Prairie Island Nuclear Generating Plant Corrective Actions for Generic Letter 2004-02

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Acronym List

ANSI	American National Standards Institute
ASME	American Society of Mechanical Engineers
ARL	Argonne Research Laboratory
BWROG	Boiling Water Reactor Owners' Group
CSS	containment spray system
CFD	computational fluid dynamics
COA	Candidate Operator Actions
ECCS	emergency core cooling system
GL	generic letter
GR	Guidance Report
GSI	Generic Safety Issue
HPSI	high-pressure safety injection
ICET	integrated chemical effects test
ICM	interim compensatory measure
L/D	length/diameter
LOCA	loss-of-coolant accident
NEI	Nuclear Energy Institute
NMC	Nuclear Management Company
NPSH	net positive suction head
NPSHA	net positive suction head available
NPSHR	net positive suction head required
NRC	Nuclear Regulatory Commission
PCI	Performance Contracting, Inc
Pdest	destruction pressure
PI	Prairie Island Nuclear Generating Plant
PWR	pressurized water reactor
RCS	reactor coolant system
RG	Regulatory Guide
RHR	residual heat removal
RMI	reflective metal insulation
RWST	refueling water storage tank
SE	Safety Evaluation
USAR	updated safety analyses report
ZOI	zone of influence

1.0 BACKGROUND

1.1 Introduction

The U.S. Nuclear Regulatory Commission (NRC) is auditing, on a sample basis (related to reactor type, containment type, strainer vendor, NRC regional office, and sump replacement analytical contractor), licensee corrective actions for Generic Letter (GL) 2004-02, "Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized-Water Reactors," dated September 13, 2004 [1], for approximately ten commercial pressurized water reactors (PWRs). The purpose of the audits is to verify, to the extent feasible, that the implementation of Generic Safety Issue (GSI-191) 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 strainers in their plants in order to resolve the GSI191 [2] sump performance issue by December 31, 2007. Prairie Island Nuclear Generating Plant (PI), which is operated by Nuclear Management Company (NMC), has proceeded to design and install new strainers in May 2006 for Unit 1 and at the time of the audit planned to install new strainers in November 2006 for Unit 2. Unit 1 was selected for focus for an audit because a major part of the design, analyses, testing and installation of the new strainer had been completed for that unit.

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

The audit commenced on October 4, 2006 when NMC presented an overview of the GSI-191 Project to the staff audit team. Following review of the presentation materials [3] and other documents provided during the overview session, the onsite portion of the audit commenced on October 23, 2006 with the staff audit team exiting the site on October 27, 2006. Several audit areas continued to be reviewed after the onsite audit was completed, with telephone conferences held on November 2 and December 6, 2006 and a final call on January 3, 2007.

Table 1 lists key NRC staff, licensee staff and contractors, and NRC consultants and identifies attendance during audit meetings.

Table 1 PI Audit Meetings

Name	Organization	Title/ Area	Project Over-view 10/4/2006	Audit Onsite Entrance 10/24/2006	Audit Onsite Exit 10/27/2006
John Lehning	NRC/SSIB	Debris Transport/ Characteristics	x	x	x
Paul Klein	NRC/DCI	Chemical Effects	x	x	
Ralph Architzel*	NRC/SSIB	Team Leader	x	x	x
Steven Unikewicz	NRC/DCI	Downstream	x	x	x
Tom Hafera	NRC/DSS	Breaks/Debris Generation	x	x	x
Andy Dunlop	NRC/Region III	Bulletin/ Modifications	x	x	x
Shanlai Lu*	NRC/SSIB	Strainer Headloss	x	x	x
Clint Shaffer	NRC - ARES Corp	Baseline	x	x	x
Ted Ginsberg	NRC-BNL	NPSH	x	x	x
Roberto Torres	NRC/SSIB	Latent Debris		x	x
Matt Yoder	NRC/DCI	Coatings	x		
Sujit Samarddar	NRC/DE	Structural	x		
Walt Jensen	NRC/DSS	Fuel/Core	x		
Weijun Wang*	NRC/EGCA	Structural			
Mahesh Chawla*	NRC/DDRL	Project Manager	x		x
Michael Scott*	NRC/SSIB	Branch Chief	x		x
Leon Whitney	NRC/SSIB	Sr Rx Sys Eng	x		
Joe Golla	NRC/PGC	GSI-191 PM	x		

Name	Organization	Title/ Area	Project Over-view 10/4/2006	Audit Onsite Entrance 10/24/2006	Audit Onsite Exit 10/27/2006
Ruth Reyes	NRC/SSIB	Rx Sys Eng	x		
Lauren Killian	NRC/Region III	RES Assignmt	x	x	x
John Adams	NRC/Region III	Sr Res Insp		x	x
Duane Karjala	NRC/Region III	Res Insp		x	x
Steve Thomas*	NMC/Prairie Island	Eng. Supervisor	x	x	x
Rick Zyduck	NMC/Prairie Island	Mgr - Design Engineering	x	x	x
Jeff Kivi*	NMC/Prairie Island	Reg Compl		x	x
Dwight Mims	NMC/Prairie Island	Site Ops Dir		x	x
Tom Palmisano	NMC/Prairie Island	Site VP		x	x
Mike Staley	NMC/Prairie Island	Design Engrng	x	x	x
Amy Hazelhoff	NMC	Lic Engineer	x		
Ed Weinkam	NMC	Dir Nucl Lic Reg Serv	x		
Gabe Salamon	NMC	Nucl Lic Mgr	x		
Tom Kendall	NMC/Point Beach	Design Eng		x	
James Wong	NMC/Palisades	Design Eng			x
Chris Kudla	PCI	Mechnical Eng			x
Jim Bleigh	PCI	Engin Sys Mgr	x		x
Mike Carlson	NMC	Eng Director		x	
Ray Phan	Areva NP	Strainer Test Eng	x	x	
Robert Janecek	Sargent & Lundy	Mech Eng		x	
Leo Kaushansky	Sargent & Lundy	Arch Engineer	x		x
Kevin McNamee	Westinghouse	Engineer	x		x

* Participated in a final audit exit telephone conference call on January 3, 2007

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 emergency core cooling system (ECCS) pumps

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

During the course of the audit, staff concluded that the PI new strainer design provides ample NPSH margin but also identified issues related to the licensee's implementation and plans that need to be assessed as part of the licensee's completion of corrective actions for GL 2004-02 [1]. These are discussed and identified as open items throughout this audit report, and were communicated to the licensee during the audit meetings and telephone conferences. The licensee is expected to address and document resolution of these open items in conjunction with its efforts to respond to GL 2004-02 [1].

1.2 Bulletin 2003-01 Response

To reduce post-LOCA sump clogging risk during 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" [4] to all PWR licensees. Overall, the Prairie Island Bulletin 2003-01 response [5], dated August 6, 2003, was clear, comprehensive and of higher than average quality. It specifically addressed the six interim compensatory measure (ICM) categories of Bulletin 2003-01. In addition, PI provided a subsequent response [6] that addressed Westinghouse Owners Group WCAP-16204, "Evaluation of Potential ERG and EPG Changes to Address NRC Bulletin 2003-01 Recommendations," [7] which evaluated eleven candidate operator actions (COAs).

Bulletin 2003-01 [4] discussed six categories of interim compensatory measures (ICMs): (1) operator training on indications of and responses to sump clogging, (2) procedural modifications if appropriate, that would delay the switch over to containment sump recirculation (e.g., shutting down redundant pumps that are not necessary to provide required flows to cool the containment and reactor core, and operating the containment spray system (CSS) intermittently), (3) ensuring that alternative water sources are available to refill the refueling water storage tank (RWST) or to otherwise provide inventory to inject into the reactor core and spray into the containment atmosphere, (4) more aggressive containment cleaning and increased foreign material controls, (5) ensuring containment drainage paths are unblocked, and (6) ensuring sump screens are free of adverse gaps and breaches.

The licensee stated that Prairie Island has the following design features in place:

(1) The absence of significant amount of fibrous material that could be a potential source of debris that could reach the sump screens;

(2) Current plant procedures with provisions to secure containment spray during the injection phase if containment pressure has been reduced below a predetermined value;

(3) Containment spray pumps that do not take a suction from the containment sump and do not operate during the recirculation phase;

(4) A requirement that only Service I level coatings can be applied inside of containment; and

(5) Absence of major obstructions on the containment floors that could prevent flow from reaching the containment sump screens. The flow paths from the upper levels of containment to the lower levels are relatively free; i.e., open stairways and/or floor grating. The reactor coolant pump and steam generator vaults have large openings that allow all liquid to spill to the containment basement elevation.

In response to Bulletin 2003-01, the licensee stated that Prairie Island had implemented the following ICMs:

(1) Although licensed operators were considered thoroughly trained on the transfer to recirculation procedures, both in the classroom and in the simulator, enhanced training relative to indications of and responses to sump clogging were implemented - ICM category #1;

(2) Briefings of operators and appropriate Technical Support Center staff were conducted to heighten sensitivity to awareness of the issues, compensatory measures that have been implemented, system indications that can be used to monitor recirculation system performance, and guidance on mitigation strategies from postulated debris blockage - ICM category #1;

(3) The minimum refueling water storage tank (RWST) level for normal operation has been administratively increased - ICM category #2;

(4) Instructions were developed to begin refilling the RWST after recirculation has been commenced, in lieu of waiting until a problem with recirculation develops - ICM category #3;

(5) Additional measures were implemented to provide more aggressive requirements for containment closeout and foreign material controls.[1] ;

(6) The containment closeout procedures were enhanced to include specific verifications that containment drainage paths are not blocked - ICM category #5;

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[1]The staff review of these procedures indicated that further enhancements were still required as discussed in Section 3.4 (page 19) of this report - ICM category #4

(7) The post-outage containment inspection procedure specifically looked at the sump trash rack for evidence of structural distress or abnormal corrosion - ICM category #6; and

(8) During the monthly containment entry after issuance of the bulletin, the previously installed sump trash racks were specifically inspected for any adverse gaps or breaches - ICM category #6.

Mitigation strategies were implemented as follows:

(a) Operators could maintain flow to the core using an alternate injection flow path with the charging system;

(b) Operators could secure the recirculation flow for a limited period of time, which might allow the postulated debris to settle out of the blockage location and free the flow path, or the re-initiation of the recirculation flow may dislodge the debris;

(c) Operators could realign the system to provide a different flow path such as the high-head recirculation could be aligned to the reactor vessel injection flow paths. Or, as another example, the high-head recirculation flow path could be used in lieu of the low-head recirculation flow path;

(d) If blockage cannot be cleared, then the operators would transition to the emergency operating procedure for a loss of emergency coolant recirculation that provides for a more aggressive cooldown and depressurization following a small break LOCA.

The Westinghouse Owners Group WCAP-16204 (issued March 2004) [7] discussed eleven Candidate Operator Actions: (1) secure one or both containment spray pump(s) before recirculation alignment; (2) manually initiate one train of containment sump recirculation earlier; (3) terminate one train of high-head injection after recirculation alignment; (4) terminate residual heat removal (RHR) pump operation prior to recirculation alignment; (5) make preparations to refill the RWST; (6) inject more than one RWST volume from refilled/diluted RWST or by bypassing RWST; (7) provide more aggressive cooldown and depressurization following a small break LOCA; (8) provide guidance on symptoms and identification of containment sump blockage; (9) develop contingency actions in response to: containment sump blockage, loss of suction, and cavitation; (10) terminate high-head injection prior to recirculation alignment; and (11) delay containment spray actuation for small break LOCA in ice condenser plants.

The licensee stated that the majority of COAs in WCAP-16204 had been previously implemented at PI in response to the actions the licensee committed to based on the Bulletin. Additional actions that the licensee implemented were COA #7 (including an emphasis on aggressive cooldown and depressurization in future periodic operator training) and COA #9 (implementing the Westinghouse Owners Group Sump Blockage Control Room Guidance into plant procedures). The WCAP-16204 position on COA #4 and COA #10 determined the actions were not considered to be risk beneficial and as such, were not implemented by the licensee. In addition, COA #11 was not applicable to Prairie island.

Based on the Prairie Island responses, the NRC staff believes that the Prairie Island Option 2 Bulletin response for compensatory measures that were or were to have been implemented will reduce the interim risk associated with potentially degraded or nonconforming ECCS recirculation functions. With the exception of several one-time actions, the licensee stated that the compensatory actions will be made permanent. The licensee indicated that one of these changes, increasing the minimum level in the RWST, will require a revision to technical specification surveillance requirement 3.4.5.1. The submittal of this technical specification change is part of Open Item 2.2-1 (page 8) of this report. Based on the licensee's response, the NRC staff considers PI to be responsive to and meet the intent of Bulletin 2003-01 [8].

1.3 Generic Letter 2004-02 September 2005 Responses

In response to the NRC staff's information request in GL2004-02, PI provided a set of responses including a 90-Day Response on March 7, 2005 [9], a Response to Request for Additional Information on July 11, 2005 [10], a letter dated August 31, 2005 which discussed the licensee's plans for conducting analyses and modifications to ensure adequate containment recirculation sump performance [11], and a supplemental response on December 13, 2005 [12].

The licensee's response included a brief overall plant description and subsequently addressed the GL 2004-02 information request [11]. The licensee described the activities performed to bring all aspects of PI into full compliance regarding the issues associated with GSI-191, including the following [11]:

- containment walkdowns to quantify potential debris sources
- debris generation and transport analyses
- calculation of required and available net positive suction head
- defining screen requirements
- screen structural analysis
- procedures to address sump screen blockage
- chemical effects analysis
- downstream effects analyses
- upstream effects evaluation

The licensee stated that the methodology used for analyzing the adequacy of the containment sump recirculation performance was Nuclear Energy Institute (NEI) 04-07 [16]. A detailed summary of the licensee's analyses was presented in the GL 2004-02 response [11]. The licensee stated that the methodology used for performing the containment walkdown was NEI 02-01, Rev. 1 [53], as modified by the NRC staff's safety evaluation.

The licensee stated that, based upon the results from the debris generation and transport analyses, modifications to the existing sump configuration and other areas of the plant are being implemented [11]. The licensee stated that passive replacement sump strainers will be installed having a surface area of approximately 800 square feet and 0.095-inch diameter perforations [11]. The licensee's generic letter response provides diagrams of the proposed strainer design.

The licensee's GL 2004-02 response [11] contained the following four commitments:

1. PI will evaluate and modify as appropriate the emergency core cooling system (ECCS) to support long-term decay heat removal and resolve the issues identified in GL 2004-02 by December 31, 2007.

2. PI will complete verification of downstream components for long-term wear by December 31, 2005, and, if necessary, the GL 2004-02 response will be amended if the final design deviates significantly from the planned design.

3. PI will submit a license amendment request to change Technical Specification Surveillance Requirement 3.5.2.8 to reflect the replacement strainer design by December 31, 2005[2].

4. PI will perform measurements to estimate the amount of latent dirt and dust inside containment every other refueling outage. Assuming that the results indicate that housekeeping practices provide an adequate level of cleanliness, the licensee stated that the frequency of these latent debris measurements may be relaxed in the future.

The discussion in the licensee's GL 2004-02 response is generally based upon underlying analyses and calculations that the staff reviewed in detail during the audit review. As a result, the staff will defer discussion on the technical issues addressed in the GL 2004-02 response to the appropriate audit report sections that address the licensee's underlying analyses.

2.0 DESCRIPTION OF INSTALLED/PLANNED CHANGES

In response to NRC GL 2004-02, PI removed the existing trash racks and installed a new Sure-Flow® strainer designed by Performance Contracting, Inc (PCI). No screens were used in the previous PI design, while the Sure-Flow® strainer is an advanced configuration intended to be very resistant to potential blockage. The diameter of the strainer holes is intended to ensure that any debris that can pass through the strainer will not cause blockage or excessive wear to components in the ECCS flow path or the containment spray system. This includes pumps, valves, nozzles, and the nuclear fuel. The new strainer is a passive component, and the only identified failure mode is structural failure. The strainer assembly is designed specifically for PI and is intended to provide both debris filtering and vortex suppression.

The following text in Section 2.1 is for the most part excerpted from various parts of the Prairie Island (PI) description of Engineering Change EC0378 (04RH04) [14]. Figures 1, 2 and 3 are drawings representing the major features of the new sump design. These changes represented a significant part of the audit review.

2.1 Containment Sump Strainer Modification

The intent of the modification is to perform the hardware changes required to bring PI into full resolution with NRC GSI-191. This modification replaces the existing Metcon grating/screens for the PI B-Sumps located outside the missile shield walls on the basement floor of the Unit 1

[2] The completion date for this commitment was subsequently extended to December 31, 2006, by a letter dated December 13, 2005 [12].

and Unit 2 Containment buildings. To prevent debris from entering the open sump, a standard floor grate that extends from the floor in an A-frame shape with 3/4 x 3-11/16 inch openings is provided to completely cover the sump inlet. The grate provides approximately 49.2 ft^2 of available flow area. Due to the size of the screen openings, only large pieces of debris were prevented from entering the sump. In addition, the sump is surrounded by a six-inch high curb which is used to prevent sediment from entering the pit. The modification installs a passive, safety-related Sure-Flow® Strainer assembly engineered and manufactured by Performance Contracting, Inc (PCI). The strainer arrangement for each of PI Units 1 and 2 consists of two strainer trains of Sure Flow® Strainer modules connecting to a common sump pit cover plate designed to form a suction chamber in the existing sump pit. The modifications was installed on Unit 1 and is scheduled to be installed on Unit 2 during the 2006 fall refueling outage.

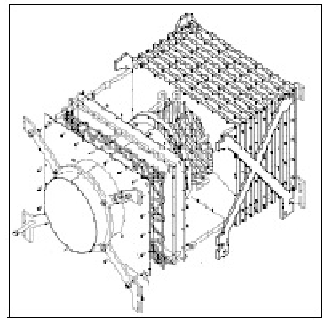

Figure 1 Single PCI Strainer Module

The effective surface area of the new strainer for each train is 413.65 ft^2, for a total of 827.3 ft^2. This will reduce flow velocity through the screens to 0.014 fps. The strainer configuration is designed to limit the head loss to 10 feet during post-LOCA design conditions.

There are 10 modules in each strainer train (Figure 3), a core tube, and mounting tracks. The modules are essentially identical with the only difference being the hole sizes in the core tube. Each module is independently supported. The modules are connected with thin gauge stainless steel bands that are used to prevent debris from entering the system between the two modules. This connection permits relative motion in the axial direction as the core tube can slide relative to the stainless steel bands.

Each module (Figure 1) is made of stainless steel perforated plate with hole-diameter of 0.085 inch. The perforated sheets are riveted together along the outside edge and shop welded to a core tube along the inner edges. The modules are located approximately 3 inches above the containment floor. As such, the six-inch high curb surrounding the sump no longer provides a barrier to prevent sediment from entering the strainers. The sump is now totally enclosed by the sump pit cover plate preventing material from falling directly into the sump without passing through the strainer assemblies (Figure 2).

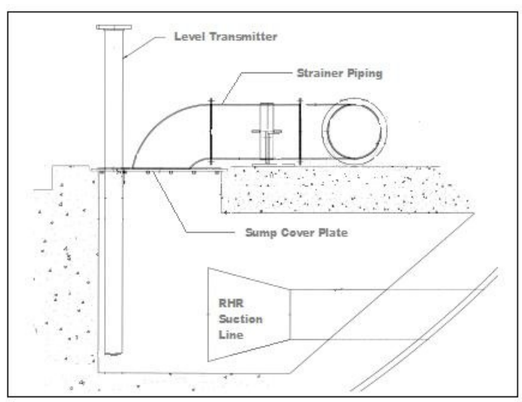

Figure 2 Containment Sump B Side View

The core tube is a 12 inch diameter, 16-gauge, stainless steel pipe. The core tubes of each module are connected together by means of a coupling sleeve fitted over the core tubes and secured by a latch. The core tube has “windows” cut in the wall to admit flow of strained water from the inside of the perforated sheets. The modules are pin connected to a mounting track, which in turn is bolted to the containment slab. The mounting track is made of structural shapes: angles and plates. The strainer design allows for disassembly, replacement of modules, or addition of future modules as needed. A 14 inch schedule 10 stainless steel pipe, double elbows (one vertical, one horizontal with an intermediate straight piece) and 14”x12” eccentric reducer sloped upwards from the first module delivers the strained water into the sump by penetrating through the sump cover plate. The vertical elbow attached to the sump cover plate is removable to allow access into the sump during outages for inspection and testing.

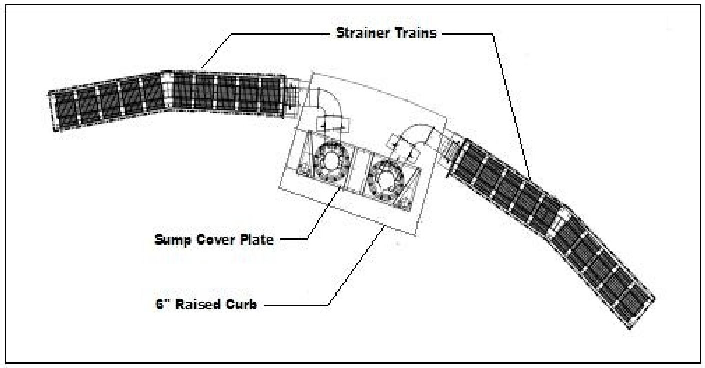

Figure 3 Prairie Island Strainer Assembly Top View

Two 6-inch pipe-stands for the B-Sump level transmitters in each of Unit 1 and Unit 2 will be relocated to the southeast and southwest corners of the sump cover plate and supported on the 6-inch wide curb 1’-3” above the sump bottom and restrained using new seismic restraints. The standpipe has seven 1-inch diameter holes above the bottom of the strainer core tube that will be sealed to prevent ingestion of air into the sump. The remaining open holes are covered with screens containing 0.063 inch square openings, which are less than the new strainer perforations. These level instruments are considered backups and would be used only as indication to inform the operator that there was sufficient level in the sump to switch from the injection to recirculation phase.

Other changes associated with this modification included capping abandoned Waste Liquid Disposal Pipes located in the sump, and relocating and/or reconfiguring several existing components to remove interferences associated with the new strainer installation.

2.2 Technical Specifications Change

Technical Specification Surveillance Requirement 3.5.2.8 requires verification that the “containment sump suction inlet trash racks and screens show no evidence of structural distress or abnormal corrosion.” Since the modification removed the trash rack and is installing a strainer assembly, the surveillance requirement needs to be revised to reflect newly installed strainers. As part of the licensee’s response to GL 2004-02, a commitment was made to revise the surveillance requirement. This Technical specification change was scheduled to be submitted to the NRC by December 31, 2006 after installation of the new strainer on Unit 2. The submittal of the technical specification change, including the associated technical specification change on minimum RWST level discussed in the Bulletin 2003-01 Response Section (page 4) of this report and evaluated by the staff as part of the staff audit team’s NPSH review (page 42), was identified as an open item pending submittal of the technical specification changes to the NRC. Following the audit on December 14, 2006, NMC submitted a License Amendment Request to Revise Technical Specifications in Support of Containment Sump Resolution [57] which addressed the above items and is being reviewed by staff for adequacy. As a result this item is no longer an open item in this audit report.

3.0 BASELINE EVALUATION AND ANALYTICAL REFINEMENTS

3.1 Break Selection

The objective of the break selection process is to identify the break size and location that presents the greatest challenge to post-accident sump performance. Sections 3.3 and 4.2.1 of the Nuclear Energy Institute (NEI) Guidance Report (GR) [16] and NRC Safety Evaluation (SE) [17] provide the criteria to be considered in the overall break selection process in order to identify the limiting break. In general, the principal criterion used to define the most challenging break is the estimated head loss across the sump screen. Therefore, all phases of the accident scenario must be considered for each postulated break location: debris generation, debris transport, debris accumulation, and sump screen head loss. Two attributes of break selection that are emphasized in the approved evaluation methodology and can contribute to head loss are: (1) the maximum amount of debris transported to the screen; and (2) the worst combinations of debris mixes that are transported to the screen. 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.

Nuclear Management Company (NMC) Calculation No. 2005-00061, "GSI 191 Debris Generation Calculation" [21] documents the assumptions and methodology the licensee applied as part of the overall break selection process, and to determine the limiting break for Prairie Island Nuclear Generating Station (PI).

Staff Evaluation

The NRC staff reviewed the licensee's overall break selection process and the methodology applied to identify the limiting break. Specifically, the NRC staff reviewed NMC Calculation No. 2005-00061, "GSI 191 Debris Generation Calculation" [21] against the approved methodology documented in Sections 3.3 and 4.2.1 of the SE and GR. The NRC staff observed that the licensee's break selection evaluation was generally performed in a manner consistent with the SE-approved methodology. Deviations from the staff-approved methodology were considered to be reasonable based on the technical basis provided by the licensee. A detailed discussion is provided below.

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

- Case No. 1 - Breaks in the reactor coolant system (RCS) with the largest potential for debris.
- Case No. 2 - Large breaks with two or more different types of debris.
- Case No. 3 - Breaks with the most direct path to the sump.
- Case No. 4 - Large breaks with the largest potential particulate debris to insulation ratio by weight.

Case No. 5 - Breaks that generate a “thin bed” - high particulate coincident with a 1/8" thick fiber bed.

The spectrum of breaks considered by the licensee is consistent with that recommended in the SE, and is also consistent with regulatory position 1.3.2.3 of Regulatory Guide 1.82, Revision 3 [18].

The SE also describes a systematic approach to the break selection process, which includes beginning the evaluation at an initial location along a pipe, generally a terminal end, and stepping along in equal increments, sized at 5 feet maximum, considering breaks at each sequential location.

The PI plant configuration consists of two reactor coolant loops, A and B, each consisting of a reactor coolant pump, a steam generator, and reactor coolant piping. On each unit, the B Loop also contains the pressurizer and associated piping. The loops are located in the containments within concrete vaults. Reflective metal insulation (RMI) is used exclusively on all reactor coolant system components.

PI did not apply a 5-foot incremental step approach to the break selection process due to the plant physical configuration as it related to the expected size of the zones of influence (ZOIs) for the insulation types involved. That is, the ZOIs essentially included the entire loop vault. The staff reviewed this approach as it applied to the PI plant configuration, and agrees that performing the analysis by considering 5-foot increments is not necessary for the reason stated by the licensee. This approach is further discussed in the Debris Generation/Zone of Influence section of this report (page 13).

The licensee considered breaks in all primary reactor coolant system piping having the potential to rely on ECCS sump recirculation. Small-bore piping was determined not to be bounding, so only piping 2 inches in diameter and larger was considered. The NRC staff found this to be consistent with the Section 3.3.4.1 of the SE, which states that breaks less than 2 inches in diameter need not be considered. For PI, feedwater and main steam piping was not considered since recirculation flow is not required for mitigation of breaks in this secondary-side piping.

The licensee evaluation identified three break locations that provided limiting conditions for each of the five break cases above:

Break S1: A hot-leg break at the steam generators inlet in the B Loop vault. This break is the limiting break from a debris generation standpoint because it affects the most RMI insulation on the major equipment in the vaults. This break is the limiting break for SE break selection criteria Case 1, Case 2, Case 4, and Case 5. The B Loop vault is also located closer to the sump, with a more direct path than the A Loop vault.

Break S2: Locations identified with the most direct path (close proximity) to the recirculation sump, which is SE break selection Case 3. Different break locations were identified for each unit, as follows:

a. For Unit 1, this break would be in the 12-inch safety injection line from the accumulator.
b. For Unit 2, this break would be in the 8-inch Train B RHR suction line.

Break S3: The pressurizer surge line at the connection to the pressurizer. This break was chosen as a large break that would affect all of the pressurizer's and associated piping's insulation. This break was found to be non-limiting for debris generation.

Based on a review of the type and quantity of insulation present, the mix of debris generated, and the proximity to the sump; the bounding postulated break was determined to be a break in the hot leg of RCS Loop B. Vault B, which houses Loop B of the RCS, was determined to have the larger potential to generate insulation debris, primarily because this vault also contains the pressurizer and the pressurizer surge line. Vault B is also located closer to the recirculation sump. Therefore, the licensee concluded that the potential for debris to transport to the recirculation sump would be greater for Vault B than for Vault A. An additional break was also included for each unit outside the vault that would allow for easy transport of debris to the sump.

The staff finds the licensee's evaluation of break selection to be acceptable. The evaluation was generally performed in a manner consistent with the SE-approved methodology. Deviations from the staff-approved methodology were judged by the staff to be acceptable based on the technical basis provided by the licensee.

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) the amount of debris generated by the break jet forces; and, (3) the size characteristics of the postulated debris. Sections 3.4 and 4.2.2 of the GR [16] and the NRC safety evaluation (SE) [17] provide the methodology to be considered in the ZOI and debris generation analytical process.

The GR baseline methodology incorporates a spherical ZOI based on material damage pressures. The size of the spherical ZOI is based, in general, on experimentally-deduced destruction pressures as they relate to the ANSI/ANS 58.2 1988 standard [20]. Once the ZOI is established, the types and locations of all potential debris sources (insulations, coatings, dirt/dust, fire barrier materials) can be identified using plant-specific drawings, specifications, walkdown reports or other such 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 GR 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 ZOI is calculated, then 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. As discussed in Section 4.2.2 of the SE, the NRC staff accepted the application of these proposed refinements for PWR sump analyses for GL 2004-02 [1] corrective actions.

Staff Evaluation

The staff reviewed the licensee's ZOI and debris generation evaluations and the methodology applied. Specifically, the staff reviewed NMC Calc 2005-0061, Rev. 1 "GSI 191 Debris

Generation Calculation" [21] against the approved methodology documented in Sections 3.4 and 4.2.2 of the staff's SE. The NRC staff found the licensee's evaluation to be consistent with the approved methodology.

The licensee applied the ZOI refinement discussed in Section 4.2.2.1.1 of the SE, which allows the use of debris-specific spherical ZOIs. Using this approach, the amount of debris generated within each ZOI is calculated and the individual contributions from each debris type are summed to arrive at a total debris source term.

Section 3.4.2.2 of the SE provides guidance for selection of a ZOI. The entries in Table 3-2 of the SE relevant to the material types for PI show the following:

Table 2 Revised[3] Damage Pressures and Corresponding Spherical ZOI Radii

Insulation Types	Destruction Pressure (psig)	ZOI Radius/ Break Diameter
Transco RMI	114	2.0
Nukon™ with standard bands	6	17.0
Mirror® with standard bands	2.4	28.6

For insulation debris, the licensee assumed ZOIs sized in accordance with this guidance in the SE. When these ZOIs were overlaid onto composite piping plans at the selected break locations, it was found that the ZOI would encompass nearly the entire vault, with the exception of the Transco RMI with its much smaller ZOI relative to the vault size.

The licensee concluded that nearly all of the insulation within the PI containment vaults that could be damaged is RMI. Most of the RMI is Mirror® with standard bands manufactured by Diamond Power Specialty Corporation. One exception is the insulation on the Unit 1 steam generators, which is Transco RMI. The licensee debris generation report also noted some potential quantities of LOCA-generated fibrous debris that would be quite small compared to the estimated latent fiber; and some calcium silicate insulation encapsulated within steel plate and located outside of the various ZOIs and therefore not a potential source of debris.

The staff considers the application of the PI-specified destruction pressures to be acceptable. Because the application of the spherical ZOI nearly encompasses the respective vaults, the quantities of debris are limited by the vault walls rather than the ZOI, with the exception of Transco RMI on the Unit 1 steam generators.

The PI-predicted generated debris is summarized in Table 7.1-1 of NMC Calc 2005-0061, Rev. 1 "GSI 191 Debris Generation Calculation [21]," for each of the four breaks analyzed. A summary of the debris is provided here for Break S1, which is the bounding break.

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[3] Table 3-2 of the SE lists the revised (compared to Table 3-1 of the GR) destruction pressures and the corresponding ZOI diameters computed as described in Appendix I to the SE for the reference cold-leg break.

Table 3 Bounding Break Insulation Debris Quantities

Insulation	Unit 1	Unit 2
Mirror® RMI (foils and jacketing)	27,735 ft^2	65,453 ft^2
Transco RMI (foils and jacketing)	2,855 ft^2	0 ft^2
Miscellaneous Fibrous Material	0.014 ft^3	0.017 ft^3
Foreign Material	177.9 ft^2	228.8 ft^2

Other sources of debris at PI include coatings debris, latent debris, and chemical effects precipitants. The coating debris generation is discussed separately in Section 3.8 (page 49), latent debris is discussed in Section 3.4 (page 19), and chemical effects precipitants are discussed in Section 5.4 (page 68). The staff reviewed the entries in this Table for the various items identified and found that the values projected are acceptable based on the acceptability of the break selection/ZOI methodology outlined above and the physical conditions at PI.

NMC Calculation No. 2005-02881 [22], provides debris size distributions for the Mirror® and Transco RMI debris. The Mirror® RMI size distribution was based on the Boiling Water Reactor Owners Group (BWROG) debris generation data, as presented in the SE (specifically, Figure VI-4 of the SE Appendix VI). For the Transco RMI, a generic size distribution was specified, i.e., 75% for small debris (< 4") and 25% for larger debris (≥ 4"). Other debris types were considered to be very fine debris. These size distributions are acceptable based on the application of the insulation-specific information and conservatisms as referenced in the SE.

In conclusion, the staff finds the licensee's ZOI evaluation to be acceptable. The evaluation was performed in a manner consistent with the SE-approved methodology. The licensee applied the ZOI refinement discussed in Section 4.2.2.1.1 of the SE, which allows use of debris-specific spherical ZOIs. The licensee applied material-specific damage pressures and corresponding ZOI radius/break diameter ratios as shown in Table 3-2 of the staff SE. The staff therefore found that the licensee provided an adequate level of technical justification with respect to ZOI analyses.

3.3 Debris Characteristics

In evaluating the licensee's analysis of debris characteristics, the staff reviewed the following documents:

- Calculation 2005-00061, "GSI 191 Debris Generation Calculation," referred to as the debris generation calculation [21],
- Calculation 2005-02881, "Post-LOCA Debris Transport to Containment Sump for Resolution of GSI-191," referred to as the debris transport calculation [22],
- Calculation ENG-ME-600, "Unit 1 Containment GSI-191 Walkdown Results," referred to as the containment walkdown report [23], and
- Calculation ENG-ME-657, Revision 2, "Sump B Strainer Head Loss Determinations," referred to as the head loss test report [24].

Several types of debris are present in the Prairie Island containment buildings, including Mirror® and Transco stainless steel reflective metallic insulation (RMI), miscellaneous fibrous debris, various types of qualified and unqualified coatings, foreign materials, and latent fibrous and particulate debris. The characteristics assumed by the licensee for each type of debris are reviewed by the staff below, with the exception of qualified and unqualified coatings (the characteristics of which are discussed in the Coatings Debris Characteristics Section (page 50) of this report).

3.3.1 Mirror® Stainless Steel Reflective Metallic Insulation

The licensee assumed a size distribution for Mirror® RMI debris based on the distance from the analyzed pipe break to the target insulation [22]. The zone of influence (ZOI) was divided into three subregions, for which separate debris size distributions were applied. The licensee stated that the methodology supporting this debris size distribution was derived from Appendix VI in the staff's safety evaluation (SE) [17]. Figure VI-4 in this appendix provides data for Mirror® RMI debris in the range of destruction pressures from 0 to 120 psi. However, as the licensee noted, the test data in Appendix VI were based on air jet testing rather than two-phase steam/water jets. Therefore, consistent with the discussion in Section 3.4.2.2 of the staff's SE, the licensee applied a 40% reduction to the destruction pressures (Pdest) given in Appendix VI to the SE [22]. The resulting Mirror® RMI debris size distribution arrived at by the licensee is shown in the following table:

Table 4 Assumed Size Distribution for Mirror® RMI Debris [22]

Debris Size	Within 2.9D of Break (Pdest ≥ 72 psi)	Between 2.9D and 3.7D from Break (72 psi < Pdest ≤48psi)	Beyond 3.7D from Break (Pdest < 48 psi)
Less than 2”	100%	3%	1%
Between 2” and 6”	0%	8%	4.5%
Greater than 6”	0%	89%	94.5%

The staff considers the Mirror® RMI debris size distribution assumed by the licensee to be acceptable because the debris size distribution follows the conservative guidance in Appendix VI to the SE and incorporates the 40% reduction in destruction pressure to account for uncertainties associated with two-phase steam/water jets that is discussed in Section 3.4.2.2 of the staff's SE.

3.3.2 Transco Stainless Steel Reflective Metallic Insulation

The licensee assumed that 75% of the Transco RMI debris would be less than 4 inches in size, referred to as small pieces, and that the remaining 25% would be greater than 4 inches, referred to as large pieces [22]. The licensee stated that this size distribution is consistent with guidance provided in Section 3.4.3.3.2 of NEI 04-07 [22].

The staff considers the licensee's assumed size distribution for Transco RMI to be acceptable because it follows the guidance in NEI 04-07 that was approved by the NRC staff's SE.

3.3.3 Miscellaneous Fibrous Debris

Several sources of miscellaneous fibrous debris were noted in the debris generation and transport calculations. These sources of fibrous material include small quantities of fiber cloth on cables, fibrous vent fan expansion bellows, and other miscellaneous fibrous material [21]. In the debris transport calculation, volumes were calculated for these sources of fibrous debris [22].

For the fiber cloth on cable insulation, the licensee assumed that the material properties of commercial low-density fiberglass are applicable (i.e., an as-fabricated density of 2.4 lb_m/ft^3, a material density of 159 lb_m/ft^3, and a characteristic diameter of 7 μm) and that this insulation has a thickness of 1/16 of an inch [22]. Based upon the debris surface areas taken from the debris generation calculation [21], a debris volume of approximately 0.12 ft^3 was calculated for the fiber cloth on cable insulation for each unit [22]. The licensee assumed that the fiber cloth on cable insulation would be destroyed into fines [22].

The licensee stated that the vent fan bellows are constructed from an asbestos product, the exact composition of which is unknown. Based upon the debris surface areas taken from the debris generation calculation [21], a debris volume of 0.098 ft^3 was calculated for vent fan bellows debris for each unit [22]. The licensee assumed that the vent fan bellows would be destroyed into fines. Based on guidance in NEI 04-07, the licensee stated that a significant range of debris properties is applicable to asbestos and that no guidance is provided to select particular values. The licensee subsequently stated that the following values were assumed for vent fan bellows debris: an as-fabricated density of 7 lb_m/ft^3, a material density of 153 lb_m/ft^3, and a characteristic diameter of 1 μm [22].

The licensee stated that the quantity of other miscellaneous fibrous material is approximately 0.015 ft^3 per unit [22]. The licensee further stated that this fibrous material was assumed to be commercial low-density fiberglass insulation, having an as-fabricated density of 2.4 lb_m/ft^3, a material density of 159 lb_m/ft^3, and a characteristic diameter of 7 μm.

The staff noted that the licensee's calculations did not provide a strong technical basis for the assumed characteristics of these sources of miscellaneous fibrous debris. However, the assumed characteristics generally appear reasonable and miscellaneous fibers appear to make up a small fraction of the overall volume of fibrous debris within containment (i.e., less than 5% of the total volume, according to the licensee's data). Furthermore, the licensee conservatively assumed that 100% of the miscellaneous fiber would become fine debris during an accident, and that 100% of the miscellaneous fiber would transport to the recirculation sump strainers. Thus, based upon the fact that the licensee's debris characteristics assumptions appear reasonable and the fact that the licensee included significant conservatism in its analytical treatment of miscellaneous fibrous debris, the staff considers the assumed characteristics for miscellaneous fibrous debris discussed above to be acceptable.

3.3.4 Foreign Materials

The licensee stated that foreign materials that may be found in containment include self-adhesive labels, stickers, and placards [21]. The licensee indicated that foreign materials are accounted for by assuming complete blockage of a surface area on the replacement strainer that is equivalent to 75% of the sum of single-sided areas of all foreign materials [21]. The licensee's debris generation and transport calculations stated that this methodology is consistent with Section 3.5.2.2.2 of the staff's SE on NEI 04-07.

The staff considers the licensee's assumptions in the debris generation and transport calculations regarding the characteristics of foreign materials to be acceptable because they are generally consistent with the guidance of NEI 04-07, as approved by the staff's SE. However, the staff noted that the licensee's strainer test plan [24] accounted for foreign materials by adding surrogate debris rather than allowing sacrificial strainer area as per the SE. Although the test plan's treatment of foreign materials was inconsistent with the discussion in the debris generation and transport calculations, testing with surrogate debris is also considered to be an appropriate general methodology by the staff's SE if the testing is performed in a manner that is prototypical of the actual plant environment. The specific details of the licensee's head loss testing are reviewed in the Prototypical Head Loss Testing Section (page 27) of this audit report.

3.3.5 Latent Debris

The licensee stated that latent debris includes dirt, dust, lint, and fibers [19]. The licensee assumed that 15% of latent debris is composed of fibrous debris, based upon guidance in Section 3.5.2.3 of the staff's SE on NEI 04-07 [17]. The licensee assumed that latent debris is composed of small fines and stated that this assumption is based upon Section 3.6.3 of the NRC staff's SE on NEI 04-07 [17].

The staff considers the licensee's assumptions regarding the characteristics of latent debris to be acceptable because they are consistent with the guidance in NEI 04-07, as approved by the staff's SE.

3.3.6 Information-Only Head Loss Calculation

The staff did not perform a detailed review the debris characteristics that were solely associated with the information-only head loss calculation presented in the debris transport calculation [22]. Although it appeared that several of the debris characteristics assumed in the information-only head loss calculation were not fully justified, these unverified assumptions did not adversely affect the strainer performance analysis because head loss testing (rather than an analytical head loss calculation) was used to validate the replacement strainer design.

3.3.7 Debris Characteristics Conclusion

The staff reviewed the licensee's assumptions concerning the characteristics of debris sources that are present in the Prairie Island containment buildings, including Mirror® and Transco stainless steel reflective metallic insulation (RMI), miscellaneous fibrous debris, foreign materials, and latent fibrous and particulate debris (note that the characteristics of qualified and unqualified coatings debris are discussed separately in the coatings debris characteristics section (page 50) of this report). The staff did not perform a detailed review of the debris characteristics associated solely with the information-only head loss calculation since this calculation was not relied upon to validate the replacement strainer design. On the basis of the preceding detailed discussion for Section 3.3, the staff generally found the licensee's debris characteristics assumptions to be acceptable, and no open items were identified.

3.4 Latent Debris

The objective of the latent debris evaluation process is to provide a reasonable approximation of the amount and types of latent debris existing within the containment and its potential impact on sump screen head loss. Section 3.5 of the NEI GR [16] and the SE [17] provide a methodology to be considered for evaluation of latent debris. In general, the GR outlined the following five generic activities to quantify and characterize latent debris inside containment: (1) estimate horizontal and vertical surface area; (2) evaluate resident debris buildup; (3) define debris characteristics; (4) determine fractional surface area susceptible to debris buildup; and (5) calculate total quantity and composition of debris. The Safety Evaluation (SE) provided alternate guidance for sampling techniques and analysis to allow licensees to more accurately determine the impact of latent debris on sump-screen performance.

PI documented the assumptions and methodology the licensee applied to determine the amount, type, and impact of latent debris on sump screen head loss in References [23] and [54]. The latent debris source term was determined through the collection of debris samples from multiple locations throughout the PI containments. Measurements were completed during the last outages prior to the audit (Cycle 23, for each unit). The characterization of latent debris followed the guidance approved in the NRC SE. For additional conservatism, the licensee nominally doubled its latent debris estimate to 200 lb_m for its head loss testing program.

Staff Evaluation

The staff reviewed the licensee's latent debris evaluations and the methodology applied. Specifically, the staff reviewed PI References [23]and [60] against the approved methodology documented in Section 3.5 of the SE.

The evaluation for latent debris at PI was performed in a manner consistent with the NRC SE-approved methodology. The latent debris source term was determined through the collection of debris samples from multiple locations throughout the PI containments. Areas sampled included those that could be exposed to containment spray and/or recirculation flow and areas not exposed to containment spray. Vertical and horizontal surfaces were included. One item of note is that it appears that steam generators (including attached feedwater and main steam piping) and reactor coolant pumps were not specifically identified as being sampled. Samples were taken at a time during the respective refueling outages when the level of dirt and dust would be much higher than during normal power operation. Subsequent to the sampling activities, but prior to unit startup, extensive cleaning was performed. These cleaning activities are consistent with normal housekeeping practices and associated administrative requirements. To provide an additional level of conservatism, the actual dirt and dust quantities assumed in the strainer performance analysis were much greater than the values determined from the measurements.

The characterization of latent debris followed the guidance approved in the NRC SE, as discussed in Section 3.3.5 of this audit report.

The documentation provided indicates that PI can substantiate that a theoretical uniform thin bed, and the high head losses associated with a thin bed effect, will not be possible with the PI replacement strainers and a conservatively assumed fiber source term. PI uses reflective metallic insulation (RMI) exclusively on system piping and components. No other fibrous insulation materials are included within a ZOI for the limiting breaks analyzed. There are some potential small sources of miscellaneous fiber associated with cable insulation and expansion bellows, which were conservatively assumed to be completely destroyed to the base fiber constituents. Additionally, the documentation reviewed by the staff assumed that all the fibrous material was transported to the strainers, which is also very conservative. This was combined with highest quantity of latent debris found at PI, which was Unit 2, with a total mass of 114.1 lb_m. This quantity of latent debris was used with the replacement strainer surface area of 827.3 ^{ft3} to a calculate a potential uniform bed of thickness on the strainer of less than 0.105 inches. This is less than the minimum thickness of 0.125 inches that is required for a thin bed per NUREG/CR-6224 [25] and the approved GR.

Another consideration that adds conservatism for PI is the known phenomenon whereby the superposition of fiber and RMI may be overly conservative for cases where relatively large amounts of RMI and trace amounts of fiber are estimated to be transported to the sump screens. Experiments have shown that fiber can become caught either within the voids of the RMI bed or at the surface of the RMI bed. This bed can have a significantly larger surface area and a lower approach velocity than the sump screen surface). Fibers may also be captured by larger pieces of RMI on the containment floor that cannot transport to the sump strainer due to insufficient tumbling velocities.

To provide additional confirmation of the PI position on fiber loading of the strainer, the staff used the surface area size of 827.3 ft^2 to calculate the minimum volume of fibrous material that would be required to form a theoretical uniform thin bed. The PI strainer design was found to require a minimum volume of 8.62 ft^3 of fibrous material to produce a theoretical uniform thin bed. When this was compared to the PI latent debris samples, Unit 1 was found to have a 22% margin and Unit 2 a 12% margin to a 0.125-inch thick theoretical uniform thin bed.

Because the PI fibrous debris source term is very low, the licensee assumes that a thin bed can not form. Consequently, certain decisions were made, including conducting head loss tests with coatings in the form of chips versus 10 μ particles. The latent fiber is the primary contributor toward the formation of a thin bed. This makes monitoring and control of latent fiber more important as a small increase in fibrous material could lead to a postulated thin bed. In light of this increased importance, PI has plans for a follow-on assessment of the latent debris. These plans are to include more substantial sampling, so that some items deemed overly-conservative can be reduced, and the latent debris source term reduced accordingly. Additionally, to ensure that the analysis remains bounding, NMC will perform measurements to estimate the amount of latent dirt and dust inside containment every other refueling outage. Assuming the results indicate that the housekeeping practices provide an adequate level of cleanliness, NMC may choose to relax this frequency.

In conclusion, the NRC staff found that the PI evaluation for latent debris was performed in a manner consistent with the SE-approved methodology, and is acceptable. However, because of the plant's sensitivity to latent fiber in the sump performance evaluation, the staff considered that the containment sampling should be strengthened. The staff considered that latent debris sampling, quantification, and monitoring should be covered in a routine and ongoing documented program. The program should include tracking, trending, and appropriate acceptance criteria. This is **Open Item 3.4.1**.

3.5 Debris Transport

The licensee analyzed debris transport in Calculation 2005-02881, "Post-LOCA [Loss-of-Coolant Accident] Debris Transport to Containment Sump for Resolution of GSI-191" [22]. The licensee stated that the calculation is applicable to Prairie Island Units 1 and 2. The transport analysis calculated how much of the debris generated during a postulated accident (computed in Calculation 2005-00061 [21]) would reach the sump strainers and further included an information-only head loss assessment to serve as a preliminary estimate for sizing the replacement sump strainers.

The licensee stated that the debris transport methodology for Prairie Island is based on guidance from NEI 04-07 [16], as modified by the associated NRC Safety Evaluation (SE) [17]. As described further in the calculation, in lieu of performing a rigorous analysis of the phenomena governing debris transport, the licensee essentially assumed that 100% of the generated debris transports to the sump strainers for all debris types [22]. The assumed quantities of debris generated by the most limiting break (i.e., break S1, a 29-inch break on the hot leg in the loop adjacent to the recirculation sump) and the assumed quantities of debris transported to the sump strainers for this break are shown below in Table 5:

Table 5 Assumed Limiting Debris Generation and Transport Quantities [22]

Debris Type	Quantity Generated by Accident		Quantity Transported to Recirculation Sump		Units
	Unit 1	Unit 2	Unit 1	Unit 2	
Miscellaneous Fiber	0.014	0.017	0.014	0.017	ft^3
Qualified Coatings	2.732	3.209	2.732	3.209	ft^3
Unqualified Coatings	2.320	2.030	2.320	2.030	ft^3
Latent Debris	104.4	114.1	104.4	114.1	lb_m
Transco Reflective Metallic Insulation	2416	0	2416	0	ft^2
Transco Reflective Metallic Insulation Jacketing	440	0	440	0	ft^2
Mirror® Reflective Metallic Insulation	23083	54479	23083	54479	ft^2
Mirror® Reflective Metallic Insulation Jacketing	4651	10973	4651	10973	ft^2
Plastic Labels, Stickers, Placards, etc.	117	160.77	117	160.77	ft^2
Light Bulbs	32.46	39.79	32.46	39.79	ft^2

Debris Type	Quantity Generated by Accident		Quantity Transported to Recirculation Sump		Units
Fiber Cloth on Cable Insulation	23.76	23.56	23.76	23.56	ft^2
Vent Fan Expansion Bellows	4.71	4.71	4.71	4.71	ft^2

The staff's review of the licensee's transport calculation recognized the licensee's assumption of 100% debris transport for all types of debris to be an analytical conservatism rather than a best estimate of realistic debris transport behavior. Thus, the licensee's debris transport results represent a conservative upper bound to the amount of debris that would be expected to transport during an actual loss-of-coolant accident (LOCA). Provided that the potential addition of non-transportable or marginally transportable debris to the head loss test flume does not prevent transportable debris from reaching the test strainer (this concern is elaborated in Section 3.6.1.5 of the staff's audit report on Watts Bar Nuclear Plant, Unit 1 [27]), the staff generally considers it a conservative position to assume that 100% of generated debris transports to the sump strainers.

The staff reviewed the licensee's head loss test report [24] to determine the quantities and characteristics of the debris added to the test flume for the design-basis case referred to as Test 1, and to specifically ensure that the large quantity of RMI debris and metallic jacketing debris would not have a nonprototypical impact on debris transport in the head loss test flume. A comparison of these debris quantities to the quantities analytically calculated to transport to the sump strainers is provided in Table 6 below. Note that the design-basis head loss test was performed for both units.

Table 6 Comparison of the Quantities of Analytically Transported Debris to the Quantities Added to the Flume for the Design-Basis Head Loss Test [22, 24]

Debris Type	Quantity Transported		Estimated Test Quantity Scaled to Actual Plant*	Units
	Unit 1	Unit 2		
Miscellaneous Fiber	0.014	0.017	0.1	ft^3
Qualified and Unqualified Coatings	5.052	5.239	6.2	ft^3
Latent Fiber	15.66	17.12	30	lb_m
Latent Particulate	88.74	96.98	170	lb_m
Reflective Metallic Insulation	25,499	54,479	1,200	ft^2
Reflective Metallic Insulation Jacketing	5,091	10,973	0	ft^2
Plastic Labels, Stickers, Placards, etc.	117	160.77	170	ft^2

Debris Type	Quantity Transported		Estimated Test Quantity Scaled to Actual Plant*	Units
	Unit 1	Unit 2		
Light Bulbs	32.46	39.79	200	ft^2
Fiber Cloth on Cable Insulation	0.12	0.12	2	ft^3
Vent Fan Expansion Bellows	4.71	4.71	6	ft^2

* Note that for several debris types, the licensee conservatively increased the quantity actually added to the test flume.

A comparison of the debris quantities in Table 6 shows that the tested quantities of debris generally bound the quantity analytically assumed to have transported, with the exception of RMI debris and RMI jacketing debris, of which only about 2% of the analytically transported quantity was added to the test flume. The reason for this is explained in detail below. The staff concluded that this reduction in the quantity of RMI used for head loss testing (which resulted in a scaled-down quantity of approximately 3 lb_m of RMI debris being added to the test flume) would prevent large quantities of marginally transportable RMI and jacketing debris from impeding significant quantities of more transportable debris from reaching the test strainer.

However, as described below, the staff also considered it appropriate for the licensee to demonstrate that the reduced quantity of RMI and jacketing debris added to the test flume did not underestimate the potential head loss impact from this debris.

3.5.1 Quantity of RMI Debris Used for Head Loss Testing

The staff's review identified a significant discrepancy between the amount of RMI insulation debris analytically assumed to have transported to the sump strainer and the amount that was actually used in the strainer qualification head loss testing program (i.e., approximately 45 times less). The staff also noted that RMI jacketing debris had not been included in the strainer qualification head loss testing program. The staff recognized that the analytical transport assumption of 100% for RMI insulation and jacketing debris appears highly conservative. However, the staff also concluded that, if debris analytically determined to transport to the sump strainers is not included in the head loss testing program, an adequate supporting technical justification should be provided.

In response to the staff's concern, the licensee provided additional justification to support the reduced quantity of RMI debris used for the strainer qualification head loss testing. The licensee stated that the original basis for the quantity of RMI used for head loss testing (1,200 ft^2) was an earlier revision of the debris transport calculation that credited the existence of a curb around the containment recirculation sump. Subsequently, the licensee stated that the debris transport calculation was revised to account for the planned replacement strainer modification, which will not include a curb. As a result of the conservative debris transport positions taken by the licensee, the removal of credit for the debris curb resulted in a highly conservative analytical assumption of 100% transport to the recirculation sump for all RMI debris and debris from its jacketing (refer to Table 5 (page 21)).

The licensee also stated that, despite the analytical assumption of 100% debris transport, in reality, a significant quantity of the RMI and jacketing debris would not reach the recirculation sump strainers. The licensee stated that a portion of the RMI and jacketing debris would be retained in the reactor coolant system loop vaults, and that fluid velocities along the containment floor would be too low to transport most of this debris to the strainers.

Using the RMI debris head loss correlation recommended in NEI 04-07 [16], the licensee calculated that, even if all of the RMI debris and its jacketing were assumed to accumulate upon the strainer in a circumscribed pattern, a negligible head loss less than one-tenth of a foot would result. The licensee further stated that, if RMI debris and its jacketing could be postulated to form a large pile that circumscribes the strainer, the resulting debris bed would be relatively porous, allowing fluid to flow through to the strainer, but filtering out a fraction of the suspended debris prior to its arrival on the strainer surface. As a result, the licensee stated that such an accumulation pattern could actually provide a potential head loss benefit by collecting debris upstream of the strainers.

Finally, the licensee also stated that, during head loss testing, RMI debris was added to the flume first to preclude interactions with other types of debris that could impede the transport of the other debris to the test strainer module. The licensee further agreed with the staff's statement that performing head loss testing with 100% of the RMI and jacketing debris generated by the accident (and analytically assumed to reach the recirculation sump strainers) could nonconservatively prevent other debris from reaching the strainers.

After reviewing the additional justification provided by the licensee (as summarized above), the staff concluded that the justification adequately supported the reduced quantity of RMI debris used for strainer qualification head loss testing. In particular, the staff agreed that significantly less than 100% of the RMI and jacketing debris would be capable of transporting to the recirculation sump strainers. Although the licensee did not provide a quantitative basis to support this conclusion (e.g., a computational fluid dynamics analysis), considering the sump flow rate and containment floor geometry for Prairie Island and the incipient tumbling velocities required to transport various sizes of RMI debris (i.e., from approximately 0.28 feet per second for small pieces up to over 1 feet per second for the largest pieces), the staff's experience strongly indicates that 100% of the RMI and jacketing debris would not transport to the recirculation sump strainers.

In addition, although the licensee's planned replacement sump strainer design does not include a debris curb, the strainers are located on the containment floor, with their upper surfaces over 1.5 feet above the floor. Thus, to cover the entire strainer, RMI debris would have to be lifted onto the upper strainer surfaces in a manner analogous to debris "climbing" over a curb, a condition similar to that for which the tested quantities of RMI and jacketing debris had originally been derived. As noted in NUREG/CR-6772 [26], the lift velocity necessary for RMI debris to surmount a 2-inch curb is approximately 0.84 feet per second. In comparison, the licensee stated that the circumscribed velocity (the velocity at the outside perimeter of the strainer) for the replacement strainer is approximately 0.044 feet per second. Furthermore, both the circumscribed velocity and approach velocity (i.e., the velocity of the flow passing through the surface of a strainer) of the licensee's replacement strainer are also significantly smaller than the approach velocity of approximately 0.2 feet per second that was necessary to hold RMI on a strainer surface for testing described in Appendix K of the NRC staff's safety evaluation report on the Boiling Water Reactor Owners Group (BWROG) Utility Resolution Guidance (URG) [28]. These velocity comparisons suggest that RMI and jacketing debris are generally unlikely to climb onto the strainer or adhere to its vertical surfaces, other than at the base of the strainer near the containment floor.

On the basis of the above discussion, the staff considered the licensee's justification for the quantity of RMI debris used for strainer qualification testing to be acceptable.

3.5.2 Debris Transport Conclusion

The licensee essentially assumed that 100% of the debris generated by a LOCA would be transported to the containment recirculation sump strainers. As discussed above, the staff generally considered this assumption to be highly conservative and acceptable for strainer design purposes. The staff also noted above that the quantity of RMI debris used for the strainer qualification head loss testing program was significantly less than the amount assumed to reach the strainers analytically. Based upon the additional justification provided by the licensee during the audit, the staff concluded that the quantity of RMI added to the flume during head loss testing was acceptable. In conclusion, the staff considered the licensee's treatment of debris transport to be acceptable and did not identify any open items.

3.6 Head Loss And Vortex Evaluation

3.6.1 Audit Scope

The new sump design proposed by the licensee uses PCI Sure-Flow® suction strainers installed on the containment floor for PI's ECCS and CSS recirculation lines. The design consists of two similar strainer assemblies. Each assembly has ten identical strainer modules (with different core tubes) attached to one another in series. Pipe is used to connect each assembly to a solid plate covering the sump pit. The total surface area of perforated plate for the two strainer assemblies is 827.3 ft^2 ([24], Page 6 of 31). Based on the debris transport calculation, 30,590 ft^2 of RMI and 11.66 lb_m of latent fibrous material is assumed to be transported to the sump region. In addition, a certain amount of labels and chemical precipitates were estimated to be present at the sump region upon initiation of recirculation. The estimated pressure loss across the strainer assembly is less than the NPSH available, and less than the available water level above the strainer.

The licensee employed the NUREG-CR/6224 correlation and the uniform debris bed assumption to calculate the head loss across the strainer as part of the initial strainer sizing and scoping analysis. Subsequently, prototypical head loss tests were performed using the Argonne Research Laboratory (ARL) testing flume and a reduced-scale prototype testing module to assess the head loss due to the debris on the surface of the strainer. An empirical correlation was used to calculate the clean strainer head loss due to strainer disks and the stainer internal structure. As part of the prototypical head loss testing program, the licensee evaluated the susceptibility of the strainers to vortex formation in addition to an analytical evaluation of vortex formation. The testing and analysis results of licensee's effort were documented in the following reports.

"GSI-191 Project Overview" Presentation slides presented by Prairie Island Nuclear Generating Plant, October 4, 2006. [3]

"Post-LOCA Debris Transport To Containment Sump for Resolution of GSI-191," Calculation 2005-02881, September 27, 2006. [22]

"Sump B Strainer Head Loss Determinations," ENG-ME-657, Rev 2, October 2, 2006. [24]

AREVA Document 51-9008730-001, Test Plan for SURE-FLOW™ (Prototype) Head Loss Evaluation for Prairie Island 1 & 2 ECCS Containment Sump Strainers. [29]

AREVA Document No. 51-9009734-003, Test Report for Prairie Island Units 1&2 ECCS Sump Suction Strainer, dated August 24, 2006. [30]

PCI Document TDI-6006-04, Revision 3, Calculations for the Clean Head Loss on SURE-FLOW™ Suction Strainers at the Prairie Island Nuclear Plant, Units 1 and 2 [31].

PCI Document TDI-6006-05, Revision 4, "Total Head Loss - Prairie Island Nuclear Plant, Units 1 and 2." [32]

PCI Document TDI-6006-07 "Vortex, Air Ingestion & Void Fraction / Prairie Island Nuclear Generating Station - Units 1 & 2," October 18, 2006 [33].

Kaufman, Andrew E, et al., "Performance Contracting, Inc. ECCS Sure-Flow® Strainer Data Report, Rev. 0, December 1996," by Performance Contracting, Inc., prepared for Electric Power Research Institute [51].

PCI Technical Document SFSS-TD01, "Methodology for Sizing the Holes and Slots in the Internal Core Tube of a Sure-Flow® Suction Strainer," May 21, 1998 [52].

The NRC staff reviewed these reports during the on-site audit and focused its audit effort in the following technical areas:

- System characterization and the design input to the head loss evaluation (page 26);
- Prototypical head loss test module design, scaling, surrogate material selection and preparation, testing procedures, results and data extrapolation (page 27);
- PCI clean strainer head loss calculation methodology and results (page 35); and
- Vortex testing procedures and the vortex formation evaluation results (page 40).

The staff evaluation regarding these four areas is provided below.

3.6.2 System Characterization and Design Input - Head Loss Evaluation

At PI, long-term recirculation water flows are drawn from a single sump that is designated as Sump B. Only the residual heat removal (RHR) system pumps can draw water from this sump. Although a break size greater than about 3 inches would activate the containment sprays, the containment spray pumps would not draw from the recirculation sump because the containment spray would only operate during the emergency core cooling systems (ECCS) injection phase. A main steam or feedwater line break would not require recirculation flow.

Flow Rate

Since only RHR pumps can directly draw water from Sump B, the maximum flow rate through the new strainer assembly is determined by the maximum RHR pump capacity. Table 1 of Reference [24] listed the maximum runout flow rate as 2600 gpm for a single train of RHR and 5200 gpm for two-train operation. The strainer head loss evaluation was performed assuming two-train RHR operation. Therefore, the maximum flow rate for each of the two strainer assemblies is 2600 gpm. The PI head loss was evaluated at flow rates of 4170 gpm for two trains and 2085 gpm for one train, considering the piping loss through the RHR piping system. Therefore, the flow rate design input of 2600 gpm per strainer train is acceptable because it bounds the maximum design flow rates.

Sump Water Temperature

The PI head loss determination indicated (page 5 of Reference [24]) that the estimated sump water temperature ranges between 60 °F and 260 °F. For the design input, 200 °F was selected as it is the temperature used to determine the minimum containment water level. Since the selected temperature for the head loss calculation is not greater than the temperature assumed for the NPSH calculation (200 °F and 254 °F), 200 °F is considered acceptable, as a higher temperature would result in lower head loss and higher containment pool water level.

Containment Pool Water Level

The licensee has performed a calculation that determines the volume of water transferred to the containment from the RWST prior to transfer to recirculation mode. The calculation determined that the minimum containment flood level is 1.4 feet above the screen for single RHR train operation and 1.77 feet for two RHR train operation during a postulated large break LOCA. The small break LOCA case results in a lower submergence, which is 0.63 feet. The staff's review and acceptance of this minimum water level calculation is addressed in Section 3.7.3 of this report (page 44).

Because the minimum water level calculation has been reviewed by the staff and considered acceptable as part of the PI NPSH evaluation [34], review effort (page 42), the calculated minimum water level for the new strainer design is considered acceptable for head loss evaluation.

Conclusion

As discussed above, the staff reviewed the analysis determining the estimated sump water temperature, minimum containment 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.

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 available NPSH margin and the minimum submergence, the licensee contracted with ARL to perform prototypical head loss testing. As shown in Figure 3.1, the prototype strainer was placed in a large test flume approximately 27 inches wide, 39 inches high, and about 21 feet long [29]. Four reduced-scale PCI strainer discs were installed at the end of the flume, and the assembly was connected with a pump suction line mounted horizontally through the end wall of the flume.

Figure 4 View of ARL test tank with PI prototype strainer installed

Pressure transmitters, a flow meter and thermocouples were installed to measure the head loss, total flow rate and the water temperature. Two debris-loaded head loss tests designed as a design basis case and a design basis with redundant screens were performed. The staff reviewed the test plan, the test report and the interpretation of the test results.

3.6.3.1 Debris Types, Quantities, and Characteristics

The specification of the debris quantities and characteristics is important to the specification of debris surrogates and debris preparation for the head loss testing. The quantities of debris used in the head loss tests for Test 1 are compared in Table 7. The potential debris accumulation on the replacement strainers was determined by NMC debris generation and transport analyses [22]. This table illustrates that the debris types and quantities used in the tests are generally conservative with respect to the plant debris assessments. For Carbonline 195 and other miscellaneous debris Test 2 doubled the Test 1 values and was therefore consistent with regard to the plant assessments. Regarding RMI, the licensee stated that the quantity of RMI debris in the test was based on a reduction during transport due to a curb. This curb was bypassed in the final design due to the physical arrangements. However, since the presence of RMI has been proved to reduce the measured head loss, the treatment of RMI debris during the head loss testing was considered acceptable (See Section 3.5.1 [(page 23)]). Alkyd coatings were used to test the unqualified coatings. Light bulb debris was treated as metallic foils. Test 2 basically doubled the debris masses used in Test 1 except for the chemical effects surrogate mass specifications which were identical for both tests.

Table 7 Comparison of PI Debris Generated and Test 1 Debris

	Plant Assessments		Test 1 - Test Parameters	
Debris Type	**Unit 1**	**Unit 2**	**Plant Scale**	**Test Scale**
Insulation Debris				
RMI	30,590 ft^2	65,453 ft^2	1,200 ft^2	17.64 ft^2
Fibrous Material	0.014 ft^3	0.017 ft^3	0.1 ft^3 (a)	0.0017 ft^3 (a)
Latent Debris				
Fiber (Nukon®)	11.66 lb_m	17.12 lb_m	30 lb_m	0.46 lb_m
Particulate (Dirt)	88.74 lb_m	96.99 lb_m	170 lb_m	2.64 lb_m
Qualified Coatings				

Debris Type	Plant Assessments		Test 1 - Test Parameters	
	Unit 1	**Unit 2**	**Plant Scale**	**Test Scale**
Carboline – Carbozinc 11	0.444 ft^3	0.914 ft^3	1.0 ft^3	7.08 lb_m (b)
Carboline – Phenoline 305 Primer	0.200 ft^3	0.067 ft^3	0.2 ft^3	0.22 lb_m (c)
Carboline – Phenoline 305 Finish	1.088 ft^3	1.895 ft^3	2.0 ft^3	2.91 lb_m (c)
Carboline – Carboline 195	1.000 ft^3	0.333 ft^3	0.5 ft^3	0.73 lb_m (c)
Total Qualified	2.732 ft^3	3.209 ft^3	3.7 ft^3	-
Unqualified Coatings				
Treated as Alkyds	2.32 ft^3	2.02 ft^3	2.5 ft^3	3.79 lb_m (c)
Foreign Material				
Treated as Fibrous Debris	28.47 ft^2	28.27 ft^2	(a)	(a)
Treated as Metallic Debris	32.46 ft^2	39.79 ft^2	40 ft^2	0.62 ft^2
Treated as Tape, labels, Tags, etc.	117.0 ft^2	160.8 ft^2	150.0 ft^2	2.3 ft^2
Chemical Effects Particulate				
Aluminum Hydroxide	-	-	198 lb_m	3.05 lb_m
Calcium Carbonate	-	-	10.1 lb_m	0.156 lb_m
(a) Test fiber volume includes miscellaneous insulation fiber and foreign fibrous materials (b) Coatings debris treated as particulate (c) Coating debris treated as paint chips				

3.6.3.1.1 RMI Debris Head Loss Assessment

NMC predicted large quantities of RMI debris accumulating at the replacement strainers (i.e., 30,590 ft^2 and 65,453 ft^2 for Units 1 and 2, respectively). The primary assumption contributing to these large quantities of RMI debris is the NMC assumption of 100% debris transport. However, during their head loss testing, only 1200 ft^2 and 2400 ft^2 of surrogate RMI debris was introduced into Tests 1 and 2, respectively. The head loss testing demonstrated that the RMI debris readily settled to the test flume floor and remained on the floor. The test flow velocities were insufficient to either lift the RMI onto the strainer or to keep RMI debris attached to a vertical screen surface. During the test it was observed (Figure 5) that the RMI debris added into the flume accumulated underneath the strainer module. The quantities of RMI debris were insufficient to cover even the lower portion of the strainer. Therefore, the RMI debris did not affect strainer head losses.

Figure 5 RMI Debris Accumulation Underneath the Strainer Module

Staff Evaluation

The staff evaluated the test plan and noted that the clearance between the test flume bottom and the bottom of the strainer is much greater than the actual clearance between the strainer bottom and the containment floor. In addition, the amount of RMI debris introduced into the test was significantly less than the scaled value. However, the staff considers it very unlikely the PI RMI debris can cause or significantly contribute to the strainer head loss for the following reasons:

1. The average strainer circumscribed velocity is estimated to be 0.044 feet per second, which reflects the magnitude of the velocity of the near field flows around the strainer. As noted in the SE, this velocity is much too slow to effectively move around even small pieces of RMI. Further, at these velocities, RMI debris cannot effectively adhere to the strainer screen surfaces.

2. Since there are no postulated breaks in the vicinity of the strainers, a direct break flow is not expected right above the replacement strainers. Therefore, turbulence is considered insignificant near the strainers and will not move RMI debris.

3. Although there is enough RMI debris postulated to more or less completely cover the strainer, it is not feasible for the debris to pile up onto the strainer. Piling of RMI onto the strainer would have occurred in the head loss tests had the design quantity of RMI been used in the tests and had the RMI been essentially dumped onto the strainer.

4. Even if all the RMI debris was assumed to accumulate around the strainer, more or less uniformly in a circumscribed pattern, the application of the RMI head loss correlation predicts head losses on the order of tenths of a foot of water.

5. If RMI debris accumulation only covered the lower portion of the strainer, it most likely would not significantly affect head loss from the RMI standpoint and it could disrupt the uniformity of the accumulation of fibrous debris. Because RMI debris is highly porous, fibers would tend to pass through the RMI to the screen surfaces.

Therefore, although the RMI debris was not treated precisely following the approved guidance in the GR during the prototypical head loss test, the staff considers that use of this information in the head loss evaluations is accepatble.

3.6.3.1.2 Tapes and Labels Head Loss Assessment

The licensee's latent debris analysis predicted substantial quantities of foreign material debris in the form of tapes, labels, tags, etc., that could obstruct significant portions of the replacement strainers should this debris actually accumulate. After applying the GR-recommended 75% area reduction factor which accounts for debris overlapping, this type of debris could potentially cover 177.9 ft^2 and 228.8 ft^2 of the strainer screen areas for Units 1 and 2, respectively; assuming 100% transport. For the head loss tests, the fiber cloth contained in cable insulation and the asbestos vent fan expansion bellows were assumed to decompose into fibers. The light bulb debris was treated as metallic foils because the glass would likely settle to the sump pool and not readily transport. During the head loss testing, the licensee stated that this type of debris did not tend to accumulate on the test strainers; rather it tended to settle to the test flume floor.

Although the licensee analytically assumed all tapes, labels, and related materials evaluated as available for transport would arrive at the strainers, the licensee claimed that this type of debris would not actually adhere to the screen surfaces and would not contribute significantly to the strainer head loss. Evidence cited by the licensee in support of this position includes:

1. The licensee stated that there was undocumented AREVA testing experience that when pieces of tape and label debris were held next to the test strainer modules, the debris fell away and settled[4].

2. The approach velocities for the PI strainers are only 0.014 feet per second and 0.044 feet per second for the screen and circumscribed approaches, respectively. As a point of reference, NRC-sponsored separate effects debris transport tests [26] determined the screen approach velocities required to adhere a piece of debris to a screen surface for a few selected materials. These tests demonstrated that it takes a screen approach velocity of about 0.12 and 0.05 feet per second to keep a piece of stainless steel RMI debris or a Nukon™ shred, respectively, from falling away from a screen. Clearly

[4]During NRC staff visits to the AREVA test site at Alden Research Laboratories, the staff did not observe significant accumulation of this type of debris on the strainer surface.

heavier debris, such as light bulb debris, would be unlikely to adhere to the strainer surfaces.

However, NMC did not provide documentation that demonstrated that the surrogate foreign debris tested was prototypical of the corresponding potential plant containment debris. Further, post-test photos shared with the staff audit team, showed pieces of miscellaneous debris, including RMI debris, embedded in the fiber layer (this could have been floating debris sticking to the strainer during drainage). Therefore, it cannot be clearly stated that none of the tapes and labels would accumulate. Clearly some miscellaneous debris could accumulate within the fibrous layer where the fibers cause the particulate debris to adhere to the screen surface. The staff determined that this is not a problem for PI because of the small amount of miscellaneous debris observed in the post-test photos considering the overall margin.

Staff Evaluation

The staff considers that the miscellaneous foreign debris at PI will not significantly increase the strainer head loss because the debris would not generally adhere to the screen surfaces and a substantial portion of this foreign debris would likely be much too heavy to transport effectively. This conclusion is based on the information presented above. Therefore, the treatment of miscellaneous foreign debris is acceptable for PI.

3.6.3.1.3 Fiber/Particulate Head Loss Assessment

During a kickoff meeting held at NRC headquarters on October 4, 2006, the licensee stated that PI had sufficient fiber in containment to form a fibrous bed of debris . The licensee-sponsored head loss testing documented in the head loss reports [30] clearly resulted in the establishment of debris beds that caused significant head losses. However, those head loss tests were not performed in complete accordance with the SE and GR guidance. Specifically, the tests were conducted with the majority of the postulated coatings debris introduced as paint chips rather than the GR-recommended 10 micron powder. After this testing approach was questioned by the staff, the licensee pointed out that there would actually be insufficient fiber to form a thin bed, i.e., that the thin bed observed during testing was the result of the extra conservatism added to the licensee's latent debris estimate. The staff's conclusion regarding the licensee's evaluation of the ability to form a thin bed is discussed in Section 3.3.3 (page 16) and Section 3.3.5 (page 18).

The current documentation of the potential PI fibrous debris includes 15.7 lb_m and 17.1 lb_m of latent fiber for Units 1 and 2, respectively; 0.04 lb_m from fibrous insulation debris; and approximately 11.0 lb_m of fiber from fiber cloth and 0.9 lb_m from asbestos bellows (assuming complete decomposition of all debris into fibers). As discussed in Section 3.3.3 (page 16) the licensee conservatively assumed a total of 27.6 lb_m and 29.0 lb_m of fibrous debris for Units 1 and 2, respectively. If a typical Nukon™ bulk density of 2.4 lb_m/ft^3 is assumed to apply to all of the fibrous debris, the predicted uniform fibrous debris bed on 827.3 ft^2 of strainer surface would be about 0.17 and 0.18 inches for Units 1 and 2, respectively, which is thicker than the GR recommended criterion of 0.125 inches. For the PI head loss testing, the latent fiber was conservatively increased to 30 lb_m. This assumption suggests the licensee recognized uncertainties in the latent debris assessments. Potential uncertainties on latent debris assessments include the limited sampling that was performed and the potential for operational variance. The licensee stated that conservatism in the latent debris assessments exists because: (1) the sampling was performed at the end of an outage when more latent debris would be expected, and (2) sampling was from perceived dirtier areas of containment. The licensee plans to perform additional latent debris assessments designed to more precisely sample the containment. The outcome of these assessments will provide evidence to support the determination of whether PI can be considered as a plant with insufficient fiber to form a thin bed.

Staff Evaluation

The staff considers the treatment of coating debris potentially not consistent with the SE and GR. This guidance states that for head loss testing with a fiber bed thickness greater than that of a thin bed, the coatings debris should be introduced into the tests as a fine particulate. However, the majority of the calculated PI coatings debris, including the ZOI coatings, was introduced as chips. These simply settled to the test flume floor during the head loss test. The licensee was planning to perform additional latent debris assessment to justify that there was insufficient latent fiber debris to form a thin bed. After the new assessment is performed, the licensee needs to evaluate whether the calculated quantity of fiber debris is sufficient to form a thin bed. If the amount of fiber debris is enough to form a thin bed, the licensee needs to justify why the coating chips were used during the head loss testing instead of fine particulate surrogate material. This is **Open Item** 3.6-1.

3.6.3.2 Scaling Methodology, Testing Procedures and Test Results Interpretation

3.6.3.2.1 Scaling Methodology

The PI strainer assemblies consist of twenty PCI SureFlow® strainer modules. The prototype strainer had a total strainer surface area of 12.2 ft^2. During the test, all the debris was introduced into the flume within one to three feet upstream of the strainer. Therefore, no credit was taken for near-field debris settlement. Assuming uniform debris distribution, PCI scaled the total debris loading based on the ratio between the total testing module surface area and the actual screen surface area. The screen approach velocity was scaled one to one. Similar to the actual stainers installed at PI, the prototype module had a core tube with open slots. One end of the core tube was covered by perforated plate and the other end was connected to the suction pipe. Since only four discs were used in the prototype module, the core tube length was much shorter than that of the actual strainer assembly. The outer diameter of the prototype core tube was 6" in comparison with the 12" diameter of the actual core tube. The test plan [29] did not provide any scaling analysis to establish the relevance between the prototype core tube and the actual core tube. Therefore, the staff questioned how the clean strainer head loss data measured during the test can be used to support the clean strainer head loss calculation using the PCI clean strainer head loss correlation.

Staff Evaluation

The testing module was scaled assuming no near-field debris settlement. The uniform debris distribution is used to scale the debris loading. The screen approach velocity was kept the same as the plant screen approach velocity. Because the debris was introduced into the test flume within one to three feet upstream of the strainer and no near-field settlement was credited, the scaling methodology is considered acceptable. However, the licensee has not developed a proper scaling analysis to demonstrate the relevance of the prototype core tube to the actual strainer, therefore the staff questioned the validity of directly applying the measured clean strainer head loss data to the new strainer head loss evaluation. This is discussed further as **Open Item 3.6-2** (page 40).

3.6.3.2.2 Testing Procedures

Prototypical head loss testing was performed by the strainer vendor following generic testing procedures, along with specific debris addition procedures, and testing implementation procedures. The generic testing procedures included the following:

Test Setup Procedure
Clean Strainer Head Loss Test Procedure
Debris Preparation Procedure
Instrumentation
Debris Head Loss Measurement Procedure

All the surrogate debris material was added in the vicinity of the testing module. This approach minimized the amount of debris that settled on the flume floor, thereby ensuring a conservative head loss measurement. For the debris load head loss test cases, the debris was first placed into buckets partially filled with water and then premixed. The debris was poured into the flume one to three feet upstream of the test strainer assembly. The debris was added into the flume in the following order: RMI, particulate and fiber. During each test, the head loss was required to stabilize at either less than a 1% increase over a 5 minute period or for at least 5 tank turnovers, whichever was longer. The fluid temperature, the total flow rate and the head loss were continuously monitored. These generic testing procedures were reviewed by the staff as part of the Watts Bar Nuclear Plant GL 2004-02 audit [27].

Staff Evaluation

The staff comments in the Watts Bar audit report [27] regarding PCI generic testing procedures do not apply to PI in general because of the little amount of potential fiber available to form a thin bed. Although the debris introduction sequence may significantly alter the head loss measurement results, the staff believes that the specific debris introduction sequence for PI would not have an unacceptable impact on the head loss. The staff considers the test procedure acceptable because of the expected bare screen area and high particulate diffusion in a relatively thin debris bed. The head loss was stabilized very quickly after the fiber was introduced a few feet upstream of the strainer. Therefore, the test termination criteria used for the PI strainer head loss test is considered acceptable. Other relevant testing procedures were previously reviewed by the staff during the Watts Bar audit [27], and they were found to be applicable to PI head loss testing.

3.6.3.2.3 Test Results Interpretation

The PI prototypical strainer test program consisted of two test runs. The first run was conducted using the design basis debris loading. The second run used twice the design basis debris loading. The clean strainer head loss was measured prior to the introduction of debris into the flume. The measured head loss results are summarized in the following table [30].

Table 8 Head Loss Test Results

Test #	Test Module Flow Rate (gpm)	Clean Strainer Head Loss (ft)	Debris Loaded Loss (ft)	Average Fluid Temperature (°F)
1	76.86	0.0203	7.766	48.0
2	76.87	0.0203	12.115	50.1

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. The licensee assumed that the head loss is directly proportional to the absolute fluid viscosity. Therefore, the predicted debris bed head loss is much lower than that listed in Table 3.1 at 200 °F.

During the on site audit, the staff identified an inconsistency between the final total head loss tabulated in Table 10-15 of Reference [24] and the calculated clean strainer head loss data provided by PCI. The licensee used the measured clean strainer head loss from the head loss testing report instead of the calculated clean strainer head loss of the entire strainer array, which is much higher. The finding resulted in the issuance of a Condition Report and relevant corrective actions. The staff was provided a copy of PI's Corrective Action Report Number AIR 01058100, dated October 27, 2006 which was in response to the error the staff identified in the head loss calculation.

Staff Evaluation

Although the staff identified a discrepancy in the licensee's head loss calculation summary report, the extrapolation methodology for debris head loss evaluation is considered acceptable because of the use of standard methodology based on the assumption that the debris bed head loss is directly proportional to the absolute viscosity.

3.6.4 Clean Strainer Head Loss Calculation

PI has a relatively high NPSH margin, therefore the licensee chose to design the new strainer with a relatively small (when compared with other PWR replacement strainers) strainer surface flow area. The PCI strainer design feature of a central core tube with open slots is used to establish an uniform flow distribution at the onset of recirculation when the strainer assembly is relatively clean. The existence of the core tube with open slots will cause an internal strainer head loss. In addition, fluid flow through the attached pipe and fittings, including the 90° bends connecting the strainer assemblies to the enclosed sump pit, is subject to pressure drop due to structural and frictional resistance. The licensee and its strainer vendor calculated the total clean strainer head loss using an empirical correlation for the core tube and the standard single phase hydraulic analysis for the exit pipe and connections [31]. The staff review of these two aspects of the clean strainer head loss calculation is discussed in the following subsections.

3.6.4.1 Strainer Attached Pipe & Fittings Head Loss

The new PI strainer assembly is attached to 14-inch outside diameter strainer discharge piping. The pipe is connected with the 12-inch outside diameter core tube through a 12"x14" reducer fabricated from 11 gauge stainless steel material. The strainer discharge flow goes through this pipe, then enters two reversed back-to-back angular transitions. After this transitional piping run, the strainer discharge flow passes through a 90°, short-radius elbow, followed by several feet of straight pipe, another 90° short-radius elbow, and then discharges into the sump pit reservoir. There is a head loss associated with each of these flow paths. PCI performed the hydraulic analysis using industry standard methodology based on Crane Technical Paper 410 [35].The fluid velocity was calculated based on a single phase flow assumption and the continuity equation. Assuming two-train operation with two low-pressure coolant injection pumps at maximum runout flow rate, the calculated head loss is 1.077 feet of water (page 30 of reference [31]).

Staff Evaluation

The licensee performed the head loss calculation for the attached piping and fittings using hydraulic analysis methods based on Crane Technical Paper 410 [35], which is considered the industry standard approach for single phase fluid flow resistance evaluation. Since no vapor flashing is expected inside the strainer following a LOCA, the flow resistance can be evaluated assuming a single phase fluid. Therefore, the overall approach using Crane Technical Paper 410 is considered reasonable.

3.6.4.2 Clean Strainer Array Head Loss

One of the unique features of PCI SureFlow® strainer is the use of uniform flow control device inside the strainer**.** The uniform flow control device is expected to provide a controlled axial pressure distribution and achieve uniform flow across the strainer array, regardless of the distance between a particular strainer disk and the exit of the core tube. Benefits of having a uniform flow control device are that the debris may tend to uniformly distribute on the surface of the strainer and it is more difficult for a vortex to form on top of the strainer modules, adjacent to the core tube exit. Absent a flow control device, flows near the pump suction may be higher than average flow across the strainer perforated surface. The challenge of having a uniform flow control device is the accurate prediction of the clean strainer head loss across the flow control device, which consists of a steel core tube with open slots of different size distributed along the tube. The PCI strainer design is different in size for each plant and has different core tubes and open slots. No standard hydraulic analysis methodology is considered applicable to the device considering the complex geometry involved. However, the total head loss across the core tube would be expected to be dominantly determined by the flow rate, the core tube length and diameter, the flow path external to the core tube and the open slot locations and sizes.

3.6.4.2.1 Core Tube Structure

Each PI strainer array has a core tube with an inner diameter of about 12 inches. Each set of open slots consists of two pairs of slots with different slot flow area and width. The different width was selected to accommodate the rectangular shape of the strainer discs. In the axial direction, every two discs share one set of open slots. Therefore, fifty sets of slots provide a flow control function for one hundred strainer discs. Each set of slots consists of two pairs of slots with different width to reflect the rectangular shape of the strainer. Axially, the further away the slot is from the exit of the core tube, the larger the slot open area. At the far end of the core tube, the tube's end face is covered by the same hole-size and spacing perforated plate as that of the strainer discs. As the head loss across the perforated plate is expected to be small, the mass flux across the end cover is expected to be greater than that of the adjacent open slots. There is an annular flow region between the core tube and the strainer discs allowing axial flow.

3.6.4.2.2 PCI Empirical Clean Strainer Head Loss Correlation

In order to predict the pressure drop across PI strainer array core tube, PCI employed an empirical correlation. The correlation is identified as Equation 2 and can be found on Page 8 of 30 of Attachment 3 of Reference [24]. PCI stated in this document that this correlation was developed based on PCI Boiling Water Reactor Prototype II test strainer head loss testing data [51]. In order to justify that this correlation is applicable to the PI strainer array, PCI compared these two strainers and summarized the major differences in Table 2 of Attachment 3 of Reference [24]. The following table lists the key geometrical differences between these two strainers.

Table 9 Key Geometric Parameter Comparisons

Strainer Parameters	Test Prototype II Strainer	PI Strainer
Strainer Shape	Circular Disk with internal star shape frame	Rectangular Shape
Core Tube External Geometry	Star Shape Flow Path Without Axial Direction Flow	Annular Flow Region Allowing Axial Direction Flow
Total Strainer Surface Area, ft^2	169	413.7
Total # of Discs	13	100
Active Strainer Length, inches	48	151.88
Perforated metal % open area	40	33.1
Core Tube ID, inches	23	11.89
Strainer Flow Rate, gpm	5000	2600

In Attachment 3 of Reference [24], PCI qualitatively compared these parameters and concluded the following:

1. Internal Core Tube Diameter and Exit Velocity Relationship

The core tube exit velocity is the single most important independent variable in predicting clean strainer head loss. Since the PI core tube exit velocity is within the range of the test data, PCI believes that the correlation is applicable.

2. Strainer Dimension

PCI concluded that the two strainers have different geometries and dimensions. However, no conclusion was provided by PCI regarding the applicability of the correlation to PI strainers despite the different geometry and dimensions.

3. Strainer Perforated Sheet Metal Head Loss

Since the PI strainer surface approach velocity is significantly less than that of Prototype II strainer, the correlation should bound the PI perforated sheet metal head loss.

4. Strainer Length Head Loss

The two strainers have significantly different lengths. PCI calculated the friction loss through the core tube of the PI strainer array and concluded that with only 0.0082 feet of water head loss, the length difference does not have significant impact.

In addition to these justifications based on analysis, PCI indicated that prototypical head loss testing was conducted with a small section of core tube and open slots. PCI concluded that the clean strainer head loss results demonstrated that the prediction based on the correlation is conservative. Based on the analysis evaluation and the testing, PCI concluded that this correlation could be conservatively applied to PI new strainer array.

Staff Evaluation

The staff reviewed the testing reports of PCI Prototype II test strainer, the PCI core tube open slot design methodology, and the calculation results based on the correlation. The staff evaluated applicability of this correlation to the PCI PWR strainer design at PI in the following four areas;

Effect of Length and Diameter

As PCI indicated in its clean strainer head loss calculation report, the pressure drop along the tube and through the perforated plate due to friction loss is very small when compared to total clean strainer head loss. Therefore, a significant part of the pressure drop is caused by flow through the open slots. The liquid experiences acceleration after passing the perforated plate, then a form loss through the narrow flow path of the open slots and then merging with the main stream after a 90° turn. Therefore, with the same exit velocity, the higher the mass flux across the open slots, the greater the total pressure drop. The smaller the core tube diameter, the higher the head loss across the core tube. The PI strainer has many more slots and a smaller inner diameter core tube than does the Prototype II. It is not clear to the staff whether the overall effect of the core tube geometry would reduce or increase the PI clean strainer head loss relative to the Prototype II.

Effects of Core Tube End Opening

The PCI prototype II strainer was tested without debris to develop the clean strainer head loss correlation. During the test, the end of the core tube furthest from the suction was open to the fluid through the same type of perforated plate. As a result, the staff was concerned that the far end opening could significantly reduce the total clean strainer head loss due to the direct flow into the core tube without going through the open slots. The magnitude of this head loss reduction can be affected by the core tube diameter/length ratio and thetotal slot/ core tube cross-sectional area ratio. The higher these two ratios, the lower the total clean strainer head loss. Comparing the testing module with the PI strainer array, the PI strainer array has a much lower core tube diameter/length ratio. Therefore, the measured total head loss through PCI prototype II strainer may not be representative of the PI's strainer array configuration.

Annular Flow Region

The PCI prototype II strainer testing module isolated the liquid inside each strainer disc and did not allow axial flow before the fluid entered the core tube. The PI strainer array is equipped with an annular flow space outside the core tube, which allows the fluid from one stainer disc to interact with another before and after entering the core tube. This geometrical configuration may enhance the axial direction flow. Its impact on the total clean strainer head loss had not been evaluated by PCI.

Prototypical Head Loss Testing

During the audit, the PCI staff indicated that the clean strainer head loss was measured during the prototypical head loss testing and that the measured clean strainer head loss was less than what was calculated using the correlation. Therefore, PCI concluded that the test results demonstrated that the correlation was conservative. The staff reviewed both the testing plan and the testing report and found that the scaling analysis was only performed to measure the debris bed head loss. No scaling analysis was performed to demonstrate the relevance of the reduced-scale testing module core tube to the PI strainer array configuration. As noted above, the staff's review revealed that the Prototype II testing module core tube diameter/length ratio was significantly greater than that of the PI strainer. Therefore, the core tube far end opening could contribute to the very low head loss observed. As a result, the staff concluded that the measured clean strainer head loss from the Prototype II head loss testing has not been demonstrated to be relevant to PI's new strainer array.

3.6.4.2.3 Clean Strainer Head Loss Evaluation Conclusion

Based on the aforementioned reasons, the staff does not believe that PCI has provided sufficient justification to demonstrate that the clean strainer head loss correlation, based on PCI Prototype II test data, can be used to conservatively predict PI strainer array clean strainer head loss. Additional justification is needed to demonstrate that the clean strainer head loss correlation is conservative. This justification should at a minimum consider the following aspects of PI strainer array compared with the PCI Prototype II testing module:

1. Significantly different diameter/length, slot open/core tube area ratio;
2. Existence of an annular flow region in the PI strainer array;
3. Different number of slots and slot's open area.

This is **Open Item 3.6-2**.

3.6.5 Vortex Evaluation

In response to NRC's request for additional information [13] regarding the evaluation of possible vortex formation on the surface of the new strainer, the licensee investigated the possibility of vortex formation as part of the strainer array testing program and evaluated the feasibility of vortex formation according to RG 1.82 Rev. 3 [18]. In Reference [33], PCI indicated that Table A-6 of RG 1.82 guidance provided the criteria for standard 1.5 inches or deeper floor grating or its equivalent to suppress vortex formation with at least 6 inches of submergence. The design configuration of the PI strainer meets and/or exceeds the 6 inches submergence due to the close spacing of various strainer components and the small hole size of the perforated plate. The configuration for PI strainer results in a minimum of 2.56 feet submergence to the top of the strainer assembly following a large break LOCA and 0.63 feet (Table 4 of Reference [24]) following a small break LOCA. Therefore, Table A-6 guidance is satisfied with respect to submergence. In addition, the water flow would have to pass through a minimum of approximately 3 inches of combined perforated plate, wire stiffener and cross-bracing. In conjunction with the existing structure submergence, the licensee concluded that these complex geometries further preclude the formation of a vortex in either the core tube or the sump.

In addition to performing an evaluation based on RG 1.82 Rev. 3, PCI also evaluated vortex formation during prototypical head loss testing for PI. The testing module was submerged less than 0.63 feet, and no vortex was observed. Therefore, PCI concluded that the PI strainer discs would not be subject to vortex-induced air ingestion.

Staff Evaluation

The staff agreed with the licensee that based on RG 1.82 Rev. 3, the PI strainer core tubes and the ECCS suction lines would not be subject to direct contact with a vortex because the core tubes and the suction lines are enclosed by the sump pit cover or the strainer discs. However, RG 1.82 Rev. 3 did not address the scenario where the vortex suppressors and the structures above the suction lines are part of the flow path between the suction line and the containment pool, and function as a fluid suction source. Therefore, addressing RG 1.82 does not preclude the possibility of vortex formation on top of the strainer discs and consequent air ingestion.

The PI reduced-scale prototypical head loss testing was conducted with the same average screen surface approach velocity as that for the actual strainer array. Because the testing module size was reduced, the circumscribed velocity was much less than that of the actual strainer. Therefore, it is not clear to the staff that the total fluid flow on top of the strainer was representative and provided a bounding condition. In addition, the size of the testing module may also affect the fluid field above the strainer. PCI has not performed an adequate scaling analysis to demonstrate the that fluid conditions above the testing module would bound the actual fluid condition relevant to vortex formation.

Overall, considering the use of PCI uniform flow device and the relative low approach velocity, the staff considers that a vortex is unlikely to form on top of the PI strainer array. However, the licensee has not provided adequate justification to demonstrate this. This is **Open Item 3.6-3.**

3.6.6 Head Loss and Vortex Evaluation Conclusions

Head Loss Evaluation

The licensee performed plant-specific prototypical strainer head-loss testing and vortex testing. The system input evaluation, the testing matrix, the testing procedures and the results were reviewed during the audit. Because the estimated head loss based on the maximum measured head loss is significantly less than the NPSH margin for the designed sump flow rate and the temperature, the staff considers that the PI new strainer will likely not cause significant head loss to challenge the ECCS NPSH margin excluding any potential head loss change due to chemical effects. However, the following open items need to be addressed by the licensee to justify the NPSH margin, the flashing margin, and lack of vortex formation.

Open Item 3.6-1:

After performing additional latent debris assessments of PI Unit 2, the licensee needs to reevaluate the assumption that there would be insufficient latent fiber debris to form a thin bed. If the amount of fiber debris is enough to form a thin bed, the licensee needs to justify the use of coating chips during the head loss testing instead of fine particulate surrogate material.

Open Item 3.6-2:

The licensee needs to provide sufficient justification to address why the PCI clean strainer head loss correlation can be applied to PI's new strainer array, considering differences from the PCI Prototype II strainer testing module. In particular, the licensee needs to address the impact of the following geometrical differences on the conservatism of the correlation:

1. Significantly different diameter/length, core tube area/slot open area ratio;
2. Existence of an annular flow region in the PI strainer assemblies;
3. Different number of slots and differences in slot's open area.

If a new head loss correlation is indicated, the licensee needs to re-evaluate the NPSH and flashing margins.

Vortex Evaluation

Because the new strainer array uses the PCI uniform flow control device and a localized high flow rate is not feasible, it is reasonable to believe that it is unlikely to form a vortex on top of the PI strainer array because of significant submergence. However, the licensee has not provided an adequate justification to demonstrate this.

Open Item 3.6-3

The licensee needs to reevaluate vortex formation to ensure design margins exist to prevent vortex formation on top of the PI strainer arrays.

3.7 Net Positive Suction Head for Containment Sump Recirculation

During the recirculation phase of a loss-of-coolant accident (LOCA), two residual heat removal (RHR) pumps are available to draw suction from a common containment recirculation sump (Sump B) to provide long-term reactor core cooling. Depending on the accident scenario and timing, the RHR pumps can also serve other functions, including providing low-pressure safety injection, providing flow to two trains of high-head safety injection pumps to support high-pressure recirculation, and providing flow to two trains of containment spray pumps.
The overall purpose of the audit was to evaluate the design adequacy of the containment recirculation sump strainers; therefore, the staff's review focused upon the net positive suction head (NPSH) margin of the RHR pumps during the recirculation phase of a LOCA.

The licensee performed calculations to establish the RHR pumps' NPSH margins during the recirculation phase of a LOCA in the absence of the planned replacement strainers and collected debris [34]. These values of NPSH margin will be used by the licensee as criteria for determining the adequacy of the replacement sump strainer design. The staff's review of the licensee's NPSH calculations is provided below.

The staff reviewed the models and calculations provided in [34] prior to the onsite audit, received additional information during the onsite audit, and reviewed assumptions, models and calculations with licensee staff during the onsite audit. The staff's review considered guidance provided by NRC Regulatory Guide 1.82 [18], NRC Generic Letter 97-04 [36], the NRC Draft Audit Plan [37], Nuclear Energy Institute (NEI) 04-07 [16], and the NRC Safety Evaluation Report on NEI 04-07 [17].

3.7.1 NPSH Margin Calculation Results

The licensee performed NPSH margin calculations for the RHR pumps in the recirculation mode. The licensee calculated values of NPSH margin for sump liquid temperatures of 200 °F and 60 °F, for large-break and small-break LOCAs , and for one and two trains of the RHR system operating in recirculation mode [34].

The NPSH margin results calculated by the licensee are presented below in Table 10 and are discussed in greater detail in the following sections of this audit report. The required NPSH is given as 14 feet for the runout flowrate of 2600 gpm [34], and the conclusion is presented that "... the available NPSH margin is approximately twice the required NPSH; i.e., a margin of approximately 100%" [34, p. 5]. This conclusion applies to both the 200 °F and 60 °F sump liquid temperature conditions. Therefore, the NPSH margin is predicted to be a minimum of approximately 14 feet. The licensee's sump strainer head loss design specification for the combination of the strainer and debris loading is 10 feet [24].

The large-break LOCA is assumed to leave the reactor coolant system (RCS) filled to the top of the nozzles, including the vessel, loop piping and the reactor coolant pumps. The small-break

LOCA is assumed to be a 3 inch break located at the top of the pressurizer. Thus, the small differences in the NPSH margin values for these two accident scenarios are partially attributable to differences in the static height of liquid above the RHR pump centerline elevation caused by different quantities of spillage from the RCS.

The staff noted that the results of the licensee's revised calculations (summarized in Table 10) showed a slightly increased NPSH available value as compared to the value of 27.8 feet listed in Table 6.2-5 of the licensee's Updated Safety Analysis Report (USAR) [38].

Table 10 - Summary of Prairie Island NPSH Margin Calculation Results [34]

Sump Pool Temperature	LOCA Break Size	RHR Trains Operating	NPSH Available (feet)	NPSH Margin (feet)[(1)]
200 °F[(2)]	Large	2	29.45	15.45
	Large	1	29.08	15.08
	Small	2	28.31	14.31
	Small	1	28.31	14.31
60 °F[(3)]	Large	1 or 2	30.24	16.24
	Small	1	29.2	15.2
	Small	2	28.35	14.35

(1) NPSH required is given as 14 feet [34].

(2) Results for 200 °F apply at the start of recirculation, corresponding to a minimum volume of water on the containment floor.

(3) Results for 60 °F apply at long times after the start of recirculation, with the total available volume of water spilled on the containment floor.

3.7.2 NPSH Margin Calculation Methodology

The licensee applied the definition of NPSH margin from Regulatory Guide (RG) 1.82 [18], which is the difference between the NPSH available (NPSHA) and NPSH required (NPSHR). The NPSHR is 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 at a specific capacity. NPSHR data is normally provided by the pump manufacturer. Appendix A to RG 1.82 also provides a recommended limit on allowed air ingestion of 2% to ensure adequate pumping performance. One of the ways in which air may be introduced into the pump is by cavitation induced by dissolved air that comes out of solution in the low pressure region of the RHR pump inlet. The licensee's calculations did not consider the effect of cavitation induced by dissolved air [34]. The staff designated **Open Item 3.7-1** for the licensee to address the issue of air ingestion on pumping performance.

The licensee computed NPSHA using a single-phase fluid hydraulic model that was constructed using plant isometric drawings and piping diagrams. The NPSHA is defined as the difference between the pressure (normally expressed as a pressure head in feet of water) of the water at the inlet to the RHR pump and the vapor pressure of the water at the assumed sump water temperature. The pressure at the inlet to the pump is equal to the pressure at the surface of the pool of water on the containment floor, plus the static head of liquid above the pump inlet centerline, minus the sum of all hydraulic losses along the flow path from the surface of the pool to the pump centerline. Of note, however, is that the calculation of NPSHA excludes the sump strainer assembly and debris bed head losses, which are evaluated separately.

The licensee's calculations include spreadsheets that compute the hydraulic head loss using a model that consists of a collection of pipe segments, elbows, valves, tees, pumps and the sump [34, Tables 3-6]. Pump flow rates are presented, and flow resistance factors are presented for the pipe segments and components using standard single-phase hydraulics methodology. Hydraulic resistance values were obtained from Crane ("Flow of Fluids," Technical Paper No. 410) [35]. Given the assumed flow rates, fluid density, containment water level and component elevations, the pressure drops along each segment and across each component are computed. The fluid head loss from the containment pool surface to each pump is computed (excluding the strainer assembly and debris bed). A hydraulic loss spreadsheet is presented for each pump.

The licensee made the conservative assumption that the pressure at the surface of the containment pool is equal to the vapor pressure of the sump water at its assumed temperature, consistent with NRC guidance with respect to NPSH margins calculations [18]. As a result of this assumption, the NPSHA is simply equal to the difference between the hydrostatic head of liquid above the RHR pumps' centerline and the fluid head loss along the suction path to the pumps. The hydrostatic head is computed using a model for the water inventory available on the containment floor at the initiation of recirculation along with information concerning the geometry of internal structures that influence the liquid level in containment.

The NPSHA is computed for each pump as a function of assumed sump temperature and pump flowrate conditions. The NPSH margin for the system is computed in feet of liquid head as the difference between the NPSHA, evaluated at the applicable sump temperature, and the NPSHR. The NPSHR is provided by the pump manufacturer from measurements at room temperature. The licensee did not use a hot fluid correction factor to decrease the NPSHR to account for elevated sump liquid temperatures following a LOCA (relative to the pump manufacturer's data at room temperature). This approach is consistent with NRC guidance for performing NPSH margin calculations [18].

Based upon the staff's audit review, with the exception of **Open Item 3.7-1** identified concerning the calculations' neglect of air ingestion, the licensee's overall NPSH margin methodology is consistent with NRC guidance.

3.7.3 Parameters Influencing NPSH Margin

One of the main parameters that govern the NPSH margin is the hydrostatic head of liquid above the RHR pump centerline, which is directly related to the volume of water on the containment floor. The total volume of water that may be spilled onto the floor is calculated from the refueling water storage tank (RWST) and accumulator volumes and injection setpoints, and spillage from the RCS. To perform a conservative NPSH calculation, the minimum volume of water on the containment floor must be evaluated, which occurs at the time that sump recirculation commences. As a result, the details of the alignment process must be considered and modeled in order to provide an estimate of the water volume drawn from the RWST up to the time that the first RHR pump is switched over to recirculation. The switch over alignment process is discussed below in the following section entitled “ECCS Configuration.”

In addition to the minimum containment water level, other significant parameters that influence the NPSH margin are the sump water temperature, pump flow rates, containment pressure, NPSHR, and suction piping frictional head loss. These parameters are discussed below.

ECCS Configuration

Water transferred to the containment and potentially available for recirculation following a LOCA includes (1) water blown down from the RCS as a result of the break, (2) RWST water and (3) accumulator water.

The plant response to a large-break LOCA involves accumulator injection, safety injection from the RWST using the safety injection pumps and the RHR pumps, and long-term recirculation using the RHR pumps. The licensee’s NPSH calculations consider three time periods following the initiation of a LOCA: (1) the period of injection from the RWST prior to the initiation of alignment for recirculation, (2) the period of alignment for recirculation and (3) the period of established recirculation.

During the injection period, the accumulators deliver water to the vessel. In the case of an large-break LOCA, the accumulators dump their entire inventory. For the small-break LOCA analyzed in the licensee’s NPSH calculation, only a fraction of the inventory from the accumulators will be delivered.

For the large-break LOCA, during the safety injection time period, RWST water is delivered via the safety injection and RHR pumps, with the computed volume delivered based upon the minimum RWST level required by Technical Specifications (68%). During the period of alignment to recirculation, procedures call for the continued operation of two safety injection pumps and two RHR pumps in injection mode until a specified time (14 minutes) that one of the RHR pumps is reconfigured to recirculation mode. The cumulative volume of water delivered by this time would depend on whether one or two trains of RHR are assumed to have functioned successfully during the injection period. Immediately after the alignment to recirculation is completed, an RHR pump would experience the minimum water level in containment. This is the limiting water level condition for the NPSHA calculation for the RHR pumps. During the period of established recirculation, the RHR pumps draw suction from Sump B and provide flow to the reactor vessel. At this point in the accident, the inventory of the RWST will be reduced to the 8% level, and the water volume delivered to the containment will be maximized.

For a small-break LOCA, the safety injection pumps provide high-pressure injection flow to the vessel from the RWST. At the time of transfer to the high-pressure recirculation mode, one RHR pump is started to provide flow to one high-head safety injection pump in the “piggy-back” mode. At this time in a small-break LOCA, the inventory of water in containment is minimized, and this volume of water is evaluated for the calculation of NPSH for the RHR pumps.

Procedures for the alignment from injection mode to recirculation mode are referenced in the licensee's calculations. These procedures were not audited by the staff. However, the information presented was checked against the "Risk-Informed Inspection Notebook for Prairie Island Nuclear Generating Plant" [39], which, together with discussions with one of the authors, provided background for the description of the LOCA scenarios and plant responses. On this basis, the staff concluded that the scenarios and plant responses are appropriate for the purpose of the NPSH margin calculations. Given the data presented for flowrates, setpoints and liquid inventories, a sampling of the licensee's calculations indicates that they are reasonable and consistent with NRC guidance.

Minimum Water Level

The water level of interest to the calculation of NPSHA is the static height of liquid as measured from the RHR pump centerline to the surface of the pool in containment. This height of water can be represented as the sum of the height of liquid from the RHR pump centerline to the basement floor, plus the additional height from the basement floor to the surface of the pool in containment. The RHR pump centerline is given as plant elevation 666.85 feet, and the basement floor is at an elevation of 697.5 feet [34]. These elevations were confirmed during the on-site audit with the aid of plant piping diagrams.

The water level in containment was computed for the various scenarios from the inventories of water delivered from the RCS, the RWST and the accumulators. The total volume of water delivered for each scenario was distributed to a number of "sinks" in containment that are delineated in the licensee's calculation. The "sinks" include sumps, cavities, other volumes, and the mass of steam in containment. The relevant containment geometry, including the occupied containment volume, is presented in the calculation [34]. The remaining water was then assumed to fill containment from the containment floor upwards, to a liquid level determined by the free volume available as a function of height above the containment floor.

The staff reviewed the balance equations used to compute the net volume of spillage and exchange of water from the primary system, including the effect of temperature, and concluded that they were reasonable based upon the staff's engineering judgment and the physical characteristics of the PI plant.

The licensee recognized that a conservative minimum volume of water in containment for the purpose of calculating the NPSHA for the RHR pumps occurs during the process of alignment from injection to recirculation. The licensee's calculation assumes that the injection pumps continue to discharge water into containment during the alignment period and that this added water continues to raise the containment water level until the first RHR pump is started in recirculation mode. The static head of liquid available at the time the first RHR pump is switched over to recirculation depends on the timing of events during the pump alignment period. According to the licensee, the timing "... used for determining RWST volume transferred while aligning for recirculation is based upon simulator evaluations" [34, p.11]. Following the onsite portion of the audit, the staff determined that a documented basis demonstrating the conservatism of these timing assumptions was not available.

As an example, for the large-break LOCA case of two operational RHR pumps, the licensee assumed that 14 minutes elapses between the start of the alignment to recirculation and the operation of the first RHR pump in recirculation mode. During this time period approximately

5,600 ft^3 of water would be transferred to containment, thereby adding additional hydrostatic head for the NPSHA calculation for the RHR pump that is started at this point in the sequence. At this time, calculations show that 21,621 ft^3 of water would be in the containment pool. Approximately 25% of this water would have been added during the alignment to recirculation. This quantity of water, based upon Table 1 of the NPSH calculation [34], would be equivalent to a containment water level increase of approximately 0.8 feet, thus increasing the NPSH margin by the same amount. Although the licensee is justified in accounting for an increase in water level during the alignment process to the time that the first RHR pump is operating in recirculation mode, the staff did not review whether the magnitude of the increase assumed by the licensee is conservative. However, since conservative analyses demonstrate that the licensee has (1) significant NPSH margin compared to the head loss across the sump strainer and debris bed and (2) sufficient margin to address flashing across the sump strainer debris bed (both of these items are discussed further in the Head loss and Vortex Evaluation Section of the audit report (page 25)), the staff does not consider this issue to be an open item. Nevertheless, the staff believes that the licensee's calculation should document the basis for considering the timing assumptions derived from the simulator results and emergency procedures to be conservative for the purpose of estimating the volume of water transferred to containment during the alignment to recirculation.

The volume of water discharged into containment during the alignment period also depends on the assumed RHR pump flowrates. For the large-break LOCA case with two trains functioning, the licensee recognized that the flowrates should be minimum estimates in order to minimize the volume of water transferred from the RWST to the sump during the transition to recirculation [34, p. 10]. The licensee used a minimum flow of 1600 gpm for one pump and cited a reference for the value. For the second pump, the licensee used a nominal maximum flowrate of 2150 gpm during the injection phase [34, p.11] based on the assumption in the NPSH calculation that one of the pumps is at its maximum flowrate in the recirculation phase. In essence, the licensee's assumption uses the logical argument that, provided no valves are manipulated, if maximum flow is assumed for one pump during the recirculation phase, then for consistency, maximum flow for this pump should also be assumed during the injection phase, even though this assumption does not minimize the volume of water in containment. Following the onsite portion of the audit, the staff noted that the assumption of maximum flow for one of the pumps results in an increase in the total volume of water transferred from the RWST of less than 2% as compared to having both pumps operating at minimum flow. In light of the minor impact of this effect compared to the licensee's margins to loss of pump NPSH and debris bed flashing, the staff did not consider this issue to be significant and further noted that the licensee's basis for assuming one RHR pump is at maximum flow may be justified as per the above discussion.

Based upon the discussion above, the staff's review of the licensee's water level calculation indicates that the relevant factors have been considered and that, in general, assumptions were made that conservatively minimize the computed water level. Following the onsite portion of the audit, the staff noted that two input assumptions to the water level calculation associated with event timing and pump flowrates during the alignment of the RHR pumps to recirculation mode had not been sufficiently justified in the licensee's calculations. However, since the overall impact of these assumptions is small compared to the conservatively calculated margins to a loss of pump NPSH margin and debris bed flashing, these issues were not designated as open items.

Sump Water and Containment Atmosphere Temperatures

Two sump water temperatures were assumed in the licensee's calculations, 200 °F and 60 °F. The licensee stated that 200 °F is conservative from an NPSH perspective because, for most of the period directly following the LOCA, the sump temperature is greater than 200 °F, and that assuming a lower temperature minimizes the contribution of the static head of water to the NPSH available. In addition, the lower temperature leads to a higher suction line head loss given the same volumetric flowrate, which is also conservative. The 60 °F case was calculated to determine the effect of liquid contraction on static head and on the resulting NPSH, which would account for conditions where recirculation continues to the point where the containment pool has cooled down significantly from its initial value.

The containment atmosphere temperature was taken as 254 °F for any time that the sump liquid temperature is greater than 200 °F. This temperature maximizes the volume of steam in the containment atmosphere which, in turn, minimizes the volume of liquid on the containment floor and the static head of liquid.

The staff considers the licensee's choices of temperatures to be conservative since they bound the values expected during a LOCA.

Pump Capacities

The assumed RHR pump capacities influence the piping frictional head loss aspect of the NPSHA calculation. For this purpose, the licensee used the runout flowrate of an RHR pump (2600 gpm), which is conservative because it maximizes suction line head losses, thereby minimizing the calculated NPSHA.

Containment Pressure

The licensee performed NPSHA calculations using conservative assumptions for containment pressure, in accordance with the guidance in Regulatory Guide (RG) 1.82 [18]. The pressure at the surface of the containment water pool was taken equal to the vapor pressure of the sump water at its assumed temperature. No increase in NPSHA was credited based upon elevated containment accident pressures resulting from the LOCA or for the initial atmospheric pressure in containment prior to the postulated LOCA.

NPSHR and the Hot Fluid Correction Factor

The NPSHR of the RHR pumps is specified in the form of a graph from the pump manufacturer [34]. The NPSHR is given as 14 feet of water at the runout flowrate of 2600 gpm and at the test temperature. The tests are usually performed by the manufacturer at room temperature, a temperature much lower than the assumed sump water temperature.

RG 1.82 [18], Section 1.3.1.5, provides guidance that a hot fluid correction factor should not be used in determining the NPSH margin [40]. Not crediting a hot fluid correction factor is conservative, and this guidance was appropriately implemented in the licensee's NPSH margin calculations. Additionally, the staff noted that the NPSHR value used by the licensee is conservative because the runout flowrate is a bounding estimate of the expected RHR flowrate.

Piping Network Head Loss

Piping head loss calculations were performed for the large-break LOCA case assuming a sump water temperature of 200 °F and the RHR pump runout flowrate of 2600 gpm. As discussed in the summary of head loss section (page 43) , the licensee performed hydraulic loss calculations with an acceptable single-phase flow methodology, using standard models and correlations from Crane [35]. Selected audit checks indicate that these calculations were acceptably performed. The computed piping network head loss (4.7 feet of water) was applied to the small-break LOCA calculations using the argument that "...the small break LOCA uses the head losses corresponding to an RHR flow rate intended to bound the maximum flow rate expected for a large break LOCA [34, p.22]." Since the small-break LOCA piping head loss depends on the pump flowrate, and the maximum RHR flowrate is also applicable to the small-break LOCA, the argument is acceptable.

The same frictional head loss was also applied to the 60 °F sump temperature cases. For the same flowrate but with a reduced temperature, the fluid kinematic viscosity is higher and, therefore the Reynolds number is lower, resulting in a higher friction factor and somewhat higher head loss. A calculational check indicates that the effect is less than 10% on the piping network head loss and less than 2% on the NSPHA. The staff concluded that, while the calculation for the 60 °F case could have been performed more accurately by using friction factors intended for this reduced temperature, the differences are acceptably small and the approximations are acceptable.

3.7.4 Net Positive Suction Head Summary

The licensee performed the NPSH margin calculations using a standard single-phase hydraulics methodology. The assumptions and the selection of physical parameters that provide the numerical basis for the calculations generally follow conservative guidance provided by RG 1.82 [18]. The staff also considered the values of the parameters used in the calculations to be largely reasonable. As a result of the staff's review, the staff considered the NPSH margin results computed by the licensee to be very likely conservative provided that the licensee acceptably resolves **Open Item 3.7-1,** which is associated with the effect of dissolved air on pumping performance.

3.8 Coatings Evaluation

3.8.1 Coatings Zone of Influence

The quantities of LOCA-generated qualified coatings debris were based on applying the spherical ZOI model. The NRC SE recommends a ZOI for qualified coatings with an equivalent radius of 10 length/diameter (L/D) for the largest pipe. The PI qualified coatings debris is based on a 12 L/D ZOI radius about a 29-inch hot-leg break. This ZOI is larger than a 10 L/D ZOI based on a 31-inch interim-pipe break, and the 12 L/D ZOI is larger than the vault in which the break is located. Therefore, the PI qualified coatings ZOI conservatively encompasses all of the qualified coatings within the vault. The staff therefore finds the licensee's treatment of the ZOI for coatings acceptable.

3.8.2 Coatings Debris Characteristics

As discussed in the Coatings Zone of Influence Section of this report (above), the licensee applied a ZOI of 12 L/D on a 29-inch hot-leg break. All coatings were assumed to fail as 10 μ particulate within the ZOI. For coating debris outside of the ZOI, the licensee assumes that all of the unqualified coatings will fail as 10 μ particulate. The quantities of unqualified coatings within containment were determined by containment walkdown assessments.

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. As discussed below and in the latent debris section of this report (page 19), it is unclear whether the plant-specific debris loading for PI results in a fiber bed across the strainer surface.

Although the licensee's analytical approach for coatings debris characteristics is acceptable to the staff, the characteristics of the coatings surrogates used in the head loss testing are not consistent with the analysis; coating chips were used in the head loss tests rather than fine particulate. The staff has concerns about the discrepancy in the debris characteristics used in the analysis and those used in the testing. During the audit representatives of PI stated that they plan to revise the latent debris calculations based on a walkdown of the Unit 2 containment. By revising the latent debris calculations the licensee plans to reduce the amount of fiber in order to justify the use of coatings chips rather than particulate in the head loss testing. The staff's concerns with the head loss testing are discussed in greater detail in the head loss section of this report (page 25) as expressed in **Open Item 3.6-1** (page 33). The staff will review any revisions to the analysis as part of the final closeout of Generic Letter 2004-02 [1].

During interaction with PWR licensees for resolution of GSI-191, the NRC staff has questioned the current industry method of assessing qualified coatings. The staff has asked licensees to either justify that their assessment techniques can accurately identify the amount of degraded qualified coatings in containment, or assume all of the coatings fail. The licensee stated that they will rely on the results of an ongoing test program conducted by Electric Power Research Institute and the Nuclear Utilities Coatings Council to validate their assessment techniques at PI. The referenced testing will subject visually sound and visually degraded coatings to physical testing, that is adhesion tests, in an attempt to show that visual assessments are capable of identifying coatings that would not remain adhered during a design basis accident. This testing has not been performed and therefore has not been reviewed by the NRC staff. Assessment of qualified coatings is **Open Item 3.8-1**, pending industry validation testing and NRC staff review of the results.

4.0 DESIGN AND ADMINISTRATIVE CONTROLS

4.1 Debris Source Term

Section 5.1 of the GR and SE discuss five categories of design and operational refinements which could affect the debris source term.

1. Housekeeping and foreign material exclusion programs
2. Change-out of insulation
3. Modification of existing insulation
4. Modification of other equipment or systems
5. Modification or improvement of coatings program

The SE states that these additional refinements should be evaluated for their potential to improve plant safety and reduce the risks associated with sump screen blockage.

Staff Evaluation

The licensee addressed these candidate refinements as follows:

1. Housekeeping and foreign material exclusion programs

   The staff reviewed the PI Containment Cleanliness, Foreign Material Exclusion, and Engineering Change Process control programs for their potential to maintain housekeeping and foreign material control. The staff found that these programs appear to adequately control their respective processes for maintenance of the debris source term as needed to maintain ECCS strainer function. One item that was noted during the audit of PI Procedure SP 1750 [2750] "Post Outage Containment Close-Out Inspection" [19] was that this procedure does not require a final verification by the Operations or Plant Manager. Although this is not a requirement, many plants consider this to be the appropriate level of verification for this program.

2. Change-out of Insulation

   The licensee has not committed to change-out of any insulation as a corrective action to meet the requirements of GL 2004-02.

3. Modification of Existing Insulation

   The licensee has not committed to modification of any insulation as a corrective action to meet the requirements of GL 2004-02.

4. Modification of Other Equipment or Systems

   The licensee indicated that a number of modifications were to be made to other equipment or systems related to the change-out of the ECCS sump strainer. Several existing components, such as cable tray supports, were to be relocated and/or reconfigured to clear space for the new strainers. The modification also removed the trash rack over the sump pit that was used to remove large pieces of debris. The licensee stated that this will remove the potential for large debris to clog upstream flow paths to the ECCS strainer. Other changes associated with this modification included capping abandoned waste liquid disposal pipes located in the sump. The staff agreed with the licensee that these additional modifications will support the new ECCS strainers in their ability to reduce the risks associated with sump screen blockage, and did not identify the need for consideration of any additional modifications in this area.

4.2 Screen Modifications

Section 5.3 of the approved GR 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 that is predicted to arrive at the screen, fully considering debris generation, debris transport, and any mitigating factors (e.g., curbing).
- The design should address the possibility of thin bed formation.

Staff Evaluation:

Based on the review described in Section 3.0 of this audit report, the staff believes that the new sump design will be able to accommodate the maximum volume of debris. However, Open Item 3.4-1 (page 20) has been identified relating to the assumed amount of latent debris as it impacts whether or not a thin bed can be formed.

5.0 ADDITIONAL DESIGN CONSIDERATIONS

5.1 Sump Structural Analysis

General guidance for considerations to be used when performing a structural analysis of the containment sump screen is contained in Section 7.1 of the NEI GR [16] and the staff SE [17]. General items identified for consideration include (1) verifying maximum differential pressure caused by combined clean screen and maximum debris load at rated flow rates, (2) geometry concerns, (3) sump screen material selection for the post-accident environment, and (4) the addition of hydrodynamic loads from a seismic event. Analysis of dynamic loads imposed on the sump screen structures due to break-jet impingement were not required for PI because no break locations have been identified that could cause direct jet impingement. No other refinements were provided in other sections of the SE.

The Nuclear Management Company (NMC) prepared a modification to replace the containment recirculation sump B grating/screens of the PI Units 1 & 2 with improved passive strainers to achieve the lowest practical head loss, thereby minimizing the impact on the residual heat removal (RHR) pump NPSH during recirculation. The calculation package that NMC prepared includes structural analyses and related calculations: “Structural Evaluation of Containment

Sump Strainers" (PCI-5343-S01) [41], "Evaluation of Sump Cover and Piping for the Containment Sump Strainers" (PCI-5343-S02)[42], and other associated documents. Those calculations were to qualify the Performance Contracting Inc. (PCI) Containment Sump Strainers, sump cover, piping, and piping supports associated with the strainers to be installed in PI Units 1 and 2. The staff review of these calculations follows.

Calculation 1: Structural Evaluation of Containment Sump Strainers (PCI-5343-S01) [41]

This calculation/evaluation presents the structural analysis of the PCI suction strainers modules as well as the supporting structures associated with the new strainers. The evaluations were performed using a combination of manual calculations and finite element analyses using the GTSTRUDL and the ANSYS finite element model computer program.

In the evaluation, seismic loads response analysis on the strainers and their supporting elements was performed to determine whether they meet Class I seismic criteria for their intended safety function after an accident. The strainer performance was analyzed to verify it can withstand the hydrodynamic loads and inertial effects of water in the containment basement, at full debris loading, without loss of structural integrity.

In the analysis, the following considerations/assumptions were used:

1. Thermal loads: Considered as zero because the strainers are free standing and the most part free to expand without restraint.

2. Pressure loads:

   (a) The normal operating pressure load (pressure drop across a clean strainer) was considered; and
   (b) The differential pressure load during accident conditions when the strainers are covered with debris was considered.

3. Dynamic loads:

   (a) The inertial effects of the added hydrodynamic mass due to the submergence of the piping were considered; and
   (b) Hydrodynamic drag loads due to sloshing were not considered. The analysis of the seismic sloshing loads for the Prairie Island strainers (AES Calculation PCI-5343-S03, "Prairie Island Strainer Sloshing Evaluation") [?], concluded that the maximum sloshing load is less than 5 lbs per module, therefore, this load can be ignored in the analysis.

4. Seismic loads: A response spectrum of the design basis earthquake defined in DIT No. 04RH04-12 was used in the analysis.

5. Wind, snow, tornado, and jet force loads: These loads were considered not applicable.

6. Flood loads: These loads were considered; however, no additional load was used in the analysis because of the submerged condition (hydrostatic load was determined to not be an issue).

7. Missiles, pipe whipping and pipe rupture loads: These loads were not considered because the licensee determined that there were no direct paths from potential break locations to the strainers.

Calculations

The licensee prepared detailed calculations of the strainer structural analysis, which include manual calculations that produced necessary input for the structural analysis which used computer software (GTSTRUDL and ANSYS), as well as the analysis outputs. The analysis results were presented in terms of maximum stress interaction ratios (i.e., calculated stress divided by allowable stress). The results showed that all ratios were smaller than 1.0 by using standards of USAS (ANSI) B31.1 Power Piping 1967 & 1998 Editions, AISC-1963 Edition, American Society of Mechanical Engineers (ASME) B&PV Code, Section III, Division 1, Subsections NB, NC, and Appendices, 1998 Edition, through 1999 Addenda, and ANSI/AISC N690-1994.

Staff Evaluation

Based on the review of the information provided, the staff concludes that; (1) The standard used in the analysis meets the guidance of NUREG-0800, Section 3.8.4 in which the ANSI/AISC Standard N690-1984 is to be followed for strainer analysis, and (2) The load combinations used in the analysis, which considered normal operating, operation basis earthquake and design basis earthquake loading conditions, are in accordance with the guide lines described in the NUREG-0800, Section 3.8.4. The seismic spectrum and damping ratios used in the dynamic analysis are reasonable and within the specification identified in RG 1.60. The analysis and calculation results showed that the proposed suction strainer modules and their supporting structures meet Class I Seismic Criteria for their intended safety function. Because an acceptable result was obtained using methods consistent with NRC-approved guidance, the staff finds the strainer structural loading to be acceptable.

Calculation 2: Evaluation of Sump Cover and Piping for the Containment Sump Strainers (PCI-5343-S02) [42]

This calculation evaluates the sump cover, piping, and the supporting structures associated with the new piping. The evaluation included all piping from and including the sump cover plate attached to the El. 698' floor slab to the strainer modules, including intermediate pipe support structures.

The evaluations were performed by combining manual calculations and computerized analysis using the AutoPIPE Program. Seismic loads response analysis on the strainer piping and their supporting elements was conducted to determine whether the structure and components meet Class I seismic criteria.

In the analysis, the following considerations/assumptions were used:

1. The piping was considered as an attachment or extension to the strainers.

2. The piping is subjected to two operating conditions: a “dry” condition with no recirculation water inside or external water present; and “wet” condition with recirculation

water. The piping “dry” state was not analyzed because this condition was considered less severe than the “wet” condition.

3. The loads considered in the analysis were weight, pressure, and thermal loads

   The weight includes the weight of the pipe and flange weights. The enclosed water inside the piping was not accounted for because of buoyancy in the “wet” condition.

   The maximum differential pressure load acting on the piping was considered as the hydrostatic pressure associated with the maximum allowed head loss through the debris-covered strainers because the piping is open-ended.

   Thermal expansion loads were determined by thermal expansion analysis based on the maximum water temperature of 253 °F.

4. Seismic Inertia Loads

   The seismic sloshing loads in PWR containment were not accounted for because they were considered insignificant by comparison with other seismic loads, according to another analysis (PCI-5343-S03, “Prairie Island Strainer Sloshing Evaluation. The inertial effects of the added hydrodynamic mass due to the submergence of the piping were considered.

   Based on the natural frequency of the system (15.9 Hz), the analyzed configuration was considered to be the bounding configuration for any potential shortening of spool pieces to align the strainer modules and avoid interferences. The calculated hydrodynamic mass in the lateral direction is 5.26 times of the mass of the water enclosed in the pipe and the vertical mass is about 2.80 times that mass. The AutoPIPE input conservatively adjusted the specific gravity of the contents to 5.26.

Calculations

The piping was qualified using the response spectra method; therefore a response spectra analysis was performed to analyze the seismic inertia loads. Horizontal and vertical spectra with 0.5% damping for the design basis earthquake load case provided at Elevation 711' - 6" were used in the analysis. To account for torsional accelerations, the spectra with a torsional arm of 100 feet were used. For evaluating stresses, displacements, loads, etc., the values obtained from the operating basis earthquake analysis were increased by a factor of 2.0 for the design basis earthquake load case. The square-root-of-the-sum-squares method was used in modal combination. The cutoff frequency was taken at 30 Hz or a minimum of 5 modes were included. Zero-period acceleration residual mass effects were considered, and its responses were added to the response spectra analysis by square-root-of-the-sum-squares.

The analysis results were given in terms of Interaction Ratio, which is the ratio of calculated maximum pipe stresses for each loading condition to their allowable stress. The allowable stresses are based on ANSI B31.1 Power Piping 1967 Edition, ASME Section III, Appendix L, and AISC - 1963 Edition. The calculation results showed that under all loading conditions considered, the interaction ratios are smaller than 0.2, therefore the calculated stresses are well below the allowable stresses. Because an acceptable result was obtained using methods consistent with NRC-approved guidance, the staff finds the evaluation of sump cover and piping for the containment sump strainers to be acceptable.

Staff Evaluation

Based on the review of the information provided, the staff concludes that the standards used in the analysis are compatible with the guidance provided in Regulation Guide (RG) 1.70, in which the ANSI/AISC Standard N690-1984 is the listed standard. The load combinations used in the analysis, which considered normal operating, operation basis earthquake and design basis earthquake loading conditions, are in accordance with the guidelines described in the NUREG-0800, Section 3.8.4. The seismic spectrum and damping ratios used in the dynamic analysis meet the provisions of RG1.60. The analysis/calculation results show that the proposed strainer piping and their supporting elements meet Class I seismic criteria for their intended safety function.

5.2 Upstream Effects

During the onsite portion of the audit, the staff discussed upstream debris accumulation and water hold-up with the licensee. While limited information in this area was presented in the debris transport report, Calculation 2005-02881, "Post-LOCA Debris Transport to Containment Sump for Resolution of GSI-191" [22], and the containment walkdown report, Calculation ENG-ME-600, "Unit 1 Containment GSI-191 Walkdown Results" [23], a complete, documented assessment of upstream debris accumulation and water hold-up was not presented in the analysis and reports provided for the staff's audit review. Therefore, the staff's discussion below is generally based upon verbal input from the licensee provided during the onsite portion of the audit.

The licensee explained how fluid from containment sprays and the ruptured pipe would drain down through various elevations of the containment building en route to the containment recirculation sump. The licensee stated that the entire 755' elevation would be directly exposed to containment spray droplets. At this elevation, spray droplets could fall (1) into the steam generator compartments, (2) into the refueling cavity, (3) through an open area in one containment quadrant, and (4) onto solid containment flooring. Spray that lands on solid flooring at this elevation can drain to lower elevations through several stairwells and through the refueling cavity drain.

To reach the containment pool, water from the containment sprays that collects in the refueling cavity must pass through a 4-inch drain pipe with a grated opening intended to prevent debris from entering the line. A photograph presented by the licensee showed that heavy structural bars for the fuel transfer car are located above the refueling cavity drain. These structural bars appeared capable of preventing a large piece of debris from covering the drain in a manner that would completely prevent flow. A licensee representative also stated that, while some debris from a pipe rupture could be blown into the upper containment and subsequently fall into the refueling cavity, due to the presence of floor grating, solid flooring, and other obstacles, most large pieces of debris individually capable of blocking the refueling cavity drain would be prevented from reaching the upper containment and refueling cavity.

The licensee stated that the next lowest containment elevations are at 733'9" and 711'6". At each of these elevations, one quadrant of the containment is directly exposed to falling spray droplets, and several stairways are present to allow fluid drainage in the areas where solid flooring exists.

Since the flooring at the 711'6" elevation is solid, the licensee stated that no spray droplets fall directly onto the basement elevation of 697'6". The licensee stated that drainage flow from the 711'6" elevation reaches the containment pool at the basement elevation primarily via stairways. The licensee also stated that in the steam generator loop compartments, drainage to the basement elevation can occur through laddered manways and along the edges of the compartments.

Based upon the explanation above, the licensee did not identify any credible mechanisms that could prevent significant quantities of drainage from the containment sprays and the ruptured pipe from reaching the containment pool.

With one exception described subsequently, the staff generally considered the verbal discussion provided by the licensee to address upstream debris accumulation to be reasonable. Based on a review of elevation diagrams of the Prairie Island containment provided in the containment walkdown report, the staff confirmed the presence of stairways (at each of the elevations described above) that appeared capable of providing ample opportunity for the drainage of post-accident debris-laden water. Except for the refueling cavity drain (which is described below), the staff did not identify any potential choke points for water draining into the containment pool.

The staff evaluated the refueling cavity drain in detail because it is a potential choke point at which substantial quantities of water could be retained if debris blockage were to occur. Based upon the licensee's photograph of the refueling cavity drain, which showed heavy bars directly above the drain that serve as fuel transfer car rails, the staff concluded that there is reasonable assurance that a single large piece of debris is not capable of blocking the refueling cavity drain opening to prevent adequate water drainage. However, the staff noted during the onsite portion of the audit that, while the licensee had presented a reasonable verbal explanation to support the position that large debris pieces are unable to reach the refueling cavity drain, this explanation (as well as the entire upstream debris accumulation evaluation) was not documented in a written, quantative evaluation that had gone through the licensee's normal calculation verification process. Subsequently, the staff also determined that the licensee's verbal explanation did not fully address the potential for smaller pieces of debris to transport into the refueling cavity (e.g., during blowdown and washdown), accumulate on top of the refueling cavity drain grating, and potentially block or significantly reduce the flow through the refueling cavity drain line. Since only a single 4-inch line is provided to drain the refueling cavity volume, the staff considers it essential that the licensee conservatively address the potential for debris blockage at this drain to result in water hold-up or reduced drainage rates.

In light of the discussion above, the staff designated it **Open Item 5.2-1** for the licensee to document a comprehensive upstream debris accumulation evaluation to capture and verify the verbal explanations provided during the onsite portion of the audit and to address the staff's concerns regarding the potential for debris accumulation to result in blockage or partial obstruction of the refueling cavity drain line.

5.2.1 Summary

During the onsite portion of the audit, the licensee provided a verbal basis to support its position that debris accumulation in the containment upstream of the recirculation sump strainer will not impede the drainage of fluid from the containment sprays and the pipe rupture. The staff designated it **Open Item 5.2-1** for the licensee to document this explanation in a written, verified evaluation which specifically addresses the staff's concerns regarding the potential for blockage at the refueling cavity drain line. With the exception of this open item, the staff considered the licensee's evaluation of upstream debris accumulation to be acceptable.

5.3 Downstream Effects

5.3.1 In-Vessel Downstream Effects

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

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

At the request of the industry, the NRC staff provided additional interpretation for 1) the requirements and acceptance criteria for long-term core cooling once the core has quenched and reflooded and 2) for the mission time that should be used in evaluating debris ingestion effects on the reactor fuel. The NRC staff provided these clarifications in a letter dated August 16, 2006 [43].

Following a large break in the reactor system after the core has been recovered with water, long-term cooling at Prairie Island will be accomplished by the low-pressure and high-pressure ECCS pumps. The Prairie Island units are classified as upper plenum injection plants in that the high-capacity, low-head injection pumps inject water directly into the upper plenum of the reactor vessel. The high-head safety injection pumps inject water into the reactor coolant system cold legs. These pumps initially take suction from the RWST, a storage tank containing borated water. When that source of water becomes depleted, the suction to the low-pressure pumps will be switched to the containment emergency sump and the high-pressure pumps will be turned off; so that only the low-pressure pumps will recirculate water from the containment sump. This water will be injected directly into the reactor vessel upper plenum above the core. At that time, the containment will contain all the water spilled from the reactor system and the water added to the containment by the containment spray. The core cooling mode by which water from the containment sump is continually recirculated to the reactor system after it spills from the break may be required for an extended period of time. During this long-term cooling period any debris that passes through the sump screens will have a high probability of being pumped into the reactor system.

Generic Letter 2004-02 requires that holders of operating licenses for pressurized-water reactors perform evaluations of the ECCS and the containment spray recirculation functions. These evaluations are to include the potential for debris blockage at flow restrictions within the ECCS recirculation flow path downstream of the sump screen, including potential blockage areas within the reactor vessel and core. Some examples of these flow restrictions are the fuel assembly inlet debris screens and the spacer grids within the fuel assemblies. Debris blockage at such flow restrictions could impede or prevent the recirculation of coolant to the reactor core leading to inadequate long-term core cooling. NMC provided evaluations for the purpose of demonstrating that debris blockage of the reactor core during the long-term cooling period is not of concern for Prairie Island (Calculation Note CN-CSA-05-44, "Prairie Island Nuclear Generation Plants Units 1 and 2 GSI-191 Downstream Effects Debris Fuel Evaluation," [44] including the potential for blockage of reactor vessel flow paths other than the core. The NRC staff review of this material is described herein.

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

During the period when sump water is recirculated following a large break LOCA at Prairie Island, all operating ECCS pumps are aligned to inject into the reactor vessel upper plenum. If the break were in a reactor system cold leg, the ECCS water would be forced through the reactor core toward the break. Core flow, including a small amount of core bypass flow, during the long-term cooling period would be equal to the total ECCS flow. If both low-pressure ECCS pumps were assumed to operate, ECCS flow into the reactor system through the reactor vessel and into the core would be maximized. The maximum flow condition is evaluated since it provides the greatest potential for debris to transport to the reactor core and subsequently lodge within flow restrictions.

Following a large hot-leg break with injection into the reactor upper plenum, water will flow into the core from above at a rate needed to replenish the water boiled away. The excess reactor coolant will be spilled out of the break. The long-term cooling period following a large hot-leg break represents a minimum core flow condition. With flow only being added above the core, the staff expects that the water in the reactor system cold-leg piping will be stagnant. This is because for flow to be established through the cold legs, water would have to be pushed over the tops of the U-bends of the steam generator tubing. Both excess ECCS flow and steam from the core would be expected to flow out of the broken hot-leg because of its lower elevation relative to the top of the steam generator tubes. Without a net flow through the core, boiling in the core would cause debris and chemicals to be concentrated. The staff requested that the licensee evaluate when boiling in the core would end following a large hot-leg break. The licensee has referred this calculation to the PWR Owners Group.

For the evaluation of potential core blockage following a hot-leg or a cold-leg break, the licensee used the methodology of WCAP-16406-P (45). The WCAP describes how particulate debris with a density that is heavier than water will settle in the reactor vessel lower plenum.

The WCAP also describes how fibrous debris with a density approximately the same as water would be carried along with the recirculated sump water but would be filtered by the sump screens and by screens located at the inlet to the fuel bundles. WCAP-16406-P was recently submitted as a topical report for NRC review. The staff plans to complete the review of this topical report early in 2007. The staff met with the PWR owners group on April 12, 2006, to discuss issues associated with downstream effects on reactor fuel. Westinghouse presented plans to develop another topical report with a more detailed fuels evaluation methodology. Conclusions from the review of both these topical reports may affect the staff's conclusions for Prairie Island closure of Generic Letter 2004-02.

The licensee provided a generic methodology for the amount of particulate debris which might flow into the reactor vessel with the ECCS water (Ref. 44 starting at page 33). The generic methodology discussed the settling potential for RMI, concrete debris, latent containment debris and coating particulates. The evaluation concludes that any small particles of RMI, concrete debris, latent containment debris and all but the smallest coating particulates that pass through the sump screen and reach the reactor vessel will settle in the lower plenum of the reactor vessel. The staff notes that ECCS pumps at Prairie Island cause ECCS water and any particulate debris to enter the core from the top. The licensee's evaluation of the size of particles which might enter the reactor vessel indicates that they are too small to be lodged within the reactor core flow paths and would therefore flow through the reactor core for a cold-leg break. The licensee has further performed an evaluation which determined that the total which may pass into the reactor vessel to be approximately 5.4 cubic feet [46]. The volume of the reactor vessel lower plenum below the core (approximately 317 cubic feet) is much larger than the volume of particulate and coatings debris. Thus, the licensee concluded that there is insufficient particulate and coating debris at Prairie Island to cause lower plenum blockage. Following a large hot-leg break for an upper plenum injection plant with all ECCS flow to the upper plenum, the core will be cooled by countercurrent flow of water and steam. Under these conditions, all particulate debris that flows into the upper plenum may settle into the core. The licensee needs to evaluate the effect of particulate debris on long-term core cooling and the potential of local debris accumulation causing core hot spots. The licensee is working with the PWR Owners Group to resolve this issue.

The licensee determined that 6.76 cubic feet of Nukon™, asbestos and latent fibrous debris might be formed within the containment of a Prairie Island unit following a large LOCA and transported to the core. The licensee conservatively assumed that 100% of the fibrous debris is transported to the containment sump. Most of the fibrous debris would be retained on the sump screens but for that which is passed through the screen, the licensee assumes that all would reach the core. The licensee used a sump screen efficiency of 95 percent to determine the volume of fibrous material which might be passed through the sump screen and passed into the reactor system. See the Component Evaluation Section of this report (page 62) for the staff's evaluation of the sump screen efficiency for Prairie Island.

The licensee used an acceptance criterion of a fibrous debris bed of no more than 0.125 inches uniformly distributed across the core. This acceptance criterion is based on pressure drop studies for boiling water reactor strainer blockage concerns in NUREG/CR-6224 [25]. Additional justification is provided by the licensee starting on page 23 of reference [44]. Using the methodology of WCAP-16406-P, the licensee calculated a maximum fiber bed thickness across the top of the core of 0.076 inches following a postulated cold-leg break. For a hot-leg break, much of the ECCS water recirculated to the upper plenum would spill out of the break and would have to pass through the sump strainers on another pass before reaching the core. The licensee believes that much of the fiber in the spilled ECCS water would be collected at the sump strainers on the subsequent passes and therefore not reach the core. For this reason the licensee believes that a large cold-leg break will be limiting for the collection of fibers at the top of the core. The staff has not finished reviewing WCAP-16406-P but notes that with a 95% assumed sump screen efficiency, if all the fibers that pass through the sump screen were to collect at the top of the core, the licensee's acceptance criterion of 0.125 inches would not be exceeded.

In addition to locations at the top of the core, the licensee also addressed other possible locations of blockage within the reactor vessel internals which might affect core cooling [47]. The smallest clearance was found to be 1.38 inches. This dimension is approximately a factor of 16 greater than the dimension of the strainer holes in the containment sump screen. The staff therefore agrees with the licensee that debris blockage of non-core reactor vessel internals is unlikely at Prairie Island.

Although the licensee addressed core blockage which might prevent ECCS water from entering the core during long-term cooling, other issues need to be resolved. These issues involve the potential for core internal heat transfer degradation between the fuel rods and the coolant in the presence of debris and chemicals in the recirculated sump water. Following a large hot-leg break at Prairie Island, continued boiling in the core will act to concentrate the debris and chemicals in the water between the coolant channels. As noted in the proceeding discussions, the licensee has not evaluated the duration of boiling in the core following a large hot-leg break. The licensee needs to determine the concentration of the debris mixture and chemicals in the core during the long-term cooling period and evaluate the potential for precipitation within the core channels. Chemical reaction of the debris with the containment spray buffering agents and boric acid from the ECCS water in the presence of the core radiation field might change the chemical and physical nature of the mixture within the reactor core. Heat transfer might be affected by direct plate out of debris on the fuel rods and by accumulation of material within the fuel element spacer grids. The licensee has stated that they will rely on an ongoing program by the PWR Owners Group to investigate the effects of local blockages within fuel elements including the effect of plate out of substances on fuel rod surfaces during the long-term cooling period. The staff will reach conclusions on the effect of debris blockage of the fuel assembly support grids at Prairie Island after the results of the generic program are submitted for review.

Conclusions:

The licensee continues to evaluate the post-LOCA consequences of debris ingestion into the reactor system and its affect on long-term core cooling. The following items remain open in the staff's review.

The licensee's evaluations are based in part on the generic methodology of WCAP-16406-P. This topical report is currently under review by the NRC staff. When the staff's review of this topical report is completed, the licensee needs to reevaluate post-LOCA downstream effects for Prairie Island (**Open Item 5.3-1**).

The PWR Owners Group is evaluating the effect on core heat transfer of materials concentrated within the reactor core in the long-term cooling period following a loss of coolant accident. At the completion of this study, the licensee needs to provide plant-specific analyses for the concentration of the various particulate and chemical compounds within the reactor core during the post-LOCA period, including chemical reactions under the effect of ionizing radiation, and to demonstrate that the condition of the core remains within acceptable limits. Such evaluations should include the effect on core heat transfer of plate out of material on to the surface of fuel rods during long-term boiling and the effect of any debris trapped between the fuel element spacer grids and the adjacent fuel rod in the production of local hot spots (**Open Item 5.3-2**).

The licensee is working with the PWR Owners Group to complete evaluations for the effects of ingested debris on long-term reactor core cooling. The licensee believes that when the evaluations are completed that the effect of debris ingestion will be shown to be small. The NRC staff will review this area when the additional material is submitted in the GL 2004-02 supplemental response.

5.3.2 Component (Ex-Vessel) Evaluation

The staff reviewed the Westinghouse generic reference document WCAP-16406-P [45] and plant-specific calculations to determine if the licensee had adequately addressed the evaluation of downstream effects on system components outside the reactor vessel.

The GR provided licensees guidance to evaluate the flowpaths downstream of the containment sump for blockage from entrained debris. The GR specified three concerns to be addressed: (1) blockage of flowpaths in equipment, such as containment spray nozzles and tight-clearance valves, (2) wear and abrasion of surfaces, such as pump running surfaces, and heat exchanger tubes and orifices, and (3) blockage of flow clearances through fuel assemblies.

The GR identified the starting point for the evaluation to be the flow clearance through the sump screen and stated that the flow clearance through the sump screen determines the maximum size of particulate debris that will pass through it. It also stated that wear and abrasion of surfaces in the ECCS and CSS should be evaluated based on flow rates to which the surfaces will be subjected and the grittiness or abrasiveness of the ingested debris. The GR recognized that the abrasiveness of debris is plant-specific.

The safety evaluation of GR Section 7.3 found that the GR statements did not fully address the potential safety impact of LOCA generated debris on components downstream of the containment sump. The SE stated:

> (t)he evaluation of GSI-191 should include a review of the effects of debris on pumps and rotating equipment, piping, valves, and heat exchangers downstream of the containment sump related to the ECCS and CSS. In particular, any throttle valves installed in the ECCS for flow balancing (e.g., high-pressure safety injection (HPSI) throttle valves) should be evaluated for blockage potential. And the downstream review should first define both long-term and short-term system operating lineups, conditions of operation, and mission times. Where more than one ECC or CS configuration is used during long- and short-term operation, each lineup should be evaluated with respect to downstream effects.

Evaluations of systems and components are to be based on the flow rates to which the wetted surfaces will be subjected and the grittiness or abrasiveness of the ingested debris. The abrasiveness of the debris is plant specific, as stated in the GR, and depends on the site-specific materials that may become latent or break-jet-generated debris.

Specific to pumps and rotating equipment, an evaluation should be performed to assess the condition and operability of the component during and following its required mission times. Consideration should be given to wear and abrasion of surfaces, (e.g., pump running surfaces, bushings, wear rings). Tight clearance components or components where process water is used either to lubricate or cool should be identified and evaluated.

Component rotor dynamics changes and long-term effects on vibrations caused by potential wear should be evaluated in the context of pump and rotating equipment operability and reliability. The evaluation should include the potential impact on pump internal loads to address such concerns as rotor and shaft cracking (NUREG/CP-0152 Vol. 5, TIA 2003-04 [59]).

The downstream effects evaluation should also consider system piping, containment spray nozzles, and instrumentation tubing. Settling of dusts and fines in low-flow/low fluid velocity areas may impact system operating characteristics and should be evaluated. The evaluation should include such tubing connections as provided for differential pressure from flow orifices, elbow taps, and venturis and reactor vessel/RCS leg connections for reactor vessel level, as well as any potential the matting may have on the instrumentation necessary for continued long-term operation.

Valve (Information Notice 96-27) and heat exchanger wetted materials should be evaluated for susceptibility to wear, surface abrasion, and plugging. Wear may alter the system flow distribution by increasing flow down a path (decreasing resistance caused by wear), thus starving another critical path. Or conversely, increased resistance from plugging of a valve opening, orifice, or heat exchanger tube may cause wear to occur at another path that is taking the balance of the flow diverted from the blocked path.

Decreased heat exchanger performance resulting from plugging, blocking, plating of slurry materials, or tube degradation should be evaluated with respect to overall system required hydraulic and heat removal capability.

An overall ECC or CS system evaluation integrating limiting or worst-case pump, valve, piping, and heat exchanger conditions should be performed and include the potential for reduced pump/system capacity resulting from internal bypass leakage or through external leakage. Internal leakage of pumps may be through inter-stage supply and discharge wear rings, shaft support, and volute bushings (NUREG/CP-1052 Vol. 5, TIA2003-04 [59]). Piping systems design bypass flow may increase as bypass valve openings increase or as flow through a heat exchanger is diverted because of plugging or wear. External leakage may occur as a result of leakage through pump seal leak-off lines, from the failure of shaft sealing or bearing components, from the failure of valve packing or through leaks from instrument connections and any other potential fluid paths leading to fluid inventory loss.

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.

The SE conclusions for GR Section 7.3 noted that evaluation of downstream effects should include consideration of term of operating lineup (long or short), conditions of operation, and mission times, as stated above. The SE also noted that consideration should be given to wear and abrasion of pumps and rotating equipment, as discussed above [59]. Licensees' downstream effects evaluations should consider system piping, containment spray nozzles, and instrumentation tubing. Valve and heat exchanger wetted surfaces should be evaluated for wear, abrasion, and plugging. Wear should be evaluated with respect to the potential to alter system flow distribution. Heat exchanger performance should be evaluated with respect to the potential for blockage or the plating of slurry materials. The HPSI throttle valves should be specifically evaluated for their potential to plug and/or wear (IN 96-27). The overall performance of the ECCS and CSS should be evaluated with respect to all conditions discussed above.

Staff Evaluation

The staff reviewed the list of all components and flowpaths considered to determine the scope of the licensee's downstream evaluation (pumps, valves, instruments, and heat exchangers, etc.). PI provided a complete and thorough listing and evaluation of instrument tubing connections. The licensee evaluation was complete and well organized. All system components and flowpaths were considered and evaluated. The staff reviewed piping and instrumentation drawings, Prairie Island Updated Safety Analysis Report (USAR), operations procedures and supporting calculations. No design discrepancies were noted.

In accordance with SE Section 7.3, the staff reviewed design and license mission times and system lineups to support mission-critical systems. Line-ups, mission times, flows and pressures used to bound downstream evaluations were in all cases conservative with respect to review and evaluation of downstream components for each specific component and failure mechanism examined by the team.

The staff also reviewed small-break LOCA, medium-break LOCA, and large-break LOCA scenarios to assess system operation. ECCS operation during small-break LOCA, medium-break LOCA, and large-break LOCAs appears to be adequate because flows and pressures achieved meet the requirements of the PI accident analysis.

The staff reviewed the licensee's analysis of the extent of air entrainment (see Section 3.6.5 for evaluation of vortexing), and concurred that there is no significant air entrainment with the ECCS that would either impact ECCS pump operation or cause air pockets in ECCS piping. The potential for water hammer and slug flow was adequately addressed.

The PI characterization and assumed properties of bypassed ECCS post-LOCA fluid (abrasiveness, solids content, and debris characterization) were appropriate, complete and conservative. The licensee assumed 100% pass-through of all material less than 110% of screen hole size. This is acceptable because they assumed material physically larger than the opening would pass through the screen and is consistent with Section 7.3 of the staff’s SE. Also, 100% of all hard particles were assumed to be carried with the process fluid.

The staff reviewed system depletion calculations. The calculations did not provide a thorough discussion or basis for the assumption of 95% efficiency (**Open Item 5.3-3**).

The staff reviewed design documents to verify opening sizes and running clearances. The staff identified minor, non-significant discrepancies that had no impact on the licensee's evaluations. The SE identifies the vulnerability of the high-pressure safety injection (HPSI) throttle valves to clog during ECCS operation. The PI HPSI valves are normally fully open, thus minimizing the potential for clogging. If an operator chooses to throttle flow, procedures and instrumentation are in place providing adequate indication and alarm. Based on common knowledge and NUREG/CR-6902, "Evaluation of Insulation Debris on Throttle-Valve Flow Performance" [58], cycling open a throttled valve will effectively clear debris and allow flow. The HPSI system was designed such that operation with fully open throttle valves is acceptable.

The licensee provided a listing of the materials of all wetted downstream surfaces (wear rings, pump internals, bearings, throttle valve plug, and seat materials). The staff reviewed this list and verified materials of construction by reviewing design drawings and licensee technical manuals. The staff noted that safety injection pump internals are hard-faced. Based on a comparison of the properties of the ECCS fluid and the materials of construction of the ECCS, the material characteristics of other system components were found by the staff to be appropriate for ECCS operation.

SE Section 7.3 notes the potential to clog or degrade equipment strainers, cyclone separators, or other components. PI has cyclone separators. The licensee provided in Calculation No. ENG-ME-654 [50] a thorough review of installation, equipment details and operation. Based on staff review of the design and installation of the cyclone separators and the properties of the post-LOCA ECCS fluid, the staff concurs with the licensee's conclusion that the cyclone separators will function as designed under all anticipated operating conditions.

The SE states that a review and assessment of changes in system or equipment operation caused by wear (i.e., pump vibration and rotor dynamics) should be performed. Also an assessment of whether the internal bypass flow increased, thereby decreasing performance or accelerating internal wear should be completed. The licensee had not evaluated potential pump hydraulic degradation due to RHR pump internal wear **(Open Item 5.3-4**).

PI used the criterion contained in American Petroleum Institute Standard (API) 610 for acceptance for pump vibration. API 610 only applies to new pumps. Therefore, when this standard is used to evaluate in-service pumps a justification must be provided. PI did not provide an evaluation supporting the conclusion that the the use of API 610 is appropriate. (**Open Item 5.3-5**).

PI used a three-body, erosive wear model for internal wear. According to NUREG/CP-0152 [59] as referenced in the SE section 7.3, the internal wear mechanism for internal, non-impeller wear is two-body. The licensee did not justify its use of the three-body model (**Open Item 5.3-6**).

Seal leakage into the auxiliary building was not quantified. An evaluation of the affects on equipment qualification, sumps and drains operation or room habitability was not performed (**Open Item 5.3-7**).

PI defined the range of fluid velocities within piping systems. PI adequately reviewed system low points and low-flow areas and found no settlement areas. Non-pump component wear evaluations appropriately used pump run-out flow.

Based on a review of Calculation ENG-ME-654 [50], Calculation TDI-6006-04 [31], plant component design drawings, plant isometrics, and piping and instrument drawings, the staff concurs with the PI conclusion that flow balances are unaffected and that there is a negligible change in system flow resistance due to accumulation of debris or wearing of piping components, and that there are no adverse affects on or concerns with ECCS system heat exchangers.

Based on a review of Calculation ENG-ME-654 [50], Calculation TDI-6006-04 [31], plant component design drawings, plant isometrics, and piping and instrument drawings, the staff concurs with the PI conclusion that there is a negligible change in system flow induced vibration due to accumulation of debris or clogging of system components.

Summary of Review

The PI review of downstream effects related to GSI-191 is conservative and robust. The licensee evaluation was complete and well organized. All system components and flowpaths were considered and evaluated. Line-ups, mission times, flows and pressures used to bound downstream evaluations were in all cases conservative with respect to review and evaluation of downstream components.

The PI HPSI valves are normally fully open, thus minimizing the potential for clogging. Procedures and instrumentation are in place such that if an operator chooses to throttle, there is adequate indication and alarm. The HPSI system was designed such that operation with fully open throttle valves is acceptable.

The licensee assumed 100% pass-through of all material less than 110% of screen hole size. Also, 100% of all hard particles were assumed to be carried with the process fluid. The characterization and assumed properties of bypassed process fluids was appropriate, complete and conservative.

HPSI pumps are hard-faced and are resistant to erosive and abrasive wear from hard particles entrained in the post-LOCA process fluid.

PI thoroughly assessed system low points and low flow areas.

The staff believes that there is a negligible change to PI system flow operating characteristics due to structures, systems or component wear, accumulation of debris or clogging of system components. This conclusion is based on the staff review of Calculation ENG-ME-654 [50] and related documentation as noted above. However, PI's analysis needed to verify this conclusion is incomplete. Specifically, the staff noted the following open items related to the methods used by the licensee.

Seal leakage into auxiliary building was not quantified. An evaluation of the affects on equipment qualification, sumps and drains operation or room habitability was not performed (**Open Item 5.3-7**).

System depletion calculations were reviewed. There was not a thorough discussion or basis for the assumption of 95% efficiency. However, It is expected that this will only have a minor impact on overall component conclusions (**Open Item 5.3-3**).

An evaluation of pump hydraulic degradation due to RHR pump internal wear was not performed (**Open Item 5.3-4**).

PI used the criterion contained in American Petroleum Institute Standard (API) 610 as acceptance criteria for pump vibration. API 610 applies to 'new' pumps. PI did not provide an evaluation supporting the conclusion that the existing pumps are as good as 'new' (**Open Item 5.3-5**).

PI utilized a three-body, erosive wear model. The internal wear mechanism for internal, non-impeller wear, is two-body. The licensee did not justify their use of the two-body model (**Open Item 5.3-6**).

In general, the evaluations were thorough and conservative.

Documents Reviewed for the Downstream Component Evaluation:

Prairie Island Nuclear Generating Station, Units 1 and 2, Updated Final Safety Analysis Report [38]
NMC Calculation No. ENG-ME-005, Analysis of Available NPSH to the RHR Pumps from the Containment Sump, Revision 5 [50]
NMC Calculation No. ENG-ME-654, Evaluation of Downstream Effects - Emergency Core Cooling System Effects, Revision 1 [31]
Calculation TDI-6006-04, Clean Head Loss - Prairie Island Nuclear Generating Plant Units 1 & 2, Revision 3 [31]
Drawing X-HIAW-1-104 Unit 1, Two Loop Plant, Reactor Coolant Loop, Rev. B
Drawing X-HIAW-1001-3, Flow Diagram Reactor Coolant System - Unit 2, Revision A
Drawing X-HIAW-1001-7, Flow Diagram Safety Injection System, Revision Y
Drawing X-HIAW-1001-8, Flow Diagram Residual Heat Removal System - Unit 2, Revision P
Drawing NF-93006-2, Reactor Vessel Level Instrumentation System, Revision C
Drawing NF-39361-5, Reactor Building Piping - Field Installed, Revision E
Drawing NF-93036, Reactor Vessel Level Capillary Tube Routing, Revision C
Drawing X-HIAW-1106-1807, Isometric Residual Heat Removal System, - Unit 2, Rev. A
Drawing X-HIAW-1106-1809, Isometric Residual Heat Removal System, - Unit 2, Rev. 8
Drawing X-HIAW-1106-1810, Isometric Residual Heat Removal System, - Unit 2, Rev. 10
Drawing X-HIAW-1106-1811, Isometric Residual Heat Removal System, - Unit 2, Rev. A
Drawing X-HIAW-1106-1812, Isometric Residual Heat Removal System, - Unit 2, Rev. 7
Drawing X-HIAW-1106-2510, Isometric Reactor Safety Injection, - Unit 2, Rev. 6
NSP Tech Manual XH-1-1393, Safety Injection Pump, Rev. 7

Drawing H-1717X, Outline Drawing 4X6X9 CP, Rev. E
Drawing X-HIAW-1001-1390, Safety Injection Pump Cross Section, Rev. J
Drawing B-22696, Piping - Seal Heat Exchanger, Rev. A
Drawing B-22697, Piping - Seal Cooling, Rev. 0
Drawing IB-7342, Assembly ½" Double Coil Heat Exchanger, Rev. 0
Pump Curve No. 28949, Safety Injection Pump Nos. 290695
Pump Curve No. 29001, Safety Injection Pump Nos. 290694S
Pump Curve No. 29008, Safety Injection Pump Nos. 290694
Parts List, Pump No. 290694 and 290695
Technical Manual No. 8020, Residual Heat Removal Pump
Drawing X-HIAW-1-126, Vertical D.S.M. Pump 6X10X18, Rev. 6
Drawing F-SP-13304, Type 1B, 2.625 Shaft Seal
Pump Curve T-32019-1, # 22 RHR Pump
Pump Curve T-32037, # 21 RHR Pump
Pump Curve T-32116, # 11 RHR Pump
Pump Curve T-32120, # 12 RHR Pump
Parts List, 6X10X18 Vertical DSM
Drawing X-HIAW-1-633-1, Orifice, Minimum Flow, Rev .A
Drawing H-SP-1580-1, Type 1B, 2.510 Shaft Seal
PINGP Procedure 1ECA-1.3, Recirculation Sump Blockage, Rev. 0
PINGP Procedure F3-17.2, Long Term Cooling, Rev. 1
PINGP Procedure SP 1089A, Train A RHR Pump and Suction Valve From RWST Quarterly Test, Rev. 10
PI GSI-191 Project Overview, NRC Audit Entrance Meeting [3]
WCAP-16406-P Evaluation of Downstream Sump Debris Effects in Support of GSI-191 Rev. 0 and 1 [45]

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. In support of the chemical effects portion of the audit, the staff reviewed the following licensee documents:

- AREVA Document 51-9008823-000, "Surrogate Chemical Affects Material Selection for Prairie Island Sump Strainer Performance Test," dated December 12, 2005 [48].

- Document 2005-09100, Rev. 0, "Prairie Island Nuclear Generating Plant Units 1&2, GSI-191 Chemical Effects Evaluation," dated April 11, 2006 [49].

The Prairie Island (PI) containment insulation materials include mostly reflective metallic insulation (RMI) with relatively low amounts of fiber. The chemical effects assessment for Prairie Island was performed relative to the test conditions for Integrated Chemical Effects Test (ICET) #1, since the ICET #1 test conditions, which used sodium hydroxide to adust pH and contained fiberglass insulation, were most similar to the Prairie Island plant-specific conditions. Screen tests were performed at Alden Laboratories using manufactured aluminum hydroxide and calcium carbonate powder as surrogates for chemical precipitates that were added to a test flume. Since the initial PI screen tests, the knowledge base for chemical effects has continued to evolve with additional tests at Los Alamos National Laboratory, Argonne National Laboratory, testing to support WCAP-16530-NP [55], and additional strainer vendor tests. Although the staff recognizes the PI flume tests were conducted based on the knowledge at that time, the staff cannot conclude that the initial tests for PI were adequate to address chemical effects as discussed below.

Behavior of precipitates can be affected by temperature, pH, and other species in the chemical system (e.g., boron, other debris such as tin). PI head loss testing was performed at ambient temperature in a non-representative test environment (e.g., potable water) using manufactured powder instead of generating hydrated precipitates with chemical addition. It is important to validate that precipitates for chemical effects tests are representative of those that would form in an actual plant environment and that the test approach does not alter the precipitates in a non-conservative manner relative to potential head loss contribution. In general, the staff expects any chemical effects testing that uses surrogate chemical precipitate or that is performed in non-representative environments will have a technical basis for why the results are acceptable. Such bases were not provided by the PI licensee. Some of the specific staff concerns relative to the chemical effects testing approach used by the strainer vendor for PI were identified in the NRC's Watts Bar Audit Report [27].

During the audit, PI personnel indicated that they are working with the PCI Owners' Group to address chemical effects. It was not clear at the time of the audit if the Owners' Group would be performing plant-specific testing or more general testing. The NRC staff expects that the timing of chemical precipitate addition during testing will be consistent with projected precipitate formation in a post-LOCA pool.

PI personnel also indicted they will be conducting another latent debris survey at the start of the Unit 2 refueling outage, in an attempt to reduce the conservatism in the existing assumption concerning the amount of latent fiber. Their goal is to demonstrate that the amount of latent fiber is less than the amount needed to form a "thin bed" on the new strainers. If PI is successful in demonstrating that the amount of fiber in their containment is not sufficient to form a "thin bed" on the strainer, it will be important to understand the minimum bed that can filter chemical products and affect head loss across the strainer bed. NRC staff has observed some chemical effect tests where the debris bed did not filter particulate in the water (i.e., not enough fiber for the classic "thin bed"), but significant head loss occurred upon subsequent introduction of chemical precipitate to the test fluid (ADAMS Accession Number ML063110561 [56]).

In summary, the PI chemical effects evaluation is still in progress. Therefore, resolution of chemical effects is **Open Item 5.4-1**. Within the resolution of chemical effects, the NRC staff indicated there is a general question related to the potential for coatings to contribute to chemical effects by: (1) leaching constituents that could form precipitates or affect other debris; and (2) changes to the paint itself due to the pool environment (the possibility that some of the PI paints turn into a product (e.g., a gel) that causes high head loss). The staff expects the PI evaluation of chemical effects will address this question.

6.0 Conclusions

Prairie Island has responded to NRC's Bulletin and Generic Letter GL 2004-02 according to the required schedule. New PCI Sure-Flow® strainers, with an effective surface area of 827.3 ft^2, have been installed in both units.

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 NMC from the NRC Office of Nuclear Reactor Regulation. This letter will consider licensee responses to GL 2004-02 requests for additional information, as well as future licensee GL 2004-02 supplemental responses reporting closure of the open items in this report and completion of GL 2004-02 corrective actions at PI.

Appendix I Open Items

Open Item 3.4-1 Latent debris sampling, quantification, and monitoring were not covered and documented in a formalized program. The program was informal and lacked tracking, trending, and appropriate acceptance criteria (page 20).

Open Item 3.6-1 The majority of coating debris in PI tests was in chip form. This is potentially inconsistent with approved guidance to use fine particulate unless there is insufficient fiber to form a thin bed. The licensee was planning to perform additional latent debris assessment to justify that there was insufficient latent fiber debris to form a thin bed. Otherwise, the licensee needs to justify use of coating chips during the head loss testing (page 33).

Open Item 3.6-2 The licensee did not fully justify that the clean strainer head loss correlation is conservative. The justification provided was based on testing of the PCI Prototype II testing module. Differences between aspects of the PI strainer array compared with the PCI Prototype II testing module include (1) significantly different diameter/length and core tube area/slot open area ratios; (2) an annular flow region in the PI strainer array; and (3) a different number of slots and slot's open area (page 40).

Open Item 3.6-3 The licensee has not performed an adequate scaling analysis to demonstrate the that fluid conditions above the testing module would bound the actual fluid condition relevant to preventing vortex formation on top of the PCI strainer arrays (page 41).

Open Item 3.7-1 The licensee's NPSH calculations did not consider the effect of cavitation induced by dissolved air and the related issue of air ingestion on pump performance (page 43).

Open Item 3.8-1 The licensee has not completed an assessment of qualified coatings to remain adhered during a design basis accident, stating PI will rely on the results of an ongoing test program conducted by Electric Power Research Institute and the Nuclear Utilities Coatings Council to validate their assessment techniques (page 50).

Open Item 5.2-1 The upstream debris accumulation evaluation was not comprehensive and had not been formalized under the normal calculation/verification process. In particular, the potential for debris accumulation to result in blockage or partial obstruction of the refueling cavity drain line was not fully addressed (page 57).

Open Item 5.3-1 The licensee evaluations of downstream component effects are preliminary; based in part on the generic methodology of WCAP-16406-P, currently under review by the NRC staff. Conclusions and findings need to be applied to the evaluation of post-LOCA downstream effects for PI (page 61).

Open Item 5.3-2	The licensee had not completed in-vessel downstream evaluations, including the effect on core heat transfer of plate-out of material on the surface of fuel rods during long-term boiling and the effect of any debris trapped between the fuel element spacer grids and the adjacent fuel rod in the production of local hot spots (page 62) .
Open Item 5.3-3	The licensee did not document a basis for the assumption of 95% efficiency in system depletion calculations (page 65).
Open Item 5.3-4	The licensee did not evaluate pump hydraulic degradation due to RHR pump internal wear (page 65).
Open Item 5.3-5	PI did not provide an evaluation supporting using the criterion contained in American Petroleum Institute Standard 610 for pump vibration, which applies to new pumps (page 65).
Open Item 5.3-6	PI did not justify use of a three-body, erosive wear model for pump internals. The industry standard model is to consider internal wear mechanism for internal, non-impeller wear, as two-body (page 65).
Open Item 5.3-7	The licensee did not quantify seal leakage associated with downstream effects into the auxiliary building, nor evaluate the affects on equipment qualification, sumps and drains operation or room habitability (page 65).
Open Item 5.4-1	The chemical effects evaluation was still in progress. The licensee has not resolved the chemical effects issue at PI (page 69).

Appendix II References

1 GL 04-02	NRC Generic Letter 2004-02, "Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized-Water Reactors," dated September 13, 2004.
2 GSI 191	GSI-191, "Assessment of Debris Accumulation on PWR Sump Performance," prioritized September 1996.
3 PI Overview	GSI-191 Project Overview, Prairie Island Nuclear Generating Plant, October 4, 2006, ML070240175.
4 NRCB, 2003	NRC Bulletin 2003-01, "Potential Impact of Debris Blockage on Emergency Recirculation During Design-Basis Accidents at Pressurized-Water Reactors," dated June 9, 2003.
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