Waterford Unit 3 GSI-191 Generic Letter 2004-02
Corrective Actions Audit Report

ENCLOSURE

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ACRONYM LIST

ADAMS	[NRC] Agency Document Management System
ANSI	American National Standards Institute
ASME	American Society of Mechanical Engineers
ARL	Argonne Research Laboratory
ASTM	American Society for Testing and Materials
BEP	best efficiency point
BNL	Brookhaven National Laboratory
BWR	boiling water reactor
BWROG	Boiling Water Reactor Owners' Group
CAD	Computer-aided Design
CES	containment emergency sump
CESS	Containment Emergency Sump Strainer
CFR	Code of Federal Regulations
CS	containment spray
CSS	Containment Spray System
CFD	computational fluid dynamics
DBA	design basis accident
DBE	design basis earthquake
DEGB	double-ended guillotine break
DP	differential pressure
EC	engineering change
ECP	engineering change package
ECCS	emergency core cooling system
EEQ	electrical equipment qualification
EOP	emergency operating procedure
EOI	equipment operating instruction
EPRI	Electric Power Research Institute
EQ	equipment qualification
ESF	engineered safety feature
FWLB	feedwater line break
GE	General Electric
GL	Generic Letter
GR	NEI 04-07 Volume 1, PWR Sump Performance Evaluation Methodology (Guidance Report)
GSI	Generic Safety Issue
HELB	high-energy line break
HPI	high-pressure injection
HPSI	high-pressure safety injection
HVAC	heating, ventilation and air conditioning
ICET	Integrated Chemical Effects Tests
ICM	interim compensatory measure
IOZ	inorganic zinc
LANL	Los Alamos National Laboratory
LAR	license amendment request
LBLOCA	large break loss of coolant accident
L/D	length/diameter
LDFG	low density fiberglass

LOCA	loss-of-coolant accident
LPI	low-pressure injection
LPSI	low-pressure safety injection
MEI	metallic encapsulated insulation
MSLB	main stream line break
NEI	Nuclear Energy Institute
NPSH	net positive suction head
NPSHa	net positive suction head available
NPSHr	net positive suction head required
NRC	Nuclear Regulatory Commission
NRR	Office of Nuclear Reactor Regulation
NUCC	Nuclear Utilities Coatings Council
PWR	pressurized water reactor
PWROG	Pressurized Water Reactor Owners Group
RAI	request for additional information
RAS	recirculation actuation signal
RCS	reactor coolant system
RG	Regulatory Guide
RMI	reflective metal insulation
RMO	Repetitive Maintenance Orders
RNG	Re-normalized Group Theory
RPV	reactor pressure vessel
RWSP	refueling water storage pool
SAMG	Severe Accident Management Guideline
SBLOCA	small break loss of coolant accident
SEM	scanning electron microscope
SE	NEI 04-07, Volume II: Safety Evaluation on NEI 04-07 Volume 1, PWR Sump Performance Evaluation Methodology
SG	steam generator
SI	safety injection
SIS	safety injection system
SRP	Standard Review Plan
TKE	turbulence kinetic energy
TS	Technical Specifications
TSP	trisodium phosphate
UFSAR	updated final safety evaluation report
URG	[BWROG] Utility Resolution Guide
WOG	Westinghouse Owners Group
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 [3], for approximately 10 commercial pressurized water reactors (PWRs). The purpose of the audits is to verify that the implementation of Generic Safety Issue 191, "Assessment of Debris Accumulation on PWR Sump Performance" (GSI-191) sump strainer and related modifications bring those reactor plants into full compliance with 10 CFR 50.46, "Acceptance Criteria for Emergency Core Cooling Systems for Light-water Nuclear Power Reactors," and related requirements, and to draw conclusions as to the probable overall effectiveness of GL 2004-02 corrective actions for the 69 U.S. operating PWRs.

Waterford Steam Electric Station, Unit 3 (Waterford 3) is operated by Entergy Operations, Inc. (Entergy), the licensee. Waterford Unit 3 is a Combustion Engineering two-loop pressurized water reactor (PWR) with a large, dry, atmospheric containment. The containment has safety-related fan coolers and containment spray for heat removal.

The onsite activities of the Waterford Unit 3 audit addressed break selection, debris generation and zone of influence (ZOI), debris characteristics, debris source term, coatings, latent debris, upstream design considerations (containment hold-up volumes and drainage), debris transport and computational fluid dynamics (CFD), head-loss and vortexing, net-positive suction head (NPSH) margin, screen modification package, sump structural design, downstream effects on components and systems, downstream effects on fuel and vessel, and chemical effects. The audits of the technical areas of sump structural design, CFD, downstream effects on fuel and vessel, chemical effects and coatings were conducted as desk audits at NRC Headquarters.

1.2 Bulletin 2003-01 Responses

The Waterford 3 response letter to Bulletin 2003-01, "Potential Impact of Debris Blockage on Emergency Sump Recirculation at Pressurized Water Reactors", dated August 7, 2003, [7], and supplemented by response letters dated October 27, 2004, October 20, 2005 and December 5, 2005, described measures which were judged by the NRC to be responsive to and meet the intent of Bulletin 2003-01 in reducing interim risk associated with potentially degraded or nonconforming emergency core cooling system (ECCS) and containment spray system (CSS) recirculation functions.

Bulletin 2003-01 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 switchover 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 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.

Waterford 3 implemented the following interim or continuing measures in response to Bulletin 2003-01:

1. Procedural operator direction to throttle or stop safety injection flow if certain conditions were satisfied;

2. Severe Accident Management Guideline (SAMG) procedures to replenish the refueling water storage pool (RWSP) from all available sources or bypass the RWSP with an alternate source;

3. A proceduralized containment building closeout process which ensures that no loose debris is present in containment following an outage or at-power entry, and that items authorized to remain in containment during power operations are in their evaluated locations;

4. A foreign materials exclusion (FME) program to prevent introduction of foreign materials into plant systems and components, including the logging of materials in and out of the ECCS sump and refueling cavity;

5. Inspection and repair of coatings on the concrete floors and walls and structural steel members surrounding the ECCS sump;

6. Verification that refueling cavity drain valves are locked open at the end of each refueling outage;

7. An ECCS sump closeout inspection to ensure that no openings in the ECCS sump screen, or around the screen penetrations, are larger than the screen mesh size;

8. Licensed operator training on indications of and responses to ECCS sump clogging, to include the identification of indications, possible responses, and emergency operating procedure (EOP) and SAMG instructions for responding to ECCS sump clogging;

9. A simulator scenario which includes ECCS sump clogging indications and responses;

10. Enhancement to the monitoring of operating ECCS and CSS pumps for indications of pump distress or loss of net positive suction head (such as erratic current, flow, or discharge pressure);

11. Inspection during each outage of refueling cavity drain lines and other ECCS sump drain lines to ensure that they are unobstructed;

12. Procedures which address the availability of a variety of alternate water sources to supplement the RWSP in the event of ECCS sump clogging, and specify the parameters which operators are directed to monitor for abnormal;

13. An operator response action upon indications of sump clogging to secure redundant high pressure safety injection pumps and containment spray;

14. Implementation in the Waterford EOPs of the recommended actions in CEN-152 Revision 5.3 supported by License Operator requalification training, including early termination of one train of high pressure safety injection (HPSI) if sump blockage is detected, but excluding alternate RCS injection (because the Waterford 3 plant lineup can not inject water directly into the RCS bypassing the RWSP);

15. A change to procedures OP-902-002, "Loss of Coolant Accident Recovery" and OP-902-008, "Functional Recovery Procedure," to add the requirement to line up and refill the RWSP as soon as critical operator actions are completed after a loss-of-coolant accident (LOCA), but not until after switchover to recirculation;

16. Continuation of a Severe Accident Management Guideline (SAMG) to inject more than one RWSP volume from a refilled RWSP;

17. Continuation of a feature in OP-902-002 to minimize primary break flow by performing a controlled cooldown and depressurization, performed as rapidly as possible within Technical Specifications requirements;

18. Continuation of operator training to monitor for sump blockage upon receipt of a recirculation actuation signal (RAS) pre-trip annunciator as well as independently from within EOP-902-002, with HPSI pump suction pressure, discharge pressure, flow, motor amperage and pump noise all being monitored; and

19. If sump blockage is detected, early termination of on train of HPSI is performed under the EOPs (as described in CEN-152, Revision 5.3);

1.3 Generic Letter 2004-02 September 1, 2005 Response

As requested by GL 2004-02, Entergy Operations, Inc. (Entergy, the licensee for Waterford 3) provided a letter dated September 16, 2005 containing technical information regarding analyses to be conducted and modifications to be implemented as corrective actions for GL 2004-02.

The licensee stated that upon completion of activities related to modifications to the containment sump strainers, the Waterford 3 ECCS and CSS recirculation functions under post-accident debris loading conditions would be in compliance with the regulatory requirements listed in Generic Letter 2004-02.

The licensee stated that containment walkdowns, debris generations calculations, debris transport and head loss calculations, downstream effects evaluations for blockage, and material procurement specifications had been essentially completed, and that the downstream effects evaluation for long-term wear was in progress and would be completed by December 20, 2005. The licensee also stated that the Waterford 3 sump strainer vendor selection was planned to be completed by December 20, 2005, and that strainer design would be conducted by that vendor. The licensee stated that the strainer would be of passive design. The licensee estimated that the new strainer would have a surface area of approximately 4250 sq. ft. to 10,000 sq. ft. depending on the results of analyses for thin bed effects and final determinations of zones of influence for metal encapsulated fiberglass. The licensee stated that these values included 125 sq. ft. of sacrificial screen surface area for tape, labels and other foreign materials.

The licensee stated that it was conducting its analyses of the susceptibility of emergency core cooling system (ECCS) and containment spray system (CSS) recirculation functions to the adverse effects of post-accident debris blockage in accordance with NEI 04-07, “Pressurized Water Reactor Sump Performance Evaluation Methodology” [1], and the NRC’s safety evaluation on NEI 04-07, “Safety Evaluation by the Office of Nuclear Reactor Regulation Related to NRC Generic Letter 2004-02, NEI Guidance Document, Pressurized Water Reactor Sump Performance Evaluation Methodology” [2]. The licensee stated that containment walkdowns were conducted in accordance with NEI 02-01, “Condition Assessment Guidelines: Debris Sources Inside PWR Containments” [14].

The licensee stated that Waterford 3 is a two-loop reactor with two steam generator (SG) cavities, with the Loop 1 cavity containing the majority of the pressurizer surge piping. However, the pressurizer is located outside of SG Cavity No. 1. The licensee discussed the seven major breaks of interest in its analyses (identical to those discussed in Section 3.1 below, “Break Selection”).

The licensee discussed the insulation, coatings, foreign material, and latent debris which would be generated from high energy line breaks using the zone of influence (ZOI) values as they were known at the time of the generic letter response. The licensee also discussed its sampling methodology for latent debris. The licensee stated that refinements could possibly be utilized for net positive suction head (NPSH) margin recovery or revisions to calculations. The licensee also stated that it might add metal jacketing to certain insulation types, or establish technical justification by which it could reduce coatings ZOIs.

The licensee stated that it was evaluating transport in accordance with NEI 04-07 [1] and the methodological enhancement in the NRC safety evaluation [2]. The licensee stated that it was considering blowdown, washdown, pool fill and recirculation mechanisms of debris transport, and that it intended to perform containment sump pool transport analysis using a computational fluid dynamics (CFD) program called FLUENT. The licensee stated that debris hold up volumes, deposition in inactive pools, and failure to lift over curbs were to be considered.

The licensee stated that 90% of the insulation in containment, including insulation exposed from within metal encapsulated insulation, would transport to the sump as small fines after erosion. The licensee also stated that 100% of latent debris and coatings particulates would transport to the sump. The licensee provided a table of debris transport fractions as they were known at the time of the generic letter response.

The licensee stated that its strainer size estimates (4250 to 10,000 sq. ft., as discussed above) were generated considering the sum of calculated fiber/particulate debris bed head loss, reflective metal insulation (RMI) debris bed head loss, and clean strainer head loss. The licensee stated that suction through the third or “swing” high pressure safety injection (HPSI) pump A/B appeared to provide the most limiting head loss case.

The licensee stated that the minimum available NPSH margin for ECCS HPSI pumps not including clean strainer head loss was 1.04 feet (also termed the “allowable head loss across the safety injection sump strainer” by the licensee), and that the expected clean strainer head loss would be less than 0.1 feet, subject to revision by the strainer vendor. The licensee stated that the strainer would be fully submerged for all LOCAs. The licensee stated that the maximum postulated head loss from debris accumulation on the submerged safety injection sump strainer had been specified to be .84 feet of water or less, and provided a table with the expected primary constituents of the debris bed in units of either square feet or cubic feet, as they were known at the time of the generic letter response.

The licensee stated that it could decide to reduce the ZOI for metal encapsulated insulation from 17D (17 pipe diameters) to 2D. The licensee stated that it planned to incorporate chemical effects head losses once test results on this effect were published, and that evaluations would be performed to determine the impact of the sump pH, spray duration, and temperature profile in the sump pool on chemical effects head loss. The licensee stated that a head loss margin was built into the strainer procurement specification.

The licensee stated that the entire basement elevation of the containment building serves as an area for collection of water introduced into the containment following a LOCA (the “sump pool”), and that in general the containment basement floor was free of obstructions which could prevent flow from reaching the sump strainers. Further, the licensee stated that the flow paths from the upper levels of containment to the lower levels are relatively free of obstructions, being open stairways or elevated floor gratings. The SG cavities (“D-rings”) were stated to have large openings to allow the water to spill to the containment basement elevation. The two six-inch refueling canal drains were stated to drain to the containment floor and remain unobstructed during a LOCA, and the four-inch path from the refueling canal to the containment sump were stated to not bypass the sump strainer.

The licensee stated that the flow paths downstream of the containment safety injection sump had been analyzed to determine the potential for blockage due to debris which passed through the containment sump strainer (“bypass flow”). All components in the recirculation flowpath were analyzed including throttle valves, flow orifices, spray nozzles, pumps, heat exchangers and valves. The results of this preliminary evaluation for flow clearances showed that some components required additional evaluation for long-term wear. The licensee stated that the strainer procurement specification required that gaps at mating surfaces within the strainer and between the strainer and the supporting surfaces not exceed the strainer penetration size.

The licensee stated that the safety injection sump area was located outside of the existing missile barriers and any zones of influence for high energy line breaks. Therefore, the strainers would not be subject to loads from missiles or expanding jets. The licensee also stated that, as required in the strainer procurement specification, the need for dedicated trash racks would be determined during the strainer design phase.

The licensee stated that it had not determined at the time of the generic letter response whether there would be a need for a change to the Waterford Unit 3 Technical Specifications.

The licensee stated that the plant modification process would identify insulation materials that are to be introduced into containment in the future, and that these materials would be evaluated to determine whether they could affect sump performance or lead to downstream equipment degradation.

The licensee stated that qualified coatings were controlled under site procedures, and that the licensee would repair or assess damaged qualified coatings to ensure that the quantities of failed coatings in the debris generation calculation would not be exceeded. The licensee stated that unqualified coatings had been identified by location, surface area and thickness, and that the majority were Original Equipment Manufacturer (OEM) coatings. The license stated that it would ensure that unqualified coatings introduced into containment in the future would be identified and tracked to ensure that the quantity in the debris generation calculation would not be exceeded.

The licensee stated that administrative procedures control the types of tags and labels that can be used inside containment, and that efforts had recently been taken to reduce tags, labels and tape inside containment. The licensee stated that it would implement a program to track tags and labels that remain inside containment to ensure that the amounts do not exceed the capacity of the sacrificial area specified in the sump strainer design (see above).

The licensee stated that at the end of an outage, a formal containment surveillance procedure is performed to ensure that items not removed receive a documented evaluation to provide an acceptable basis for them to remain in containment. The licensee stated that, as part of outage containment closeout processes, the sump and sump screens are inspected for damage or debris, and refueling canal drains are inspected to verify they are not obstructed and that there are no potential debris sources in the refueling canal area that could obstruct the drains.

The license stated that, after the containment walkdowns were conducted to identify potential debris sources and conservatively measure the amount of latent dust and dirt in containment (at a time during the outage of expected maximum levels of dust and debris), extensive cleaning was performed consistent with normal housekeeping practices and associated administrative requirements. To add conservatism, the amounts of these materials entered into the analysis were much greater than the measured values. The licensee stated it would perform the latent dust and dirt identification and measurement walkdown in containment every third outage, with the possibility that the frequency could be relaxed based on adequate levels of cleanliness being determined.

Entergy provided a supplemental GL 2004-02 response in a letter dated December 19, 2005. The licensee stated that it had determined that a Technical Specification change would not be required to support corrective actions in response to GL 2004-02.

The licensee also stated that its downstream effects analysis had modeled the impact of debris for a 30-day LOCA duration as specified in the Waterford 3 Final Safety Analysis Report (FSAR), Chapter 15. The licensee stated that its analysis had concluded that the calculated HPSI and CS pumps' wear ring gaps would exceed their clearance acceptance criterion, the three-inch system flow orifices with 1.116-inch bore would develop unacceptable increases in flow, and the calculated increase in flow rate in the CS nozzles would exceed their acceptance criterion. The licensee stated that it was further evaluating these components in order to arrive at acceptable resolutions.

2.0 DESCRIPTION OF PLANNED CHANGES

The Waterford 3 emergency core cooling systems (ECCS) includes: 1) the high-pressure safety injection (HPSI); 2) the low-pressure safety injection (LPSI); and 3) the containment spray (CS) system. The HPSI, LPSI, and CS pumps are started following a LOCA, and initially all pumps take suction from the refueling water storage pool (RWSP). When the RWSP level reaches the low-level setpoint, the LPSI pumps are stopped and the HPSI and CS pumps are realigned to take suction from the recirculation sump. The maximum flow through the recirculation sump would be approximately 6,470 gpm, based on pump run-out flow rates, consisting of two HPSI pumps (pumping 985 gpm each) and two CS pumps (pumping 2,250 gpm each). The established bounding containment sump pool conditions are 120 ^{0}F to 230 ^{0}F and a minimum flood level of approximately 5.37 ft. above the floor elevation. The containment recirculation sump is alternatively termed the Safety Injection Sump (SIS) at Waterford Unit 3.

New replacement strainers, designed by General Electric (GE), were installed at Waterford Unit 3 during the fall 2006 outage. The total strainer screen area is approximately 3,700 ft^2. The replacement strainer assembly has 11 strainer modules attached to an interconnecting plenum. Each module, comprising 17 square disks that are 40 inches to a side, is oriented so that the primary strainer surfaces are horizontal. The height of the plenum underneath the modules is 8.38 inches, and the top plate of each module is 60.78 inches off the sump floor.

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 NEI PWR Sump Performance Task Force Report NEI 04-07, “Pressurized Water Pressurized Water Reactor Sump Performance Evaluation Methodology,” May 28, 2004 (the “Guidance Report” or “GR”) [1] and the Safety Evaluation by the Office of Nuclear Reactor Regulation Related to NRC Generic Letter 2004-02, Nuclear Energy Institute Guidance Report, NEI 04-07, “Pressurized Water Pressurized Water Reactor Sump Performance Evaluation Methodology,” NRC/NRR Staff Report, Revision 0, December 6, 2004 (the “Safety Evaluation” or “SE”) [2], provide the NRC-approved criteria to be considered in the overall break selection process for identifying the limiting break.

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

Section 3.3.5 of [2] 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 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 with at least a 1/8" fiber bed).

The calculational report prepared by Sargent & Lundy, S&L Report No. 2004-07780, "Debris Generation Due to LOCA within Containment for Resolution of GSI-191," [15] documents the assumptions and methodology the licensee applied as part of the overall break selection process to determine the limiting break for Waterford Unit 3.

NRC Staff Audit

The NRC staff reviewed the licensee's overall break selection process and the methodology applied to identify the limiting break as presented in the licensee calculational report [15] and discussed the selection process and methodology with the licensee's analytical contractor during the onsite audit week. Seven breaks were identified that would encompass the worst case situations and were evaluated in detail. The spectrum of breaks evaluated by the licensee was found to be generally consistent with that recommended in the SE and consistent with regulatory position 1.3.2.3 of Regulatory Guide 1.82, Revision 3 [5]. Deviations from the staff-approved methodology were considered to be reasonable based on the technical basis provided by the licensee. These deviations are discussed below.

Rather than systematically evaluating all potential break locations by evaluating breaks incrementally along the piping as recommended in the GR, the licensee selected characteristic breaks based on piping diameters and relative locations. The largest diameter high-energy piping is the reactor coolant system (RCS) hot leg piping. The largest zones-of-influence (ZOI) would therefore be associated with the hot leg piping. Of the seven potential breaks identified by the licensee for further analysis, four breaks were associated with the hot leg piping. Two of the identified potential breaks are associated on the RCS cold leg piping. A seventh break was postulated for the pressurizer surge piping because that piping was outside the steam generator (D-ring) compartments and relatively near the sump recirculation strainers. In accordance with the GR and SE, small-bore piping was not evaluated.

The specific breaks evaluated were:

Waterford 3 Break S1: Break S1 was postulated in the RCS Loop 1 hot leg piping near the steam generator (SG).

Waterford 3 Break S2: Break S2 was postulated in the RCS Loop 1 hot leg piping within the primary shield wall with its ZOI contained between the reactor pressure vessel (RPV) and the shield wall.

Waterford 3 Break S3: Break S3 was postulated in the RCS Loop 2 hot leg piping near the SG.

Waterford 3 Break S4: Break S4 was postulated in the RCS Loop 1 hot leg piping at the tee between SG 1 hot leg and the pressurizer surge line, similar to Break S1, except that the Break S4 is a GR recommended ASME Standard Schedule 160 14-inch alternate break size, which is substantially smaller than the hot leg diameter of 42-inches.

Waterford 3 Break S5: Break S5 was postulated in the RCS Loop 1 cold leg piping near a reactor coolant pump.

Waterford 3 Break S6: Break S6 was postulated in the RCS Loop 2 cold leg piping near a reactor coolant pump.

Waterford 3 Break S7: Break S7 was postulated at the connection of the surge line to the pressurizer and is located in the pressurizer room outside of the SG compartments, in the proximity of the safety injection sump.

The Waterford 3 ZOIs based on the hot leg pipe diameter essentially encompassed the majority of the SG compartments for all insulation types, except the metallic encapsulated insulation (MEI), which encapsulated Owens-Corning fiberglass. For example, the hot leg ZOI diameter for Nukon® insulation was about 119 ft, which would encompass virtually all of the RCS loop piping in the SG compartment. The staff verified through discussions with the licensee's analytical contractor that the MEI ZOI associated with the hot leg piping also maximized the generation of debris from the fiberglass insulation encapsulated within the MEI. Further, no "shadowing effect" was considered whereby insulation on the far side of equipment from the break would be protected from destruction. The hot leg break selections ensure that the upper bound quantities of insulation debris were conservatively estimated.

Breaks S1 and S3 are both located on hot leg piping, which is the largest pipe diameter in the reactor cooling system, and would therefore have the largest ZOIs and the potential capability to generate the largest quantities of debris. These breaks were evaluated as breaks that would generate the greatest quantities of debris.

Break S2 within the primary shield wall with its ZOI contained between the RPV and the shield wall would essentially destroy RPV insulation, which has a different composition than the insulation types for Breaks S1 and S3. The RPV insulation, however, consists entirely of stainless steel reflective metallic insulation (RMI), for which the RMI debris would neither effectively transport to the strainers nor effectively accumulate on the strainers. Even if the RMI were to accumulate on the strainers, it likely would not cause significant head loss at the low strainer approach velocities associated with the large Waterford 3 replacement strainers. Therefore, Break S2 was not evaluated beyond estimating the bounding debris quantities. The staff found this acceptable based on previous observations of the behavior of RMI debris.

The licensee initially developed Break S4 based on the GR risk-informed design basis analysis methodology, which recommended a Schedule 160 14-inch postulated break for the much larger hot leg, but later the licensee ceased to pursue the application of this alternate break methodology. Because the alternate break methodology was not pursued, and debris from Break S4 would be bounded by debris from Breaks S1 and S3, Break S4 was not evaluated beyond estimating the bounding debris quantities.

The 30-inch cold leg breaks, Breaks S5 and S6, result in substantially smaller ZOIs than the 42-inch hot leg breaks. The bounding quantities of LOCA-generated debris for the cold leg breaks are smaller than the quantities for the hot leg breaks. The debris generation evaluation discussed below demonstrated that the largest debris quantities correspond to hot leg Break S3.

The consequences of Break S7 were evaluated throughout the GSI-191 resolution efforts of the licensee because that break would occur outside the steam generator compartments and in proximity to the safety injection sump, and its debris would be more likely to transport to the recirculation strainers. The quantities of debris estimated to be generated and subsequently transported to the recirculation sump were substantially less than the quantities associated with the other breaks primarily due to the much smaller ZOIs associated with Break S7 (since the pipe diameter for the pressurizer surge pipe is only 10.126 inches). Further, the types of debris generated by Break S7 would be similar to the other breaks; therefore Break S7 did not represent a worst case blockage situation and was therefore not important to the overall Waterford 3 GSI-191 resolution, even though some head loss tests were conducted based on Test S7 debris quantities.

The licensee determined that neither main steam line breaks (MSLB) nor feedwater line breaks (FWLB) would require the ECCS or CSS to operate in the recirculation mode so that sump strainer clogging would not be an issue for these events.

As previously noted, the staff finds the licensee’s evaluation of break selection to be generally consistent with the SE-approved methodology (with acceptable deviations as discussed above) and to therefore be acceptable.

3.2 Debris Generation/Zone of Influence (Excluding Coatings)

The objective of the debris generation/ZOI process is to determine, for each postulated break location: (1) the zone within which the break jet forces would be sufficient to damage materials and create debris, (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 [1] and the NRC SE [2] provide the methodology to be considered in the ZOI and debris generation analysis.

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 the pressures relate to the ANSI/ANS 58.2 1988 standard (ANSI/ANS 58.2) [17]. Once the ZOI is established for a selected break location, the types and locations of all potential debris sources 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 [2] 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, and then added to arrive at a total debris source term. The NRC staff concluded in [2] 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 [2], the NRC staff accepted the application of these proposed refinements for pressurized water reactor (PWR) sump analyses for GL 2004-02 [3] corrective actions.

NRC Staff Audit

The staff reviewed the licensee's ZOI and debris generation evaluations and the methodology applied as presented in the licensee calculational report No. 2004-07780 [15]. The staff discussed the licensee's evaluations with the licensee's analytical contractor during the onsite audit and compared the licensee's methodology to the approved methodology documented in sections 3.4 and 4.2.2 of [2].

The radii assumed by the licensee for insulation ZOIs are shown in Table 1. The radii values for Transco RMI, Nukon®, and Min-K were adopted directly from the SE and are therefore acceptable. The licensee assumed that the destruction of Microtherm would be similar to that of Min-K based on the insulations' material similarities. Because the ZOI of 28.6D (28.6 pipe diameters) assumed for both Min-K and Microtherm would effectively destroy all of both of these insulation types located within a SG compartment, the application of this radius to Microtherm is conservative and is therefore acceptable.

Table 1. Waterford 3 Insulation ZOI Radii

Insulation Type	ZOI Radius/Break Diameter
Transco RMI	2
Transco Metal Encapsulated Fiberglass (MEI)	2
Nukon17	17
Min-K 28.6	28.6
Microtherm	28.6

The licensee's basis for assuming a pipe diameter zone of influence radius of 2D for the metal encapsulated fiberglass insulation (MEI) was not adequately justified. The licensee assumed that, because the MEI fiberglass was encapsulated in a Transco metallic jacketing similar to that used for Transco RMI insulation, the fiberglass insulation would be completely protected because the jacketing would not be penetrated. This assumption was not addressed in either the GR or the SE.

The basis the licensee cited for the 2D ZOI for Transco RMI insulation was the Boiling Water Reactor Owners Group (BWROG) debris generation data [18]. The 2D ZOI corresponds to a destruction pressure of about 114 psig. The BWROG test data, however, does not support the assumption that the Transco metallic jacketing would completely support any insulation materials contained within the jacketing at destruction pressures less than 114 psig. For example, during Tests 21-1 and 21-3 from the BWROG air jet debris generation testing, which subjected Transco RMI insulation cassettes to pressures of 17 and 10 psig respectively, one cassette was disassembled in each test, thereby exposing the internal RMI foils to further destruction. This indicates that some of the Waterford 3 MEI residing outside a 2D ZOI could be damaged to the extent of exposing the fiberglass to further destruction. Given this fact that the fiberglass insulation residing outside the 2D ZOI could contribute to the debris generation quantities, the Waterford Unit 3 assumption of complete jacketing protection has not been adequately justified.

In addition, the target insulation cassettes used in the BWROG testing were substantially longer than the characteristic width of the air jet when placed close enough to the nominal three-inch nozzle to achieve a jet stagnation pressure of 114 psig on the cassette centerline. This means that a significant portion of the cassette was exposed to substantially lower pressures than 114 psig, which in turn most likely reduced cassette destruction. Had the same cassette been located in front of a hot leg pipe break at pressures corresponding to 2D, the cassette would be completely engulfed by the break jet flow and its level of destruction could be much worse.

The need for the licensee to justify its assumption of a 2D ZOI for the Waterford Unit 3 metal encapsulated insulation (MEI) fiberglass[1] is designated as **Open Item 1**.

The licensee's bounding debris quantity estimates are summarized in Table 2 below. The following observations can be made from Table 2:

- Only Break S2 was predicted to generate RMI debris, which was predicted to be generated from reactor pressure vessel (RPV) RMI insulation. All the RMI insulation is stainless steel. Since Break S2 would not generate a worst case debris load, RMI debris does not appear in the head loss test debris load summary.

- The licensee conservatively evaluated the generation of Nukon® debris outside of the ZOI due to the impact of the containment sprays and/or submergence within a water pool. Nukon® insulation is typically covered by at least a canvas covering and would therefore not be significantly damaged by either the sprays or submergence.

- The licensee evaluated the debris generation for MEI fiberglass based on both a conservatively large 17D ZOI and the inadequately justified 2D ZOI (see Open Item 1 above), so that both estimates would be available for a later decision as to which assumption to choose for the head loss testing. The licensee subsequently tested its new strainer using the 2D ZOI estimate.

- The Min-K and Microtherm insulation debris quantities are relatively minor compared with the fibrous insulation. However, because these debris types can cause substantial head losses, these small quantities are potentially important to consider in conducting head loss testing.

- Basing the MEI fiberglass debris on the 2D ZOI estimate, more fibrous debris would be generated by Break S3 than by Break S1, and the largest quantities of fibrous debris would occur for Breaks S3 and S6, which would each generate 1,459 ft^3 of fibrous debris. Subsequent head loss testing with maximum fiber debris loads was based on the Break S3 debris loads. Note that the ZOI for Break S3 was substantially larger than the ZOI for Break S6, but the two breaks generate the same quantities of debris. This indicates that all of the Nukon® insulation on the Loop 1 RCS piping would essentially be destroyed by either break.

[1] For insulations other than RMI foils, the staff has not accepted a 2D ZOI for insulation materials encased in a Transco cassette. But during the San Onofre audit, the staff did accept a 4D ZOI for Transco encapsulated mineral wool [37].

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

Debris Type	Break S1	Break S2	Break S3	Break S4	Break S5	Break S6	Break S7
Metallic (ft^2)							
Transco RMI	0	8750	0	0	0	0	0
Fibrous (ft^3)							
Nukon within ZOI	558	290	1081	519	558	1081	79
Nukon outside ZOI	198						219
MEI Fiberglass - 17D	1527	3	961	283	1527	961	0
MEI Fiberglass - 2D	24	0	180	Undetermined*	24	180	0
Particulate (ft^3)							
Min-K	0.4						0
Microtherm	4.2						0.6

* Because the licensee decided not to pursue the alternate break methodology further, the licensee did not determine the quantity of MEI fiberglass debris for Break S4 when the 2D ZOI was assumed. If the alternate Break S4 is used in the subsequent head loss evaluation, this debris quantity would have to be determined.

The breaks selected by the licensee for subsequent head loss evaluation were Breaks S3 and S7. Break S3 would generate the largest quantity of debris; and Break S7 represents the break with the closest proximity to the recirculation sump. Separately, Breaks S1, S5, S6, and S7 were chosen as representative breaks detailed CFD transport analysis as breaks that would conservatively maximize debris reaching the strainer. Break S1 was chosen as representative of hot leg breaks and therefore the Break S1 transport results were applied to Break S3.

The licensee noted quantities of fire barrier blankets at Waterford Unit 3 that were made of Kaowool with an exterior cover made of Sil-Temp, and Hemyc electrical fire wrap blankets, but which were not subsequently identified as debris sources. The licensee's analytical contractor stated that the fire protection materials were all located outside of any of the identified ZOIs.

Other sources of debris at Waterford Unit 3 include latent debris and coatings debris, which are discussed in Sections 3.4 and 3.8 of this report, respectively, and chemical effects precipitates, which are discussed in Section 5.4 of this report.

The licensee presented its estimated and assumed debris size characteristics in its debris generation report [16]. The staff reviewed the licensee debris size distributions with the following conclusions:

- For RMI debris, the licensee adopted the GR recommendation of 75 percent for small fines and 25 percent for large piece debris. The staff accepted this assumed size distribution as conservative for Waterford 3 because this assumption had previously been accepted in the SE as generically conservative guidance.

- For Nukon® debris, the licensee adopted the size distribution scheme used in the NRC - sponsored volunteer plant study, which was documented in Table VI-1 of [2]. The licensee used guidance from Appendices II and VI of [2], to arrive at a distribution of eight percent, 25 percent, 32 percent, and 35 percent for fines, small pieces, large pieces, and intact debris, respectively. In the adoption process, the licensee combined fines and small piece debris distribution values in Table VI-2 of [2] to arrive at a total of 33 percent for a combined small fines category. For comparison, another assessment for the small fines category for Nukon® with a 17D ZOI was documented in Table II-2 of Appendix II of [2] and that determination was 22 percent, which demonstrates the conservatism of the licensee determination of 33 percent. Of this 33 percent, one-quarter was assumed to be fines, which was the conservative finding from the NUREG/CR-6369 study resulting in the eight percent fines and 25 percent small pieces categories from Table VI-1 of [2], which is slightly more conservative than the volunteer plant distribution shown in Table VI-2 of [2]. The staff finds the licensee size distribution acceptable because the distribution leads to a conservative estimate for debris transported to the strainers.

- For the MEI fiberglass, the licensee assumed that 100 percent of the debris would be fines. The key characteristic of fines is that this debris would be expected to remain suspended in water, even at relatively quiescent conditions. Because this assumption represents the extreme conservative position in terms of maximizing calculated debris transport to the sump screens, it is acceptable to the staff.

- For Min-K and Microtherm, the licensee assumed that 100 percent of the debris would be fine particulate. Because this assumption represents the extreme conservative position in terms of maximizing the calculated debris transport to the sump screens, it is acceptable to the staff.

In conclusion, the staff finds the licensee's ZOI evaluation to be acceptable with the exception of the inadequate justification for the 2D ZOI for the MEI fiberglass, which was identified as Open Item 1. Otherwise, the evaluation was performed in a manner consistent with the methodology of [2].

3.3 Debris Characteristics

The staff reviewed the Waterford 3 licensee's assumptions regarding the characteristics of post-accident debris to verify that the assumed characteristics were conservative with respect to debris transport, debris bed head loss, and other areas of the sump performance analysis. The licensee's discussion of debris characteristics was primarily provided in the debris transport calculation [16] and also in the debris generation calculation [15].

The analyzed debris loading for Waterford 3 included Nukon low-density fiberglass (LDFG) insulation, Owens-Corning Thermal Insulating Wool (TIW) II LDFG, reflective metallic insulation (RMI), Min-K, Microtherm, qualified coatings, unqualified coatings, latent particulate debris, latent fibrous debris, and foreign materials such as tape, tags, and stickers [16]. The following subsections describe the licensee's assumptions regarding the characteristics of these types of debris, with the exception of the characteristics of coatings debris, which are discussed separately in Section 3.8. A summary of the assumed plant debris characteristics for non-coatings debris is provided below in Table 3.

Table 3: Summary of Assumed Characteristics for Non-Coatings Debris

Debris Type	Size Distribution	Macroscopic Density (lbm/ft^3)	Microscopic Density	Characteristic Size
Nukon LDFG Within Zone of Influence	8% Fines 25% Small Pieces 32% Large Pieces 35% Intact	2.4	Not Reported	Not Reported
Nukon LDFG Eroded by Containment Spray/Pool Submergence	100% Fines	2.4	Not Reported	Not Reported
Owens-Corning LDFG	100% Fines	Not Reported	Not Reported	Not Reported
Reflective Metallic Insulation	75% Fines 25% Large Pieces	Not Reported	Not Reported	Not Reported
Min-K	100% Fines	Not Reported	Not Reported	Not Reported
Microtherm	100% Fines	Not Reported	Not Reported	Not Reported
Latent Particulate Debris	100% Fines	Not Reported	Not Reported	Not Reported
Latent Fibrous Debris	100% Fines	Not Reported	Not Reported	Not Reported
Foreign Materials	Intact Sheets	N/A	N/A	N/A

For most debris types, values for macroscopic and microscopic densities and characteristic size are listed in Table 3 as not having been reported in the licensee's analysis. Some of these physical properties had apparently been included in the original version of the debris transport calculation; however, along with the accompanying head loss scoping calculation, this information was deleted in the revision of the transport calculation provided for the staff's audit review [16]. During the onsite audit, the licensee pointed out that debris characteristics were alternately provided in the head loss test specification [26]. However, the staff's review of the head loss test specification identified that the debris characteristics provided were for the surrogate debris used for head loss testing, as opposed to the actual sources of debris expected at the plant.

Although, based upon the information presented in the head loss test specification, many of the surrogate debris materials chosen by the licensee appeared identical to or representative of the actual plant debris, comprehensive documentation demonstrating that the physical characteristics of all surrogate debris for head loss testing are representative of the actual plant debris was not provided in the analysis provided to the staff for the audit review. Therefore, the licensee needs to develop comprehensive documentation of the characteristics (macroscopic densities, microscopic densities, and characteristic debris sizes) of the actual plant debris at Waterford 3 and compare these characteristics to the surrogate debris properties used for head loss testing, justifying any differences. The staff designates this as **Open Item 2.**

3.3.1 Nukon Low-Density Fiberglass in a Zone of Influence

The licensee assumed a size distribution for Nukon low-density fiberglass debris of eight percent fines, 25 percent small pieces, 32 percent large pieces, and 35 percent intact cassettes. The licensee explained that this size distribution was used in lieu of the 60 percent small fines/40 percent large pieces distribution values provided in Nuclear Energy Institute (NEI) 04-07 [1] because the NEI size distribution is based on a damage pressure of 10 psig (corresponding to a 12.1D spherical zone of influence (ZOI)) that was obtained from single-phase air-jet testing. However, consistent with the staff's safety evaluation (SE) on NEI 04-07 [2], the licensee's debris generation calculation used a reduced damage pressure of 6 psig for Nukon (corresponding to a larger 17D spherical ZOI) because the SE recommended that damage pressures for specific debris sources that were derived from air-jet testing be reduced by 40% to account for potential increases in damage caused by a two-phase steam-water jet that could result from a high-energy line break at a pressurized-water reactor (PWR). As a result of the enlargement assumed for the Nukon ZOI, the licensee stated that a smaller fraction of the generated debris would be in the form of small fines than the 60 percent value provided in NEI 04-07 [1]. Therefore, the licensee used existing destruction testing results reported in Appendices II and VI in the staff's SE [2] as the basis for the debris size distribution assumed for Waterford 3 (i.e., eight percent small fines, 25 percent small pieces, 32 percent large pieces, and 35 percent intact cassettes) [16].

The size distribution the licensee assumed for Nukon debris is consistent with the staff calculation for Nukon provided in Appendix II of the SE [2]. Therefore, the staff considers the licensee's Nukon debris size distribution to be appropriate. The staff noted that the licensee's head loss test specification [26] indicated that Transco low-density fiberglass was used as a surrogate material for Nukon. The staff considers this material to be a reasonable surrogate for Nukon because of the similarity of the physical characteristics of these two types of low-density fiberglass.

3.3.2 Nukon Low-Density Fiberglass Affected by Containment Spray or Pool Submergence

The licensee assumed that debris generated by containment spray or submergence in the active containment pool would become 100% fines. The licensee's debris transport calculation stated that this assumption is acceptable because debris generated in this fashion is unjacketed and is generated through erosion. The licensee stated that the only type of debris at Waterford 3 that is generated through interaction with containment spray or submergence is Nukon low-density fiberglass.

The staff considered the licensee's assumption that 100 percent of the Nukon exposed to containment spray or submergence in the active containment pool erodes to fines to be conservative because this assumption tends to increase the quantity of debris that is capable of reaching the sump strainers.

During the audit, the licensee stated that the Nukon insulation potentially exposed to sprays and submergence is predominately enclosed in a woven cloth cover. The licensee further stated that the cloth cover would likely be capable of retaining the underlying insulation fibers. The licensee indicated that it may in the future take some credit for the woven cloth cover. Provided that the licensee can demonstrate that the woven cloth cover is robustly attached to the insulation material, some credit may be appropriate to reduce the quantity of Nukon debris currently assumed to result from erosion due to containment sprays and submergence in the active containment pool.

As stated in Section 3.3.1 above, the licensee's head loss test specification [26] indicated that Transco low-density fiberglass was used as a surrogate material for Nukon, and the staff considers this material to be a reasonable surrogate for Nukon for the reason stated in that section.

3.3.3 Owens-Corning Low-Density Fiberglass

The licensee's debris transport calculation [16] stated that, since no destruction pressure data is available for Owens-Corning TIW Type II insulation, 100% of this insulation within the ZOI of an analyzed break is modeled as being destroyed as fines, in accordance with Section 3.4.3.3 of the staff's SE on NEI 04-07 [2].

The staff considered the licensee's assumption that Owens-Corning TIW Type II insulation is destroyed into 100% fines to be acceptable because the assumption is consistent with the recommendation in NEI 04-07 [1] that was accepted by the staff's SE [2]. During the audit, the licensee stated that consideration was being given to comparing this insulation to Nukon in an attempt to justify a more realistic debris distribution than the conservative assumption of 100 percent fines. The staff indicated that this approach may be reasonable provided that (1) the physical properties of Nukon and Owens-Corning TIW Type II insulations can be demonstrated to be sufficiently similar and (2) the jacketing of the Owens-Corning TIW Type II insulation can be demonstrated to be sufficiently similar to the jacketing of the Nukon insulation used for the comparison. The staff also noted that the debris size distribution is dependent upon assumptions made concerning the size of the ZOI.

The staff noted that the licensee's head loss test specification [26] indicated that Transco low-density fiberglass was used as a surrogate material for Owens-Corning TIW Type II. The staff considers this material to be a reasonable surrogate for Owens-Corning TIW Type II because of the similarity of the physical characteristics of these two types of low-density fiberglass.

3.3.4 Reflective Metallic Insulation

The licensee stated that the stainless steel reflective metallic insulation (RMI) installed at Waterford Unit 3 was manufactured by Transco Products, Inc. Based upon guidance provided in NEI 04-07 [1], the licensee stated that Transco RMI debris was assumed to be destroyed into 75 percent fines and 25 percent large pieces. The licensee further stated that this size distribution was based upon NRC-sponsored testing conducted by Siemens, which is further described in NUREG/CR-6808 [27].

The staff considered the licensee's size distribution assumed for Transco stainless steel RMI to be acceptable because it is based upon a conservative recommendation in NEI 04-07 [1] that was accepted by the staff's SE [2]. In the worst-case head loss scenarios tested by the licensee no RMI was used because, under the low-velocity flow conditions and elevated strainer geometry applicable to the Waterford 3 strainer, previous head loss testing experience has shown that RMI has a negligible or even beneficial effect on debris bed head loss. Therefore, the staff concluded that the specification of additional debris properties for RMI is unnecessary.

3.3.5 Min-K

The licensee assumed that 100 percent of Min-K within an analyzed ZOI would be destroyed into 100 percent fines [16]. The licensee stated that this assumption is consistent with the guidance in NEI 04-07 [1] and Appendix VI of the staff's SE [2]. Because the assumed size distribution is consistent with the NEI 04-07 guidance that was approved by the SE, the staff considers the assumed size distribution of 100 percent fines to be acceptable for Min-K debris.

The staff noted that densities and characteristic sizes were not provided in the licensee's analysis for the Min-K material installed at Waterford Unit 3. From information available in NEI 04-07 [1], as supported by data on the Min-K manufacturer's website [28], the staff understood that the macroscopic ("as-fabricated") density of the type of Min-K commonly used on piping systems is approximately 20 lbm/ft^3. However, the head loss test specification [26] stated that the density of the flexible Min-K Mix 182 surrogate debris used to represent debris from the Min-K installed at Waterford 3 is 14.5 lbm/ft^3.

Since a macroscopic density was not specified for the Min-K installed at Waterford Unit 3, it was not clear to the staff whether a discrepancy exists between the density of the Min-K in the plant and the density of the Min-K surrogate debris that was tested. If such a discrepancy exists, a non-conservative effect may result because the quantity of Min-K debris in the plant is estimated on a volumetric basis. Therefore, if the Min-K installed at Waterford Unit 3 is denser than the surrogate material used for head loss testing, the head loss test may underestimate the expected quantity of Min-K debris. While the overall quantity of Min-K installed at Waterford Unit 3 is small, the staff notes that microporous materials such as Min-K have been shown to have a significant potential for inducing high head losses. The staff expects the licensee to address this issue in its resolution of Open Item 2 above.

3.3.6 Microtherm

The licensee assumed that 100 percent of Microtherm within an analyzed ZOI would be destroyed into 100 percent fines [16]. The licensee stated that this assumption is consistent with the guidance in NEI 04-07 [1] and Appendix VI of the staff's SE [2]. Because the assumed size distribution is consistent with the NEI 04-07 guidance that was approved by the SE, the staff considers the assumed size distribution of 100% fines to be acceptable for Microtherm debris.

The staff noted that densities and characteristic sizes were not provided in the licensee's analysis for the Microtherm material installed at Waterford Unit 3. From information available in

NEI 04-07 [1], as supported by data on the Microtherm manufacturer's website [29], the staff understood that the macroscopic ("as-fabricated") density of the type of Microtherm commonly used on piping systems is approximately 20—22 lbm/ft^3. Although the head loss test specification [26] did not specifically identify the surrogate debris used for Microtherm (although a density of 14.5 lbm/ft^3 for the surrogate material is specified therein) and the strainer hydraulic sizing report indicated (presumably erroneously) that low-density fiberglass was used as the surrogate [30], the staff concluded that the surrogate material used for Microtherm was most likely Microtherm Super G, as stated in the strainer module test report [31].

In any case, since a macroscopic density was not specified for the Microtherm installed at Waterford Unit 3, it was not clear to the staff whether a discrepancy exists between the density of the Microtherm in the plant and the density of the surrogate debris that was tested. If such a discrepancy exists, a non-conservative effect may result because the quantity of Microtherm debris in the plant is estimated on a volumetric basis. Therefore, if the Microtherm installed at Waterford Unit 3 is denser than the surrogate material used for head loss testing, the head loss test may underestimate the expected quantity of Microtherm debris. While the overall quantity of Microtherm installed at Waterford 3 is small, the staff notes that microporous materials such as Microtherm have been shown to have a significant potential for inducing high head losses. The staff expects the licensee to address this issue in its resolution of Open Item 2 above. Specifically, the staff expects the licensee to identify the surrogate material used for Microtherm debris and, if the material is different than the Microtherm installed in the plant, to demonstrate that the material properties are representative of the actual plant debris.

3.3.7 Latent Particulate Debris

The licensee stated that 100 percent of latent particulate debris is modeled as fines, consistent with the position in the SE [2] on NEI 04-07 [1], which indicates that latent particulate consists of loose dirt and dust particles. The staff considers this size distribution to be acceptable because it is consistent with the staff's SE on NEI 04-07.

The licensee stated that size 800 Electrocarb black silicon carbide was used as the surrogate debris material for latent particulate debris. Based upon the manufacturer's website, this surrogate material has a density of approximately 200 lbm/ft^3 and a characteristic particle diameter of approximately 10 microns. Although the density of the surrogate debris is somewhat greater than the latent particulate debris density reported in the SE (approximately 170 lbm/ft^3), the staff considers the surrogate material reasonable for two main reasons. The smaller particle diameter of the silicon carbide (as compared to the measured latent particulate debris properties) could lead to higher head losses for debris beds with sufficient filtration efficiencies. Also, the density difference is small, and therefore head loss differences due to differences in settling tendencies would not be large.

3.3.8 Latent Fibrous Debris

The licensee stated that 100 percent of latent fibrous debris is modeled as fines, consistent with the position in the SE [2] on NEI 04-07 [1], which indicates that latent fibrous debris consists of loose, individual fibers. The staff considers this size distribution to be acceptable because it is consistent with the staff's SE [2] on NEI 04-07 [1].

The licensee stated that low-density fiberglass was used as the surrogate debris for latent fibrous debris. This surrogate material was approved in the staff's SE [2] on NEI 04-07 [1], and therefore it is acceptable.

3.3.9 Foreign Materials

The licensee stated that, since no information is available for the disintegration of foreign materials such as tape, tags and stickers at Waterford Unit 3 in a post-LOCA environment, these materials are modeled as transporting to the sump screen intact. As a result, the licensee assumed that these materials would form an impermeable blockage on the sump screen, acting to reduce the total sump strainer surface area. Based on guidance in the staff's SE, the licensee accepted a reduction in strainer area equal to 75 percent of the original single-sided area of the foreign materials.

The licensee's assumed characteristics for foreign materials are acceptable because they are consistent with guidance in the staff's SE [2].

3.4 Latent Debris

3.4.1 Scope of Audit

Latent debris is unintended dirt, dust and other particulates, paint chips, fibers, pieces of paper, tags, plastic, tape, adhesive and non-adhesive labels, and fines or shards of thermal insulation, fireproof barrier, or other materials that are already present in the containment prior to a postulated high energy line beak. The objective of the latent debris evaluation process is to provide an estimate of the types and amounts of latent debris existing in containment for the purpose of assessing that material's potential impact on sump screen head loss. Waterford Unit 3 performed an evaluation of the potential sources of debris within containment following the methodological guidance provided in the NEI GR [1] and NRC SE [2]. These references provide guidance for quantifying the mass and characteristics of latent debris inside containment.

The following approach is recommended in [1] and [2]: (1) estimate the total area available in containment for debris deposition, including both horizontal and vertical area contributions, (2) physically survey the containment to determine the mass of debris present, (3) determine the fraction of total area that is susceptible to debris buildup, (4) calculate the total quantity and composition of debris in containment, and (5) define the debris composition and physical properties. These elements are addressed in the Waterford Unit 3 report [15].

3.4.2 Latent Debris Sampling Methodology

Dust, Particulate, Lint

The licensee identified surface areas within containment that are available for accumulation of latent debris and defined seven surface areas categories. After accounting separately for horizontal and vertical surface configurations, a total of eleven area types were defined. The surface area of each of the eleven area types was computed with the aid of plant drawings. All of the individual area contributions were tabulated in Attachment 8.8, Appendix A, "Latent Debris Determination" of [32]. Gratings were conservatively estimated as floor areas.

The walkdown plan for evaluating the latent debris mass and the quantity of labels, stickers, etc., found in the Waterford Unit 3 containment is presented in [33].

The latent debris mass, including dust, particulate and lint was evaluated using a total of 47 sample locations, involving 4 samples for each surface area type. The sample locations are identified in [33]. At each location a pre-weighed cloth was used to swipe, or scoop debris from, a surface area of between 1 ft^2 and 100 ft^2. The weight difference of the cloth before and after sample collection represents the weight of the sample for the sample location.

For each of the eleven area types, the four measured sample masses and the surface area sampled using the cloth were used to compute the mean sample mass per unit area, the standard deviation of this quantity, and the 90 percent confidence limit of the quantity. This 90 percent confidence limit (90 percent of samples would have a value lower) was conservatively used as the representative latent debris sample mass per unit area for the specific area type sampled.

The total mass of latent debris present in containment on each of the eleven area types was calculated from the measured debris masses by multiplying the computed sample mass per unit area by the actual surface area of containment associated with the specific area type. The masses identified with each area type were summed to provide the total latent debris in containment.

The sampling methodology for measurement of latent debris mass and the statistical analysis performed as summarized above follows the guidance of [1] and [2] and therefore the staff finds it to be acceptable.

<u>Tapes, Labels, Stickers and Broken Glass</u>

The licensee presented the walkdown plan for tags, labels and stickers in [33]. The quantitative results of the walkdown were presented in Attachment 8.9, Unqualified Labels of [32]. Each sign and label found in containment was identified by location and surface area. All were assumed to be transportable. The sum of the individual areas was taken as the total area of tags, labels and stickers. One-hundred percent of the area was used as the total.

The licensee assumed that broken glass could be transported to the safety injection sump, and that broken containment light bulb glass within the ZOI could be the contributor. The surface area of 50 spheres, each with 4-inch radius, was taken to represent the glass surface area.

The walkdown methodology for tallying the inventory of tags, labels, stickers is reasonable because it appears to be comprehensive and to adequately reflect actual materials in containment, and using 100 percent of the total surface area at the strainer surface is conservative and acceptable. The inclusion of the light bulb debris is also conservative.

3.4.3 Latent Debris Mass and Tags and Labels Results

The results of the Waterford 3 analysis for latent debris mass and quantity of tags and labels, etc., are presented in Table 4. The total quantity of latent dirt, dust and lint computed from the sample measurements and surface areas was 238.9 lbm. Waterford Unit 3 conservatively adopted 250 lbm to be used for the purpose of specification of additional debris mass for the screen head loss calculation. An analysis to determine the individual contributions of particulate and fiber was not performed. However, for the purpose of sump screen design, Waterford Unit 3 assumes that the latent debris consists of 15% fiber and 85% particulate, as recommended in [2].

The total quantity of tapes, tags and labels and glass was determined to be 151 ft^2. This is the quantity that was used as the sacrificial area for sump screen design.

Table 4: Waterford 3 Latent Debris Results

Latent Debris Category	Quantity	Type
Dirt, Dust, and Lint	238.93 lbm	Assumed 15% Fibrous and 85% Particulate
Tape, Tags and Labels Glass (from bulbs) Total for this Category	81 ft^2 70 ft^2 151 ft^2	Assumed fully transportable

3.4.4 Summary

The latent debris and tags, labels and other materials assessment methodology followed the guidance of [1] and [2], contains a number of conservatisms, and therefore is acceptable. No open items were identified.

3.5 Debris Transport

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

- blowdown transport, which is the vertical and horizontal transport of debris throughout containment by the break jet;

- washdown transport, which is the downward transport of debris due to fluid flows from the containment spray and the pipe rupture;

- pool-fill transport, which is the horizontal transport of debris by break flow and containment spray flow to areas of the containment pool that may be active (influenced by recirculation flow through the suction strainers) or inactive (hold-up or settling volumes for fluid not involved in recirculation flow) during recirculation flow; and

- containment pool recirculation transport, which is the horizontal transport of debris from the active portions of the containment pool to the suction strainers through pool flows induced by the operation of the emergency core coolant system (ECCS) and containment spray system (CSS) in recirculation mode.

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

The staff reviewed the debris transport analysis for Waterford Unit 3, which was primarily contained in the debris transport calculation [16]. The debris transport calculation stated that the transport methodology used for Waterford Unit 3 is based on the methodology in Nuclear Energy Institute (NEI) 04-07 [1], as modified by the NRC Safety Evaluation (SE) [2], and Regulatory Guide (RG) 1.82 [5]. The licensee used logic trees to calculate debris transport fractions for (1) small and large pieces of Nukon low-density fiberglass (LDFG) debris, (2) intact pieces of Nukon LDFG, and (3) large pieces of reflective metallic insulation (RMI) from the zone of influence (ZOI) of each analyzed pipe rupture to the sump strainers, considering the blowdown, washdown, pool fill, and recirculation processes [16]. The licensee's logic trees were based upon a generic model recommended in [1].

The licensee did not use logic trees to compute transport fractions for fine debris, foreign materials, and unqualified coating chips. In lieu of a detailed analysis, the licensee conservatively assumed 100 percent transport for all fine debris and foreign materials. Debris assumed to be generated as 100 percent fines included Nukon LDFG eroded by containment spray or submergence, Owens-Corning Thermal Insulating Wool (TIW) II LDFG, Min-K, Microtherm, latent particulate debris, latent fibrous debris, qualified and unqualified coatings destroyed within the ZOI, and unqualified zinc primer. The licensee developed a customized methodology for analyzing the transport of unqualified coating chips that is described and evaluated in Section 3.5.5.2 of this report.

The licensee's debris transport methodology used assumptions from both the NEI 04-07 [1] baseline methodology as well as several analytical refinements from Section 4.0 of the NEI guidance document [1]. In particular, the licensee used FLUENT, a computational fluid dynamics (CFD) code, to simulate the flow of water in the containment pool during the recirculation phase of a LOCA. The following subsections discuss the licensee's overall transport methodology in detail, noting any specific issues the NRC staff identified during the audit review.

3.5.1 Blowdown Transport

In light of the complexity of modeling the distribution of dynamic steam and air flows in containment following a pipe rupture, the licensee used the simplified methodology for blowdown transport presented in NEI 04-07. The licensee stated that the blowdown transport analysis was also based on the methodology from NUREG/CR-6369 (the Drywell Debris Transport Study that was performed for boiling-water reactors (BWRs)) [20], Section 3.6.3.2 of NEI 04-07 [1], and Appendix VI of the staff's SE on NEI 04-07 [2].

The licensee stated that Waterford 3 has a mostly uncompartmentalized containment, with the exception of the existence of a pressurizer compartment. Based upon the NEI methodology for this containment configuration, the licensee stated that all RMI debris (both small and large pieces) was conservatively postulated to fall directly into the containment pool rather than being blown into the upper containment [16]. Although NEI 04-07 does not specifically state that all post-accident debris should be modeled as directly falling into the containment pool, the licensee conservatively took this position in [16]. The licensee considered this approach reasonable based upon guidance in NEI 04-07 that large debris may be modeled as falling directly into the containment pool and the expectation that the majority of the small debris blown into upper containment would eventually be washed down into the containment pool [16].

The staff considered the licensee's approach for analyzing blowdown transport to be conservative for the purpose of evaluating debris transport to the sump strainers. In particular, although the assumption that all post-accident debris directly enters the containment pool is not realistic, it ensures that no credit is taken for the capture and sequestration of debris at higher elevations of containment. As a result, the quantity of debris available for transport to the sump strainers is conservatively maximized. While this approach is conservative with respect to sump strainer sizing, without adequate technical justification, the staff would not consider the assumption that no debris is blown into the upper containment to be generally acceptable for other purposes, such as analyzing the susceptibility of the refueling cavity drains (or other choke points in containment) to debris blockage. This subject is addressed in Section 5.2 of this audit report.

3.5.2 Washdown Transport

Since the licensee assumed that 100% of the post-LOCA debris would be deposited directly into the containment pool, a detailed washdown analysis was not performed by the licensee [16]. Although the licensee's discussion of washdown transport included a limited discussion of the potential for some small pieces of debris to adhere to wet surfaces, inertial debris capture was ultimately not credited in the analysis [16].

The licensee did not perform a detailed evaluation to determine the locations where debris would be washed down into the containment pool. In general, the location where debris enters the recirculation pool may have a strong influence on the debris transport fraction in an analysis for which less conservative assumptions are made. However, based upon the incorporation of significant conservatism in the existing Waterford Unit 3 transport analysis (primarily the licensee’s assumption that many types of post-accident debris will be generated as highly transportable fines that are blown directly into the containment pool and the licensee’s use of the maximum continuous velocity along the flowpath to the containment sump in determining debris transport), the staff did not consider the licensee's lack of a detailed washdown analysis to be significant.

3.5.3 Pool-Fill Transport

The licensee did not create a detailed model of debris transport resulting from shallow, high-velocity sheeting flows that may occur during the pool fill-up phase. However, the licensee stated that, for breaks within the steam generator cavities, all debris within the cavities would be assumed to transport out of the cavities during pool fill-up due to the high velocity expected at the sheeting flow wave fronts [16]. The licensee's debris transport analysis did not credit inactive holdup volumes with capturing post-accident debris [16].

The staff considers the licensee's choice not to credit debris settling in inactive pool volumes within the post-LOCA containment pool to be conservative because it maximizes the quantity of debris available to transport to the sump strainers during the recirculation phase of an accident. The staff also noted that the Waterford 3 replacement strainers are installed on top of a suction plenum box, the top of which is 8 inches above the containment floor. This tends to minimize the impact of the shallow, high-velocity pool-fill transport flows during the injection phase because any debris would have to climb the 8 inch box wall to reach the strainers [16]. The staff's review did not identify the potential for significant quantities of debris to transport to the sump strainers during the filling of the containment pool early in the injection phase of the accident beyond that already accounted for in the existing analysis as reaching the strainers during the recirculation phase of the accident. Therefore, the staff considered the licensee's treatment of pool-fill transport to be acceptable.

3.5.4 Containment Pool Recirculation Transport

The licensee computed flow velocity and turbulence fields in the containment pool during the recirculation phase of a LOCA with the aid of the FLUENT computational fluid dynamics (CFD) code [16]. As described in more detail below, the licensee compared the flow velocities resulting from the CFD simulations to experimentally generated debris transport thresholds to determine the quantities of debris reaching the containment recirculation sump. The staff's discussion below evaluates the licensee's assumptions, analytical models, and calculations associated with determining the containment pool recirculation debris transport fractions, including a summary of the CFD simulations performed by the licensee. A more detailed review of the licensee's CFD analysis is contained in Appendix III of this audit report.

3.5.4.1 Pool Recirculation Transport Scenarios Analyzed

The licensee performed twelve CFD simulations using the FLUENT code, including four scenarios with the original sump screen configuration and a containment pool depth of 5.05 ft, six scenarios with the replacement sump strainers and a containment pool depth of 5.37 ft, and two scenarios with the replacement sump strainers and a containment pool depth of 11.57 ft.

The four original CFD scenarios (referred to as Scenarios 1–4) were used to compute the debris transport fractions for the replacement sump strainer design that are reported in the licensee’s debris transport calculation [16] and which are reported in Section 3.5.6 of this report. The containment pool depth of 5.05 ft used for these scenarios represented the analyzed minimum containment pool water level at the time the original CFD scenarios were performed. The licensee stated that the bounding break with respect to the quantity of debris that reaches the containment sump is Break S3 (a rupture of the 42-inch hot leg in the east steam generator cavity) or Break S6 (a rupture of the 30-inch cold leg in the east steam generator cavity), which are expected to generate equivalent quantities of debris [16, 30]. The licensee did not perform a separate CFD simulation for Break S3; instead, the transport fractions for this break were inferred based upon the computed transport fractions for a mirror-image hot leg break in the west steam generator cavity (Break S1). The licensee stated that, since the flowpath from the west steam generator cavity was considered more constricted than that from the east steam generator cavity, using the transport fractions calculated for Break S1 is conservative for Break

S3. Slightly larger transport fractions (but lower total quantities of transported debris) were calculated for the CFD scenario simulating a rupture of the 10.126-inch pressurizer surge line (Break S7), which is located near the containment sump. The licensee stated that a detailed transport analysis was not presented for Break S2 (a hot-leg rupture inside the reactor cavity) because, based upon the geometry of the reactor cavity, only a small amount of debris generated from this break (predominately RMI) was judged to be capable of transporting to the sump. The staff considered the licensee's selection of recirculation transport scenarios to be reasonable with respect to ensuring the computation of conservative debris transport fractions because the licensee modeled representative breaks in both steam generator cavities, including breaks in close proximity to the containment recirculation sump.

The licensee stated during the audit that the purpose of performing the second set of six CFD scenarios (Scenarios 5–8, 11, and 12) was to ensure that the limiting containment pool flow conditions had been analyzed with respect to the transport of coating chips. In particular, the licensee stated that the breaks considered in this second set of six analyses were generally located outside the steam generator cavities, since the original four CFD simulations did not fully examine the containment pool flow patterns resulting from breaks outside the cavities. The containment pool depth of 5.37 ft was based upon a revised version of the minimum water level calculation [34] that accounted for the design minimum usable volume of the refueling water storage pool (RWSP).

The final two CFD scenarios (Scenarios 9 and 10) were performed at the maximum containment water level of 11.57 ft in order to consider the effect of relocating trisodium phosphate (TSP) baskets in containment (to support the installation of the replacement sump strainer) on the time necessary for the buffer to mix with the containment pool water and achieve a uniform pool pH. These two scenarios are not reviewed in detail in this report because their application is beyond the audit scope.

3.5.4.2 Debris Transport Metrics

A summary of the metrics used by the licensee to analyze debris transport during containment pool recirculation is provided in Table 5 below. Since one of the four originally analyzed breaks (Break S7) could generate turbulence near the containment sump, the licensee used different debris transport metrics for this configuration, as compared to the metrics used for breaks located remotely from the sump (each of which are provided in Table 5 below).

Table 5: Metrics Used for Analyzing Debris Transport During Recirculation

Debris Type	Incipient Tumbling Velocity (ft/s)	Curb Lift Velocity (ft/s)
Stainless Steel RMI (Break Near Sump)	0.20	0.30
Stainless Steel RMI (Breaks Far From Sump)	0.28	0.84
Nukon LDFG (Break Near Sump)	0.06	0.25
Nukon LDFG (Breaks Far From Sump)	0.12	0.29
Unqualified Coating Chips	0. 40	Not Reported

The licensee's debris transport metrics were based on experimental transport data reported in NUREG/CR-6772 [19]. For breaks located far from the containment sump, the licensee chose data from NUREG/CR-6772 that had been generated from tests with a flow diffuser, which dampened turbulence and straightened the flow in the test flume. For the break located near the sump, the licensee chose data that had been generated from tests without flow diffusers and with water returned to the test flume in a manner intended to generate turbulence (either from free-falling water or through a submerged pipe) [16].

The staff considered the transport metrics the licensee used for RMI and Nukon to be appropriate. The debris samples in the tests reported by NUREG/CR-6772 were representative or conservative with respect to the size of the debris expected at Waterford Unit 3. The staff agreed that the licensee appropriately considered the effect of turbulence in selecting debris transport metrics. Furthermore, the use of the incipient tumbling velocity as a transport metric is conservative because this is the velocity at which the first pieces of debris begin to move, as opposed to the velocity at which the bulk of a given type of debris is capable of transporting.

The curb lift velocity metrics the licensee used for RMI and Nukon debris were based upon the previous sump screen design. In that design, the licensee stated that a curb with an effective height of 3.75 inches was created by the combination of the screens resting on a 3/4-inch plate and being surrounded by a 3-inch piece of angle iron. During the audit, the staff questioned whether the replacement strainer design incorporates a debris curb and further questioned whether the licensee had adequately accounted for the tendency of debris to form a ramp around the debris curb, which could assist subsequent pieces of debris in surmounting the curb. The licensee stated that the replacement sump strainer design sits on a suction plenum that is raised eight inches above the containment floor elevation and that the suction plenum would inhibit floor-transporting debris from reaching the sump strainer in a manner similar to a debris curb. In light of the significant increase in the effective curb height for the replacement strainer design, the staff considered the curb lift velocity metrics used in the existing transport analysis to be conservative for the replacement strainers, even without consideration of debris ramping effects.

The staff questioned the licensee’s metric of 0.4 ft/s for the incipient tumbling velocity of unqualified coating chips because the licensee's transport analysis did not provide a comparison of the physical characteristics (e.g., size, thickness, density, degree of curl) of the various types of unqualified coating chip debris postulated for Waterford Unit 3 with the properties of the chips for which the 0.4-ft/s metric had been experimentally derived. The sources of experimental data used by the licensee to analyze coating chip transport included NUREG/CR-6772 [19] and an NRC slide presentation from a public meeting which reported preliminary results from the coating debris transport testing reported in NUREG/CR-6916 [35]. Without an adequate comparison of the physical characteristics of the Waterford Unit 3 coating debris to the characteristics of the debris used for the transport tests, the staff could not confirm that the licensee’s application of the coating debris transport data was conservative. Therefore, the need for the licensee to provide an analysis that shows that the coating debris test data credited by Waterford Unit 3 was generated using coating chips that are representative of or bounding with respect to the plant-specific failed coating chips is designated as **Open Item 3**.

3.5.4.3 Fibrous Debris Erosion

The licensee's debris transport calculation [16] recognized that, while large or small pieces of exposed fibrous debris may not be transportable under low velocity flow conditions, erosion of settled pieces of fibrous debris should be considered. Since the licensee assumed that Nukon LDFG debris generated by containment sprays and submergence and all of the Owens-Corning TIW II LDFG debris would be destroyed into fines, the discussion of erosion below applies only to large and small pieces of Nukon LDFG debris generated within the zone of influence of a pipe rupture.

The licensee stated that Section III.3.3.3 of Appendix III to the staff's SE [2] suggests that, in lieu of specific erosion data, 90 percent of the small and large pieces of fibrous debris analyzed as settling in the containment pool should be considered to erode into fines over a 30-day period. The licensee stated that the SE position was based on data in NUREG/CR-6773 [36], for which one of the long-term integrated transport tests was performed at pool velocities of approximately 0.15 ft/s in the vicinity of the simulated pipe break and sump screen. Since the licensee considered the flow velocities in the Waterford 3 containment pool to be comparable to those in the applicable test from NUREG/CR-6773, the assumption of 90 percent erosion was applied for Waterford 3 [16]. The licensee stated that large pieces of dislodged insulation with intact jacketing were not considered to erode, which is consistent with the position taken in the staff's SE [2].

The staff agrees that the licensee's positions regarding fibrous debris erosion are consistent with the staff's SE and considers them to be acceptable. In particular, one of the analyzed breaks for Waterford Unit 3 is located in the direct vicinity of the sump. As a result, significant quantities of debris could end up in a region of the containment pool where the velocity and turbulence would be relatively high during the recirculation phase of a LOCA. Similar to the staff's review of previous audit reports and pilot audit reports [37,38,39], if future revisions of the debris transport calculation attempt to justify a reduction in the quantity of settled fibrous debris assumed to erode, the staff would expect that a technically defensible basis such as testing be provided to support this position.

3.5.5 Approach for Calculating Debris Transport Fractions During Recirculation

The licensee assumed 100 percent transport for all fine debris. The only types of debris for which settling was considered were large pieces of stainless steel RMI, large and small pieces of Nukon LDFG, and unqualified coating chips.

3.5.5.1 Approach for Calculating RMI and Nukon Debris Transport Fractions

The licensee used the same general approach for calculating debris transport fractions for large pieces of RMI and large and small pieces of Nukon. All debris in these categories was assumed to fall directly into the active portion of the containment pool. The licensee assumed that the percentage of this debris approaching the sump from the east and west halves of the containment would be equal to the percentage of flow approaching the sump from each half of containment (e.g., if 60 percent of the flow in the CFD simulation was found to approach from the east annulus region, then 60 percent of the generated debris for that scenario would be assumed to approach from the east half of containment, whereas the remaining 40 percent of both the flow and debris would be assumed to approach from the west half of containment).

A diagram of the Waterford Unit 3 containment pool just above the floor elevation is provided below as Figure 1 to illustrate the flow pattern around the east and west sides of the containment annulus on its approach to the containment sump. Figure 1 was extracted from the licensee's debris transport calculation [16].

The licensee then compared the velocity calculated from the CFD simulation on each side of containment with the velocity metric for each type of debris to determine the quantity of debris that would reach the sump area. If the maximum continuous velocity predicted by CFD exceeded the transport metric along the limiting flowpath selected by the licensee, the licensee assumed that all debris on that side of the containment transported to the sump; if the velocity along the pathway did not exceed the metric, none of the debris from that side of containment was assumed to transport. Finally, the licensee compared the velocity around the containment sump with the curb lift velocity transport metric for these debris types to determine whether each type of debris would be capable of surmounting the 8-inch suction plenum to accumulate on the sump strainers.

Although the staff considered most aspects of the licensee's approach for computing transport fractions for pieces of RMI and Nukon debris to be either reasonable or conservative, the staff had two concerns with the licensee's approach that are described below.

The first concern is that the staff concluded that there is inadequate technical basis for the licensee to assume that the percentage of debris transporting along the east and west sides of containment is equal to the percentage of flow approaching the sump from the east and west side of containment. Although there are limited conditions under which the licensee's assumption may be reasonable, the staff expects that the location of the break would generally have a significant impact on which side of containment debris will transport, regardless of the flow split between the east and west sides of containment. The staff's expectation is borne out by most of the plots of pathlines from the breaks to the containment sump that are included in the debris transport calculation for the CFD simulations performed by the licensee [16]. These plots suggest that debris transport would be generally biased toward the side of containment on which the break occurred and, in many cases, overwhelmingly so. Furthermore, as noted in the debris transport calculation, the flow in the Waterford Unit 3 containment pool was found to be highly three-dimensional [16]. This observation further suggests that the use of the total flow to the sump from the east and west sides of containment (i.e., a summation over the vertical flow distribution across the entire 5.05-foot depth of the containment pool) may not be a reasonable predictor of the direction of travel for pieces of Nukon and RMI debris transporting predominately only several inches above the containment floor. The lack of technical validity of the licensee's assumption is significant because the use of the assumption could result in non-conservatively low debris transport fractions under some conditions if sufficient countervailing conservatisms are not incorporated into the analysis.

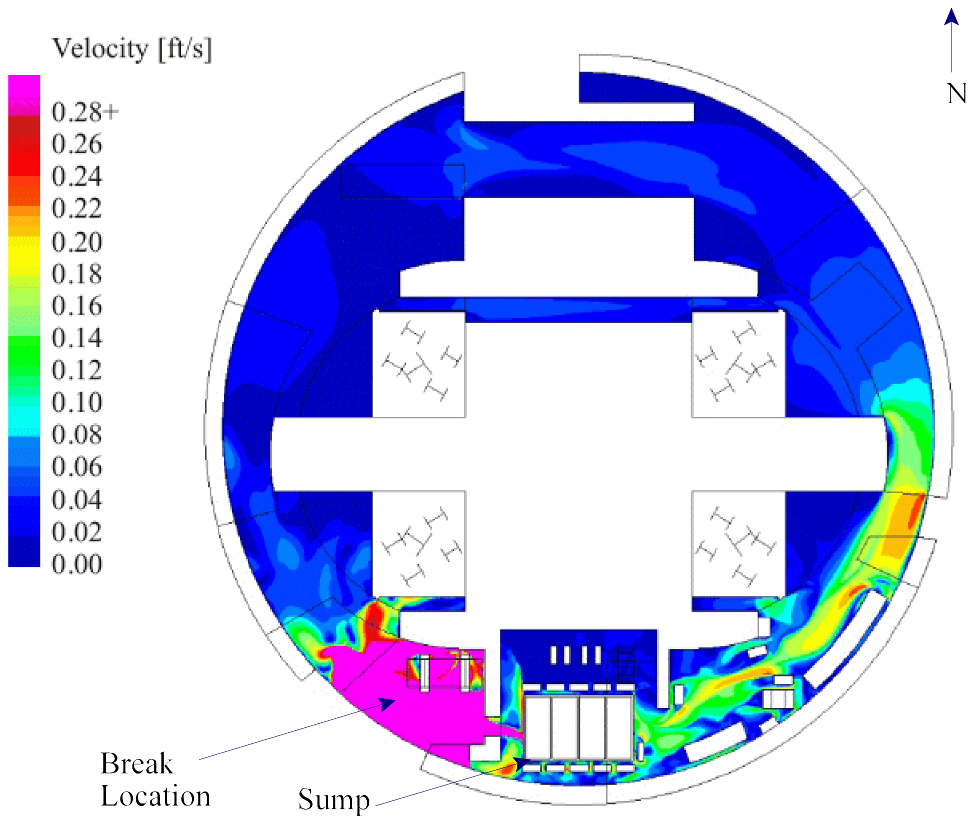

Figure 1: Waterford 3 Containment Pool Flow Velocity for Break S7

The second concern is that the licensee's debris transport calculation did not clearly define the point at which the transport paths from the east and west sides of containment to the sump strainers were assumed to begin. Although the results of the licensee's transport calculation were consistent with the interpretation that the transport path on the side of containment with the pipe rupture begins at the point where this break water enters the containment pool, the licensee could not explain where the transport path on the opposite side of containment was assumed to begin.

For a related case in point, consider Figure 1 above. Clearly, as the licensee determined, the transport metric for Nukon LDFG for the S7 Break (0.06 ft/s) is exceeded on the west side of containment. However, the licensee further determined that no transport from the east side of containment would occur for this break. While it is clear that the flow velocities in the clockwise direction from the break to the sump in the annulus around the steam generator compartments is too low to transport all but suspended debris, there is a flow stream in the southeast quadrant that appears to be significantly in excess of both the assumed tumbling transport metric of 0.06 ft/s for near-sump Break S7, as well as the assumed transport metric of 0.12 ft/s for breaks far from the sump (see Table 5 above). Analogous observations were made concerning the other breaks analyzed by the licensee. As a result of these observations, the staff questioned the licensee's basis for assuming that no debris would be transported to the sump via flow streams such as those identified in Figure 1 above. In particular, the staff noted that debris could be situated in relatively high velocity flow streams on the side of containment opposite the break due to transport occurring during the blowdown, washdown, and pool-fill-up phases of the LOCA. The licensee did not provide a sufficient basis during the audit to resolve the staff's questions in this area.

The staff recognized that the licensee's approach incorporated conservatism in generally assuming 100 percent transport from the side of containment where the break occurs, whereas, realistically, the transport fraction would be somewhat lower. However, sufficient information was not provided for the staff to determine to what extent this conservatism compensated for the potential non-conservatisms associated with the two concerns described above. Therefore, the need for the licensee to address the staff's concerns that (1) the licensee did not adequately justify that the percentage of debris transporting along the containment floor from the east and west sides of containment is equal to the percentage of flow approaching the sump from the east and west sides of containment and (2) the licensee's lack of a clear definition of the starting points for debris transport paths may have contributed to an underestimation of debris transport on the side of containment opposite the break, is designated as **Open Item 4**.

3.5.5.2 Approach for Calculating Unqualified Coating Debris Transport Fractions

The debris transport calculation states that the majority of the unqualified coatings at Waterford Unit 3 are on the containment dome and liner [16]. Other miscellaneous equipment coated with unqualified coatings is also specified in the transport calculation, including reactor coolant pump motors, structural steel, and concrete [16].

The licensee's coating chip transport analysis assumed that 6% of the total quantity of failed unqualified coatings would be less than 400 microns in diameter (i.e., behaving more like particulate than chips). Debris from these failed coatings was considered capable of remaining in suspension in the containment pool. The remaining 94 percent of the coating debris inventory larger than 400 microns was assumed to be capable of settling under favorable flow conditions. The licensee's justification for this size distribution is discussed in the next paragraph. To determine how much of the 94 percent of coating chips capable of settling would actually settle, for a representative sample of the breaks analyzed the licensee took a ratio of the fraction of the containment pool floor area with flow velocities less than 0.2 ft/s at a height of three inches to the entire containment pool floor area and added a small conservative margin to the calculated fraction. The licensee used the value of 0.2 ft/s as the velocity necessary to keep coating chips in suspension based upon coatings test results reported in NUREG/CR-6916 [35].

The licensee's assumed size distribution for failed unqualified coating debris was based on the results of tests with a similar epoxy coating system that were performed for the NRC by Westinghouse Savannah River Company [41]. However, the actual size distribution for coating debris used by the licensee followed a model developed by Westinghouse for downstream effects analysis [42] that was intended to be conservative with respect to the Savannah River test data (i.e., biased toward smaller chips). Following the onsite audit, the staff performed a limited review of the coating chip test data referenced by the licensee in the Savannah River test report [41]. The staff noted that (1) the Savannah River data deliberately omitted coating debris smaller than 100 microns from the size distribution analysis due to limitations in available optical equipment, (2) the number of chips in the largest chip size categories that were the dominant contributor to the total collected mass was very small (i.e., two or three chips), and (3) the selection of chips analyzed was a "subjectively chosen subset" of all of the coating debris collected [41]. While the conservative biasing applied by Westinghouse may compensate for the issues cited by the staff, this position was not adequately supported in the Westinghouse paper [42] or the debris transport calculation [16].

In addition, the staff determined that the licensee's basis for assuming that coating chips less than 400 microns in diameter would tend to settle in the containment pool was based on an industry guidance document that incorrectly applied coating chip test data. The criterion of 400 microns for determining settling potential was outlined in the Westinghouse paper [42] and further reproduced in the downstream effects evaluation methodology report, WCAP-16406-P, Draft Revision 1 [43]. WCAP-16406-P argues that, because the experimentally determined settling velocity for epoxy paint chips with a 400-micron thickness (based on data reported in NUREG/CR-6772 [19]) is on the order of the typical core inlet plenum velocity, epoxy chips larger than 400 microns would tend to settle under such flow conditions. Although this statement is physically reasonable, the subsequent discussion in WCAP-16406-P [43] and the Westinghouse paper [42] inappropriately combines the diameter and thickness of a paint chip into a chip "size." Yet it is essential to treat these dimensions distinctly; as an example, the coating chips used for the experimental testing from NUREG/CR-6772 [19] cited in WCAP-16406-P had effective diameters on the order of 1/8 inch (3175 microns) to 1 inch (25400 microns), and thicknesses of approximately 400 microns. Clearly, chips of this size are not representative of coating debris with a diameter of 400 microns and a thickness of this same order (i.e., essentially a particle) with respect to debris transport behavior. In summary, based on the guidance provided in the two references described above, the licensee's debris transport calculation misapplied data from coating chip transport tests with 400-micron-thick coating chips to coating debris with a 400-micron diameter. (The staff notes that the guidance regarding coating chip settlement in Draft Revision 1 of WCAP-16406-P reviewed above was not fundamentally revised in Revision 1 of WCAP-16406-P, dated August 2007 [139]. This issue was addressed in the Limitations and Conditions section of the staff's safety evaluation on WCAP-16406-P [140], which stated that the WCAP appendix containing the guidance on coatings that is discussed above is outside the scope of the safety evaluation. The staff's safety evaluation on WCAP-16406-P further references the safety evaluation of NEI 04-07 [2] as a source of staff guidance concerning failed coatings.)

The staff also noted that the discussions of coating debris settling in WCAP-16406-P [43] and the Westinghouse paper [42] were clearly intended to be used for analyzing the settling of coating debris downstream of the sump strainers, specifically in the core inlet plenum inside the reactor vessel. As compared to typical flows in a containment pool, which would be predominately horizontal and could include sources of localized turbulence, typical flows in a core inlet plenum following a loss-of-coolant accident (LOCA) would be vertical and relatively quiescent. Thus, the fundamental relevance of the analysis in WCAP-16406-P and the Westinghouse paper to the conditions in the Waterford 3 containment pool was not apparent to the staff, and the use of these analyses to determine debris transport in a containment pool was not adequately justified by the licensee.

Finally, the licensee's debris generation calculation [32] indicated that approximately 12 percent of the containment spray drainage would be expected to enter the containment pool in the vicinity of the containment sump. Since failed coating chips may be entrained in this drainage local to the containment sump, the staff questioned whether the licensee had addressed the potential for coating chips to transport to the strainers by falling into the containment pool near the strainers, and accumulating on the strainer surface as the chips sink in the containment pool. The licensee stated that this potential means of coating chip transport had not been evaluated in the debris transport analysis.

Based upon the discussion above, the staff did not consider the licensee's methodology for analyzing the transport of failed unqualified coatings to have been adequately justified. Conservatisms in the analysis, including the use of 0.2 ft/s as the threshold velocity for suspending coating chips and the lack of credit for the strainer being raised approximately 8 inches above the containment floor, may compensate for some degree of potential nonconservatism associated with the staff's concerns. However, the licensee did not provide an adequate basis during the audit for the staff to conclude that the calculation of coatings debris transport remains conservative overall. Therefore, the need for the licensee to explain how it has addressed the four below deficiencies in the existing transport analysis for unqualified coating chips (discussed in detail above) is designated as **Open Item 5**:

- The licensee did not have adequate data to justify the assumed size distribution for failed coating chips;

- The licensee improperly applied settling data for coating chips with a 400-micron thickness to particle-like coating debris with a 400-micron diameter;

- The licensee did not justify the use of an analysis intended for the vertical flow conditions typical of a reactor vessel core inlet plenum for the horizontal flow conditions in the Waterford 3 containment pool; and

- The licensee did not consider the possibility that coating chips that fall into the containment pool in the vicinity of the sump may transport to the sump in suspension in the containment pool prior to settling on the containment floor.

The staff also noted that the initial revision of the debris transport calculation had assumed that coating debris is 100 percent fine particulate. Although Revision 1 of the transport calculation [16] inserted additional discussion which modified this position, including the assumption that certain types of coatings fail in the form of chips, the revised calculation was not systematically edited to remove the now-contradictory original position that coatings fail as 100 percent fine particulate. The staff recommended that the licensee correct the identified inconsistency regarding assumptions on the form of certain types of unqualified coatings debris.

3.5.6 Overall Transport Results

In accordance with the methodology described by the staff above, the licensee's debris transport calculation [16] provides results for each CFD scenario, both in terms of the debris transport fractions and the total quantities of debris that arrive at the containment recirculation sump. These quantities are summarized in Tables 6 through 9 below.

As shown in Table 6 below, the licensee used the debris transport fractions calculated for CFD Scenario 3 to determine the transported quantities of debris for three different breaks. First, Scenario 3 was performed specifically to model Break S1, a hot-leg break in the west steam generator cavity. Break S3, a hot-leg break in the east steam generator cavity, is a mirror-image break to S1 that is located on the side of containment that is slightly less constricted. As a result, the licensee stated that the transport fractions for CFD Scenario 3 would bound Break S3. Finally, because Break S4 is located in approximately the same location as Break S1, the licensee considered the transport fractions calculated for CFD Scenario 3 to be representative of Break S4. Based upon review of the licensee's discussion above, the staff considers the licensee's use of CFD Scenario 3 to calculate debris transport fractions for Breaks S1, S3, and S4 to be reasonable for calculating containment pool flow conditions as an input to determining debris transport fractions.

Table 6: Debris Transport Calculation Results for CFD Scenario 3 Breaks S1, S3, and S4

Debris Type	Transport Fraction	Quantity Transported		
		Break S1	Break S3	Break S4
Stainless Steel RMI	0.75	N/A	N/A	N/A
Nukon LDFG (within ZOI)	0.59	329 ft^3	638 ft^3	306 ft^3
Nukon LDFG (containment sprays / submergence)	1	198 ft^3	198 ft^3	198 ft^3
Owens-Corning TIW II LDFG (2D ZOI)	1	24 ft^3	180 ft^3	N/A
Min-K	1	0.4 ft^3	0.4 ft^3	0.4 ft^3
Microtherm	1	4.2 ft^3	4.2 ft^3	4.2 ft^3
Qualified Coatings (5D ZOI)	1	25.1 ft^3	25.1 ft^3	25.1 ft^3
Unqualified Coatings (inorganic zinc)	1	12.8 ft^3	12.8 ft^3	12.8 ft^3
Unqualified Coatings (other)	0.27	11.1 ft^3	11.1 ft^3	11.1 ft^3
Latent Fiber	1	37.5 lbm	37.5 lbm	37.5 lbm
Latent Particulate	1	212.5 lbm	212.5 lbm	212.5 lbm
Foreign Materials	1	151 ft^2	151 ft^2	151 ft^2

Table 7: Debris Transport Calculation Results for CFD Scenario 2, Break S5

Debris Type	Transport Fraction	Quantity Transported
Stainless Steel RMI	0.75	N/A
Nukon LDFG (within ZOI)	0.59	329 ft^3
Nukon LDFG (containment sprays/submergence)	1	198 ft^3
Owens-Corning TIW II LDFG (2D ZOI)	1	24 ft^3
Min-K	1	0.4 ft^3
Microtherm	1	4.2 ft^3
Qualified Coatings (5D ZOI)	1	25.1 ft^3
Unqualified Coatings (inorganic zinc)	1	12.8 ft^3
Unqualified Coatings (other)	0.27	11.1 ft^3
Latent Fiber	1	37.5 lbm
Latent Particulate	1	212.5 lbm
Foreign Materials	1	151 ft^2

Table 8: Debris Transport Calculation Results for CFD Scenario 1 / Break S6

Debris Type	Transport Fraction	Quantity Transported
Stainless Steel RMI	0.75	N/A
Nukon LDFG (within ZOI)	0.59	638 ft^3
Nukon LDFG (containment sprays/submergence)	1	198 ft^3
Owens-Corning TIW II LDFG (2D ZOI)	1	180 ft^3
Min-K	1	0.4 ft^3
Microtherm	1	4.2 ft^3
Qualified Coatings (5D ZOI)	1	25.1 ft^3
Unqualified Coatings (inorganic zinc)	1	12.8 ft^3
Unqualified Coatings (other)	0.27	11.1 ft^3
Latent Fiber	1	37.5 lbm
Latent Particulate	1	212.5 lbm
Foreign Materials	1	151 ft^2

Table 9: Debris Transport Calculation Results for CFD Scenario 4 / Break S7

Debris Type	Transport Fraction	Quantity Transported
Stainless Steel RMI	0.775	N/A
Nukon LDFG (within ZOI)	0.60	47 ft^3
Nukon LDFG (containment sprays/submergence)	1	219 ft^3
Owens-Corning TIW II LDFG (2D ZOI)	1	N/A
Min-K	1	N/A
Microtherm	1	0.6 ft^3
Qualified Coatings (5D ZOI)	1	N/A
Unqualified Coatings (inorganic zinc)	1	12.8 ft^3
Unqualified Coatings (other)	0.20	8.4 ft^3
Latent Fiber	1	37.5 lbm
Latent Particulate	1	212.5 lbm
Foreign Materials	1	151 ft^2

In the licensee's debris transport calculation [16], the debris transport fraction for unqualified coatings other than inorganic zinc was reported as having a value of one. However, the licensee also stated that the quantity generated by the LOCA was 41.7 ft^3, and the quantity transported was either 8.4 ft^3 or 11.1 ft^3, depending on the CFD scenario. During the audit, the staff noted that the accepted definition for a debris transport fraction is the quantity of debris transported to the sump divided by the total amount generated by the LOCA and suggested that the licensee correct the reported debris transport fractions for unqualified coatings other than inorganic zinc (as was done by the staff in Tables 6 through 9 above) to ensure consistency with the accepted definition of debris transport fraction. This discrepancy is insignificant for overall conclusions regarding debris transport because the licensee's strainer design is based upon the quantities of debris transported rather than the reported debris transport fractions. As discussed above, the licensee's resolution of Open Item 5 will ensure that the total quantities of debris calculated as reaching the strainers are conservative.

As noted previously in Section 3.5.4.1, all of the debris transport fractions presented above were based on the four original CFD scenarios performed by the licensee. The original CFD runs were all performed with the original sump screens, and further anomalously modeled reactor cavity drainage as spilling over the top of the cavity as opposed to draining normally through the cavity drain lines (despite the fact that the cavity drains were assumed not to be blocked for the purpose of calculating the containment water level). The licensee's debris transport calculation did not provide a basis for the staff to conclude that the original CFD simulations bound the expected flows in the containment pool with the replacement strainer.

Furthermore, although a set of additional CFD simulations was performed for certain breaks with the replacement strainer (including two simulations with previously analyzed breaks with the anomaly regarding drainage from the reactor cavity corrected), the licensee did not include a complete set of velocity and turbulence contour plots in the debris transport calculation to allow an assessment of whether the debris transport fractions calculated for the original strainer are bounding for the replacement strainer configuration. As a result, the need for the licensee to provide justification that the debris transport fractions in the transport calculation are representative of the replacement strainer configuration is designated as **Open Item 6**.

3.5.7 Conservatism in the Debris Transport Analysis

The staff noted several substantive sources of conservatism in the licensee's debris transport analysis, including the following:

- The licensee assumed that 90 percent of the large and small pieces of fibrous debris that settle in the containment pool would become fines that would transport to the sump strainers over a 30-day period. This assumption was based upon guidance in Appendix III of the staff's SE [2] on NEI 04-07 [1]. The assumption of 90 percent erosion for large and small pieces of settled fibrous debris adds considerable conservatism to the licensee's transport analysis.

- The licensee modeled the pumps (i.e., both trains of high-pressure safety injection and containment spray) that were assumed to be running during the sump recirculation phase of the accident as operating at run-out flows. At run-out, pump flows are maximized, thereby maximizing the flow in the containment pool and supporting a conservative estimate of debris transport to the containment sump. Provided that the licensee acceptably resolves Open Item 7 below regarding the potential single failure of a low-pressure safety injection pump to stop automatically following the switchover to sump recirculation, the staff concludes that the sump flow rate used by the licensee is conservative with respect to predicting debris transport.

- The licensee assumed that all generated debris would be directed downward to the containment pool during the blowdown phase of a LOCA. As such, no credit was taken for capturing debris on gratings or other structures and equipment in upper containment. Although a significant fraction of captured debris could eventually be washed back down to the containment pool, assuming 100 percent of the debris directly enters the containment pool during blowdown is conservative with respect to the sump strainer design.

- The licensee adopted the conservative baseline assumption that 100 percent of the small fines of fibrous and particulate debris would transport to the suction strainers. Although small fines of fibrous and particulate material are expected to have very high transport fractions, the assumption of complete transport for these types of debris is conservative.

- The licensee did not credit debris holdup in the reactor cavity or the inactive normal containment building sump. Although the licensee noted that the potential for debris hold up in inactive pool volumes at Waterford 3 appears to be small, completely neglecting debris holdup is conservative.

- The licensee's transport analysis did not fully credit the 8-inch suction plenum between the containment floor and the bottom of the replacement strainer in serving as a curb to reduce debris transport onto the strainers. For analyzing the transport of RMI and Nukon LDFG debris, the licensee only credited a curb of 3.75 inches in height, based upon the original sump screen design. The licensee did not credit a curb at all in determining the debris transport fraction for coating chips.

- In determining whether various kinds of floor-transporting debris would be capable of being lifted onto the sump strainers from the containment floor area near the sump, the licensee conservatively interpreted the velocity contours around the sump in a manner that bounds the expected behavior of the debris.

- The licensee generally used transport metrics for computing debris transport that are conservatively low for the debris sizes to which they were applied.

Although the effect of these conservatisms is difficult to quantify, the staff recognizes that they tend to provide confidence that the overall results of the transport calculation are conservative. During the audit, the licensee stated that consideration is being given to revising the transport calculation and several of its inputs to remove some of the existing conservatisms. Potential revisions discussed with the staff included the following:

- The use of test data to reduce the quantity of debris assumed to erode in the post-accident containment pool;

- The use of analysis or test data to reduce the quantity of Nukon LDFG debris assumed to be generated through containment spray erosion and submergence;

- The use of analysis to reduce the assumed zone of influence and erosion rates for Owens-Corning TIW II LDFG by comparing this insulation to Nukon LDFG, for which test data exists for both jet destruction and erosion; and

- The use of test data to reduce the zone of influence for Nukon from 17D to 5D, which would reduce the quantity of debris available to transport to the containment sump.

The staff noted that the licensee's overall debris transport fractions generally appeared to have been calculated in a conservative manner and agreed that, provided the licensee resolves the open items identified by the staff, some reductions in conservatism appear possible. However, in addition to the identified open items there are uncertainties and/or potentially non-conservative assumptions of lower significance in the licensee's analysis, which, in the staff's judgement, are currently offset by the weight of existing conservatisms outlined above. Examples of these second-order uncertainties and potential non-conservatisms are as follows:

- Due in part to the compartmentalized geometry of the Waterford 3 containment building, the licensee's calculated debris transport fractions appeared sensitive to the location and kinetic energy of flows from the break into the containment pool. For example, the licensee assumed that the flow from the 42-inch hot-leg breaks would be deflected by the steam generator pedestals and the flow would consequently be divided between two steam generator compartments. However, as a result of the uncertain orientation of the ends of the ruptured piping, the flow from the break need not occur as the licensee assumed, which could impact the calculated debris transport fractions.

- Similar to the discussion of break flow in the previous bullet, the licensees's existing modeling of drainage from the containment sprays represents a potential uncertainty. The staff considered the licensee's distribution of the spray drainage evenly over 9 separate regions of containment to be reasonable. However, the licensee's analysis did not consider whether concentrated streams of drainage could exist within each of the 9 spray drainage regions.

- Uncertainties exist in modeling the transport of debris in the blowdown, washdown, and pool fill transport modes, which prevent accurate prediction of the location of containment debris at the initiation of the recirculation phase of the accident. As a result, these uncertainties are currently accounted for in the licensee's analyses through a conservative specification of the initial location of debris for each break (directly under the break) and the transport of the debris to the strainer (in the highest flow rate path from the break location to the strainer) at the onset of recirculation.

As discussed with the licensee during the audit, the staff did not consider these uncertainties and potential non-conservatisms to be significant in light of the conservatisms discussed above. Had the debris transport calculation been substantially less conservative, however, some of these uncertainties might have risen to the level of open items. Therefore, the staff recommended that the licensee assess the impact of future reductions in conservatism in relation to potential non-conservatisms and uncertainties, including those not listed above, to ensure that any future revisions of the sump performance analysis remain conservative overall.

3.6 Head Loss, Vortexing and Net Positive Suction Head Margin

3.6.1 Head Loss and Vortexing

3.6.1.1 Audit Scope

The new sump installed in Waterford Unit 3 by the licensee uses a single train of General Electric (GE) strainers connected to a common sump which provides a water source for two independent trains of ECCS and CS pumps. The strainer array consists of 11 horizontally stacked disk modules connected via a header or plenum. The plenum carries the water, after it has passed through the perforated plate and the internal portion of the modules, to the containment sump. The perforations in the strainer plate consist of 3/32-inch diameter holes. The GE strainer design also incorporates a mesh over the strainer surface. The mesh is termed a "debris plate" and is designed to mitigate thin bed effects. Each module consists of seventeen 40-inch square strainer disks. The total surface area of perforated plate for the strainer array is 3699 ft^2 [30]. Based on the debris transport calculation, a combination of Transco RMI Foil, Nukon fiber, Min-K, Microtherm, Owens Corning TIW II Fiberglass, qualified and unqualified coatings, latent debris, and miscellaneous foreign materials was estimated to be transported to the sump. The quantities of the calculated debris varied depending on different break locations. The new strainer is designed to accommodate a target maximum pressure loss across the sump of 1.5 ft-water according to reference [31]. Testing determined that the actual maximum head loss would be 1.015 ft. This resulted in a calculated margin of 0.485 ft for chemical effects. However, later NPSH analysis found that the HPSI B pump has only 0.33 ft of calculated margin.

GE employed previous head loss testing results and correlations developed from the tests for the initial strainer sizing and scoping analysis. After the initial analysis, plant-specific prototypical head loss tests were performed for reduced-scale and large-scale strainer modules. The results of the initial plant-specific testing indicated the need to enlarge the strainer plates because it was determined that in the original smaller strainer size, the gaps between the strainer plates could become filled, resulting in unacceptable head loss. Additional testing was then conducted using the larger strainer area for scaling. After it was determined that the larger strainer area was acceptable for the limiting debris load cases, confirmatory testing was completed to verify other debris loads were also maintained within the design head loss for the strainer. As part of the prototypical head loss testing program, the licensee evaluated the susceptibility of the strainers to vortex formation.

The NRC audit effort focused on the following technical areas:

1. System characterization and the design input to the head loss evaluation;

2. Prototypical head loss test module design, scaling, surrogate material selection and preparation, testing procedures, testing results and data extrapolation;

3. Vortex testing procedures and the vortex formation test results.

3.6.1.2 System Characterization and Design Input to the Head Loss Evaluation

Waterford 3 utilizes a group of systems to mitigate the effects of design basis LOCA accidents. A containment sump is required to provide long-term cooling following a LOCA. The systems requiring containment sump operation can be divided into to two subgroups: the Safety Injection System (SIS), which provides borated water injection or recirculation to the reactor coolant system in the event of primary system break, and the containment spray system (CSS).

The SIS at Waterford Unit 3 consists of three major components: Safety Injection Tanks (SITs), Low Pressure Safety Injection (LPSI) pumps and High Pressure Safety Injection (HPSI) pumps. The Refueling Water Storage Pool (RWSP) supplies the initial source of water for the SIS and CSS pumps. According to the design, the LPSI pumps are tripped when transferring from the initial RWSP injection mode to the containment sump recirculation mode, while the HPSI pumps run in both modes of operation. This action occurs automatically when RWSP level reaches a predetermined low level and is termed a Recirculation Actuation Signal (RAS). The LPSI pumps therefore are not supposed to take suction from the containment emergency sump during a LOCA event (until a later boron precipitation phase when a single LPSI pump is started manually).

The Containment Spray System (CSS) pumps assist in containment cooling and reduce pressure within the containment by spraying water from the RWSP as a mist. The mist helps to cool and condense the steam that exists within the containment following a LOCA. Following a RAS, the CSS pumps also take suction from the containment sump and therefore add to the flow through the strainer and sump piping.

3.6.1.2.1 Flow Rate

The containment emergency sump provides a reservoir of water for the HPSI and CSS pumps following a RAS. In the recirculation phase of a design basis LOCA scenario, two trains of HPSI and CSS pumps take water from the sump. The sump would need to supply 6740 gpm of flow to the two trains of HPSI and CSS pumps based on calculated maximum flow for the four pumps. The licensee determined that this flow rate results in the most limiting case for the CSS pump NPSH, although the HPSI pumps in general are more limiting for NPSH margin. Therefore, the design flow rate input for the new strainer is 6470 gpm. The HPSI B pump is the limiting component for NPSH, having only 0.33 ft of available NPSH margin. The LPSI flow is assumed to be zero since the pumps are designed to trip following a RAS [57].

Staff Evaluation

The staff reviewed the calculations that describe the LOCA event characterizations and found that the inputs used in the calculations contain one questionable assumption. The licensee assumed that both LPSI pumps are shut off following a RAS. The licensing basis for the LOCA analysis requires that a single active failure of the most limiting component be considered. However, the licensee does not assume that a failure of a LPSI pump to trip after RAS is credible because operator actions are expected to stop the pump within a "reasonable" time in the event of a single failure (see Open Item 7 below). The staff questioned this logic because there are potential LPSI pump control or breaker failures that could require more than a simple operator action to secure the pump. In this case, the most limiting single failure may be the failure of a LPSI pump to trip, including operation of the LPSI pump for a duration determined by the pump control system failure mode including the time it takes plant staff to detect and address the failure.

The limiting parameter for a LPSI pump failure-to-stop scenario is the higher flow that is created through the sump and strainer by the additional pump in operation. The additional flow creates higher head losses through the strainer and pump suction piping beyond the current design values, leading to reduced pump NPSH margins. The total flow rate through the sump assuming one LPSI pump failure to trip is estimated to be more than 9000 gpm instead of 6470 gpm for a large break LOCA. It is expected that this flow rate will challenge the NPSH margins for the pumps taking suction from the recirculation sump. A related analytical consideration is increased strainer bypass at the higher flow rates in existence for the duration of LPSI pump operation during the recirculation phase, potentially leading to increased downstream component wear. Another related analytical consideration is increased flow and turbulence from the break location to the strainers, leading to increased debris reaching the strainers. The need for the licensee to provide results of analysis of the potential effects of a LPSI pump failure to stop on a RAS signal is designated **Open Item 7**.

3.6.1.2.2 Sump Water Temperature

It was stated in Reference [57], the containment pressure/temperature analysis, that the sump water temperature was calculated to range from an initial 215 °F down to an eventual 120 °F following a LOCA. This calculation is considered to be a conservative estimate for the sump water temperature immediately following a LOCA because bounding initial conditions are used in the calculation. For example, the heat source and the temperatures are maximized at the start of the event and conservatisms are included to reduce energy removal. The temperature at the beginning of recirculation varies based on many potential variables: the size of the break, the location of the break (affecting the blowdown rate), the temperature of the service water, the number of ECCS and CSS pumps running, the initial temperature of the RWST. Therefore, 212 °F is a good approximation of the maximum sump water temperature.

The ECCS and CS pump NPSH [45] calculations assume a temperature of 212 °F for the NPSH available calculation, which is conservative for maximizing the affect of vapor pressure on pump NPSH. There are two effects which counteract this conservatism at higher temperatures. First, there is a slight increase in static head available due to the higher temperature due to a higher pool height from lower density water. Lower frictional losses from the lower viscosity of water at a higher temperature also tend to increase NPSH available. However, the vapor pressure effect is greater than the static and frictional head increases described above. Therefore, the overall effect of using a higher temperature for the NPSH calculations is conservative.

As described above, for the piping head loss calculation [45], the higher the temperature, the lower the head loss due to lower dynamic viscosity of the fluid. The effect is similar for the strainer head losses so a higher temperature would be non-conservative when calculating head loss. Therefore, the licensee conservatively corrected the strainer debris head loss determined by testing to a lower accident temperature of 120 °F [30, 54, 55, 56] resulting in the maximum expected debris head loss.

Staff Evaluation

The staff reviewed the analysis determining the bounding sump water temperature for the strainer head loss calculation. The staff agrees that the use of 212 °F as the temperature for the NPSH calculation will yield an overall conservative value. The use of the sump water temperature of 212 °F for head loss is conservative because its use, in conjunction with the assumption that the containment is at atmospheric pressure, has the same result as setting the vapor pressure equal to the initial containment (atmospheric) pressure as recommended by RG 1.82. The staff accepts that, as temperature decreases during the event, the change in the vapor pressure term in the NPSH available calculation increases NPSH available faster than the frictional and static head losses decrease the NPSH available. Therefore, the use of 212 °F (a relatively high but representative value early in the event) for the NPSH available calculation, in conjunction with the use of 120 °F for the strainer head loss, is conservative.

3.6.1.2.3 Containment Pool Water Level

The licensee has performed a calculation (Reference [34]) that determines the volume of water transferred to the containment from the RWSP combined with the amount of water available to the sump from 3 out of 4 SITs prior to transfer to recirculation. The licensee assumed that one SIT volume was not available to establish the containment sump level for a large break LOCA as a conservatism. The minimum sump pool water level for a large break LOCA was calculated to be -5.28 ft (or 5.72 feet above the containment floor, which is at elevation -11.00 ft). If the SITs do not inject water, for example in the case of a small break LOCA, the 2664 ft^3 of water from the SITs are not included in the water level calculation. In this case the sump pool water level is calculated to be -5.63 ft. This lower containment sump pool level is 5.37 feet above the containment floor. The strainer design uses the lower level of 5.37 feet above the containment floor. This is conservative from a vortexing and NPSH perspective since the available strainer coverage and head of water to the pumps is minimized.

Since the top of strainer disks are designed to be about 5.0 ft above the containment floor (based on a 52.8 inch tall strainer sitting atop an 8 inch tall plenum) [31], the minimum strainer submergence during a large-break LOCA is about eight inches, and about four inches for a small-break LOCA. The maximum head loss is estimated to be 1.5 ft of water based on the qualification testing and margin added for chemical effects [30]. Therefore, for both large-break and small-break LOCAs, the head loss across the strainer is greater than the minimum strainer submergence. As a consequence, vapor flashing of the sump fluid could occur inside the strainer during the recirculation phase of a LOCA. This issue, and its associated Open Item 12, are discussed further in section 3.6.1.3.3 of this report.

Staff Evaluation

The staff reviewed the analysis determining the minimum containment water level. The use of the lower level (considering that the SITs do not inject) is conservative. The assumption that the reactor cavity drains are plugged is also conservative. However, the calculation did not account for the following: water holdup due to condensation films; water holdup due to spray droplets in containment atmosphere; and refill of the reactor pressure vessel with cold water. Also, the refueling water storage pool (RWSP) water temperature should be assumed at the initial containment temperature to minimize the mass of water injected before recirculation. These issues are documented in Open Item 13 in the Minimum Water Level section of Section 3.6.2.3.3**.** In addition, the staff considered that there is a potential for the refueling cavity drain to become at least partially plugged resulting in additional holdup as documented in Open Item 16 in Section 5.2 of this report.

3.6.1.3 Prototypical Head Loss Testing

The licensee contracted GE to perform the scoping head loss analyses to support the initial design efforts. GE also performed head loss testing based on the selected strainer surface area and the calculated debris loading. GE used both a sector or reduced-scale head loss testing apparatus, and a module or large-scale prototypical head loss test loop. The module testing was done for test cases for which enough debris to form a circumscribed bed was projected. For cases with smaller fibrous loads, sector tests were used.

The module test facility consisted of a testing apparatus, pump, connecting piping, and instrumentation. The 10 inch suction flange on the strainer was reduced to a four inch pipe to match the recirculation pump and magnetic flow meter. The flow from the strainer was routed through the flow meter, the pump, a control valve, and finally back to the return header.

The small-scale sector head loss test loop is shown in Figure 2. The loop consisted of a 1250-gallon tank that was approximately 82 inches in diameter and 4.5 feet deep. For the sector tests the strainer disks were oriented horizontally as in the plant. The bottom of the strainer was located six inches above the tank floor. The center of the top disk terminated in a 12-inch flange that was connected to suction hoses and a pressure transducer. For the flow rates required in these tests, up to two pumps were connected to the test strainer. Each pump had a maximum flow rate of 70 gpm. The pump outlets were connected via piping to a flow meter, control valves and then to the tank through a central flow manifold.

The sector tests were run in two basic modes. Completely stirred tests used agitation to maintain the debris in suspension in an attempt to get all debris onto the test strainer. Partially

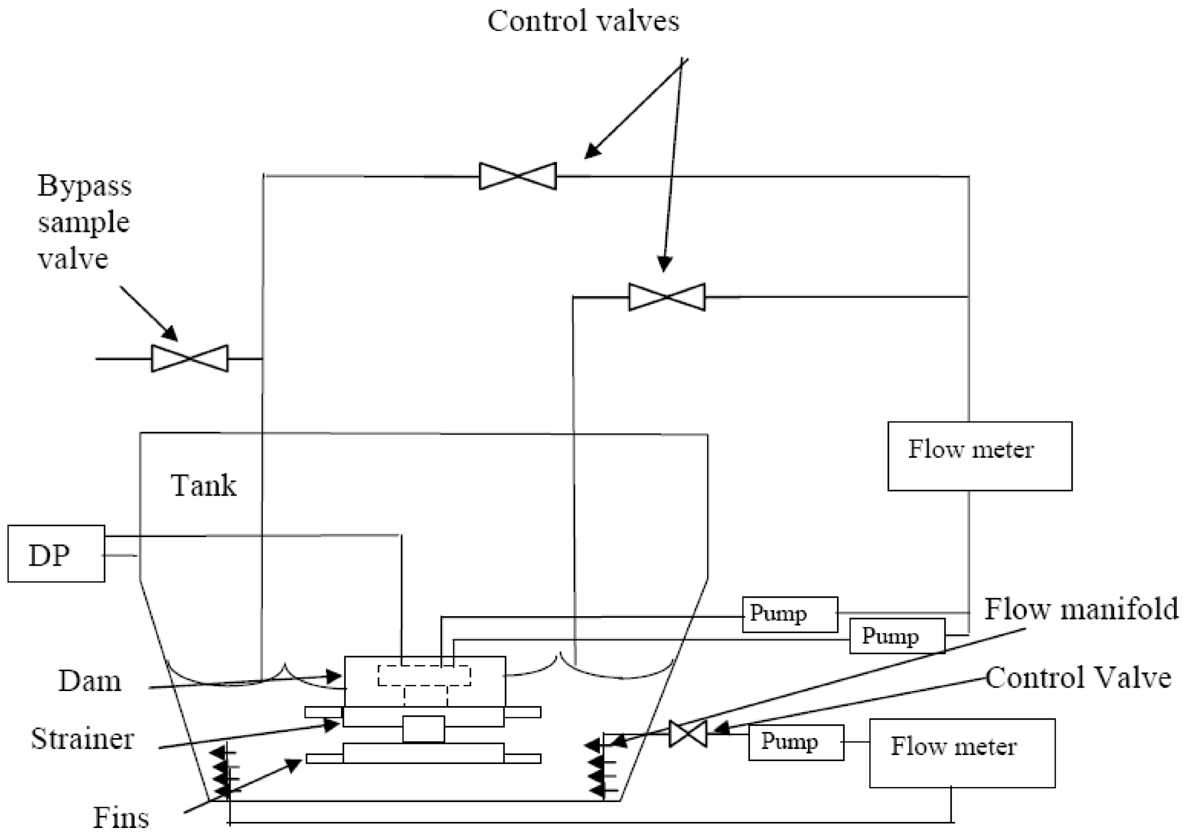

Figure 2 - Sector Head Loss Test Loop

stirred tests did not use agitation, and therefore allowed settling of debris to occur (modeling near field settlement that could occur in the plant). Two variable speed agitators were used to help prevent settling in the test tank for completely stirred tests and to help suspend debris uniformly prior to starting the test strainer flow for partially stirred tests. For all tests, there was a tee in the return line with a valve to allow bypass samples to be taken.

The sector test facility was only used for debris loads that were not predicted to form a circumscribed bed.

3.6.1.3.1 Debris Types, Quantities, and Characteristics

Of the postulated break locations that were analyzed for debris generation and debris transport, breaks S3 and S7 were selected for head loss testing. Break S3 was chosen because it was evaluated to produce the largest amount of fiber and equal amounts of particulate debris when compared to other breaks. Break S7 was chosen because it resulted in turbulence being added to the sump pool and required stirring throughout testing to simulate the turbulence. The maximum fiber debris generation was predicted for Breaks S3 and S6, which would each result in the transportation of 1,016 ft^3 of fine fibrous debris to the strainers. All breaks except S7 were evaluated to have the same predicted coatings debris quantity based on the 5D ZOI for coatings, and all breaks would have the same latent and foreign debris loads. The debris loads specified for head loss testing for Breaks S3 and S7 are shown in Table 10 below. Chemical effects precipitates were not included in the head loss testing because at the time of the testing the chemical loading had not yet been determined. The foreign debris was not added to the test debris loads because the total replacement screen area assumed for testing was conservatively reduced by an area of 151 ft^2 to simulate the accumulation of all foreign debris on the screen. This treatment is considered conservative because the GR/SE guidance allows the use of a sacrificial screen area to accommodate 75 percent of the total foreign material estimated to be in the containment, while the licensee used 100 percent of the total. The tested strainer modules screen surface areas were scaled down from the full 151 ft^2 for testing.

Table 10: Bounding Quantities of Debris for Head Loss Testing

Debris Type	Units	Break S3	Break S7
Nukon® Fiber Blankets	(ft^3)	836	266
Owens-Corning TIW II Fiberglass	(ft^3)	180	0
Min-K	(ft^3)	0.4	0
Microtherm	(ft^3)	4.2	0.6
Qualified Coatings (5D)	(ft^3)	25.1	0
Unqualified Coatings - IOZ	(ft^3)	15.1	15.1
Unqualified Coatings - Other	(ft^3)	18.7	16.3
Latent	lbm	250	
Foreign Materials	(ft^2)	151	

The quantities for the unqualified coatings are somewhat larger than the corresponding quantities estimated in the debris transport evaluation. The rationale for these differences was not provided but because these increases are conservative the unqualified coatings debris loads used in the head loss testing are acceptable. The other debris loads used in the testing were found to be consistent with those predicted to transport to the strainer.

The test program was run in parallel and as part of the design of the strainer for Waterford Unit 3. The amounts of debris used in different tests varied as design parameters changed. The plant strainer size was adjusted based on testing results when testing showed that the sizing of the strainer was inadequate to handle the predicted debris loads. The test module dimensions did not change for subsequent testing. Therefore, to compensate, the scaling parameters were changed to reflect the change in plant strainer area. In addition, the amounts of debris were changed during the testing program as refinements to the ZOIs for various materials were made. These changes were documented in the revisions to the GE test specification [52].

Staff Evaluation

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

The licensee did not compare either the densities or the porosities for the Waterford 3 fibrous materials, which included Nukon® and Owens-Corning fiberglass plant insulations, with the Transco insulation used as a testing surrogate. For past NRC research, it has been accepted that Transco had a similar density to that of Nukon® such that these two materials are basically interchangeable in testing. Per the manufacturers specifications, found on the manufacturer's web site, the Owens-Corning fiberglass insulation used at Waterford 3 has the same density as Nukon. In addition, Transco was contacted by the staff, and Transco provided a density value for their fibrous insulation that is identical to that for Nukon. Therefore the use of the Nukon density for all of the fiberglass insulations and the use of Transco as a surrogate is acceptable.

When scaling the surrogate quantities of particulate matter for testing, the licensee correctly maintained solid volumes whenever the densities differed between the plant material and the surrogate material. Maintaining the volume is important from a head loss testing perspective because it keeps the numerical quantity of the particles the same, and therefore the head losses due to the particulates in the debris bed would be similar to the actual material. Maintaining volume will also maintain the correct number of particles (if particle sizing is also maintained). Size distributions were not provided for Min-K or Microtherm for either the postulated plant debris or the surrogate test debris, but these materials were completely reduced to small fines for testing. Expected size distributions are not available in the GR or SE guidance, so destruction to 100 percent fines is considered appropriate and conservative. It is likely that the actual size distribution during a LOCA would include some larger particulates and pieces that would not contribute to head loss as much as the fines.

The Min-K was supplied to the licensee as a particulate from a Min-K insulation manufacturer, and the Microtherm debris was created mechanically and then sifted through a 0.1 inch-by-0.1 inch mesh. Since these materials were not present in great quantity the small fines and particulate size distributions used by the licensee are considered acceptable.

Table 11: Selection of Surrogate Test Debris

Postulated Plant Debris	Surrogate Material	Justification
Fibrous	Transco Insulation (Density not reported)	Transco is a low-density fiberglass (LDFG) insulation similar to Nukon®
Min-K	Min-K Mix F182 Insulation (Density of 14.5 lbm/ft^3)	Both plant and surrogate debris is manufactured from Min-K insulation
Microtherm	Microtherm Super G Insulation (Density of 14.5 lbm/ft^3)	Both plant and surrogate debris is manufactured from Microtherm insulation.
Qualified Coatings	ElectroCarb® Black Silicon Carbide (Density of 94 lbm/ft^3)	Mean Silicon Carbide particle diameter was 9.5 μm compared to GR recommendation of 10 μm, and particle density of 94 lbm/ft^3 is on par with typical epoxy coatings densities.

Postulated Plant Debris	Surrogate Material	Justification
Unqualified Coatings – Inorganic Zinc (IOZ)	Carbo-Zinc (Density of 211 lbm/ft^3)	Source of particulate was the base ingredient of the IOZ coatings; therefore, particulate would be prototypical of plant IOZ coatings.
Unqualified Coatings – Other	ElectroCarb® Black Silicon Carbide (Density of 94 lbm/ft^3)	Mean Silicon Carbide particle diameter was 9.5 μm compared to GR recommendation of 10 μm, and particle density of 94 lbm/ft^3 is on par with typical epoxy coatings densities.
Latent Fibers	Transco Insulation (Density not reported)	Transco similar to GR-recommended Nukon® insulation
Latent Particulates	ElectroCarb® Black Silicon Carbide(Density of 94 lbm/ft^3)	Silicon carbide particulate conservatively finer and lighter than latent particulate

The fibrous debris, and Min-K, Microtherm and coatings particulates were scaled properly based on the ratio of plant screen area to test sector area for the sector testing. For the large-scale testing, the debris was scaled from the plant strainer circumscribed area to the test module circumscribed area. This is considered acceptable because the module testing was designed for maximum loading, which resulted in a circumscribed bed. The sector testing was designed to test debris loads that are insufficient to form a circumscribed bed.

The use of ElectroCarb® Black Silicon Carbide to simulate coatings debris other than the inorganic zinc (IOZ) coatings is acceptable. The size distribution provided by the licensee is characteristic and perhaps somewhat conservatively low with respect to the GR recommendation and SE-accepted 10 μm particles for coatings particulate. The silicon carbide density of 94-lbm/ft^3 would cause the near field debris settling behavior of the surrogate particulate to be prototypical of non-IOZ particulate coatings debris.

The use of ElectroCarb® Black Silicon Carbide to simulate latent particulate is acceptable because its lighter weight compared to latent dirt would reduce near-field settling and its finer sized particulate would have a greater effect on head loss than would the coarser latent dirt.

The use of Carbo-Zinc for the IOZ coatings debris is acceptable because the source particulate of the Carbo-Zinc was actually the base ingredient for the manufacturing of the IOZ paint. The GR recommendation of 10 μm particles for coatings particulate was based on the assumption that the coatings would break down into the constituent particles. Because the licensee used the actual base ingredient of the coatings for testing, the licensee source material is prototypical.

Only break S2 was predicted to result in the creation of RMI debris. Due to the lack of other types of debris created for this scenario, that break did not have high head loss potential. Due to the low velocities present in the containment pool and at the disk surfaces, RMI debris would not transport to the strainer in significant quantities. RMI debris on the containment floor would not be expected to be forced by flow up onto the strainer in significant quantities. Note that the top surfaces of the strainers are not perforated and therefore any falling RMI would have to move sideways to get onto the active strainer surface. With the very low predicted strainer approach velocities, it is highly unlikely that any RMI would migrate into the gaps, and not credible that a significant amount could block the strainer surfaces. Therefore, the absence of RMI debris in the testing is acceptable.

Conclusion

Ideally, the selection of surrogate materials should be based on the comparison of the bulk and material densities and the fiber diameters to ensure that both the filtration and flow resistance characteristics are conservative. Although the characteristics of the fibrous material were not evaluated by Waterford 3 prior to the testing, information provided later shows that the fibrous surrogate was acceptable. NRC acceptance of the surrogate selections for testing is based on the following:

- The fibrous test debris (Transco) was a relatively close match to the plant debris.
- The particulate surrogate was similar or conservative with respect to the plant debris.
- The Min-K and Microtherm insulation preparation was conservative for likely debris characteristics following a LOCA.

Therefore, the selection of debris surrogates is considered acceptable by the staff.

The amounts of debris used for testing were verified to be correctly scaled from the plant to the test facility. The debris scaling included corrections for the volumetric difference of particulate debris due to differences in density. The scaling for large-scale testing and small-scale testing was appropriate.

Although the debris surrogates were selected properly, there is one issue with debris preparation that could significantly affect the head losses attained during testing. The preparation of the fibrous debris (surrogate materials for low-density fiberglass) was not demonstrated to be fine enough to provide behavior that prototypically represents the debris postulated to occur during the analyzed scenarios. Debris sizing can have a significant effect on transport and debris bed formation, and therefore headloss. The need to ensure that an adequate volume of fibrous debris was reduced to fines is discussed as Open Item 8 listed in Section 3.6.1.3.2 of this report, along with additional details regarding the low-density fiberglass surrogate issue.

3.6.1.3.2 Test Procedures

GE adopted a systematic set of testing procedures for Waterford Unit 3 for the conduct of head loss tests. These procedures address debris preparation, temperature, head loss, flow rate measurement, debris introduction, and test termination. GE conducted both small-scale and large-scale head loss testing. The small-scale tests were referred to as the sector tests (single disks), [24] and the large-scale tests were referred to as the module tests (multiple disks) [53]. The sizing of the Waterford Unit 3 replacement strainer, which was re-designed based on the test data from the sector and module test reports, is documented in [30]. The test loop equipment and different types of tests conducted are described in Section 3.6.3 above. The sector, or small-scale tests, were conducted with debris loads that could not result in a circumscribed bed around the strainer. For loads that could result in a circumscribed bed, the large-scale, or module test facility was used.

The staff reviewed the GE module test plan [53] and noted the following test procedure. Prior to the addition of debris to the test loop, the recirculation pump was started and clean head loss was measured. The recirculation pump was then stopped until the debris was added to the test tank. Water level was controlled during the test. GE used a fibrous insulation that had already been mechanically shredded by the manufacturer. The fiber and particulate debris was added into the test loop and kept suspended by agitation until the recirculation pump was started. After the recirculation pump was started, head loss data was collected. In addition, bypass samples were taken for determination of strainer debris bypass. After it was determined that the test head loss termination criteria had been reached, the recirculation pump was stopped and the tank was drained to allow observartions of the test article.

For the Waterford Unit 3 strainer design, the maximum screen approach velocity, corresponding to 6,470 gpm and 3,699 ft^2 of strainer surface, is 0.0039 ft/s, and the corresponding circumscribed approach velocity for a circumscribed area of 586.7 ft^2 is 0.025 ft/s. Therefore, the flow velocity approaching the Waterford Unit 3 replacement strainers would be substantially slower than the velocities required for lifting such debris as RMI, typical paint chips, or even fibrous shreds from the sump pool floor onto the strainer.

Because it is likely that only fine debris such as individual fibers and particulate can accumulate on the Waterford Unit 3 strainers, the licensee's head loss evaluation should focus on this fine debris accumulation and on how well the test apparatus and procedures simulate the effects of fine debris. The surrogate debris was machine shredded such that only a small portion was prototypical of the Waterford 3 postulated fine fibrous debris. This was established through discussions with the GE onsite representative and GE's testing contractor Continuum Dynamics, Incorporated. The head loss test reports for Waterford also had pictures of post-test debris showing that a significant amount of clumping of shreds had occured, indicative of relatively coarse shredding. Most of the debris was larger and more intact than what would be expected to transport to the strainer in the post-LOCA pool. Because the GE preparation of fibrous debris did not create debris that matched the characteristics of the debris predicted to form in the debris generation and transport analyses, the bed that formed during the testing was likely not prototypical of what would be expected in the plant. The staff was able to determine the size of the fibrous debris by observing photographs of the post-test strainer modules in conjunction with observations of the strainer head loss behavior during testing. The licensee's debris generation and transport analyses demonstrated that the fibrous debris at the strainers would be the very fine debris that would remain suspended given low sump pool velocities. The licensee predicted that all of the larger fibrous debris would either remain on the sump pool floor or accumulate adjacent to the strainer plenum. The lack of appropriate fractions of fine debris resulted in non-prototypical effects on the head loss testing that included: 1) an enhanced near-field settling effect in both the modular tests and the partially stirred sector tests, reducing debris reaching the strainer during testing; 2) a reduced uniformity of the debris accumulation on the test strainer surfaces as observed on post-test photographs of debris accumulation on the strainer surfaces, likely resulting in reduced head losses; and 3) a reduced density of the fiber bed on the strainer surface, likely resulting in reduced head losses for a given amount of fibrous debris.

Related to the issue of fiber preparation method is the reduced potential for formation of a debris thin bed during testing. Most head loss testing attempts to identify whether a thin bed can form because it usually results in the maximum head loss across the strainer. The identification of this debris combination would likely provide the limiting head loss for the strainer. A thin bed creates a high head loss across the strainer due to a combination of fine fiber and particulate debris (including chemical particulates). A typical thin bed has been considered to be about 1/8 inch thick. Formation of a thin bed depends on a relatively uniform accumulation of fibrous debris on the strainer surface. The thin bed fibrous debris filters particulate debris. As more particulate debris is caught in the fiber bed the bed becomes denser and the head loss increases. The increase in head loss results in further bed compaction and better filtration. This process continues until the maximum head loss is attained. Because the Waterford 3 fibrous debris surrogate was not fine enough to represent postulated post-LOCA debris, a fibrous thin bed was not formed on the strainer uniformly to the extent it could be in the plant post-LOCA.

The non-uniform bed formation during Waterford Unit 3 head loss testing was most evident by the sudden drops in head loss that occurred during fully stirred sector testing. The actual phenomena occuring during the sector head loss tests is not known with certainty. However, the staff inferred from Waterford Unit 3 test data showing sudden large head loss drops that the accumulation of shreds within the sector gap may have caused an entrance dam to form and then give way. If this phenomenon occurred, the shreds entered the gap and were no longer influenced by the turbulence from pool stirring, and normal settling corresponding to terminal settling within a calm pool of water would allow the shreds to settle onto the lower gap strainer surface close to the outer perimeter of the disk, forming a dam. Once the dam had built up in the gap at the outer edges of the sector sufficiently to cause a substantial head loss across that dam, the dam debris would give way and be pushed inward with the effect of partially clearing a portion of the strainer surface, thereby resulting in a sudden decrease in measured head loss across the strainer. This inferred behavior may be unique to strainer modules with horizontal strainer plates. The staff concludes that the head loss drop behavior during Waterford 3 sector gap testing was likely not prototypical of Waterford Unit.

The need for the licensee to describe how it has implemented prototypically fine fibrous debris preparation in its head loss testing is designated as **Open Item 8.**

The GE Waterford Unit 3 sector test matrix included Test S7-4S-13.8A that had enough fibrous debris to form a uniform layer of fiber slightly thicker than 1/8 inch. However, presumably due to the damming effect of the larger fibrous pieces, the debris accumulation in this test is believed to have been very non-uniform. The observed head loss drops and post-test debris appearance indicated that a thin bed had not been allowed to form. In fact, many areas of the strainer screen surface observed after tank draindown showed only minor debris accumulation, confirming that a bed had only partially formed. Test S7-2S-40.3 had the next thinnest predicted layer of debris, whereby a uniform layer would have been 0.57 inches thick, which is considerably thicker than the typical thin-bed formation of 1/8 inch (.125 inches). A uniform bed thickness of about 0.18 to 0.25 inches would have had more potential for thin-bed formation, but no such test was conducted by the licensee.

All attempts to test for a thin-bed were based on Break S7 debris loads which include a much smaller portion of particulates, including coatings and problematic insulation particulates, than break S3. According to the guidance provided in the SE, the potential for developing a thin bed should be evaluated regardless of the actual quantities of insulation debris available to form the bed. Additional information provided in the SE shows that higher particulate-to-fiber ratios and the presence of particulate insulations like Min-K and Microtherm result in higher thin bed head losses should a thin bed form. The thin-bed testing for Waterford 3 would have been more appropriately based on a break capable of forming the most particulate debris and most problematic types of particulate debris. In fact, Waterford 3 Break S3 debris loads are more limiting for thin bed formation due to the greater amounts of Min-K, Microtherm, and coatings particulate debris generated from that break. The licensee testing only used the Break S3 debris mix to test circumscribed bed head loss in the large-scale or module test facility. The licensee testing procedures were not adequate to ensure the determination of the peak head losses associated with the potential formation of a thin-bed debris bed because the most problematic debris loading was not tested in a thin bed scenario, and because an adequate range of fibrous insulation thicknesses for thin bed formation were not included in the test program. The need for the licensee to describe and justify how it has conducted adequate testing to determine thin bed peak head losses is designated as **Open Item 9**.

In addition to the non-uniform bed issue, the inadequate destruction of fibrous debris resulted in a larger amount of debris accumulating on the bottom disks of the strainer during the module testing. The accumulation of debris on the lower disks is another example of non-uniform debris accumulation. Had the debris been shredded into truly fine fibers, the accumulation of fibers would have likely been uniform from the top to the bottom of the strainer. If GE had tested with very fine fibrous debris, it is quite likely that higher head losses would have been measured in the fully loaded module tests due to a denser bed and more uniform loading.

The licensee introduced all debris into the test tank prior to operating the test rig recirculation pump. This testing method placed all debris within a few feet of the strainer prior to operating the recirculation system. Following a LOCA, debris would be dispersed throughout containment such that substantial time would be required before the majority of the LOCA-generated and latent debris would accumulate in the sump pool. Once the debris had accumulated in the sump pool, pump operation would be needed to draw the debris toward the strainers. Other debris, such as erosion products, unqualified coatings debris, and chemical effects precipitants, would tend to be generated well after the pumps were started. Therefore, the licensee procedure of introducing all of the debris prior to operating the pumps is not prototypical of the plant LOCA scenario. The problem with this non-prototypical aspect of the GE testing is that the debris, as a concentrated mass, approached the strainer much more rapidly than would be expected in the plant. The rapid approach may have contributed to the early external bridging of the strainer gaps and likely caused a bulkier and lower-density accumulation than would be prototypical of a slower debris introduction of fine debris. The lower density of the debris bed adversely affects particle filtration efficiency.

In addition to causing a bulky bed formation, introduction of an excessively high concentration of debris has been observed to cause excessive agglomeration of fibrous material and particulate and resultant non-prototypical settling of the debris in the test tank near-field. In the fully stirred cases, it is likely that the debris would be resuspended and little to no effect would occur. However, for the partially stirred tests, there may not have been sufficient energy available to resuspend any debris that agglomerated and settled to the floor of the test tank.

The addition of the fibrous debris in a mass close to the test strainer results in two non-prototypical effects as described above. The need for the licensee to provide the results of assessment of the potential for non-prototypical settling and non-prototypical bed formation due to debris agglomeration during partially stirred strainer testing is designated as **Open Item 10.**

The test flume contained tri-sodium phosphate (TSP) basket mockups intended to represent TSP baskets in the plant. The TSP baskets have been permanently relocated in the plant so that they are no longer adjacent to the strainers. Therefore, the TSP baskets should not have been included in the test mockup. At the time of the audit the licensee had not demonstrated that the TSP mockups did not result in non-prototypical blockage near the strainer test module, which would result in a non-conservative reduced amount of debris reaching the strainer. The need for the licensee to describe and justify how it has resolved the potential for non-prototypical flows during module testing due to "solid modeled" TSP baskets located near the strainer modules is designated as **Open Item 11**.

Two of the initial sector (less than circumscribed bed) head loss tests resulted in measured head losses of 16 ft or greater. Both of these tests, Tests S3-1S-15.5A and S7-2S-81, were based on the Revision 0 replacement strainer design, which was substantially smaller in dimension than the final strainer design. In addition, the tests were also based on the 10D ZOI for coatings, rather than the 5D ZOI assumed for the final design. Because of the decreased loading due to increased strainer dimensions and the decreased amount of coating debris, the licensee concluded that the tests did not apply to Waterford Unit 3. In part, the licensee's rationale was that increasing the strainer size not only decreases the per area loading, but reduces the velocity flowing through the debris bed. Both of these changes can significantly reduce head loss.

The licensee's explanation for the high head losses in both tests was a heavy load of particulate embedded within the fiber debris that filled the sector strainer gap. While this explanation could explain the high head losses associated with these tests, the question still exists as to whether such a debris accumulation could occur with the final replacement strainer. For such an accumulation to occur, there needs to be sufficient fibrous debris accumulation to fill the strainer gaps but not enough to quickly build a circumferential accumulation. Once the gaps between the strainer disks are filled, further debris accumulation would be a buildup of particulate debris circumferentially, resulting in a circumferential thin-bed formation. The licensee’s explanation for why a circumferential thin-bed formation could not occur in the plant was that gravitationally driven preferential loading of debris accumulation toward the bottom of the strainer modules would preclude a circumferential thin-bed formation. This explanation is valid if the preferential loading seen in the module testing is prototypical of the replacement strainer. However, as discussed above, if the test debris had been prepared prototypically fine, this preferential loading may have occured to a much reduced degree. While the thin-bed circumscribed accumulation may be difficult to form on a full-sized replacement strainer, it should not be completely dismissed as a concern. Because the resolution of Open Item 8 (non-prototypically fine fibrous debris preparation) and Open Item 10 (non-prototypical bed formation due to debris agglomeration) will result in resolution of this issue for Waterford Unit 3, circumferential thin-bed formation is not considered an additional open item for this audit. However, this phenomenon should be considered as a potential issue at other plants where there is enough fiber to create a circumscribed bed.

The test termination criteria for tests for Waterford Unit 3 early strainer testing were based on the single criterion of head loss increases being less than one percent in ten minutes. For the final tests, the criterion was tightened to one percent in 30 minutes. The test termination criteria did not specify a minimum number of tank water turnovers (complete circulation of the tank volume). For the sector tests, the number of turnovers were 24 for test S7-1S-59.2-CS and 8.5 for test S7-2S-100A-CS. For module test S3-2M-100A-PS, the approximate number of turnovers was 65.

Most of the Waterford Unit 3 testing runs had 15 or more test volume turnovers. For all test runs the head loss appeared to be asymptotically approaching a maximum, even for the test run which was concluded at 8.5 test volume turnovers. Therefore, the staff considered Waterford Unit 3 testing termination criteria to be adequate.

3.6.1.3.3 Maximum Head Loss and Strainer Submergence

During the audit of the Waterford Unit 3 strainer design, the NRC determined that the maximum head loss across the strainer was greater than the strainer submergence (see Section 3.6.1.2.3 of this report). The licensee and its vendors had not considered the potential consequences of the strainer head loss being greater than its submergence. In such a situation, with fluid in the strainer at or near saturation temperature, flashing or steam voiding may occur within the debris bed or internal to the strainer. The flashing can result in additional head loss across the debris bed due to two-phase flow. In addition, the vapor could change the fluid flow characteristics internal to the strainer and possibly to the ECCS and CSS pumps. The need for the licensee to provide the results of evaluation of the potential for and effects of vapor flashing due to strainer head loss being greater than the strainer submergence is designated as **Open Item 12.**

3.6.1.3.4 Scaling Methodology

The GE reduced-scale sector head loss test [24] represented one strainer gap, while the large-scale test [31] had ten full-size strainer disks. The plant modules have 17 disks. During the testing, the debris was introduced into the flumes uniformly. GE scaled the sector (small-scale) debris loading based on the ratio between the total testing sector strainer area and the plant surface area. The sector tests were designed to test cases that would not completely fill the strainer gaps with debris. For the module (large-scale) testing, circumscribed area was used because the module testing was designed to test for a fully-loaded circumscribed bed of debris. A circumscribed bed is one that fills the strainer gaps with debris and fully engulfs the strainer screen "module" (in the test case, a 10 disk portion of a module) with debris. The screen approach velocity was scaled one to one, again using perforated plate area for sector testing and circumscribed area for module testing.

The GE head loss testing used the appropriate strainer area (screen and circumscribed) to scale the debris loading. Sacrificial screen area was proportionately subtracted out for miscellaneous debris such as tags, tape, etc. The screen circumscribed approach velocity was maintained for the module (large-scale) tests. The sector (small-scale) tests used perforated plate flow velocity for scaling. The module testing was designed to test circumscribed bed head loss, and sector testing was designed to test for cases where the strainer gap was not filled. The test configuration and equipment were adequate, depending on the test being run, to prototypically or conservatively model flow through the strainer. Based on the above, the scaling methodology for flow velocities and debris is considered acceptable.

3.6.1.3.5 Test Results and Interpretation

The final qualification of the replacement strainer was based on one large-scale circumscribed bed case, one small-scale partial load case, and one small-scale full load head loss case. Table 12 below lists the results and the comparison with the relevant reduced-scale head loss test results.

Table 12: Large-Scale Head Loss Tests Results

Debris Loading	Test Type & ID	Head Loss (inches of water)[1]
Partial Load (Table 5-2 of [24])	Reduced Scale Test S7-1S-59.2-CS	9.5
Full Load (Table 5-2 of [24])	Reduced Scale Test S7-2S-100A-CS	10.6
(Table 5-2 of [53])	Large Scale Test S3-2M-100A-PS	8.6

[1] The head loss is the tested module head loss (debris plus scaled clean strainer head loss) plus the calculated module exit head loss (defined in Section 3.6.1.4 below) plus the calculated plenum loss.

The licensee concluded that the maximum measured debris head loss is 10.6 inches at the test temperature of 93 ^{o}F. The test results were scaled to the design temperature.

Because all of the test series were performed around the design basis flow rate and at room temperature, and the strainer design target temperature is 120 ^{o}F, GE used a viscosity-based extrapolation scheme to determine the corrected head loss. It was determined that the maximum debris head loss is 0.605 feet of water when corrected to 120 ^{o}F.

Staff Evaluation

Not considering potential chemical effects, GE used an extrapolation scheme based on Darcy's Law to predict the maximum debris bed head loss at 120 ^{o}F. The major correction required is for the temperature effect of viscosity. Because the scaled flow rate is very close to the plant strainer flow rate and is very low, the flow regime is always laminar. A similar extrapolation methodology has been used by most strainer vendors and is considered acceptable.

3.6.1.4 Clean Strainer Head Loss

In order to maximize the strainer surface area in the available space of the Waterford 3 containment, eleven strainer modules were connected to the pump intakes via a plenum, as shown in Figure 3. Six of the strainer modules are situated directly over the sump. Two modules are beside the sump toward the center of the containment, and three modules are located in a line to the side of the sump. The three modules located to the side are connected via a single plenum.

The total strainer head loss is the summation of the clean strainer head loss and the debris bed head loss. The licensee calculated the clean strainer head losses using industry standard, widely accepted methods for flow in pipes and ducts. The total head loss was considered to be the plenum head loss added to the strainer module internal head loss and the module exit loss. The module exit loss is the head loss when the flow exits the circular cross-section of the interior of the strainer module and enters the larger rectangular plenum. Since the flow inside the strainer and plenum is in the turbulent regime, the calculated total head loss was practically independent of temperature.

The total plenum head loss for the most remote module was calculated to be 0.41 ft at temperature of 120 ^{o}F. This plenum head loss was applied to all modules, although the plenum losses for other modules would certainly be lower. During the onsite portion of the audit the licensee stated that the conservatism associated with this approach may need to be reduced when chemical effects are considered. The head loss calculation for the plenum is located in Appendix B of Ref. [30].

The internal clean strainer head loss was measured during testing. The measured value was then adjusted to account for instrument uncertainty in the head loss measurement. The head loss was then scaled to a full module size (17 disks) using industry accepted hydraulic methods. The scaling was completed in each of the scaling reports, Ref. [54, 55, 56]. The internal clean strainer losses determined in the scaling reports were also added to the debris head losses for reporting purposes.

Staff Evaluation

Because an industry standard flow resistance calculation evaluation for pipes and ducts was used to calculate the strainer internal head losses, the methodology is considered acceptable. Appropriate conservatism was added to the analysis for consideration of instrument uncertainty. The application of the maximum plenum head loss to all strainer modules is certainly conservative. Based on the above, the staff found the clean strainer head loss determination to be acceptable.

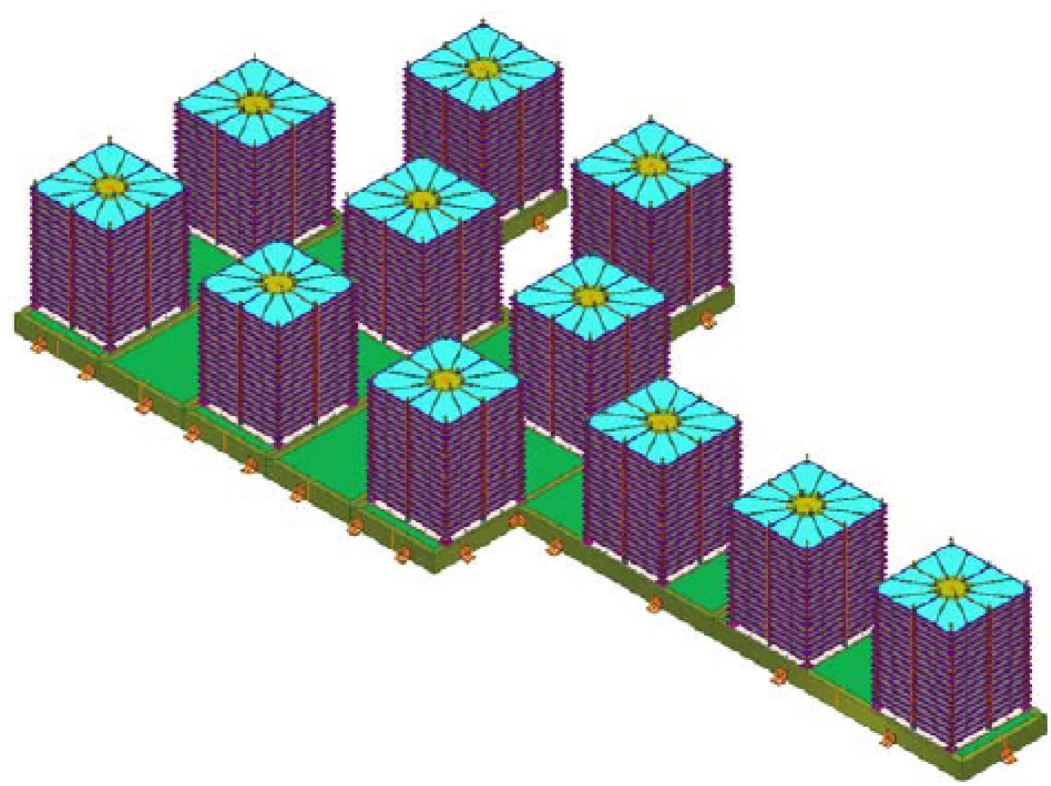

Figure 3 - Waterford 3 Strainer Array

3.6.1.5 Vortex Evaluation

In response to NRC's RAI [58] 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 testing program. As part of the large-scale strainer module head loss testing and small-scale sector testing, the licensee conducted observations for vortexing. No vortex formation was observed during the module tests. However, during sector testing, prior to debris addition, with scaled flows at about 200 percent of the expected maximum actual flow, pre-vortex formations were observed. The formation was a surface depression. No air was ingested into the strainer.

Staff Evaluation

The licensee performed large-scale module tests and small-scale sector tests to evaluate the possibility of vortex formation on top of the strainer array. No vortex formations were noted during testing with scaled flow rates and strainer submergence at design values. With flows at double the scaled plant maximum flow rate, pre-vortex formations were noted but no air ingestion occurred. The staff finds the licensee's methods for identifying the potential for vortex formation to be acceptable.

3.6.2 Net Positive Suction Head Margin

3.6.2.1 Net Positive Suction Head Audit Scope

The licensee performed net positive suction head (NPSH) margin calculations for pumps credited with taking suction from the containment recirculation sump to provide long-term recirculation cooling to the reactor core and containment building following postulated accidents. At Waterford 3 these recirculation pumps are the High-Pressure Safety Injection (HPSI) pumps and the Containment Spray (CS) pumps. Low-Pressure Safety Injection (LPSI) pumps are secured at switchover to recirculation.

The staff reviewed the significant models and assumptions of the licensee's NPSH calculations and discussed these calculations with licensee personnel during the audit. The staff's review used guidance provided by NRC Regulatory Guide (RG) 1.82 [5], NRC Generic Letter 97-04 [4], the NRC Audit Plan [6], Nuclear Energy Institute (NEI) 04-07 [1], and the NRC Safety Evaluation Report on NEI 04-07 [2].

3.6.2.2 ECCS and CS Configurations in Recirculation Mode

The Waterford 3 Safety Injection System (SIS) includes two independent, parallel, trains of HPSI and LPSI pumps that inject and/or recirculate water into the Reactor Coolant System (RCS), and two Containment Spray System pumps. A third HPSI pump (HPSI A/B) serves as an installed spare that is used when a HPSI pump is out for maintenance. At the start of a LOCA all pumps take suction from the Refueling Water Storage Pool (RWSP) (during injection mode of operation). Additionally, four Safety Injection Tanks (SITs) would automatically discharge and flood the core following depressurization of the RCS below the SIT tank pressures [44, p. 6.3-1].

When low water level signals indicate that the RWSP water level is down to 10 percent, a recirculation activation signal is generated. As a result of this signal, the suction of all pumps

(CS, LPSI, HPSI) is swapped from the RWSP to the SIS sump (hereafter termed the "recirculation sump"). The recirculation sump consists of a single volume in which a low flow-resistance, vertically-oriented, divider plate (a floor grating) is placed to create two complete, but not independent, volumes from which flow is taken to the two SIS pump trains. LPSI pump operation is normally automatically terminated upon a recirculation activation signal. As a result, normally only the HPSI and CS pumps are realigned to take suction from the recirculation sump. However, it is improbable, but conceivable, that an LPSI pump may fail to automatically trip upon the recirculation actuation signal, and that a LPSI pump could therefore take suction from the recirculation sump at the commencement of recirculation. This possibility was identified as Open Item 7 in Section 3.6.1.2.1.

3.6.2.3 NPSH of the ECCS and CS Pumps

3.6.2.3.1 Summary Presentation of NPSH Results

The licensee performed NPSH calculations for the HPSI and CS pumps using a model and input parameters that the licensee considered to be conservative and applicable to both a large-break loss-of-coolant accident (LBLOCA) and a small-break loss-of-coolant accident (SBLOCA) [45]. The NPSH results are presented in Table 13 below, and are applicable for both large- and small-break LOCA conditions (NPSH Available is "NPSHa", and NPSH Required is "NPSHr" in Table 13).

Table 13: Assumed Operating Conditions and NPSH Margin Results for Waterford 3 HPSI and CS Pumps

Pump	Sump Water Temperature (°F)	Pump Flow Rate (gpm)	NPSHa[1] (ft)	NPSHr (ft)	NPSH Margin[2] (ft)
HPSI A	212	985	22.553	19.253	3.301
HPSI A/B (in A train)	212	985	21.697	18.894	2.803
HPSI B	212	985	22.605	21.765	0.840
HPSI A/B (in B train)	212	985	21.728	18.894	2.833
CS A	212	2250	24.830	18.453	6.377
CS B	212	2250	24.861	18.629	6.232

[1]NPSHa does not include screen and debris head losses which total 0.513 ft for all cases.

[2]NPSH Margin does not include screen and debris head losses which total 0.513 ft for all cases.

The results for NPSHa and NPSH Margin shown in Table 13 do not include the hydraulic losses attributable to the sump screen and debris bed. However, the licensee's results for NPSHa and NPSH Margin presented in [45, p.2] included the hydraulic losses of the sump screen and debris bed. The staff recalculated both the NPSHa and NPSH Margin to remove the losses due to the sump screen and debris bed losses. Additionally, the licensee presented the NPSH

Margin in units of “%” of the NPSHr. The staff converted the NPSH Margin values in Table 13 into the more standard units of feet (“ft”) of head.

The NPSH Margins presented in Table 13 are all greater than the combined head losses of the sump screen and debris bed, which the licensee calculates as 0.513 ft [45]. As shown in Table 13, the minimum NPSH Margin calculated by the licensee is for the HPSI B pump, with a computed NPSH Margin of 0.84 ft. Therefore the actual NPSH Margin for the HPSI B pump is 0.327 ft of head.

The major reason for the difference in margin between the three HPSI pumps is that the as-manufactured measured NPSHr for the HPSI B pump is larger than for the other two HPSI pumps.

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

3.6.2.3.2 Summary of the NPSH Margin Calculation Methodology

The definition of NPSH margin from Regulatory Guide (RG) 1.82 [5] is the difference between the NPSH available (NPSHa) and NPSH required (NPSHr). RG 1.82 defines NPSHa as the total suction head of liquid, determined at the first stage impeller, less the absolute vapor pressure of the liquid. RG 1.82 defines NPSHr as the amount of suction head, over vapor pressure, required to prevent more than 3% loss in total head of the first stage of the pump at a specific capacity (due to factors such as cavitation and the release of dissolved gas). For convenience, NPSH values are generally reported as pressure heads, in units of feet of water.

In general, the NPSHa is computed as the difference between the containment atmosphere pressure at the pump inlet and the vapor pressure of the water at its assumed temperature, plus the height of water from the surface of the containment pool to the pump inlet centerline, minus the hydraulic losses for the flow path from the flow inlet at the containment floor to the pump inlet nozzle (not including the head loss contribution from the sump strainer and debris bed).

The licensee conservatively assumed that the containment pressure is equal to the sump water vapor pressure (ignoring air pressure in containment). As a result, the NPSHa is represented simply by the difference between the height of the water column above the pump centerline and the hydraulic friction losses because the NPSHa calculation terms for containment pressure and sump water vapor pressure cancel.

The height of water from the surface of the containment pool to the pump inlet centerline was obtained by the licensee from a combination of plant isometric drawings and calculations of minimum water level on the containment floor. This calculation approach is standard U.S. industry practice, and is therefore considered acceptable.

The licensee used the pump manufacturer’s data for the NPSHr. This is discussed further in Section 3.6.2.3.3 below.

The licensee computed hydraulic piping losses using Pipe-Flo, a piping fluid analysis software package [46], a single phase fluid hydraulics methodology. This piping network software is a standard engineering tool and is similar to the Crane methodology [47], a tool widely used in the United States. Therefore, its use for the hydraulic piping network flow calculations is considered acceptable.

The staff concluded that U.S. industry standard definitions and standard practice calculation methodologies associated with NPSH margin analysis were used in the licensee's calculations, and are acceptable. See the NPSH Required and the Hot Fluid Correction Factor section of Section 3.6.2.3.3 below for a significant exception relating to using the pump manufacturer's data for the NPSHr of the ECCS pumps.

3.6.2.3.3 Consideration of Main Parameters Influencing the NPSH Margin

Main parameters potentially influencing pump NPSH margins are the water height from sump pool surface to pump inlet nozzle centerline, sump water temperature, containment atmosphere temperature, pump flow rates, containment pressure, pump NPSHr values and the hot fluid correction factor, piping network hydraulic losses, and decay heat. These parameters are discussed below.

Minimum Water Level

The water level of interest to the NPSHA calculation is the minimum static height of liquid as measured from each HPSI and CS pump suction centerline from the surface of the pool in containment. The HPSI pump suction centerlines are at a plant elevation of -30.6 ft [44, p. 6.3-8; 7, p. 3]. The CS pump suction centerlines are at a plant elevation of -32.50 ft [45, p. 4].

The sources of water available to form a pool in the containment building are the RWSP, the SITs and spillage from the break in the Reactor Cooling System. Waterford Unit 3 conservatively assumed that the only source of water is the volume of water available in the RWSP [34, p. 2].

While the FSAR indicates that the RWSP contains a volume of 548,016 gallons of water [44, Table 6.3-5A], Waterford Unit 3 conservatively assumes only 383,000 gallons of water would have been injected into the primary system when the switchover to recirculation is signaled as a result of a 10 percent level indication of the RWSP. The availability of a water volume of 383,000 gallons is assured by surveillance activities that require confirmation of a minimum indicated RWSP water level of 83 percent [48], which includes the calibration of volume vs. percent of reading, and added margin [49].

The minimum sump water level was computed by using the volume of water available and accounting for fill-up of sump cavities and tunnels in containment, and fill-up at the containment floor accounting for the displacement of water caused by the presence of structures of various types, including the irregular shape of the containment boundary. The licensee correctly included several mechanisms that would be responsible for preventing volumes of water from flowing to the containment pool, thereby limiting the water level. These include retention of water in the normally dry containment spray header, and retention of water as vapor in the containment atmosphere. The minimum water level was computed by the licensee to be at a plant elevation of -5.63 feet of water [34, p.1].

However, the staff found that certain water holdup mechanisms were not modeled in the analysis of minimum containment pool water level: (1) water holdup due to condensation films; (2) water holdup due to spray droplet holdup in the containment atmosphere (as opposed to water vapor holdup in the containment atmosphere); and (3) refill of the reactor pressure vessel with colder and therefore denser water. Further, in that analysis (4) the RWSP water temperature should have been specified to be at the warmer normal operating containment temperature, reducing (as a result of reduced liquid density) the mass of water available from the RWSP to raise the containment pool water level. Neglecting these mechanisms is non-conservative because their inclusion in the analysis would tend to decrease the minimum water level and would therefore decrease the calculated NPSH margins. The licensee should explain how the four water holdup mechanisms are modeled in the analysis of minimum containment pool water level. The need to address these four omitted mechanisms in the Waterford 3 minimum water level calculation, or justify why they were not modeled, is designated as **Open Item 13**.

An additional potential holdup mechanism may be caused by insulation debris being blown to, and resulting in blockage of, the drains of the refueling canal. This holdup mechanism is discussed in Section 5.2 of this report in connection with Open Item 16.

Decay Heat

RG 1.82, Revision 3 [5], Section 1.3.1.4, states that, "The decay and residual heat produced following accident initiation should be included in the determination of the [sump pool] water temperature. The uncertainty in the determination of the decay heat should be included in this calculation..." The licensee provided containment calculations that include prediction of containment atmosphere pressure and temperature, and sump water temperature [50]. Decay heating was modeled in the GOTHIC computer code. However, a detailed review of the assumptions governing the decay heat model was beyond the scope of the staff's audit.

Sump Water Temperature

The Waterford Unit 3 large break LOCA calculations show that recirculation begins at approximately 3250 seconds following the break, at which time the containment pressure is 47 psia, the sump water temperature is 160 ^{0}F and the containment atmosphere temperature is 248 ^{0}F [50]. The sump water temperature increases, reaches a peak temperature of approximately 215 ^{0}F at about 40,000 seconds, then decreases steadily thereafter.

For the purpose of computing the static level of liquid in containment, the sump water temperature was conservatively assumed to be 60 ^{0}F by the licensee. This value minimizes the static level of liquid [34, p. 16] and, therefore, is conservative.

For the purpose of calculating the hydraulic head loss, a value of 212 ^{0}F was assumed. This choice is non-conservative, since it decreases the kinematic viscosity and decreases the hydraulic head losses in the system, resulting in a calculated increase in both NPSHa and NPSH Margin. However, the licensee stated that at 212 ^{0}F the sump water vapor pressure equals the initial containment atmosphere pressure and, therefore, no credit is taken for the effect of containment (steam) overpressure on the NPSH Margin. The licensee stated that if a lower temperature were assumed, the vapor pressure of the sump water would be below atmospheric and NPSH Margin credit could be taken for this difference. From this point of view the licensee concluded that 212 ^{0}F is a conservative temperature.

The licensee assumption of 212 ^{0}F rather than some lower temperature results in a modest overestimation of the NPSHa. Although by itself this fact suggests that a lower sump water temperature would be more appropriate for the hydraulic head loss contribution to the NPSHa calculation, the licensee’s calculation conservatively assumed that the pressure at the surface of the containment pool is equal to the vapor pressure of the sump water at its assumed temperature. As a result of the significant conservatism inherent in this assumption, the staff considered the use of a sump temperature of 212 ^{0}F to be appropriate for Waterford Unit 3 in that it results in an NPSH calculation that is conservative overall.

Containment Atmosphere Temperature

The containment atmosphere temperature is taken by the licensee as 260 ^{0}F for the purpose of calculating the mass of steam in the containment atmosphere that is unavailable to condense and add water to the sump. This assumed containment temperature is conservative with respect to the calculated [50] containment atmosphere temperature at switchover to recirculation of 248 ^{0}F since the vapor density is higher at elevated temperature. The resulting mass of water in the sump is reduced compared with a lower containment atmosphere temperature, and the minimum static head for the NPSH calculation is therefore conservatively reduced.

Pump Flow Rates

The pump flow rates presented above in Table 13 are the run-out (maximum) flow rates [44, Table 6.3-2] for the HPSI and CS pumps. Since these are the maximum flows to be obtained from these pumps, they are considered conservative because they lead to the highest hydraulic head losses and the maximum NPSHr. These flowrates are therefore considered acceptable.

Containment Pressure

The NPSHa calculations were performed with assumptions regarding containment pressure that are in accordance with Regulatory Guide (RG) 1.82 [5]. The pressure at the surface of the containment pool was taken to be equal to the saturation pressure of the sump water at its assumed temperature. Therefore, the NPSH margin calculation did not credit any contribution to the NPSHa resulting from the difference between the containment pressure resulting from the LOCA-generated steam atmosphere and the sump water vapor pressure. As a result, the calculated NPSHa, due to cancellation of the containment pressure term and the vapor pressure term at the pump suction, reduced to the difference between the hydrostatic head of liquid above the pump centerline and the fluid head loss in the suction piping. The staff considers the licensee's assumptions regarding containment pressure to be conservative due to neglect of elevated containment pressure following a LOCA.

NPSH Required and the Hot Fluid Correction Factor

The NPSHr specification for the pumps was presented in the form of graphs from the pump manufacturer [45]. The licensee used these graphs and performed a least squares analysis on data taken from the curves. The NPSHr for the HPSI and CS pumps were computed from the least squares fit curves at the pump's respective runout flow rates.

Regulatory Guide (RG) 1.82 [5], Section 1.3.1.5, provides guidance that for NPSH margin calculations, a hot fluid correction factor should not be used to scale the value of NPSHr determined with room temperature fluid to a reduced value based upon the applicable post-accident fluid temperature. Neglecting the hot fluid correction factor is conservative, and the staff confirmed that this factor was appropriately not used in the licensee's NPSH margin calculations.

Piping Network Head Loss

The hydraulic suction piping losses were computed using a single-phase hydraulics computer code, Pipe-Flo [46]. A schematic diagram of the Pipe-Flo hydraulic model of the Waterford Unit 3 ECCS is presented in [45]. The Pipe-Flo code is an industry standard for hydraulics calculations, and is similar to the widely used Crane methodology [47]. Given the assumed flow rates and fluid density, the pressure drops along each segment and across each component are calculated, and the fluid head loss from the containment pool surface to each pump is computed. The assumed temperature was 212 ^{0}F and the runout flow rates presented in Table 13 were used. Identical assumptions were made for performing the head loss calculations for both the SBLOCA and the LBLOCA. This is reasonable, since the flow rates were assumed to be the runout flow rates, which are a function of the pump design characteristics and not the operating conditions.

As discussed above (in the section titled “Sump Water Temperature”), the hydraulic head loss is somewhat underestimated by the choice of 212 ^{0}F as the sump water temperature. This effect, however, is a modest one compared with the conservative assumption of neglecting the effect of vapor pressure on the NPSHa and NPSH Margin and is therefore acceptable.

3.7 Coatings Evaluation

3.7.1 Coatings Zone of Influence

As stated in the NRC SE, for protective coatings, the staff position is that the licensees should use a coatings ZOI spherical equivalent determined by plant-specific analysis, based on experimental data that correlate to plant materials over the range of temperatures and pressures of concern, or a default value of 10 length/diameter (L/D). The licensee applied a coatings ZOI with an equivalent radius of 5 L/D based on jet impingement testing conducted by Westinghouse. The test data referenced by the licensee is documented in the Westinghouse Report WCAP-16568-P, “Jet Impingement Testing to Determine the Zone of Influence (ZOI) for DBA-Qualified/Acceptable Coatings.” The staff has reviewed WCAP-16568-P and determined that its application in the Waterford 3 analyses is acceptable. Inside the ZOI, 100% of the qualified coatings were assumed to fail as pigment sized particles (10 μm). The staff finds the licensee’s treatment of the ZOI for coatings acceptable.

3.7.2 Coatings Debris Characteristics

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 percent 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.

For degraded qualified coatings, Waterford Unit 3 used data from Savannah River test report WSRC-2001-0067, which was sponsored by the NRC Office of Research, to establish a size distribution for the debris. The use of plant-specific test data to justify coatings debris size is accepted by the NRC staff’s SE. The specific testing referenced by Waterford Unit 3 was performed on the Carboline Phenoline 305 and CarboZinc 11 coating system. This is the same coating system used at Waterford Unit 3. Therefore, the staff finds that it is reasonable for the licensee to use the Savannah river test data to establish a size distribution for their degraded qualified coatings at Waterford Unit 3.

Waterford Unit 3 treats all of the inorganic zinc primer associated with degraded qualified coatings as fine particulate. Degraded qualified epoxy coatings are treated as six percent fine particulate. The remainder of the degraded qualified coatings are treated as larger particles or chips of varying size, based on the Savannah River data.

As a conservatism, the licensee assumed 100 percent failure of the qualified coatings above the polar crane. These coatings are treated as degraded qualified coatings because they are inaccessible for a thorough examination or remediation. Although it is unlikely that 100 percent of the coatings are degraded and will fail, because a complete assessment of these coatings is not possible without erecting scaffolding, the licensee assumed that they fail. The staff finds this to be a conservative and acceptable assumption for the debris generation calculation.

The licensee assumed that the debris characteristics for the unqualified coatings are the same as for qualified coatings. The test data cited to justify the qualified coatings debris characteristics is specific to Carboline Phenoline 305 coating, which will perform differently than the various unqualified coatings in the Waterford 3 containment. The final Waterford 3 coatings analysis should treat the unqualified debris per the SE (particulate), justify treatment in the same manner as the degraded qualified coatings, or make use of available data for unqualified coatings debris characteristics. The need for the licensee to justify treating unqualified coatings debris characteristics in the same manner as for qualified coatings is designated as **Open Item 14**.

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 prove that their assessment techniques can accurately identify the amount of degraded qualified coatings in containment, or assume all of the coatings fail. In response to the staff concerns, EPRI sponsored a project (see EPRI Report No. 1014883 July 2007) to collect coating adhesion data for coating systems applied in the containments of operating U.S. nuclear power plants to provide confirmatory support for coating inspection methods that rely upon visual inspection as an initial step. Waterford 3 voluntarily participated in this testing effort and provided valuable data to the report. The staff has reviewed this report and determined that it provides adequate supporting evidence that the containment coatings monitoring approach contained in ASTM D-5163, as implemented by licensees, and endorsed by USNRC in Regulatory Guide 1.54, Rev.1, and NUREG 1801, Vol. 2, Appendix XI.S8, is valid.

4.0 DESIGN AND ADMINISTRATIVE CONTROLS

4.1 Debris Source Term

Section 5.1 of NEI 04-07 [1] and the NRC staff's accompanying safety evaluation (SE) [2] discusses five categories of design and operational refinements associated with the debris source term considered in the sump performance analysis.

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

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

4.1.1 Housekeeping and Foreign Material Exclusion Programs

The staff reviewed Waterford Unit 3 procedures for inspection of containment [59]; an excerpt from the plant nuclear management manual regarding development of engineering changes [60]; procedures for housekeeping [61]; a design control summary [62]; qualified and unqualified coatings management directives [64, 65] and a procedure for labeling systems and components [66]. These plant documents provide administrative controls to ensure that the debris source term affecting the recirculation sump following a LOCA is bounded by the existing analysis. Based upon the administrative controls for plant modifications and containment materials listed above, the licensee indicated that materials introduced into the Reactor Building as part of the plant modification process (e.g., insulation materials, equipment signs and tags) would be reviewed to ensure that adverse interactions with the emergency sump would not occur.

Consistent with the information provided in the 60-day response to NRC Bulletin 2003-01, the licensee implemented a proceduralized containment building closeout process to minimize the amount of loose debris (rags, trash, plastic, wood, scaffolding, clothing, etc.) present in containment following an outage that could be transported to the ECCS Sump and cause restriction of pump suctions during LOCA conditions. Items authorized to remain in containment during power operations are verified to be in their evaluated locations. A site procedure is used to verify that the containment building is ready for heat-up and power operations. This procedure meets technical specification surveillance requirements and commitments for containment inspection requirements. Once the containment building is ready for closeout, operations personnel inspect containment for any loose debris in an effort to ensure no loose debris remains which could be transported to the ECCS sump.

The licensee proceduralized the Foreign Material Exclusion (FME) Program to prevent inadvertent introduction of foreign materials into plant systems and components. The highest order of FME is applied to the ECCS sump and refueling cavity. If during an outage the ECCS sump or refueling cavity are accessed, foreign material exclusion controls are implemented, and items taken into and out of the these areas are logged. Furthermore, any work or activity performed in containment on or near an open structure, system, or component includes appropriate FME controls. As part of the coating inspections performed every refueling outage, the concrete floors and walls, and structural steel members, surrounding the ECCS sump on each elevation are inspected. Failed coatings that could become dislodged and fall in the vicinity of the ECCS sump are repaired prior to start-up. Provisions are in place, per site procedures, to maintain the post-outage conditions should a containment building entry be required while at power or during a brief forced outage. In these cases, the responsible groups for the containment entry verify that the areas of the containment building affected by the entry have no loose debris present which could be transported to the ECCS sump.

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

4.1.2 Change-Out of Insulation

The licensee has not committed to change-out insulation in order to reduce the debris source term as a corrective action in response to GL 2004-02.

4.1.3 Modification of Existing Insulation

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

4.1.4 Modification of Other Equipment or Systems

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

4.1.5 Modification or Improvement of Coatings Program

The licensee is implementing changes in coatings procedures consistent with the Waterford Unit 3 September 2005 GL 2004-02 response. The licensee provided the staff the procedures with the proposed modifications, and the staff found the intended changes to represent marked improvements over the procedures in the current coatings program. Modifications to the coatings management and containment cleanliness procedure [61,65] were made to ensure potential debris sources are minimized. The licensee added refined procedures for both (1) the tracking and quantification of unqualified coatings, and (2) the engineering inspection of the reactor building protective coatings. The staff reviewed the proposed coatings procedures changes and found them to represent appropriate improvements.

4.2 Screen Modification Package

The licensee performed a 10 CFR 50.59 evaluation of the safety impacts of the emergency sump. The licensee concluded that the design change does not adversely impact sump design functions as stated in the Updated Final Safety Analysis (UFSAR). Specifically, the 10 CFR 50.59 evaluation addressed the following points:

- The original rectangular, box-like recirculation sump screen on the sump inlet was removed and replaced with eleven modular stacked disk assemblies, each with an eight-inch plenum.

- The sump low level switch (SI-ILS-6706) was relocated to the top of the plenum. This relocation was seismically designed, and it does not change the original function or elevation of the device. The recirculation sump level transmitters (SI-ILT-7145A and SI-ILT-7145B) were temporarily removed to allow for installation of the new strainers and then returned to their existing mountings. Their design function did not change.

- The new sump screen necessitated the relocation of 19 of the 33 total trisodium phosphate (TSP) baskets from their original locations to the northeast and northwest areas of the containment. This move will prevent the baskets' interference with the new strainer function in accident conditions. The baskets will remain at the same elevation in the plant, and the local flow in the new locations will maintain the capacity for dissolution such that the post-accident sump water pH will be greater than or equal to 7.0 as originally evaluated.

- The replacement strainer hole size is 0.09375 inches, where the original size was 0.078 inches.

- The containment floor was found to be structurally adequate for the additional load imposed by the replacement strainers and plenum.

- The trash racks for the recirculation sump are considered to be the floor grating at the -four foot elevation in containment. No modifications were performed to this grating. There are no large pieces of debris which can be reasonably postulated to transport through the trash racks to the new strainers. Neither are there LOCA-generated missiles which can be reasonably postulated to penetrate these trashracks. Visual inspection is performed every refueling outage to detect any mechanical damage to or degradation of the grating-design trash racks.

The change to a larger strainer whole size is non-conservative in terms of downstream plugging and wear, but the effects from an increase in strainer bypass particle size are considered in Section 5.3.1 and Section 5.3.2 of this audit report to the extent that licensee downstream analyses are complete.

Staff Evaluation

The NRC staff reviewed the licensee's 10 CFR 50.59 screening evaluation of its sump modification. The staff noted that the 10 CFR 50.59 evaluation showed no change in the licensing basis of the plant. The licensee concluded that no change to technical specifications incorporated in the license would be required, and that no aspect of the change met the criteria of 10 CFR 50.59 (c) (2). All planned modifications maintained the original design functions of the recirculation sump components. In summary, the staff identified no concerns with the licensee's 10 CFR 50.59 evaluation.

5.0 <u>ADDITIONAL DESIGN CONSIDERATIONS</u>

5.1 Sump Strainer Structural Analysis

5.1.1 Structural Qualification of the Sump Strainer Assembly

Dynamic and static structural analyses were performed by General Electric Corporation (GE) for the licensee to qualify the new containment sump suction strainer, plenum, partition, sensor components, component supports, and welds. The strainer is a GE-developed modular stacked disk strainer built upon passive technology. In the Waterford Unit 3 design the strainers are symmetric laterally about a vertical axis. That is, they look the same viewing from the west as from the north. Axial direction corresponds to the vertical direction. The strainers are designed to be bolted to plenums. The plenums are bolted to sump floor. The partitions are designed to be placed between two strainer assemblies and bolted with angles supported from sump walls. The sensor support is mounted to the plenum. The strainer assembly is qualified for loadings associated with dead weight (including debris weight), seismic (including hydrodynamic mass), the differential pressure due to head loss, and thermal expansion. The load combinations are described in the design specification (GE document 26A6870) [122]. Although the suction strainer, partition, plenum, and sensor support are not American Society of Mechanical Engineers (ASME) Code Section III items, ASME Boiler and Pressure Vessel (B&PV) Code , Section III, 1989 edition, subsections NC and ND [125] were conservatively used as a guidance for the GE strainer structural evaluation.

In the structural qualification, Finite Element Analysis (FEA) using the ANSYS computer program was performed by the licensee to verify the structural integrity of all components of the strainer assembly (suction strainers, plenum, partition, sensor, component supports, and welds). For the perforated plates of the disk set, equivalent solid plate analysis using the FEA model was utilized based on the guidance from ASME Section III code, appendix A-8000. The results of the stress analysis of the strainer assembly are documented in the stress analysis report [70].

A containment maximum temperature of 269.3° F during a LOCA was used per the Design specification.

A value of 1.0 psid differential crush pressure loading corresponding to a fully debris loaded strainer was used in the structural design.

A 2% structural damping was used in OBE &SSE seismic analyses.

5.1.1.1 Strainer Assembly

Utilizing a detailed FEA, the licensee calculated the natural frequencies and mode shapes in air and under water. The stresses in strainer base plate, perforated plates, frames, fingers, strainer supports, and strainer base plate bolt reactions were obtained from the FEA. Loads used in the stress analysis included the weight of the strainer and debris, crush pressure due to pump operation, lateral and vertical seismic accelerations based on the first mode frequency, hydrodynamic loads, and thermal expansion loads. Equivalent static analysis was performed as the strainer, plenum, and partition assemblies achieved the first mode frequencies less than the Zero Period Acceleration (ZPA) value of the seismic response spectrum.

Staff Evaluation

Using the criteria and allowable stresses from ASME Section III B&PV Code, the licensee computed safety factors and showed them to be acceptable for Design, Level B, and Level D service levels for strainer assembly, base plate, perforated plates, frames and fingers, and support bases. Based on a review of these evaluations, the NRC staff finds that they are consistent with the codes and standards cited and are therefore acceptable.

5.1.1.2 Plenum Assembly

Utilizing a detailed finite element model, the licensee calculated the natural frequencies and mode shapes in air and under water. The stresses in plenum assembly, and reactions at the brackets and bolts were obtained from the FEA. Using the criteria and allowable stresses from ASME Section III B&PV Code, the licensee developed safety factors (the ratio of allowable stress to computed stress from FEA) and showed them to be acceptable for Design, Level B, and Level D service levels for the plenum assembly. Hilti Kwik anchor bolts were qualified based on interaction of tensile and shear loads.

Staff Evaluation

Using the criteria and allowable stresses from ASME Section III B&PV Code, the licensee computed safety factors and showed them to be acceptable. The interaction ratio for anchor bolts was shown to be less than one, and hence is acceptable. The stresses are within the allowable limits. The NRC staff finds that these evaluations are consistent with the codes and standards cited and are therefore acceptable.

5.1.1.3 Partition Assembly

Utilizing a detailed finite element model, the licensee computed natural frequencies and mode shapes in air and under water. The stresses in the partition assembly, and reactions at the brackets and bolt reactions at the base and sump wall were obtained from the FEA. Using the criteria and allowable stresses from ASME Section III B&PV Code, the licensee computed safety factors and showed them to be acceptable for Design, Level B, and Level D service levels for the partition assembly. Hilti Kwik anchor bolts were qualified based on interaction of tensile and shear loads.

Staff Evaluation

Using the criteria and allowable stresses from ASME Section III B&PV Code, the licensee computed safety factors were computed and showed them to be acceptable. The interaction ratio for anchor bolts was shown to be less than one, and hence is acceptable. The stresses are within the allowable limits. The NRC staff therefore finds that these evaluations are acceptable.

5.1.1.4 Sensor Assembly

The sump water level sensor support is mounted to the plenum. Utilizing a detailed finite element model of sensor assembly, the licensee computed natural frequencies and mode shapes in air and under water. The stresses in the sensor assembly and sensor lower bracket loads and sensor bolt reactions were obtained from the FEA. Using the criteria and allowable stresses from ASME Section III B&PV Code, the licensee computed safety factors and showed them to be acceptable for Design, Level B, and Level D service levels for the sensor assembly.

Staff Evaluation

Using the criteria and allowable stresses from ASME Section III B&PV Code, the licensee computed safety factors and showed them to be acceptable. The stresses are within the allowable limits. The NRC staff therefore finds that these evaluations are acceptable.

5.1.1.5 Weld Analysis

The licensee used ANSYS FEA results to calculate the load transfer through the welds. These forces were then used to calculate the stresses based on the weld section properties for plug welds between the fingers and perforated plate, and fillet welds between the finger frame and perforated plate. Weld stresses were calculated for simultaneous application of loads for service level D. Appropriate weld quality factors provided in Table ND-3923.1-1 of ASME Section III B&PV Code were applied.

Staff Evaluation

Using the criteria and allowable stresses from ASME Section III B&PV Code, the licensee showed the computed weld stresses for plug welds and fillet welds to be less than the corresponding allowables. The NRC staff therefore finds that these evaluations are acceptable.

5.1.2 High Energy Pipe Break Analysis in the Vicinity of the Recirculation Sumps

The staff asked the licensee whether it had addressed possible high-energy line breaks (HELBs) in the vicinity of the recirculation sumps. The licensee responded by providing several drawings and an evaluation performed by the strainer vendor.

Section 3.6 of the Waterford Unit 3 Updated Final Safety Analysis Report (UFSAR), "Protection Against Dynamic Effects Associated with Postulated Rupture of Piping," describes design bases and protective measures to ensure that containment, essential equipment, and other essential structures are adequately protected from the dynamic effects associated with the postulated rupture or break of high-energy reactor coolant pressure boundary piping. The Safety Injection System, including both pre- and post-recirculation actuation signal lineups, is addressed in Section 3.6 of the Waterford Unit 3 UFSAR, and potential dynamic effects on containment recirculation sumps are not specifically addressed.

Waterford Unit 3 Jet Impingement Location Sketch, Page 1 of 1 "Jet Impingement Cones at -11 ft elevation that impact near the eastern side of the Safety Injection Sump" [126] is a plan drawing of the piping in the vicinity of the recirculation sumps. This drawing shows that the only high-energy line locations near the sump strainers are at least thirty feet away and blocked by the grating at the -four ft elevation and a concrete shield wall located near the strainers.

Staff Evaluation

It is clear from review of the provided drawings that the high-energy lines in containment can not physically reach the recirculation sumps, and therefore no whipping of the pipes on the sump strainers can occur.

A review of all drawings providing different views of the plant layout and jet impingement cones from the high-energy line breaks indicates that none of the high-energy lines will impose any jet impingement loads on the replacement sump strainers. In section 3.1 of Calculation No. GENE-0000-0048-9192 (SIS Sump Strainer HELB Report) [123] it was stated that Waterford 3 has evaluated the dynamic effects due to the pipe breaks of high energy piping inside containment. In [123] it was also stated that there is no jet impinging on the strainers, and therefore no jet impingement loads need to be considered for Waterford Unit 3 replacement suction strainers. Based on the above considerations, the staff concludes that the licensee has appropriately addressed possible high-energy line breaks in the vicinity of the recirculation sumps.

5.1.3 Questions Posed to GE Through the Licensee

5.1.3.1 Pipe Whip and Missile Impact

In [123] there is no statement provided concerning the pipe whip on the new strainer assembly. Also, in [123] there is no statement provided concerning any missiles impacting the new strainer assembly. The staff requested a summary of evaluations concerning pipe whip and missile impact, and references for the documents evaluating the new strainer assembly for pipe whip, and missile impact.

Staff Evaluation

In response to staff's question, GE responded for the licensee by stating that section 3.5 of the UFSAR (WSES-FSAR-Unit 3) [44] evaluates missiles inside and outside the Waterford Unit 3 containment. Table 3.5-4 of [44] contains a list of the potential missiles inside containment. None of these are located in an area where they can impact the strainers.

Appendix 3.6A of the USAR and a Jet Impingement Location Sketch provided by Entergy show that the closest high-energy line breaks are located over 20 feet from the closest strainer, and due to the presence of pipe whip restraints closest to the break, there is no possibility of whipping pipes impacting of the strainer. GE stated that the HELB report [123] will be revised to provide definitive statements in the conclusions concerning pipe whip and missile impacts to the new strainer assembly and will clarify the bases for these conclusions. The staff finds the clarification about pipe whip and missile impact to be acceptable. The need for the licensee to revise the HELB report [123] to provide definitive statements in the conclusions concerning pipe whip and missile impacts to the new strainer assembly and clarification of the bases for those conclusions is designated as Part 1 of multi-part sump strainer structural **Open Item 15** (note that there are nine total parts to this open item, all similar in nature in that they relate to revisions and/or corrections to sump strainer structural documentation).

5.1.3.2 Damping (OBE, & DBE/SSE Spectra)

Section 4.2.15.2 of [122] prescribes two percent of critical for structural damping for Operating Basis Earthquake (OBE) analysis, and four percent of critical for structural damping for Safe Shutdown Earthquake (SSE) analysis. The staff requested clarification of the damping values for the OBE and SSE spectra in Figures 1 through 6 of [122], and the damping values utilized in the sump strainer structural analysis. In response to the NRC's question, GE stated that the damping value will be clearly identified on the spectra in the Design Specification [122] as two percent for both OBE and SSE. GE also stated that it will revise the design specification to clearly identify the damping to be two percent.

Staff Evaluation

Use of two percent damping for SSE is conservative and therefore is acceptable. The need for the licensee to revise the sump strainer design specification [122] to clearly identify the damping to be two percent is designated as Part 2 of multi-part sump strainer structural **Open Item 15.**

5.1.3.3 Crush Pressure

The staff requested clarification of the definition of the term Differential Crush Pressure during strainer operation (Pcr) in section 6.1 of [70]. The staff also requested the basis for the Pcr value of 1.0 psi used in the structural analysis of the replacement strainer assembly.

Staff Evaluation

In response to the staff's inquiry, GE stated that Pcr is the pressure difference across the strainer components; it is the static pressure outside the strainer minus the static pressure inside the strainer system. The differential crush pressure is analogous to design pressure for a pressure vessel in that it is the limiting pressure loss across the equipment specified for hydraulic system design.

For Waterford Unit 3, the limiting pressure loss across the strainer system is specified to be 1.5 ft of water (Section 4.2.7 of [122]) at hydraulic design conditions of 6470 gpm over the temperature range of 120ºF to 230ºF. For mechanical design, a value of 1.0 psi (2.5 ft of water) that bounds the hydraulic system design requirement was selected and used in the mechanical design analysis to demonstrate structural adequacy of the equipment. The licensee stated that the value selected provides a reasonable and achievable mechanical design margin in balance with meeting the practicalities of design and fabrication of the hardware.

The staff finds the clarification of the term differential crush pressure and the basis for the use of a value of 1.0 psi in the structural design of the sump strainer to be acceptable because this value conservatively bounds the hydraulic system design requirement.

5.1.3.4 Load Combinations

The staff identified that some of the load combinations for strainer and support structures as shown in Section 6.1 of [123]) were incorrect and were also inconsistent with the Section 4.2.16.2 of [122].

The findings noted by the staff were also identified by GE in a self-audit and documented in internal GE Corrective Action Reports (CARs). CAR 42400, which concerns the design specification, and CAR 42405, which concerns the stress report, were both issued on February 27, 2007. These CARs identified the errors and discrepancies and the required corrective and preventative actions. While CAR resolutions are not yet complete, GE stated that the load combinations issue described above will be corrected by revisions to the design specification and to the stress report. The two documents will then be correct and consistent in regards to load combinations.

Staff Evaluation

In response to the NRC's questions, GE stated that the errors as well as the discrepancies in the load combinations listed in the sump strainer design specification and the sump strainer stress analysis report will be corrected. GE also stated that the correct load combinations were used in the calculations by the analyst in stress analysis report, though not shown correctly. The staff finds the load combination information developed by GE to be acceptable. The need for the licensee to correct errors and discrepancies in the sump strainer design specification [123] and stress analysis report [70] is designated as Part 3 of multi-part sump strainer structural **Open Item 15.**

5.1.3.5 Temperature Delta

Temperature Delta is defined as the difference between the temperature at which a component is installed and the temperature of the component when in service in the plant. The staff pointed out that the temperature Delta listed as 149.3 ^{0}F in the last column of Tables 6-1, 6-2, 6-3 and 6-4 of [70] for strainer Level B, for Plenum Level D, for Partition Level D, and for Sensor Level D., and Plenum-Partition-Sensors Level D should be (269.3 ^{0}F - 70 ^{0}F) = 199.3 ^{0}F.

In response GE agreed and stated that the "Temperature DELTA (^{0}F)**" columns in each table should be, and will be corrected to 199.3 ^{0}F in next revision of [70].

GE stated that the impact of these deviations in temperature delta is inconsequential for the following reasons:

a) The equipment is constructed of a single material, austenitic stainless steel. Therefore, there are no significant differential thermal expansions within the structures, and no thermal stresses would be developed.

b) The equipment is not restrained in the vertical direction, permitting free thermal expansion.

c) Clearances at mounting bolt-bolt hole locations permit thermal expansion and that insignificant thermal expansion stresses would be developed.

d) What is significant and as addressed correctly is the material allowable stress at design temperature. The value cited in the stress report, section 7.0 is 15,420 psi (for 304L stainless steel) at 269 ºF, which is conservative.

Staff Evaluation

GE agreed that the temperature Delta shown as 149.3 ^{0}F is incorrect, should be 199.3 ^{0}F, and would be corrected in an upcoming revision to [70]. However, GE stated that the results are unaffected and provided the rationales listed above. The staff finds that GE's response regarding temperature Delta and material allowable stress to be acceptable based on consideration of items a, b, c and d listed above. The need for the licensee to correct the temperature delta in the sump strainer stress analysis report [70] is designated as Part 4 of multi-part sump strainer structural **Open Item 15**.

5.1.3.6 Inertial Accelerations

The staff requested explanation of the inertial acceleration values used for strainer design listed in Tables 6-1, 6-2, 6-3 and 6-4 of Section 6.2 of [123].

In response GE stated that the inertial acceleration values used in the analyses were extracted directly from the design envelope spectra contained in [122]. However, the values reported in the stress report are the ANSYS input values adjusted to account for hydrodynamic mass and debris load to facilitate the ANSYS analyses. Since hydrodynamic mass and debris load are also reported in these same tables, the reader cannot ascertain which values were actually used in the analysis. Therefore, Tables 6-1 through 6-4 of [122] will be revised to reflect the seismic accelerations specified in the design specification.

The first structural frequencies of the strainers and plenums are, in all cases, substantially above the amplified response region of the response spectrums, and therefore the use of Zero Period Acceleration (ZPA) acceleration values is acceptable. Therefore, a 1.5 factor on acceleration is not necessary and was not applied. These acceleration values will be clarified in the next revision to the stress report to comply with the design specification.

Staff Evaluation

GE stated that the first structural frequencies of the strainers and plenums are, in all cases, substantially above the amplified response region of the response spectrums and use of ZPA accelerations values is acceptable, and that Tables 6-1 thru 6-4 of [70] will be revised by GE to reflect the seismic accelerations specified in the design specification. These acceleration values will be clarified in the next revision to the stress report to comply with the design specification. NRC staff finds that GE's response and the rationale for using the ZPA accelerations are acceptable based on the first structural frequencies of the strainers and plenums. The need for the licensee to clarify the sump strainer acceleration values in the sump strainer stress analysis report [70] is designated as Part 5 of multi-part sump strainer structural **Open Item 15.**

5.1.3.7 Perforated Plate Analysis

The displacements for only solid plate were listed in Appendix A, Table A-1 of [70]. The staff noted that the displacements for perforated plate were not listed. The staff also identified that the stress multiplier k (= E/E*) to be applied to equivalent plate analysis stress results listed as 1.47, was incorrect. This may impact the strainer stress results. Hence, the strainer stresses listed in Table 2-1 (sht. 13), & Appendix-C (sht. 57) of [70], where a k factor value of 1.47 was used, should be revisited and corrected as appropriate.

In response GE stated that Table A-1 is in error since it omits the perforated plate column and that it will be corrected on the next revision to [70].

Review of the displacement numbers by GE showed that the calculated E*/E is 0.43 and κ = 2.33. Since the reported 1.47 value is incorrect, the stresses listed in Table 2-1 of [70] were re-evaluated considering the increase of κ from 1.47 to 2.33. Because the perforated plate reported stresses show substantial margin for 1.0 psi pressure loading, the reported safety factors listed in Tables 2-1, 8-2 and 8-3 of [70] will remain greater than 1.0 for κ = 2.33, Therefore, there will be no impact on structural adequacy conclusions. GE stated that corrections to the affected tables will be made on next revision to [70].

Staff Evaluation

GE acknowledged that both E*/E and κ listed respectively as 0.62 and 1.47 for perforated plates are incorrect. GE stated that the correct values for E*/E and κ respectively should be 0.43 and 2.33. GE will recompute the safety factors utilizing the correct k factor for the perforated plates. Corrections to the affected tables will be made by GE on next revision to [70]. The staff agrees with the statement that there will be no impact on structural adequacy conclusions for perforated plates due to higher value of k because of substantial margins. The need for the licensee to correct the values for E*/E and κ in the sump strainer stress analysis report [70] is designated as Part 6 of multi-part sump strainer structural **Open Item 15.**

5.1.3.8 Deflections

The staff noted that the whole Strainer Deflection, summarized in Appendix C (FEA Fig. C-1), and the Plenum Deflections summarized in Appendix D (FEA Figs. D-9 & D-11) of [70] are not the maximum magnitudes.

GE responded by stating that the staff's assertion is correct. There is no basis for the maximum deflections as stated in [70]. Structural adequacy is demonstrated by the stress levels. The incorrectly listed maximum deflections will be corrected on next revision to the stress report.

Staff Evaluation

In response to the staff's question, GE acknowledged that the maximum deflection values listed for the whole strainer and plenum are incorrect and will be corrected in next revision to [70]. Since the structural adequacy is demonstrated by the stress levels, there is no impact on the structural acceptability of the strainer. The NRC staff therefore finds the GE's response to be acceptable. The need for the licensee to correct the whole strainer and plenum maximum deflection values in the stress analysis report [70] is designated as Part 7 of multi-part sump strainer structural **Open Item 15.**

5.1.3.9 Bounding Plenum Geometry for Structural Qualification

The strainer assembly consists of a total of 11 strainers. Six strainers sit on the plenum directly over the sump pit, and five strainers sit on the plenum on the containment floor. Two of those five strainers are to the north of the sump, and three are to the east as shown in Figure 3 above. It was stated in Appendix D of [70] that the T-shaped plenum portion with 5 strainers (three strainers in a line on the containment floor and two adjacent strainers over the sump pit) was the most critical portion, and was selected for the FEA analysis. The staff requested a clarification as to whether an exploratory analysis or FEA analysis of the L-shaped plenum portions with 3 strainers (two above the sump, one on the containment floor) was performed to verify the assumption that T-shaped plenum with 5 strainers is more critical from all aspects. GE responded by stating that such alternate (exploratory) calculations were performed to verify that the T-shape plenum analyses are bounding.

Alternate hand calculations were also performed by GE to verify the adequacy of the dead weight plus pressure load carrying capacity of the sump cover assemblies.

Staff Evaluation

Based on the review of the information provided by GE, the staff agrees that the T-shaped plenum analysis is bounding. The structural evaluations of the strainer assembly are therefore acceptable.

5.1.3.10 Safety Factors and Stress Limits

The staff identified errors in some of the stress limits in Tables 2-2, 2-4, and 8-12 of [70] and safety factor values in Tables 8-5, 8-11, and 8-12 of [70]. The staff also noted incorrect units were listed for stress limits in Tables 8-1 through 8-12 of [70].

In response, GE acknowledged the errors identified by the staff and agreed to correct the errors in the next revision to [70]. GE stated that there will be no impact on structural adequacy conclusions.

Staff Evaluation

GE acknowledged the errors pertaining to the listed safety factors and allowable stress limits identified by the staff, and noted that there will be no impact on the structural adequacy conclusions. These errors will be corrected by GE on issuance of the next revision to [70]. The staff finds that the GE's response is acceptable because of the substantial margins in the safety factors that remain after accounting for the effects of the errors. The need for the licensee to correct stress limits and safety factor values in certain tables of [70] and certain units used for stress limits in certain tables of [70] is designated as Part 8 of multi-part sump strainer structural **Open Item 15**.

5.1.3.11 Hydrodynamic Mass Calculation

The staff noted that Table 1, “Summary of Hydrodynamic Masses for Disc Stacks Active and Passive Strainers” of [122] addresses 24 inch, 36 inch, and 48 inch square discs, while Waterford Unit 3 strainers have 17 stacked discs 40 inch square (strainer modules of 40 inch length x 40 inch width x 48.7” height). The staff requested GE to provide hydrodynamic masses for longitudinal and lateral axes for Waterford 40 inch square stacked disc strainer. The staff also requested GE to verify and correct the hydrodynamic masses used in Tables 6-1.1, 6-2.1, 6-3.1 and 6-4.1 of [70].

GE stated that the hydrodynamic masses reported in the tables are not correct, but that they will be corrected in the next revision to [122]. The effects of the incorrect values were acknowledged by GE. GE issued CAR 43130 to address the above discrepancies, the required corrective actions, and preventative actions and stated that resolution of the discrepancies had begun.

Staff Evaluation

GE acknowledged that the hydrodynamic masses in Tables 6-1 and 6-2 of [70] are not correct and would be corrected in the next revision to [70]. In the interim, GE conducted recalculations using the correct hydrodynamic mass values and re-computed the minimum safety factors, and showed that the safety factors remain greater than one and all the stresses in the limiting strainer and plenum assemblies remain in compliance with the stress limits specified in the design specification [122]. In addition, GE issued CAR 43130 to address the discrepancies, the required corrective actions, and preventative actions. The staff finds that the sump strainer assembly safety factors remain acceptable based on recomputations with corrected hydrodynamic mass. The need for the licensee to address the discrepancies noted in the hydrodynamic mass calculation is designated as Part 9 of multi-part sump strainer structural **Open Item 15.**

5.1.3.12 Overall Sump Strainer Structural Conclusion

The staff finds the overall sump structural analysis for the new Waterford Unit 3 containment sump strainer suction strainer, plenum, partition, sensor components, component supports, and welds to be acceptable based on a review of the SIS sump strainer stress report, the hydrodynamic mass calculation for the sump strainer, the SIS sump strainer HELB report, additional evaluations performed by GE in response to staff questions, and review of referenced documents. However, as indicated in the multi-part Open Item 15 for this report section, various revisions and updates to sump strainer structural documents are needed.

5.2 Upstream Effects

To evaluate upstream effects, the staff reviewed the UFSAR [57], the transport calculation [16], the debris generation calculation [128], the containment water level calculation [34], photographs of the containment, and several plant drawings of the containment. These documents were reviewed in order to evaluate the licensee's treatment of potential blockage at containment drainage flow choke points and other upstream effects. No baseline document or walkdown procedures to specifically identify choke points or obstructions was provided for review.

The debris generation calculation [128] provides a general description of the flow from the spray system to the sump. As summarized below, in that document the licensee described how water discharged from the CSS spray headers located between plant elevations 175 ft and 205 ft would pass through various plant elevations en route to ultimately draining into the containment sump formed on elevation -11 ft.

A review of the documentation provided to the staff shows that at and above the operating floor elevation at 46 ft, the flooring is primarily grating above the steam generator cavities and around the outer edge of the Reactor Building [128, 57]. There are significant non-grated areas on the 46 ft elevation. Portions of the floor at this elevation are concrete, and these solid portions drain to grated areas with no obstructions. Therefore, spray flow will either pass through gratings into the steam generator compartments or will fall onto the operating floor at elevation 46 ft. Above this elevation, the refueling canal is open to the spray falling from above.

The debris transport calculation [16] described the potential for blockage of the refueling canal drains. The calculation determined that blockage of the drains is unlikely. This determination was based on the probability of the drains becoming blocked. There are two six-inch drains in the bottom of the refueling cavity. However, the assumption that large pieces of debris could not block the drains is potentially non-conservative. It is possible for large debris to be blown upward into the containment and land in the refueling canal. The large debris could either land on the drain, or more likely wash to the drains either partially or completely blocking the flow from the canal.

The licensee demonstrated that there are several physical obstructions that would likely prevent debris from falling directly onto the refueling canal drains. However, based on study of containment layout drawings and pictures, the staff concluded that it had not been adequately demonstrated that holdup in the refueling cavity would not occur. Even a partial blockage of the drains by large or small pieces of debris could cause a significant holdup of water in the refueling canal. The need for the licensee to summarize how it has evaluated the potential for holdup in the refueling cavity due to falling debris is designated as **Open Item 16**.

Drawings show that the structure at elevation 21 ft is composed of gratings and concrete. The areas outside the refueling cavity and reactor and steam generator compartments will allow water to flow through gratings, or flow to the gratings and then fall to the lower containment elevations. Drawings show the steam generator compartments to be open at the 21 ft elevation. In general, the steam generator compartments have no obstructions that would prevent the flow of water from the above to the bottom of the compartments.

The reactor cavity is a potential significant holdup for water in containment. However, in the containment water level calculation [34] the reactor cavity is assumed to fill up to the 7.5 ft elevation before overflowing to communicate with the recirculation sump.

According to drawings, elevation -four ft is the first major floor level above the basement elevation (-11 ft). The flooring at this elevation is also constructed of both concrete and grating. The solid flooring at these elevations can drain to the grated areas with no obstructions.

The basement level elevation (-11 ft) is relatively open allowing free flow to the sump. The CFD analysis in [16] shows the flow velocities at this elevation for various scenarios. Although several physical features (e.g., grating and curbs) may hold up some pieces of large debris, and the floor slopes slightly away from the recirculation sump, the flow of water to the sump would not be significantly impeded.

Based upon the information that has been reviewed and summarized above, with the exception of potential holdup in the refueling cavity, the staff concluded that water drainage in the Waterford Unit 3 containment would not in general be susceptible to being trapped in unanalyzed hold up locations.

The staff's review of upstream effects focused upon the drainage flowpaths through the refueling canal and reactor cavity because of the potential for the drains for these large volumes to retain substantial quantities of water if the drains were to become blocked by debris.

5.3 Downstream Effects

5.3.1 Downstream Effects - Components and Systems

The GR provides licensees guidance on evaluating the flowpaths downstream of the reactor building emergency sump for blockage from screen bypass debris.

The GR and the SE identify the following aspects to be included in the downstream evaluation:

- Recognition that flow clearance through the sump screen determines the maximum size of particulate debris.

- Evaluation of wear and abrasion of surfaces in the emergency core cooling and containment spray systems based on flow rates to which the surfaces will be subjected and the grittiness or abrasiveness of the plant-specific ingested debris.

- Review of the effects of debris on pumps and rotating equipment, piping, valves, and heat exchangers downstream of the sump. In particular, any throttle valves installed in the ECCS for flow balancing should be evaluated for blockage potential.

- Definition of long-term and short-term system operating lineups, conditions of operation, and mission times. For pumps and rotating equipment, assess the condition and operability of the component during and following its required mission times.

- Evaluation of component rotor dynamics changes and long-term effects on vibrations caused by potential wear, including the potential impact on pump internal loads, to address concerns such as rotor and shaft cracking.

- Consideration of system piping, containment spray nozzles and instrumentation tubing, including settling of dusts and fines in low-flow/low fluid velocity areas. Consideration of tubing connections for differential pressure from flow orifices, elbow taps, venturis, and reactor vessel/RCS piping leg instrument lines. Consider any potential impact that matting of screen bypass fiber and particulates may have on instrumentation necessary for continued long-term operation.

- Evaluation of valve and heat exchanger wetted materials for susceptibility to wear, surface abrasion, and plugging that may alter the system flow distribution.

- Evaluation of heat exchanger degradation resulting from plugging, blocking, plating of slurry materials with respect to overall system required hydraulic and heat removal capability.

- Evaluation of the overall system integrating limiting conditions. Include evaluation of the potential for reduced pump/system capacity resulting from internal bypass leakage or through external leakage.

- Evaluation of leakage past seals and rings caused by wear from debris fines to areas outside containment with respect to fluid inventory, overall accident scenario design, and licensing bases environmental and dose consequences.

NRC Staff Audit:

Waterford Unit 3 used PWR Owners Group WCAP-16406-P, "Evaluation of Downstream Sump Debris Effects in Support of GSI-191," Revision 0 in their assessment of their ECCS and components. The NRC staff has not accepted Revision 0 as a valid process for downstream reviews. Subsequently, the PWROG revised and submitted a draft Revision 1. Revision 1 is currently under review as a topical report by the NRC staff.

The licensee's evaluation did not provide a similitude evaluation demonstrating that the methodology described by WCAP-16406P bounds or is applicable to the conditions found in Waterford Unit 3. The need for the licensee to provide the results of a similitude evaluation for WCAP-16406-P versus conditions at Waterford 3 is designated as **Open Item 17.**

The staff reviewed the licensee's preliminary downstream evaluation of all components and flowpaths within the scope of the licensee's downstream evaluation (pumps, valves, instruments, and heat exchangers, etc.). Waterford Unit 3 representatives provided piping and instrumentation drawings, operations procedures and supporting calculations. The licensee's evaluation was incomplete in that in almost all cases assumptions, bases for assumptions, and source documents were not clearly identified, nor were their specific applications in the evaluations shown. The licensee's provision of assumptions, bases for assumptions and source documents for its downstream evaluation is designated as **Open Item 18.**

In accordance with SE Section 7.3, the staff reviewed design and license mission times and system lineups to support mission critical systems. The mission times for shutdown cooling (SDC), high-pressure injection (HPI) and containment spray (CS), were stated to be 30 days in the licensee's downstream effects evaluation. The licensee did not provide a clearly defined technical basis or supporting documentation for the 30-day mission times for these systems. The staff notes that, while 30 days is a common mission time and may be bounding, this assumption was not validated by the licensee. ECCS mission times may vary. For example, HPI may not be needed to support recirculation for a full 30 days, while SDC may be required to support core cooling for 30 days or longer. The need for the licensee to provide clearly defined technical bases for the designated mission times for SDC, HPI and CS is designated as **Open Item 19**.

The licensee did not show that the line-ups, flows and pressures used to bound downstream evaluations were conservative. Further, the licensee did not clearly define the range(s) of fluid velocities within piping systems. Also, minimum and maximum system flow assumptions were not incorporated into the downstream effects evaluation consistent with conservative component evaluation. The need for the licensee to develop and justify conservative, bounding values for system lineups, fluid flows and system pressures for downstream effects analysis is designated as **Open Item 20**.

The licensee used design pump curves, versus degraded, actual or modified pump curves. The need for the licensee to justify the use of design curves, or to re-analyze for degraded, actual or modified pump curves is designated as **Open Item 21.**

The staff reviewed small-, medium-, and large-break LOCA scenarios as described in the licensee's downstream evaluation [129]. ECCS operation during small- , medium-, and large-break LOCAs appeared to be adequate in that flows and pressures achieved met the requirements of the Waterford 3 accident analysis.

The licensee did not provide an analysis of the extent of air entrainment (apart from vortexing), within the ECCS that may either impact ECCS and CSS pump operation or cause air pockets in ECCS or CSS piping. Neither did the licensee address the potential for waterhammer and slug flow. The need for the licensee to provide results of analysis of ECCS air entrainment (apart from vortexing) and the potential for waterhammer and slug flow is designated as **Open Item 22**.

The initial Waterford Unit 3 assessment of characterization and properties of bypass debris in ECCS post-LOCA fluid (abrasiveness, solids content, and debris characterization) assumed 100 percent particulate pass-through, which is conservative. Using 100 percent pass-through, licensee wear calculations showed unacceptable wear in the HPSI and CS pumps' wear rings, based upon the wear criteria of WCAP-16406-P. Licensee calculations also showed that the three-inch HPSI orifice wear limits would be exceeded, as well as the limits for wear of the spray nozzles. The licensee is re-evaluating the quantities and properties of the post-LOCA ECCS fluid, as well as coating transport properties. The licensee did not evaluate the impact of orifice wear on ECCS System flow balance. The need for the licensee to re-calculate downstream component wear due to strainer bypass debris and provide the results is designated as **Open Item 23**.

The SE identifies the vulnerability of the high-pressure safety injection throttle valves to clogging during ECCS operation. Waterford Unit 3 has two-inch motor-operated globe valves in the HPSI header which open to a pre-set position once a safety injection actuation signal is received. This position is verified every refueling outage, and may vary due to setpoint drift. The licensee did not perform a HPSI flow analysis considering the full range of possible recirculation throttle valve positions or failure of the valve to open to its pre-set position. The need for the licensee to re-perform its HPSI recirculation throttle valve clogging analysis considering the full range of possible recirculation throttle valve positions or failure of the HPSI throttle valve to open to its pre-set position and provide the results is designated as **Open Item 24**.

The staff reviewed emergency operation procedure OP-902-002 for LOCA recovery. The downstream effects evaluation [129] did not reflect the OP lineups or other operational procedures in the downstream effects evaluation. The need for the licensee to describe how it has incorporated actions of its operational procedures in the downstream effects evaluation is designated as **Open Item 25**.

The licensee's evaluation in [129] included a listing of the materials of all wetted downstream surfaces (wear rings, pump internals, bearings, throttle valves, plugs, and seat materials). The staff reviewed this list and verified materials of construction to be correctly identified in the evaluation through review of drawings of and owner's manuals for the various components.

ECCS and CS pumps are original plant equipment. Modifications and testing of these components, such as the HPSI B pump, have been performed over the life of the plant. The downstream component wear evaluation assumed ECCS pump wear rings to be “as-good-as-new”. The evaluation did not provide a basis for this assumption. The need for the licensee to justify ECCS pump wear rings to be “good as new,” or to determine a more conservative condition for these rings is designated as **Open Item 26.**

The SE states that a review and assessment of changes in system or equipment operation caused by wear (e.g., pump vibration and rotor dynamics) should be performed. Also, the SE states that an assessment of whether the pump internal stage-to-stage bypass flow increases, thereby decreasing performance or accelerating internal wear, should be completed. In [129] the licensee did not provide an evaluation of HPSI pump stage-to-stage degradation and its effect on pump hydraulic performance. The need for the licensee to provide the results of evaluation of HPSI pump stage-to-stage degradation and its effect on pump hydraulic performance, and then provide the results of a pump vibration and rotor dynamics evaluation, is designated as **Open Item 27.**

The licensee did not evaluate ECCS and CS pump seal leakage for its effect on Safeguards Room environmental conditions. ECCS and CS pump leakage was not quantified, nor was an evaluation performed of leakage effects on equipment qualification and room habitability. The need for the licensee to summarize its evaluation of ECCS and CS pump leakage effects in its Safeguards Room evaluation is designated as **Open Item 28**.

Waterford Unit 3 personnel did not review debris settling at system low points and low flow areas. The review is needed in order to factor this information onto the licensee’s downstream blockage, wear, erosion and flow distribution evaluations. The need for the licensee to summarize how it has determined the effects of settled material at ECCS system low points and integrate these effects into the downstream effects evaluation is designated as **Open Item 29.**

The licensee did not perform overall system flow evaluation(s) considering the results of the various component wear evaluations to prevent potential pump run-out conditions or increased system resistence to the extent that system function is challenged. The need for the licensee to consider the results of the various component wear evaluations, perform an overall system flow evaluation, and provide the results is designated as **Open Item 30.**

5.3.2 Downstream Effects - Fuel and Vessel

The licensee had not yet conducted evaluations of the downstream effects of post-LOCA debris and chemicals on reactor vessel internal components, including the reactor core. Such evaluations are needed to demonstrate that long term core cooling is maintained in accordance with CFR 50.46. The need for the licensee to provide the results of an analysis of downstream effects of post-LOCA debris and chemicals on the fuel and vessel is designated as **Open Item 31**.

5.4 Chemical Effects

The staff was not able to draw any conclusions concerning the Waterford Unit 3 chemical effects evaluation since the licensee has made little progress evaluating potential chemical effects and testing has not yet been performed. Therefore, the need for the licensee to provide the results of resolution of chemical effects at Waterford Unit 3 is designated as **Open Item 32**.

6.0 CONCLUSIONS

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 Entergy Operations, Inc., from the NRC Office of Nuclear Reactor Regulation. This letter will consider licensee responses to GL 2004-02 requests for additional information (RAIs), and/or 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 Waterford Unit 3.

APPENDIX I: Plant-Specific Open Items

These open items are plant-specific in nature. Responses to these open items will have a scope beyond the information guidance of the “Content Guide for Generic Letter 2004-02 Supplemental Responses” (ADAMS Accession Number ML071060091). The licensee should summarize in its GL 2004-02 supplemental response (due to the NRC in February 29, 2008) how these open items have been addressed.

Open Item 1: The licensee should justify its assumption of a 2D zone of influence (ZOI) for the Waterford Unit 3 metal encapsulated insulation (MEI) fiberglass.

Open Item 2: The licensee should provide comprehensive documentation of the characteristics (macroscopic densities, microscopic densities, and characteristic debris sizes) of the actual plant debris at Waterford Unit 3 and compare these characteristics to the surrogate debris properties used for head loss testing, justifying any differences.

Open Item 3: The licensee should provide an analysis that shows that the coating debris test data credited by Waterford Unit 3 was generated using coating chips that are representative of or bounding with respect to the plant-specific failed coating chips.

Open Item 4: The licensee should (1) justify that the percentage of debris transporting along the containment floor from the east and west sides of containment is equal to the percentage of flow approaching the sump from the east and west sides of containment and (2) provide a clear definition of the starting points for debris transport paths to avoid contributing to an underestimation of debris transport on the side of containment opposite the break.

Open Item 5: The licensee should explain how it has addressed the following four deficiencies in the existing transport analysis for unqualified coating chips: (1) lack of adequate data to justify the assumed size distribution for failed coating chips, (2) improper application of settling data for coating chips with a 400-micron thickness to particle-like coating debris with a 400-micron diameter, (3) lack of justification of the use of an analysis intended for the vertical flow conditions typical of a reactor vessel core inlet plenum for the horizontal flow conditions in the Waterford Unit 3 containment pool, and (4) lack of consideration of the possibility that coating chips that fall into the containment pool in the vicinity of the sump may transport to the sump in suspension in the containment pool prior to settling on the containment floor.

Open Item 6: The licensee should justify that the debris transport fractions in the transport calculation are representative of the replacement strainer configuration.

Open Item 7: The licensee should provide results of analysis of the potential effects of a low-pressure safety injection (LPSI) pump failure to stop on a recirculation actuation signal (RAS).

Open Item 8: The licensee should describe how it has implemented prototypically fine fibrous debris preparation in its head loss testing.

Open Item 9: The licensee should describe and justify how it has conducted adequate testing to determine thin bed peak head losses.

Open Item 10: The licensee should provide the results of assessment of the potential for non-prototypical settling and non-prototypical bed formation due to debris agglomeration during partially stirred strainer testing.

Open Item 11: The licensee should describe and justify how it has resolved the potential for non-prototypical flows during module testing due to "solid modeled" tri-sodium phosphate (TSP) baskets located near the strainer modules.

Open Item 12: The licensee should provide the results of evaluation of the potential for and effects of vapor flashing due to strainer head loss being greater than the strainer submergence.

Open Item 13: The licensee should explain how the following four additional water holdup mechanisms are modeled in the analysis of minimum containment pool water level or justify why they are not modeled: (1) water holdup due to condensation films, (2) water holdup due to spray droplet holdup in the containment atmosphere (as opposed to water vapor holdup in the containment atmosphere), and
(3) refill of the reactor pressure vessel with colder and therefore denser water, and (4) the reactor water safety pool (RWSP) water temperature specified to be at the warmer normal operating containment temperature.

Open Item 14: The licensee should justify treating unqualified coatings debris characteristics in the same manner as for qualified coatings.

Open Item 15: The licensee should summarize how it has addressed the following aspects of structural analysis for the new strainer:

Part 1 - The licensee should revise the high-energy line break (HELB) report to provide definitive statements in the conclusions concerning pipe whip and missile impacts to the new strainer assembly and clarification of the bases for those conclusions.

Part 2 - The licensee should revise the sump strainer design specification to clearly identify the damping to be two percent.

Part 3 - The licensee should correct errors and discrepancies in the sump strainer design specification and stress analysis report.

Part 4 - The licensee should correct the temperature delta in the sump strainer stress analysis report.

Part 5 - The licensee should clarify the sump strainer acceleration values in the sump strainer stress analysis report.

Part 6 - The licensee should correct the values for E*/E and κ in the sump strainer stress analysis report.

Part 7 - The licensee should correct the whole strainer and plenum maximum deflection values in the stress analysis report.

Part 8 - The licensee should correct stress limits, safety factor values and certain units used for stress limits in certain tables of the sump strainer stress analysis report.

Part 9 - The licensee should address discrepancies identified in the hydrodynamic mass calculation.

Open Item 16: The licensee should summarize how it has evaluated the potential for holdup in the refueling cavity due to falling debris.

Open Item 18: The licensee should provide the assumptions, the bases for assumption and the source documents for its downstream evaluation of components and systems.

Open Item 19: The licensee should provide clearly defined technical bases for the designated mission times for shutdown cooling (SDC), high pressure injection (HPI) and containment spray (CS).

Open Item 20: The licensee should develop and justify conservative, bounding values for system lineups, fluid flows and system pressures for the downstream effects components and systems analysis.

Open Item 21: The licensee should justify the use of design curves, or re-analyze for degraded, actual or modified pump curves for the downstream effects components and systems analysis.

Open Item 22: The licensee should provide the results of analysis of emergency core cooling system (ECCS) air entrainment (apart from vortexing) and the potential for waterhammer and slug flow.

Open Item 23: The licensee should re-calculate downstream component wear due to strainer bypass debris and provide the results.

Open Item 24: The licensee should re-perform its high-pressure safety injection (HPSI) recirculation throttle valve clogging analysis considering the full range of possible recirculation throttle valve positions or failure of the HPSI recirculation throttle valve to open to its pre-set position, and provide the results.

Open Item 25: The licensee should describe how it has incorporated actions of its operational procedures into the downstream effects evaluation.

Open Item 26: The licensee should justify emergency core cooling system (ECCS) pump wear rings to be "good as new," or determine a more conservative condition for these rings.

Open Item 27: The licensee should provide the results of evaluation of high-pressure safety injection (HPSI) pump stage-to-stage degradation and its effect on pump hydraulic performance, and should provide the results of a pump vibration and rotor dynamics evaluation.

Open Item 28: The licensee should summarize its evaluation of ECCS and CS pump leakage effects in its Safeguards Room.

Open Item 29: The licensee should summarize how it has determined the effects of settled material at emergency core cooling system (ECCS) system low points and integrate these effects into the downstream effects evaluation.

Open Item 30: The licensee should consider the results of the various component wear evaluations and perform an overall system flow evaluation, and should provide a summary of the results.

General Open Items

These open items are general in nature. The "Content Guide for Generic Letter 2004-02 Supplemental Responses" (ADAMS Accession Number ML071060091) provides guidance for the development of response to these open items.

Open Item 17: The licensee should provide the results of a similitude evaluation for WCAP-16406-P versus conditions at Waterford Unit 3.

Open Item 31: The licensee should provide the results of an analysis of downstream effects of post-LOCA debris and chemicals on the fuel and vessel.

Open Item 32: The licensee should provide the results of resolution of chemical effects at Waterford Unit 3.

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APPENDIX III: Licensee Computational Fluid Dynamics Simulations

As described in Attachment 1 to the debris transport calculation [16], the licensee used computational fluid dynamics (CFD) to simulate the flow field in the Waterford Unit 3 containment pool during sump recirculation as an input to the debris transport calculation. Specifically, the flow patterns were predicted in a pool of water at the base of the containment building for different loss-of-coolant accident (LOCA) scenarios using CFD techniques. A brief explanation of each case is discussed below.

The CFD scenarios simulated by the licensee are listed in Table 3.5.5.1-1 through Table 3.5.5.1-3 of [16]. The CFD analysis was performed by RWDI, Inc., a subcontractor to Sargent and Lundy, using the FLUENT CFD code.

The objective of the staff's review in this area was to evaluate the adequacy of the physical assumptions and numerical approaches used in the Waterford Unit 3 CFD analysis to ensure that the analysis predicted flow velocities, turbulence, and other containment pool flow parameters in a manner that would lead to conservative debris transport results. The staff's review focused on two main aspects: (1) examining the assumptions and explanations provided in the licensee's debris transport calculation concerning the CFD analysis and (2) executing the FLUENT code using several of the Waterford 3 containment condition input decks provided by the licensee. Specifically, the staff ran the cases that reflect the installed replacement strainer, comparing the resulting contour plots of velocity and turbulent kinetic energy with those provided by the licensee.

III.1 Pool Recirculation Transport Scenarios Analyzed

The licensee performed an analysis of the total quantity of debris generated for seven postulated LOCAs as discussed in the licensee's debris generation calculation [16]. Simplified break descriptions are as provided in Table III-1 below:

Table III-1: LOCA Scenarios Simulated

Break Location	Description of Pipe Break
Baseline Breaks	
Break S1	Hot leg break in west steam generator (S/G) cavity
Break S2	Hot leg break in reactor cavity
Break S3	Hot leg break in east steam generator cavity
Break S5	Crossover break in west steam generator cavity
Break S6	Crossover break in east steam generator cavity
Break S7	Pressurizer surge line break in pressurizer room
Alternate Breaks	
Break S4	Pressurizer surge line break in west steam generator cavity

The licensee stated that the breaks considered in the original evaluation had the focus of maximizing debris production and transport velocities in the immediate vicinity of the recirculation sump (south quadrant of the containment). However, for the justification of failed coating maximum settling, these are not necessarily the limiting breaks. The licensee added two additional evaluations to quantify the effect on settling. These are Break S8 and S9, and break descriptions are as stated in Table III-2 below:

Table III-2: Additional LOCA Scenarios Simulated for Settling

Break Location	Description of Pipe Break
Break S8	Crossover break in west steam generator cavity north side
Break S9	Crossover break in east steam generator cavity north side

Using CFD, the licensee analyzed ten pool recirculation transport scenarios, as summarized in Table III-3 below.

Table III-3: Pool Recirculation Transport Scenarios

Scenario #	Screen Modeled	Break Location	Description of Pipe Break
1	Original	S6	Crossover break in east steam generator cavity south side
2	Original	S5	Crossover break in west steam generator cavity south side
3	Original	S1	Hot leg break in west steam generator (S/G) cavity
4	Original	S7	Pressurizer surge line break in pressurizer room
5	New	S6	Crossover break in east steam generator cavity south side
6	New	S6	Crossover break in east steam generator cavity south side
7	New	S7	Pressurizer surge line break in pressurizer room
8	New	S7	Pressurizer surge line break in pressurizer room
9	New	S6	Crossover break in east steam generator cavity south side
10	New	S7	Pressurizer surge line break in pressurizer room
11	New	S8	Crossover break in west steam generator cavity north side
12	New	S9	Crossover break in east steam generator cavity north side

Scenarios 1 through 4 were based on the existing (original) sump screen configuration, Scenarios 5 through 12 were conducted to assess the impact of the new strainer modules being installed in Waterford Unit 3. Scenarios 9 and 10 were modeled with the new strainer modules at a minimum flow rate and maximum flood height. The staff review focused on scenarios 5, 6, 7, 8, 11 and 12 (scenarios with new strainer modules). Since Scenarios 9 and 10 were based on a lower break flow rate resulting in less debris transport, these scenarios are not considered limiting cases. Therefore, these scenarios were not analyzed for the audit.

Breaks S2, S3, and S4 were analyzed in the licensee's debris generation calculation [32]. However, these breaks were not selected for CFD analysis. The licensee's justification for not analyzing recirculation pool transport for Break S2, S3, and S4 are as follows:

Break S2: Break S2 is a hot leg break in the reactor cavity. This break is not selected for CFD analysis because the quantity of debris that would be transported to the safety injection sump for a break in the reactor cavity is small when compared to the other breaks, and therefore Break S2 will be bounded by the scenarios that were analyzed.

Break S3: Break S3 is a hot leg break in the east S/G cavity and is the mirror image of Break S1. Since the flow path from the west S/G cavity (Break S1) to the safety injection sump is more constricted than the flow path from the east S/G cavity (Break S3) to the safety injection sump, the velocities associated with Break S1 will bound those associated with Break S3. Therefore, the recirculation transport fractions for Break S3 are bounded by the recirculation transport fractions from Break S1.

Break S4: Break S4 is located at approximately the same location as Break S1. Therefore, the recirculation transport fractions for Break S4 can be estimated using the recirculation transport fractions from Break S1.

The staff agrees with the licensee's position that Break S2 is bounded by the scenarios that were analyzed and Breaks S3 and S4 are bounded by Break S1. In particular, Break S1 would bound the recirculation pool conditions for the Break S4 (in the pressurizer surge line), since the 42-inch S1 break at the same location would generate significantly more debris for similar pool transport conditions.

Based upon the licensee's modeling of breaks in both steam generator cavities, including breaks in close proximity to the containment recirculation sump, the staff considered the licensee's selection of recirculation transport scenarios to be reasonable with respect to ensuring the computation of conservative debris transport fractions. However, the modeling of Break S1 was based on the existing sump screen configuration and not re-performed to reflect the new strainer configuration. The licensee did not provide a technical basis to demonstrate that the transport fractions derived from the original CFD calculations for the old sump screen remain bounding for the replacement strainer. See Section 3.5.6 of this report for further discussion of this issue and a related Open Item.

A discussion of the licensee's break selection analysis is presented in Section 3.1 of this audit report. The type and total quantity of debris generated for the postulated LOCAs used in the CFD calculations are discussed in Section 3.2 of this report. A discussion of the characteristics of the generated debris is provided in Section 3.3 of this report.

III.2 Containment Spray Modeling

The licensee's debris transport calculation [16] stated that the containment spray inflow to the containment pool was modeled as flows at the surface of the water. Fourteen inlet flow locations were used to distribute the containment spray inflow of 4,500 gpm (2,250 gpm per pump). A diagram was provided in the licensee's debris transport calculation [16] to illustrate the position of these spray flow inlet locations.

The methodology supporting the distribution of the containment spray flow among the fourteen inlet flow locations was provided in the debris generation calculation [32] (Section 5.7 and 6.1 of the Debris Generation Calculation report). The licensee specified that the maximum flow of 2,250 gpm per pump is the run-out flow for these pumps.

Based upon the information provided by the licensee, the staff concluded that the licensee's general methodology for computing the containment spray drainage pattern appears reasonable. Furthermore, based upon the use of run-out flow for the maximum containment spray flow, the staff concludes that the sump flow rate used by the licensee is conservative with respect to predicting debris transport.

III.3 CFD Convergence Criteria

The licensee's criteria for determining that the containment flows predicted in the CFD simulations have converged to steady-state conditions were discussed briefly in Appendix G to Attachment 1 of the debris transport calculation [16]. The discussion in Appendix G states that convergence is judged through a variety of measures and notes that monitoring residual values alone may not be sufficient to ensure that convergence has been achieved. The discussion also states that additional monitoring parameters were placed in specific locations within the CFD model to assist in determining when the mass flow through certain openings and flow velocities in regions of interest had achieved relatively steady values.

As a means of further investigating the licensee's convergence criteria, the staff conducted an extended simulation using the licensee's FLUENT input decks. Based upon plots of the residual values of the staff's simulation, the staff concluded that the CFD results had converged to an acceptable degree. The staff agrees with the licensee's statement in Appendix G that ensuring acceptable convergence of a CFD simulation may entail more effort than simply monitoring residual values, and, in light of the licensee's additional monitoring parameters and the staff's additional simulation analyses, the staff did not identify any concerns for Waterford 3 in this area.

III.4 Modeling of Obstacles and Potential for Pool Flow Blockage

Attachment 1 to the debris transport calculation [16] discusses the modeling of flow obstacles in the containment pool and references the debris generation calculation [32], which has further information on this subject. The licensee stated that simplifications were made in the process of modeling flow obstructions and other aspects of the pool geometry, but that, in each case, the simplifications were biased toward achieving a conservative result. A conservative result in this context would be that a higher water velocity is predicted for the simplified case.

As an example of modeling simplifications, the licensee stated that, since there is no documented basis for the percentage of trisodium phosphate (TSP) that will be dissolved by the onset of recirculation, it was assumed in most cases run by the licensee that no TSP dissolves prior to the onset of recirculation. In those cases all TSP baskets were modeled as solid obstructions (Scenarios 1 through 4) to induce higher pool velocities. On the simulations conducted to assess the impact of the new strainer configuration on the flows in the containment, the TSP baskets were modeled as solid (for Scenarios 5, 7, 11 and 12), and for Scenarios 6 and 8 the TSP baskets were modeled as being open. The staff generally considers the modeling of the TSP baskets as solids conservative since it tends to lead to higher pool velocities in the vicinity of the baskets than modeling them as porous mesh. However, the staff considered the licensee's sensitivity runs with open TSP baskets (Scenarios 6 and 8) to be valuable for understanding the containment pool flow fields following the dissolution of the TSP and notes that the licensee also performed essentially identical simulations to Scenarios 6 and 8, but with the TSP baskets modeled as solid (Scenarios 5 and 7).

As another example of modeling simplification, the reactor drainage tank was represented with a rectangular block having a width and height equal to the diameter of the true round tank.

In general, the staff considers modeling simplifications to be acceptable provided that they do not lead to non-conservative results. Based upon a sampling review of the licensee's modeling of flow obstructions, the staff did not identify any concerns with the licensee's modeling of containment pool flow restrictions.

Separately, the staff's review of diagrams of the containment floor geometry in Attachment 1 to the debris transport calculation [16] did not result in the identification of any areas where debris blockage of flow passages appeared capable of significantly altering the containment flow field.

III.5 Adequacy of Computational Mesh Size

In Attachment 1 to the debris transport calculation [16], the licensee briefly described the computational grid used to perform the CFD analysis. The licensee stated that the initial grid mesh was coarse, meaning that as small a number of cells (250,073 cells) were used to create the mesh. During the simulation runs additional cells were added to refine the computational mesh to capture details in flow in areas of interest.

The license stated that the total number of computational cells ranged from approximately 935,000 to approximately 1,269,000 cells over all the simulation runs. After the adaptive meshing process was completed, the licensee stated that the characteristic length of the computational cells ranged from approximately 0.14 inches at the floor level in the break flow region to 14.3 inches at the north end of the containment pool where flow details were not as important.

The staff considers the number of cells used in the licensee's CFD model to be reasonable based upon past experience with modeling containment pools with CFD. Based upon this past experience, the staff did not conduct independent CFD simulations to assess the impact of changes to the computational mesh.

III.6 CFD Flow Rates

The debris transport calculation [16] discusses the maximum containment recirculation sump flow rates and references the debris generation calculation [32], which has further information on this subject. The licensee assumed a maximum high-pressure safety injection flow of 1,970 gpm (985 gpm per HPSI pump) for a total flow into containment building of 6,470 gpm (break flow and 4500 gpm of CSS flow). These flows are the run-out flow for these pumps. This approach is a conservative estimate of debris transport to the containment sump since at run-out pump flows are maximized.

Based upon the information provided by the licensee, the staff concluded that the licensee's general methodology for computing the containment recirculation flow appears reasonable. Furthermore, based upon the use of run-out flow for the maximum containment recirculation flow, the staff concludes that the flow rate used by the licensee is conservative with respect to predicting debris transport.

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