	Fines	100%	100%	5%
Unqualified High Temperature Aluminum (Outside ZOI)	Chips	100%	100%	100%
Unqualified Epoxy / Epoxy Phenolic (Outside ZOI)	Chips	28%	2%	2%
Unqualified Alkyd Enamel (Outside ZOI)	Chips	100%	100%	100%
Latent Particulate	Fines	100%	100%	5%
Latent Fiber	Fines	100%	100%	5%

3.5.7 Conservatism in the Debris Transport Calculation

The staff noted several significant sources of conservatism in the licensee's debris transport calculation [41], including the following:

- No credit was taken for capturing fine debris on the debris interceptors throughout containment.
- No credit was taken for the settling of fine debris in the incore instrumentation tunnel.
- For the IR sump design case, all of the fibrous debris calculated to erode over a 30-day period in the post-LOCA containment pool during the post-LOCA mission time of the containment sump was assumed to arrive at the strainer at the initiation of sump recirculation.
- The licensee did not credit debris holdup in the reactor cavity or the inactive normal containment building sump.
- The licensee performed the CFD analysis of the flow in the containment pool assuming the minimum containment water level for a large-break LOCA, which will be 1.19 ft following a proposed change to the minimum refueling water storage tank low-level setpoint. Assuming a conservatively low water level in the containment pool tends to increase the velocity and turbulence in the pool, resulting in conservative predictions of debris transport.

The effect of these conservatisms is difficult to quantify. The staff was unable to conclude that the conservatisms noted above, when weighed against the uncertainties and potential non-conservatisms also noted, resulted in an overall transport evaluation that is conservative or prototypical. Therefore, the staff concluded that open items in this section were necessary.

3.6 Head Loss and Vortex Evaluation

3.6.1 Head Loss and Vortexing Background Information

The audit in this subject area concentrated on IP3 although some information for IP2 was also reviewed. This Unit 2 information was reviewed because the licensee had not yet completed work to obtain similar information for Unit 3. The Indian Point approach is to provide a single strainer design that is applicable to both units. However, there are differences in the containments' physical layouts. The most significant is that the vapor containment sump in Unit 2 is somewhat smaller than that for Unit 3. The smaller sump has required the installation of some strainer modules on the containment floor. Installation on the floor results in a reduced submergence for the strainers; therefore, it is a significant difference. The IR strainers are almost identical between the units, but because of other differences between the units, the licensee has decided to evaluate the units separately. Unless otherwise noted, this section discusses the Unit 3 strainer installation and testing. The licensee stated that the qualification of the Unit 2 strainer will follow a similar methodology.

The new IP3 sump design uses a train of Enercon Top Hat strainer modules installed in the IR sump and a separate train of Top Hat strainer modules in the VC Sump. At IP3, only the IR pumps take suction directly from the IR sump. The IR pumps supply water to the spray headers and reactor, or for smaller breaks to the suction of the safety injection pumps. The RHR pumps can take suction from the VC sump under accident conditions. The RHR pumps provide redundancy to the IR pumps and perform the same functions that the IR pumps provide during recirculation. The strainer designs consist of banks of strainer modules installed within the IR sump pit and the VC sump pit on the lowest level of the containment. The strainers do not extend above the containment floor. In order to reduce the amount of debris reaching the strainers, the IP3 strategy is to direct the water flow through the instrument tunnel. The instrument tunnel provides an area of relatively low flow and low turbulence that will allow some debris to settle out. The tunnel is below the basement floor level, so debris that settles there is expected to remain there throughout any accident sequence.

The IR strainer module filters the water entering the sump, and then allows it to flow through a manifold and into an attached open sump. The IR pumps are direct submersion pumps mounted with their suctions submerged in the sump. The new VC sump strainer modules are also attached to a manifold that is connected to the existing suction pipe. The strainer modules for both the IR and VC sumps are below the containment floor level within a pit. (On Unit 2, there are some strainers associated with the VC sump mounted on the floor above the pit level as discussed above.) The strainer modules, connecting ductwork, and suction box are completely sealed with no ability to communicate with the atmosphere above the minimum sump level.

The IR and VC strainer assemblies consist of several Top Hats connected to a manifold. Each Top Hat consists of two concentric hollow cylinders that allow flow through both the inner and outer surface of each cylinder. Each cylinder annulus contains a bypass prevention material that is similar to steel wool. This limits the amount of debris that will pass through the strainer to downstream components.

Five different sized strainers were installed in order to maximize the strainer surface area within the sumps. The outer diameter of the outer cylinders is either 12 or 12.5 inches. The inner diameter of these cylinders is either 10 or 10.5 inches. The outer and inner diameters of the inner cylinders are 7 or 7.5 inches and 5 or 5.5 inches respectively. The length of the Top Hats ranges from 15.5 to 43.5 inches. The resulting total net surface areas are about 3156 ft^2 for the Unit 2 and Unit 3 IR sumps, 1182 ft^2 for the Unit 2 VC sump, and 1058 ft^2 for the Unit 3 VC sump. These net areas of the strainers' surface allow flow. Areas of the strainer that are occluded by welds or structural members are not included in these areas. The gross screen areas are about 3759 ft^2 for the Unit 2 and 3 IR sumps, 1352 ft^2 for the Unit 2 VC sump, and 1207 ft^2 for the Unit 3 VC sump [44]. The gross and net screen areas are used for various calculations pertaining to strainer performance.

The debris transport calculation evaluates the debris to be considered transported to the sump region. The amount of debris that is generated and transports depends on the size of the break being evaluated. The licensee evaluated small-, alternate-, and large-break LOCAs. The debris loads used for testing are bounded by the transport quantities for the large-break LOCA. The licensee used these debris amounts during testing. The amount of the various debris types predicted to arrive at the IR and VC sumps is presented in Tables 3.6-1 and 3.6-2 (on page 59 below). In addition, it is anticipated that some chemical precipitates will be present at the sump region following initiation of recirculation, and that additional chemical precipitates will form as the event progresses.

The IP3 licensee designed a unique method of reducing debris transport to the strainer. The licensee modified the recirculation flow path to force the fluid to flow down through the instrument tunnel before returning to the sumps. This approach will allow larger and heavier debris to settle in the instrument tunnel such that it cannot reach the strainer. Based on the transport analysis, this flow path should result in a relatively small amount of larger debris reaching the strainer. Therefore, any debris concern for this strainer would relate to fine, easily suspendable debris.

Because the VC sump strainer is much smaller than the IR sump strainer, the accumulation of similar quantities of debris on it would result in the limiting head loss. Therefore, some of the full load testing resulted in head losses much greater than would be expected for the IR sump strainer.

Alion tested for prototypical head loss for debris without chemical effects using their test flume. The test array was comprised of nine Top Hats connected to a manifold. The gross area of the test array was 135.9 ft^2. In order to account for chemical precipitate loading on the strainer, Alion used a small vertical head loss test facility to perform a 30-day chemical effects test. The test included scaled quantities of surrogate materials from the Indian Point containments and attempted to duplicate post-LOCA sump conditions. Section 5.4 below discusses the results of the chemical effects testing.

An empirical correlation was used to calculate the clean strainer head loss due to the perforated cylinder surfaces, the bypass eliminator, and the strainer internal structure. The correlation is based on testing conducted by Alion that determined the flow losses due to the Top Hats. A standard calculation was performed to determine the head losses associated with the manifold. The largest Top Hat and manifold contributions to clean strainer head loss were added, resulting in a conservative value [52].

Non-chemical effects head loss testing had been completed at the time of the audit [43]. The non-chemical debris testing indicated that the head loss across the strainer assembly is less than the NPSH margin available for the IR and RHR pumps. The information from the chemical effects testing had not yet been incorporated into the final head loss and a final head loss calculation had not been completed for either unit. The NRC staff was allowed to review a preliminary Unit 2 head loss calculation, but was not able to obtain a copy for reference because of its preliminary nature. The final head loss calculation is intended to show acceptability of the strainer in all areas including head loss, vortexing, air evolution, and flashing. Because this report had not been completed and verified, this audit could not draw final conclusions regarding the evaluations in the head loss analysis. However, the methodology used for the testing and the final calculation was evaluated.

3.6.2 System Characterization-Design Input to Head Loss Evaluation

The licensee evaluated LOCA scenarios and identified events that may lead to recirculation through the emergency sump. The two units at Indian Point were analyzed separately due to differences in the VC sumps. The IR sumps for Units 2 and 3 are identical. Because the VC sumps are smaller and more limiting, the evaluations were done separately for each unit. This audit concentrated on Unit 3.

The Indian Point units use a group of systems to mitigate the effects of design basis accidents. The ECCS includes the RHR pumps and safety injection pumps. These pumps require a supply of borated water for injection into the reactor following a break. In addition to the pumps, the ECCS has passive accumulators that inject a large volume of water into the RCS following a large-break LOCA. The RWST initially provides the initial source of borated water for the ECCS and containment spray pumps. The containment spray system sprays water into the containment to condense the steam released from the break and to reduce fission product concentrations in the containment atmosphere. This spray cools and assists in depressurization of the containment.

After the RWST is emptied, the internal recirculation pumps, taking suction from the IR sump, provide a long-term source of water for cooling the RCS. If the IR Pumps are not available, the RHR pumps, taking suction from the VC sump, perform these functions. This phase of the accident is termed recirculation because external water sources have been exhausted and cooling water recirculates from one of the sumps in the containment back into the RCS and the containment spray headers, as required. Only the IR pumps take suction on the IR sump and only the RHR pumps take suction from the VC sump. These pumps provide injection of water directly into the RCS. The IR and RHR pumps can also directly provide recirculation spray flow. Recirculation spray continues until containment conditions allow it to be secured.

In order to swap from RWST injection to the recirculation mode, operators are required to realign the systems. The swap over occurs between the RWST Low Level Alarm and the RWST Low-Low Level Alarm. As the operators are swapping from injection to recirculation, one containment spray pump remains running with its suction aligned to the RWST until the RWST Low-Low Level Alarms. This ensures continued containment cooling and fission product removal, and maximizes the amount of borated water delivered to the sump for the recirculation phase.

3.6.2.1 Flow Rate

The containment pool provides a reservoir for an adequate source of water for the IR and RHR pumps following the manual switch over to the sump [52]. The licensee indicated in [52] that for the design LOCA scenario, the maximum flow rate through the IR strainer is 5263 gpm with both IR pumps running. The maximum flow through the VC strainer is 3586 gpm [44]. Conservatively high flow rates used for test scaling were 5400 and 3700 gpm for the IR and VC sumps respectively [52].

Staff Evaluation

The staff reviewed the calculations that describe the LOCA event characterizations and found that the inputs used in the calculations were reasonable. The conclusions of the calculations for a large-break LOCA are supported by licensing basis documents and other technical information collected on site. The staff therefore finds the flow rates used in the strainer analysis to be acceptable.

3.6.2.2 Sump Water Temperature

The design temperature range for the strainer is 60-258 °F [52, 53]. The maximum temperature of the sump water during recirculation is 258 °F according to the IP3 Updated Final Safety Analysis Report. The maximum temperature for the strainer head loss correction is 212 °F. This value is conservative for head loss correction at any time that the sump water temperature is above this value. The minimum temperature of 60 °F is used for the clean strainer head loss and is a conservative value that will maximize the head loss. At the time of the audit, the licensee had not completed a final calculation that scales test data to predicted accident conditions. In general, Alion performs a temperature scaling calculation that credits the viscosity and density changes of water as a function of temperature and extrapolates the temperature effect on head loss over the mission time of the strainer.

Staff Evaluation

The staff reviewed the information regarding the bounding sump water temperature for the strainer head loss and NPSH calculations. The staff agrees that the use of 212 °F as the limiting temperature for temperatures above this value will yield a conservative result. In addition, the use of 60 °F for the clean strainer head loss calculation will result in a conservative value.

The most conservative assumption regarding the pool temperature for the strainer head loss calculation alone would be to assume the minimum pool temperature expected during recirculation. This would maximize the strainer head loss due to the higher water viscosity at cooler temperatures. In practice, this results in very large head losses and is not realistic or necessary because water temperatures are very high at the beginning of the event resulting in lower head losses. As the event progresses, water temperatures decrease, but NPSH margin increases so that the additional head loss due to more viscous, cooler water is offset by the larger margin. It is also important to note that temperature scaling based on viscosity may not be valid if the debris bed formed during testing contained bore holes, channels, or similar imperfections that would allow turbulent flow through the bed. Alion performed flow sweeps of the strainer and debris bed at the completion of testing to verify that bore holes or channeling were not present. Based on the results of the flow sweeps, Alion performed a regression analysis to determine the turbulent and laminar components of flow. The temperature corrections based on these findings are slightly more conservative than if an assumption of 100% laminar flow through the strainer and debris bed were used.

Because the strainer head loss calculation including scaling for sump pool temperature had not been completed at the time of this audit, the staff cannot make a judgment as to its acceptability, although the methodology the licensee evidently plans to use was acceptable.

3.6.2.3 Containment Sump Pool Water Level

The licensee has calculated the volume of water transferred to the containment from the RWST combined with the amount of water available to the sump from the accumulators prior to transfer to recirculation mode [54]. The minimum water level at the beginning of recirculation for a large-break LOCA is determined to be at 47.07 ft, or 1.07 ft above the floor level of 46 ft. The pool level corresponding to alarming of the RWST on Low-Low Level is calculated to be 47.97 ft, or almost 2 ft above the containment floor.

The minimum water level for a small-break LOCA may not include water inventory from the accumulators. The licensee assumes the accumulators are isolated and would not provide inventory to the containment sumps for a small-break LOCA. The sump level for a small-break LOCA is therefore about 0.5 ft lower than for a large-break LOCA at the start of recirculation and about 0.25 ft lower after containment spray switchover.

The licensee evaluation conservatively assumes that minimum volumes, based on technical specification minimum tank and accumulator levels, are added from the accumulators and RWST. The analysis also assumes maximum water temperatures in the accumulators and RWST prior to injection. These assumptions minimize the water mass added to the sump. The containment floor elevation is 46 ft. The minimum elevation of the water for a large-break LOCA is 47.07 ft at the start of recirculation, increasing to 47.97 ft prior to ending injection of the mass in the RWST. This indicates that there is 1 ft of water above the sump floor at the onset of recirculation and 2 ft of water after the completion of RWST injection. The strainers are installed in sump pits below the containment floor elevation. (Some of the strainers associated with the Unit 2 VC sump are installed on the floor [54].) Discounting the Unit 2 VC sump strainers which had not yet been fully evaluated, the minimum strainer submergence is 1.07 ft. At the time of the audit, the licensee was planning to reduce the RWST Low Level Alarm to increase the minimum water level at the start of recirculation to 47.19 ft. Based on testing to date, this submergence is less than the maximum corrected head loss across the screen [43]. Therefore, water vapor flashing needs to be evaluated to ensure it would not occur inside the strainer during the recirculation phase of a large-break LOCA. Some credit for containment pressure may be needed for the flashing evaluation. The final head loss analysis should evaluate the potential for flashing within the debris bed, strainer, and pump suction piping.

The licensee discussed vortex formation [52] and stated that with 6 inches of submergence [42 and 43] pre-vortex and vortex formations were observed under high strainer head loss conditions. Six inches of submergence is less than the minimum expected under the limiting small-break LOCA conditions. This issue is discussed further in the vortex evaluation below.

The void fraction downstream of the debris bed is to be addressed by the licensee as part of the final calculation. This area could not be reviewed during the audit because the information was not yet available.

The water level above the strainer during testing was significantly lower than the minimum predicted 12 inches for a large-break LOCA and about equal to that expected for a small-break LOCA.

The staff reviewed the analysis determining the minimum containment flood level [54]. The calculation contains some conservatism as discussed above, and provides an adequate basis for the water level covering the strainers. Because of the potential for vortex formation and flashing, the final strainer evaluation should address these issues.

Because the initial testing observed and documented vortex formations, and it is standard practice to evaluate the potential for vortexing, the staff has confidence that an open item is not required to track this issue. The adequacy of this evaluation will be reviewed during the review of the licensee’s supplemental response for GL 2004-02.

Conclusion

As discussed above, the staff reviewed the analysis determining the estimated sump water temperature, minimum ECCS sump pool water level and the maximum flow rate through the sump for the strainer head loss calculation. Because these design inputs were developed either based on the previous licensing basis calculations or bounding values selected for the head loss evaluation, the staff considers them acceptable.

Although the design inputs are acceptable, conclusions regarding how they affect the performance of the strainer cannot be made until the final strainer evaluation is completed. Areas impacted by the water temperature, sump pool water level and flow rate through the strainer include the evaluation of head loss, vortex formation, and vapor flashing within the strainer and debris bed.

3.6.3 Prototypical Head Loss Testing

In order to demonstrate that the new strainer head loss for the most limiting LOCA case is less than the IP3 design input of 2.5 feet [55], the licensee performed prototypical head loss testing. As described above, testing was conducted using the test facilities at Alion Science and Technologies.

The test loop at Alion consists of a closed recirculation loop as shown in Figure 4. A centrifugal pump recirculates water through the loop. The flow rate was adjustable by controlling the speed of the pump motor. Additionally the flow rate could be adjusted by means of a valve in the upstream line. The flow rate through the loop was continuously measured using differential pressure flow meters. The temperature of the water was measured using a Type K thermocouple. The test tank consisted of Plexiglas tank about 6 ft wide, 10 ft long, and 6 ft high. A box was built within the tank to simulate the installation of the strainer modules in the plant sump (see Figure 5). An Enercon Top Hat strainer array consisting of nine Top Hats was used for testing. During testing, water was maintained at about 6 inches above the strainer array, which is prototypical of the minimum water level expected during a small-break LOCA. Agitation of the water outside the box was provided to prevent excessive settling of debris.

Calibrated differential pressure transducers measured the head loss across the strainer.. Continuous head loss measurements were taken throughout each test along with the total flow rate and the water temperature. The debris was introduced directly at the surface of the strainer. The tank was stirred to ensure that a majority of the debris deposited on the strainer surface.

Figure 4 Alion Test Loop Schematic

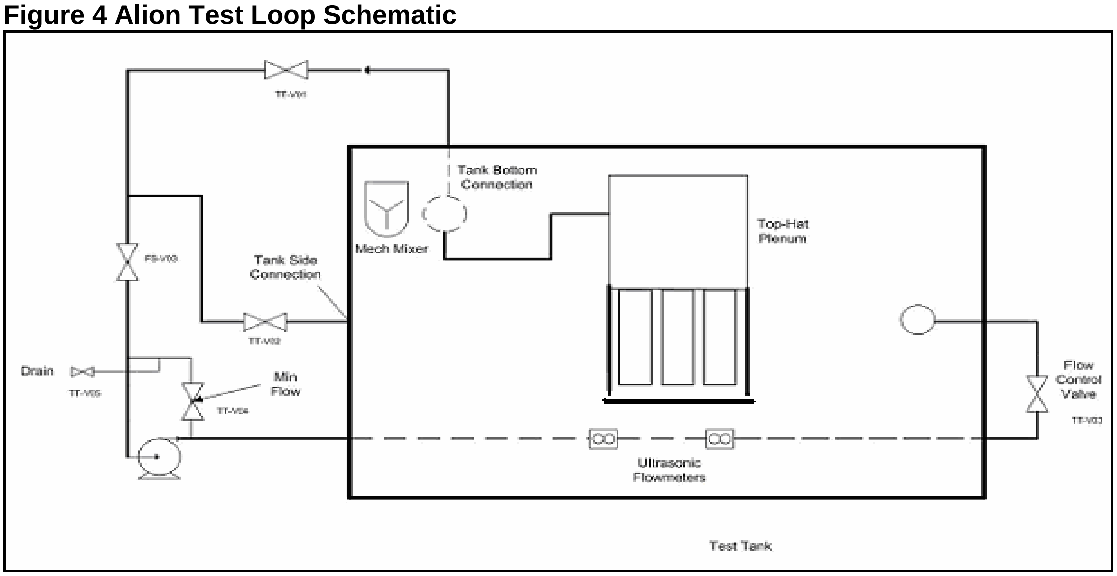
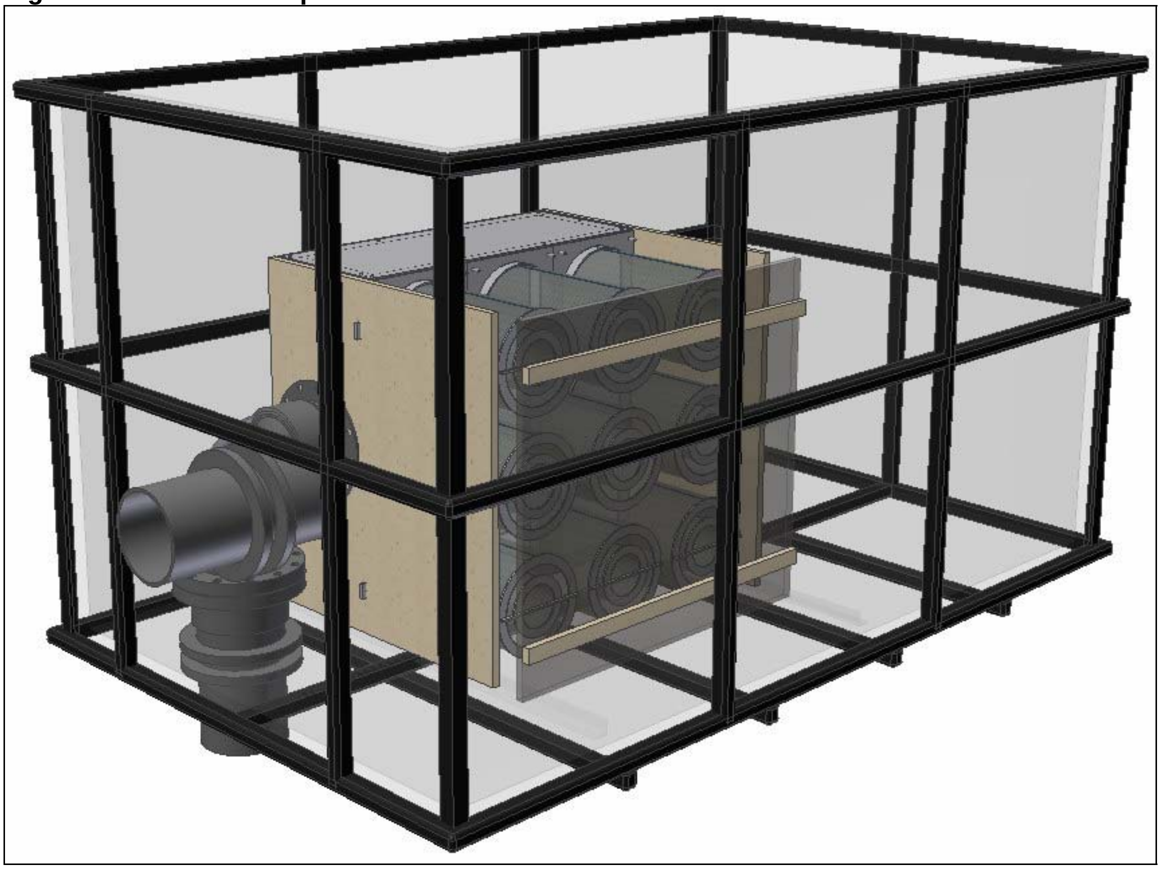


Figure 5 Alion Test Loop



Two head loss tests were run to measure the response of the strainer to varying debris loads and flow rates [43]. The tests included steps to attempt to create a thin bed and one test ended with sufficient fibrous and particulate debris to show the results of all postulated debris arriving at the VC sump strainer. For the IP3 test, a circumscribed bed debris load was not calculated because the testing is conducted in a pit that models the sump pits at IP3 including a conservative volume surrounding the Top Hats. Because the plant strainers are located in pits, this is a valid method to test for a circumscribed bed. If the strainers were on the floor of the containment additional evaluation of a circumscribed bed would have to be conducted. This is the case for the Unit 2 VC sump strainer.

The staff reviewed the test plan, the test report, and the interpretation of the test results. The tests were run at two flow rates. The maximum design strainer flow at IP3 is 5400 gpm for the IR sump and 3700 gpm for the VC sump. However, because the VC sump is much smaller than the IR sump, the scaled flow rate through the test strainer for the VC case is about double that of the IR case. Therefore, the flow rate used to build the test debris beds was based on the VC sump case. This is conservative because higher flow rates result in more bed compaction and larger head losses. Flow sweeps were used to determine clean- and debris-laden strainer head losses at other flow conditions and to check for bore holes or channeling in the debris bed.

The tests for IP3 were run for between 24 and 32 hours. The tests did not include chemical precipitates and were not run long enough to determine whether time-related variables would affect the head loss. The licensee plans to use the results of Alion chemical effects testing performed at Vuez to account for chemical and time degradation effects. The staff discussed with the licensee issues with the chemical effects testing conducted at Vuez. The issues are discussed in the chemical effects section (page 92) of this audit report. A final head loss calculation was not completed at the time of the audit, so the staff could not reach conclusions regarding the acceptability of the overall head loss

3.6.3.1 Debris Types, Quantities, and Characteristics

The specification of the debris quantities and characteristics is important to the choice of debris surrogates and debris preparation for the head loss testing. The predicted quantities of debris used to determine the amount of debris for head loss testing for IP3 are shown in Tables 3.6-1 and 3.6-2 for the IR and VC sumps, respectively [41].

The miscellaneous debris is not included in the test debris load for scaling of the test debris quantities. The Alion report [43] for the testing states that the labels, tags, and other items that could occlude areas of the strainer will be accounted for in the IP3 strainer certification calculation using head loss correlation relationships.

Open Item 3.6-1 is identified to assess and justify whether any extrapolation of head loss based on head loss correlation relationships can be shown to be realistic or conservative. It should be noted that this open item applies generally to manipulation of test results, including uses other than addressing strainer blockage due to miscellaneous debris. During the audit, the staff reviewed a preliminary final head loss calculation for IP2. The calculation contained similar data extrapolation for various strainer conditions. The staff concern with extrapolation of test data in this manner is that it is potentially non-conservative. In the past, the staff has accepted the extrapolation of test results to lower flow rates and higher temperatures because they are expected to be conservative. However, extrapolation to lower temperatures, higher approach velocities, smaller strainer areas, or different debris loads can be non-conservative. The staff position is that licensees should perform a prototypical or conservative head loss test for each potentially bounding scenario and base strainer head loss evaluations on these tests.

The potential debris accumulation on the replacement strainers was determined by quantifying debris within the ZOI of interest and adding latent and coating debris. The licensee evaluated the amount of each type of debris for each break within a break size category. Conservatively, the amount of debris assumed to reach the strainer was taken from the break that created the most of that type of debris. In almost all cases the limiting debris resulted from one of the postulated large-break LOCAs. There was one exception in that the RPV nozzle break resulted in a significant amount of RMI. The transport evaluation showed that the RMI is not predicted to reach the strainers.

The Transport Section of this report (3.5) discusses how the amounts of debris predicted to arrive at the strainer were determined. The debris loads actually used in the tests were scaled down from the plant debris loads based on the ratio of the actual versus tested strainer areas (i.e. 135.9/1206.9=0.113 (VC sump), 135.9/3759.9=0.036 (IR sump)) [43]. The debris scaling is based on gross strainer area, which includes some areas that do not allow flow because there are supporting members or similar blockage of that strainer area. Flow scaling is based on the net strainer area, which subtracts the blocked areas.

Table 3.6-1 IP3 Bounding Debris Quantities Transported to IR Sump

Debris Type	Large-break LOCA	Alternate-break LOCA	Small-break LOCA	RPV Nozzle
Metallic (ft^2)				
RMI	0	0	0	0
Fibrous (lb_m)				
Nukon®	457.7(3)*	117.8(7)	5.6(11)	0
Temp-Mat™	596.1(3)	354.7(5)	143.3(9)	336.5(13)
Mineral Wool	19.1(3)	5.5(7)	0	0
Unspecified Fiberglass	30.9(1)	12.0(5)	1.1(11)	0
Latent Fibers	37.5			
Particulate (lb_m)				
Asbestos	215.7(2)	140.8(6)	35.7(10)	0
Calcium Silicate	71.7(3)	1.9(5)	98.0(12)	0
Coatings	572.4			812.0
Latent Particulate	212.5			
Chips (lb_m)				
Epoxy/Epoxy Phenolic	231.9			
* The number in parentheses indicates the design case break scenario associated with the given type and quantity of debris.				

Table 3.6-2 IP3 Bounding Debris Quantities Transported to VC Sump

Debris Type	Large-break LOCA	Alternate-break LOCA	Small-break LOCA	RPV Nozzle
Metallic (ft^2)				
RMI	0	0	0	0
Fibrous (lb_m)				
Nukon®	404.6(3)*	105.4(7)	5.0(11)	0
Temp-Mat™	583.0(3)	346.3(5)	140.1(9)	336.5(13)
Mineral Wool	18.6(3)	5.4(7)	0	0
Unspecified Fiberglass	27.2(1)	10.8(5)	1.0(11)	0
Latent Fibers	37.5			
Particulate (lb_m)				
Asbestos	215.7(2)	140.8(6)	35.7(10)	0
Calcium Silicate	71.7(3)	1.9(5)	98.0(12)	0
Coatings Particulate	571.6			812.0
Latent Particulate	212.5			
Chips (lb_m)				
Epoxy/Epoxy Phenolic	16.0			
* The number in parentheses indicates the design case break scenario associated with the given type and quantity of debris.				

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 detail in Section 3.3 of this report.

The licensee discussed the debris characteristics primarily in the debris generation [25] and debris transport [41] calculations. ALION head loss testing reports [43, 44, and 45] provided information regarding the surrogate test material for head loss testing.

The analyzed debris loading for IP3 includes RMI debris, fibrous insulation debris, particulate insulation debris, qualified coatings, unqualified coatings, latent particulate debris, latent fibrous debris, and foreign materials such as tape, tags, glass, and stickers. Chemical effects precipitates were not included in the head loss testing completed by the time of this audit.

Because the RMI is only installed on the RPV, a nozzle break is the sole scenario that would produce RMI debris. Based on the debris generation and transport analyses, the licensee judged that it would be very unlikely that significant RMI debris would transport to the strainers. Based on these evaluations, RMI debris was not included in head loss testing. The staff accepts the licensee's approach for screening RMI debris from further consideration.

The licensee's debris generation analysis shows that the types of fibrous insulation available in containment that could potentially become debris include Nukon®, Temp-Mat™, mineral wool, and some fiberglass for which the manufacturer could not be determined. The licensee's transport analysis demonstrates that most of the debris accumulation would be due to transport of suspended fine fibers. Some small pieces of fiber would also transport. The licensee assumed that 10% of small- and large-piece debris on the floor would subsequently erode into fine fibrous debris; however, the staff considered that this percentage was not adequately supported (see Open Item 3.5-2, page 43). Because additional erosion could occur, the head loss testing may have been conducted with non-conservative amounts of fine fiber. The surrogate materials used by the licensee in head loss testing for the fibrous debris were either the same as the plant material or similar to the plant insulation. The staff accepts the licensee surrogate fibrous insulation materials used in the head loss testing as either prototypical or conservative with respect to the actual IP3 materials.

The IP3 containment contains substantial quantities of calcium silicate in at least two types. Some of the calcium silicate insulation was manufactured using asbestos fibers. The other type of calcium silicate used some other form of fiber. The transport analysis assumed that fines from both types of calcium silicate transport completely to the strainer. Larger pieces were shown not to transport. Larger pieces of calcium silicate debris located in the sump pool could erode, giving up very fine, highly transportable particles. The licensee assumed that neither type of larger calcium silicate debris would erode or dissolve. These assumptions were considered not adequately justified (see Open Item 3.5-1 (page 34) and Open Item 3.5-3 (page 44)). Therefore, the amount of calcium silicate used in the testing may have been non-conservative. Thermo-12™ Gold IIG calcium silicate insulation manufactured by Industrial Insulation Group, LLC was obtained in a powder form for use as a surrogate for the IP3 head loss testing. Based on licensee testing and microscopic comparisons between several types of calcium silicate, the staff accepts that the Thermo-12™ Gold IIG calcium silicate powder is a reasonable surrogate for the IP3 calcium silicate.

The licensee assumed that latent fibers comprise 15% of the total latent debris mass measured in the containment and that the latent fibrous debris is composed of 100% small fines. Nukon® fibers were used for the latent fibrous debris during testing. The staff considers the characteristics assumed for latent fibrous debris to be acceptable because the staff SE recommends using a latent fiber surrogate with properties equivalent to those of Nukon®.

The licensee assumed that particulate material comprises 85% of the total latent debris mass measured in the containment and that the latent particulate debris is composed of 100% fine particulate. Silica sand was used as a surrogate material for latent dirt and dust debris in the head loss testing. The size distribution of the surrogate sand mixture was prepared to be consistent with the latent dirt/dust size distribution provided in the SE [5]. Therefore, the staff considers the characteristics assumed for latent particulate debris to be acceptable.

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 and Transite board. The fire stops are not within the ZOIs considered in the analysis and are not predicted to break down in post-LOCA conditions. Therefore, no debris was predicted to be generated from these materials. The staff considers the licensee's assumption regarding the ability of the fire stops to remain intact reasonable based on the information provided.

A walkdown assessment of the miscellaneous debris provided estimates of areas for tape, equipment labels, and tags, and the number of tie wraps. The licensee conservatively assumed that this material would fully transport to and accumulate on the sump strainers. Rather than introduce surrogate miscellaneous debris into the head loss testing, the licensee planned to extrapolate head loss testing results resulting from the reduced gross screen area due to the miscellaneous debris. The staff considers this type of extrapolation to be potentially non-conservative, as previously discussed (Open Item 3.6-1 (page 58)).

The staff reviewed the IP3 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 debris characteristics used in the debris CFD transport analysis were acceptable, but there are open items associated with the erosion of debris within the sump pool. In addition, the extrapolation of test results to account for blockage of the strainer from miscellaneous debris is potentially non-conservative and has been identified as an open item as discussed above.

3.6.3.2 Scaling Methodology, Testing Procedures and Test Results Interpretation

3.6.3.2.1 Scaling Methodology

The IP3 strainers consist of sets of Top Hats. The IR sump strainer has 249 Top Hats that are 21.5 inches long. The VC sump is a smaller volume than the IR sump. To maximize the available strainer area in that sump, more than one length Top Hat type was used. The VC sump contains twelve 33.5 inch, nine 23.5 inch, six 15.5 inch, and twenty-four 43.5 inch Top Hats. The total area for the IR sump is 3759 ft^2 gross and 3156 ft^2 net. The gross area for the VC sump is 1207 $ft^{2,}$ and the net area is 1058 ft^2. On Unit 2, the IR sump strainer is identical to the Unit 3 strainer. However, due to differences in the VC sump volumes the Unit 2 VC sump strainer is much different. Because the VC sump is smaller in Unit 2, some strainer modules had to be installed on the floor above the sump pit.

The licensee used the net strainer area to scale test approach velocity, while the gross area is used to scale the debris to be included in testing. The test strainer consisted of an array of nine Top Hats with a gross area of 135.9 ft^2. The net area of the test strainer was 114.1 ft^2. The test array Top Hats were the same size as the IR sump Top Hats [43].

Because the testing was designed to test both the VC sump and IR sump strainers under various conditions, flow rates between 195 gpm and 399 gpm were used for testing. Flow rates outside this range were used for flow sweeps during testing.

The overall debris-scaling factor for the testing was 0.03625 for the IR sump and 0.1126 for the VC sump based on the areas described above. Alion scaled the test flow rate based on the ratio between the net testing module surface area and the actual strainer net surface areas. The Top Hats were installed in the test setup in a manner that simulates the installation of the modules in the sump. Plywood walls were built around the test array to geometrically and volumetrically simulate a scaled strainer array. During the audit, Alion stated that the volume surrounding the test array was slightly conservative. That is, the volume containing the test array was slightly smaller than the scaled volume from the actual strainer array. By ensuring this conservatism, Alion did not have to consider scaling for a circumscribed bed as the bed would form prototypically or conservatively during the test.

With the exception of not subtracting the sacrificial area for the miscellaneous debris, the scaling methodology was typical of strainer vendors and is appropriate for the IP3 case. The issue with adjusting for miscellaneous debris after testing, rather than subtracting it prior to conducting the scaling, is discussed above (Open Item 3.6-1 (page 58)). The remainder of the scaling approach is appropriate because the test facility modeled the important aspects of the layout of the strainer modules, the spaces between the strainer modules, and the spaces between the strainer modules and adjacent sump pit walls. Excepting the treatment of miscellaneous debris, the staff considers the licensee's scaling methodology acceptable for the following reasons:

- The scaling factor methodology was appropriate because the test debris load was based on active strainer area and full plant debris load,
- The highest screen approach velocity tested was bounding compared to the actual scaled plant flow,
- The enclosure around the Top Hats provided a volume that was scaled conservatively to ensure prototypical or conservative formation of a circumscribed bed during testing if one would form in the plant.

3.6.3.2.2 Testing Procedures

Prototypical head loss testing was performed by the strainer vendor following its testing procedures. The test procedures were presented in the test plan [42]. The test report [43] presented the head loss results. The staff reviewed the Alion test procedures for introduction of debris, the test termination criteria, and the test matrix. The test facility is described in section 3.6.3 above.

During testing, the Alion approach was to introduce the debris in the test tank near the strainer module enclosure. Although the test report states that the debris was added directly over the strainer enclosure, Alion personnel stated that this was not the case and that the debris was added to the tank outside the area immediately over the strainer enclosure. Mechanical stirrers were used to reduce debris settling within the tank and a canoe paddle was occasionally used to re-entrain debris from the bottom of the tank. These measures provided a good means of reducing near field settling, since post-test photos show that only small amounts of fibrous debris settled on the tank floor or hung up on components within the tank. The Alion method of introducing the debris outside of the strainer box probably also encouraged the finer debris to transport to the strainer sooner. However, the stirring could introduce non-prototypical debris distribution on the strainer by forcing larger pieces of fibrous debris onto the strainer. This larger debris could disturb or preclude the formation of a thin bed. Additionally, the rate of introduction of fibrous debris in the proximity of the strainer module can influence the compaction of the accumulated fiber bed. However, Alion added the fibrous debris for the thin bed test in ⅛ inch increments, waiting a minimum of 5 pool turnovers between additions.

For thin bed testing, Alion added all of the particulate debris to the test flume prior to adding any fibrous debris. This is considered conservative because it provides the highest potential for a high particulate-to-fiber debris bed ratio with generally lower bed porosities.

Since Alion did not stop a test with a thin bed debris load, but continued to add debris to the test loop, there are no post-test photos of a thin bed case to determine how the fibrous debris was entering and depositing on the strainer modules while there was a limited amount of fibrous debris on the strainer [104]. During testing, any view of the strainers was not possible because of the particulate debris clouding the water. It should be noted that post-test photos can be misleading because the debris may shift when the water is drained from the test loop. Therefore, evaluation of the photos must be done carefully with this in mind.

Alion uses shredded fibrous debris for testing of strainer head loss. During the audit the staff discussed the preparation of fibrous debris at length with IP personnel and their vendors. The testing used generically shredded fiber, which is boiled and later shredded with a leaf shredder. Prior to addition to the test tank, the fibers are placed in containers and stirred with a drill-driven stirrer. The fibrous size distribution is not verified to match the distribution predicted by the transport calculation. The staff concluded that the debris that had created the debris beds during testing contained significant amounts of fiber that were larger than what is predicted by the transport analysis to reach the strainer. This was verified by observing photos of the beds formed during testing and observation of tests performed at the Alion test facilities.

In general, with respect to debris preparation and introduction, the staff has concluded that the most limiting head losses are likely to occur from the uniform deposition of fine fibrous debris in conjunction with particulate and chemical debris. It is likely non-conservative to test with a generic mixture of fibrous debris and methods that force large pieces of debris to reach the strainer. This is especially important for thin bed testing. This method of testing is likely to result in non-conservative results because non-prototypically sized fiber can reach the strainer resulting in a debris bed with lower porosity. **Open Item 3.6-2** is identified for the licensee to show that testing was conducted with a mixture of fibrous debris that matches the predictions of the transport calculation, or provide an evaluation that shows the testing was conservative. A more conservative thin bed test approach would include only the finest fiber predicted to reach the strainer. Fine fibers are considered to be those that are easily suspendable and remain suspended with small turbulence. The staff considers that thin bed test conditions should attempt to build a uniform bed of fine fiber unless it can be demonstrated that a uniform bed will not form in the plant.

Chemical effects testing was conducted separately from the physical debris testing described in this section. The staff observed testing at the Alion chemical test facility. The findings of the staff observation regarding how the results of chemical effects testing may be applied to the IP strainer head loss calculation are included in the chemical effects section of this report (page 92).

The testing documents specified termination criteria for the IP strainer testing. The termination criteria included head loss change of ≤ 1% in 60 minutes and five pool turnovers or more total flow. The criteria also allowed the test coordinator to shorten of lengthen the test if necessary. The staff has stated in its head loss review guidance [92] that 15 pool turnovers should be allowed to ensure relatively complete filtering of fine particulate debris. Based on the flow rate, system volume, and test times it, is apparent that the turnover criterion was met for the tests. In addition, the head loss plots show that the head losses were relatively stable prior to stopping the tests. Because the tests simulated various debris loads for both the VC and IR strainers under varying debris loading, the tests added debris in steps. The plot for the full load test shows generally flat or decreasing head loss between debris additions. For the thin bed test, the head loss trends varied between debris additions. Some trends were flat, some increasing, and some decreasing. The time between additions was adequate to ensure adequate turnovers for filtering of particulate debris based on the recommended 15 tank turnovers recommended by the staff.

In the test report, Alion provided plots of temperature, flow, turbidity, and head loss versus time. These plots show that over the short term, head loss changes are reasonably flat and that head loss sometimes decreases. However, after some debris additions, the plots showed a steady increase in head loss until the next debris addition or flow change. Instead of extrapolating data to the ECCS operating time requirement, the licensee plans to use the Vuez 30-day period chemical effects testing results to determine the head loss increase that will occur over the ECCS mission time. Issues with the chemical effects testing at Vuez are presented in Section 5.4 below.

Based on its review, the staff concluded that improvements should be made to the fiber preparation and debris introduction portions of the testing to ensure prototypical bed formation (Open Item 3.6-2 (page 63)). In addition, the staff concluded that it is more appropriate to scale the test strainer based on a plant strainer area reduced by the appropriate amount for miscellaneous debris (Open Item 3.6-1 (page 58)).

3.6.3.2.3 Test Results Interpretation

The IP3 strainer test program consisted of two separate tests. One test was a full-load test and the other was a thin bed test. The tests were conducted using incremental debris additions in order to model various debris loads on the IR and VC strainers. Because the licensee believes that the limiting case is presented by the VC sump strainer, the test results interpretation concentrated on the VC strainer. According to licensee and Alion personnel, the testing also included points that were representative of IR strainer loadings. However, the applicability of the testing to the IR strainer is not documented in the test report [43]. This test report provides all of the available documentation on the test results. Apparently, the data from the testing will be extrapolated to the conditions that would be experienced by the IR strainer. Because the IR strainer is the primary strainer that would be used to respond to a LOCA at IP3, the staff considers that the testing should directly address this strainer. **Open Item 3.6.3** was identified regarding the licensee's documentation that the testing conducted for IP3 is directly applicable to the IR strainer and not only applicable to the VC strainer. The documentation should show that the design and actual performance of the test were carried out such that the IR strainer design conditions were tested or bounded.

The methods for interpretation of the data collected during this test were reviewed by the staff. The areas reviewed included both the debris head loss and the clean strainer head loss. These areas are discussed in this section. Results of each test including those made to gather information will be discussed in this section.

Test 1 was a full-load test. The test procedure added fibrous and particulate debris in homogeneous batches and ultimately ended with 115% of the scaled total debris predicted to arrive at the VC sump. This test was run at a flow rate scaled to 3700 gpm for the VC sump. After the final two debris additions, the pump could not maintain adequate steady-state flow; therefore, the flow was allowed to decay and stabilize at a lower value. In the absence of data at the desired flow rate, Alion extrapolated data to the higher flow rate using a linear extrapolation method. Extrapolating to higher flow rates is potentially non-conservative. This is associated with and covered by Open Item 3.6-1 (page 58). These extrapolated values were later extrapolated to the higher temperature condition expected at the sump early in the accident. The staff considered the extrapolation method for temperature appropriate because extrapolation to a higher temperature is considered conservative due to the lower head loss associated with the higher temperatures. The uncorrected head loss for Test 1, prior to the reduction of flow, was 13.58 ft. At a reduced flow rate, after the final debris addition, the head loss was 19.88 ft.

Although the results of this testing were preliminary and the final strainer evaluation has not been completed, based on the testing described above, it appears that the VC sump is not capable of handling the entire debris loading without head loss beyond the allowable NPSH margin. At the time of the audit, the licensee was still considering the best method for a solution to the strainer issue. The testing (subject to final evaluation and review), indicated that the IR sump is capable of performing under the full containment debris load (excluding chemical effects). Subsequent to the audit, the staff held a discussion with the Indian Point licensee regarding the overall approach that would be used to resolve the GSI-191 issue. The licensee indicated that it was planning on crediting the IR sump for 24 hours without a passive failure of components associated with that sump. Details regarding the specific evaluations regarding the implementation of this approach have not been finalized yet.

A flow sweep was conducted to determine if boreholes or channeling had occurred in the debris beds. Because of high head losses that occurred during Test 1, the final flow sweep in the increasing flow direction could not be completed due to the inability of the pump to operate under such high head loss conditions. The flow sweep in the lower flow direction showed that channeling had probably not occurred during testing because the change in head loss was roughly proportional to the change in strainer approach velocity. This is considered an appropriate method of determining whether channeling has occurred in the debris bed.

Test 2 was a thin bed test. This test was also run at a flow rate scaled to the 3700 gpm associated with the VC sump strainer. The test was run with the full particulate load added at the start and ⅛ inch scaled theoretical debris bed increments of fibrous debris added with 5 pool turnovers between increments. After the first ½ inch of theoretical scaled fiber was added in four steps, two additional fibrous debris additions were made. These supplemental additions brought the total theoretical bed thickness up to an equivalent thicknesses of 0.61 inches and 0.94 inches. These two bed thicknesses matched two of the thickness steps in Test 1. The range and increments of fiber addition, combined with the lack of debris settlement observed during the testing, should have been able to allow a thin bed to form. Although the debris introduction sequencing appears to have been adequate based on the head loss leveling off prior to the next debris addition, the staff finds the thin bed test results to be potentially non-conservative because of the debris preparation and introduction, and agitation added to the tank as discussed in Open Item 3.6-2 (page 63) . The maximum uncorrected head loss for Test 2 was 2.03 ft.

The comparable test results (with similar debris loads) from Tests 1 and 2 confirmed that testing with the particulate debris added prior to the fibrous debris generally results in higher head losses than if the debris is added as a homogeneous mixture.

The flow sweep conducted for Test 2 showed that the head loss change with respect to strainer approach velocity was at least linear. Therefore, it was unlikely that pressure-driven changes in head loss had occurred during the test, and therefore temperature extrapolation could be accomplished conservatively. Alion uses a turbulent/laminar velocity split to correct for temperature in these cases. Alion believes that for thin beds there will be some turbulent contribution to the head loss. Based on the relatively low head losses observed, the results of the flow sweep, and a review of the test data, the staff concluded that a significant pressure-driven reduction in head loss did not occur for Test 2. The use of the Alion temperature correction that includes consideration of turbulent and laminar flows results in a reduced temperature correction. Therefore, the Alion temperature correction method is conservative compared to a straight viscosity temperature correction.

Summary of Test Results Interpretation

In general, the licensee methodology for evaluation of test results was reasonable. The flow sweeps performed during the testing are a good method of checking for debris bed degradation caused by differential pressure. The flow sweeps for both tests indicated that channeling had not occurred. The extrapolation of data to head losses significantly higher than those measured to attain results for flow rates that the pump could not produce may be non-conservative. In addition, the thin bed test results may have been affected by debris preparation, introduction, and tank turbulence (Open Items 3.6-1 and 3.6-2). In addition, the test results were not clearly linked to the IR strainer, but concentrated on the VC strainer (Open Item 3.6-3).

Based on the measured head loss test data, the licensee used an extrapolation methodology to calculate the debris bed head loss at the specified fluid temperature. For the temperature scaling, the licensee assumed that the head loss is directly proportional to the absolute fluid viscosity for the full-load test, and proportional to a numerical model using viscosity and density as physical constants for the thin bed test. Use of the model that considers both viscosity and density provides a head correction that is conservative compared to a correction based on viscosity alone. Therefore, the staff considers the temperature corrections to be acceptable.

Final evaluation of the acceptability of the head loss for IP3 could be completed by the staff because the results of the head loss testing were not compiled into a finalized head loss calculation.

3.6.4 Clean Strainer Head Loss Calculation

The clean strainer head loss measured in the test flume is not identical to what would be experienced in the plant. The test strainer modules were similar to the plant strainer modules, and were connected to a similar manifold. However, the plant contains many more modules, and the manifold in the plant is significantly larger. The additional plant head losses associated with flow through the larger manifold were not tested. The exit losses associated with the discharge of the fluid from the manifold into the sump were also not tested. Because the test did not fully represent the clean strainer head losses they were calculated in the preliminary head loss calculation, then later added to the debris head loss in the preliminary head loss calculation.

The Alion strainer design uses Top Hats to increase the available surface area over which to distribute any debris. The very large surface area results in extremely low head loss across the surface. However, there are internal losses associated with the strainer, the debris bypass eliminator, and the manifold. Because the strainer is comprised of many Top Hat modules connected to a manifold, and the design does not include any flow control design to ensure uniform approach flow, the flow into the clean strainer will be greater near the pump suction. In addition, in this application, the debris bypass eliminator causes head loss across each Top Hat. The head loss differences between sections of the manifold are relatively low because the manifold volume is relatively open resulting in relatively low flow velocities. The differences in head loss across various strainer modules will result in higher flow through some modules. The higher flow will result in more debris reaching these modules first. As debris entrains on the modules with higher flow, the differential pressure across those modules will increase and flow will then move to a cleaner module. Similarly, debris will tend to collect at the base of the Top Hat first because the draw of the pump is physically closer to the base than the distant end of the Top Hat. Debris entrainment on the strainer can be affected by these small suction pressure differences. However, any significant debris accumulation would redirect flow away from that area due to the increased differential pressure it causes. The calculation assumes flow distributed equally among all Top Hats, which will maximize the clean strainer head loss value.

The clean strainer head loss calculation included two cases for each strainer. The first case is associated with the strainer modules and the manifold in the clean condition. The second case of the calculation is completed for current design basis of 50% screen blockage. The staff review of these two parts of the clean strainer head loss calculation is discussed below.

The vendor calculated the total clean strainer head loss for the modules and the manifold using a standard single-phase hydraulic analysis for pipes and ducts [52]. However, the analysis was put into a spreadsheet and calculated because of the many flow streams modeled within the manifold. This method also allowed for solutions at multiple flow conditions.

The total clean strainer head loss was considered the manifold head loss calculated in the spreadsheet added to the strainer module or Top Hat head loss and the Top Hat exit loss. The

Top Hat exit loss is the head lost due to the velocity change when the flow exits the module and enters the manifold. Since the flow inside the strainer modules and manifold is in the turbulent regime, the calculated total head loss was practically independent of temperature. The licensee calculated the clean head losses at a conservatively low temperature of 60 °F.

The losses for various sized Top Hats were determined by testing. The Top Hat head loss was added to the other values calculated to determine the overall clean head loss.

The value for the clean strainer head loss on the VC strainer was 0.646 ft at 3700 gpm and the clean strainer head loss for the IR strainer was 0.340 ft at 5400 gpm. All clean strainer head loss values were calculated at 60 °F.

The 50% blockage calculation showed that, due to the very large strainer surface area and resulting low flow velocities, the head loss change was negligible between 50% blocked and clean strainer values. This shows that the strainer meets the current licensing basis of 50% blocked.

Staff Evaluation

The clean strainer calculations were based on standard hydraulic relationships and module loss values determined during testing. Therefore, the basis for the hydraulic loss calculation is acceptable to the staff.

3.6.5 Vortex Evaluation

The licensee and its strainer vendor investigated the possibility of vortex formation as part of the strainer array testing program. Alion observed pre-vortex and full air core vortex formation during the IP strainer-testing program. The testing was conducted with about 6 inches of water covering the strainer. For IP3, the minimum strainer submergence is about 12 inches for a large-break-LOCA and 6 inches for a small-break-LOCA at the onset of recirculation. After injection from the RWST is complete, the submergence is about 24 inches for a large-break-LOCA and greater than 18 inches for a small-break LOCA. The test procedure defined all vortex type formations as acceptable as long as air would not be pulled into the strainer.

During the full load test, after most of the debris had been added to the test flume, head loss was about 14 ft, and pre-vortex formations were noted. After the final debris addition was completed, head loss increased to greater than 22 ft. With this large head loss present, random full air-core vortex formations were noted to occur. These formations drew air into the pump suction line. In order to finish the test, the flow was reduced to about 75% of the original rate. After the flow was reduced, no additional vortex formations were recorded.

The staff discussed the vortex formation with the licensee and its strainer vendor during the audit. Because the final calculation was not available for review at the time of the audit, a formal vortex evaluation was not available. However, the licensee indicated that the probability of vortex formation was unlikely. Some of the reasons cited were that the vortex formations were only seen at extremely high head losses that would not be present in the plant. In addition, the testing was conducted at about one-half of the expected minimum large-break-LOCA strainer submergence in the plant.

Although IP2 was not the subject of this audit, the staff noted that due to the volume of the Unit 2 VC sump some VC strainer modules would be placed on the containment floor. The placement of strainers on the floor would result in a lower submergence and would therefore make vortex formation more likely. Because the submergence in Unit 3 is about one foot for a large-break LOCA and the Top Hat diameter is about one foot, Unit 2 is likely to have a very small submergence for the Unit 2 VC sump strainers.

3.6.6 Head Loss and Vortex Evaluation Conclusions

Head Loss Evaluation

The results of the plant-specific head loss tests scaled to 3700 gpm for the VC sump were extrapolated to show that the maximum head loss of 25.62 ft occurred for the worst-case expected LOCA debris loading at the test temperature. The testing was attempted at the scaled flow rate but because of excessive head loss the flow rate was reduced and the results extrapolated to the design condition. These results were then corrected to the design accident temperature, resulting in a head loss of 9.01 ft at 212 °F. This correction used a straight viscosity temperature correction. Because the initial extrapolation was to a higher velocity, the result is potentially non-conservative, as documented in Open Item 3.6-1.

For the thin bed test, the maximum head loss at test temperature was 3.29 ft. This result was corrected to 212 °F, with a resulting head loss of 2.24 ft. This correction used both viscosity and density for the head loss correction because the thin bed head loss exhibited both laminar and turbulent properties during the flow sweep conducted at the end of the test. The staff found the extrapolation of the thin bed test data acceptable.

IP3 plans to use the results of the 30-day chemical effects testing to determine long-term head losses associated with the debris bed. Therefore, no data extrapolation for time was conducted.

The scaling methodology was appropriate. In addition, the flow sweeps ensured that no boreholes or channeling were present in the debris bed. This indicates that temperature scaling of the test results can be accomplished conservatively.

The design inputs for sump pool level, sump pool temperature, and system flow rates were found to be adequate.

The debris surrogates were chosen and prepared appropriately with the exception of the fineness of the fibrous debris. The amounts of debris used for testing were appropriate.

The clean strainer head loss calculations were appropriately conducted.

The licensee performed plant-specific prototypical strainer head-loss testing. The system input evaluation, the testing matrix, the testing procedures and the results were reviewed during the audit. Several issues associated with strainer head loss were identified during the audit resulting in the three open items discussed above.

Although the licensee had not completed a final head loss evaluation, the staff has confidence that the licensee will complete an analysis that evaluates the required parameters. This confidence is based on the review of partially completed evaluations during the audit. The staff review of the licensee supplemental response to GL 2002-04 will verify that the strainers will support operation of the ECCS with adequate NPSH margin.

Vortex Evaluation

Alion looked for vortex formation during testing. Significant vortex formations were observed during the tests. There was no formal vortex evaluation presented to the staff during the audit. Therefore, the staff could not reach conclusions on this topic. However, the staff believes that, for IP3, vortex formation is unlikely based on the test observations. For IP2, a separate evaluation will be required because of the additional VC sump Top Hats mounted on the containment floor (higher in elevation than the IP3 strainers by about one foot). Therefore, it is recommended that the future prototypical strainer testing also include observations for signs of vortex formation.

3.7 Net Positive Suction Head

IP3 has two containment recirculation sumps, the IR sump, which is the preferred sump for long-term cooling, and the VC sump, which is the secondary back-up sump for long-term cooling. These sumps collect water discharged during a LOCA and provide the water for pumps used to cool the reactor core and containment atmosphere. In the IP3 design, two IR pumps draw suction from the IR sump. Two RHR pumps draw suction from the VC sump. The licensee performed NPSH margin calculations for these pumps which are credited with recirculating sump water to provide long-term cooling to the reactor core and containment atmosphere following a postulated accident.

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 [6], NRC Generic Letter 97-04 [10], the NRC Audit Plan [11], NEI 04-07 [4], and the NRC SE on NEI 04-07 [5].

3.7.1 Summary of NPSH Margin Calculation Results

Table 3.7-1 presents the results of the NPSH margin calculation for the limiting cases for the IR and RHR pumps operating in the recirculation-cooling mode following a large-break LOCA [55]. The NPSH results presented here do not include sump strainer and debris head losses. In Table 3.7-1, NPSH available is abbreviated “NPSHa,” and NPSH required is abbreviated “NPSHr.”

Table 3.7-1 IP3 NPSH Margin Results for the IR and RHR Pumps

Calculation Case	Pump	System Configuration	Time in Transient	Sump Suction Water Temperature (°F)	Pump Flow Rate (gpm)	NPSHa (ft)	NPSHr (ft)	NPSH Margin (ft)
I	Internal Recirculation Pumps	2 IR pumps, 2 RHR HX , 1 spray header, 4 cold legs	Full recirculation	242.8	2638/2625	9.84	6.5	3.34
II	Internal Recirculation Pumps	1 IR pump, 2 RHR HX, 4 cold legs	Start of Recirculation	242.8	2484	8.85	6.25	2.60
III	Internal Recirculation Pumps	1 IR pump, 1 RHR HX , 1 spray header, 4 cold legs	Full recirculation	242.8	4124	9.84	9.25	0.59
IV	Residual Heat Removal Pumps	1 RHR pump, 1 RHR HX, 1 spray header, 4 cold legs	Full recirculation	242.8	4099	24.66	16	8.66
V	Residual Heat Removal Pumps	1 RHR pump, 1 RHR HX, 4 cold legs	Start of recirculation	242.8	2886	27.14	10	17.14

The minimum NPSH margin for the IR pumps occurs for a case in which only one of the two pumps is operational and supplies flow to one RHR heat exchanger, one spray header and injection to four RCS cold legs. This case provides the maximum flow through a single IR pump and, consequently, the maximum NPSHr and minimum NPSH margin. In these calculations, the licensee used NPSHr data the pump vendor provided for IR pumps at IP2. Data subsequently provided by the vendor for the IR pumps at IP3 demonstrated smaller NPSHr values, which would provide larger NPSH margins. The licensee, however, did not present NPSH margin calculation results using these smaller NPSHr values. There is more discussion related to the NPSHr in Section 3.7.3 below.

The minimum NPSH margin for the RHR pumps occurs for the case of a single RHR pump supplying flow to two RHR heat exchangers and to all four RCS cold legs. This case provides the maximum flow through a single RHR pump, maximum hydraulic head loss and the minimum NPSH margin.

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

Regulatory Guide 1.82 [6] defines NPSH margin as the difference between the NPSHa and NPSHr; 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; and 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.

In general, the NPSHa may be calculated by taking the difference between the atmosphere pressure above the fluid 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).

To avoid relying upon containment accident pressure to demonstrate adequate performance of the IR and RHR pumps, the licensee conservatively assumed that the difference between the containment atmosphere pressure and the vapor pressure of the sump water is zero. Additionally, the IR pumps at IP3 are direct submersion pumps and contain no suction-side piping and, therefore no suction-side head losses. As a result, the remaining term in the NPSHa formulation is the static head of liquid above the suction of the IR pumps [55].

The NPSHa for the RHR pumps was computed as the height of water from the surface of the containment pool to the pump inlet level minus the suction-side hydraulic losses. As in the case for the IR pumps, no credit was taken for containment accident pressure [55].

The formulation for the NPSHa used by the licensee for the IR and RHR pumps is consistent with regulatory guidance. In particular, the lack of credit for containment accident pressure in demonstrating adequate performance for the IR and RHR pumps follows NRC guidance in Regulatory Guide 1.82 and is conservative.

3.7.3 Parameters Influencing NPSH Margin

The major contributing parameters to the NPSHa calculations are discussed below.

Emergency Core Cooling System Configuration

During the injection phase of a LOCA, the ECCS system discharges water from four passive accumulators whenever the RCS pressure is below the accumulator discharge pressure. For large-break LOCAs the RCS pressure falls rapidly, and the entire inventory of accumulator water would be discharged. The three high-head safety injection pumps and the two RHR pumps would draw suction from the RWST and would provide water to the reactor core with resulting spillage out of the break and onto the containment floor. In addition, two containment spray pumps supply cooling water to the containment spray headers, taking suction from the RWST [53].

The switchover from the injection phase to the recirculation phase of the accident is initiated after the RWST low-level alarm setpoint is reached [53]. Redundant recirculation sump level indicators allow plant operators to verify that the water level in containment is sufficient to support operation of the IR pumps [53]. During the transition to recirculation, the IR pumps are started to recirculate water collected by the IR sump to cool the reactor core, and flow from the RWST to the reactor core via the safety injection and RHR pumps is terminated. One containment spray pump continues to draw suction from the RWST to provide flow to the containment spray headers until the RWST level reaches the low-low setpoint, at which time the IR pumps would provide all flow to the spray headers. Thus, at the start of recirculation, the IR pumps do not provide flow to the containment spray headers, whereas subsequently (e.g., once the RWST reaches its low-low level setpoint), operators would open valves on the spray recirculation lines to allow the IR pumps to provide flow to the spray headers. These two cases are considered in Table 3.7-1.

At the start of recirculation, it is expected that the IR sump would be in operation with two IR pumps in operation. The VC sump would be in stand-by mode, and would only be used if adequate core and containment cooling could not be provided by the IR system. The limiting NPSH case for VC sump operation shown in Table 3.7-1 occurs for the system configuration that maximizes the flow rate through a single RHR pump.

Pump Flow Rates

The pump flow rates that are used by IP3 to estimate the suction head losses and the NPSHr for the IR and RHR pumps were computed using hydraulic models of the flow networks and the manufacturer's specified pump curves. For the IR pumps, the manufacturer's pump curve was adjusted to account for a higher operating motor speed to provide maximum flow rates for the NPSH calculations.

The Fathom single-phase incompressible hydraulics code [56] was used to model the flow on the discharge side of the IR and RHR pumps. This code was used together with conservative pump characteristics to obtain the flow rates shown in Table 3.7-1. While the Fathom code was not reviewed as part of this audit, the methodology for computing the flow rates is standard engineering practice and is therefore acceptable. The flow rates are considered conservative since they are computed for system configurations that provide maximum single-pump flow rates using conservative pump characteristics.

During the audit, it was found that a plant procedural change had raised the minimum measured flow requirement to each loop during the recirculation phase of a LOCA. The staff designated Open Item 4.2-1 (on page 81) for the licensee to determine whether the procedural change would affect the flow rates that have been computed for the NPSH calculations, presented in Table 3.7-1.

Containment Sump Pool Water Level

The water volume released to the containment is computed from the time of the LOCA initiation through the recirculation phase of the event. The available water volume includes contributions from the accumulators, the RWST, the reactor vessel and the spray additive tank.

The net volume of water available to form the containment pool is computed from the volume of liquid released to containment, reduced by the total holdup volume attributable to a number of physical mechanisms. These reductions include condensation films on surfaces within containment, water added to spray system piping, droplets suspended in the containment atmosphere, water absorbed in insulation, RCS water volume shrinkage due to the exchange of initially hot water with cooler water at the sump temperature, and water trapped in the refueling canal and reactor cavity [54]. The IP3 model contains a correlation for the sump pool water level as a function of the volume of water in the containment pool [57]. This correlation was constructed using a model of the IP3 containment geometry that accounts for the presence of pits, trenches, the reactor cavity, walls, etc. The net water available is used with the correlation to predict the sump pool water level. The water level is computed for a number of cases for conditions that include those relevant to the cases shown in Table 3.7-1.

The IP3 water level calculation appears complete in terms of inclusion of sources of water and also in terms of inclusion of the relevant water holdup mechanisms. The containment pool water volume versus sump water level calculation is based on a detailed model of the containment geometry. The model used to compute the water level appears reasonable and contains conservative elements. Therefore, the staff finds this model acceptable.

Sump Water Temperature and Containment Vapor Temperature

The NPSH calculations are carried out for a sump water temperature of 242.8 °F, the peak sump water temperature following switchover to recirculation [58]. This is acceptable because the vapor pressure of water is high and in any case, no credit is taken for the difference between the containment pressure and sump water vapor pressure. For computing the sump water level, a sump water temperature of 173 °F is used, which is the temperature 24 hours following the LOCA. This gives a higher water density than the peak sump water temperature following switchover and a lower static water level for the NPSH calculation, which is conservative and acceptable.

The containment vapor temperature is taken as 254 °F, the computed [58] peak vapor temperature following the switchover to recirculation. This maximizes the holdup of vapor in the containment atmosphere, reduces the mass of water in the sump pool and decreases the static water level. This is conservative for the purpose of NPSH margin calculations and is therefore acceptable.

Suction Flow Path Hydraulic Head Loss

The IR pumps are of a submerged design and have no suction-side piping. As a result there are no hydraulic losses. For these pumps the only contribution to the calculated NPSHa is the static head of liquid.

The suction flow hydraulic head loss contributions to the NPSHa were calculated for the RHR pumps. The suction-side hydraulic head losses were calculated using the Fathom hydraulic network analysis code [56]. The staff considers this head loss calculation to be acceptable because it makes use of an industry-standard approach.

NPSH Required

The NPSHr values shown in Table 3.7-1 for the RHR and IR pumps are taken from the manufacturer's pump specifications [55]. The NPSHr values used in the calculations for the IR pumps were based on test results for the IR pumps at IP 2.

The licensee's NPSH calculation assumed that the IP3 IR pumps will be replaced with "…the same replacement pumps as in Indian Point Unit 2 …" [55]. As a result, it may be expected that NPSHr tests on the IP3 pumps would provide the same NPSHr data as the IP2 pumps.

However, the NPSHr curve [59] provided by the pump vendor for the new IP3 pumps demonstrated smaller NPSHr values for all IR pump flow rates in the range of interest [55]. At 4000 gpm, the certified NPSHr for the IR pumps at IP3 is approximately 3 ft of water smaller than the corresponding certified value for the IP2 pumps.

Based on this discrepancy, the audit team questioned the applicability of the NPSHr tests provided by the pump vendor for the IR pumps at IP3. The IP3 and IP2 IR pumps are nominally the same pumps, as discussed above. Yet, the certified NPSHr results provided by the pump vendor are significantly different. Both the IP3 and IP2 IR pumps are three-stage direct immersion pumps. The licensee informed the staff that the certified pump specifications provided by the vendor states that the NPSHr for the IP3 IR pumps was based on a single-impeller test. The staff designated as **Open Item 3.7-1** that the licensee demonstrate or justify the applicability of single-impeller NPSHr test results to the three-impeller (three-stage) IR pumps at IP3.

The licensee assigned what it considered an initial bounding head loss value due to the new sump strainers for the IR pumps of 2.5 ft of water and for the Containment sump of 2.0 ft of water [55]. The licensee concluded that, based on the Unit 3 replacement pump NPSHr test results, the IP3 replacement IR pumps “are acceptable for use by providing acceptable low head safety injection system recirculation and NPSH performance…” [55]. This licensee conclusion cannot be evaluated by the audit team until the open items identified in this audit report have been resolved and a final strainer head loss value has been determined. When the final strainer head loss value is determined, the staff expects that the licensee will revise the existing NPSH calculation to incorporate this final value in the normal course of updating calculations that interface with the head loss calculation. Therefore, an additional open item is not specified for the licensee to update the NPSH calculation, since this action is implicitly addressed through the staff’s open items on establishing a final strainer head loss.

Regulatory Guide 1.82 [6], Section 1.3.1.5, provides guidance that the NPSHr used in NPSH margin calculations should not be reduced based on the operating temperature of the working fluid. Neglecting the effect of temperature on NPSHr is conservative, and the staff confirmed that this factor was appropriately neglected in the licensee's NPSH margin calculation.

<u>LOCA Break Size</u>

The NPSH results presented in Table 3.7-1 apply to the case of a large-break LOCA. The licensee did not present comparable complete calculation results for a small-break LOCA. For the small-break LOCA, with the primary system still at elevated pressure, the IR pumps would provide flow from the recirculation sump to the high-head safety injection pumps (piggyback mode) [53]. For the small-break LOCA, and for calculating the sump water level, the licensee conservatively assumed that plant operators would isolate the accumulators before they complete discharging. Thus, the assumption is conservatively made that accumulators do not discharge water to the containment. As a result, the containment water level would be lower by half a foot to a foot as compared to the large-break LOCA, depending on the specific scenario and reference time [54, p. 7]. However, under small-break LOCA conditions the flow rate through the IR pumps would be limited by the maximum flow rate of the safety injection pumps, which is 675 gpm per pump, plus a small flow rate through the IR pumps’ minimum flow lines (e.g., 160 gpm per pump) [53, 6]. The NPSHr for the IR pumps at such flow rates would be roughly 6 ft of water, based on the pump vendor’s data [55]. This reduced NPSHr would offset somewhat the lower static head of water available for the limiting small-break LOCA and result in an NPSH margin of roughly the same magnitude as large-break LOCA Cases I and II in Table 3.7-1, above. Thus, large-break LOCA Case III would continue to be the limiting condition for the IR pumps. Similar reasoning would apply for the less-limiting case of a small-break LOCA with the RHR pumps providing flow to the safety injection pumps in piggyback mode. Based upon the pump vendor's data [55], the staff expects that the benefit from the reduced NPSHr for the RHR pumps under small-break LOCA conditions would be more pronounced than for the IR pump case. Therefore, the staff concludes that large-break LOCA conditions can be considered as the limiting case with respect to the NPSH margin analysis.

3.7.4 Net Positive Suction Head Summary

The methodology used by the licensee for the NPSH margin calculation followed guidance provided in NEI 04-07 [4] and the NRC SE [5]. The defining equations used by the licensee in the NPSH margin calculation are correct. The minimum water level in containment was computed using a model that appears complete, and appears to include all relevant water sources and holdup mechanisms. The flow rates used in the calculation that produces the minimum NPSH margin are conservatively based on a system configuration which maximizes the flow through a single IR pump, and standard hydraulic methods were used to compute the flow rates.

The suction head losses for the RHR pumps were computed using standard engineering hydraulics methodology. The NPSHr was taken from the manufacturer's pump curves at the maximum flow rate, and the effect of temperature on NPSHr was not credited, as per NRC guidance [6].

The audit team designated one open item concerning the applicability of the NPSHr test results provided by the pump vendor to the IR pumps at IP3 [59]. As discussed above, the applicability of single-impeller NPSHr test results to the three-stage IP3 IR pumps should be addressed by the licensee.

3.8 Coatings Evaluation

3.8.1 Coatings Zone of Influence

The licensee applied a coating destruction ZOI with an equivalent radius of four break diameters (D) for epoxy coatings and 4.28D for un-topcoated inorganic zinc. This contrasts with the NRC SE [5] recommended ZOI of 10D. The licensee referenced jet impingement testing conducted by Westinghouse as the basis for the ZOIs it used. The test data referenced by the licensee are documented in the Westinghouse Report WCAP-16568-P, "Jet Impingement Testing to Determine the ZOI for Design Basis Accident Qualified/Acceptable Coatings [22]."

As stated in the NRC SE, for protective coatings, the staff position is that the licensee 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 10D. The NRC staff has completed its review of WCAP-16568-P and has concluded that licensees may use this report as the basis for using a reduced ZOI of 4D or greater for epoxy coatings and a ZOI of 5D or greater for un-topcoated inorganic zinc coatings.

However, licensees should provide a technical basis for the applicability of the testing to their plant-specific coatings. For example, if the licensee has an epoxy coating that was not actually included in the test series, it should provide a justification that shows why its epoxy would perform in the same manner as the tested epoxy. The staff position is documented in the draft review guidance issued in September 2007 [60] and in the revised guidance issued in March 2008 [92]. The licensee provided an evaluation [61] of the similarity of coatings used in the IP3 containment to the coatings tested in the Westinghouse report to justify the applicability of the test report. The staff has no issues with the licensee's evaluation that the IP3 coatings would perform in the same manner as the tested coatings. However, the staff does not accept the licensee's conclusion that a ZOI of 4.28D is acceptable for un-topcoated zinc. The licensee's basis for this number is contained in the same Westinghouse report mentioned above [61] The staff found this basis inadequate because it conflicts with the staff review guidance and with the recommendation in the Westinghouse topical report WCAP-16568-P [22]. The WCAP recommends a ZOI of 5.0 for inorganic zinc. The staff has accepted that value via review guidance. The value of 5.0 was recommended by Westinghouse to account for uncertainties in the testing including new coatings in the tests versus aged coatings in the plants. Therefore, the use of a coatings ZOI of 4.28D instead 5.0D for un-topcoated inorganic zinc is designated **Open Item 3.8-1**. Initial feedback from the licensee's engineering staff during the audit is that this open item will have only a minor impact on the quantity of zinc coating debris generated during a design basis accident.

3.8.2 Coatings Debris Characteristics

The carbon steel surfaces in containment at IP3 were specified to be coated with Carboline CarboZinc 11™ primer with a Carboline Phenoline 305™ epoxy topcoat, or approved Keeler & Long alternative. The total dry film thickness for this system was specified to be less than 9 mils dry film thickness. The concrete surfaces were specified to be coated with a Keeler & Long and/or Carboline epoxy system up to 72 mils dry film thickness depending on location and system chosen [62].

The NRC staff's SE addresses two distinct scenarios for formation of a fiber bed on the sump screen 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 screen. 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 screen openings should be used.

IP3 is considered by the staff to be a high-fiber plant due to the quantity of fibrous piping insulation. The licensee treated all coating debris, both that within ZOI, and the degraded, and unqualified coatings outside the ZOI, as fine particulate of 10-micron size that will readily transport to the sump with the exception of the degraded/unqualified epoxy coating outside the ZOI. Degraded epoxy coating outside the ZOI was assumed to fail as small, 1/32 inch long chips, 6 mil thick. The 6-mil thickness is equal to the smallest specified dry film thickness of the top coat. The Keeler & Long and Alion test reports [66, 67] prepared for Comanche Peak were used to justify the assumption that the degraded epoxy will fail as chips. The staff reviewed the test reports and the licensee's evaluation [63] of the applicability of these reports and determined the IP3 assumption was acceptable and adequately conservative. Taking the entire quantity of failed degraded epoxy as 1/32 inch chips is conservative in that approximately half of the debris in the autoclave test remained larger than ¼ inch. The smaller chips will transport more readily than larger chips and therefore the assumption is conservative.

The licensee had also documented an evaluation of the applicability of an EPRI test report [65] documenting design basis accident testing of common unqualified original equipment manufacturer coatings used in the nuclear industry. This test report analyzed the failure characteristics of original equipment manufacturer coating samples. The staff agrees that the test report is applicable to IP3. However, the staff does not agree with one of the conclusions made by the licensee in regards to how to use the data. The licensee concluded that only 80% of the unqualified alkyd coatings outside the ZOI would fail in a design basis accident [63]. This conclusion was based on its interpretation of the EPRI report in which they considered two data points of 95% and 98% failure of alkyd coatings as outliers and discarded them. The staff found this justification inadequate. The NRC staff's position, documented in the coating review guidance [60], is that due to the high degree of scatter of the test data, 100% of the original equipment manufacturer alkyd coatings should be assumed to fail. The need for the licensee to justify its assumed alkyd failure rate is designated **Open Item 3.8-2**. Initial feedback during the audit from the licensee's engineering staff was that this issue is insignificant because the reduction in alkyd failure rate was not credited in the debris generation calculation.

The quantity of coating debris and methodology for determining it were reviewed by the staff. The quantity of coating debris calculated for IP3 is acceptable, with the exception of untopcoated zinc ZOI (Open Item 3.8-1 above). As a conservative measure, the licensee treated the coatings inside the sump as degraded because they are no longer accessible for routine inspections. The staff finds this approach to be conservative and acceptable for the debris generation calculation.

The staff reviewed the containment coatings condition assessment practice to provide a level of confidence that the licensee's assumptions and input into the coating debris analysis are valid and that there is an ongoing program in place to maintain the condition assessment. The licensee did not have a visual condition assessment procedure at the time of the audit. Currently, the licensee performs periodic containment coatings assessments during the containment examinations required by American Society of Mechanical Engineers, Chapter XI Section IWE. The staff reviewed the IWE report for the last outage (3R14 in March 2007), and found it to be acceptable because it was thorough and well documented. The results were comparable to the results reported from a March 2005 walkdown [49]. The staff noted that there is an open Preventative Maintenance Change Request to create a preventive maintenance task for a containment coating inspection on a refueling outage frequency. The requested due date for the request was December 31, 2007. There is also an open Corrective Action (CR-IP3-2007-3352) to revise the Structural Monitoring Maintenance Rule corporate procedure, ENN-DC-150. The purpose of the corporate procedure revision is to document that the coatings condition assessment program is included in structural monitoring. The due date for the corrective action was February 27, 2008. The staff also noted that the licensee's Generic Letter 2004-02 response, Item 2 (f) contains a commitment to have a coatings program in place by December 31, 2007. The staff did not consider implementation of the commitment, incomplete at the time of the site audit, an open item because it the licensee had a controlled process in place to implement the program by a specified date.

4 DESIGN AND ADMINISTRATIVE CONTROLS

4.1 Debris Source Term

Section 5.1 of NEI 04-07 [4] and the NRC staff's accompanying SE [5] 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 a 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 screen 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 staff reviewed the IP3 procedure for foreign material exclusion [68], the procedure for containment post-outage cleanliness verification [69], and the procedures for design change control [70, 71, and 72]. These plant procedures, taken together, provide administrative controls to help ensure that the LOCA debris source terms affecting the ECCS recirculation sump's performance remain bounded by the existing analyses. These procedures, described briefly below, are used to verify that the containment building is ready for heat-up and power operations and that the ECCS sumps are effectively free of debris. These procedures satisfy technical specification surveillance requirements and commitments for containment and ECCS sump inspection.

The licensee has implemented a containment building closeout process [69] to minimize the amount of loose debris (rags, trash, plastic, clothing, etc.) present in containment that could be transported to the ECCS sumps and cause restriction of flow to the pumps during a LOCA.

The licensee has implemented a program [70, 71, and 72] to control design changes to ensure that design inputs to the sump analyses are addressed in the design change documents.

The licensee has implemented a foreign material exclusion program [68] to prevent the inadvertent introduction of foreign materials into plant systems and components. If the interior of a closed system or component is accessed, foreign material exclusion controls are implemented to track items taken into and out of foreign material exclusion controlled areas. This procedure is also implemented to verify operability of the ECCS sump and strainer prior to returning to operation after an outage.

The staff determined that the licensee's housekeeping, foreign material exclusion programs and design control programs appear to adequately control their respective processes for maintenance of the debris source term, as needed, to help maintain adequate ECCS strainer functionality.

4.1.2 Change-Out of Insulation

IP3 has not replaced any insulation materials as part of the resolution of GSI-191.

4.1.3 Modification of Existing Insulation

IP3 has not modified any insulation materials as part of the resolution of GSI-191.

4.1.4 Modification of Other Equipment or Systems

Staff reviewed the modification package for the IP3 ECCS sump strainer upgrade [33] that address modifications to ECCS sump strainers. The modification includes the installation of flow diverters that facilitate debris settling by channeling flow from the containment pool to the sump strainers through the in-core instrument tunnel.

The licensee has no plans for other debris source-term related modifications.

4.1.5 Modification or Improvement of Coatings Program

The coatings program review is discussed in Section 3.8.2 of this audit report.

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.

Entergy completed modifications to the Unit 3 IR sump screen and VC sump screens [33]. The passive design included increasing the surface areas of the sump screens to 4300 square feet and 800 square feet, respectively. Additionally, Entergy installed flow channeling devices and debris catchers. This portion of the design created areas where debris would settle thereby limiting the amount of material that could potential reach the sump screen.

Staff Evaluation:

Due to IP Unit 3's design being a complicated resolution, Entergy submitted a revised response to GL 2004-02 [32]. The response discussed the need for technical specification changes, license amendments and deviations for various aspects of plant response to a potential LOCA. At the conclusion of the audit these proposed changes had not all been either submitted and/or approved by the NRC. These changes were to include changes to Technical Specification RWST low level alarms, replacement of buffer material specified in the Technical Specifications with alternate material, relaxation of single failure criteria during recirculation, alternate break methodology for LOCA analysis, and licensing requirements related to dual sump capability. The licensee intended to submit the appropriate licensing actions as needed based on the results of sump strainer testing. Following the audit the licensee withdrew the amendment request for a change to the RWST low level alarm setpoint range [103], decided against pursuing the alternate break methodology, and requested changes to the single failure criteria during recirculation (See summary of February 28, 2008 meeting [104]). The staff approved the IP2 buffer change request on February 7, 2008 [90] and the licensee submitted a request to change the technical specification for buffering for IP3 on February 28, 2008 [91].

During review of the screen modifications, it was determined that a procedure revision had raised the minimum measured flow requirement to each loop during the recirculation phase of a LOCA. The staff identified a need to determine if, as a result of this change, the maximum flow assumed in the sump modification calculations is conservative with regard to NPSH requirements and assumed containment flow conditions. The licensee captured this issue in condition report CR-IP3-2007-04492 and the staff identified it as **Open Item 4.2-1**.

Based on the review described in Section 3.0 of this audit report, the staff was not able to conclude the new sump design will be able to accommodate the maximum volume of debris because several of the analyses and experiments had not been completed. Additionally, Entergy is relying on the approval of licensing actions as part of their design assumptions, and these actions have not been approved. However, the specific design features of the strainer and flow diverters appear to adequately limit head loss created by the postulated amounts of insulation, coatings, foreign materials, and latent debris. When Entergy addresses the open items identified in this report (Appendix I Open Items), the staff will be able to reach a conclusion as to the adequacy of the strainer modification.

5 ADDITIONAL DESIGN CONSIDERATIONS

5.1 Strainer Structural Analyses

The licensee performed dynamic and static structural analyses to qualify the new containment sump strainer assemblies and various flow barriers/gates associated with the modification package. The revised internal recirculation portion of the ECCS is comprised of the IR sump strainer structure, the VC sump strainer structure, the "Top-Hat" strainers, and several aforementioned flow barriers and gates.

Consistent with the guidance of NEI 04-07 [4] and the corresponding SE [5], the sump strainer assemblies and flow barriers were qualified for loading combinations associated with dead weight, seismic considerations (including hydrodynamic mass), differential pressure loading due to head loss across the strainers or gates, and temperature effects. The differential pressures to be utilized for the structural design of the various components were analytically determined by the licensee and documented in NEA-06-079 [78].

The American Institute of Steel Construction, Manual of Steel Construction 9th edition [73] was used as guidance for the qualification of the sump strainer structures, the “Top-Hat” strainers, and the flow barriers and gates. In instances where [73] did not contain specific guidance (e.g. material strength reduction due to increased temperature and stainless steel bolting qualification), the 1989 American Society of Mechanical Engineers Boiler and Pressure Vessel Code, Section III [24] was used.

Each of the structures was evaluated at a temperature of 300 °F, which is a conservative design value when compared to the calculated maximum temperature of 260.6 °F specified in the licensee’s containment integrity analysis [74].

The damping value employed for seismic analysis was 0.5% for a design basis earthquake as stated in Reference [75]. This value is conservative when compared to the damping values of Regulatory Guide 1.61 [79].

5.1.1 IR Sump Structural Evaluation

The frequency and modal shape analysis of the IR sump structure was performed using GTSTRUDL analysis software. The licensee specified in the calculations that this software is acceptable for this purpose because it is commercially available and has been procured and maintained under Enercon Service’s Quality Assurance Program. The results of this analysis were then incorporated into a response spectrum analysis. GTSTRUDL was used to perform a stress check on the structural members of the frame assembly against the [73] allowable limits. Additionally, output from the GTSTRUDL analysis was input to various hand calculations to qualify plates, bolts, studs, and induced local stress values in the structural members. Conservatively, in almost all cases, the faulted load case stress values were compared to the normal allowable stress limits, which are lower than those required for faulted loads. When the faulted load case results could not be qualified to the more conservative normal allowable values, they were shown to be in compliance with the appropriate faulted allowable stresses.

Staff Evaluation

The staff performed a review of the calculation inputs and methodology. This review concluded the licensee adhered to the concepts embodied in the Standard Review Plan Section 3.8.4 [77]. Using the criteria and the allowable stress limits from [73] and [24] as applicable, the structural components of the strainer module were shown to be within the acceptable range. Because the methodology adheres to that which is approved in the Standard Review Plan and because the induced stress results are shown to be within the allowable stress limits of accepted industry standards [73] and [24], the staff concluded that the concepts and procedures used in this analysis are acceptable.

5.1.2 VC Sump Structural Evaluation

Similar to the IR sump structural evaluation, the frequency and modal shape analysis of the VC sump structure also was performed using GTSTRUDL analysis software. The results of this analysis were then incorporated into a response spectrum analysis. GTSTRUDL was used to perform a stress check on the structural members of the frame assembly against the [73] allowable limits. Additionally, output from the GTSTRUDL analysis was input to various hand calculations to qualify plates, bolts, studs, and induced local stress values in the structural members. Conservatively, in almost all cases, the faulted load case stress values were compared to the normal allowable stress limits. When the faulted load case results could not be qualified to the more conservative normal allowable values, they were shown to be in compliance with the appropriate faulted allowable stresses.

Staff Evaluation

The staff performed a review of the calculation inputs and methodology. This review concluded the licensee adhered to the concepts embodied in [77], section 3.8.4. Using the criteria and the allowable stress limits from [73] and [24] as applicable, the structural components of the strainer module were shown to be within the acceptable range. Because the methodology adheres to that which is approved in the Standard Review Plan and because the induced stress results are shown to be within the allowable stress limits of accepted industry standards [73] and [24], the staff concluded that the analysis is acceptable.

5.1.3 Sump Strainer Top-Hat Evaluation

The Top-Hat strainers were determined to be seismically rigid members with a natural frequency much greater than 33 Hz. The peak safe shutdown earthquake acceleration from the applicable spectral curves was applied with a multi-mode factor of 1.5. Hand calculations were employed to determine the stresses induced in the Top-Hat strainer modules.

The perforated cylinders were considered as solid cylinders for analytical purposes. In order to account for the loss of strength due to perforation, the material properties of the Top-Hat strainer modules were adjusted in accordance with [76].

Staff Evaluation

Using the criteria and the allowable stress limits from [73] and [24] as applicable, the structural components of the Top-Hat strainer module were shown to be within the acceptable range. Because the licensee appropriately applied accepted industry standards, the staff concluded that the concepts and procedures used in this analysis are acceptable.

5.1.4 Evaluations for North, South, and Miscellaneous Flow Barriers; and Containment Gates

Four separate calculations were performed to qualify several flow barriers and containment gates. The method of qualification consisted of a GTSTRUDL analysis model of each of the structures (including a stress check of the structural members against the [73] allowable limits) supplemented by hand calculations for anchor bolts, baseplates, and connections.

Staff Evaluation

During the review of the calculations for the flow barriers and gates, the staff identified an incorrect, higher allowable stress value utilized in the qualification of the A193 Grade B8 CL 2 bolting material. The error was contained in only one calculation (CON035-CALC-04) and was rectified by the licensee. After employing the correct allowable stress, the component was still found to be within the appropriate stress limits. The staff found the resolution of this issue acceptable.

Additionally, the staff identified a 9% overstress on a member that was being evaluated for the localized effects of torsion (calculation CON035-CALC-05). In the evaluation, however, the licensee had conservatively used a “normal” allowable stress in conjunction with a “faulted” load. Thus, adequate margin existed within the “faulted” allowable stress increase to absorb the overstress and properly qualify the member. The staff found the resolution of this issue acceptable.

With the exceptions and resolutions noted above, the licensee properly applied the criteria and the allowable stress limits from [73] and [24] as applicable to the structural components of the flow barriers and gates. All results were shown to be within the acceptable range. For these reasons, the staff concluded that the concepts and procedures used in this analysis are acceptable.

5.1.5 High-Energy Line Break Evaluation

To address the possible effects of a high-energy line break, Nuclear Change Response ER-06-3-005 [33] states, “The IR Sump is located inside the crane wall…and is surrounded by the concrete barrier…Therefore, the high-energy lines outside of this barrier will not impact the IR Sump.” It continues by stating, “There are high-energy lines inside this barrier, however none of these line breaks require post LOCA recirculation. Therefore, (the) IR Sump does not need to be evaluated for jet impingement or pipe whipping force.” The acceptance of “leak before break” analysis methodology eliminated the main RCS loops as potential sources of damage to the VC sump. Applicable portions of [77] were employed to further eliminate potential damage to the VC sump from piping attached to the main RCS loops. Finally, the pressurizer surge line and main steam/feedwater piping were also eliminated because of the concrete walls which physically separate the piping from the new VC sump components.

Staff Evaluation

While on site, the staff performed a review of pertinent isometric and physical drawings to verify that no jet impingement or pipe whipping force needed to be evaluated in the structural analysis calculations. Based on this review, the staff concluded that the licensee had appropriately addressed possible high-energy line breaks in the vicinity of the new strainer modules and sumps.

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 plant drawings, discussed the issue with licensee and vendor staff, and reviewed other references provided by the licensee. The staff also reviewed several containment layout drawings to verify the assumptions contained in these documents and verify the available flow paths to the sump. The staff review evaluated the licensee's treatment of potential blockage at containment drainage flow choke points and other upstream effects. The licensee provided a baseline document containing a walkdown to specifically identify choke points or obstructions. The walkdown [48] did not identify any unanalyzed holdup volumes. The only significant holdup volume identified was the refueling canal, should the drain become blocked. IP3 has evaluated the amount of water that will be retained in the refueling canal and has also installed a strainer over the refueling canal drain to minimize the potential for it becoming blocked with debris. The walkdown documented that the flowpaths from the spray headers and the postulated break locations to the sump would allow the spray and break fluid to reach the sump.

The minimum water level calculation [54] reviewed by the staff during the on-site portion of the audit makes the following allowances for holdup in the analysis: water holdup in the reactor pit/instrument tunnel and other smaller volumes, water holdup on condensed films and heat structures, water holdup and films on platforms and structures, and water required to fill spray piping. These holdups appear to be properly accounted for in the calculation. In addition, the holdup of water required to fill the initially empty engineered safety features piping was appropriately accounted for and increased by 5% to allow for additional volume that could be held up in components with larger cross sections than the piping diameter (e.g. valves). A 500 ft^3 holdup for miscellaneous, potentially unaccounted for volumes was added to the total holdup volume. For small-break LOCAs, it was conservatively assumed that no accumulator water is added to the volume on the containment floor. For some large-break LOCA events, for some break locations, the minimum water level calculation assumes that the unaffected steam generators and pressurizer do not immediately refill with water. This allows the water from these components to provide inventory to the sump. As the RCS cools, these components refill and sump inventory is reduced. The staff reviewed the basis for this assumption and the calculation results and found them to be acceptable.

The licensee installed a strainer over the refueling canal drain to ensure that the drain could not become blocked by debris created during a LOCA. The staff reviewed the design of the strainer and found it to be robust. The minimum water level calculation accounts for a holdup in the refueling canal due to the head loss in the drain line. The staff finds the holdups accounted for in the minimum water level calculation to be adequate based on the discussion above.

The minimum water level calculation also made appropriate conservative assumptions regarding initial conditions including: minimizing RWST, pressurizer, and accumulator volumes; and maximizing RWST, accumulator, containment, and RCS temperatures. These assumptions lead to a more conservative (lower) calculated containment sump level.

The Containment Transport Paths Walkdown [48] provides a description of the containment from the perspective of how water would flow from a postulated break and the spray system to the sump. The Walkdown Report provides a general description of the flooring and obstructions to flow that exist in the containment. The spray headers discharge water between 118 and 134 feet above the operating deck [53]. The operating deck is at the 95 ft elevation. The water will pass through various plant elevations before ultimately draining onto the containment floor on elevation 46 ft. The sumps at IP3 are pit type sumps located below the floor level. A review of the documentation provided to the staff shows that at and above the operating floor elevation the flooring is primarily concrete, with some areas of grating and solid steel. Spray falling on the operating floor flows down to the next elevation (68 ft) through the areas around the steam generators, the stairwells, and the grated areas on the operating floor. The concrete portions of the floor have approximately 3-inch lips that direct any water to columns or grated areas which allows the water to fall to the 46 ft elevation. In addition, there is a gap between the containment wall and the concrete floor areas that will allow water to flow to the next lower level.

At the operating floor elevation, the refueling canal is also open to the spray falling from above. As described above, the minimum water level calculation [54] assumed that the refueling canal drains could not become blocked and the spray water would be available to the sump. By design, water can flow from the refueling canal to the containment sump through a 4-inch drain located in the lower portion of the refueling canal. A blind flange is installed in the refueling cavity drain line during refueling operations. This flange is removed from the drain line as part of the administrative controls in containment entry and egress procedure OAP-007 [69]. The installation of the strainer over the refueling canal drain line is a good practice to help ensure that the maximum possible water is available to the recirculation sumps.

The reactor pit/instrument tunnel is a significant volume below the sump suction that can entrap debris and prevent it from reaching the sump, being a dead-ended volume. This is called an inactive volume for most PWRs. However, IP3 uses the reactor pit and instrument tunnel as part of the transport path to the sump. Water is routed through the sump to allow debris to fall out and deposit under the reactor so that it will not reach the strainers. Spray water drains through the open annulus around the reactor vessel down into the reactor pit and the incore instrumentation tunnel. In addition, LOCA break flow can enter the reactor pit directly. The calculation [54] assumes that the reactor pit fills and all water is entrapped and not available to the recirculation sump until its level reaches the level where it overflows onto the floor.

The calculation for containment water level includes the volume of the reactor pit and instrument tunnel.

Drawings and walkdowns show that the RCS compartment between the 95 ft and 46 ft elevations has no major concrete floors. There are several grated platforms that would pose no choke points for the spray flow falling from above. There are large components in the RCS compartment. However, they will not result in any significant water hold up. Also in the RCS compartment are the recirculation sump room and the residual heat exchanger rooms. These rooms provide the components protection from pipe whip and jet impingement. The staff concluded that these rooms have adequate access ways to allow water flow to the floor area based on a review of containment drawings.

Based on the information reviewed as summarized above, the staff concluded that water drainage in the IP3 containment would not be susceptible to being trapped in unanalyzed hold up locations. The staff's review of upstream effects focused upon the potential holdups in the refueling canal and reactor pit because of the potential for these large volumes to retain substantial quantities of water. The licensee assumed that the reactor pit becomes filled, but remains part of the active pool. Based on the modification that installed a strainer over the refueling canal drain and the calculation performed to determine the holdup in the refueling canal due to head loss in the drain line, the staff finds the holdup postulated for that area to be acceptable. 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 Background

The Code of Federal Regulations, Title 10, Part 50, Section 50.46 requires, in part, that each boiling or pressurized light-water nuclear power reactor be provide with an ECCS that is designed so that its calculated cooling performance, following a postulated LOCA, limits peak cladding temperature and cladding oxidation (within specified parameters), maintains a coolable geometry, and provides long-term core cooling such that the calculated core temperature is maintained at an acceptably low value and decay heat is removed for the extended period of time required by the long-lived radioactivity remaining in the core.

At IP3, long-term core cooling is accomplished by pumping water (spilled reactor coolant and refueling water) from the in-containment recirculation or VC sumps through the RHR heat exchangers into the reactor vessel via the hot and cold leg piping. The pumped coolant spills out of the RCS via the pipe break, flows along the containment building floor and returns to the sumps after passing through the sump strainers via the reactor cavity or through debris barriers to be pumped back to the reactor. The low-pressure containment recirculation pumps and/or RHR pumps and the high-pressure safety injection pumps (piggybacking off the low-pressure pumps) circulate the coolant. This core-cooling mode, by which water is continuously circulated from the sump(s) to the RCS and back to the sump(s), may be required for an extended period (One year at IP3 per its licensing basis). During this long-term cooling period, debris that is washed into the containment pool may pass through the sump strainers and be introduced into the ECCS and the RCS.

Generic Letter 2004-02 requests that holders of operating licenses for pressurized-water reactors evaluate the ECCS and the containment spray system recirculation functions in light of information provided in the GL and take necessary actions, as required, to ensure system function. These evaluations are to include the potential for debris blockage at flow restrictions and wear of components within the ECCS recirculation flow path downstream of the sump strainer. Examples of flow restrictions that the licensee should evaluate are throttle valves, flow and restriction orifices, 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 and lead to inadequate long-term core cooling. Examples of components susceptible to wear include rotating equipment, restriction orifices and throttle valves.

5.3.2 Downstream Effects – In-Vessel

NRC staff's concern for debris blockage of the reactor core is primarily related to the plant recovery following a large-break LOCA, because that scenario can introduce the greatest amount of debris into the RCS. Therefore, the audit evaluation emphasizes long-term core cooling following large breaks in the primary coolant system piping.

Following a large-break LOCA at IP3, the low-pressure and high-pressure ECCS pumps are aligned to inject water 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. During the long-term cooling period, core flow (including a small amount of core bypass flow) would be equal to the total ECCS flow. If all ECCS pumps were to operate, ECCS flow into the reactor coolant system and into the core would be maximized. Therefore, this maximum flow condition provides the greatest potential for debris transport to the reactor core, potentially resulting in restriction of coolant flow.

With a large break in a cold leg, coolant injection into the reactor cold legs will result in a reduced rate of flow into the core, 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. The rate of ECCS water reaching the core will likely be limited to that needed to replenish the water that boils off. Therefore, much of the pumped water will spill out of 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, therefore, would lead to additional spillage from the break.

For a cold leg break, continued boiling in the core would 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, could potentially change the chemical and physical properties of the mixture. Also, heat transfer could be affected by direct plate out of debris on the fuel rods and by accumulation of material within the fuel element spacer grids.

Audit Observations:

The licensee had not completed its in-vessel downstream effects evaluations. The licensee continues to evaluate the post-LOCA chemical effects on long-term core cooling. The licensee stated that it is participating in the PWR Owners Group's generic program that is addressing in-vessel downstream effects of particulate, fibrous and chemical debris on long-term core cooling. The PWR Owners Group has developed Topical Report WCAP-16793-NP [19] to address this issue and, at the time of this audit, had submitted it to the NRC for review. The licensee stated that it would use the results and guidelines of the generic evaluations in WCAP-16793-NP to address in-vessel chemical effects at IP3. Due to the ongoing evaluation of in-vessel chemical effects, the evaluation was identified as **Open-Item 5.3-1**.

The licensee stated that it had completed the in-vessel downstream evaluations for the effects of sump strainer debris bypass. The licensee provided two calculations [85, 86], supporting its conclusion that blockage of flow paths within the pressure vessel by fiber and particulates is not a concern. Reference [85] demonstrates that 1 ft^3 of fiber bypassing the sump strainer could result in a uniform, ⅛ inch thick fiber bed being deposited across the bottom of the core. This fiber bed, in conjunction with particulate debris, could result in blockage of coolant flow through the core. The calculation also concludes that for the LOCA-generated debris mix calculated for IP3, a strainer efficiency of 99.58 percent would be required to limit the total bypassed fiber volume to 1 ft^3.

To reduce the volume of fiber bypass, the IP sump strainers incorporate “Debris Bypass Eliminators” in all strainer top-hat modules. Reference [86] states that bypass testing of the IP strainers, using the plant-specific approach velocity of 0.02 ft/sec demonstrated that fiber bypass is 5.2 lbm per 1000 ft^2 of strainer area, resulting in a total of 22.56 lbm of fiber bypass. Using the Nukon fiberglass insulation density of 2.4 lbm/ ft^3 the volume of bypassed fiber is calculated to be 9.4 ft^3. The fraction of the bypassed fibers longer than 1000 μm was determined to be less than 2 percent, with 80 percent of the fibers being less than 500 μm. Based on an evaluation of clearances within the fuel assemblies, the licensee’s analysis concluded that fibers shorter than 1000 μm would pass through the core and not form a fiber bed. Therefore, the licensee assumed that only 2 percent of the total bypassed fiber (0.188 ft^3) could accumulate at the core inlet; a quantity insufficient to form a 1/8 inch thick filtering thin-bed Therefore; with the “Debris Bypass Eliminators” installed, the licensee concluded that there will not be fiber or debris of a sufficient size or quantity in the vessel to block coolant flow through the core. The assumption that fibers shorter than 1000 μm would not accumulate at the core inlet has not been conclusively demonstrated. Further, industry sponsored strainer testing has shown that fiber beds significantly thinner than 1/8 inch have yielded measurable pressure losses. As such, the PWROG is currently preparing guidance to be included in WCAP-16793-NP to address core inlet pressure losses due to fiber, particulates and chemical precipitates that bypass the sump strainer. Until the revised WCAP is issued, the in-vessel downstream effects is considered an open issue and part of Open Item 5.3-1 above.

Note: Since the performance of this audit, the NRC has completed the review of WCAP-16793-NP, Rev. 0, and has issued a draft SE containing 13 conditions and limitations. As the current WCAP revision and SE do not address the effects of the combination of chemical precipitates, particulate and fibrous debris on core inlet blockage, a revised WCAP and associated SE may be forthcoming. Although NRC approval of a topical report is not required for a licensee to reference that report, the licensees should be aware of, and address, any relevant issues the staff may have with specific topics contained in the report.

5.3.3 Downstream Effects-Components (Excluding Vessel)

NEI 04-07 (Guidance Report) and the associated NRC SE provide licensees guidance on evaluating the flow paths downstream of the containment sump for blockage from coolant-entrained debris. These documents identify the following topics 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 should be performed 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 should be performed. 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) [17, 18].
- 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 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 should 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 out of slurry materials should 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.

To provide a consistent approach for plants to address the Guidance Report identified issues, the industry developed WCAP-16406-P [16, 12] to provide tools for licensees to use in performing their plant-specific evaluations.

Audit Observations:

IP3 elected to follow the guidance in WCAP-16406-P, “Evaluation of Downstream Sump Debris Effects in Support of GSI-191,” Revision 0 [16] to assess the performance of their ECCS and containment spray system downstream components. Subsequently, the Westinghouse Owners Group issued WCAP 16406-P “Evaluation of Downstream Sump Debris Effects in Support of GSI-191,” Revision 1 [12] to address NRC comments. The licensee was in the process of revising the ex-vessel component evaluations to address the guidance of the revised WCAP. The analyses were not completed to the point where they could be audited. The licensee provided the following calculations for staff review.

- CON033-RPT-003, “Downstream Effects Evaluation At Indian Point 3,” [87]

- “GS-1790, ECCS Debris Ingestion Evaluation - Ingersoll Rand 267APKD-3 Recirculation Pumps - Ingersoll Rand 8 X 20W RHR PUMPS - PACIFIC 2.5 JTCH-10 Safety Injection Pumps,” [80]
- IP-RPT-05-00406; “SPX Process Equipment / Valve Susceptibility To Debris Clogging” [81]

The above three calculations were performed to revision 0 of WCAP 16406-P. A preliminary draft copy of the in-process revision to calculation CON033-RPT-003 was also provided for on-site review only. The revised evaluation addressing wear of the recirculation sump pumps, RHR pumps and safety injection pumps was not made available for staff review. The need to complete the ongoing evaluation of ex-vessel downstream effects on piping components and ECCS pumps was identified as **Open-Item 5.3-2.**

In [87] (including the pending revision) and [81], the licensee evaluated the components in the ECCS piping downstream of the containment sumps to determine the potential for blockage and wear due to debris passing through the sump strainer(s). The evaluation addressed components in the circulation flow path(s) including throttle valves, flow orifices, spray nozzles, heat exchangers, instrument taps and isolation and control valves. However, the evaluations were not complete as the debris source terms and system flow rates had not been finalized.

The licensee evaluated the in-containment recirculation pumps, RHR pumps and safety injection pumps and concluded that the wear on the pumps is negligible and therefore, the licensee expects the pumps to survive the postulated LOCA scenario and remain fully functional [80]. The IP downstream debris mix is primarily credited for this outcome. However, it should be noted that the revised calculation might have a different outcome.

The staff based its evaluation of the licensee’s down-stream effects component evaluations on review of the recirculation flow path(s) shown on piping and instrument diagram drawings [82, 84]. Based on this review, the staff concludes that all the affected system components are being addressed.

The sump strainers installed at IP3 are designed to remove virtually all fibers and debris larger than 1000 microns (0.04 inches). Therefore, the licensee expects that the required ECCS/containment spray system components will survive their mission times.

Following SE Section 7.3, the staff reviewed the licensee-stated design and mission times and system lineups to support mission-critical systems. The Indian Point mission time for the evaluation of equipment supporting recirculation was defined, by the licensee, as one year in [80]. The primary focus was on the capability of equipment to withstand the post accident environmental conditions of temperature, pressure, humidity, radiation, submergence, etc. The specified mission time is conservatively longer than the mission time of 30 days, which the licensee is using for strainer and debris evaluations responsive to the concerns of GL 2004-02. Of note, the related 10 CFR 50.46(b)(5) criterion states; “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.”

5.4 Chemical Effects

The staff reviewed the licensee's chemical effects evaluation, comparing it with the guidance provided in Section 7.4 of the GSI-191 SE.

The IP3 insulation materials include Nukon, Temp-Mat™, Thermal-Wrap, mineral wool, and Calcium silicate. Sodium tetraborate is used to control the pH in the pool that would form on the containment floor following a LOCA.

On November 12 through 15, 2007, staff from the Divisions of Component Integrity and Safety Systems traveled to the VUEZ facility in Levice, Slovakia to observe chemical effects testing performed by Alion Science and Technology in support of GSI-191 resolution. Although the majority of the testing observed by the staff was conducted for Indian Point, the staff was also able to observe the conclusion of several tests for Three Mile Island Unit 1. Based on observation of the testing conducted by Alion Science and Technology at the VUEZ facility, as well as information shared via teleconferences, the staff provided feedback to Alion and the licensees using their services.

Overall, the staff considered the Alion/VUEZ testing effort to be highly valuable from the standpoint of providing insight into the nature of chemical reactions in a post-accident containment pool. However, modeling these complex reactions in a manner that is prototypical of a nuclear power plant is a very challenging task, and the staff identified a number of issues in the Alion/VUEZ test methodology and implementation that should be resolved. The issues associated with the integrated chemical effects testing at VUEZ are described in Appendix II of this report. They are also summarized in Appendix I Open Items, of this audit report. These issues had not been adequately addressed by Alion or IP3 at the time of the site audit. Testing issues associated with the VUEZ facility has been identified as **Open Item 5.4-1** for chemical testing issues (see details in open item "VUEZ Testing Chemical," page 97) and **Open Item 5.4-2** for non-chemical issues (see details in open item "VUEZ Testing Non-Chemical, " page 97).

In addition to the specific issues the staff has raised in regards to the VUEZ testing, chemical effects remain as general **Open Item 5.4-3** for the IP3 audit. Chemical effects test data were not available for staff review at the time of the audit. In addition, the licensee and its vendor have not settled on the final methodology that will be used to apply the chemical test data to the larger scale head loss test results. For this reason, the staff was unable to review any methodology for resolution of chemical effects.

5.5 Alternate Methodology

Under the current licensing basis for IP3, the licensee stated that a single passive failure could result in the loss of recirculation from the IR sump, which is the preferred source of water for providing long-term cooling to the reactor core and containment building [37]. If the IR sump is not available, the VC sump, which has a smaller strainer, can provide a secondary source of water for long-term cooling. The licensee stated that the VC sump recirculation pathway is not protected against all possible single active failures (e.g., the failure of a sump suction valve) [37]. This is acceptable under the current licensing basis, as the licensee only has to postulate a passive failure or an active failure during recirculation, not both, as long as the IR sump is qualified for the duration of the accident.

During the audit, the licensee stated that aspects of the alternate methodology described in Section 6 of NEI 04-07 [4] may be applied by IP3 to demonstrate the adequacy of the replacement sump strainers. The licensee was planning to make a final determination as to whether the alternate methodology would be used after considering the results of 30-day integrated chemical effects head loss testing that was ongoing at the time of the audit. The licensee stated that if testing demonstrated that both the IR and VC sumps were capable of withstanding the worst-case debris loading, use of the alternate break methodology would not be necessary. However, if the testing did not demonstrate that the VC or IR sump strainers could handle the full-plant debris load, use of the alternate methodology and plant licensing basis changes or both might be used to demonstrate the adequacy of the design of the replacement strainers.

At the time of the audit the licensee's sump performance calculations included analysis of the debris generation, transport, and head loss associated with alternate break sizes. However, due to uncertainties discussed above as to the necessity of using the alternate methodology, the licensee did not have documentation specifically addressing which aspects of the alternate methodology would be invoked or how staff expectations regarding the alternate methodology stated in the SE [5] on NEI 04-07 would be addressed.

In discussions during the audit, the staff provided guidance to the licensee on specific aspects of the alternate methodology. As stated in Section 6 of the SE on NEI 04-07, the staff clarified that approval of the alternate methodology does not preclude a licensee from being required to submit an exemption from regulations if an exemption is necessary for a licensee to implement aspects of the alternate methodology (e.g., if the criteria in 10 CFR 50.46 are not satisfied). The staff further emphasized that, while the alternate methodology would allow licensees to rely on non-safety-related or non-single-failure-proof equipment to mitigate LOCAs larger than the alternate break size specified in Section 6.2 of the SE, in accordance with the principles of risk-informed decision making in Regulatory Guide 1.174 [38], mitigating equipment and/or operator actions should be demonstrated to have adequate reliability. Based on the assumptions made in Section 6.5 of the SE (e.g., that a plant's core-damage frequency is less than 10^{-4}/year), a target reliability for equipment or operator actions sufficient to support a sump failure probability of less than 2×10^{-2}/demand was considered adequate, although the exact values were recognized in the SE to be plant-specific. The SE also states that, in accordance with Regulatory Guide 1.174, a monitoring program should be established which includes a means to adequately track and trend the performance of equipment (including supporting systems) that, when degraded, can affect the sump performance analysis.

During the audit, the staff and licensee also discussed the possibility of changes to the IP3 licensing basis to exclude non-credible passive failures from the plant-licensing basis if the non-credibility of these failures could be established. Alternately, the licensee stated that, based on inspections and analysis, it may be possible to demonstrate that certain passive failures would not be credible within a certain time following a LOCA (e.g., within 24 hours of the initiation of the LOCA). The licensee indicated that the latter approach would not require the VC sump to be operated in response to a passive failure of the IR sump until a majority of the post-LOCA debris in containment had accumulated on the IR sump strainers (see related discussion above in Section 3.5.4.3 and other parts of the Debris Transport Section).

Since the licensee had not made a final determination on whether to use the alternate methodology, and thus had not fully developed a plan to implement the methodology, the staff's review in this area was limited. However, as described above, the staff provided feedback on the licensee's plans regarding the alternate methodology, including emphasis on satisfying the guidance in Section 6 of the SE on NEI 04-07.

6 Conclusions

Entergy has responded to NRC's Bulletin 2003-01 [3] and Generic Letter GL 2004-02 according to the required schedule for IP2 and IP3. The licensee installed new Enercon IR and VC basket (Top Hat) type strainers, with effective surface areas of 3156 ft^2 and 1058 ft^2, respectively, in Unit 3. For Unit 2 a similar sized IR strainer has been installed, and a 412 ft^2 VC strainer has been installed with an additional 770 ft^2 scheduled for installation in the spring 2008 refueling outage. Additionally IPEC installed flow-channeling barriers that route the post-LOCA water into the reactor sump and then up through the incore instrumentation tunnel to the VC annulus through openings in the crane wall before entering the IR or the VC sump/extension. This flow path was designed such that a large quantity of the LOCA-generated debris will settle in the reactor sump or elsewhere in the containment before reaching the IR or VC sump strainers.

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. The staff's considerations regarding this letter will include review of licensee responses to GL 2004-02 as well as licensee responses to the open items in this report and completion of GL 2004-02 corrective actions at IPEC.

Appendix I Open Items

Open Item 3.5-1 (page 34): Capture of Small Fibrous Debris on Gratings

An adequate technical basis was not provided to support the assumption that 40 percent of small pieces of fibrous debris will be captured on gratings in the upper containment. The licensee should provide a justification for this assumption or revise it as determined appropriate.

Open Item 3.5-2 (page 43): Long-term Fibrous Debris Erosion

An adequate technical basis (e.g., test data) was not provided to support the assumption of 10 percent fibrous debris erosion in the containment pool over a 30-day period. The licensee should provide a justification for this assumption or revise it as determined appropriate.

Open Item 3.5-3 (page 44): Long-Term Erosion of Calcium Silicate Debris

The testing performed with the IP2 calcium silicate with asbestos (that is being applied to IP3) was not performed for a sufficiently long period to give high confidence of no erosion of the material, as opposed to a small erosion rate that could lead to a significant fraction of erosion over a 30-day period the post-LOCA mission time of the containment sump. The licensee should provide justification for its conclusions about erosion of this material.

Open Item 3.5-4 (page 44): Plant-Specific Erosion of Calcium Silicate Insulation

The licensee should provide justification for the use of erosion data from the IP2 calcium silicate with asbestos to the IP3 calcium silicate without asbestos.

Open Item 3.5-5 (page 47): Time Dependent Analyses of VC Sump Transport

The licensee plans to credit time-dependent debris transport for qualification of the VC Sump. The licensee should provide adequate technical justification to demonstrate that the time-dependent model is conservative, considering the issues raised in Section 3.5.4.6 of the audit report.

Open Item 3.6-1 (page 58): Head Loss Correlation Use for Design Bases

The analysis techniques used in the strainer certification calculation for IP2 used the NUREG-6224[1] head loss correlation to adjust the test data. The licensee should demonstrate that a test was conducted that bounds applicable scenarios or should justify its present approach of extrapolating head loss data based on a correlation.

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[1] G. Zigler, J. Brideau, D. V. Rao, C. Shaffer, F. Souto, and W. Thomas, "Parametric Study of the Potential for BWR ECCS Strainer Blockage Due to LOCA Generated Debris," Final Report, NUREG/CR-6224, SEA-93-554-06-A:1, October 1995 [8].

Open Item 3.6-2 (page 63): Fibrous Debris Preparation and Introduction during Array Testing

The licensee should show that testing was conducted using a debris mix that matches its transport calculation or should show its existing method is conservative.

Open Item 3.6-3 (page 65): Internal Recirculation Sump Testing and Analyses Documentation

Test procedures and test results concentrated on the vapor containment sump and did not provide clear traceability to show that these tests bounded the internal recirculation sump conditions. The licensee should provide a summary of the testing and analysis results applicable to the internal recirculation sump.

Open Item 3.7-1 (page 75): Internal Recirculation Pumps, Vendor Testing Using Single-Stage Impeller

The licensee should provide a justification for the application of data from single-stage testing to the three-stage IP3 internal recirculation pumps.

Open Item 3.8-1 (page 77): Zone of Influence for Un-topcoated Zinc

The licensee used a 4.28 length/diameter spherical equivalent zone of influence for un-topcoated zinc. This value is less than the five length/diameter zone of influence that was recommended by a Westinghouse report and accepted by the staff. The licensee should revise its existing calculations to conform with the current staff position or justify the current approach, and should provide a summary of how this issue has been resolved.

Open Item 3.8-2 (page 78): Failure of Alkyd Coatings

The licensee is assuming only 80 percent of the alkyd original equipment manufacturer coatings outside the zone of influence will fail. The NRC staff's position is that 100 percent failure should be assumed (i.e., all 29.6 lbs). The licensee should revise its existing calculations to conform to the current staff position or justify assuming less than 100 percent failure of the alkyd coatings, and should provide a summary of how this issue has been resolved.

Open Item 4.2-1 (page 81): Raised Minimum Flow Requirement Effect on Net Positive Suction Head Calculation

During the audit, it was determined that a procedure revision had raised the minimum measured flow requirement to each loop during the recirculation phase of a LOCA (Condition Report CR-IP3-2007-04492). Because of this change, the licensee needs to determine whether the maximum flows assumed in the sump modification calculations are conservative with regard to net positive suction head requirements and debris transport velocities. The licensee should provide a summary of this determination.

Open Item 5.3-1(page 88): Evaluations of Downstream Effects In-Vessel

The licensee's evaluation of in-vessel downstream chemical effects was not available for review as it was under development. The licensee should provide a summary of assumptions, methods, and analysis results for the in-vessel chemical effects evaluations. The licensee's evaluation of in-vessel downstream effects did not provide sufficient evidence that a problematic debris bed will not form at the core inlet. Therefore, in-vessel downstream effects evaluations will remain open. The licensee may chose to evaluate these effects by showing its plant conditions are bounded by the final WCAP-1793 and final NRC SE, when issued. The licensee may alternately address the issue without reference to these documents.

Open Item 5.3-2 (page 91): Evaluations of Downstream Effects of Debris on Systems and Components

The licensee's evaluations of the downstream effects of debris on systems and components were preliminary. The evaluations were under revision to incorporate the evaluation methods of Revision 1 of WCAP 16406-P and to update debris transport and flow rate parameters. The licensee should provide updated flow rates, a summary of methods and results of debris transport tests and evaluations, and a summary of pump-wear and component effects calculation methods and results.

Open Item 5.4-1 (page 92): VUEZ Testing Chemical Issues

The staff has identified a number of outstanding issues with the integrated chemical effects head loss testing performed for IP3 by Alion at the VUEZ test facilities. The resolution of the following chemical issues associated with this testing is considered an open item:

- Whether the pH profile for the test was conservative with respect to both material dissolution and precipitate formation
- Timing of hydrochloric and nitric acid additions
- Timing of lithium hydroxide additions
- Impact of initially high pH condition created by fiber and calcium silicate sitting in the de-ionized water prior to chemical additions
- Potential impact of thermal cycling on test fluid to simulate a heat exchanger
- Modeling of zinc and aluminum coatings as solid samples (as mass) rather than particulate (as surface area)
- Impact of discarding material from pre-boiling of fibers; versus including that material in the test tank
- Uneven mixing of test fluid due to large amounts of coupons and sample baskets in the tank
- Impact of removing test fluid for sampling and for making room for coupons and baskets
- Over-packing of fiber in baskets, such that the fibers may be too dense to interact with the test fluid

The licensee should provide a summary of how these issues have been addressed.

Open Item 5.4-2 (page 92): VUEZ Testing Non-Chemical Issues

The staff has identified a number of outstanding issues with the integrated chemical effects head loss testing performed for IP3 by Alion at the VUEZ test facilities. The resolution of the following non-chemical issues associated with this testing is considered an open item:

- The Alion/VUEZ procedure of pouring of debris beds onto the test screen results in the formation of unusually porous debris beds with low head loss, as compared to debris beds formed under flow conditions representative of the plant post-LOCA.

- The Alion "bump-up factor" methodology has not been demonstrated to be valid for scaling the head loss results of the VUEZ testing to a strainer module. In particular, the differences in the characteristics of the debris beds formed in the array testing at the Alion test facilities and the flat plate at VUEZ have not been adequately accounted for in the scaling process.
- The difference in the sequences of debris addition for the Alion array testing and the VUEZ flat plate testing has not been adequately justified.
- The debris size distribution used for the VUEZ testing has been observed to contain clumps and agglomerations, which lead to the formation of non-uniform debris beds that are not representative of debris beds that are predominately formed by fines.
- The existing calculations for IP3 do not clearly explain how the debris loadings for the VUEZ test cases were derived or justify why they are considered bounding with respect to the strainer design.
- Repeatability of the VUEZ head loss test results has not been adequately demonstrated.
- Measurement uncertainties associated with the recorded head loss test results at VUEZ have not been accounted for analytically in the head loss calculations, demonstrated to be negligible, or demonstrated to be bounded by other conservatisms.

The licensee should provide a summary of how these issues have been resolved.

Open Item 5.4-3 (page 92): Chemical Effects Methodology

Chemical effects test data were not available for NRC staff review at the time of the audit. In addition, the licensee and their vendor have not settled on the final methodology that will be used to apply the chemical test data to the larger scale head loss test results. For this reason, the staff was unable to review the methodology for resolution of chemical effects. The licensee should provide a description of its chemical effects methodology, including details as described in the NRC staff's chemical effects review guidance [92].

Appendix II: Staff Observation of Testing Performed at Alion/VUEZ

Introduction

Two Nuclear Regulatory Commission (NRC) staff members traveled to Levice, Slovakia, on November 10–15, 2007, to observe integrated chemical effects head loss testing performed by Alion/VUEZ. The testing performed during the staff's trip was mainly for Indian Point Energy Center; however, the staff also observed testing and informal experiments associated with Three Mile Island Nuclear Generating Station and Waterford Steam Electric Station.

The Alion/VUEZ integrated chemical effects head loss tests are 30-day experiments that attempt to model the dissolution of source materials (e.g., insulation and metals such as aluminum) in a post-accident containment sump pool, the chemical reactions of any dissolved species that could potentially lead to precipitate formation in the pool, and the head loss contribution associated with any chemical precipitates formed.

Alion is a vendor providing testing and analytical services to various pressurized-water reactor (PWR) licensees to support demonstration that these licensees' sump strainers would perform acceptably following a loss-of-coolant accident (LOCA) in the presence of plant-specific debris and chemical precipitates. VUEZ is a Slovakian company sub-contracting to Alion, which owns the test facilities and supplies test technicians for the 30-day integrated chemical head loss tests described in this report.

Overview of Indian Point Testing

During the staff's visit, four of the six small-scale loops at VUEZ were used to perform testing for Indian Point (IP) Units 2 and 3. Figure 1 and Figure 2, below, show the small-scale loops at VUEZ.

Figure 1: VUEZ Small-Scale Loops

Figure 2: View Inside One Small-Scale Loop

The staff observed part of the pre-test activities to support the IP testing, the preparation and addition of debris for bed formation, the preparation and insertion of debris sample baskets and metallic coupons for dissolution and corrosion, and the preparation and introduction of chemical solutions added in the first few days of the testing.

As observed by the staff, the initial steps of the test specification used by Alion for the IP testing consisted of the following basic process: After filling each test tank and heating the test fluid, flow through the loop was adjusted to match the surface approach velocity for the test screen to that of the IP plant strainers. Then a debris bed was formed by pouring a homogeneous slurry of test debris onto the perforated-plate test screen. Following debris bed formation, the test was allowed to run for 24 hours to stabilize the measured head loss. Then boric acid and lithium hydroxide were added to the test tank to simulate the concentration present in the sump fluid. Non-transportable debris and metal coupons were also submerged in the test tank to simulate sources of materials that would be available in the plant containment pool for corrosion and dissolution. Once measurements of flow, temperature, and pH were taken, the 30-day test period was considered to begin. After 50 minutes, sodium tetraborate buffer was added to the tank, along with additional lithium hydroxide, hydrochloric acid, and nitric acid. As the test continued, the vendor planned to reduce the test tank temperature in accordance with the plant-specific temperature profile, collect and analyze samples of the test tank fluid at scheduled intervals, remove certain metallic coupons and debris samples, and carry out a number of other steps outlined in the test procedure.

To compensate for the fact that the maximum temperature limit of the VUEZ test facility (190 °F) was lower than the maximum post-LOCA temperature postulated for IP, for modeling the corrosion and dissolution of certain types of debris and metallic coupons, the test vendor submerged in the test tank quantities in excess of the scaled amount at the start of the test. The additional debris materials were later removed from the test tank at various intervals determined by the vendor. The vendor performed analytical calculations to determine appropriate quantities of additional debris and removal times that would compensate for the temperature limitation of the VUEZ test facility. The staff did not review these vendor calculations during the trip to VUEZ.

The following sections of this trip report describe staff observations of specific aspects of the testing at VUEZ.

<u>Debris Preparation Process</u>

The staff observed the vendor's practices for fragmenting and weighing the quantities of debris specified in the test plan. An example of the prepared debris prior to being homogeneously mixed into a slurry of water is shown below in Figure 3.

Based on observations and reviews of Alion/VUEZ test procedures, the staff understood that the procedures specified a generic debris size distribution for all plants tested at VUEZ. That is, the size distribution of the prepared test debris was not compared to the size distribution in a specific plant's debris transport calculation to ensure prototypicality. For the IP testing, the staff understood that the plant transport calculation predicted that the fibrous debris reaching the strainers would be nearly 100% fines, in contrast to the generic distribution assumed at Vuez.

Figure 3: Prepared Debris Prior to Mixing in Water

Fragments of debris were added to a pitcher full of water taken from the test loop and mixed together for roughly five minutes with an electric hand mixer. The staff observed that the amount of water added to the pitcher was roughly constant for each test case. As a result, the cases with larger quantities of debris tended to experience significantly more agglomeration due to the higher concentration of debris in the slurry. The test vendor did not have criteria in place to determine whether or not the concentration of debris slurries was adequate to prevent non-prototypical agglomeration. A photograph showing a clump of agglomerated debris being poured onto the test strainer is provided below in Figure 4.

Figure 4: Agglomerated Debris Being Poured Onto Test Screen

Debris Bed Formation

Debris was poured onto the test screen from the pitcher in which it was mixed. The debris in the pitcher was constantly stirred as it was poured onto the test screen. The debris was poured through a funnel that a test technician moved over the test screen in an effort to form a debris bed of uniform height. Based on the staff's observations, the debris bed pouring process generally lasted several minutes.

Since, by virtue of their density, debris pieces tended to settle to the bottom of the pitcher, the staff observed that the slurry poured from the bottom of the pitcher was significantly clumpier than that poured from the top of the pitcher. The test technicians partially accounted for this phenomenon by drawing additional water from the test loop and using it to dilute the remainder of the debris slurry when it appeared overly concentrated. However, as shown above in Figure 4, this general practice did not prevent agglomerated clumps of debris from being poured onto the test screen. During the formation of several debris beds, the staff observed that the agglomeration of debris was sufficiently problematic to cause blockage in the funnel being used to add debris to the bed. The test technician then had to use the stirring rod to clear out the funnel and resume bed formation.

Indian Point Test Observations

Prior to the testing, the staff received a copy of the IP test specification and reviewed this document. Four test cases were considered therein, the majority of which were composite cases intended to bound two or more different accident scenarios.

The first test for IP was performed in Loop 1 of the small-scale test rig. The staff observed that the poured bed formed was clumpy, and noted that the largest clumps of agglomerated debris from the bottom of the pitcher ended up on the top of the poured debris bed. Some of these clumps of debris were repositioned manually with a stirring rod in an attempt to create a more uniform debris bed, although this action did not seem to affect the measured head loss. As the debris bed was being poured, several times the staff noted that the funnel being used to direct the debris slurry onto the test screen became clogged with large clumps of debris that had to be cleared out with a stirring rod. As the funnel was being maneuvered over the debris bed, the staff observed that the lower end of the funnel sometimes scraped along the top surface of the debris bed, disturbing the upper layers of the bed and apparently contributing to the agglomeration of debris in the funnel.

While the debris bed was being formed in Loop 1, flow through the loop was observed to drop to zero. The vendor stated that this flow stoppage was likely due to debris blockage at a throttle valve in the test loop. The apparent blockage at the throttle valve resulted in at least the upper layers of the debris bed being formed by gravity alone, as opposed to the flow through the test screen. A negligible head loss was measured following the formation of this debris bed, which is shown below in Figure 5.

The vendor then prepared a debris slurry representing a different loading condition for Loop 2 and poured it onto the test screen. The measured head loss after bed formation registered a small increase, but did not appreciably rise above zero. No flow anomalies were detected during the pouring of the debris bed. The staff noted that the fiber in the debris bed was unexpectedly fluffy and porous, although the frequency of agglomerated clumps of debris appeared lower than for the Loop 1 bed.

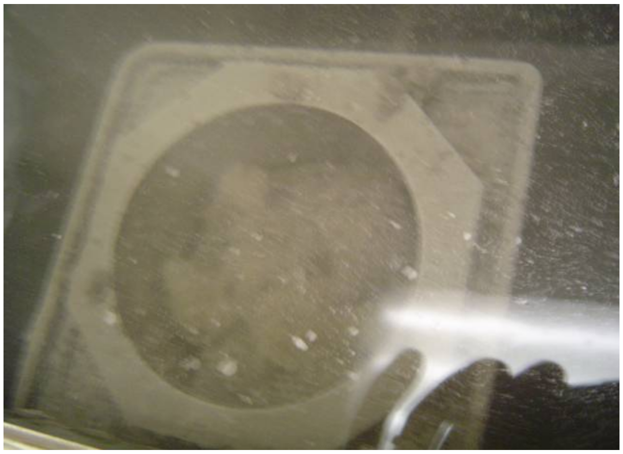

Figure 5: Initial Debris Bed Poured in Loop 1

Because of the debris agglomeration observed during the formation of the debris beds in Loops 1 and 2, prior to pouring the debris bed for Loop 3, the vendor poured the debris slurry onto a spare test screen to determine whether it had been adequately mixed up to remove the clumpiness. The staff considered it a good testing practice to verify that the consistency of the debris slurry is adequate prior to adding it to the test loop. The slurry to be added to Loop 3 was found to be too clumpy by the pre-test check, as shown below in Figure 6.

Figure 6: Pre-Test Pour of Loop 3 Debris Slurry

As a result, the Loop 3 debris slurry was mixed for an additional period with a hand mixer. The re-mixed slurry was then added to Loop 3. Verification of whether the additional mixing was adequate to break up the observed debris clumps was not performed prior to the addition of the slurry to the test tank. The staff observed that clumps remained in the debris slurry, and as described regarding Loop 1 above, the test technician had to use the stirring rod to clear clogs in the funnel and to reposition debris on the test screen. The staff concluded that the benefit of performing additional mixing of a debris slurry is limited if the concentration of debris in the slurry is excessive.

Approximately half an hour after the formation of the bed in Loop 3, a considerable fraction of the debris from the bed was observed to have floated up from the bed to the surface of the water in the test tank. See Figure 7, below. Subsequently, a coarse wire mesh was placed over the chimney (i.e., the cylindrical volume surrounding the debris bed and test screen) to prevent additional debris from floating up from the bed, as shown below in Figure 8.

Figure 7: Flotation of Part of Debris Bed

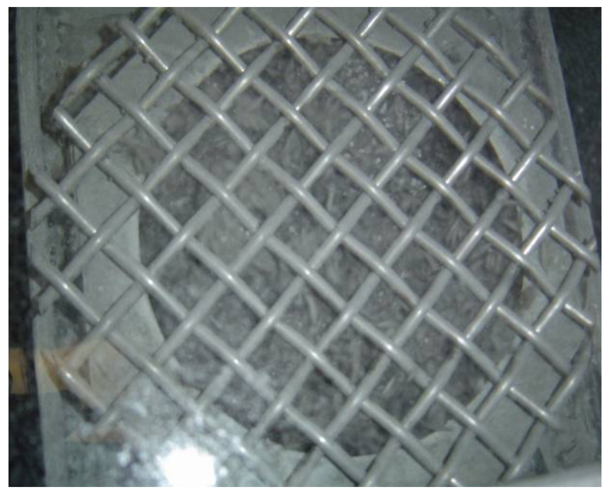

Figure 8: Wire Mesh Placed Over Chimney

At this juncture, a significant fraction of the debris bed in Loop 1 was also observed to have floated up to the surface of its tank. As a result, a small area of clean strainer became visible in Loop 1. Test vendor personnel hypothesized that the observed debris flotation could be the result of exposing Temp-Mat™ binder to hot water, resulting in the generation of gas bubbles that become trapped in the debris bed and cause buoyancy. However, the staff questioned this response, since the IP test plan stated that the Temp-Mat™ debris to be used for the test should have been pre-boiled. Based on additional discussions with the vendor and the staff's visual observations of the prepared test debris, it appeared that the Temp-Mat™ debris added for the initial tests (see Figure 3, above) had not been pre-boiled, as per the test procedure.

As a result of the flotation of parts of the debris beds from Loops 1 and 3, the test vendor determined that the tests being performed in these loops should be terminated and restarted with Temp-Mat™ that had been pre-boiled. Prior to the restart of Loops 1 and 3, roughly 17–20 hours after the beds had initially been formed, the staff recorded the following approximate measured head losses in Loops 1 – 4:

Table 1: Approximate Measured Head Losses Prior to Restarting Loops 1 and 3

Loop	Measured Head Loss Channel 1 (kPa)	Measured Head Loss Channel 2 (kPa)
1	0.02	-0.01
2	0.09	0.15
3	3.4	3.5
4	-0.02	0.09

As expected from the partial uncovery of the test screen, the head loss measured in Loop 1 was essentially equivalent to the clean strainer value. Surprisingly, however, despite a significant loss of material from the bed, the head loss measured in Loop 3 was the highest among all four IP loops, approximately 20 – 30 times higher than the loop with the next highest head loss.

Prior to performing a full cleanout of Loops 1 and 3 and retesting these conditions, the test vendor decided to perform a partial cleanout of Loop 1 and an informal test with the same debris loading but with heat-treated Temp-Mat™ debris. When the debris bed for this informal test was poured into Loop 1, the staff observed that the debris bed was significantly fluffier and more porous than expected. Although the theoretical thickness for this bed was calculated by the test vendor as being approximately 0.9 inches (2.3 cm), the staff observed that the formed bed actually filled the chimney to its top, a depth of approximately 2.75 inches (7 cm). The formed debris bed in Loop 1 was, therefore, approximately 3 times thicker and more porous than expected. As a result, the staff concluded that the head loss measured across this debris bed was likely a significant underestimate of the prototypical head loss value.

Figure 9, below is a photograph of the debris bed with heat-treated Temp-Mat™ in Loop 1 near the end of the formation process. Debris can be seen spilling over the edges of the chimney. A similar result occurred when the same debris bed was later re-poured in Loop 3 for the formal re-test after Loops 1 and 3 had been fully cleaned out, as shown in Figure 10.

Figure 9: Debris Bed Filling to Top of Chimney

Figure 10: Re-Poured Debris Bed Mounding Above Top of Chimney

Based on the results of the sensitivity test with heat-treated Temp-Mat™, the test vendor subsequently performed a full cleanout of Loops 1 and 3 and repeated these test cases using heat-treated Temp-Mat™. Significant flotation of debris from formed beds was not observed during subsequent tests using heat-treated Temp-Mat™. Shortly after re-pouring the debris beds in Loops 1 and 3, the measured head losses in Loops 1 – 4 were recorded to be as follows:

Table 2: Approximate Measured Head Losses Following Restart of Loops 1 and 3

Loop	Measured Head Loss Channel 1 (kPa)	Measured Head Loss Channel 2 (kPa)
1	0.1	0.09
2	0.16	0.21
3	0.07	0.1
4	0.13	0.16

Note that, while a gradual temperature reduction in Loops 2 and 4 apparently was partially responsible for the measured head loss increase as compared to the values reported in Table 1, the majority of the head loss increase was likely attributable to gradual compression of the non-prototypically porous debris beds under flow.

<u>Pre-Test Bed Formation Experiments</u>

Prior to the beginning of the 30-day tests for IP, the test vendor performed several pre-tests to verify adequate debris bed formation for several IP debris loadings prior to initiating the formal, long-term integrated tests.

The staff questioned the vendor's usage of a homogeneous debris preparation and addition process and also questioned whether any testing had been performed at VUEZ using a heterogeneous debris preparation and addition process. In response to the staff's question, vendor personnel stated that bed formation pre-tests for IP had examined these issues and exhibited significant variation in head loss dependent upon these test parameters. The vendor provided the results of the IP pre-tests to the staff, as summarized below in Table 3.

Table 3: Pre-Test Results Demonstrating Effect of Debris Sequencing

Case	Homogeneous Preparation and Addition	Heterogeneous Preparation and Addition
2	< 0.1 kPa	0.2 kPa
4	~ 1 kPa	~ 18 kPa

For both of the pre-test cases, the heterogeneous preparation and addition of debris resulted in a larger head loss. For Case 4, in particular, the measured head loss for the heterogeneous case was roughly twenty times greater than the homogeneous case before the test was terminated due to cavitation of the test pump.

The staff questioned the basis for such a large discrepancy between the homogeneous and heterogeneous preparation and addition cases and questioned the test vendor's basis for considering the heterogeneous case as not being prototypical of the actual plant condition. The test vendor considered the homogeneous debris addition process to be representative based upon the fact that debris would tend to be mixed up in a post-LOCA containment pool. The staff recognized this point, but noted the following:

- The concentration of debris in a post-LOCA containment pool would be much lower than the pitcher used to mix debris at VUEZ. Therefore, the staff expected the degree of agglomeration at VUEZ to be significantly higher than the actual plant condition, which would be non-conservative with respect to debris bed head loss.
- Although some types of debris may be mixed in a post-LOCA containment pool, the processes of transport and filtration will naturally tend to segregate somewhat the different types of debris in the debris bed. For example, larger pieces of floor-transporting debris are likely to have difficulty climbing onto upper surfaces of a strainer, and fine particulate would not be appreciably filtered by a debris bed until a fibrous layer and coarser particulate have accumulated.

Consequently, the staff concluded that the prototypicality of the VUEZ test procedures using a homogeneous preparation and addition sequence had not been adequately demonstrated. Furthermore, the staff noted that the array testing in Warrenville uses a heterogeneous sequence for thin-bed testing. Other strainer vendors also use heterogeneous debris sequencing for various array tests. The staff questioned the basis for using the VUEZ results to generate a bump-up factor for thin-bed testing in Warrenville (or other vendor test site) if a different debris addition sequence is used for the two tests.

<u>Metal Coupons and Debris Sample Baskets</u>

The staff noted several issues concerning the interaction of the test fluid with the debris samples and coupons in the test tanks. The debris sample baskets used for the testing were typically shaped like a tray, allowing for fluid interaction with the material in the basket only through one open screened surface at the top. Thus, due to the geometry of the sample baskets, there was only minimal flow of water past the samples, and minimal interaction of the test fluid with the sample materials. This problem was compounded by the fact that, for the test cases observed by the staff, the sample baskets were densely packed with debris. Furthermore, in a number of cases, one type of material was densely packed on top of a second material inside the basket, providing the lower material a shielding effect from the test fluid. Figure 11, below, shows a sample basket that is densely packed with two types of fibrous debris. The compressed layer of white fibrous material on the top (Temp-Mat™ high-density fiberglass) likely limited the interaction of the test fluid with the yellow fibrous material underneath (Nukon® low-density fiberglass).

Figure 11: Sample Basket with Densely Packed Layers of Debris

In addition, the scaling factors associated with several of the IP tests observed by the staff required a significant number of sample baskets and metallic coupons, which filled a substantial fraction of the available test tank volume. Stacked or closely spaced baskets have the potential to limit further the interaction of the test fluid with the sample materials in the baskets. In addition, the staff observed in one test that a sample coupon was inserted in the test tank with one side very close or adjacent to the wall of the test tank, which appeared to prevent appreciable flow of the test fluid to approximately half of the coupon surface area. All of these issues are tied to the staff's larger concern that the sample materials added to the test tank may not be able to interact with the test fluid in a representative manner. As a result, fewer chemical species could be dissolved into the test fluid, and, therefore, there may be a non-representative reduction in the potential for formation of chemical precipitates in the VUEZ test loop.
Figure 12, below, shows a test tank filled with closely spaced coupons and sample baskets.

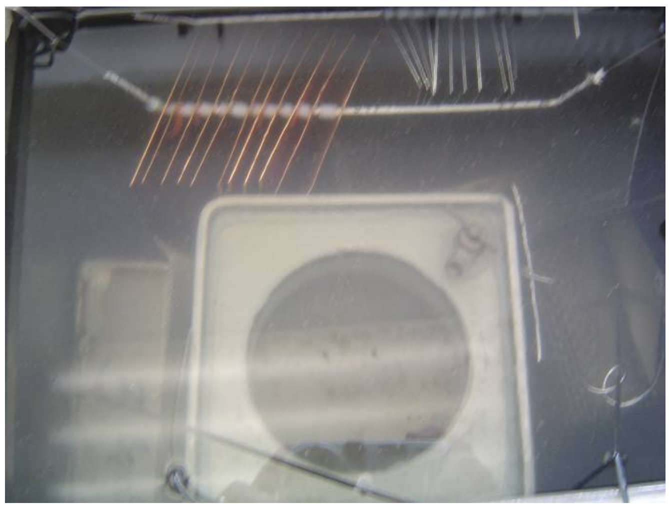

Figure 12: Test Tank Filled With Coupons and Sample Baskets

For the IP tests observed by the staff, care was taken to thoroughly mix the tank fluid by mechanical mixing after the addition of the boric acid. This mixing was done because, as VUEZ personnel indicated during the staff's visit, it can take longer than 4 hours to completely mix the fluid in the test tank. This same procedure was not used when the buffer, hydrochloric and nitric acids, and the last portion of lithium hydroxide were subsequently added to the test. The lack of mixing following the addition of these latter chemicals was due in part to the inability to get a mechanical mixer into the tank due to physical limitations caused by the volume being taken up by coupons and baskets of material in the tank at the time of the latter additions. The mixing of these chemicals into the bulk fluid would take longer than the initial addition of boric acid due to the complex geometries and uneven flow zones created by the coupons and baskets. The reason this issue is a potential concern to the staff is that the timed removal of coupons and baskets in the test protocol (some of which may be removed only 50 minutes into the test) was based on the expected time the samples would have to interact with the chemicals in the test fluid. If the chemicals are not well mixed with the test fluid, then the coupons and baskets may not experience the level of chemical interaction they are assumed to achieve prior to their removal from the test tank.

The staff also noted that, previously, Alion personnel had informed the staff that 1 L/min was typically the lowest flow rate desired for testing at VUEZ. The vendor had stated that informal experiments had been performed at this flow rate, and that the flow conditions in the tank were sufficient to prevent settling of fine material and ensure adequate circulation in the tank. The staff noted that one of the IP test loops was run at a velocity of approximately 0.8 L/min. The vendor stated that this reduced flow rate was not expected to significantly alter transport and flow behavior in the tank. However, the staff also noted that the IP test tanks were filled with a large number of coupons and sample baskets, as shown above in Figure 12. Based on discussions with the test vendor, the informal experiments on which the typical 1 L/min lower flow rate limit was based had been conducted in an open tank. Thus, the vendor had not considered the potential for the large number of flow obstructions present in the tank for the IP testing to create low-flow zones that could affect fluid interactions with sample materials and debris settling potential.

Temperature and pH Profiles

The selection of test parameters for the VUEZ loops, such as temperature and pH profiles, is critical for designing a test procedure that is conservative with respect to predicting the impact of chemical effects. For a plant for which the dominant chemical precipitates are aluminum-based, an example of a conservative protocol could be to bias the early part of a test toward the upper range of post-LOCA temperatures to conservatively predict dissolution. The latter part of the test could then be conducted at the lower range of post-LOCA temperatures to favor precipitation of dissolved materials. Similarly, with respect to the pH of the test fluid, higher pH conditions may favor greater dissolution of certain materials, such as aluminum, while lower pH values would create conditions that favor precipitation of species such as aluminum hydroxide. It was not clear to the staff the IP testing had considered the limiting temperature conditions for precipitate generation and head loss.

Based upon a review of VUEZ test procedures and observations of testing at the VUEZ facility, specific areas that are included in the staff's concerns about the test pH profile include the timing of various chemical additions. The hydrochloric and nitric acid additions to the VUEZ test loop occur early in the test. However, in a postulated LOCA scenario, these acids would be expected build in slowly over the course of the event, resulting in a lower pH later in the scenario. With respect to dissolution of aluminum, it may be more conservative to have the test loop operating at a higher pH in the early part of the test, and then lower the pH later in the test sequence to promote precipitation of the aluminum in solution. Similarly, the lithium hydroxide injection occurs after the test has been underway for some time and is coincident with the buffer addition. In a postulated LOCA scenario, the lithium hydroxide would be in the pool from the onset, thus elevating the pH from the beginning. Again, the timing of the addition of these chemicals may impact the dissolution rate of aluminum in the test loop. Another observation made by the staff during the testing for IP was that, when the debris used to form the bed (i.e., fibers and particulate) was allowed to sit in the test loop for 8–10 hours prior to the first chemical additions, the pH of the loop rose from roughly neutral to approximately 9.5. So high an initial pH (i.e., prior to buffer dissolution) is not representative of operating PWRs' buffered containment pools, although it may be representative of potential pH variations in unbuffered containments. It is unclear to the staff whether this starting condition impacts the remainder of the test and whether that potential impact has a deleterious or beneficial effect from a material dissolution and precipitation standpoint. The degree to which these chemical additions and material contributions to pH affected the outcome of the IP testing is unclear to the staff.

Thermal Cycling

The existing VUEZ testing does not address the effect of a sudden temperature drop from a heat exchanger and the potential for thermal cycling of the sump fluid. The staff is concerned that dissolved species may remain in solution in the VUEZ loop because they remain at a relatively stable temperature (slowly decreasing over 30 days), but those same species may form precipitates if subjected to a rapid temperature decrease. These precipitates may foul a heat exchanger or may serve as a nucleation site for further precipitation if they are formed and then passed back to the bulk fluid. If these precipitates were to form in a heat exchanger it is unclear if they would go back into solution when exposed to elevated temperature or if they would remain insoluble and either adhere to the heat exchanger or return to the containment pool in suspension with the sump fluid. During a teleconference with the staff, Alion stated that equipment was being procured to analyze this effect. Additional detail on how these tests will be conducted and their results could provide a basis to resolve the issue.

Modeling of Zinc and Aluminum Coating Surface Areas

Debris from failed zinc and aluminum coatings is being represented by solid zinc and aluminum coupons in the VUEZ testing. These coatings however are postulated to fail as fine particulate material. Dissolution of large pieces of these metals may not be representative of the dissolution of significantly smaller chips or particles of failed coatings debris (e.g., in terms of surface-area-to-volume ratio). The result may be that a lower concentration of material is dissolved in the test tank than would be for the sump pool. The resulting aluminum concentration from metal coupons may not be representative of the actual scenario. This may be a significant concern since aluminum-based precipitates are a major contributor to chemical effects for many plants. Therefore, licensees should ensure that metallic coupons representing zinc and aluminum coatings are scaled based on the surface area of the coating debris in its failed form. Subsequent discussions with Alion following the staff's observation of the IP testing at VUEZ confirmed that the surface area of the metallic coupons used for the IP testing was based upon the scaled surface area for the failed coating debris. As a result, the staff considered this issue to be resolved for IP.

Pre-Boiling Fibrous Debris

The protocol for the IP tests observed at VUEZ directed boiling of Temp-Mat™ and Nukon® fibers to drive off the binder material prior adding this fibrous debris to the test tanks. In a similar fashion, some fibrous debris was baked to help drive off any binder material. The staff agrees that in a head loss test that does not consider chemical dissolution and precipitation from the test materials, it may be expedient to prepare the fibers in this way. Although baking insulation simulates the interaction of the fibers with hot surfaces during service, the outer layers of the insulation will be subjected to much lower temperatures than the layers adjacent to the pipe. Furthermore, boiling insulation has the potential to remove significantly more material from fibrous insulation than baking, which is more representative of what would occur due to exposure to hot piping. Thus, in an actual accident scenario, some insulation binder material from destroyed insulation would likely be present in the sump pool and could potentially contribute to chemical reactions. In contrast, at VUEZ, the discolored water used to boil the fibrous debris was discarded rather than being added to the test tank. Based on discussions with the test vendor and licensee, the staff did not have confidence that an adequate basis had been provided to conclude that the discarded solution containing binder material did not include materials that could contribute to the formation of chemical precipitates.

Removal of Fluid from Test Tank

In the IP tests observed by the staff, several liters of test fluid were to be removed from the test tank in order to accommodate all of the debris and buffering chemicals added to the tank. The removal of this fluid resulted in the fluid volume of the test tank being reduced and the concentrations of the chemicals in the loop being varied from the test specification. In addition, based upon a review of VUEZ test procedures, approximately 5% of the loop volume could be removed through the process of taking liquid samples from the test volume. The fluid samples could contain dissolved or suspended chemical species. The test vendor did not provide a basis to justify that the effect of removing these quantities of fluid from the test tank was negligible.

Measurement Uncertainties

Based upon a review of the VUEZ test procedures, the staff questioned how the vendor accounted for measurement uncertainties associated with equipment at the VUEZ test facility. Considering uncertainties associated with the flow rate measurement, flow control system, head loss measurement, and temperature measurement, and considering that variances of independent random variables are additive, the staff expected that a non-negligible uncertainty would be associated with the VUEZ head loss results. In addition, the staff further expected that uncertainties associated with the test fluid temperature could affect the timing of the corrosion process. (For example, Alion estimated in its test procedure that corrosion rates double about every 18 °F.) Thus, uncertainty associated with temperature measurement would also introduce uncertainty in the timing of chemical precipitate induced head loss. The test vendor did not provide a basis to conclude that measurement uncertainties are negligible for the VUEZ testing.

Test Repeatability

Confidence should exist that the VUEZ tests are repeatable. During the trip, vendor personnel discussed Three Mile Island testing that was in progress and indicated that it showed some evidence of repeatability. The staff expects that data for slightly varied test conditions should also be capable of providing evidence of repeatability if it correlates with expected behavior.

However, based upon the staff's observations from the trip to VUEZ, evidence for the repeatability of the debris bed formation process was not conclusive. Although some of the tests appeared to demonstrate repeatability, other tests demonstrated significant variability. Among the IP test results considered by the staff are two pre-test cases, four test cases, and two repeat test cases that became necessary when significant portions of two debris beds floated away.

Bump-Up Approach

The specific methodology and technical basis for using a bump-up factor to account for the head loss due to chemical effects is not clear to the staff. The bump-up approach is based on the theory that the incremental head loss from a given quantity of chemical precipitate (after scaling) will be the same for the VUEZ debris bed as for the plant condition. One of the important assumptions upon which this theory depends is that the VUEZ debris bed and the actual plant debris bed should have sufficiently similar characteristics with respect to filtering out and spatially accumulating chemical precipitates. Based upon testing conducted to date, it is not clear to the staff that geometric differences and other factors do not influence the debris beds' properties (e.g., porosity, compression, thickness), and thus add significant uncertainty to the bump-up factor approach. It is also not clear how the bump-up approach ensures that boreholes or differential-pressure effects do not adversely affect the scaling approach. The bump-up approach was not discussed in detail during the staff's trip to VUEZ.

Observations of Three Mile Island Tests

When the staff arrived at the VUEZ facility, two test cases for Three Mile Island were running in Loops 5 and 6. The vendor stated that these two loops had been running for approximately two weeks. Based upon visual observation of these two loops, the staff identified two concerns associated with the Three Mile Island testing.

The first concern was associated with warping observed around the edges of the debris bed. As can be seen in Figure 13, below, the debris bed had pulled away from the edge of the chimney, leaving a gap along the circumference of the debris bed.

Figure 13: Debris Bed With Warping Around Circumference

This effect can be observed in Figure 13 most clearly in the 7 or 8 o'clock position of the debris bed. The gap did not appear to extend all the way through the thickness of the debris bed to the surface of the screen. Nevertheless, the staff was concerned with the warping along the edges of the debris bed because flow could presumably pass through the gap between the bed and chimney, thereby bypassing a significant fraction of the debris bed cross section. As a result, the VUEZ testing could underestimate the head loss expected for this debris loading condition.

The vendor speculated that the reason for the formation of the gap around the edge of the debris bed was related to the slight curvature of the test screen. Although, initially, the test screens used at VUEZ had been completely flat, in order to reduce the potential for air accumulation beneath the debris bed, slightly curved screens were used for later testing, including the IP and Three Mile Island testing observed by the staff. The staff considered the vendor's hypothesis a partial explanation of the observed behavior, but expected that the significant magnitude of the warping was also the result of the VUEZ debris beds' being formed with excessive porosity and thickness (see discussion above). Later, after being exposed to flow and differential pressure, the pores in the bed were compressed or collapsed. As a result, the debris beds shrank significantly and the edges pulled away from the chimney. Regardless of the cause, the staff considered this issue a concern because the test vendor did not demonstrate that the observed debris bed warping was either prototypical of expected behavior for the plant strainer or that it did not have a significant effect on the VUEZ test results.

The second concern was that the staff discovered a sample basket lying upside down in one of the Three Mile Island test loops. The sample basket found upside down was a rectangular prism with five solid sides and one side covered by wire mesh screen material. The sample basket was observed by the staff to be oriented such that the open screened side of the basket was against the tank floor, which prevented the test fluid from interacting with material inside the sample basket. The upside-down sample basket can be seen in the bottom of the test tank in Figure 14, below. Figure 15 provides a close-up of a sample basket taken on the laboratory counter to illustrate better the design of the sample baskets. Based upon the observation of the sample basket being upside down, the staff questioned the representativeness of the chemical environment for that test and further questioned the quality assurance practices being used at the VUEZ facility.

Figure 14: Upside-Down Sample Basket in Three Mile Island Test

Figure 15: Close-Up of Sample Basket Lying Upside Down

Based upon observations made by the staff at the test site, the head losses measured for the Three Mile Island debris beds were in the range of 2–4 kPa at roughly 20 °C.

Observations from Waterford Pre-Test

The test vendor planned to conduct long-term testing for Waterford 3 in the VUEZ large-scale test facility. The vendor planned to use the large-scale facility for the Waterford 3 testing because the expected bed thickness (approximately 11 inches) was significantly in excess of the depth of the chimney in the small loops (approximately 2.75 inches). In light of the large fibrous debris loading, the vendor performed a preliminary test with only non-chemical debris to determine whether proceeding with integrated chemical testing was warranted.

The large-scale test facility is shown in Figure 17 and Figure 16, below. Figure 17 provides an external view of the large-scale facility, and Figure 16 provides a view of the inside of the tank prior to the addition of the Waterford 3 debris onto the test screen located inside the chimney in the center of the tank.

The debris preparation process for the Waterford 3 pre-test was similar in principle to that used for the smaller-scale tests for IP. However, due to the larger quantity of fibrous debris and the larger-scale test screen, the debris slurry was prepared in a plastic barrel rather than the pitcher used for the small-scale testing. The slurry was then batched into the test loop by transferring it in stages from the barrel to the pitcher to the screen. The pouring of debris from the pitcher to the test screen is shown in Figure 18, below.

Figure 17: External View of Large-Scale Tank

Figure 16: Internal View of Large-Scale Tank

The staff did not review the test procedure or make detailed observations of the Waterford 3 pre-test. The main staff observation from this test was that there was very little water in the debris slurry, which resembled thick oatmeal, when poured onto the test screen. Particularly near the end of the debris addition, the concentrated debris slurry showed a high degree of agglomeration into clumps and small pieces. The degree of agglomeration appeared to be non-prototypical since, based on an audit conducted at Waterford 3 in July 2007, the analytical fibrous debris size distribution transporting to the strainers was considered to be predominately fines.

Figure 18: Addition of Debris to Large-Scale Loop

Despite this issue of excessive debris agglomeration, the measured head loss increased steadily until the 30-kPa (10-ft) differential pressure limit of the test loop was reached and the pre-test was terminated. Unlike typical head loss tests, the majority of the head loss increase from the poured debris bed appeared to be almost exclusively due to compression of the debris bed and the migration of fine debris through the debris bed, as opposed to the gradual filtration of debris suspended in the test fluid. This observation also applies to the small-scale VUEZ head loss tests the staff witnessed being performed for IP.

Open Items on VUEZ Testing

Based in part on the discussion above, the staff identified a number of issues for Alion to address with regard to the testing being performed at the VUEZ facility. These issues were communicated to Alion, along with other issues identified based upon a review of the vendor's test procedures, via several teleconferences, which are summarized in an NRC memorandum with enclosures [102]. Alion is currently in the process of responding to the issues raised by the staff regarding the VUEZ testing outside the Indian Point audit review process with the intent of resolving these issues on a generic basis. Upon receipt of the generic responses from Alion, the staff will perform a review to determine whether any outstanding issues remain that need to be addressed by specific plants relying upon tests performed at the VUEZ facility.

The specific Alion/VUEZ testing issues applicable to Indian Point that the staff designated as open items during the audit are listed in Appendix I of this audit report (page 97). The Indian Point licensee is expected to respond to open items from the audit that are associated with the Alion/VUEZ testing in accordance with the normally allotted period of 60 days from the issuance of the audit report.

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