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UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

July 13, 2007

Mr. David W. Dodson
Supervisor, Station Nuclear Licensing
Dominion Nuclear Connecticut, Inc.
Millstone Power Station
Building 475, 5th Floor
Rope Ferry Road
Waterford, CT 06385

SUBJECT: MILLSTONE POWER STATION, UNIT NO. 2 - REQUEST FOR PROPRIETARY REVIEW OF DRAFT CORRECTIVE ACTIONS AUDIT REPORT FOR GENERIC SAFETY ISSUE - 191 RELATED TO GENERIC LETTER 2004-02

Dear Mr. Dodson:

Please find enclosed the Nuclear Regulatory Commission (NRC) staff's draft corrective actions audit report for Millstone Power Station, Unit No. 2 regarding Generic Safety Issue - 191, related to Generic Letter 2004-02, "Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized-Water Reactors," dated September 13, 2004.

The NRC staff is requesting that the enclosed draft report be reviewed by Dominion Nuclear Connecticut, Inc., and affiliated containment sump screen vendors and analytical contractors for any proprietary content. Pursuant to Section 2.390 of Title 10 of the *Code of Federal Regulations* (10 CFR), we have determined that the enclosed draft report does not contain proprietary information. However, we will delay placing the draft report in the public document room for a period of 10 working days from the date of this letter to provide you with the opportunity to comment on any proprietary aspects. If you believe that any information in the enclosure is proprietary, please identify such information line-by-line and define the basis pursuant to the criteria of 10 CFR 2.390. After 10 working days, the draft report will be made publicly available. The final report will be issued after making any necessary changes and will be made publicly available.

Please contact me at 301-415-3204 with any questions regarding this request.

Sincerely,
/ra/

John Hughey, Project Manager
Plant Licensing Branch I-2
Division of Operating Reactor Licensing
Office of Nuclear Reactor Regulation

Docket No. 50-336

Enclosure:
As stated

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Millstone Power Station Unit 2 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
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
FCS	Fort Calhoun Station
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
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
OECD	Organization for Economic Co-operation and Development
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
RNG	Re-normalized Group Theory
RMI	reflective metal insulation
RMO	Repetitive Maintenance Orders
RWST	refueling water storage tank
SAMG	Severe Accident Management Guideline
SBLOCA	small break loss of coolant accident
SCE	Southern California Edison
SEM	scanning electron microscope
SA	[strainer] screen assembly
SE	NEI 04-07, Volume II: Safety Evaluation on NEI 04-07 Volume 1, PWR Sump Performance Evaluation Methodology
SI	safety injection
SIS	safety injection system
SONGS	San Onofre Nuclear Generating Station
SPI	Site Program/Procedure Impact
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.

Millstone Power Station, Unit 2 (Millstone 2 or MP2) is operated by Dominion Nuclear Connecticut, Inc., the licensee.

The onsite activities of the Millstone 2 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, head-loss and vortexing, net-positive suction head (NPSH) margin, screen modification package, downstream effects on components and systems, and chemical effects. The audit of the technical areas of pipe whip and jet impingement on the new strainer, and downstream effects on fuel and vessel, were conducted as NRC Headquarters desk audits.

1.2 Bulletin 2003-01 Responses

The Millstone 2 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 November 10, 2004, May 17, 2005, and August 26, 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.

Millstone 2 has implemented the following interim or continuing measures in response to Bulletin 2003-01:

1. A loss of coolant accident (LOCA) strategy in which, for small-break LOCAs where reactor vessel and pressurizer level, reactor coolant system (RCS) subcooling and steam generator heat removal can be maintained or restored, high pressure safety injection (HPSI) pumps will be throttled or stopped;

2. A strategy for larger LOCAs (where HPSI throttle/stop criteria are not met), in which ECCS injection will continue until low level is reached in the RWST, sump recirculation is initiated, HPSI pump flow and pump current are monitored to detect potential inadequate net positive suction head (NPSH) due to debris blockage in the sump, and potentially one HPSI pump is stopped;

3. An existing checklist-based containment inspection procedure which includes visual inspection for loose material, removal of loose debris, removal of temporary equipment used in containment, the restraint of any temporary material that is to be left in containment, and inspection for any debris which could block containment drainage paths;

4. A post-refueling filtered draindown procedure for the refueling pool in which normal drains are opened and left open to drain collected water to the containment sump;

5. A comprehensive sump screen inspection procedure required by Technical Specifications to be completed each refueling outage;

6. Implementation of Westinghouse Owners Group (WOG)-developed Combustion Engineering Owner's Group (CEOG)-specific Emergency Procedure Guideline (EPG) strategies and interim compensatory measures relating to loss of sump recirculation;

7. Changes to Emergency Operating Procedure (EOP) 2532, "Loss of Coolant Accident," to address the potential for sump screen blockage, adding monitoring of HPSI pump discharge and suction pressures as indications of adequate recirculation flow (if sump blockage leads to inadequate HPSI flow, steps are specified for stopping containment spray, throttling HPSI to the minimum needed for decay heat removal, and refilling the RWST), with similar changes to EOP 2540CI, "Functional Recovery of RCS Inventory Control;"

8. Operator training for the sump blockage issue and on the sump blockage-related procedure changes in the classroom and simulator, including review of guidance on symptoms and identification of containment sump blockage as well as contingency actions in response to containment sump blockage, loss of suction and cavitation;

9. A January 2004 Generic Fundamentals licensed and non-licensed operator refresher training session on pumps and the sump clogging issue, with specific emphasis on NPSH and cavitation, and indications for both, as well as a February/March 2004

simulator training set for licensed operators and Shift Technical Advisors addressing a large-break LOCA with sump recirculation;

10. Modification of the EOPs to initiate actions to refill the RWST once injection from the RWST has stopped and the RWST has been isolated;

11. Technical Support Center guidance to potentially inject more than one RWST volume from a refilled or bypassed RWST; and

12. Operator procedures to conduct aggressive cooldown and depressurization following a Small Break LOCA.

The NRC staff considered the licensee's Millstone 2 response for compensatory measures to reduce the risk associated with potentially degraded or nonconforming ECCS or CSS recirculation functions, and also considered the actions taken by the licensee to be responsive to and meet the intent of Bulletin 2003-01.

1.3 Generic Letter 2004-02 September 1, 2005 Response

In response to, and as requested by GL 2004-02, Dominion Nuclear Connecticut, Inc. (DNC, the licensee for Millstone 2 Power Station) provided a letter dated September 1, 2005, containing technical information regarding analyses to be conducted and modifications to be implemented as corrective actions for GL 2004-02.

The licensee described its ECCS system design which includes low pressure safety injection (LPSI) pumps, HPSI pumps, and containment spray (CS) pumps, and four safety-related containment air recirculation coolers which use a closed cooling water system. The licensee described the initial post-LOCA RWST injection operations initiated upon a high containment pressure signal, sump recirculation operations initiated on a low RWST level signal, and containment spray operation cooled by a heat exchanger in each train to remove heat from the containment. The licensee also described LPSI pump operation to effect long-term boron precipitation control through either hot-leg or cold-leg recirculation.

The licensee stated that upon completion of activities related to modifications to the containment sump strainers, the Millstone 2 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 existing sump screen would be replaced with a new sump strainer with increased surface area that, at the start of recirculation would be fully submerged. The licensee also stated that selected insulation materials were planned to be replaced with a insulation materials of a different type with fewer adverse effects.

The licensee stated that containment walkdowns had been completed to quantify potential debris sources in containment, verify flow paths and recirculation flow choke points, and gather data for conceptual design of a replacement strainer. The debris generation calculation, downstream effects evaluations for blockage, and the procurement specifications were stated to have been drafted and in review. The debris transport and head loss calculation, chemical effects evaluation, and the downstream effects evaluation for long-term wear were stated to be in progress. The licensee stated that it anticipated no licensing basis changes requiring NRC approval for Millstone 2.

The licensee stated that a debris generation calculation had been prepared and provided a summary of debris types for the worst-case LOCA. Transport and head loss calculations were stated to be in progress, and the licensee noted that head loss testing would be conducted to determine the actual head loss for the postulated debris load on the replacement strainer. The licensee stated that that replacement of the existing debris screens was expected, and that the new strainers would be of passive design, have a high surface-to-volume ratio with 0.0625 (1/16)-inch diameter perforations, and have at most a surface area of 7900 square feet.

The licensee stated that it was considering replacement of calcium silicate insulation that could contribute to LOCA-generated debris with an insulation of a different type that has fewer adverse effects, and that there was ongoing analysis of debris laden fluid downstream blockage and wear potential.

The licensee stated that changes will be made to the containment coatings program, design control procedures, containment inspection procedures, and housekeeping procedures to control potential debris sources so that the governing debris generation and transport analyses would remain valid.

The licensee stated that head loss testing of specific plant debris loads and specific strainer designs would be conducted as necessary to determine final head loss and required strainer area.

The licensee stated that it was participating in industry testing regarding coatings zone of influence (ZOI) and head loss testing of chemical precipitates, and that uncertainties regarding head loss due to chemical precipitates and results from downstream effects evaluations could impact the final size of the strainers and perforations. The licensee stated that the final surface area of the strainer would have sufficient margin to account for uncertainties.

The licensee stated that its analysis of the susceptibility of the ECCS and CSS recirculation functions to the adverse effects of post-accident debris blockage was performed using methodology in the Nuclear Energy Institute (NEI) Guidance Document NEI 04-07, "Pressurized Water Reactor Sump Performance Evaluation Methodology," dated December 16, 2004 (the "Guidance Report" or GR), as modified by the NRC Staff Safety Evaluation Report (the "Safety Evaluation" or SE) for NEI 04-07.

The licensee described its completed and planned evaluations in the following areas: break selection, insulation, coatings, foreign material control, debris transport methodology, strainer head loss, and downstream effects, as well as an exception taken to GR and SE break selection guidance for considering breaks at regular five foot intervals along reactor coolant system (RCS) piping, with rationale for why the limiting break for debris generation had still been selected.

The licensee stated that the minimum available NPSH margin for the ECCS pumps in the recirculation mode at switchover to sump recirculation, not including the clean screen head loss, was 0.84 feet, and the limiting pumps were the HPSI pumps. The maximum postulated head loss from debris accumulation on the submerged sump screen was specified (strainer design requirement) to be 0.6 feet of water or less.

The licensee stated that the primary constituents of the debris bed at the sump screen were expected to include reflective metal insulation, Nukon fiber insulation, fiberglass insulation, mineral fiber, encapsulated mineral wool, calcium silicate, qualified and unqualified coatings, latent debris, and miscellaneous debris such as stickers and tags. The licensee further stated that sump strainer suppliers were currently developing plans and schedules to quantify the additional head loss associated with chemical precipitants, and that the licensee had pans to evaluate the adequacy of the strainer design and would include margin for head loss due to chemical precipitants once the test results to quantify that head loss were known.

The licensee stated that evaluation of the flow paths downstream of the containment sump to determine the potential for blockage due to debris passing through the sump strainer was then in progress. The assumed sump strainer opening size was 1/16" for this analysis. The actual strainer opening size in the replacement strainer would be decided as a part of the final design. The licensee stated that the new strainer design would ensure that gaps at mating surfaces within the strainer assembly and between the strainer and the supporting surface would not be in excess of the strainer perforation size.

The licensee stated that the scope of the downstream flow blockage evaluation included the components in the recirculation flow paths such as throttle valves, flow orifices, spray nozzles, pumps, heat exchangers, and valves, and that the Millstone 2 fuel vendor was performing evaluations for blockage through the reactor vessel internals as well as for blockage of the reactor fuel.

The licensee stated that verification that close tolerance downstream components are not susceptible to plugging or wear due to extended post-accident operation was in progress. Specifically, wear evaluations of flow orifices, heat exchangers, and ECCS pumps were in progress, with throttle valves used for flow balancing in the injection lines being the most susceptible valves to wear. The licensee stated that, based on the wear analysis results, additional valves might be evaluated.

The licensee stated that instrumentation required during the post-LOCA recirculation had been identified and the corresponding root valves were being evaluated for clearance and wear. Evaluations of instrumentation for debris settling in the instrument lines were stated to be in process.

The licensee stated that the preliminary design for the replacement sump strainer did not include trash racks, and that the ECCS sump is located outside the missile barriers and any high-energy line break zones of influence. The licensee further stated that preliminary analysis had indicated that the strainer is subject to loads from expanding jets or pipe whip from nearby high-energy lines, but that the replacement strainer would be designed to withstand these loads without collapse or structural damage. In addition, the strainer would be designed to withstand loads imposed by the accumulation of debris, pressure differentials under predicted flow conditions as specified in the design requirements, and seismically generated loads.

The licensee stated that changes to the existing ECCS sump screen would be evaluated under 10 CFR 50.59, and that appropriate changes to the Millstone 2 licensing basis would be conducted as determined by the 10 CFR 50.59 evaluation.

The licensee stated that programmatic controls for containment debris sources would be put into existing procedures to ensure that the potential containment debris load is adequately controlled to maintain ECCS pump NPSH margin. The licensee specifically addressed control of piping and equipment insulation, latent debris, coatings, foreign material and recirculation flowpaths.

2.0 DESCRIPTION OF PLANNED CHANGES

Millstone 2 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. Two emergency core cooling system (ECCS) suction pipes extend 11 inches above the containment floor with no sump pit. Recirculation switchover is automatic in that the sump isolation valves open on low refueling water storage tank (RWST) level, and the low pressure safety injection (LPSI) pumps stop. The high pressure safety injection (HPSI) pumps and Containment Spray (CS) pumps continue in operation at switchover. Two long headers of Atomic Energy of Canada, Limited (AECL) strainer modules approximately 40 feet in length have been fitted to the two ECCS suction pipes via a common water box. The two strainer module headers extend along the reactor vessel shield wall at a 90° angle to each other. The strainer headers have "fins" on both sides. The fins have vertically-oriented faces of corrugated steel (60° angle) with 1/16 inch circular holes. The distance between the fins (fin pitch) is approximately 10 inches. There are a total of 6000 ft^2 of strainer face in the two headers.

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 in order to identify 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 signficantly 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.

The NRC staff determined that the following documents provided by the licensee for Millstone 2 contained information related to the Break Selection analytical process:

- Debris Generation Calculations GSI-191-ECCS-04161M2 Rev.0 [166]
- CCN 1 to Calculation GSI-191-ECCS-04161M2 [167]
- Debris Source Inventory Walkdown Report 77-5036649-01 [168]
- Evaluation of IN 2005-26 for MP2 M2-EV-05-0030 [169]
- Technical Evaluation discussing Sump Recirculation following a Main Steam Line Break (MSLB) M2-EV-05-0026 [170]
- MP2 letter to NRC on Cal Sil dated 11-29-05, 05-784 [171]

NRC Staff Audit:

The NRC staff reviewed the licensee's overall break selection process and the methodology applied to identify the limiting break. Specifically, the NRC staff reviewed the documents referenced above against the approved methodology documented in Sections 3.3 and 4.2.1 of the SE and GR. The NRC staff found that the licensee's break selection evaluation was generally performed in a manner consistent with the approved SE methodology. Deviations from the staff-approved methodology were considered to be reasonable based on the technical basis provided. A detailed discussion is provided here. Section 3.3.5 of the staff SE describes a systematic approach to the break selection process which includes guidance for identification of break locations that rely on recirculation to mitigate the event:

Case No. 1 - Breaks in the 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 spectrum of breaks evaluated by the licensee is consistent with that recommended in the SE and is also consistent with regulatory position 1.3.2.3 of Regulatory Guide 1.82, Revision 3 (Ref [5]). However, during the on-site phase of the audit, members of the Millstone staff indicated that the Reactor Coolant System piping that makes up the "loop-seal pipe" from the steam generator cold leg nozzle to the reactor coolant pump suction went below the -3' 6" floor grating. This could make a break in this piping a limiting break for the Break Selection Case #3 criterion, "a direct path to the containment sump," and could also expose the strainer to high jet forces and hydraulic loads. The licensee did not confirm this piping arrangement does not potentially result in a new limiting case for Break Criterion Case #3, nor did the licensee assess the pipe whip and jet impingement effects from the "loop-seal pipe" in its revised sump structural analysis. The need for the licensee to confirm the "loop-seal pipe" piping arrangement does not result in a new limiting case for Break Criterion Case #3 is designated as **Open Item 1**. The need for the licensee to address possible "loop-seal pipe" pipe whip and jet impingement effects is discussed in Section 5.1 "Sump Structural Analysis - Pipe Whip and Jet Impingement."

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

The Millstone 2 plant configuration consists of two reactor coolant loops (A and B), each consisting of a steam generator, two reactor coolant pumps, and reactor coolant piping. Each loop is contained in a concrete enclosure referred to as the east and west steam generator (SG) cavities. These are essentially equivalent with respect to piping and equipment insulation, with the following exceptions:

- The pressurizer is located adjacent to the east SG cavity;
- The regenerative heat exchanger is located within the west SG cavity; and
- The shutdown cooling line is located within the west SG cavity.

Based on piping isometric drawings, piping plan and section drawings, equipment location drawings, insulation drawings, civil/structural drawings, and equipment drawings, the licensee determined that the SG cavities are essentially identical with allowances needed only for the three items identified above. To apply this SG cavity symmetry, the insulation destruction was modeled for the east SG cavity without considering the pressurizer. Then the pressurizer insulation destruction was added to that inventory to obtain the insulation debris inventory for the east SG cavity breaks. For the west SG cavity breaks, the insulation debris inventory associated with the regenerative heat exchanger and the shutdown cooling lines was added to the original east SG cavity insulation debris inventory results.

The licensee did not apply a 5-ft incremental step-wise approach to the break selection process due to the plant physical configuration as it related to the expected size of the coolant line break zones of influence (ZOIs) for the insulation types involved because the ZOIs essentially included the entire SG cavity. Instead, the staff reviewed this approach as it applied to the Millstone 2 plant configuration, and agreed that performing the analysis by considering 5-ft increments was not necessary due to this large relative size of the relevant ZOIs.

The licensee considered breaks in all primary reactor coolant system piping having the potential to rely on Emergency Core Coolant System (ECCS) sump recirculation. Only piping 2 inches in diameter and larger was considered. The NRC staff found this to be consistent with Section 3.3.4.1 of the SE, which states that breaks less than 2 inches in diameter need not be considered. For Millstone 2, feedwater and main steam piping were not considered since recirculation flow is not required for mitigation of secondary-side breaks.

Licensee documentation listed reflective metal insulation (RMI), Nukon, flexible elastomeric, mineral fiber, and encapsulated mineral wool inside the SG compartments. The licensee documentation also showed some calcium-silicate insulation within the steam generator cavities, but the licensee stated that this material had all been removed during the most recent refueling outage. Updated documentation showing the latest insulation types and amounts was provided for review at the on-site audit.

The licensee evaluation in the reference documents, utilizing the cavity symmetry, as mentioned above, identified three break locations that provided limiting conditions for each of the 5 break selection criteria above:

> Break S1: A hot leg break at the #1 steam generator inlet.
>
> Break S2: A hot leg break at the #2 steam generator inlet.
>
> These two breaks are for all practical purposes identical from an insulation debris generation standpoint. Neither break was shown to be significantly limiting, and the analysis shows the amounts and types of debris from these two breaks to be nearly the same. Proximity to the sump was found to be only a minor concern due to the licensee-assumed transport scheme of assuming all "small" debris transports and all "large" debris will not. These breaks are limiting for SE break selection criteria Case 1, Case 2, Case 4, and Case 5.
>
> Break S3: The reactor coolant pump (RCP) 2A discharge line has the most direct path to the sump (SE break selection criteria Case 3), but the smaller size of this line (32 inches vs. 42 inches for a hot leg) and associated ZOI make this a non-limiting break location.

A fourth break, in the pressurizer surge line, was included in the documentation as a preliminary evaluation for the Alternate Methodology identified in Chapter 6 of the SE, but the Alternate Methodology was not used at Millstone 2.

The licensee was asked during the audit about potential reactor vessel (RV) nozzle breaks generating RV annulus insulation debris. The licensee stated that all of the insulation mounted on the RV is reflective metallic insulation (RMI) manufactured by Diamond Power Specialty Company. Because RMI debris would not likely transport out of the reactor cavity area or accumulate in significant quantity on the large trains of replacement strainer modules, and this metallic debris would not cause substantial head losses even if it were to accumulate in the vicinity of the new strainer modules, RV nozzle breaks were not evaluated. The staff considered the licensee position to be acceptable for the reasons stated by the licensee.

The licensee stated that a review of smaller (less than 2 inches in diameter as defined in the SE) break LOCAs indicated a lower strainer head loss than for the larger break LOCAs analyzed. Smaller breaks would generate substantially less debris; might not activate Containment Spray, thereby reducing debris transport to the strainers; and would result in reduced ECCS flow rates (with a corresponding reduction in strainer head loss) to the core due to flow resistance at the break. On the negative side, the sump pool water level would be somewhat lower for small breaks than for the large breaks, which would reduce the NPSH margin. The licensee judged the reductions in debris generation and transport associated with small breaks to have a far more influential effect on strainer head loss than would be the reductions in NPSH margin. Based on the information provided by the licensee, the staff agrees with this justification and considers the position acceptable.

3.2 Debris Generation/Zone of Influence (Excluding Coatings)

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

The GR baseline methodology incorporates a spherical ZOI based on material damage pressures. The size of the spherical ZOI for a material, if known, is based, in general, on experimentally-deduced destruction pressures as they relate to the ANSI/ANS 58.2 1988 standard [19]. Once the most limiting (largest) ZOI is established, the types and locations of all potential debris sources (insulations, coatings, dirt/dust, fire barrier materials) can be identified using plant-specific drawings, specifications, walkdown reports or other such reference materials. The amount of debris generated is then calculated based on the amount of materials within the most limiting ZOI.

Section 4.2.2 of the SE discusses proposed refinements to the GR methodology that would allow application of debris-specific ZOIs. This refinement allows the use of a specific ZOI for each debris type identified. Using this approach, the amount of debris generated within each ZOI is calculated, then added to arrive at a total debris source term. The NRC staff concluded in its SE that the definition of multiple, spherical ZOIs at each break location corresponding to damage pressures for potentially affected materials is an appropriate refinement for debris generation. As discussed in Section 4.2.2 of the SE, the NRC staff accepted the application of these proposed refinements for PWR sump analyses for GL 2004-02 [4] corrective actions. The NRC staff determined the following documents provided by Millstone contained information related to the Debris Generation/ZOI evaluation process:

- Debris Generation Calculations GSI-191-ECCS-04161M2 Rev.0 [153]
- CCN 1 to Calc GSI-191-ECCS-04161M2 [154]
- Debris Source Inventory Walkdown Report 77-5036649-01 [155]
- Evaluation of IN 2005-26 for MP2 M2-EV-05-0030 [156]
- MP2 letter to NRC on Cal Sil dated 11-29-05, 05-784 [158]
- M2 ERC on Reactive Metal Quantities in Ctmt [159]
- MP-PROC-ADM-OA 8, REV=007-00 [160]
- Reduced Debris Load ERC 06 0015 [161]
- SP 2605I-001, REV=008-05 [162]
- SP 2605I, REV=007-01 [163]

Staff Evaluation

The staff reviewed the licensee's ZOI and debris generation evaluations and the methodology applied. Specifically, the staff reviewed the documents referenced above against the approved methodology documented in Sections 3.4 and 4.2.2 of the staff's SE. The NRC staff found the licensee's evaluation to be consistent with the approved methodology. The staff concluded that, with the exceptions of the open items identified below, the licensee's evaluation is acceptable based on this consistency with the SE guidance.

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

Section 3.4.2.2 of the SE provides guidance for selection of a ZOI. The entries in Table 3.2-1 of the SE relevant to the material types referenced for Millstone 2 show the following:

Table 3.2-1 Revised Damage Pressures and Corresponding Volume-Equivalent Spherical ZOI Radii

Insulation Types	Destruction Pressure (psig)	ZOI Radius/ Break Diameter
Transco RMI	114	2.0
Unjacketed Nukon Nukon with standard bands Knaupf	6	17.0
Cal-Sil	24	5.45

The Millstone 2 Debris Generation calculation (Ref. [153]) was not final. The documentation reviewed included change pages that still showed calcium silicate debris generation, a material that the licensee stated had been completely removed from the potential ZOI regions; and also discussed debris generated by submergence and containment spray erosion, which had been deleted from the head loss test debris. The licensee was correct in deleting the submergence/spray-generated debris, because all of the insulation remaining in the LOCA ZOIs has sufficient covering to preclude significant debris generation by erosion and similar processes. The finalization of the Millstone 2 debris generation calculations is designated as **Open Item 2**.

The debris generation calculation identifies the following types of insulation types as remaining within the ZOIs in the Millstone 2 containment: Transco RMI; Nukon fabric; Transco encapsulated (metal cassettes) mineral wool; Cal-Sil (calcium silicate insulation); mineral fiber with stainless steel (SS) jacketing; and Claremont Fiberglass. Not all of these insulation types are specifically identified in the SE. The Claremont fiberglass insulation was treated by the licensee as a low-density fiberglass (LDFG) roughly equivalent to Nukon. The mineral fiber manufacturer was not specified by the licensee. However, the licensee conservatively determined the expected volume of mineral fiber generated in a LOCA based on Knaupf LDFG insulation destruction pressure and ZOI values, based on the higher destruction pressure and lower ZOI for mineral fiber shown in the SE. Because no ZOI or test data was referenced in the SE for Transco encapsulated mineral wool, the relatively large 17D radius was assumed for this insulation material as well. It is notable that mineral wool has a higher bulk density than Nukon, and also that the Transco metallic cassettes should provide significant protection to the mineral wool. These are conservative factors that were not specifically credited by the licensee. In summary, the licensee's positions for insulation types not identified in the SE are considered appropriate and acceptable.

Licensee personnel stated that all Cal-Sil was recently removed from inside the steam generator cavities within the containment, so that there is no longer any plausible high-energy line break that can impact the remaining Cal-Sil in containment. This was confirmed by the NRC staff by evaluating system piping drawings. The remaining Cal-Sil insulation is located in the containment penetration area, outside of all LOCA ZOIs. Further, metal jacketing protecting the remaining Cal-Sil insulation would prevent significant damage due to containment spray, and none of this calcium silicate would become submerged.

The calcium silicate insulation removal within all LOCA ZOIs, and the location and jacketing of the remaining calcium silicate insulation, significantly reduce the potential for formation of calcium phosphate precipitate at Millstone 2, and the resultant negative effects on screen head loss. For a more detailed review of this issue, see the Chemical Effects evaluation in Section 3.6. of this report. The information in Section 3.6 of this report leads the staff to conclude that the contribution of calcium phosphate from trisodium phosphate (TSP)-calcium silicate chemical reaction in Millstone 2 is not significant with respect to sump screen debris loading when compared to the other potential sources of debris.

The containment debris walkdown report Ref. [155] also identifies Armaflex and flexible elastomeric insulation on some piping that would be included in the ZOIs identified. Reference [153] states: "Elastomeric foam has a closed-cell structure that prevents absorption of water, and allows it to float on water. Therefore, elastomeric foam insulation does not pose a credible source for screen blockage, and for the purpose of this calculation, it is excluded from the debris quantity." Technical data sheets were provided to the NRC staff to show the characteristics of this insulation, confirming this position.

A summary of the expected LOCA Generated Debris is included in Table 6.2-1 of [154] for each of the four breaks analyzed. A reduced summarization of the expected insulation debris generation quantities is provided in Table 3.2-2 below:

Table 3.2-2: Summarization of Expected Debris Generation Quantities

Debris Type	Break S1	Break S2	Break S3	Break S4
Transco RMI Foil, ft^2	1239.6	1454.7	652.8	331.2
Claremont Fiberglass, ft^3	110.1	110.1	25.9	11.3
Nukon™, ft^3	1135.1	1152.0	992.0	363.1
Mineral Fiber, ft^3	297.3	297.3	244.1	30.1
Transco Encapsulated Mineral Wool, ft^3	159.4	159.4	159.4	159.4
5% Margin-Fiber Insulation, ft^3	85.6	86.4	71.1	28.2

As noted in Table 3.2-2, an additional 5% of fiber insulation was added for evaluation purposes for conservatism. The data indicate that there are some considerations that can affect the values of debris generated. The physical radius of a 17D ZOI around a 42-inch pipe break would be approximately 60 ft. Such a sphere would encompass essentially the entire affected SG cavity (graphical materials that overlaid the ZOI onto the SG cavities were not provided by the licensee). Because of this, the quantities of debris generated are limited by the cavity walls rather than the size of the ZOI, with the exception of the small ZOI for the Transco RMI. The insulation on the pressurizer is being replaced with Transco RMI under the pressurizer replacement project. This places the pressurizer outside the ZOI for the large hot leg break, so the pressurizer insulation does not contribute to the debris load.

In general, the debris generation evaluation for the LOCA-generated insulation debris is considered to be conservative because the licensee consistently used either SE-accepted practices or values, or clearly used conservative approaches.

Other sources of debris at Millstone 2 include coatings debris, latent debris, and chemical effects precipitants. The coating debris generation is discussed separately in Section 3.7, latent debris is discussed in Section 3.4, and chemical effects precipitates are discussed in Section 3.6. The staff reviewed the entries in Table 6.2-1 from [154] for the various items identified and found that the values projected are reasonable for Millstone 2 based on the information and assumptions provided by the licensee regarding the plant configuration and materials loading.

In conclusion, the staff finds the licensee's Debris Generation/ZOI evaluation to be acceptable. The evaluation was performed in a manner consistent with the approved SE methodology. The licensee applied the ZOI refinement discussed in Section 4.2.2.1.1 of the SE, which allows use of debris-specific spherical ZOIs. Where appropriate, the licensee applied material-specific damage pressures and corresponding ZOI radius/break diameter ratios as shown in 3.2-1 of the staff SE. For insulation types not found in the SE, the licensee applied reasonable, or conservative, substitute values for insulation properties; and provided adequate technical justification for these positions. The staff found that the licensee provided an adequate level of technical justification with respect to the Debris Generation/ZOI analyses.

3.3 Debris Characteristics (Excluding Coatings)

The specification of debris characteristics is important to analytical transport and head loss evaluations and to the specification of surrogate materials for head loss testing. The licensee discussed Millstone 2 debris characteristics in the Millstone 2 debris characteristics report [164], debris generation report [153], debris transport report [97], and reduced-scale head loss test report [165]. The potential LOCA-generated sources of debris for the Millstone 2 containment include debris from five types of insulation: Nukon™; Claremont fiberglass; mineral fiber; Transco encapsulated mineral wool; and Transco RMI. The potential quantities of debris from these insulation types were shown on Table 3.2-2 in the Debris Generation/ZOI section above. Besides the insulation sources, other potential debris sources include latent fiber, latent particulate, foreign material debris, and coatings debris. The NRC staff review findings for the licensee's debris characteristics designations for each debris type (except for coatings) are provided below (see Section 3.7 for a coatings debris characterization discussion).

Nukon™ Insulation

A LOCA inside the Millstone 2 containment could generate substantial quantities of Nukon™ insulation debris. The licensee adopted the SE [2]-accepted radius of 17D for the postulated ZOI. The licensee's assumed size distribution of 8 percent for fines, 25 percent for small exposed pieces, 32 percent for large exposed pieces, and 35 percent for debris still encased in jacketing, was developed from the confirmatory research guidance in the SE appendices.

The licensee assumed that 100 percent of the Nukon fines would transport to the strainers and that the transport fractions of the larger Nukon debris could be predicted using the floor tumbling and lift velocities method in their containment pool CFD transport analysis. The licensee assumed transport velocities taken from NUREG/CR-6772 [17]. The tumbling velocities were established as 0.12 ft/s and 0.35 ft/s respectively for small/large pieces of exposed debris and for large jacket covered debris. The assumed lift velocities of 0.29 ft/s and 0.70 ft/s for small/large pieces of exposed debris and for large jacket covered debris respectively were based on a four-inch high curb around the containment sump and obtained by interpolating between the 2 and 6-in lift velocities from [17] for Nukon™. These velocities are valid for relatively uniform and non-turbulent flows.

The licensee assumed the GR recommendation for Nukon™ head loss characteristics. The bulk and material densities were 2.4 lbm/ft^3 and 159 lbm/ft^3 respectively. The fibers were assumed to be nominally 7 μm in diameter with a specific surface area of 171,000/ft [ft^2/ft^3].

Claremont Fiberglass Insulation

The licensee did not provide any debris characteristics specific to the Claremont fiberglass insulation. Rather, the licensee stated the Claremont insulation was low-density fiberglass (LDFG) insulation sufficiently similar to Nukon™ such that the Nukon™ characteristics could be adapted to the Claremont fiberglass. The licensee stated that this assumption was made without specifically comparing the characteristics of the Nukon™ and the Claremont fiberglass. This assumption would normally not be acceptable since debris characteristics can affect analyses such as transport calculations. However, for Millstone 2, the quantities of Claremont debris are not signficant relative to the quantities of other types of fibrous debris (Table 3.2-2 above shows that the potential volume of Nukon™ debris is 10 times that of the Claremont debris). The licensee assumption of Nukon™ debris characteristics for the Claremont fiberglass debris is therefore acceptable due to the limited quantities of the Claremont insulation in the Millstone 2 containment.

Mineral Fiber Insulation

The licensee adopted the SE [2]-accepted Nukon™ radius of 17D as the postulated mineral fiber insulation ZOI. The 17D ZOI is acceptable because: 1) the 17D spherical ZOI would encompass a large fraction of the steam generator compartment; and 2) the dominant fibrous debris source is Nukon™ as shown in Table 3.2-2 above.

For transport purposes, the licensee assumed that all of the mineral fiber would be destroyed into fine debris that would completely transport to the sump strainers. Therefore, there was no need to specify debris transport characteristics for the mineral fiber.

For head loss characteristics, the licensee assumed the bulk and material densities were 5.5 lbm/ft^3 and 159 lbm/ft^3, respectively. The fibers were assumed to be nominally 7.5 μm in diameter with a specific surface area of 160,000/ft.

Transco Encapsulated Mineral Wool Insulation

The licensee also adopted the SE-accepted Nukon™ radius of 17D for the postulated mineral wool insulation ZOI. The 17D ZOI is acceptable because: 1) the 17D spherical ZOI would encompass a large fraction of the steam generator compartment and 2) the mineral wool is encapsulated inside Transco jacketing that should provide substantial protection to the wool fibers.

For transport purposes, the licensee assumed that all of the mineral fiber would be destroyed into fine debris that would completely transport to the sump strainers. Therefore, there was no need to specify debris transport characteristics for the mineral fiber.

For head loss characteristics, the licensee assumed the bulk and material densities were 10 lbm/ft^3 and 90 lbm/ft^3, respectively. The fibers were assumed to be nominally 5 μm in diameter with a specific surface area of 240,000/ft.

Transco Stainless Steel Reflective Metallic Insulation

The licensee adopted the GR-recommended radius of 2D for the postulated ZOI for the Millstone 2 RMI, and the licensee assumed the GR-recommended size distribution for the RMI, that is, 75 percent small fines debris and 25 percent large piece debris. This ZOI radius and debris size distribution was accepted in the SE and is therefore acceptable for Millstone 2.

The licensee assumed that 100 percent of the fines would transport to the strainers and that the transport fraction of the larger debris could be estimated using the floor tumbling and lift velocities method in their containment pool CFD transport analysis. For the large debris, the transport tumbling and lift velocities were 0.28 ft/s and 0.84 ft/s, respectively, which were obtained from [17]. These velocities are valid for relatively uniform and non-turbulent flows.

For head loss characteristics, the licensee assumed an inter-foil gap width, K_t, of 0.003 ft, which can be appropriately used in the SE-accepted RMI head loss correlation for purposes of scoping the strainer screen size.

Latent Debris

[Latent Debris is further discussed in Section 3.4 of this report.] The licensee adopted head loss debris characteristics for fibrous latent debris that were recommended in NUREG/CR-6877, "GSI-191: Separate-Effects Characterization of Debris Transport in Water" [17]. The licensee assumed the bulk and material densities were 2.4 lbm/ft^3 and 93.6 lbm/ft^3, respectively. The fibers were assumed to be nominally 5.5 µm in diameter with a specific surface area of 171,000/ft.

For latent particulate, the licensee adopted the recommendations from Appendix V of the SE. For a bulk density, the SE recommended a range from 63 to 75 lbm/ft^3, while the licensee assumed 65 lbm/ft^3. The SE recommended a specific gravity of 2.7 for the material density, which corresponds to the 168.4 lbm/ft^3 assumed by the licensee. The licensee assumed the SE [2]-recommended specific surface area of 106,000/ft that corresponds to a nominal spherical particle diameter of 17.3 µm. Because the licensee followed the SE guidance, its latent particulate characteristics are acceptable.

Because all latent debris was assumed to transport completely to the sump strainers, no transport characteristics needed to be specified by the licensee.

Foreign Debris

The licensee did not provide any debris characteristics for the foreign debris. As discussed in Section 3.4 of this report, Millstone 2 accounts for tags, labels, tape and other materials by assignment of 150 ft^2 of sacrificial area of the sump screen based on a plant walkdown. Therefore, because, in effect, 100% transport of foreign debris is assumed, debris characteristics for foreign debris were not specified by the licensee.

3.4 Latent Debris

[Latent debris is further discussed in Section 3.3 of this report.]

3.4.1 Scope of Audit

Millstone 2 performed an evaluation of the potential sources of "latent debris", using guidance provided by the NEI Guidance Report (GR) [1] and the NRC Safety Evaluation Report [2]. Latent debris is that debris that is present in containment before a postulated LOCA occurs, as opposed to debris that would be generated during a LOCA. Such debris could include fibers, particulates (e.g., dust and dirt), and tags and labels. The NEI GR provides recommendations for quantifying the mass and characteristics of latent debris inside containment. The following baseline approach is recommended: (1) estimate the total area, including both horizontal and vertical area contributions, (2) survey/sample the containment to determine the mass of debris present, (3) define the debris composition and physical properties, (4) determine the fraction of total area that is susceptible to debris buildup, and (5) calculate the total quantity and composition of debris.

The staff reviewed the Millstone documents which addressed the measurements and calculations used to quantify the mass and characteristics of latent debris in containment.

3.4.2 Latent Debris Sampling Methodology

The Millstone latent debris sampling methodology is described in "Latent Debris in Accumulation in Millstone 2 Containment," Millstone Calculation No. ENG-04154M2, Rev. 0 (March 2006) [144]. The licensee document stated that the surfaces in the Millstone containment were divided into vertical and horizontal surface categories, and the surface area of each category was estimated. The containment was surveyed to determine the mass of debris present. For each area category at least three latent debris samples were taken and weighed. An area of $2ft^2$ was sampled at each location. The latent debris mass for each surface category was computed using the total area for the surface category and the average mass of debris per unit area derived from the sampling. The total mass of latent debris was then obtained by summing the masses computed for each surface category.

The licensee did not perform a physical characterization of the samples. Instead, as stated in the GR [1], the licensee "...assumed the composition and physical properties of the debris, using conservative values..." [1, pages 3-35], and specified that the "...fiber contributes 15 percent of the mass of the total estimated inventory..." as recommended by the SE [2].

Based on the staff's review of the above licensee document, and comparison between it and [1] and [2], the staff concludes that the licensee's methodology follows the guidance of [1] and [2] and is therefore acceptable.

3.4.3 Latent Debris Mass Results

The quantitative estimates of the surface areas for each surface area category are presented in [3]. Based on the staff's review of the above licensee document, and comparison between it and [1] and [2], the methodology for performing these estimates follows the guidance of Ref. [1] and [2] and is therefore acceptable.

Two latent debris surveys were taken during two Millstone 2 outages (2R16 and 2R17), and are reported in [144] and [145]. The engineering data reports are provided in [146] and [147]. The latent debris masses obtained from these two sets of data were 130 lbm (2R16) and 77 lbm (2R17).

A feature of the 2R17 data is that for the painted steel, concrete and insulated surface categories the total latent debris estimated for containment from the measured samples was zero, whereas in the 2R16 sampling a total of 53 lbm was calculated based on measured sample values. The auditor checked the engineering data reports and found that the data entered supports the reported result. This accounts for the large part of the difference between the total masses obtained from the two sets of data. In general, many more zero mass samples were reported during the 2R17 sampling than in 2R16. No explanation is presented in [147].

On the basis of the two surveys and the calculated total masses, Ref. [148] states that Millstone selected 200 lbm as the value to be used for the latent debris mass [148] that allows some margin. Ref. [149] specifies 229 lbm of latent fiber is to be assumed for strainer design, and Ref. [150] shows that 220 lbm was assumed for the purpose of design of the large-scale test program. Despite the variability of the two survey-based estimates of total latent debris mass, the staff believes that the estimate of 229 lbm is reasonable and conservative based upon the survey results and calculations, since it is well in excess of the maximum of the two sample-based mass loadings.

The latent debris that was sampled at Millstone was not characterized. The assumption is made that 15 percent of the debris is latent fiber, and that 85 percent is latent particulate [148]. This assumption is consistent with findings of a study of latent debris in four plants [151], and is consistent with the guidance provided in the NRC SE [2, page 50]. The fiber/particulate fraction assumption is therefore found to be acceptable.

Millstone 2 accounts for tags, labels, tape and other materials by assignment of 150 ft^2 of sacrificial area of the sump screen [149]. At the on-site audit, staff was informed that this sacrificial area was arrived at by a plant walkdown to determine the area of tags and labels on components in the Millstone 2 containment [152]. This methodology is a conservative approach because it uses actual values from the containment, and not all tags and labels would migrate to the sump, and this approach is therefore acceptable.

3.5 Debris Transport

The licensee analyzed debris transport for Millstone 2 in Calculation GSI-191-ECCS-04162M2, Revision 0 [97] and Change 1 to this calculation [131]. Revision 0 of the debris transport calculation was prepared by Sargent and Lundy, and Change 1 to the calculation was performed by the licensee. Revision 0 of the calculation consists of three parts: (1) a description of characteristics of the debris generated by the analyzed high-energy pipe ruptures, (2) a calculation of the amount of debris that would reach the containment recirculation sump, and (3) a preliminary scoping analysis of head loss and screen performance characteristics.

This section of the audit report focuses on the debris characteristics relevant to transport behavior and the calculation of the quantities of debris transporting to the recirculation sump. Staff review of the preliminary head loss analysis was not necessary because the licensee did not rely upon this part of the calculation to demonstrate the adequacy of the replacement strainer design.

Debris transport analysis estimates the fraction of debris that would be transported from debris sources within containment to the sump suction strainers following a loss-of-coolant accident (LOCA) or other high-energy line break requiring containment sump recirculation. Generally speaking, debris transport 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.

The licensee stated that the debris transport methodology used for Millstone 2 is based on the methodology in [97] as modified by [131], and Regulatory Guide (RG) 1.82 [5]. The licensee used logic trees to calculate the transport of debris from the zone of influence (ZOI) of each analyzed pipe rupture to the sump strainers, considering debris transport phenomena associated with the blowdown, washdown, pool fill, and recirculation processes. The licensee's logic trees were based upon a generic model recommended by NEI 04-07. The licensee quantified these logic trees to calculate transport fractions for the following types of debris: (1) small and large pieces of Nukon and low-density Claremont fiberglass debris, (2) intact debris covers/jacketing, and (3) large pieces of Transco stainless steel reflective metallic insulation (RMI) [97]. The licensee did not use logic trees to compute the transported quantities for small fines, coatings, and latent debris, since these types of debris were generally assumed as fully transporting to the sump strainers (except for latent particulate debris, as described below in Section 3.5.4.7).

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

Through onsite discussions with licensee personnel, the staff learned that the licensee has plans to revise the existing debris transport analysis that was reviewed for this audit. In particular, licensee personnel indicated that a CFD analysis would be performed with the replacement strainer design that was installed in Fall 2006 (as opposed to the existing analysis, which modeled the previous sump screen), and noted that some of the conservatisms in the existing analysis may also be removed. Therefore, in addition to reviewing the acceptability of the licensee's existing transport analysis, where appropriate, the staff also mentions in the below sections relating to transport general analytical considerations for the licensee's consideration in revising the existing debris transport calculation.

3.5.1 Blowdown Transport

The licensee stated that the blowdown transport analysis was based on the methodology from NUREG/CR-6369 (the Drywell Debris Transport Study that was performed for boiling-water reactors (BWRs)) [132], 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 Millstone 2 has a mostly uncompartmentalized containment, with the exception of the existence of a pressurizer compartment. In light of the complexity of modeling the distribution of steam and air flows in containment following a pipe rupture, the licensee used the simplified methodology for blowdown transport presented in Section 3.6.3.2 of NEI 04-07.

Based upon this methodology, 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 [97]. Although NEI 04-07 does not specifically state that all fibrous debris should be modeled as directly falling into the containment pool, the licensee conservatively took this position [97]. The licensee subsequently stated that all LOCA-generated debris was conservatively modeled as falling directly into the containment pool [97]. 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 upon the expectation that the majority of the small debris blown into the upper containment would eventually be washed down to the containment pool [97].

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 the upper containment) to debris blockage (addressed in Section 5.2 of this audit report).

3.5.2 Washdown Transport

Although inertial debris capture was ultimately not credited, 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 [97]. However, since the licensee had assumed that 100% of the post-LOCA debris would be deposited directly into the containment pool, a detailed washdown analysis was not presented [97].

In general, the location where debris enters the recirculation pool may have a strong influence on the debris transport fraction. However, based upon the incorporation of significant conservatism in the existing Millstone 2 transport analysis, primarily the assumption that all post-accident debris has already been blown directly into the containment pool, and the licensee's use of the highest continuous velocity between the pipe break and the containment sump to compute debris transport fractions in the containment pool during recirculation (this methodology is described further in Section 3.5.6), the staff concludes that a detailed washdown analysis is not necessary for Millstone 2.

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. The licensee's debris transport analysis states that the Millstone 2 containment has no significant inactive holdup volumes other than the reactor cavity and normal containment building sump [97].

The licensee's pool-fill transport discussion was based on the analytical premise that, due to permanent physical obstructions in containment (such as the shield wall and the refueling canal), for debris to be trapped in the reactor cavity, the break location and target material would have to be within the primary shield wall (e.g., a reactor vessel nozzle break impinging on reactor vessel insulation) [97]. The licensee stated that debris transport into the reactor cavity through pool fill-up would be minimal because there is no path from the containment sump pool to the reactor cavity at the minimum flood elevation [97]. On this basis, the licensee considered the potential for debris retention at hold-up points or inactive pool volumes to be insignificant with regard to the transport of debris to the containment recirculation sump. Importantly, in both cases, the reactor cavity hold-up volume and the normal containment building sump, the licensee's calculations took no credit for debris hold-up.

The staff considers the licensee's neglect of debris settling in inactive pool volumes within the post-LOCA containment pool to be appropriate 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 bottom of the Millstone 2 replacement strainers is located 7 inches above the floor of containment (as opposed to being below the surrounding containment floor grade in a pit). Due in part to the strainers' raised configuration, the staff's review of the licensee's post-LOCA debris sources did not identify the potential for significant quantities of debris not already accounted for in the existing analysis as reaching the strainers during the recirculation phase of the accident to transport to and accumulate on the sump strainers during the filling of the containment pool. Therefore, based upon the information provided in the licensee's debris transport calculation, the staff considered the licensee's existing analysis 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 [97]. The licensee stated that the CFD input decks physically model the Millstone 2 containment from the containment floor level (plant elevation of -22.5 ft) to the minimum post-LOCA containment water level (plant elevation -18.27 ft) [97]. Major containment obstructions were included in the CFD model, including steam generator pedestals, the reactor head stand, various tanks, heating, ventilating, and air conditioning (HVAC) equipment, trisodium phosphate (TSP) baskets, stairs, and support columns [97]. The licensee's CFD analysis was based upon the previous sump screen; however, the licensee stated that plans exist to perform additional CFD analyses with the replacement sump strainer design. Based upon discussions with licensee personnel, the staff understood that the licensee's revised transport results may be used as an input to future chemical effects head loss testing for the replacement strainer design. The licensee's use of a CFD analysis based on the previous screen design provides an adequate model for determining debris transport for Millstone 2 because of the significant conservatisms that were incorporated into the analysis, as summarized below in Section 3.5.8.

As described in more detail below, the licensee compared the flow velocities resulting from the CFD simulation 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.

3.5.4.1 Pool Recirculation Transport Scenarios Analyzed

Using CFD, the licensee analyzed four pool recirculation transport scenarios, as summarized in Table 3.5.4.1-1 below [97].

Table 3.5.4.1-1: Pool Recirculation Debris Transport Scenarios Analyzed by Licensee

Scenario	ECCS/CSS Trains Running	Pipe Break	Description of Pipe Break
1	2	S3	A 30-inch double-ended guillotine rupture at the outlet of Reactor Coolant Pump 2A in the west steam generator cavity
2	2	S1	A 42-inch double-ended guillotine rupture at the hot leg nozzle to the east steam generator
3	2	S2	A 42-inch double-ended guillotine rupture at the hot leg nozzle to the west steam generator
4	1	S3	A 30-inch double-ended guillotine rupture at the outlet of Reactor Coolant Pump 2A in the west steam generator cavity

Once recirculation begins, the licensee stated that the flow through each of these breaks is contained within the surrounding steam generator enclosure until it flows into the containment pool at elevation -22.46 ft [97].

The licensee's justification for analyzing the four scenarios listed in Table 3.5.4.1-1 [97] is summarized in Table 3.5.4.1-2 below.

Table 3.5.4.1-2: Licensee's Justification for the Four Analyzed Recirculation Transport Scenarios

Scenario	Justification
1	Chosen due to the proximity of Break S3 to the containment recirculation sump.
2	Chosen because Break S1 is a hot leg break, which typically generates the largest quantity of debris (due to the increased diameter of the hot leg in the Combustion Engineering plant design).
3	Chosen because Break S2 is a hot leg break, which typically generates the largest quantity of debris (due to the increased diameter of the hot leg in the Combustion Engineering plant design). In addition, Break S2 is located close to the containment recirculation sump.
4	Chosen to consider Break S3 for single train operation.

The licensee stated that a debris transport analysis was not performed for Break S4, which is a 14-inch alternate break located at the hot leg nozzle to the west steam generator (i.e., the same location as Break S1) [97]. The licensee's justification for not analyzing recirculation pool transport for this break is that the quantity of debris transported to the sump strainer would be bounded by the four scenarios that were analyzed [97].

The staff agrees with the licensee's position that Break S4 is bounded by the four analyzed pool recirculation scenarios. In particular, it is clear that Scenario 2 would bound the recirculation pool conditions for Break S4, since the 42-inch S1 break at the same location would generate significantly more debris for similar but slightly more severe pool transport conditions.

Based upon the licensee's modeling of breaks in both steam generator compartments, 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. A complete review of the licensee's break selection analysis is presented in Section 3.1 of this audit report.

3.5.4.2 Debris Transport Metrics

A summary of the metrics used by the licensee [97] to analyze debris transport during containment pool recirculation is provided in Table 3.5.4.2-1 below:

Table 3.5.4.2-1: Metrics Used for Analyzing Debris Transport During Recirculation

Debris Type	Incipient Tumbling Velocity (ft/s)	Curb Lift Velocity (ft/s)
Transco Stainless Steel RMI Foils	0.28	0.84
Nukon Low-Density Fiberglass	0.12	0.29
Insulation Covers / Jacketing	0.7	None Measured

For the Transco RMI foils debris and Nukon low-density fiberglass debris, the licensee chose both the incipient tumbling velocity metric and the curb lift velocity metric based upon experimental data reported in [142]. The curb lift velocity metric for Transco RMI is conservative because this metric is based upon a 2-inch curb height, which is smaller than the licensee's existing curb height of 4 inches. The curb lift velocity for Nukon is based upon a linear interpolation between reported results for 2-inch curbs and 6-inch curbs. The staff considers this approximation physically reasonable and appropriate based upon the expected upward concavity of curb lift velocity as a function of curb height.

The licensee applied the debris transport metrics for Nukon low-density fiberglass debris to Claremont low-density fiberglass debris. The staff considered this treatment to be acceptable because (1) the Nukon and Claremont insulations are both low-density fiberglass and (2) the quantities of Claremont fiberglass debris generated at Millstone 2 are less than 10 percent of the quantities of Nukon fiberglass debris for the analyzed breaks.

The licensee's incipient tumbling velocity metric for insulation covers/jacketing is based upon experimental data described in NUREG/CR-3616 [134] for RMI jacketing. This technical report indicates that different tumbling velocities were measured for RMI jacketing, depending upon whether the concave side was facing up or down. The licensee stated that the tumbling velocity metric for the more conservative condition was chosen (concave up). The licensee stated that the available literature does not include curb lift velocities for insulation covers, but used engineering judgment to state that, because the size and density of RMI foils makes them resistant to lifting over curbs, larger and/or denser insulation jacketing covers could not be transported over a 4-inch curb. The licensee further concluded that the jacketing for other insulations is sufficiently similar to that of RMI to apply both of the transport metrics for RMI jacketing to the covers/jacketing debris from all insulation.

The staff considers the licensee's tumbling velocity metric for insulation covers/jacketing to be conservative, since it is based upon the worst case orientation of this debris on the containment floor. The licensee's approach with respect to the curb lift velocity metric is not rigorous, and the staff feels that, under certain conditions, a large thin sheet of foil could actually tumble over a curb more easily than a small thin sheet. However, the staff considers the licensee's assumption that insulation jacketing cannot be lifted over a curb to be acceptable because (1) from the discussion in NUREG/CR-3616 [134], the 0.7 ft/s incipient tumbling velocity appears to be associated with a sliding motion, indicating that tumbling is not the expected transport mechanism for this type of debris, (2) a much higher velocity of 1.8 ft/s is necessary to move insulation covers with their concave side down, and (3) even if the insulation covers/jacketing could reach the containment recirculation sump, the replacement strainer circumscribed velocity of approximately 0.02 ft/s is not close to the range necessary to hold such a large piece of debris against its surface. Therefore, the staff considers the licensee's debris transport metrics for insulation jacketing and covers to be acceptable.

The staff noted that for the Millstone 2 replacement strainer, the impact of falling water from several postulated breaks splashing down into the containment pool may lead to very high levels of turbulence in the vicinity of the strainer. If the flow velocity at the perimeter of the strainer approaches the curb lift velocity metric for a certain type of debris and significant turbulence is also present, it may not be physically realistic to apply curb lift velocity data from experiments performed under flow conditions with relatively low turbulence. As discussed further in Section 3.5.6 below, the staff did not consider this issue to be an open item in the existing Millstone 2 transport calculation due to the presence of substantial conservatisms in the licensee's methodology.

The licensee's debris transport calculation [97] did not employ a turbulent kinetic energy (TKE) metric to specify the intensity of flow turbulence as an approach for crediting the settling of fine debris. However, in discussions with the staff during the onsite audit, licensee personnel indicated that the use of such a metric could be considered in future revisions to the transport analysis. In response, the staff noted that, while settling of fine particulate may be realistic given sufficient time and sufficiently low TKE, to date, no approaches following this methodology have addressed all of the staff's concerns. In particular, several of the staff's concerns with crediting the settling of fine debris using a TKE metric approach were identified in past audit reports for San Onofre Nuclear Generating Station [136] and Fort Calhoun Station [138], as well as the pilot audit report for Crystal River Unit 3 [112]. In these reports, NRC staff concerns included the following: (1) using TKE and vertical flow velocity separately as independent metrics may non-conservatively neglect the potential for a correlation or synergy between these quantities, and (2) approaches using TKE metrics have not generally been benchmarked against experimental data to ensure their validity. Other issues identified with this approach include (1) accounting for the inherent uncertainties associated with modeling turbulence using a CFD code and (2) ensuring that the CFD model is set up to conservatively predict TKE.

3.5.4.3 Debris Interceptors and Curbs

The licensee's previous containment recirculation sump screen (on which the current version of the debris transport analysis is based) included a 4-inch curb [97]. As a result, the debris transport calculation currently credits this curb for stopping certain types of debris prior to their reaching the sump screen [97]. The staff noted that the replacement strainer design drawings did not appear to include a curb. In response to a staff question during the onsite audit, the licensee confirmed that the replacement sump strainer does not include a curb; however, the licensee stated that the replacement strainer will be located approximately 7 inches above the surface of the containment floor. The licensee concluded that raising the strainer off of the floor will produce an effect similar to the existing curb.

The staff further questioned whether the licensee had considered the potential for a debris "ramp" to accumulate at the base of the replacement strainers. The staff noted that the formation of a debris ramp could reduce the lift velocity required to transport debris over a curb or gap and/or limit the amount of debris that could be sequestered. The licensee stated that the potential for debris ramping was not addressed in the existing version of the debris transport calculation, but that this effect may be considered in the revised calculation that is planned to assess the impact of the replacement strainer modification.

Due to the raised design of the replacement strainers and the significant degree of conservatism in the licensee's existing debris transport calculation, the staff considers the licensee's assumption of a debris curb being present around the sump strainer to be acceptable, even without consideration of ramping effects. However, if significant conservatisms are removed from the calculation, the staff would expect the licensee to evaluate whether a more realistic model of debris ramping effects should be implemented.

3.5.4.4 Fibrous Debris Erosion

The licensee's debris transport analysis [97] 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. All else being equal, the licensee noted that the fibrous debris erosion rate tends to be larger in shallower pools than in deeper pools [97]. The licensee noted that Section III.3.3.3 of Appendix III to the staff's SE [2] suggests that, in lieu of specific erosion data, 90% of the small and large pieces of fibrous debris analyzed as settling in the containment pool should be considered to erode into fines over a 30-day period. The licensee stated that the SE position was based on data in NUREG/CR-6773 [135], 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 Millstone 2 containment pool to be comparable to those in the applicable test from NUREG/CR-6773, the assumption of 90% erosion was applied to Millstone 2 [97]. The licensee stated that large pieces of debris with intact jacketing were not considered to erode, which is consistent with the position taken in the staff's SE [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. However, some of the postulated breaks for Millstone 2 are located in the direct vicinity of the sump and replacement strainers. 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 [136, 137, 138], 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, would exist to support the assumption of reduced erosion.

3.5.4.5 Potential Impacts of Break Flow Drainage Onto the Replacement Strainers

Based upon information provided by the licensee in support of the audit [97, 142, 143], the staff understands that several modules of the Millstone 2 replacement strainers are located almost directly beneath postulated locations of pipe ruptures that can initiate LOCA events. While, as described further in Section 3.5.5.1 below, the strainers are over 20ft below the analyzed breaks, water spilling from these breaks could nevertheless impact the containment pool in the vicinity of these strainer modules, creating substantial turbulence and high flow velocities around these modules. The effects of spillage from the pipe rupture could be positive or negative, and may be difficult to predict, as discussed below.

One potential result of highly turbulent flows resulting from pipe break spillage near the replacement strainers could be the inhibition of strainer debris bed formation. The staff has observed turbulence-induced bed disruption during several head loss tests performed by strainer vendors. The inhibition of debris bed formation by turbulence may provide a benefit by reducing the head loss for certain breaks by maintaining relatively clean strainer area. However, crediting this potential effect in the strainer design basis may be challenging, since the occurrence of a strainer-clearing effect from every possible break cannot be guaranteed (e.g., for a pipe rupture that occurs far from the sump strainers). Furthermore, if a continuous debris bed is credited with filtering debris to reduce the downstream effects debris source term, then a LOCA that continually clears the debris bed from the strainer may not be conservative for analyses of downstream effects. In addition, turbulence and surface disturbances induced by water spilling from a pipe rupture that splashes down onto the replacement strainers could create air ingestion concerns. Finally, if the break flow splashes down nearby but not directly onto the strainers, the turbulence induced around the strainers may increase the quantity of debris transporting to the strainers.

Because the licensee's existing calculations [97] did not account for the extension of the new strainers beyond the vicinity of the previous sump screen, these calculations did not consider the impact of break flow falling into the containment pool directly above the strainers. By addressing the considerations in the previous paragraph, the licensee should establish the adequacy of the more expansive replacement strainer design that could be directly exposed directly to break flow drainage turbulence. The need for the licensee to evaluate the potential adverse effects of break flow drainage turbulence is designated **Open Item 3**.

3.5.4.6 Mineral Wool and Mineral Fiber Insulations

The licensee assumed that mineral wool and mineral fiber insulations would become 100% fines if located within the ZOI for an analyzed pipe rupture [97]. This assumption was based upon guidance provided in the GR [1], which recommends that a size distribution of 100% fines be assumed absent experimental data. The licensee did not generate logic trees for modeling the transport of mineral wool and mineral fiber fines, since 100% of fine debris was modeled as transporting to the containment recirculation sump.

The staff concludes that the licensee's debris size distributions and transport assumptions for mineral wool and mineral fiber are acceptable because the assumption of 100 percent fines is a significant conservatism. The licensee's conservative treatment of mineral wool and mineral fiber debris avoids the need to consider questions raised by the staff in previous audit reports [136, 137] regarding the size distribution, tumbling velocity, and buoyancy of this debris.

3.5.4.7 Latent Particulate Debris

The licensee's debris transport calculation [97] states that guidance for calculating the transport of latent debris is provided in the NRC staff's SE [2]. The licensee stated that particulate latent debris does not all transport to the containment recirculation sump. The licensee stated that, according to the results in Table 5 of NUREG/CR-6877 [140], 22 percent of latent particulate debris generally will not transport due to its size and material composition (e.g., nuts, bolts, cable ties, rags, and other large or dense materials). The licensee further stated that this position is also reflected in the NRC staff's SE [2]. The licensee also stated that the NRC SE additionally allows the assumption that 7.5 percent of the transportable latent debris passes through the strainer without contributing to head loss.

The staff noted that both NUREG/CR-6877 [140] and Section 3.5.2.3 of the SE on NEI 04-07 [2] state that 22 percent of the latent particulate debris mass determined from raw samples taken above the recirculation pool flood level may be assumed to be non-transportable and that 7.5 percent of the latent particulate debris may be assumed to penetrate the sump strainer without contributing to debris bed head loss. Due to its general consistency with NUREG/CR-6877 and the staff's SE, the staff concluded that the licensee's treatment of latent particulate debris appeared reasonable overall. However, the staff noted that the licensee's reduction of latent debris transport from the entire containment by 22 percent may be slightly non-conservative, since a reduction for non-transportability is explicitly allowed in NUREG/CR-6877 and the staff's SE only for the containment latent debris contribution from above the recirculation pool flood level. In light of the significant conservatisms in the licensee's existing transport calculation that are described further in Section 3.5.8 of this audit report, the staff does not consider this possible slight non-conservatism to be an open item.

3.5.5 Computational Fluid Dynamics Analysis

As described in Attachment 1 to the debris transport calculation [97], the licensee used computational fluid dynamics (CFD) to simulate the flow field in the Millstone 2 containment pool during sump recirculation as an input to the debris transport calculation. For the staff's audit review, the licensee provided four FLUENT input decks that were intended to simulate the steady-state containment pool flow fields existent during the recirculation phase of a large-break LOCA. The CFD scenarios simulated by the licensee are listed in Table 3.5-1 of the debris transport calculation [97]. The CFD analysis was performed by RWDI, Inc., a subcontractor to Sargent and Lundy [97].

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 CFD analysis to ensure that the predicted flow velocity, turbulence, and other containment pool flow parameters 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 input decks provided by the licensee. Due to time constraints imposed by the audit process, initial delays in receiving the input decks, and assumptions by the licensee that led to conservative overall debris transport results, the staff did not perform a detailed review of all aspects of the CFD analysis. The discussion below describes the staff's review of several important areas of the licensee's CFD analysis.

3.5.5.1 Modeling Kinetic Energy Influx from Break and Containment Spray Flow

When water draining from upper containment elevations enters the containment pool, its kinetic energy is shared with surrounding fluid elements in the pool, thereby affecting the flow in the containment pool (most strongly in areas immediately surrounding the drainage location). As a result, the staff reviewed the licensee's modeling of kinetic energy influx into the containment pool via drainage flows from the analyzed LOCA pipe ruptures and the containment spray system.

The licensee's debris transport analysis did not describe the modeling assumptions used for the kinetic energy influx due to the flow from the pipe rupture or containment spray drainage. However, Table 5.1-1 in the licensee's debris generation calculation "Debris Generation Calculations GSI-191-ECCS-04161M2 Rev.0" [153] indicates that the four postulated break locations are all located at a plant elevation of 5.83 ft [153]. Since the containment floor elevation is at -22.5 ft and the minimum pool depth is 4.23 ft [97], water from the break could potentially fall approximately 24 ft prior to entering the containment pool. Based upon the staff's review of the licensee's CFD input decks, it appeared that the kinetic energy influx to the pool resulting from this elevation change had not been fully included in the model. Although the licensee's approach may still be physically reasonable (e.g., if the break flow were to lose energy by cascading onto intervening structures on its way to the pool), a technically defensible basis for such a model was not provided. An analogous comment appears to hold regarding the kinetic energy influx from containment spray drainage.

As a result of the substantial conservatisms in the licensee's transport analysis that are listed in Section 3.5.8 of this report, the staff did not consider the licensee's potentially nonrepresentative modeling of kinetic energy influx from break flow and containment spray drainage to be an open item. In particular, the methodology for determining the debris transport fractions (described in Section 3.5.6) and the assumption that 90 percent of large and small pieces of fibrous debris undergo erosion and subsequently transport to the strainer (described in Section 3.5.4.4) appear to provide a sufficient degree of conservatism to overcome the potentially nonrepresentative modeling of the influx of kinetic energy from the break and sprays.

3.5.5.2 Containment Spray Modeling

Sixteen inlet flow locations were used to distribute the containment spray inflow of 3,300 gpm for two operating trains (1,650 gpm for a single operating train), and a diagram was further provided in the transport calculation to illustrate the spatial position of these spray flow inlet locations [97]. The licensee distributed these spray flow inlet locations around the containment in an attempt to represent the expected pattern of spray drainage flow into the containment pool. The licensee's debris transport calculation [97] stated that the containment spray inflow to the containment pool was modeled as an evenly distributed flow at each inlet flow location.

The methodology supporting the distribution of the containment spray flow among the sixteen inlet flow locations was provided in the debris generation calculation [153]. The licensee indicated that the containment spray droplets were assumed to be distributed uniformly across the containment atmosphere at plant elevation 38.5 ft and were modeled as falling vertically downward through the open areas of containment until they strike a solid surface or fall into the containment pool [153]. The licensee further stated that the containment spray runoff flow from each side of a solid surface was computed by taking a ratio of the length of that side to the total open perimeter of the solid surface [153]. The licensee stated that the location of curbs and other obstructions was considered in this assessment [153].

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 (1) the conservatism in the licensee's overall debris transport methodology, particularly the 90 percent-erosion assumption for settled pieces of fibrous debris, (2) the dominance of the break and sump flows on the Millstone 2 containment flow pattern, and (3) the staff's experience reviewing similar calculations during previous audits [e.g., 136], the staff concluded that expected perturbations to the assumed containment spray drainage flow pattern would not likely have a significant effect on the overall transport results.

Despite its acceptable application in the current Millstone 2 transport calculation, the staff noted that the licensee's model for introducing the containment spray flow as a uniformly dispersed flow at each individual inlet flow location appeared to be nonphysical. In particular, the staff noted that some spray flow draining off of containment structures may have the potential to enter the containment pool as concentrated streams with the potential to penetrate into the pool. As a result, the velocity and turbulence along the containment pool floor beneath some containment spray inlet flow locations could be larger than predicted by the licensee's current model. While the conservative debris transport assumptions in the licensee's existing calculation clearly bound any non-conservatism introduced by this effect, if reductions to conservatisms are applied in a future revision to the analysis (e.g., a reduction to the 90 percent-erosion assumption for settled pieces of fibrous debris), the staff would expect the licensee to consider whether more detailed modeling is necessary to ensure that the overall transport methodology remains conservative.

3.5.5.3 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 E to Attachment 1 of the licensee's debris transport calculation [97]. The discussion in Appendix E states that convergence is judged through a variety of measures and recognizes that monitoring residual values (i.e., small imbalances in the iterative solution) may not alone be sufficient to ensure that convergence has been achieved [97]. The discussion in Appendix E 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 [97].

During the onsite portion of the audit, the staff asked questions to obtain further information regarding convergence criteria, but these questions could not be answered because the responsible sub-contractor from RWDI, Inc., was not present and could not be reached by telephone during the discussion on debris transport. However, based upon the names of the input decks provided to the staff for audit review, the staff subsequently inferred that the number of iterations used for the four CFD simulations ranged between 1150 and 5478.

As a means of further investigating the licensee's convergence criteria, the staff conducted extended simulations using the licensee's FLUENT input decks for CFD Scenarios 1 and 2. CFD Scenario 1 was run for 6000 iterations, and CFD Scenario 2 was run for 16500 iterations. Based upon (1) plots of the residual values and other monitors set up by the licensee and (2) a comparison of the staff's containment pool velocity and turbulent kinetic energy contours with those generated by the licensee, the staff concluded that the licensee's CFD results from Scenarios 1 and 2 for Millstone 2 had converged to an acceptable degree. The staff agrees with the licensee's statement in Appendix E that ensuring acceptable convergence of a CFD simulation may entail more effort than simply monitoring residual values. However, due to the lack of detail in the Appendix E discussion, it was not clear to the staff whether the vendor's CFD methodology is generally robust with respect to ensuring a converged solution and notes that potential concerns associated with convergence have been identified in a previous audit [136]. However, in light of the staff's extended simulation analyses for Millstone 2 CFD Scenarios 1 and 2 (which showed acceptable convergence), as well as the overall conservatism of the Millstone 2 transport evaluation (see Section 3.5.8), the staff did not identify any concerns for Millstone 2 in this area.

3.5.5.4 Turbulence Modeling

Attachment 1 to the debris transport calculation [97] states that the licensee used the renormalized group k-epsilon (RNG k-ε) turbulence model in the CFD input decks. The licensee stated that this 2-equation model is superior to simpler models in its ability to reflect conditions in highly swirling flow and in regions with low velocities [97]. The licensee also noted in Attachment 1 that the RNG k-ε model was used in the volunteer plant CFD analysis presented in Appendix III of the staff's SE [2].

As a means of investigating the applicability of the RNG k-ε turbulence model to the flow in the Millstone 2 containment pool, the staff performed sensitivity runs of CFD Scenarios 2 and 3 using a more advanced turbulence modeling option, referred to as the Reynolds Stress Model (RSM). The 7-equation RSM option is more computationally intensive than the RNG k-ε option because it solves an equation for each component of the Reynolds stress tensor. However, the RSM tends to be more physically sound than the RNG k-ε option for flow patterns exhibiting strong streamline curvature, swirl, and rotation.

The staff's initial sensitivity run of CFD Scenario 3 with the RSM option showed relatively minor differences in the velocity contours in localized areas where significant turbulence and/or swirling flow patterns were present as compared to the licensee's results for Scenario 3. A subsequent staff sensitivity run of CFD Scenario 2 with the RSM option predicted somewhat larger and more widespread flow differences, especially in the presence of swirling flow patterns; however, the general flow features remained similar to the licensee's results for Scenario 2. Based upon these results, the staff concluded that the overall impact of the differences between RNG k-ε predictions and the RSM predictions did not impact the licensee's overall transport results for CFD Scenarios 2 and 3 due to the significant conservatisms in the licensee's overall debris transport methodology (see Section 3.5.8), particularly the licensee's decision to compute debris transport based upon the highest pathway of continuous velocity between the break and the recirculation sump.

3.5.5.5 Modeling of Obstacles and Potential for Pool Flow Blockage

Attachment 1 to the licensee's debris transport calculation [97] discusses the modeling of flow obstacles in the containment pool and references the debris generation calculation [6], which has further information on this subject. The licensee recognized that obstructions could impact the flow field and attempted to model these obstructions explicitly in regions having high local flow velocities or otherwise having significant interest to the problem (e.g., regions near the sump, significant flow obstacles, etc.) [97]. 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 either had little impact on the flow or were biased toward achieving a conservative result [97].

As an example of modeling simplifications, the licensee noted in the debris transport calculation that all trisodium phosphate (TSP) baskets were modeled as solid obstructions [97]. As another example, objects such as the primary drain tank and quench tank heat exchanger were represented with rectangular blocks having a width and height equal to the diameter of their actual rounded shapes [97], which tends to overestimate the degree of flow resistance.

In general, the staff considers modeling simplifications to be acceptable provided that they do not lead to non-conservative results. The staff notes that, although overestimating the degree of restriction caused by objects in the containment pool may generally add conservatism, depending upon the containment pool flow pattern, this general rule may not always hold (for example, overestimating blockage of a high-velocity containment flow channel could result in redirecting flow toward an area of containment with lower flow velocities where it could artificially settle). 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. In addition, the staff's review of diagrams of the containment floor geometry in Attachment 1 to the debris transport calculation [97] and the FLUENT input decks provided to the staff for audit review did not identify any areas where debris blockage of flow passages appeared capable of significantly altering the containment flow field.

3.5.5.6 Adequacy of Mesh Size

In Attachment 1 to the debris transport calculation [97], the licensee briefly described the computational grid used to perform the CFD analysis. The licensee stated that a relatively coarse base grid was set up, and, during the course of the simulation, additional cells were added to refine the computational mesh to capture details of the flow in selected areas of interest [97].

The license stated that approximately 300,000 cells were used for the coarse base grid, and that, using adaptive mesh refinement based on velocity gradient, the total number of computational cells was increased to approximately 1.2 million [97]. After the adaptive meshing process was completed, the licensee stated that the characteristic length of the computational cells ranged from approximately 0.3 inch in the region adjacent to the containment recirculation sump to 14 inches in regions where flow details were not considered as important (e.g., the relatively quiescent area of the pool far from the sump and break location) [97].

The staff considered the number of cells used in the licensee's CFD model to be reasonable based upon engineering judgment and past experience with modeling containment pools with CFD. Based upon this past experience, the overall conservatism of the licensee's debris transport analysis (see Section 3.5.8), and time constraints in conducting the audit review, the staff did not conduct independent CFD simulations to assess the impact of changes to the computational mesh.

3.5.5.7 CFD Flow Rates

In Revision 0 of the licensee's debris transport calculation [97], the licensee provided the maximum containment recirculation sump flow rates for single-train operation (i.e., one high-pressure safety injection (HPSI) pump, one low-pressure safety injection (LPSI) pump discharging into the hot leg to mitigate boron precipitation, and one containment spray (CS) pump) and dual-train operation (i.e., two HPSI pumps, one LPSI pump discharging into the hot leg, and one CS pump) [97]. Although these sump flow rates were subsequently revised in Change 1 of the debris transport calculation [131], the flow rates in Revision 0 of the calculation had been used in the CFD input decks provided for the staff's audit review. Table 3.5.5.7-1 (taken from [97]), below, provides these flow rates, as well as the individual flow rates associated with the break and containment sprays from Revision 0 of the debris transport calculation and the licensee's CFD model.

Table 3.5.5.7-1: Flow Rates Modeled in CFD Input Decks

ECCS Configuration	CFD Scenarios	Break Flow (gpm)	Spray Flow (gpm)	Total Sump Flow (gpm)
Single Train	4	4850	1650	6500
Dual Train	1, 2, 3	5700	3300	9000

A sampling review performed by the staff concluded that the flow rates in Table 3.5.5.7-1 were appropriately modeled in the licensee's CFD input decks.

In Change 1 of the transport calculation, the licensee subsequently stated that the maximum (dual-train) sump flow is 6800 gpm [131] based upon a refined flow analysis described in an emergency core cooling system (ECCS) flow analysis calculation [141]. The licensee noted during the onsite audit that the planned revision to the CFD model may incorporate this reduction in the analyzed sump flow rate.

In Section 3.6.2.2 of this report, the staff identified an open item associated with the potential for increased sump flow resulting from the failure of one LPSI pump to trip following the switchover to recirculation. The staff expects the licensee's resolution of this open item to ensure that the analyzed flow rates used for the CFD analysis are acceptable for Millstone 2.

3.5.6 Approach for Calculating Debris Transport Fractions During Recirculation

The licensee used a conservative methodology to determine the fraction of each type of post-LOCA debris transported to the containment recirculation sump during recirculation. Using the results of the CFD analysis described above, the licensee determined the highest continuous flow velocity connecting the break to the containment sump for each analyzed scenario. The licensee then compared these bounding velocities to experimentally derived debris transport metrics for tumbling transport (see Section 3.5.4.2 above for further information on the licensee's transport metrics) for each scenario to determine the quantity of each debris type that would tumble along the containment floor to the recirculation sump screen. The licensee stated that a comparison was then performed to determine whether the highest velocity around the perimeter of the sump exceeded the curb lift velocity transport metric to determine whether debris of each type would be capable of being carried over the curb and onto the previously installed sump screen.

The staff considers the licensee's methodology of comparing the highest continuous velocity between the break location and the containment recirculation sump to experimentally derived tumbling transport metrics to be conservative for determining debris transport fractions. In reality, most post-accident debris would be subjected to velocities that are less than the maximum velocity. The staff performed a sampling review to assess whether the licensee had appropriately implemented the methodology for tumbling debris transport described above, and no concerns were identified.

Similarly, the staff also considered the licensee's methodology for comparing the maximum velocity at the perimeter of the sump to the curb lift velocity metric to be conservative because this comparison overestimates the quantity of debris that is capable of being carried over the curb. In particular, the use of a conservative maximum velocity metric tends to offset the licensee's non-conservative neglect of factors such as turbulence, debris ramping, or other phenomena that could tend to increase the opportunity for debris to climb over a curb. As a result of the substantial transport conservatisms that are listed in Section 3.5.8 of this report, the staff considered the licensee's neglect of turbulence, debris ramping or other phenomena that could tend to increase the opportunity for debris to climb over a curb not to be an open item. However, if significant conservatisms are removed from the transport calculation, the staff would expect the licensee to evaluate whether a more realistic model of such phenomena should be implemented.

The staff performed a limited sampling review to assess whether the licensee had appropriately implemented the methodology described above regarding the transport of debris over a curb. In general, the staff found the licensee's implementation to be acceptable. However, the staff noted that the maximum curb lift velocity for fibrous debris in CFD Scenario 2 (0.27 ft/s) is very close to the metric (0.29 ft/s), and that, in limited areas, the CFD-predicted velocity actually exceeds the metric. Furthermore, in the staff's sensitivity run for Scenario 2, even after relatively steady state conditions were achieved, the amplitude in fluctuations of the maximum sump perimeter velocity remained approximately 5–10 percent of the estimated steady-state velocity value. The licensee made similar observations, but did not consider the issue significant due to the conservative assumption that 90% of the large and small pieces of fibrous debris that do not reach the sump erode into fines and subsequently transport to the sump.

The staff agrees that the licensee's position is conservative with respect to the existing calculation; however, if significant reductions in conservatism are implemented in the revision to the transport calculation planned by the licensee, the staff would expect that the licensee would evaluate whether a more detailed model of debris behavior in the vicinity of the strainers is necessary. In particular, flow turbulence and flow shifts due to the accumulation of debris on a strainer could affect whether debris is capable of surmounting a curb in locations where the flow velocity closely approaches the curb lift velocity metric. But, to repeat, due to the overall conservatism in the licensee's existing transport calculation, the staff considers the licensee's current implementation of the methodology for debris transport over a curb to be acceptable.

3.5.7 Overall Transport Results

In accordance with the methodology described by the staff above, the licensee's debris transport calculation [97, 131] 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 the tables below.

The licensee's debris transport results for CFD Scenarios 1 and 4 are identical. CFD Scenarios 1 and 4 both model a 30-inch double-ended pipe rupture at the base of a reactor coolant pump in the west steam generator cavity (Break S3); however, for Scenario 1, two trains of ECCS are assumed to be operating, and for Scenario 4, only one train is assumed to be operating. While the identical transport results for these two scenarios is in part due to conservative assumptions in the licensee's methodology, a comparison of plots of the CFD-generated velocity contours in Attachment 1 to the licensee's debris generation calculation [97] for these two cases also shows striking similarity. As a result of these observations, the staff concluded that the containment pool flow pattern during recirculation is dominated by the flow from the break, as opposed to flow from the containment sprays. Although, as shown in Table 3.5.5.7-1, break flow is slightly reduced during single-train operation of the ECCS, the flow reduction does not appear to have a significant impact in the current CFD analysis for Break S3.

Table 3.5.7-1 Debris Transport Calculation Results for CFD Scenario 1 (Break S3)

Debris Type	Transport Fraction	Quantity Transported
Claremont Fiberglass	0.65	16.8 ft^3
Nukon Fiberglass	0.65	644.8 ft^3
Mineral Fiber	1.0	244.1 ft^3
Mineral Wool	1.0	159.4 ft^3
Margin for Fiberglass	0.65	46.2 ft^3
Qualified Coatings	1.0	14.1 ft^3
Unqualified Coatings	1.0	8.8 ft^3
Margin for Coatings	1.0	2.3 ft^3
Latent Fiber	1.0	45 lbm
Latent Particulate	0.78	184 lbm
Foreign Materials Allowance	1.0	150 ft^2
Transco RMI Foils	0.75	466.3 ft^2
Margin for Transco RMI Foils	0.75	23.3 ft^2

Table 3.5.7-2: Debris Transport Calculation Results for CFD Scenario 2 (Break S1)

Debris Type	Transport Fraction	Quantity Transported
Claremont Fiberglass	0.59	65.0 ft^3
Nukon Fiberglass	0.59	675.4 ft^3
Mineral Fiber	1.0	297.3 ft^3
Mineral Wool	1.0	159.4 ft^3

Margin for Fiberglass	0.59	50.5 ft^3
Qualified Coatings	1.0	32.8 ft^3
Unqualified Coatings	1.0	8.8 ft^3
Margin for Coatings	1.0	4.2 ft^3
Latent Fiber	1.0	45 lbm
Latent Particulate	0.78	184 lbm
Foreign Materials Allowance	1.0	150 ft^2
Transco RMI Foils	0.75	885.5 ft^2
Margin for Transco RMI Foils	0.75	44.3 ft^2

Table 3.5.7-3: Debris Transport Calculation Results for CFD Scenario 3 (Break S2)

Debris Type	Transport Fraction	Quantity Transported
Claremont Fiberglass	0.65	71.6 ft^3
Nukon Fiberglass	0.65	755.0 ft^3
Mineral Fiber	1.0	297.3 ft^3
Mineral Wool	1.0	159.4 ft^3
Margin for Fiberglass	0.65	56.2 ft^3
Qualified Coatings	1.0	32.8 ft^3
Unqualified Coatings	1.0	8.8 ft^3
Margin for Coatings	1.0	4.2 ft^3
Latent Fiber	1.0	45 lbm
Latent Particulate	0.78	184 lbm
Foreign Materials Allowance	1.0	150 ft^2
Transco RMI Foils	0.75	1039.1 ft^2
Margin for Transco RMI Foils	0.75	52.0 ft^2

Table 3.5.7-4: Debris Transport Calculation Results for CFD Scenario 4 (Break S3)

Debris Type	Transport Fraction	Quantity Transported
Claremont Fiberglass	0.65	16.8 ft^3
Nukon Fiberglass	0.65	644.8 ft^3

Mineral Fiber	1.0	244.1 ft^3
Mineral Wool	1.0	159.4 ft^3
Margin for Fiberglass	0.65	46.2 ft^3
Qualified Coatings	1.0	14.1 ft^3
Unqualified Coatings	1.0	8.8 ft^3
Margin for Coatings	1.0	2.3 ft^3
Latent Fiber	1.0	45 lbm
Latent Particulate	0.78	184 lbm
Foreign Materials Allowance	1.0	150 ft^2
Transco RMI Foils	0.75	466.3 ft^2
Margin for Transco RMI Foils	0.75	23.3 ft^2

3.5.8 Conservatisms 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 computed debris transport by considering the flowpath having the highest continuous velocity between the break location and the containment recirculation sump. This method adds a significant degree of conservatism to the licensee's overall debris transport results, since a large fraction of the debris would realistically encounter smaller flow velocities, which could reduce the amount of debris actually reaching the sump strainers.

- 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% 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% of the small fines of fibrous and particulate debris would transport to the suction strainers (with the exception of latent particulate debris – see Section 3.5.4.7). Although small fines of fibrous and particulate material are expected to have a very high transport fraction, the assumption of complete transport for these types of debris is conservative.

- The licensee performed the four CFD scenarios for large-break LOCA cases assuming a bounding minimum containment sump pool water level that corresponds to a small-break LOCA. For a large-break LOCA, the water level would actually be slightly increased due to additional contributions from sources such as the Safety Injection Tanks (SITs). This additional water would tend to reduce flow velocities in the containment pool and reduce the impact of turbulence from the break and containment sprays. Not accounting for the increased containment sump pool water level is conservative.

- The licensee did not credit debris holdup in the reactor cavity and the inactive normal containment building sump. Although the licensee noted that the potential for debris hold up in inactive containment pool volumes at Millstone 2 appears to be small, completely neglecting debris holdup in inactive pool volume calculations is conservative.

- The licensee assumed that 100 percent of mineral wool and mineral fiber debris would be in the form of transportable fines. In reality, a distribution of sizes would be expected for these types of debris, for which the larger pieces would have lower transport potential. Although mineral wool and mineral fiber are not the dominant type of insulation debris at Millstone 2, the licensee's treatment of these types of debris is conservative in maximizing the quantity of fibrous debris transporting to the straSiners.

- 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. This assumption was based upon guidance in Appendix III of the staff's SE [2] on NEI 04-07 [1]. The assumption of 90% erosion for large and small pieces of settled fibrous debris adds considerable conservatism to the licensee's transport analysis.

While the overall impact of these conservatisms is difficult to quantify, the staff concludes that sufficient conservatism has been incorporated into the debris transport analysis to address the impact of all issues identified in the preceding discussion as potential non-conservatisms.

Furthermore, the staff expects that the conservative transport fractions shown above in Tables 3.5.7-1 through 3.5.7-4 (which assumed that the previous sump screen is installed) will bound the transport results for the planned replacement strainers. This expectation is based primarily on the observations that (1) the licensee's existing transport methodology incorporates substantial conservativisms, (2) a single pipe rupture would not have the capability of creating such high-velocity and high-turbulence flows around the entire surface area of the large, spatially distributed replacement strainer, as compared to the previous, more localized sump screen, and (3) for the most limiting break close to the pump suctions, the average transport path length for debris would be longer for the replacement strainer. Therefore, completion of the licensee's planned CFD analysis for the replacement strainer geometry was not designated as an open item.

As discussed above, the licensee stated that the future CFD analysis for the replacement strainers will also reduce the degree of conservatism in the existing model and will likely tend to reduce the calculated transport fractions. The staff's foregoing audit report discussion provides considerations focused on ensuring that the computed transport fractions for the revised CFD analysis modeling the replacement strainer's geometry represent conservative values.

3.5.9 Debris Transport Summary

The NRC staff reviewed the licensee's debris transport analysis (including the computational fluid dynamics (CFD) model) to determine whether it was consistent with the sump performance methodology approved in the staff's SE [2]. The staff's review found that the analysis was generally consistent with the SE and identified both conservative and potentially non-conservative assumptions in the licensee's methodology.

As discussed above, among the assumptions that are potentially non-conservative, the staff identified that (1) the licensee had not provided sufficient justification to support the modeling of kinetic energy influx into the containment pool from flows from the break and containment spray drainage, (2) the licensee's curb lift velocity metrics were based upon flows with significantly less turbulence than some of the flows predicted for Millstone 2, (3) the licensee did not consider the potential for debris to form a ramp at the base of a curb or strainer, and (4) the licensee's modeling of containment spray drainage as a dispersed flow appeared nonphysical at certain containment locations where more concentrated spray drainage flows would be expected. However, as discussed previously, the staff did not consider these potential non-conservatisms to be open items based upon the significant conservatisms incorporated into the licensee's debris transport analysis, which are partially listed in Section 3.5.8 above.

The staff determined that the conservatisms in the licensee's debris transport analysis are adequate to address the potential non-conservatisms identified in Section 3.5 of this audit report. Therefore, no open items were identified for the licensee's current debris transport analysis, and the staff concluded that the Millstone 2 transport methodology is acceptable.

3.6 Head Loss, Vortexing and Net Positive Suction Head Margin

3.6.1 Head Loss and Vortexing

3.6.1 Head Loss And Vortex Evaluation

3.6.1.1 Audit Scope

The new ECCS sump strainer installed in Millstone Unit 2 uses two trains of AECL strainer modules connected to a common sump structure enclosing two trains of ECCS suction pipes. This arrangement provides the water source for two independent trains of ECCS and containment spray (CS) pumps. The water enters the perforated plate surface of each strainer "fin" and is collected by a common header for each strainer module. Some fins were shortened to accommodate surrounding sump area structures. The strainer design incorporates orifices designed to force uniformity in the rates of flow across the various fins of both strainer trains.

The total surface area of perforated plate available from both strainer trains is 6,120 ft^2 [137]. Based on the debris transport calculation, a combination of reflective metal insulation foil, Claremont Fiberglass, Nukon™, Mineral Fiber, Mineral Wool and coating debris is estimated to be transported to the strainers. The amount of these debris varies with different break locations. The new trains of strainers are designed to achieve a target maximum pressure loss of 2.3 ft-water [153].

The licensee employed the NUREG/CR-6224 [11] head loss correlation and the uniform debris bed assumption to calculate the head loss across the strainer as part of initial strainer sizing and scoping analysis. Then, prototypical head loss tests were performed using reduced-scale and large-scale strainer head loss testing. As part of the prototypical head loss testing program, the licensee evaluated the susceptibility of the strainers to vortex formation.

The testing and analysis results of licensee's effort were documented in eleven reports [118-121, 122, 124-129]. The NRC staff reviewed these reports and focused its strainer head loss and vortexing audit in the following technical areas:

- System Design
- Prototypical head loss test module design, scaling, surrogate material selection and preparation, testing procedures, results and data extrapolation;
- Vortex testing procedures and the vortex formation test results.

3.6.1.2 System Design

Millstone 2 utilizes a two systems to mitigate the effects of design basis LOCA accidents. These systems require the use of the containment sump to provide long term cooling following a LOCA. The two systems requiring containment sump operation are the ECCS, which provides borated water injection to the reactor coolant system in the event of primary system break, and the CSS, which cools the containment atmosphere.

The ECCS at Millstone 2 consists of four major components: Safety Injection Tanks (SITs); Refueling Water Storage Tank (RWST), Low Pressure Safety Injection (LPSI) pumps and High Pressure Safety Injection (HPSI) pumps. When RWST level reaches a predetermined low level a Sump Recirculation Actuation Signal (SRAS) is generated. According to the plant design, the LPSI pumps are tripped when transfering from the initial RWST/Safety Injection Tanks (SITs) injection mode to the containment sump pool recirculation mode, while the HPSI pumps remain in operation. One LPSI pump is restarted later in the LOCA event for the boron precipitation phase.

The CSS system pumps spray water from the RWST or the containment sump pool as a fine mist in the upper containment. The mist helps to cool the containment and condense the steam that exists following a LOCA. By taking suction from the containment sump pool following an SRAS, the CSS pumps add to the flow through the strainer trains and ECCS suction piping.

3.6.1.3 Prototypical Head Loss Testing

The licensee employed Sargent & Lundy to perform the scoping head loss analyses to support the initial strainer design efforts. Based on the selected strainer surface area and the calculated debris loading, Atomic Energy of Canada, Limited (AECL), the strainer vendor, performed head loss testing using both a reduced-scale head loss testing apparatus and a large-scale prototypical head loss test loop. The reduced-scale test facility, shown in Figure 3.6.1.3-1, consisted of a 90-inch diameter, open plastic tank with a maximum fill height of 56 inches. The fin/header test section was positioned on the floor of the tank and was attached to a piping system leading to a pump below the tank. The pump was capable of producing flow rate between 1 to 100 gpm. The strainer test module had one central fin and two half fins to each side with adjustable pitches (fin separation). The fins were constructed from perforated stainless steel with a perforation size of 1/16 inch and a corrugated plate bend angle of 60°. The fins were dimensionally the same size and of the same construction/design as the fins for the installed

Millstone 2 strainer.

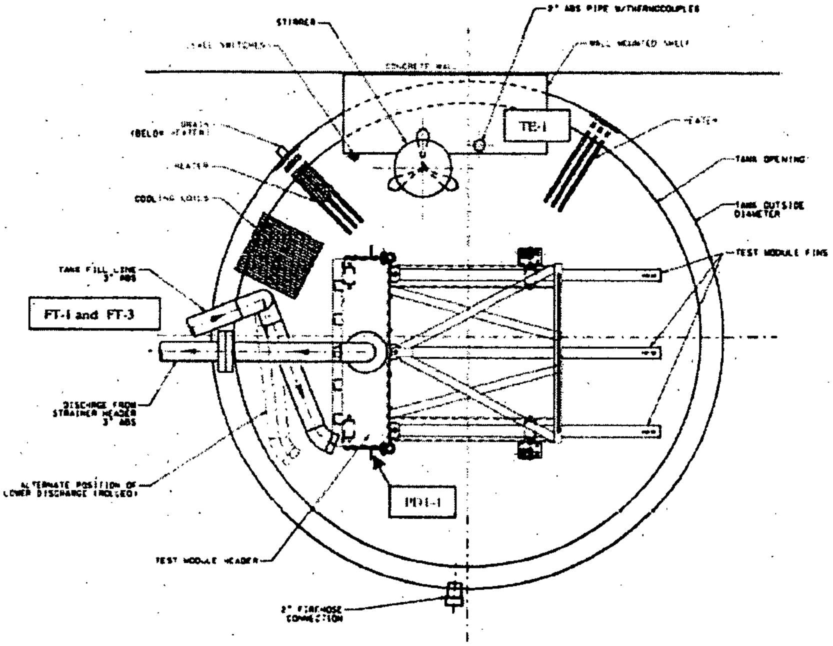

Figure 3.6.1.3-1 Reduced Scale Head Loss Test Loop

The large-scale head loss test loop is shown in Figure 3.6.1.3-2. It consisted of an open, lined tank that was 64 inches deep, 8 feet wide and 19 feet long, and had an external piping system connected to a pump, and the strainer test module positioned on the floor of the tank. The test loop accommodated a test strainer module that was approximately 1/16 the size of the plant replacement strainer in screen surface area. Each strainer fin on this module was in the same size as the full size fin to be used in the plant. The test loop was capable of producing a flow rate from 5 to 3000 gallons per minute.

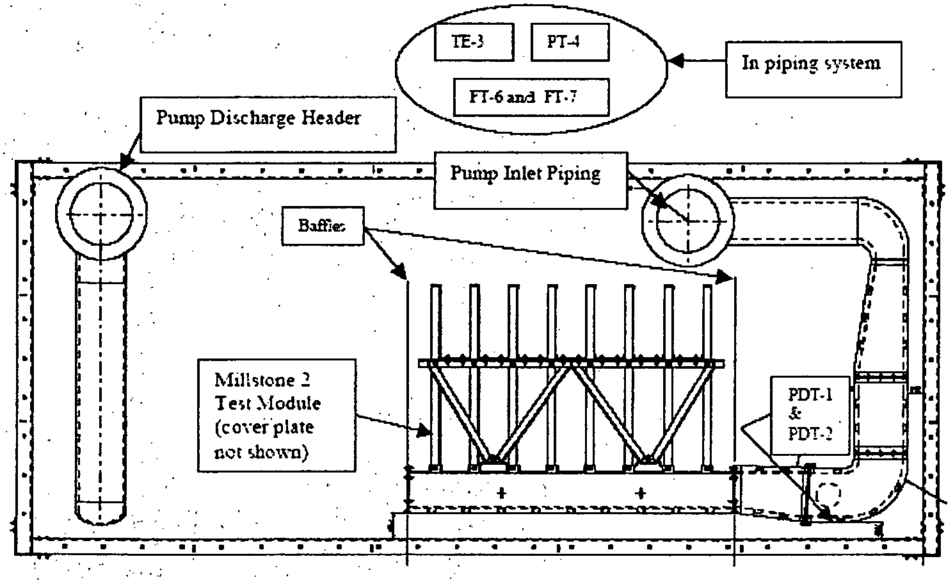

Figure 3.6.1.3-2 Large Scale Head Loss Loop

AECL used the reduced-scale head loss test loop to perform a series of tests to determine the thin bed thickness, optimize the total surface area and fin pitch for normal debris. In addition, the reduced-scale test loop was used to perform chemical effects and bypass tests. Based on the reduced-scale head loss test loop results, the final strainer module design was tested using the large-scale head loss test facility for thin bed head loss tests and full debris load tests. The staff reviewed the debris surrogate material selections, the testing procedures, the scaling methodology and the test results interpretation, and concluded that the various head loss tests proved that the newly installed strainers have an acceptable head loss based on the licensee's flow assumptions and calculated debris amounts.

3.6.1.3.1 Debris Types, Quantities, and Characteristics

Based on the transport analysis, the types of debris and the respective quantities applicable to the strainer head loss evaluation are shown in Table 3.6.1.3.1-1. These values were in the purchase specifications for the new replacement strainer [122]. The largest debris quantities can be seen to be associated with Break No 2.

Table 3.6.1.3.1-1 Specification of Debris Source Terms for the Sump Passive Strainer

Debris Type	Units	Break 1	Break 2	Break 3
INSULATION				
Transco RMI Foil	ft^2	929.8	1091.1	489.6
Claremont Fiberglass	ft^3	115.5	127.8	63.0
Nukon ™	ft^3	675.4	755.0	644.8
Mineral Fiber	ft^3	297.3	297.3	244.1
Transco Encapsulated Mineral Wool	ft^3	159.4	159.4	159.4
COATINGS				
Qualified	ft^3	36.1	36.1	15.5
Unqualified	ft^3	9.7	9.7	9.7
LATENT				
Fiber	lbm	45	45	45
Particulate	lbm	184	184	184

FOREIGN Materials	150 ft^2 of Sacrificial Area Required

A compilation of head loss characteristics of the debris types as used in head loss scoping calculation obtained from the Millstone documents is shown in Table 3.6.1.3.1-2 (except for RMI). These characteristics were used in analytical analyses for initial scoping analysis and in selecting materials used in the head loss testing, but were not used in the final strainer qualification testing. RMI debris is not used in the test because it is expected not to accumulate on the screen due to low flow velocities in the sump pool.

Table 3.6.1.3.1-2 Millstone Unit 2 Debris Head Loss Characteristics For Scoping Head Loss Calculation

Debris Type	Bulk Density (lbm/ft^3)	Material Density (lbm/ft^3)	Nominal Diameter (μm)	Specific Area (ft^2/ft^3)
Fibrous Debris				
Nukon™	2.4	159	7	171,000
Clarement Fiberglass	2.4[a]	159	7	171,000
Mineral Fiber	5.5	159	7.5	160,000
Mineral Wool	10	90	5	240,000
Latent Fiber	2.4	93.6	5.5	171,000
Particulate Debris				
Epoxy	65[b]	94	10[c]	183,000
Inorganic Zinc	65[b]	457	10[c]	183,000
Latent Particulate	65[b]	168.6	17.3	106,000

a - Millstone applied the Nukon™ properties to the Claremont fiberglass on the basis that both insulations are low-density fiberglass (LDFG).
b - Sargent & Lundy applied the 65 lbm/ft3 bulk particulate density to all types of particulate except for calcium silicate [122].
c - GR-recommended conservative diameter.

The characteristics in Table 3.6.1.3.1-2 appear to be reasonable representations of the Millstone debris types except for the generic use of 65-lbm/ft^3 bulk particulate density by Sargent & Lundy [122]. This is the bulk density used in the past for Boiling Water Reactor (BWR) suppression pool iron oxide corrosion products and was the density used in the earlier NUREG/CR-6224 head loss correlation work [11]. This density is reasonable for the latent particulate where the SE recommended a number between 63-lbm/ft3 and 75-lbm/ft3, but it is much too high for the epoxy coatings particulate and too low for the inorganic zinc particulate. A calculation of the porosity for the epoxy results in a porosity of 0.3 (i.e., 1 - 65/94 = 0.3), which is much too low, since the porosity of a fine particulate is typically in the neighborhood of 0.8. Since this bulk density was only used in thin-bed head loss scoping analyses, it does not represent a problem for the replacement strainer qualification.

Table 3.6.1.3.1-3 Comparison of Test Debris with Potential Plant Debris

Potential Plant Debris	Test Debris	Justifications
Transco RMI Foil	Transco Stainless Steel RMI Foil	Same manufacturer
Nukon™	PCI Nukon™	Same manufacturer
Claremont Fiberglass	PCI Nukon™	Substituted alternate LDFG material
Mineral Fiber	Knauf Pipe Insulation	Comparable bulk densities
Transco Encapsulated Mineral Wool	Transco Encapsulated Mineral Wool (Fibrex)	Same manufacturer
Latent Fiber	PCI Nukon™	Recommended in NUREG/CR-6877
Qualified Coatings	Walnut Shell Flour (passed through #325 sieve)	Relatively low particle density to conservatively enhance the transportability.
Unqualified Coatings		
Latent Particulate		

Table 3.6.1.3.1-3 provides a comparison of test debris against potential plant debris. The RMI foil tested was essentially the same material as the plant insulation; however, the plant and test debris foil thicknesses were not compared. In any case, the RMI foils did not accumulate on the test strainer and would not accumulate on the plant replacement strainers as indicated by the near field approach velocities (maximum of about 0.022 ft/s).

Regarding the fibrous debris, the Nukon™ and mineral wool debris was tested with debris manufactured from similar insulation material. The manufacture of Nukon™ has been relatively standardized so the license concluded that the insulation procured for testing should be nearly identical to the plant insulation. The manufacture of mineral wool is known to be much less standardized, meaning that there could be some difference between the plant insulation and the tested insulation (e.g., the variance in the particulate content versus fiber content among batches). The licensee justified the use of Nukon™ as a surrogate for the Claremont fiberglass by noting that both were low density fiber glass (LDFG) and that the quantity of Claremont insulation was small relative to that of Nukon™ (six times more Nukon™ than Claremont).

The acceptability of using Knauf insulation to simulate the plant mineral fiber is more problematic because these two insulations may well have been manufactured from different materials, and may have different fiber diameters and densities. The Knauf insulation is available in a range of densities, but apparently the type chosen for testing had a density of 7-lbm/ft^3 (Page 6 of 27 of [130]) compared to the 5.5-lbm/ft^3 (Page 5-3 of [125]) density of mineral fiber. However, since it was demonstrated [125] that the debris eventually ended up accumulating on the strainer testing module, the density difference did not have an impact on the debris settlement and the consequent head loss.

Staff Evaluation

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. The staff found the fibrous surrogate selections for testing acceptable based on the following:

- Approximately 2/3 of the fibrous test debris (Nukon™ and mineral wool) was a relatively close match to the plant debris, and
- The limiting head loss was associated with the formation of a thin-bed debris bed, for which the exact combination of the fiber mixed is not as important because the dominant factor affecting the head loss magnitude is the sludge density limit of the particulate.

The thin-bed test procedure covered a range of fiber thicknesses to ensure bed optimization with respect to causing head losses. Therefore the staff considers the selection of fibrous materials for testing to be acceptable.

3.6.1.3.2 Use of Walnut Shell Flour as Particulate Surrogate Material

AECL used walnut shell flour to simulate all plant coatings and latent debris particulate debris. With regard to both qualified and unqualified coatings debris, AECL's testing objective was to accumulate the scaled-down bounding volumes of particulate on the test strainer with particles approximating the nominal GR-recommended 10 μm diameter particle size. AECL initially attempted to test with silicone carbide particulate but, according to AECL, encountered such extensive settling within the test tank and deposition even within the circulation piping that the test objective of accumulating the majority of the particulate on the strainers could not be reasonably achieved. The material density of the silicone carbide was 196-lbm/ft^3 whereas the density of the primary coating debris (epoxy) is 94-lbm/ft^3. The silicone carbide was selected based in its size distribution, which basically reflected the GR 10 μm recommendation. Subsequently, AECL used the walnut shell flour with a density of approximately 81-lbm/ft^3 to simulate the coatings particulate. During the audit, AECL staff stated that most of the walnut shell flour did in fact accumulate on the test strainer, rather than settling or depositing, thereby resolving the non-prototypical settling encountered with the silicone carbide.

Staff Evaluation

With regard to the head loss characteristics of the walnut flour, the only information provided directly to the staff was a particle size distribution obtained from the manufacturer. This size distribution, which is converted to volume fractions, is shown in Figure 3.6.1.3.2-1 below [125]. A detailed comparison of the walnut flour with coatings particulate was not available for review. The AECL analysis [page 5-3 of 124] of the walnut particle size distribution determined that the average size was about 23 μm, and (from a specific surface area consideration based on spherical particle shape assumption) the effective particle size was about 32 μm. This means that the walnut flour particles were a factor of about 3.2 larger than the GR recommendation, which translates to a factor of 10 decrease for head loss impact. Note that at the very low approach velocities associated with the Millstone replacement strainer, the head loss is approximately linear with the square of the specific surface area [123]. The specific surface area for the waltnut flour size distribution, assuming spherical particles, is about 57,000 ft^2/ft^3, as compared to 183,000 ft^2/ft^3 for the SE-assumed particulate. Therefore, if only the walnut flour hydraulic characteristics are considered, a conclusion could be drawn that walnut flour may not be a good surrogate material to meet GR and SE coatings requirements.

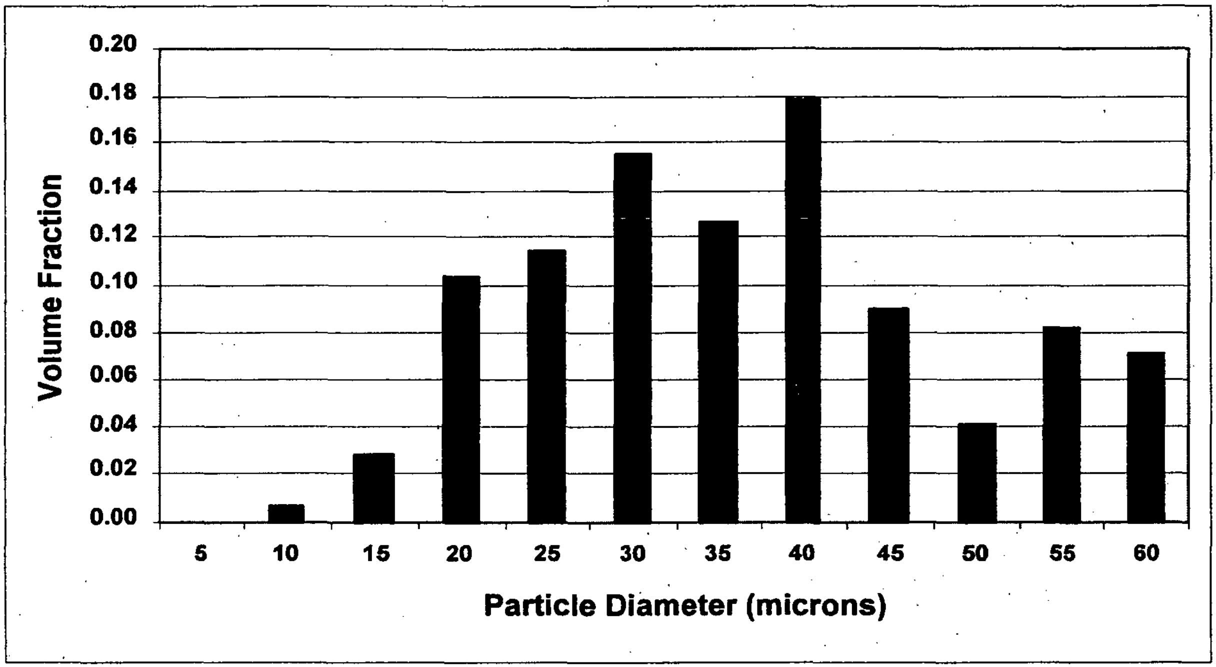

Figure 3.6.1.3.2-1 **Walnut Shell Flour Particle Size Distribution**

The staff conducted its own evaluation of the use of walnut shell flour for head loss testing. The staff found that the flour consists of mostly cellulose with about 28% lignin and a few other ingredients in lesser amounts. Normally, the cellulose products (e.g., wood surfaces) have a somewhat honeycomb structure. It is reasonable to assume that in mechanically breaking such a structure into particulate the particles may not be spherically shaped. The particles could for example be more plate-like than spherical. If the particles are not spherical, then the effective specific surface area of the walnut flour cannot be estimated using a simple geometrical formula.

Subsequent to the onsite audit, the NRC staff attempted to deduce the specific surface area of the walnut flour from the AECL test data [124, 125] using the NUREG/CR-6224 correlation [11]. First, AECL tests were selected by the staff for which the debris accumulation on the strainers was reasonably uniform with respect to the screen surface area. It was noted that the full debris load tests filled the gaps between the fins sufficiently so that the effective flow area for head loss was no longer that of the screen surfaces, and would be much lower. Next, tests which were clearly terminated early before the head losses stabilized were deselected, and the silicone carbide tests were also deselected. The remaining AECL tests consisted of one large-scale thin-bed test, seven reduced-scale thin-bed tests, and one reduced-scale thick-bed test. The thick-bed test, Test M2-12, had a nominal accumulated bed thickness of 2.7-inch (referred to as the "theoretical thickness"). For the one thick-bed test, the input specific area was adjusted until the head loss prediction equaled the experimental head loss determination. This determination was a specific surface area of 210,000 ft^2/ft^3, about 3.7 times higher than the analytical estimate based on the average particulate size of 22 μm which suggests the particles are substantially non-spherical in shape.

For the thin-bed tests, the bulk density of the walnut shell flour needs to also be specified before the specific surface area can be deduced from the data. AECL likely used the bulk density to perform its comparative thin-bed head loss calculations, but the density was not reported in the test reports. One internet source provided a walnut shell flour dry bulk density ranging from 22-lbm/ft^3 to 74-lbm/ft^3. A second source provided a density of 39-lbm/ft^3 for flour sieved through a 325 mesh. The NRC staff used the 39-lbm/ft^3 bulk density to deduce specific surface areas from the thin-bed tests, recognizing this source of uncertainty. The results of this analysis are shown in Figure 3.6.1.3.2-2 below.

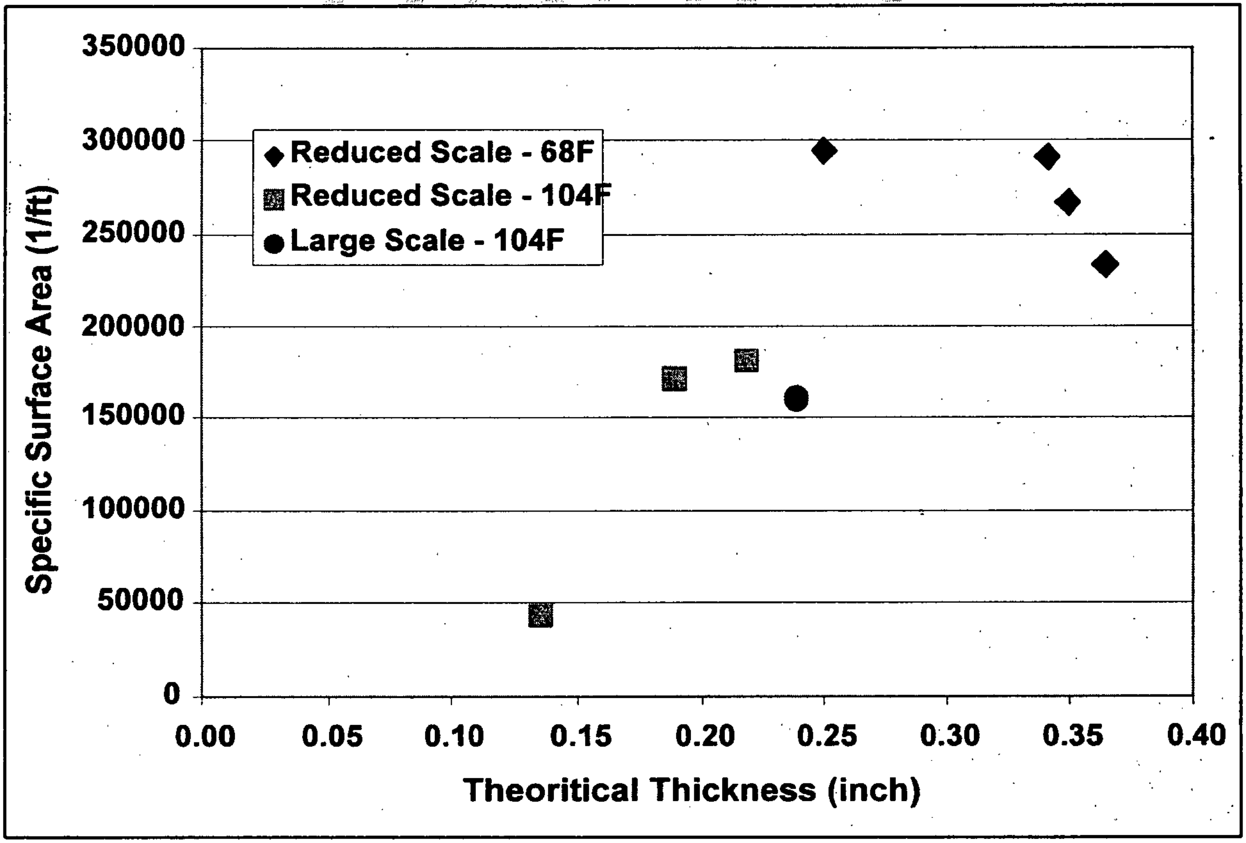

Figure 3.6.1.3.2-2 Walnut Shell Flour Specific Surface Areas Experimentally Deduced by NRC Staff from Thin-Bed Tests

The following observations were made from Figure 3.6.1.3.2-2:

- Walnut shell flour specific surface area increases, in general, with fiber bed thickness. The most likely reason for this behavior is that the filtration efficiency increases with bed thickness. A thicker bed filters ever finer particles, and finer particles have greater impact on surface area and head loss. The specific area started to decline again for the three thickest tests, which could be simply a ramification of test variances and analytical uncertainties, or perhaps the thickest thin-bed tests were beginning to transition from thin-bed to mixed debris beds.

- The tests associated with the highest specific surface area (> 200,000 ft^2/ft^3) were all conducted at a water temperature of 68 °F. The colder temperature as compared to the maximum design (accident) sump pool temperature of 210 °F means a higher viscosity, a higher associated head loss, more compression of the fibrous debris, and subsequently more efficient filtration. More efficient filtration means more of the finest particles are filtered, which drives up the effective specific surface area of those particulates.

- The staff deduced specific-surface area values for walnut shell flour, which are shown in Figure 3.6.1.3.2-2. These values are close to that for hypothetical 10 μm spherical particles (183,000 ft^2/ft^3) found in the GR [1]. As demonstrated in [11], head loss characteristics are strongly correlated to specific surface area. Therefore, the experimental evidence strongly indicates that the head loss characteristics of the walnut shell flour are close to the GR-recommended 10 μm spherical particle, and may even be conservative with respect to the GR guidance.

Table 3.6.1.3.2-3 below summarizes the results of the staff's comparison of walnut shell flour and coatings particulate.

Table 3.6.1.3.2-3 Perspective Comparison of Walnut Shell Flour and Coating Particulate

	Debris Size	**Transport**	**Filtration**	**Head Loss Evaluation**
Coatings Particulate (According to SE)	Fine (10 μm)	100% Transportable	100%	10μm Spherical Particles
Walnut Shell Flour	Relatively Coarse (~ 23 μm)	Limited settlement	High efficiency	6 to 12 μm Equivalent Spheres (from testing)
Acceptance Rationale	Different than SE value.	Close to 100% transportable	Close to 100%	Equivalent head loss behavior

The AECL head loss testing for Millstone 2 with walnut shell flour provided the following results:

- Nearly complete transport of the flour to the strainers occurred (limited near field debris settling),
- The larger particulate size (> 10 μm) of the walnut flour apparently resulted in high filtration efficiencies in thicker thin-bed tests,
- The experimentally-deduced specific surface areas seem to suggest that the walnut shell flour head loss characteristics are similar to the 10 μm particulate recommended by the GR, and
- Since the amount of latent particulate is very small compared to the total amount of particulate in the plant debris, the selection of walnut shell flour to represent the latent debris particulate or other surrogate material is considered have little impact on the overall debris bed head loss.

Therefore, considering transport, filtration and head loss of the walnut shell flour surrogate material, walnut shell flour simulates the Millstone 2 coating particulate and latent particulate in an acceptable manner. These similarities overcome the particle size disparities because of the equivalent head loss behavior as shown in Table 3.6.1.3.2-3.

A separate concern was raised in the licensee's documentation with respect to the stability of the walnut shell flour in water. Would the walnut particles absorb water and expand, thereby altering the particle size distribution and hence the head loss characteristics? AECL conducted simple table top scale tests to ascertain whether the walnut flour would expand in water. Walnut flour was soaked in water in 2 ml test tubes for about three days. An overall average increase in water height of only 2.3% was observed. AECL's simple test demonstrated that, although the walnut flour does absorb some water, the absorption did not result in significant expansion. Therefore, the walnut shell flour moisture absorption did not adversely impact the ability of the flour to adequately simulate the coating debris. In addition to the water absorption testing, the ability of the walnut flour to coagulate into larger particulate was sensed by rubbing wetted samples between two fingers. While the coagulation testing was very subjective, the indication was that the flour would not readily coagulate. Therefore, the staff concluded that walnut shell flour is stable in water for the head loss testing purposes.

3.6.1.3.3 Test Procedures

AECL adopted a set of testing procedures to conduct the head loss tests. These procedures include debris preparation procedures, procedures to measure temperature, head loss and flow rate, debris introduction procedures and test termination procedures.

AECL used a water jet from a pressure washer to separate fibers after small fiber batts were broken into smaller pieces using a leaf shredder. After the fiber was processed, for reduced and large scale thin bed head loss tests, the particulate debris was introduced before the first batch of the fibrous debris. Then the fiber debris was incrementally added into the test loop until the peak thin-bed head loss was. This method effectively tested multiple thicknesses of fibrous debris within a single test. For full debris load tests, the particulate was introduced proportionately with the fibrous debris.

As part of the test module design AECL arranged a baffle and skirt around the test module to reduce the disturbance caused by the turbulent flow eddies generated by the stirrer and the return flow. In this way, the debris bed would not be disturbed, while near field debris settlement was minimized. Based on the staff's review of AECL's full-scale post-test evaluation [125], the staff concluded that the procedures resulted in minimum near-field settlement.

As part of testing termination process, AECL head loss testing encountered a problem that had not been previously noted by the staff. AECL testing used river water as its water source, and in at least one test a growth of bacteria was noted that substantially increased head loss. Specifically, large-scale Test M2LS-2 was declared invalid due to this problem. One contributing factor to the ability of bacteria growth to interfere with head loss determinations was the relative long test times that these tests were conducted (i.e., days rather than hours). For example, the key qualification test, large-scale Test M2LS-4, started on July 26, 2006 at 4:36 p.m. and concluded July 30, 2006 at 7:00 a.m. (i.e., a period of 86.5 hours [3.6 days]). The most interesting aspect of this observation is that, if the head loss testing time was extended too long to achieve stable head losses, the unrealistic biological effect may introduce unnecessary uncertainties. AECL developed a procedure to kill the bacteria by adding nitric acid for subsequent large-scale head loss cases.

Staff Evaluation

The staff has reviewed the AECL test procedures and found that the flow control and the instrumentation procedures were consistent with normal hydraulic test practice. The staff raised a question about the debris arrival time at the strainer in the real plant. It has been postulated that the particulate could arrive before much of the fiber. For example, a large portion of the fiber debris may be due to erosion of settled pieces of fiber over the 30-day mission time. However, in the AECL testing both particulates and fiber were introduced together. The staff questioned whether a thin-bed accumulation in the real plant could effectively trap the particulate and then additional fiber would accumulate on top of that, thereby adding to the thin-bed head loss. In other words, the final, long-term debris load head losses could exceed the thin-bed head losses due to layering. The AECL staff supporting the Millstone 2 onsite audit agreed with this potential but noted the following:

- In the real plant there would be substantial particulate migration within a debris bed toward the screen due to very low approach velocity and therefore little compression of the debris bed; and

- The outer accumulation of uncompressed fiber without significant particulate would not cause much additional head loss.

Based on post-test evaluation of the debris bed, AECL concluded that the particulates traveled through the entire debris bed and there was reasonably uniform particulate distribution throughout the bed [125]. Based on staff review of this evaluation, the staff agreed with AECL's conclusions that significant layering would not be expected at Millstone 2 because of its specific fiber types and low flow velocities.

Regarding the abnormal head loss increase due to bacteria growth, AECL declared Test M2LS-2 final head loss measurement invalid and developed procedures to control the bacteria in the test loop for other test runs (nitric acid was added to change the pH). Because it was demonstrated that other test runs did not experience similar abnormal head loss increases, the bacteria control procedure is considered effective. Nitric acid had no apparent potential to create particulates because it is fully dissolved when added and there was no indication that it causes the formation of new chemical byproducts in subsequent tests.

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

3.6.1.3.4 Scaling Methodology

The AECL reduced-scale head loss test had one full fin and two half fins, while the large-scale test had eight full size fins, minimizing localized flow distortion and generally making them physically representative of the actual strainers installed at Millstone 2. During the test, all the debris was introduced into the flume outside of the baffles, and stirrers were used to minimize the debris settlement outside of the baffle area. Therefore, debris settlement was minimized. Assuming uniform debris distribution, AECL scaled the total debris loading based on the ratio between the total testing module surface area and the actual screen surface area, which has been commonly used in strainer vendors' testing protocols. The screen approach velocity was scaled one to one. Because of the configuration and uniform flow control device of the new Millstone 2 strainers, the staff considers this scaling approach acceptable.

3.6.1.3.5 Test Results and Interpretation

The final qualification of the replacement strainer was based on two large-scale thin-bed and full load head loss tests. Table 3.6.1.3.5-1 below lists the results and the comparison with the relevant reduced-scale head loss test results.

Table 3.6.1.3.5-1 Large-Scale Head Loss Tests Results

Debris Loading	**Test Type & ID**	**Head Loss (psi)**
Thin Bed (Table 5 of [125])	Reduced Scale Test M2-22	0.81
	Reduced Scale Test M2-27	0.68
	Large Scale Test M2LS-4	0.88
Full Load (Table 7 of [125])	Reduced Scale Test M2-23	0.27
	Reduced Scale Test M2-26	0.25
	Large Scale Test M2LS-3	0.29

The licensee concluded that the maximum measured debris head loss is 0.88 psi at 104 °F. The strainer debris head loss determined by testing was then corrected (scaled) to a maximum design (accident) temperature of 210 °F, close to the ECCS and CSS pump NPSH calculation temperature of 212 °F. The use of the sump water temperature of 210 °F for head loss is reasonable because it is the saturated temperature for the minimum containment pressure. The value bounds the head loss calculation (Reference [118]) and is based on the current licensing basis minimum containment pressure for LOCA scenarios. Because all of the test series were performed around the design basis flow rate and the strainer design target temperature is 210 °F, AECL used a linear extrapolation scheme to determine the viscosity-corrected head loss based on the maximum measured debris bed head loss. It was determined that the maximum head loss for the worst case debris load is 0.35 psi.

Staff Evaluation

Not considering potential chemical effects, AECL used a linear extrapolation scheme (pressure drop proportional to the viscosity) to predict the maximum debris bed head loss at 210 °F. Because the flow rate is very low close to the strainer, and the flow regime is estimated to be laminar, the friction loss is proportional to the viscosity. Therefore, the linear extrapolation scheme is considered to be appropriate.

3.6.1.4 Clean Strainer Head Loss

In order to maximize the strainer surface area in the available space of Millstone Unit 2 containment, two trains of strainer modules were connected to the pump intakes, as shown in Figure 3.6.1.4-1. Initially, all these strainer modules were designed to be connected to the central common header. However, after an undocumented large-scale strainer head loss test demonstrated that the strainer arrays without uniform flow control experienced sequential debris deposition and the final total head loss was much higher than that with an uniform debris distribution, AECL decided to add an internal orifice to each strainer module to force a uniform flow through the entire array. Figure 3.6.1.4-2 shows the internal orifice and the connection with the large central flow path. The orifices for all these modules were sized to provide appropriate resistance to correctly balance the flow. In this way, all modules from both trains are expected to experience reasonable uniform debris deposition and lower overall head loss.

The total strainer head loss is the summation of the internal (clean strainer) head loss and the debris bed head loss. AECL calculated the clean strainer head loss using standard methods for flow in pipes and ducts [129]. Since the flow inside the strainer is in the turbulent regime, the calculated total pressure drop was essentially independent of temperature. Therefore, the total clean strainer head loss was calculated to be 0.094 ft for a total scaled testing flow rate of 6800 gpm (marginally higher than the expected 6200 gpm in the plant).

Staff Evaluation

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

3.6.1.5 Head Loss Summary

In summary, the licensee performed plant-specific prototypical strainer head loss testing to measure the head loss across the AECL strainer arrays with Millstone Unit 2 plant specific debris loading. The testing matrix, the testing procedures and the system input evaluation were reviewed during the audit. Because the predicted total debris bed head loss of 0.35 psi [127] under the design temperatures conditions is significantly less than the 2.3 ft NPSH margin predicted, the staff considers the licensee's head loss evaluation adequate under the current LOCA single failure assumption (excluding any potential head loss change due to chemical effects). With the design input provided by the licensee, AECL performed thorough hydraulic analyses, developed a proper strainer design, and conducted well-defined head loss tests providing a solid justification for the current design. However, two NPSH-related open items documented in Sections 3.6.2.2 and 3.6.2.3.1 of this report should be addressed by the licensee.

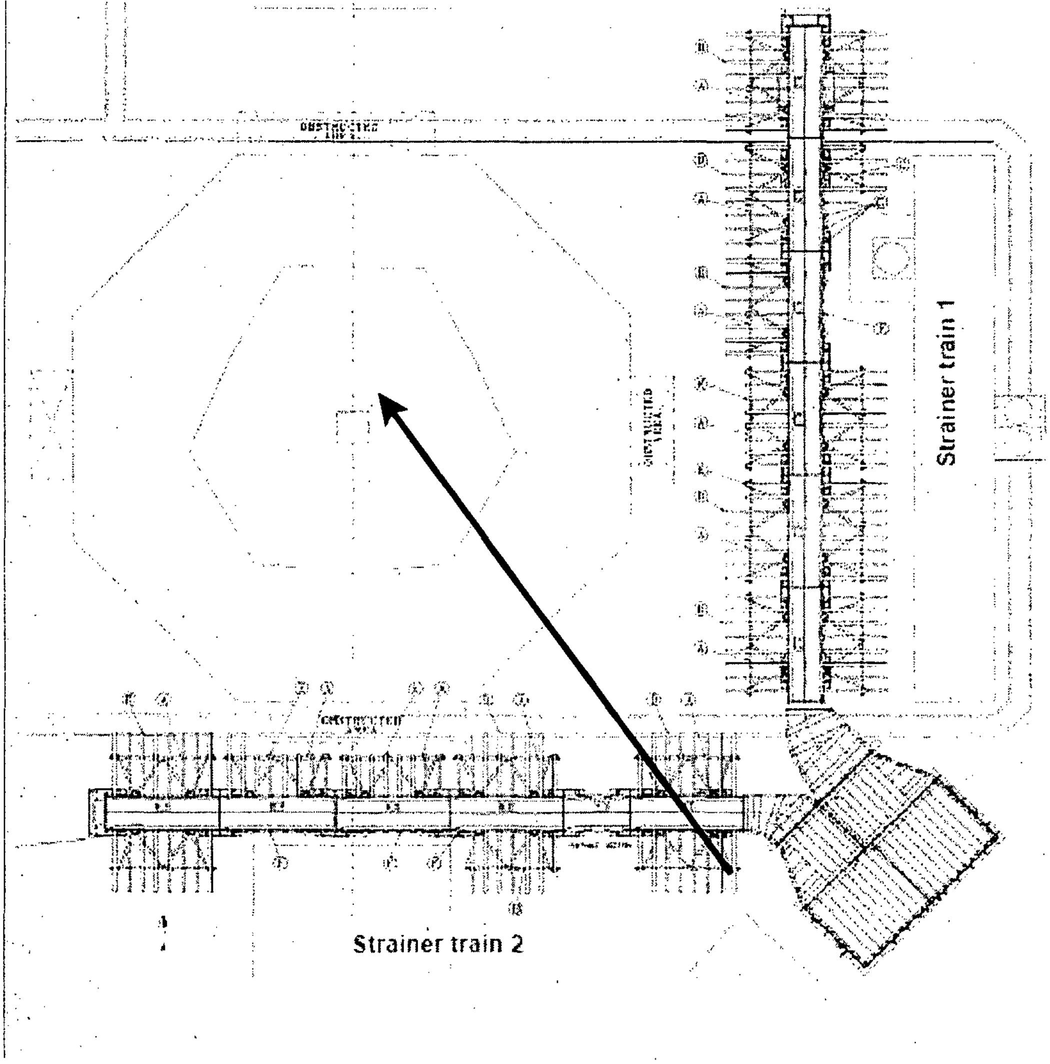

Figure 3.6.1.4-1 Millstone Unit 2 Strainer Array.

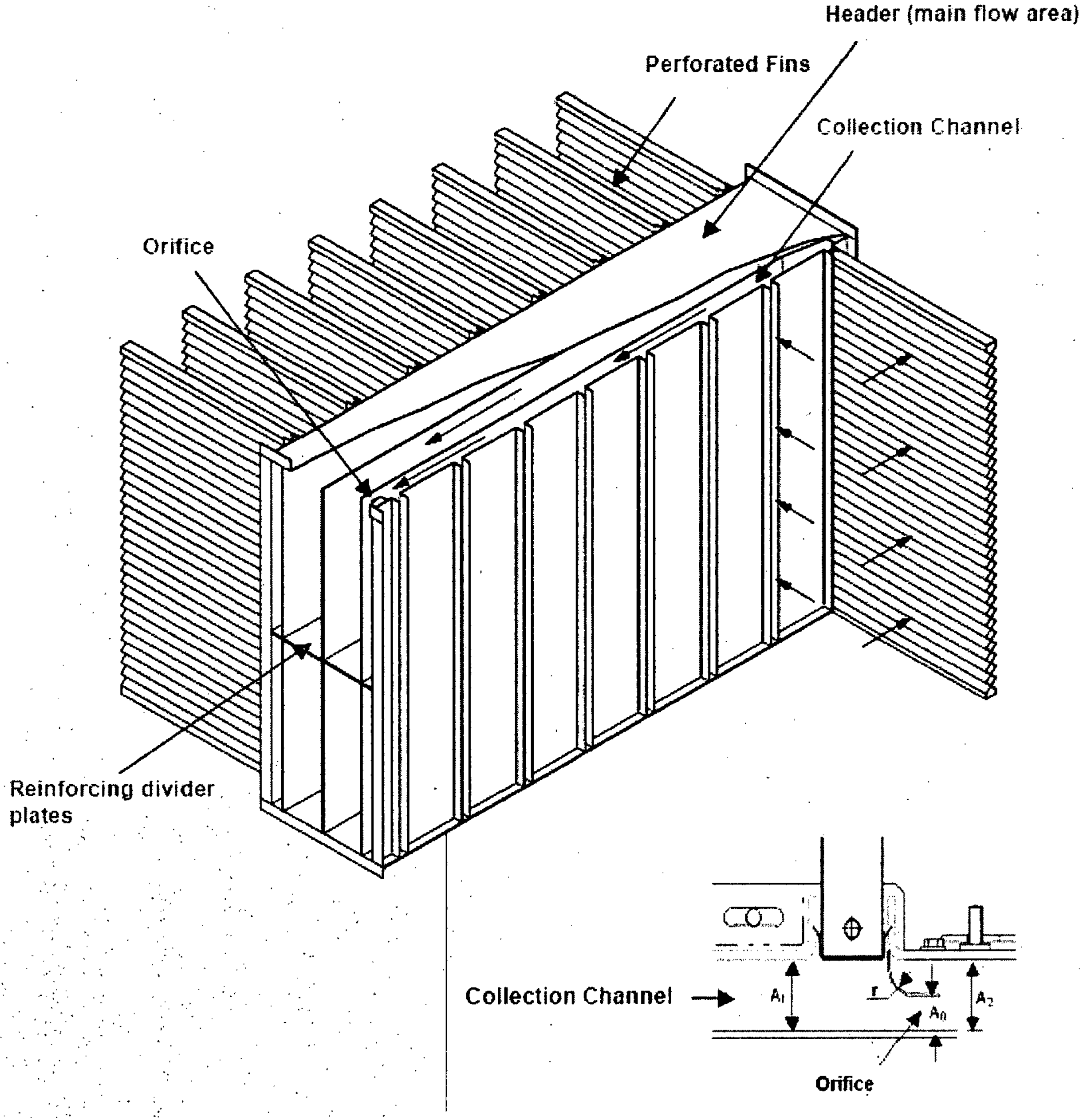

Figure 3.6.1.4-2 Strainer Module Internal Orifice.

3.6.1.6 Vortex Evaluation

The licensee investigated the possibility of vortex formation as part of the strainer array testing program. As part of the large scale strainer array head loss test, the licensee conducted a clean strainer head loss test and a strainer air ingestion test [125]. Prior to debris head loss testing, air ingestion was evaluated at several rated flow rates: 50%, 75%, 100% and 125%.

It was reported on Page 7-3 of Reference [125] that the water level was gradually lowered from

10" submergence to 0", i.e, to the top of the strainer fins. No air ingestion nor evidence of hollow-core vortices was observed at any tested submergence levels. Because the minimum water depth above the strainer is 0", the licensee concluded that the selected strainer design is free from vortex formation on top of the strainer fins for the representative Millstone 2 flow rates.

Staff Evaluation

The licensee performed full-scale strainer fin tests to evaluate possible vortex formation on top of the strainer array. The staff concluded that the licensee's test practices were acceptable because the full-size strainer fins were used with a minimum submergence of 0" and a flow rate if up to 125% of the rated flow. With the orifices used in the strainer array to force uniform flow, 125% of the rated flow provided a bounding flow rate to account for the uncertainties of the debris distribution. Therefore, the staff agrees with the licensee that the new strainer array is not subject to vortex formation down to a minimum submergence of 0" under the currently designed rated flow. This conclusion could change based on **Open Item 4** below, which concerns assumptions of maximum strainer flow rate.

3.6.2 Net Positive Suction Head Margin

3.6.2.1 Net Positive Suction Head Margin Audit Scope

The Millstone Power Station Unit 2 (Millstone 2) licensee performed net positive suction head (NPSH) calculations to establish the NPSH margins for emergency core cooling system (ECCS) and containment spray system (CSS) pumps during the recirculation heat removal and boron precipitation modes [93-99]. The ECCS and CSS pump NPSH margins are calculated by subtracting the NPSH required (NPSHR) by the pumps from the NPSH available (NPSHA) without considering losses due to the proposed sump strainers and the analyzed debris loading. Demonstration of adequate NPSH margin for the ECCS and CSS pumps provides assurance that these pumps will function as designed during a design-basis accident. The licensee also used the results of the NPSH margin calculation to support the adequacy of the design specification for the allowable head loss for the emergency containment sump replacement strainer and debris bed. The staff's review of the licensee's NPSH calculations is provided below.

The staff reviewed the models and calculations provided in [93-99] prior to the onsite audit, received additional information during the onsite audit, and reviewed assumptions, models and calculations with licensee staff during the audit. The review used guidance provided by NRC Regulatory Guide (RG) 1.82 [5], NRC Generic Letter 97-04 [4], the NRC Draft 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 CSS Configurations in Recirculation Mode

Among other components, the Millstone 2 ECCS includes two independent trains of safety injection equipment designed to provide core cooling in the event of a loss-of-coolant accident (LOCA). Specifically, each train of ECCS includes a low-pressure safety injection (LPSI) pump and a high-pressure safety injection (HPSI) pump, along with their supporting components. A third HPSI pump serves as a spare (swing) pump. The CSS, which is also composed of redundant trains, provides spray flow to the containment atmosphere when necessary to mitigate a high-energy line break in containment. Both trains of the ECCS and CSS can be aligned to take suction from a common containment sump, consisting of the layer of water pooled on the containment floor following a LOCA. There is no recirculation sump pit at Millstone 2 [112].

ECCS and CSS operation during the recirculation phase of a LOCA is discussed in [96] and is described in the Millstone 2 FSAR [15]. LOCA event trees are presented in [111]. The ECCS provides emergency cooling water to the reactor, and the CSS provides spray flow to the containment during the injection and recirculation modes of operation. The normal response of the plant to a LOCA involves operation of both trains of the ECCS and CSS. During the injection mode, all pumps take suction from the refueling water storage tank (RWST). Additionally, during a LBLOCA, water is provided from the safety injection tanks (SITs). Once the RWST level is lowered to the sump recirculation actuation signal (SRAS) setpoint, the suction of the HPSI and CSS pumps is switched from the RWST to the containment sump and the LPSI pumps are automatically tripped off.

During long-term recirculation from the containment sump, the ECCS is aligned to provide combined hot and cold leg recirculation for boron precipitation control. The preferred alignment for boron precipitation control is to align one LPSI pump for hot leg recirculation through the shutdown cooling (SDC) warm-up line. Information concerning the ECCS analytical model, including plant piping and instrumentation diagrams, is provided in [109], and descriptions of ECCS system configurations are discussed in [96]. The licensee stated that the maximum flow configuration of the ECCS for long-term recirculation involves operation of two HPSI pumps aligned for cold leg recirculation, one LPSI pump aligned to mitigate boron precipitation, and two CSS pumps. Based on these assumptions, the containment recirculation sump flowrate would be approximately 6800 gpm [96].

Application of the single-failure criterion to the LOCA analysis requires an analysis of the failure of one train of ECCS and CSS pumps, which leaves the second train fully functional. This eventuality is accounted for in the licensee's NPSH analysis. As discussed with the licensee during the audit, another potentially limiting single failure would be the failure of one LPSI pump to automatically trip upon the receipt of an SRAS. This single failure is of potential concern because, as the result of differences in the discharge path flow resistances, the sump flow rate would be significantly higher for a LPSI pump failing to stop following an SRAS (9000 gpm) than for the configuration in which one LPSI pump is aligned in boron precipitation mode (6800 gpm). As a result, the single failure of a LPSI pump to stop automatically would lead to increased flow through the containment sump, which would result in increased frictional losses in shared header elements of the ECCS and CSS, thereby reducing pump NPSH margins.

The licensee's calculation did not evaluate the failure of a LPSI pump to trip automatically on an SRAS as part of the Millstone 2 NPSH analysis, based upon the licensee's understanding that manual operator actions could be taken to quickly stop the LPSI pump. However, following further discussion with the staff, the licensee reconsidered the single failure of a LPSI pump to trip automatically and was unable to confirm that this failure could be addressed immediately through manual operator actions. The licensee subsequently issued a condition report (CR) to ensure that follow-up actions would be taken to address the potential concern.

The staff concluded that, if the licensee's follow-up review can neither demonstrate that the single failure of a LPSI pump to trip on an SRAS is incredible nor demonstrate that it can be addressed through immediate operator actions, the licensee should (1) review the strainer performance analysis to identify all areas that are affected by the non-conservatively low sump flow rate assumed in the analysis and (2) address any impacts of the non-conservative flow assumption that are identified in the existing analysis. Licensee evaluation and resolution of the potential for reduced pump NPSH margins and other adverse effects on the sump performance analysis as the result of a single failure of a LPSI pump to trip following the receipt of an SRAS is designated as **Open Item 4**.

3.6.2.3 NPSH of the ECCS and CSS Pumps

3.6.2.3.1 Summary Presentation of NPSH Results

The licensee performed NPSH calculations for the HPSI, LPSI, and CSS pumps in the recirculation mode, where the pumps draw suction from the common containment sump. The methodology and calculation results are presented in several documents [93-99]. The NPSH calculations had undergone a number of revisions resulting from changes in assumptions. The most recent set of calculation results are found in [96], with the results summarized in Table 3.6.2-1 below. While different NPSH results are presented in various other documents, the values found in Table 3.6.2-1 incorporate the latest relevant assumptions.

Table 3.6.2-1 presents the results of four calculational cases, involving the recirculation and boron precipitation flow configurations of the ECCS system. The water level on the containment floor for these cases is 4.71 ft, [96, page 8] and the pump suction temperature is taken as 212°F. The licensee chose flows that would maximize hydraulic losses, thereby minimizing pump NPSH margins. These maximum flow rate values are representative of LBLOCA flow conditions rather than small-break LOCA (SBLOCA) conditions, for which the flows are expected to be considerably lower.

Case 2A2a represents the normal ECCS and CSS configuration while operating in sump recirculation mode directly following switchover, with both trains operational. In this case, the LPSI pumps have automatically tripped following the receipt of the SRAS. Case 2B2a assumes single-train operation for both HPSI and CSS, with both LPSI pumps having automatically tripped following the SRAS. Flow rates for these cases are set near the maximum values. Cases 29 and 30 simulate the ECCS and CSS configuration during the boron precipitation mode of operation during the longer-term sump recirculation phase of the LOCA. In these cases the flow rates are not the runout flow rates, but are based upon valve positions and flow resistances corresponding to procedural lineups for simultaneous hot and cold leg recirculation following a LOCA.

At the conclusion of onsite discussion of the licensee's assumptions and analysis supporting Table 3.6.2-1, the staff had questions regarding the particular accident sequences to which the results applied, and to the actual magnitudes of the NPSH margins that were presented. These questions were resolved during a teleconference following the onsite audit [115]. The results of Table 3.6.2-1 are based on a sump water level of 4.71 feet for the HPSI and LPSI pumps and 4.23 feet for the CSS pumps (see discussion of the containment water level assumed for the CSS pumps below). The flow conditions in Table 3.6.2-1 are intended to model a LBLOCA. According to [99] (the latest sump water level document) the minimum water level analyzed for a SBLOCA is 4.71 feet, while that for an LBLOCA is 5.87 feet. To more accurately approximate increased NPSH margins resulting from the increase in calculated containment water level during an LBLOCA, the licensee modified the values in Table 3.6.2-1.

To account for this increased water level for the LBLOCA case, the minimum NPSH margin for the HPSI pumps in Table 3.6.2-1 (0.83 feet), should have been modified by adding 1.16 feet (5.87 feet – 4.71 feet), resulting in a value of 1.99 feet for the LBLOCA allowable head loss. However, the maximum allowable sump strainer head loss the licensee appropriated for the design specification to the strainer vendor was 2.3 feet [98]. Through a teleconference with the licensee following the onsite audit, the staff confirmed that the licensee's maximum allowable head loss value of 2.3 feet had been derived based upon an incorrect perception of the assumptions underlying the HPSI pumps' NPSH margin values reported in Table 3.6-1 [115]. As a result of this perception, the licensee incorrectly added 1.5 feet to the minimum HPSI pump NPSH margin in Table 3.6.2-1 [115] (0.83 feet) to arrive at the allowable head loss design specification of 2.3 feet. During the teleconference, the licensee stated that the applicable calculation will be revised to address this error [115]. Pending the licensee's final resolution of the error concerning the HPSI pumps' NPSH margin, the staff designated this NPSH margin error issue as **Open Item 5**.

The maximum head loss for the strainer and accumulated debris from the head loss test experiments was 0.94 feet (from Large Scale Test M2LS-4, described further in Section 3.6.3.5 of this audit report [112]), which is less than the actual allowable head loss value of 1.99 feet (discussed above). Therefore, the licensee's error regarding the HPSI pump NPSH margin in the replacement strainer design specification did not ultimately appear to have had an adverse impact on the design of the replacement strainer.

According to [100] the NPSH Margin results for the HPSI and LPSI pumps (operating in boron precipitation mode) were calculated assuming that the "current sump screen blockage...will be set to zero." This is appropriate, since the NPSH margin is typically calculated for the hydraulic system exclusive of the sump strainer and debris. However, the NPSH margin values presented in Table 3.6-1 for the CSS pumps are taken directly from [106], with the clean screen head loss of the existing sump screen included in the calculation results. In addition, the sump water depth was assumed to be 4.23 feet in [106], rather than the latest value of 4.71 feet. As a result, the licensee stated that the NPSH margin for the CSS pumps is conservative [100, p. 9].

The licensee stated that the bounding value of minimum NPSH margin for sump strainer design would be realized for an LBLOCA, since this is the condition for maximizing debris on the strainer and maximizing head loss across the strainer. The licensee did not provide NPSH margins for the SBLOCA, stating that this will be addressed in future work [115]. The licensee expects that the future analysis for the SBLOCA cases using more realistic flow modeling will demonstrate that the NPSH margins are greater than the head loss from the clean strainer plus the contribution from post-accident debris [115]. Licensee completion of the NPSH margin calculations for the SBLOCA cases is designated as **Open Item 6**.

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 (due to factors such as cavitation and the release of dissolved gas) at a specific capacity. For convenience, NPSH values are generally reported as pressure heads, in units of feet of water. The limiting pressure at which cavitation in the pump housing could occur is either the vapor pressure at the assumed fluid temperature, or the pressure at which the volume fraction of air is 2%, the recommended limit on allowed air ingestion in RG 1.82 [5, Appendix A]. One of the ways in which air may be introduced into a pump suction is by the release of air that is dissolved

Table 3.6.2-1: Licensee's ECCS and CSS Pump Flows and NPSH Margins[3]

Case	HPSI Pumps				LPSI Pumps				CSS Pumps				Total Sump Flow (gpm)
	P41 A/B[4]		P41 B/C[4]		P42 A		P42 B		P43 A		P43 B		
	Flow (gpm)	NPSH Margin (ft)	Flow (gpm)	NPSH Margin (ft)	Flow (gpm)	NPSH Margin (ft)	Flow (gpm)	NPSH Margin (ft)	Flow (gpm)	NPSH[2] Margin (ft)	Flow (gpm)	NPSH[2] Margin (ft)	
Two train recirculation (2A2a)	680.7	1.3	680.6	1.68	N/A		N/A		1650	0.82	1650	1.02	4661
One train recirculation (2B2a)	688.8	0.83	N/A		N/A		N/A		1650	0.82	N/A		2339
Two train hot & cold leg recirc through SDC line (Case 29)	681.9	0.92	406.0[1]	12.4	2403.7[1]	12.1	N/A		1650	0.82	1650	1.02	6792
One train hot & cold leg recirculation through SDC line (Case 30)	N/A		412.1[1]	11.6	N/A		3568.9[1]	6.6	N/A		1650	1.02	5631

[1] Note: These flowrates are computed from hydraulic calculations.

[2] Note: The NPSH Margins for the CSS pumps are from [106].

[3] Note: A water level of 4.71 feet was used for HPSI AND LPSI pumps. A level of 4.23 feet was used for the CSS pumps.

[4] Note: HPSI pump P41B is the spare "swing" HPSI pump that can be aligned as a substitute for

either the P41A or P41C pump.

in the sump water as it flows into the low pressure region of the pump inlet. The licensee considered both fluid vaporization and release of dissolved air in its assessment. In this audit report, the release of dissolved air is discussed in Section 3.6.2.4 below.

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). However, as explained below in Section 3.6.2.3.3, the licensee conservatively neglected containment pressure, assuming that the NPSHA is simply the difference between the height of the water column above the pump centerline and the hydraulic friction losses. This practice is consistent with Revision 4 of Section 6.2.2 of the NRC Standard Review Plan (SRP) [117]. The licensee used standard methodology for determining the NPSHR, which is also discussed further in Section 3.6.2.3.3 below.

Based on the audit review, the staff concluded that the standard definitions associated with NPSH margin analysis were used in the licensee's documents. A more detailed review of the main parameters influencing the calculated NPSH margin for the ECCS and CSS pumps is provided below.

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 and containment atmosphere temperature, pump flow rates, containment pressure, NPSHR 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 ECCS and CSS pump centerline to the surface of the pool in containment, which can be represented as the sum of the height of liquid from the pump centerline to the containment floor, plus the additional height from the containment floor to the surface of the pool in containment. The containment floor is at an elevation of -22'-6" [99], and the pump suction centerlines are at the -43'-7" level. These elevations were confirmed during the onsite audit with the aid of plant isometric drawings.

The minimum depth of the water pool measured from the containment floor to the surface of the pool in containment was computed by the licensee for the SBLOCA and the LBLOCA accidents [99, 113]. The hydrostatic head was computed using a model for the water inventory available to the containment floor upon operation of the pumps along with information concerning the geometry of internal structures that influence the liquid level in containment and other physical phenomena that affect the availability of water to pool on the containment floor. The licensee identified and quantified sources of water that are released to the containment building, and mechanisms that would prevent water from accumulating on the containment floor [99, 113].

For the LBLOCA, both the RWST and SITs deposit their water on the containment sump floor, whereas for the SBLOCA the SITs do not contribute to the volume of water spilled onto the containment sump floor. As a result, the water level above the containment floor will be at a minimum for an SBLOCA.

The licensee's latest calculation results lead to a minimum containment water level for the LBLOCA of 5.87 feet, and 4.71 feet for the SBLOCA minimum water level [99]. An earlier, more conservative sump water level of 4.23 feet was used for the CSS NPSH margin calculation [106].

Following a LOCA, the licensee assumed that the reactor vessel would retain water up to the nozzles at the assumed sump water temperature. The licensee assumed that all water that collects in the refueling cavities is drained back to the containment sump. This assumption was discussed during the onsite audit, and is addressed in Section 5.2 of this audit report, which contains one open item concerning the potential for partial blockage of the refueling cavity drain screen to lead to a limited volume of water being held up in the refueling cavity. Other physically relevant mechanisms that would prevent water from reaching the containment sump that were considered in the licensee's analysis include holdup as steam in the containment atmosphere, water absorbed by insulation material, and water held up on floors. The effect of the variation of the reactor cavity volume with elevation was taken into account.

However, the staff's review of the licensee's minimum water level calculation revealed some additional assumptions that appear to be non-conservative (Reference [99]). First, the licensee assumed a flat containment floor at elevation -22 ft. 6 inches. The floor is actually sloped with the highest elevation at -22 ft. 6 inches and the lowest at -22 ft. 8 inches [116]. Second, the licensee assumed that the ventilation ducts in the lower containment remain intact during a LOCA and displace water, thus increasing the pool height. Third, the calculation has no provision for water droplets in transit from the containment spray header to the pool, or the water filling the normally empty containment spray pipes. Fourth, the licensee has not adequately accounted for water held up in condensate films on containment structures. Fifth, the licensee's minimum water level calculation did not appear to address all SBLOCAs, such as a break near the top of the pressurizer, which could result in additional water hold up in the reactor coolant system above the vessel nozzles. Sixth, as noted above, the licensee did not account for a limited volume of water hold up in the refueling cavity due to partial drain screen blockage.

The licensee should evaluate the impact of these six potential minimum water level non-conservatisms identified by the staff and assess their impact on the minimum containment water level calculation. The results of this analysis should be factored back into the calculations that are affected by the containment minimum water level (e.g, ECCS and CS pump NPSH calculations) and other relevant parts of the strainer design analysis. This issue is designated as **Open Item 7**.

Sump Water and Containment Atmosphere Temperatures

The licensee stated that "the post LOCA sump temperature post-SRAS is 182.6°F" [99, page 6]. However the sump water temperature is taken by the licensee as 212°F for the NPSH calculations [96, page 9]. No reference to transient accident sequence analysis calculations is provided for the choice of 212°F as the appropriate temperature. In a related document [97, p.14], it is stated (also without reference) that "The active water temperature is between 100°F and 212°F during recirculation."

The choice of the upper limit value of 212°F from the analyzed range of sump water temperatures discussed above minimizes the water density, thereby maximizing the static head of liquid. This choice also minimizes the kinematic viscosity of the sump water and, hence, minimizes head losses through the ECCS piping network. Both of these factors result in modest increases to NPSHA as the sump water temperature is increased. Although by itself, this fact suggests that the minimum sump water temperature would be most appropriate for 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°F to be appropriate for Millstone 2 to generate an NPSH calculation that is conservative overall.

The containment atmosphere temperature is taken by the licensee as 260°F, corresponding to the temperature at the switchover to recirculation. This temperature is used to compute the mass of steam in the containment atmosphere that is unavailable to condense and add water to the sump, thereby minimizing the sump pool height. This is conservative with respect to the NPSH margin calculation since the vapor density is higher at elevated temperature, and the resulting mass of water in the sump is therefore minimized compared with a lower containment atmosphere temperature.

Pump Flow Rates

The pump flow rates presented in Table 3.6-1 above for Cases 2A2a and 2B2a are near the maximum capacities for the HPSI (680 gpm) and CS (1650 gpm) pumps, based on the manufacturer's pump curves. Similarly, for Case 29 one HPSI pump and the CSS pumps are assumed operating at near maximum capacity, as are the CSS pumps for Case 30. These assumptions are conservative from the point of view of flow rate and therefore piping head losses in the ECCS. The licensee believes that these flowrates are too conservative for SBLOCAs and intends, in future work, to model the hydraulic system using more realistic flowrate estimates for this event.

For both Cases 29 and 30, one HPSI pump and one LPSI pump (maximum capacity 4500 gpm [107, Table 6.3-2]) are assumed to be configured in the boron precipitation control mode, and are both operating at flow rates less than their maximum values. For these cases, the flow rates are those calculated based upon the flow distribution computed from the pump curves, specific valve configurations, and valve resistances that correspond to the operating procedures for the boron precipitation control phase of the recirculation mode of decay heat removal. For these cases, the licensee calculated the "maximum flow" using "...design pump curves for all of the pumps, maximum LPSI pump and HPSI pump throttle valve positions, two HPSI injection valves on one train closed and with at least one LPSI cold leg injection valve open as required in the EOP 2541 Appendix 18A [96, page 8]." For these cases, the licensee's calculational procedure used realistic pump curves, conservatively assumed maximum valve positions, and incorporated instrument uncertainty in establishing the valve positions for maximum flow.

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 from the elevated containment pressure resulting from the LOCA or the initial atmospheric pressure in containment prior to the postulated LOCA. As a result, the calculated NPSHA was simply equal 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 in their neglect of elevated containment pressure following a LOCA.

NPSHR and the Hot Fluid Correction Factor

The NPSHR specification of the pumps was presented in the form of graphs from the pump manufacturer. The NPSHR at room temperature for the HPSI pumps was given in [96] as approximately 22 feet at maximum flowrate, which agrees with the pump curves presented in [94, Attachment K].

Regulatory Guide (RG) 1.82 [5], Section 1.3.1.5, provides guidance that a hot fluid correction factor should not be used to scale the value of NPSHR determined at room temperature to a reduced value based upon the applicable post-accident fluid temperature in calculating NPSH margin. Neglecting the hot fluid correction factor is conservative, and the staff confirmed that this factor was appropriately neglected 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, PROTO-FLO [108]. The PROTO-FLO hydraulic model of the Millstone 2 ECCS is described in [109]. The PROTO-FLO code is an industry standard for hydraulics calculations, and is similar to the Crane methodology [110]. Given the assumed flowrates 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°F, and the flowrates presented in Table 3.6.2-1 were used.

Identical assumptions were made for performing the head loss calculations for both the SBLOCA and the LBLOCA. Assuming equal flowrates for both sequences may be reasonable for Cases 2A2a and 2B2a of Table 3.6-1, since the maximum flowrates were used. However, for Cases 29 and 30, several of the flowrates were computed based on flow distribution calculations, in which the reactor vessel pressure would influence the resulting flowrates. For these cases, therefore, it is not clear that the flowrates are the same for both a SBLOCA and LBLOCA. Licensee performance of an analysis to determine the minimum NPSH margin for a SBLOCA, which captures the concern regarding the potential difference between LBLOCA and SBLOCA flowrates, is designated as **Open Item 6** above.

Decay Heat

RG 1.82, Section 1.3.1.4, provides guidance that "The decay and residual heat produced following accident initiation should be included in the determination of the [sump] 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 [114]. Decay heating is modeled in the CONTRANS computer code that was used in these calculations. However, a detailed review of the assumptions governing the decay heat model was beyond the scope of the staff's audit.

3.6.2.4 Dissolved Air

Containment sump water may contain dissolved air which, if released from solution, would form gas bubbles within the ECCS or CSS. Air may be released from solution as it flows from the containment sump through the piping system at locations where the pressure decreases along the flow path to an ECCS or CSS pump. Upon reaching the pump this air could cause degradation of pumping performance if the volume fraction of the released air exceeds 2%, the recommended limit on allowed air ingestion in RG 1.82 [5, Appendix A].

Ref. [97] contains an analysis of the release of dissolved air from the sump water under the influence of decreasing pressure as the sump water flows from the containment sump to a pump inlet nozzle. The analysis includes the pressure drop across a strainer and debris bed, in addition to the hydraulic losses across the ECCS piping system. The analysis assumes that air released from solution becomes saturated with water vapor. The objective of the analysis is to predict the combined volume fraction of steam and air at the pump inlet nozzle for comparison with the 2% limit.

The analysis appropriately makes use of Henry's Law to relate the gas content of the water to the local pressure and thereby to the released volume of air, expressed in terms of the void fraction. The staff considered the licensee's assumption that the air is saturated with water vapor to be reasonable based upon the physical conditions inside the containment following a LOCA.

A set of calculation results is presented in Attachment 3 of Ref. [97] for a case in which a debris bed is formed over the strainer with a head loss of 0.84 feet of water. The initial containment pressure is 17 psia, and the sump water temperature is 212°F. The calculation result indicates that a small void fraction (0.27 percent by volume) is generated as a result of the pressure drop across the debris bed. However, the results also show that the evolved gas is dissolved back into solution by the time the water reaches the pump inlet nozzle, where the void fraction is predicted to be zero. The licensee's result suggests that pump performance degradation by air bubbles resulting from dissolved gas release would not occur.

During the audit, the staff did not perform a detailed review of the licensee's methodology and results regarding dissolved air.

3.6.2.5 NPSH Margin Conclusion

As described above, the methodology used by the licensee for the NPSH margin calculations generally followed NRC guidance provided by RG 1.82 [5]. There is a level of conservatism built into the NPSH margin calculations due, in part, to the neglect of elevated post-LOCA containment pressure on the available NPSH. The staff also reviewed the elements of the model that were used to perform the NPSH margin calculations. The relevant phenomena were generally included in the model. Some calculations have been verified, and the hydraulic analysis of the NPSH calculation for the HPSI pump was reviewed during the on-site audit.

It is a characteristic feature of Millstone 2 that the pump NPSH margins are small. This condition arises as a result of (1) a static head of liquid measured from the containment floor to the pump nozzle centerline of approximately 21 feet and (2) an NPSHR of approximately 22 feet. The NPSHA is computed by adding the height of the sump pool (4.7 feet to 5.87 feet) to the 21 feet, and subtracting the hydraulic losses in the suction piping (approximately 2.5 feet).

Based upon the information calculated by the licensee presented in Table 3.6-1 [96], the minimum NPSH margin for the HPSI pump during a LBLOCA is approximately 1.99 feet. The maximum head loss expected for the Millstone 2 strainer and accumulated debris is 0.94 feet [112]. The measured head loss, therefore, is less than the maximum allowable head loss for an LBLOCA.

As discussed above, the staff identified four open items regarding the licensee's NPSH margin analysis, which include the following: (1) the licensee should evaluate the potential single failure of one LPSI pump to trip upon the receipt of an SRAS for the NPSH analysis and other areas of the sump performance calculations, (2) the licensee should address and correct the error identified concerning the NPSH margin for the HPSI pumps in the replacement strainer design specification, (3) the licensee should evaluate the minimum pump NPSH margin for the SBLOCA case, and (4) the licensee should evaluate the minimum water level calculation to address the potential non-conservatisms identified above by the staff. With the exception of these four open items, and noting that the dissolved air calculation was not reviewed in detail during the audit, the staff considered the NPSH margin analysis to be acceptable because the methodology generally incorporated sufficient conservatism.

3.7 Coatings Evaluation

3.7.1 Coatings Zone of Influence

The quantities of LOCA-generated qualified coatings debris available for transport to the sump were based on applying the spherical zone of influence (ZOI) model. The NRC SE [2] for NEI 04-07 [1] recommends using a spherical ZOI for qualified coatings with an equivalent radius of 10 Diameters (D) of the postulated ruptured pipe. This was the method used by the licensee. The total surface area and volume of equipment and platform support steel coating within the break ZOI were calculated by the licensee. Wherever a structural member was partially within the break ZOI, the entire member surface area and coating volume are considered to be impacted by the break. All coatings within the ZOI were assumed to fail as particulate and transport 100 percent to the sump, which is the bounding case for a high fiber plant. The controlling break for the quantity of coating debris generation was a 42-inch hot leg break.

The staff finds that the licensee's treatment of the ZOI volume for qualified coatings is in accordance with the guidance [1] & [2] and is therefore acceptable.

3.7.2 Coatings Debris Characteristics

As discussed above, the licensee applied a spherical ZOI of 10D for qualified coatings. The 42-inch hot-leg break was the controlling break for determining the quantity of coating debris. For calculating coating debris transport outside of the ZOI, the licensee assumed that all of the unqualified coatings in containment will also fail as particulate with 100% transport to the sump. This is consistent with the guidance in the NRC SE which requires coatings debris for fiber plants (Millstone Unit 2 is a high fiber plant) to be highly transportable.

The quantities of unqualified coatings within containment were determined based on the results of containment walkdown assessments performed during the 2R17 refueling outage in November 2006. Margins of 1000 sq. ft. of coatings on structural steel and 1200 sq. ft. of coatings on the liner plate were added to the walkdown results to accommodate potential future discovery of degraded or unqualified coatings. This approach of performing a walkdown and adding margin to the results to accommodate potential future degradation is acceptable to the staff.

However, the staff questions the method of assessing qualified coatings by visual inspection only. The licensee has not performed any in-situ testing to validate the visual assessment methods. Therefore, the validation of the licensee's visual assessment methodology of determining qualified coatings is designated as **Open Item 8**. Further, the licensee has not confirmed the acceptability of bare zinc primer after blistered or otherwise degraded topcoat has been removed. The inorganic zinc primer was originally applied as part of a qualified, two coat, Service Level I coating system. At Millstone 2 the inorganic zinc primer that remains after a degraded top coat is removed is considered qualified by the licensee based on engineering judgement alone. The licensee has not justified that residual zinc primer alone remains a qualified coating system after the topcoat is removed. This lack of justification is therefore designated as **Open Item 9**.

The replacement strainer design was tested at AECL's Chalk River Laboratory in Canada using walnut shell flour as the surrogate debris source to simulate coating debris. Portions of the model testing were witnessed by NRR staff. A trip report [92] for this visit to AECL documents the staff's observations. The walnut shell flour used had a size range from 2 to 60 microns with an average particle size of approximately 22 microns. The density of the walnut shell flour is somewhat lower than that for coating debris (81 lbs/ ft^3 vs. 94 lbs/ ft^3), and therefore it will transport as readily as coatings debris. Also, the average walnut shell flour particulate size of 22 microns is within the range recommended in the NRC SE. The staff therefore believes the AECL testing using the walnut shell flour is adequately representative of coatings debris generation and transportability at Millstone 2. For additional discussion on the acceptability of the use of walnut shell flour see Section 3.6.1 on head loss effects.

In summary, with the exception of the open items identified above, the staff finds the licensee's analytical treatment of qualified and un-qualified coatings debris at Millstone 2 to be acceptable.

4.0 DESIGN AND ADMINISTRATIVE CONTROLS

4.1 Debris Source Term

There was no detailed review in this technical area. The staff plans to review the licensee's discussion of its analyses for Section 5.1 of the GR [1] in the Millstone 2 supplemental Generic Letter 2004-02 response the NRC expects to receive at the end of 2007.

4.2 Screen Modification Package

Section 5.3 of the GR [1] provides guidance and considerations regarding potential sump screen designs and features to address sump blockage concerns. Specifically, the attributes of three generic design approaches are addressed. These include passive strainers, backwash of strainers, and active strainers. The NRC Safety Evaluation on the GR [2] does not specifically support any single design, but rather emphasizes two performance objectives that should be addressed by any sump screen design:

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

In addition, the design needs to address other issues that have become more potentially problematic since the SE was written, including chemical effects.

The licensee provided a compact disk (CD) with a large number of documents related to the Millstone 2 GSI-191 analyses. The NRC staff identified the following documents potentially containing information related to the Screen Modification Package:

- DCRM2-05009, Rev. 0, Replacement of ECCS Sump Strainer per Generic Letter 2004-02, GSI-191 [82]
- DCRM2-96020A, Rev. 0, (1996 Replacement Screen), Containment Recirculation Sump Screen Enclosure Redesign [83]
- ECR 25203-ER-05-0016, Rev. 0, Transmittal of Millstone Unit 2 Design Inputs for debris and head loss calculations and ECCS sump screen design for GSI-191 resolution [84]
- Excerpt from 2-16-73 letter (Screen Divider Basis) [85]
- MIL2-34325-EQA-001, Rev. 0, Environmental Qualification Assessment - Replacement Containment Sump Strainer [86]
- MIL2-34325-IP-001, Rev. 0, Installation and Maintenance Procedures - Replacement Containment Sump Strainer [87]
- MD-PROC-ADM-OA 8, Rev. 007, Housekeeping of Station Buildings, Facilities, Equipment, and Grounds [88]
- SP2604J-001, Rev. 004, Containment Sump Inspection [89]
- SP 2604J, Rev. 007, Containment Sump Inspection [90]
- TS Change Request 06-646, Use of Generic Terminology for Emergency Core Cooling System Containment Sump Strainers (LBDCR 06-MP2-031 and 06-MP3-029) [91]

The new Millstone 2 containment sump strainer is, in part, an enclosure that surrounds the two RHR pump suction pipes in the containment building at the -22' 6" elevation. The RHR piping extends approximately 11 inches above the -22 ft 6 inch elevation floor, and a vortex breaker is contained in each pipe. The main "sump enclosure" around these pipe openings is a box made of solid plates with a manway on one side to allow access for inspections.

Two flow headers comprised of individual strainer modules extend out from the main sump enclosure approximately 40 feet in the eastern and northern directions. These flow headers are constructed so as to equalize the flow distribution through the header over its entire length. Perforated hollow fins (strainer disks) are attached to these flow headers to allow ECCS recirculation flow to the main "sump enclosure."

The strainer assembly, including the "sump enclosrure," is constructed entirely of stainless steel, with plate perforations sized to prevent large particles and debris from passing through and clogging the containment spray nozzles or HPSI throttle valves. The total filtration surface of the strainer is approximately 6000 square feet.

The strainer assembly is designed to support the full flow rate from both trains of ECCS simultaneously. Atomic Energy of Canada, Limited (AECL), the Millstone 2 strainer vendor, has performed hydraulic analysis and testing to demonstrate the pressure drop across the new containment strainer with worst-case debris load is less than 2.3 feet [82]. This pressure drop has been calculated by the licensee to ensure sufficient net positive suction head is available to support proper operation of the ECCS pumps. Bypass testing and calculations have been done to demonstrate that debris which passes through the ECCS strainers will not cause enough blockage or wear of any components in the recirculation flow path to prevent long-term cooling. The staff review of this testing and calculations is contained in Section 3.6.1 "Head Loss and Vortexing" and Section 5.3.1 "Downstream Effects - Components and Systems" of this report.

The Millstone documentation indicates that new containment strainer is designed to meet the existing licensing bases as delineated in Technical Specification Sections 3/4.5.2 and 3/4/5/3, 10 CFR 50, Appendix A, 10 CFR 50, Appendix B, and 10 CFR 50.46 as follows:

4.2.1 Failure Modes and Effects Analysis (FMEA) (as reported in Section 3.2 of Ref. [82])

> "A Failure Modes and Affects Analysis was performed to confirm that there is no credible failure mechanism that will cause a failure of the strainer and challenge the independence and redundancy of the containment spray and ECCS systems. This includes evaluation of debris loads and the potential for high energy line breaks that could impact the strainers.
>
> The strainers are passive devices with no moving parts. As such, there are no internal sources of failures and an active failure of the strainer does not need to be considered.
>
> The original strainer design had a perforated divider screen between the two ECCS suction pipes. This design feature was evaluated by AECL on 4/12/2006 for the new strainer design as follows:
>
>> 'In the new screen design if only one of the pumps is operating, roughly half of the flow would be required to pass through the divider plate to the operating pump. (The other half would come from the strainer modules connected directly

to the active pump intake.) In other words, half of the flow that passes through the 6000 ft^2 strainer would now have to pass through a perforated divider plate having a screen area of perhaps 10 to 50 ft^2. Even if only 0.1% of the postulated 1200 ft^3 of fibrous debris passed through the main strainer, this would result in a bed thickness of roughly 0.3 inches on a 50 ft^2 divider plate. (The exact fraction of fiber passing through the screen is not yet known, but could be greater than 0.1percent.) Because of the relatively high approach velocity through the divider plate (on the order of 60 times greater than for the main screen), the head loss through this screen would be greater than through the rest of the strainer, which would effectively disable half of the strainer and cause a higher than acceptable head loss for the operating pump.'

There is no credible failure that could cause failure of part of the sump screen. The strainer design was evaluated for damage due to a high energy line break. The evaluation determined no pipe whip or jet impingement concerns exist in containment for elevations within five feet of the containment floor (calculation PR-V, ref. 3.5.45). The replacement strainer is less than this height and thus is not subject to damage from pipe whip or jet impingement. The strainer is designed to withstand design basis earthquake loading and hydraulic loading prior to and during operation.

The strainer is located under the steam generator cubicles. As such, there may be debris generated by the LOCA that will be washed toward the strainer from above. The large debris will be captured by intervening floor grating and structures. The strainer is a strong structure that is resistant to damage from this debris. In addition, the non-QA cover plate to be installed above the strainer will also protect the strainer from falling debris. Periodic inspections of the strainer for gaps and breaches are conducted per the Technical Specifications, and will detect any incidental damage to the strainer during normal operation.

The existing Failure Mode Analysis documented in the Millstone 2 Updated Final Safety Analysis Report (UFSAR) Table 6.3-6 does not consider failure of the sump trains of strainer modules. As such, the existing strainer partition plate was not considered a necessary part of the design to ensure redundancy.

Since there is no credible failure that could cause damage to part of the strainer assembly, there is no need to separate strainer trains in the new design, and as presently described in UFSAR section 6.3.4.1 (pg 6.3-13):

> 'There is no undue risk to the health and safety of the public from the failure of a single active component during the injection mode of operation or from a single failure of any passive or active component during the recirculation mode of operation.'"

The staff concurs with this analysis pending completion of the strainer structural - pipe whip and jet impingement analysis to be completed by the licensee as discussed in Section 5.1 of this report.

4.2.2 Plant Configuration (as reported in Section 3.4 of Ref. [82])

"The new strainer is installed to cover the containment recirculation pipes (lines #24-

> HCB-1) on the containment floor elevation -22' 6". It will be installed such that it will not intrude on adjacent plant equipment's ability to perform its intended function and will also provide adequate access to the surrounding equipment for maintenance. Detailed installation instructions will be provided in DCN DM2-00-0060-06.
>
> The Containment water level instrumentation LT 8242 and LT 8243 has been evaluated for potential blockage or impact by debris post LOCA. The switches have been determined to not require modification to protect them from potential blockage or damage from debris. The switches are floating balls on a central column. There is nothing around them to capture debris. They are located on a wall that runs East-West on the south end of containment. They are protected from any LOCA impact forces by this wall. The switch on the east end of the wall is near the existing strainer. The existing strainer design will pull flow from all directions, including past these level switches. The new strainer design is composed of 2 headers with fins mounted on the sides. These headers are directed north and west (sic) of the sump and are on the other side of the wall from these switches. As a result, all flow will be directed toward these headers and no longer will be pulled past these switches. As a result it was concluded that the switches are unlikely to be compromised."

Section 7.0 of [82] lists 17 licensee "Open Items" that must be completed prior to "Final Release" of the modification, and two additional licensee open items that are considered enhancements.

The 10 CFR 50.59 evaluation for the strainer modification, included in Reference [82], was incomplete was limited to evaluating the proposed ECCS sump strainer design based on the pre-existing Millstone 2 design requirements for its original ECCS sump strainers. Portions of the new design requirements and the associated evaluation methodologies for the ECCS sump strainers (e.g., chemical effects, downstream effects on components and systems, downstream effects on the fuel and vessel), are currently being developed by the PWR Owners Group and are undergoing NRC review and approval. Once the new design requirements and associated generic PWR Owners Group methodologies are finalized, the proposed design will be evaluated against the new design requirements. The licensee stated during the audit that the reviewed 10 CFR 50.59 evaluation would then be revised to address new design requirements as appropriate. According to Generic Letter 2004-02, demonstration of compliance with the new design requirements is not required until modifications are complete, and the licensing basis is updated (prior to December 31, 2007).

Procedure SP 2604J "Containment Sump Inspection" used at Millstone 2 [82], calls for periodic inspections and requires the following checks:

1. Subsystem inlets are *not* restricted by debris

2. Sump components show *no* evidence of structural distress (damage, such as dents or breaches) or corrosion

3. Sump strainer is *not* blocked by any debris

4. Inside of [main] sump enclosure has *no* debris and *no* degradation which is generating debris (i.e., degraded coating, degraded concrete, etc.)

5. ECCS inlet piping and vortex suppressors show *no* indication of structural distress or corrosion or abnormal conditions.

These inspections are required to be performed at least once every 18 months.

NRC Staff Evaluation

The NRC staff reviewed [82] to assess the overall approach for resolution of sump blockage. The NRC staff observed that the licensee's overall strainer modification approach appears reasonable for addressing the maximum debris volume expected, and a potential thin bed condition. However, because the adequacy of the new strainer is highly dependent on the acceptability of the various analyses that establish required performance (i.e., debris generation, debris transport, debris accumulation and head loss, structural evaluation, etc.), further design changes could be necessary as the licensee finalizes the various ongoing aspects of the sump performance evaluation. These items are discussed in detail in other sections of this audit report. Examples include the ongoing chemical effects testing, the licensee's assumption on the protective coatings zone of influence (ZOI), and the downstream effects analysis. The analyses of these individual aspects of the sump evaluation will form the technical basis for confirming adequacy of the new strainer design to address GL 2004-02.

The screen modification package documentation (DCR [82] and its included 10 CFR 50.59 evaluation) was written based on a number of documents that are being revised, and are not up to date with the latest design information. In some cases, this could effect the overall conclusions (examples: chemical effects evaluation, downstream effects evaluation of HPSI pumps, structural considerations, etc.). The large number of licensee open items identified by Millstone 2 in the modification package [82] were found to still be unresolved. A number of these are consistent with open items found by the NRC during this audit. Many are similar to NRC open items but with different levels of detail (e.g., one specific analytical consideration discussed by the audit team at the site audit exit meeting was the heat sink properties of the mass of the new strainer metal and those properties' potential effect on core reflood time). The modification package and 10 CFR 50.59 evaluation should be updated with the expected final configuration and supporting information and calculations. Because of this, identification of individual open items associated with the DCR and 10 CFR 50.59 was not considered to be appropriate at this time. Completion of the Millstone 2 sump blockage modification package [82], its included 10 CFR 50.59 evaluation, and supporting information and calculations is designated as **Open Item 10**.

At the end-of-week site audit exit meeting new Dominion Millstone 2 Condition Report (CR-07-00905) was discussed which documented the NRC Millstone 2 GSI-191 audit open items as they were known by the staff and the licensee at that time. The CR concluded that no open items appeared to impact the replacement strainer compliance with the current licensing basis. It was noted by the audit team and site resident staff at the end-of-week site exit meeting that the replacement strainer design and performance had not been explicitly compared with the *original (and continuing) licensing basis, for which the worst case at Millstone 2 was LPSI pump* failure to stop upon a recirculation actuation signal. In response, near the end of the site audit week the licensee wrote Condition Report (CR) "CR-07-00939" for the purpose of ensuring documentation of how the new in-plant design would meet the original (and continuing) licensing basis. CR-07-00939 concluded that, for the debris load assumed for the original screen, the much larger replacement screen size of the replacement strainers would ensure a smaller head loss through the new strainer. The staff also notes that the licensee has removed significant quantities of insulation from the containment as part of its GL 2004-02 corrective actions, reducing debris load at the strainer for a variety of LOCA scenarios.

The NRC staff reviewed the applicable test procedures used to perform a visual inspection and verify that each ECCS train containment sump suction inlet is not restricted by debris and that the strainers show no evidence of structural distress or abnormal corrosion. The staff found the scope and frequency of the strainer inspections to be consistent with the guidance in the SE and acceptable for monitoring the integrity and cleanliness of the strainer assembly on a periodic basis.

The licensee provided an evaluation in [82] of containment water level instrument susceptibility to damage or mis-operation from debris or impact forces. The level instrument design, physical location, and post-LOCA flow conditions were considered. The licensee concluded that it was unlikely for these level instruments to be compromised. The staff considers the technical justification provided for the evaluation of the containment water level instruments to be appropriate based on the expected post-LOCA conditions and their function.

5.0 ADDITIONAL DESIGN CONSIDERATIONS

5.1 Sump Structural Analysis - Pipe Whip and Jet Impingement

While onsite, the staff reviewed Revision 2, Change 1 of Calculation PR-V, "Charging, Letdown, Steam Generator Blowdown, & Pressurizer Spray Pipe Whip Restraints Inside of Containment," [177] which received final engineering approval on August 19, 2005. The reason for the change was stated as follows:

> "In support of the proposed upgrade of the Containment Sump system at [Millstone] Unit 2, a review of the charging system pipe breaks and the associated pipe whip restraints was conducted to verify that no interactions with the new sump design would occur .... This CCN is being issued to ... verify that the original conclusions of Technical Evaluation M2-EV-98-0163 remain valid."

Technical Evaluation M2-EV-98-0163, Revision 0 is entitled "High Energy Line Break (HELB) Review Inside Containment." The staff was provided with a copy of this document as well.

On page 4 of Calculation PR-V, CCN 02/01, there was a discussion of the "proposed sump screen expansion." This discussion addressed the four piping lines that run above the then existing sump screen (two charging lines, an auxiliary spray line, and a letdown line), and concluded that, although each of these lines would whip following a pipe break, existing supports, structural steel, and/or piping within the general area would adequately protect the existing sump screen. In addition, the CCN concluded that no secondary missiles of sufficient energy to damage the screens would be created. The discussion continued that review of the likely hinge points for these lines indicated that they would rotate, so that, as long as the new screen is maintained below a height of 5 feet above the containment floor, the whipping pipes and associated jet impingement effects of the postulated breaks would not impact the screens. The new screens, including supports, fins and angle-iron fin supports on top of the fins, are approximately 47 inches in height.

During and after the onsite portion of the audit, the staff communicated to the licensee that the plan dimensions of the new sump strainers are significantly greater than the plan dimensions of the old sump system. While the old sump system was localized at the ECCS/CSS pump suction piping, the new sump strainers extend deep into containment in two long trains of strainer modules. This much different configuration could impact the conclusions drawn by the licensee regarding pipe whip and jet impingement on the new strainer modules.

After the onsite audit, the staff requested piping drawings that would show the postulated breaks in the vicinity of the new sump system, and asked the licensee to confirm that these breaks had been evaluated for the potential effects of pipe whip and jet impingement on the new sump system. The licensee was requested to provide any calculations which addressed the effects of the postulated breaks.

As discussed in Section 3.1 "Break Selection," the staff notes that during the on-site phase of the audit, members of the Millstone staff indicated that the Reactor Coolant System piping that makes up the "loop-seal pipe" from the steam generator cold leg nozzle to the reactor coolant pump suction went below the -3' 6" floor grating. This could make a break in this piping a limiting break for the Break Selection Case #3 criterion, "a direct path to the containment sump," and could also expose the strainer to high jet forces and hydraulic loads. The licensee did not confirm this piping arrangement does not potentially result in a new limiting case for Break Criterion #3, nor did the licensee assess the pipe whip and jet impingement effects from the "loop-seal pipe" in its revised sump structural analysis.

On February 2, 2007, the licensee informed the staff that additional detail was needed in Calculation PR-V, Revision 2 (i.e., a potential Change 2 to that document). This detail would demonstrate more clearly a basis for the acceptability of the new strainer design in terms of pipe whip and jet impingement. The licensee stated that the task was being administratively controlled under the Millstone 2 Corrective Action Program and had a scheduled completion date of June 22, 2007. Licensee completion of development of additional pipe whip and jet impingement detail in Calculation PR-V, Revision 2 to account for the larger dimensions of the new sump strainers is designated as an **Open Item 11.**

5.2 Upstream Effects

The objective of the upstream effects assessment is to evaluate the flowpaths, chokepoints and other mechanisms upstream of the containment recirculation strainers which may result in holdup of reactor coolant inventory. Section 7.2 of the GR [1] and the SE [2] provide guidance to be considered in the analysis of upstream effects. The GR identifies two parameters important to the evaluation of upstream effects: (1) containment design and postulated break location, and (2) postulated break size and insulation materials in the LOCA zone-of-influence (ZOI).

The NRC staff determined that the following documents provided by the licensee contained information related to the Millstone 2 upstream effects evaluation:

- Calculation 07077-US(B)-003, Rev. 01, MP2 Minimum Water Level Following a Loss of Coolant Accident (LOCA) [68]
- Calculation 07077-US(B)-002, Rev. 00, Maximum Containment Water Level During LOCA [69]
- Calculation 07077-US(B)-002, CCN1, Maximum Containment Water Level During LOCA [70]

During the on-site phase of the audit, the NRC staff also requested and received in hard copy the following documents:

- Calculation 96020-1366M2, Rev. 01 "Water Hold-Up in Containment" [71], and
- Plant Design Change Request PDCR #2-62-84 (for design of the refuel pool drain screen) [72]

Staff Evaluation:

The staff reviewed the documents referenced above, along with the Millstone 2 containment layout drawings included in Reference [59], to assess how the licensee evaluated the flow paths from the postulated break locations and containment spray washdown to identify and, in some cases, take measures to mitigate potential hold-up volumes and fluid choke points. The staff also reviewed the above documents and interviewed licensee personnel to verify that the licensee considered water holdup from the entrapment of debris before reaching the recirculation strainers.

The GR provides examples of locations to evaluate for holdup of liquid upstream of the sump screen: narrowing of hallways or passages, gates or screens that restrict access to areas of containment (such as behind the bioshield or crane wall), and the refueling cavity drain line. The staff reviewed the minimum flood containment evaluation [68] to determine if the licensee evaluated locations for flow path clearance or blockage.

The Millstone 2 containment is designed such that potential for upstream holdup and flow choke points is very limited. The upper and intermediate containment floors contain large areas of grating, and numerous flowpaths to allow water to flow to the basement elevation. The reactor cavity seal has large access covers that are removed for normal reactor operations. These provide an alternate drain path for the refueling cavity. Allowances were made for hold-up of water due to saturation of the Nukon insulation in the reactor bioshield cavity area.

However, the staff found that the licensee's evaluation of the potential water hold-up flow mechanisms which result in the minimum volume in the sump pool did not appear to contain allowances for all locations and mechanisms for water holdup in the Millstone 2 containment (e.g., empty containment spray piping filled during recirculation, water which may become trapped in containment ventilation ductwork, the airborne containment spray water volume during recirculation, the volume related to the sloping containment floor, and water sheeting on the surfaces of objects in containment such as equipment, cables, steel supports, ductwork, and containment walls). The staff considers licensee analytical consideration of these potential holdup mechanisms to be **Open Item 12**.

Separately addressed herein, the refueling cavity appears to have a potential to provide a location for significant water hold-up post-LOCA. Completed Plant Design Change Request PDCR #2-62-84 [72] for design of the refuel pool drain screen enclosures was provided for review at the on-site audit in response to an NRC request. According to Millstone personnel, the screen enclosures consisted of 18-inch boxes with a 2-inch hole mesh. A detailed review of this document was not performed while on site. Upon returning from the site audit, the staff noted that item 4.4 on page 3A of [72] states the following:

> The base of the enclosure shall be made of ½ inch thick SS plate which will be in 2 triangular pieces; this arrangement will provide a ½ inch gap at the bottom of the enclosure to allow water to drain to the floor level. Without the gap, a 2 inch high dam is

created and complete draindown would be prevented.

Reference [71] states the following on page 10: "The clogging of the drains is not a concern during a LOCA since the locations of the breaks are remote from the refueling cavities. It is not likely for large pieces of insulation debris to fall into the reactor cavity due to a break in one of the coolant loops."

However, the staff noted that the postulated ZOIs extend upward on the steam generators beyond the operating floor, and there are not any continuous gratings across the SG compartments that would preclude debris from being blown into the upper containment during a LOCA and subsequently falling into the refueling area. Transport of debris to the refuel pool drain screen enclosures could potentially block the ½" gaps discussed above, leading to a 2 inch pool of water remaining in the refueling cavity. This volume was not accounted for in the Millstone 2 Upstream holdup analysis. The licensee should evaluate the potential for debris to be transported into the refueling cavity from LOCA blowdown and Containment Spray washdown, and subsequently result in a refueling cavity holdup volume. The staff considers licensee evaluation of the potential for a refueling cavity holdup volume to be **Open Item 13**.

5.3 Downstream Effects

5.3.1 Downstream Effects - Components and Systems

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

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

The staff safety evaluation of GR Section 7.3 [2] found that the GR statements did not fully address the potential safety impact of LOCA generated debris on components downstream of the containment sump. The staff stated that:

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

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

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

Component rotor dynamics changes and long-term effects on vibrations caused by potential wear should be evaluated in the context of pump and rotating equipment operability and reliability. The evaluation should include the potential impact on pump internal loads to address such concerns as rotor and shaft cracking (NUREG/CP-0152 Vol. 5, TIA 2003-04, "Proceedings of the Eighth NRC/ASMR Symposium on Valve and Pump testing," July 2004).

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

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

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

An overall ECCS or CSS evaluation integrating limiting or worst-case pump, valve, piping, and heat exchanger conditions should be performed and include the potential for reduced pump/system capacity resulting from internal bypass leakage or through external leakage. Internal leakage of pumps may be through inter-stage supply and discharge wear rings, shaft support, and volute bushings (NUREG/CP-1052 Vol. 5, TIA 2003-04). Piping systems design bypass flow may increase as bypass valve openings increase or as flow through a heat exchanger is diverted because of plugging or wear. External leakage may occur as a result of leakage through pump seal leak-off lines, from the failure of shaft sealing or bearing components, from the failure of valve packing or through leaks from instrument connections and any other potential fluid paths leading to fluid inventory loss.

Leakage past seals and rings caused by wear from debris fines to areas outside containment should be evaluated with respect to fluid inventory, and overall accident scenario design and licensing bases environmental and dose consequences."

Staff Evaluation

The staff reviewed the list of all components and flowpaths considered to determine the scope of the licensee's downstream evaluation (pumps, valves, instruments, and heat exchangers, etc.) and found the licensee evaluation to be complete and well organized. All system components and flowpaths were considered and evaluated. Piping and instrumentation diagrams (P&IDs), UFSAR, operations procedures and supporting calculations were reviewed with no design discrepancies discovered.

In accordance with SER Section 7.3, the staff reviewed design and license mission times and system lineups to support mission critical systems. The listing of system line-ups, mission times used to evaluate downstream was complete and consistent with the licensee's FSAR and Operating procedures.

The staff also reviewed all LOCA scenarios (i.e., small-break, medium-break, and large-break LOCAs) to assess system operation. ECCS operation during small-break LOCAs, medium-break LOCAs, and large-break LOCAs may need to be re-assessed following component wear and pluggage evaluations which the licensee has not yet performed. This is designated as **Open Item 14**. System flow and balance calculations to incorporate the results of downstream evaluations have not yet been performed. This is designated as **Open Item 15**.

The licensee determination of the characterization and properties of ECCS post-LOCA fluids (abrasiveness, solids content, and debris characterization) was not complete. The licensee is revising its characterization and properties of ECCS post-LOCA fluid. If planned small-scale testing at AECL produces a less severe characterization than those already assumed, the licensee may pursue using those results rather than using the currently draft assumptions. Determination of the characterization and properties of ECCS post-LOCA fluids is designated as **Open Item 16.**

System debris depletion quantification calculations were included as part of the draft downstream evaluation package. It was stated that these calculations are being revised and have not yet been accepted by the licensee. Also, system debris depletion rates may be re-assessed if the rates in the planned small-scale testing are greater than currently being used in draft documents. Completion of system debris depletion quantification calculations is designated as **Open Item 17**.

The staff reviewed design documents to verify opening sizes and running clearances of ECCS and CSS equipment. Opening sizes and running clearances appear to be well documented in the licensee draft documents. The SE [2] identifies the potential for the high-pressure safety injection (HPSI) throttle valves to clog during ECCS operation. The licensee evaluation of the vulnerability of HPSI throttle valves to clog was thorough and complete. The conclusion of the evaluation was that the HPSI throttle valves do not clog during post-LOCA ECCS operation.

The licensee provided a listing of the materials for all wetted downstream surfaces (wear rings, pump internals, bearings, throttle valve plug, and seat materials). The staff reviewed this list and verified wetted component materials of construction by reviewing design drawings and licensee technical manuals. The information was correctly transcribed into the draft downstream evaluation report [34].

SE Section 7.3 notes the potential to clog or degrade equipment strainers, cyclone separators, or other components. The Millstone 2 ECCS and CSS do not have cyclone separators or other in-line or ancillary strainers.

The SE states that a review and assessment of changes in system or equipment operation caused by wear (i.e., pump vibration and rotor dynamics) should be performed. Also, the SE states that an assessment of whether pump internal bypass flow increases, thereby decreasing performance or accelerating internal wear, should be completed. The licensee stated that the draft Millstone 2 Downstream Evaluation Report [34] with regard to pump performance and operation was being re-performed at the time of the audit. The current draft evaluation is being completely revised. Completion of pump performance evaluations is designated as **Open Item 18**.

During staff review of [34], it was noted that an evaluation of pump hydraulic degradation, total developed head (TDH), and flow due to internal wear had not been performed. Completion of these evaluations is designated as **Open Item 19**.

Additionally, the range of pressures and flows used by the licensee in the draft downstream evaluation to evaluate pump internal wear rates may not be adequate to predict degradation or assess operability in that minimum flows (per EOP) and/or pump run-out flows were not considered. Evaluation of downstream effects using minimum and run-out flows is designated as **Open Item 20**.

The draft downstream evaluation utilized a three-body, erosive wear model. The internal wear mechanism for internal, non-impeller pump wear is two-body (NUREG/CP-0152 Vol. 5, TIA 2003-04, "Proceedings of the Eighth NRC/ASMR Symposium on Valve and Pump testing," July 2004). A justification was not provided for the use of the three-body model. Revision or justification of the three-body model is designated as **Open Item 21**.

The draft downstream evaluation utilized the criterion contained in American Petroleum Institute Standard (API) 610 as acceptance criteria for pump vibration. API 610 applies to 'new' pumps. Millstone 2 did not provide an evaluation supporting the conclusion that the existing pumps are "as good as new." Justification for use of API 610 is designated as **Open Item 22**.

The licensee did not quantify additional pump seal leakage into the Safeguards Room due to wear or abrasion. The licensee has detailed alarm, alarm response and room environmental analyses. These analyses may need to be re-assessed based after seal leakage is quantified. Evaluation of pump seal leakage is designated as **Open Item 23**.

The licensee appropriately defined the range of fluid velocities within piping systems used in the draft evaluation [34]. In that document Millstone 2 adequately reviewed system low points and low-flow areas and found no settlement areas. Non-pump component wear evaluations appropriately used high pump run-out flows.

The licensee has not yet assessed whether the system, piping, component flow resistance or flow balances have changed due to wear or clogging. The existing calculations and analysis assume no degradation or changes to system resistance. The licensee indicated that this evaluation would be performed after the component wear assessment calculations are complete. Completion of flow resistance and flow balance evaluations is designated as **Open Item 24**.

The licensee has not yet assessed whether ECCS and CSS piping vibration response would change due to wear, clogging, changes in system resistence or changes in system operation. The existing calculations and analysis assume no degradation or changes to system resistance. The licensee indicated that this evaluation would be performed after the component wear assessments are complete. Completion of vibration evaluations is designated as **Open Item 25**.

The licensee provided a complete listing and evaluation of instrument tubing connections in [34]. Based on review of this information, the staff concurs with the licensee that there are no adverse affects (pluggage, wear or heat transfer) or other concerns with ECCS system heat exchangers [34].

5.3.2 Downstream Effects - Fuel and Vessel

Before the onsite week, the staff reviewed documentation provided by the licensee on its methodology for evaluating core blockage, and the staff noted that the documents provided lacked an evaluation of the amount and character of the debris which might enter the reactor coolant system and reactor pressure vessel. During the onsite audit, the licensee stated that it was "completely revising" its analysis of downstream effects on the fuel and vessel. Licensee completion of its analysis of downstream effects on the fuel and vessel is designated as **Open Item 26**.

5.4 Chemical Effects

The NRC staff reviewed the licensee's chemical effects evaluation, comparing it with the guidance provided in Section 7.4 of the NRC staff's safety evaluation. In support of the chemical effects portion of the audit, the NRC staff reviewed [27-31].

The Millstone Unit 2 containment materials that are projected to become debris during a LOCA include reflective metallic insulation (RMI), fiberglass, mineral fiber, mineral wool, and containment coatings.

Trisodium phosphate (TSP) is stored in the lowest elevation in the Millstone 2 containment in order to buffer a post-LOCA containment pool. During a presentation to the staff, Millstone 2 representatives indicated there are no plans to change the buffer from TSP. Earlier chemical effects testing sponsored by the NRC (NRC Information Notice 2005-26, "Results of Chemical Effects Head Loss Tests in a Simulated PWR Sump Pool Environment.") showed that in the presence of a TSP-buffered solution, dissolved calcium can combine with phosphate to form a calcium phosphate precipitate that can result in significant head loss across a fibrous debris bed. Therefore, during the refueling outage in October 2006, the licensee replaced all calcium silicate insulation at Millstone 2 that was within any pipe break zone of influence. Since Millstone intends to continue using TSP, the staff noted that it is important that the chemical effects evaluation include all potential sources of calcium (e.g., calcium silicate, concrete, other calcium containing non-metallic containment materials) to ensure the potential amount of calcium phosphate precipitate that forms in the postulated post-LOCA containment pool is accurately determined.

At the time of the audit, the Millstone 2 approach to evaluation of chemical effects was still under development. Licensee representatives indicated during the audit that Sargent and Lundy will be preparing an initial estimate of post-LOCA chemical precipitate, using the WCAP-16530-NP chemical model. AECL will be responsible for conducting bench-top tests and reduced scale tests to evaluate plant specific chemical effects. The staff was not able to draw any conclusions concerning the Millstone 2 chemical effects evaluation since the licensee's analytical and testing approach is under development and testing has not yet been performed. Therefore, resolution of chemical effects at Millstone 2 is designated as **Open Item 27**.

Within the resolution of chemical effects, there is a general open item across the PWR reactor fleet related to the potential for coatings to contribute to chemical effects by: (1) leaching chemical constituents that could form precipitates or affect other materials (e.g., increase aluminum corrosion rates), designated as **Open Item 28** for Millstone 2; or (2) changes to the paint itself due to the pool environment (i.e., the potential for some of the coatings chips to turn into a product that causes high head loss), designated as **Open Item 29** for Millstone 2.

Outside of the audit process for Millstone 2, the PWR Owner's Group has submitted information (ADAMS Accession No. ML070950119) to the NRC that responded to the staff's question (1) above (**Open Item 28** above). If the staff determines that the information provided by the PWR Owner's Group demonstrates that the potential chemical effects from coatings are insignificant, the staff will consider **Open Item 28** to be closed.

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 Dominion Nuclear Connecticut, 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 Millstone 2.

Appendix I

Open Items

Open Item 1:	The licensee had not confirmed that the "loop-seal pipe" piping arrangement does not result in a new limiting case for Break Criterion Case 3.
Open Item 2:	The licensee had not finalized the Millstone 2 debris generation calculations.
Open Item 3:	The licensee had not evaluated the potential adverse effects of break flow drainage turbulence.
Open Item 4:	The licensee had not evaluated and resolved the potential for reduced pump NPSH margins and other adverse effects on the sump performance analysis as the result of a single failure of a LPSI pump to trip following the receipt of an SRAS.
Open Item 5:	The licensee's had not resolved a 1.5 foot error in the HPSI pumps NPSH margin calculation.
Open Item 6:	The licensee had not completed the NPSH margin calculations for the SBLOCA cases.
Open Item 7:	The licensee should evaluate the impact of six potential minimum water level non-conservatisms identified by the staff and assess their impact on the minimum containment water level calculation.
Open Item 8:	The licensee had not validated its visual assessment methodology of determining qualified coatings.
Open Item 9:	The licensee had not justified that residual zinc primer alone remains a qualified coating system after the topcoat is removed.
Open Item 10:	The licensee had not completed the Millstone 2 sump blockage modification package, its included 10 CFR 50.59 evaluation, and supporting information and calculations.
Open Item 11:	The licensee had not completed development of additional pipe whip and jet impingement detail in Calculation PR-V, Revision 2 to account for the larger dimensions of the new sump strainers.
Open Item 12:	The licensee's evaluation of the potential water hold-up flow mechanisms which result in the minimum volume in the sump pool did not appear to contain allowances for all locations and mechanisms for water holdup in the Millstone 2 containment (e.g., empty containment spray piping filled

during recirculation, water which may become trapped in containment ventilation ductwork, the airborne containment spray water volume during recirculation, the volume related to the sloping containment floor, and water sheeting on the surfaces of objects in containment such as equipment, cables, steel supports, ductwork, and containment walls).

Open Item 13: The licensee had not evaluated the potential for debris to be transported into the refueling cavity from LOCA blowdown and Containment Spray washdown, and subsequently result in a refueling cavity holdup volume.

Open Item 14: The licensee may need to re-asses ECCS operation during small-break LOCAs, medium-break LOCAs, and large-break LOCAs following component wear and pluggage evaluations.

Open Item 15: The licensee had not performed system flow and balance calculations to incorporate the results of downstream evaluations.

Open Item 16: The licensee determination of the characterization and properties of ECCS post-LOCA fluids (abrasiveness, solids content, and debris characterization) was not complete.

Open Item 17: System debris depletion quantification calculations were being revised and may also be re-assessed if the rates in the planned small-scale testing are greater than currently being used in draft documents.

Open Item 18: The licensee had not completed re-performing the Millstone 2 Downstream Evaluation Report with regard to pump performance and operation.

Open Item 19: An evaluation of pump hydraulic degradation, total developed head (TDH), and flow due to internal wear had not been performed.

Open Item 20: The range of pressures and flows used by the licensee to evaluate pump internal wear rates may not be adequate to predict degradation or assess operability in that minimum flows (per EOP) and/or pump run-out flows were not considered.

Open Item 21: The draft downstream evaluation utilized a three-body, non-impeller pump erosive wear model. The internal wear mechanism for internal, non-impeller wear is two-body (NUREG/CP-0152 Vol. 5, TIA 2003-04, "Proceedings of the Eighth NRC/ASMR Symposium on Valve and Pump testing," July 2004). A justification was not provided for the use of the three-body model .

Open Item 22: The draft downstream evaluation utilized the criterion contained in American Petroleum Institute Standard (API) 610 as acceptance criteria for pump vibration. API 610 applies to 'new' pumps. The licensee did not provide an evaluation supporting the conclusion that the existing pumps are "as good as new."

Open Item 23: The licensee did not quantify additional pump seal leakage into the Safeguards Room due to wear or abrasion. The licensee has detailed alarm, alarm response and room environmental analyses. These analyses may need to be re-assessed based after seal leakage is quantified.

Open Item 24: The licensee had not assessed whether the system, piping, component flow resistance or flow balances have changed due to wear or clogging.

Open Item 25: The licensee had not assessed whether ECCS and CSS piping vibration response would change due to wear, clogging, changes in system resistence or changes in system operation.

Open Item 26: The licensee had not completed a complete revision of its analysis of downstream effects on the fuel and vessel.

Open Item 27: The licensee had not resolved chemical effects.

Open Item 28: The licensee had not resolved the potential for coatings to leach chemical constituents that could form precipitates or affect other materials (e.g., increase aluminum corrosion rates).

Open Item 29: The licensee had not resolved potential changes to the paint itself due to the pool environment (i.e., the potential for some of the coatings chips to turn into a product that causes high head loss).

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