San Onofre Nuclear Generating Station Unit 2 and Unit 3 GSI-191 Generic Letter 2004-02 Corrective Actions Audit Report

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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.

The San Onofre Nuclear Generating Station (SONGS) Units 2 and 3 are essentially identical in design and are operated by Southern California Edison (SCE), the licensee. The licensee conducted the Unit 2 and Unit 3 GL 2004-02 corrective actions in an essentially identical manner. Therefore this audit report does not distinguish between the two units in its analysis and conclusions.

The onsite activities of the SONGS GSI-191 audit were conducted in two phases. The first audit phase was conducted the week of August 7, 2006, and 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, computational fluid dynamics (CFD), net-positive suction head (NPSH) available, and screen modification package. The second audit phase was conducted the week of September 25, 2006, and addressed chemical effects, head-loss and vortexing, and downstream effects on components and systems (including net-positive suction head required). The audit of the technical areas of sump structural analysis and downstream effects on fuel and vessel were conducted as NRC Headquarters desk audits.

1.2 Bulletin 2003-01 Responses

The SONGS August 1, 2003 response letter to Bulletin 2003-01, "Potential Impact of Debris Blockage on Emergency Sump Recirculation at Pressurized Water Reactors" [47], and supplemented by response letters dated October 13, 2004, July 15, 2005 and September 8, 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; (6) ensuring sump screens are free of adverse gaps and breaches.

In its response to Bulletin 2003-01, SCE stated that SONGS had implemented the following interim compensatory measures::

1. Operators are provided with and trained on safety injection (SI) throttle stop criteria predicated on satisfying certain plant conditions (e.g., reactor coolant system (RCS) sub-cooling, pressurizer level);

2. Operators are provided with four methods for filling the refueling water storage tank (RWST): blended makeup, spent fuel pool crosstie, primary tanks, and the opposite unit RWST;

3. Operators are directed to initiate makeup as required to the RWST, to maintain RWST level greater than 19 percent, and to evaluate the need for additional makeup to the RWST;

4. A Containment Cleanliness and Loose Debris Program is in place which provides for “clean as you go” work activities, cleaning of accessible areas before containment closeout, Health Physics Manager containment cleanliness inspections, and containment cleanliness inspections from a pool of 70 qualified representatives from a broad divisional cross-section of station personnel;

5. A coatings assessment program is in place for SONGS Units 2 & 3 Service Level 1 coatings used in containment, which are procured, applied, and maintained by Southern California Edison (SCE) or their contractor to comply with American National Standards Institute (ANSI) N101.2 and NRC Regulatory Guides, with certain exceptions;

6. Condition assessment walkdowns of Service Level 1 coatings inside containment are performed each refueling outage, with repair (or with repair scheduling) as degraded or nonconforming coatings are identified;

7. A multi-discipline working group, the San Onofre Coatings Inspection Team, provides continuous assessment of the SONGS coatings program to ensure continued compliance with regulatory and industry standards;

8. Various material controls are in place to restrict the use of and control materials in containment which could potentially block the containment emergency sump (CES);

9. A containment closeout critical valve verification is performed; it includes checking that the refueling pool fill/drain line valve from the refueling cavity to the CES area is locked open and the flange is removed;

10. A containment emergency sump surveillance is conducted during refueling outages to verify all gaps in the sump screen greater than 0.090 inch are sealed or reduced to no greater than 0.090 inch.

11. Licensed operator requalification training is conducted to address loss of flow or loss of

pump suction while in the recirculation mode of emergency core cooling, including indications of sump clogging and review of related severe accident management guidelines (SAMGs).

12. When appropriate to protect the reactor core, operators are directed to inject more than one RWST volume from a refilled RWST;

13. Operators are directed to conduct aggressive cooldown and depressurization following a small-break loss-of-coolant accident (LOCA) to avoid recirculation operations;

14. Operators are provided with guidance on symptoms and the identification of containment sump;

15. Operators are provided with contingency actions in response to containment sump blockage, loss of ECCS and CSS pump suction, and cavitation of ECCS and CSS pumps (these actions are taken should the pumps show unstable flow, discharge pressure or motor amperage); and

16. SONGS has identified RWST bypass (direct RCS injection) borated and un-borated water sources with flowpaths from the spent fuel pool, the unaffected unit RWST, the condensate system, the fire service water system, and other water volumes which would be available post-LOCA.

1.3 Generic Letter 2004-02 September 1, 2005 Response

In response to, and as requested by GL 2004-02, Southern California Edison (SCE, the licensee for SONGS Unit 2 and Unit 3) 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 stated that it was working to confirm that the SONGS Unit 2 and Unit 3 Emergency Core Cooling Systems (ECCS) and Containment Spray Systems (CSS) would function under debris loading conditions and would be in compliance with applicable regulatory requirements. The licensee stated that it would demonstrate this compliance through a combination of analysis, mechanistic evaluations, testing, modifications to replace sump screens, and other potential modifications for debris loading reduction, sump inventory control, and downstream effects mitigation. The licensee stated that it did not plan to submit License Amendment Requests (LARs) in conjunction with resolution of Generic Safety Issue 191 at SONGS, and that it was working to complete design, procurement, fabrication, delivery and installation of replacement sump screens, and other modifications by the GL 2004-02 corrective actions completion date of December 31, 2007. The licensee stated that if new information, or the resolution of chemical or downstream effects issues would affect its ability to complete the work on either unit by the corrective actions due date, it would notify the NRC.

In its September 1, 2005 response, SCE reported the major analyses and evaluations which had been completed in support of its GSI-191 evaluations, listed plant modifications that had been identified for completion, and listed major engineering and analyses efforts and programmatic changes which were then outstanding.

Completed major analyses and evaluations included containment walkdowns, calculations of minimum flood levels, debris generation, sump screen flow rates, debris transport, net positive suction head (NPSH), head loss at the screen, maximum screen size, preliminary screen size, and downstream effects. The identified plant modifications were installation of replacement sump screen, removal of microporous insulation, and modification of steel gates at entries to the bioshield to reduce the potential for debris blockage and holdup of recirculating water. The remaining major engineering and analyses efforts included:

- Design and procurement of replacement sump screens;
- Resolution of potential susceptibility of the ECCS and CSS pump mechanical seals to increased leakage due to the debris mix passing through the seals;
- Resolution of potential susceptibility of the ECCS and CSS pump mechanical seal cyclone separators to debris blockage;
- Development of a reduced qualified protective coatings zone of influence (ZOI);
- Validation of the 8% head loss margin adjustment factor for chemical effects (SONGS uses Trisodium Phosphate (TSP) as a post-LOCA pH buffering agent, and pertinent debris loads are primarily mineral wool fibrous insulation, making the NRC's Integrated Chemical Effects Test (ICET) 2 generally applicable, but SCE stated that chemical effects values were subject to follow-on sump screen vendor testing, and SCE evaluations and walkdowns); and
- Containment insulation configuration control to ensure the amounts and types of insulation remain within acceptable debris loading design margins.

SCE stated that:

- Analyses of debris generation, transport and head loss through a sump screen debris bed conformed to the industry guidance report Nuclear Energy Institute (NEI) 04-07 Volume I (GR) [1] as approved in the NRC safety evaluation (SE) on the GR [2], except as noted elsewhere in the SCE September 1, 2005 letter;
- Analyses for downstream effects in the ECCS and CSS flowpaths follow WCAP-16204-P, Rev. 0 [83]; and
- Evaluation of chemical effects relating to head loss follow an NEI letter to the industry dated July 29, 2005.

SCE identified Westinghouse Electric Company, LLC as its primary contractor, with Alion Science and Technology and Enercon Services as subcontractors.

SCE provided an extensive listing of methodologies applicable to various aspects of the SONGS GSI-191 analyses, the intended or current use of which is summarized as follows:

- Containment walkdowns would be performed in accordance with NEI 02-01, Revision 1, “Condition Assessment Guidelines: Debris Sources Inside PWR Containments,” dated September, 2002 [117];
- Pipe break and debris generation evaluations would be performed in accordance with

NEI 04-07 as approved by the NRC SE;

- SCE stated that it had determined that the Mineral Wool insulation at SONGS, which has stainless steel Transco cassettes, has a cassette destruction pressure equal to the Transco stainless steel cassette destruction pressure for reflective metal insulation (RMI). For conservatism, SCE doubled the 2D ZOI for RMI cassettes to a 4D ZOI for SONGS Mineral Wool cassettes (a 2D ZOI means that destruction occurs within two pipe diameters of the pipe rupture - a “2D” zone of influence of the high energy steam plume);

- Flow-3D commercial software was used for computational fluid dynamic calculation of debris transport under recirculation conditions;

- SCE stated that mineral wool erosion, shown in test data to consist primarily of small, loosely attached pieces of fiber breaking off from larger pieces, would taper off after 24 hours. SCE rounded the 24 hour erosion total from 7% to 10% for conservatism;

- Alion Science and Techology calculations of sump screen head loss utilized HLOSS code;

- Hydraulic and material properties testing of mineral wool would be based on Alion Science and Technology testing rather than on the properties in the NEI 04-07 methodology as approved by the NRC SE;

- Based on the low fluid approach velocities at the SONGS replacement strainers, instead of the Los Alamos Report LA-UR-04-5416, “Screen Penetration Test Report,” November 2004 sump screen capture efficiency of 95% the SONGS fuel evaluation used a 97% capture efficiency; and

- The vendor’s replacement strainer structural evaluation would be expected to use SONGS-specific input conditions.

SCE stated that the minimum NPSH margin (NPSH Available minus NPSH Required) for the ECCS and CSS pumps during recirculation, exclusive of clean screen and screen debris head losses, were calculated to be 5.0 feet of H_2O (with the high pressure injection (HPSI) pumps being limiting). SCE stated that each replacement sump screen was expected to have approximately 800 square feet of surface area, and the screens were to be 100% submerged at switchover to recirculation. SCE further stated that the calculated head loss across the replacement screens was calculated to be aproximately 3.3 feet of H_2O (3.6 feet of H_2O after application of an 8% chemical effects head loss margin adjustment factor).

SCE stated that it had evaluated the potential wear and blockage of components from particulate and fiber including heat exchanges, orifices, spray nozzles, instrumentation tubing, pumps and valves, as well as the reactor vessel and fuel, and that evaluations had shown that blockage of the smallest flow restriction in the ECCS and CSS flowpaths would be precluded by procurement of replacement screens with a hole size of 3/32 inch diameter or less.

2.0 DESCRIPTION OF PLANNED CHANGES

SCE will replace its original sump strainers (Unit 3 complete, Unit 2 fall 2007) with vertically oriented, Enercon design, cylindrical “Top Hat” strainers attached to a large plenum box. The SONGS sump in each unit is divided into two separate “trains,” feeding two separate trains of Emergency Containment Cooling System (ECCS) and Containment Spray System (CSS) pumps.

3.0 BASELINE EVALUATION AND ANALYTICAL REFINEMENTS

3.1 Break Selection

The objective of the break selection process is to identify the break size and location that presents the greatest challenge to post-accident sump performance. Sections 3.3 and 4.2.1 of the GR [1] and SE [2] provide the criteria to be considered in the overall break selection process in order to identify the limiting break. In general, the foremost criterion used to define the most challenging break is the estimated head loss across the sump screen. Therefore, all phases of the accident scenario must be considered for each postulated break location, including debris generation, debris transport, debris accumulation, and sump screen head loss. Two attributes of break selection that are emphasized in the approved evaluation methodology and can contribute to head loss are: (1) the maximum amount of debris transported to the screen; and (2) the worst combinations of debris mixes that are transported to the screen. Additionally, the approved methodology states that breaks should be considered in each high-pressure system that relies on recirculation, including secondary side system piping, if applicable.

ALION-CAL-SONGS2933-02, "San Onofre Units 2 and 3 GSI 191 Containment Recirculation Sump Evaluation: Debris Generation Calculation," [13] documents the assumptions and methodology the licensee applied as part of the overall break selection process, and to determine the limiting break for SONGS.

Staff Evaluation

The NRC staff reviewed the licensee’s overall break selection process and the methodology applied to identify the limiting break. Specifically, the NRC staff reviewed San Onofre Calculation No. ALION-REP-SONGS2933-001, "San Onofre Units 2 and 3: Characterization of Events that May Lead to ECCS Sump Recirculation,” [33] against the approved methodology documented in Sections 3.3 and 4.2.1 of the SE and GR. The NRC staff observed that the licensee’s break selection evaluation was generally performed in a manner consistent with the approved SE methodology. Deviations from the staff-approved methodology were considered to be reasonable based on the technical basis provided by the licensee. A detailed discussion is provided here.

The NRC staff’s review found that the licensee evaluated a number of break locations and piping systems, and considered breaks that rely on recirculation to mitigate the event. The following break location criteria were considered:

Break Criterion No. 1 - Breaks in the RCS with the largest potential for debris;

Break Criterion No. 2 - Large breaks with two or more different types of debris;

Break Criterion No. 3 - Breaks with the most direct path to the sump;

Break Criterion No. 4 - Large breaks with the largest potential particulate debris to insulation ratio by weight; and

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

This spectrum of breaks is consistent with that recommended in the SE and is also consistent with regulatory position 1.3.2.3 of Regulatory Guide 1.82, "Water Sources for Long-Term Recirculation Cooling Following a Loss-of-Coolant Accident," Revision 3 [4].

The licensee considered breaks in the primary coolant system piping having the potential for reliance on ECCS sump recirculation. The licensee reviewed the SONGS Unit 2 and Unit 3 accident analysis and operational procedures to determine which accidents may require sump recirculation. The licensee concluded, and the staff concurs, that a primary coolant system piping large break loss of coolant accident (LBLOCA) and certain primary coolant system piping small break LOCAs (SBLOCAs) would require ECCS sump recirculation. The licensee considered other high energy line breaks (e.g., secondary side breaks) and determined that sump operation was not required.

For small breaks, only piping that is 2" in diameter and larger was considered. The NRC staff found this to be consistent with the Section 3.3.4.1 of the SE, which states that breaks less than 2 inches in diameter need not be considered. Section 3.3.5 of the SE describes a systematic licensee approach to the break selection process which includes beginning the evaluation at an initial location along a pipe and stepping along in equal increments (5 foot increments per the SE) considering breaks at each sequential location. However, the SONGS 2 and 3 break selection process did not apply such a systematic approach. Licensee representatives stated that the selected locations were the obvious selections relative to the 5 break selection criteria above, so that a 5 ft. increment approach was not required. The licensee stated that due to the size of the ZOI applied in the analyses, and the consequent volume of debris generated, it was not necessary to evaluate 5-ft increments. NRC staff agrees with the licensee’s rationale regarding why performing the analysis by considering 5-ft increments is not necessary at SONGS.

The licensee evaluation identified break locations that provided limiting conditions for each of the 5 break selection criteria above. For SE break selection criterion No. 1 (“Break Criterion No.1"), the licensee identified three possible breaks locations: both loops of the RCS hot leg inside steam generator compartments inside the bioshield; and a break at the reactor vessel nozzles. The results of the licensee’s evaluation of insulation debris generation for Break Criterion No. 1 determined that all three breaks are limiting based on either the type or amount of debris generated.

The licensee determined that the debris generated by the three limiting cases for Break Criterion No. 1 bounded the debris generated for Break Criterion No. 2 “large breaks with two or more different types of debris.” The debris combinations generated by the breaks of Break Criterion No. 1 are reflective metal insulation (RMI) and mineral wool, and RMI and Microtherm^{TM}. The licensee concluded that these three breaks generate the largest amount of debris, and also the most limiting combinations of debris. The NRC staff finds this to be appropriate.

For Break Criterion No. 3, "breaks with the most direct path to the sump," the licensee concluded that the most limiting case is a break at the 16-in shutdown cooling line. The licensee used piping on P&IDs (piping and instrument diagrams), as well as piping arrangement, plan and physical arrangement drawings to determine possible break locations. The NRC staff agrees that a break at the 16-in shutdown cooling line is the most limiting case for Break Criterion 3 since it is the largest line that is in the proximity of the sump and it generates both mineral wool and RMI debris.

For break selection criterion No. 4, "large breaks with the largest potential particulate debris to insulation ratio by weight," the licensee concluded that the most limiting case is a break at a reactor vessel nozzle within the reactor cavity, which is bounded by Break Criterion No. 1. Of the three different types of insulation identified within the containment, Microtherm^{TM} is predominately particulate insulation material. This type of insulation is on the reactor vessel. Since a significant portion of the Microtherm^{TM} within the reactor cavity would be destroyed in Break No. 1, the NRC staff agrees that it is the most limiting case.

For break selection criterion No. 5, “breaks that generate a thin-bed,” the licensee identified two possible breaks locations: break at the hot leg and a break at the reactor vessel nozzle, which are bounded by Break Criterion No. 1

To develop a head-loss margin analytical conservatism for possible future use, the licensee evaluated the potential reduction in debris source term following replacement of the mineral wool on the steam generators with RMI. The insulation replacements will be performed in the Unit 2 October, 2009 outage and in the Unit 3 October, 2010 outage. The insulation replacement does not change the break selection results. Technical issues related to these insulation replacements are covered in the debris generation analysis section of this report (Section 3.2).

In summary, the licensee determined that a postulated LBLOCA within Loop 1 and 2 at the steam generator hot legs generates the largest quantities of mineral wool and RMI debris. A break near the reactor vessel nozzle generates a large amount of RMI and Microtherm^{TM} debris which has the potential to cause significant head loss at the containment emergency sump strainer both from fiber and particulate debris. A break at the 16-in shutdown cooling line is considered in the proximity of the sump, and generates mineral wool and RMI debris which will likely transport to the containment emergency sump. Therefore, the licensee concluded that these reactor coolant system breaks generate the largest amount of debris, and also the worst combination of debris with the possibility of being transported to the containment emergency sump strainer.

The licensee evaluated all phases of the plant-specific accident scenarios to develop debris generation values for the breaks listed in the previous summary paragraph. These accident scenario cases are:

1. Case 1: RCS hot leg break inside steam generator compartment Loop 1 (limiting break for SE break selection criteria 1, 2 and 5);

2. Case 2: RCS hot leg break inside steam generator compartment Loop 2 (limiting break

for SE break selection criteria 1, 2 and 5);

3. Case 3: Nozzle break in reactor cavity (limiting break for SE break selection criteria 1, 2, 4 and 5)

4. Case 4: Shutdown cooling line break outside steam generator compartments (limiting break for SE break selection criterion 3); and

5. Case 5: Hot leg break after steam generator replacement.

Section 3.2 of this report, "Debris Generation/Zone of Influence (Excluding Coatings)," addresses debris generation for these cases.

In conclusion, as discussed throughout this section, the NRC staff found that break selection was generally performed in a manner consistent with the approved SE methodology. Selective deviations from the staff-approved methodology appeared reasonable based on the technical bases provided by the licensee.

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 is based, in general, on experimentally-deduced destruction pressures as applied using the methods of the ANSI/ANS 58.2 1988 standard. Once the ZOI is established, the types and locations of all potential debris sources (insulations, coatings, dirt/dust, fire barrier materials) can be identified using plant-specific drawings, specifications, walkdown reports or other such reference materials. The amount of debris generated is then calculated based on the amount of materials within the most limiting ZOI.

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

The GR and SE also provide guidance on debris size distribution and characterization for the various debris types within a ZOI. Size distribution and characterization of debris are important parameters that are used in the transport and head loss analyses. Testing of various materials has provided general guidelines for fractions of "large pieces" and "fines" based on the location of debris sources within the region of a ZOI.

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ALION-CAL-SONGS2933-02, Revision 1, “San Onofre Units 2 and 3 GSI-191 Containment Recirculation Sump Evaluation: Debris Generation Calculation” [59], documents the assumptions and methodology the licensee applied to determine the ZOI and debris generated for each postulated break. To address questions raised by the NRC staff during the audit, supplemental justification was provided by the licensee in Alion documents ALION-REP-SONGS-3987-01 “Additional Justification for Mineral Wool 4D ZOI Values Utilized in ALION-CAL-SONGS2933-02 ‘San Onofre Units 2 and 3 GSI-191 Containment Recirculation Sump Evaluation: Debris Generation Calculation’,” [22] and ALION-REP-SONGS-3987-02 “Additional Justification for Microtherm Debris Generation Calculated in ALION-CAL-SONGS2933-02 ‘San Onofre Units 2 and 3 GSI-191 Containment Recirculation Sump Evaluation: Debris Generation Calculation’.” [23]

The NRC staff reviewed the licensee’s ZOI and debris generation evaluations and the methodology applied. Specifically, the NRC staff reviewed the SONGS calculations against the approved methodology documented in Sections 3.4 and 4.2.2 of the SE. The NRC staff found the licensee’s evaluation to be largely consistent with the approved methodology. However, the NRC staff has concerns with the level of technical basis provided for the assumptions used for the ZOIs for the mineral wool and Microtherm insulations in the SONGS containments.

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

The sources of debris at SONGS included insulation debris, coatings debris, and latent debris. The coating debris generation is discussed separately in Section 3.7 and latent debris is discussed in Section 3.4. The licensee concluded that there are three types of insulation inside the SONGS containment that could potentially form debris following a LOCA. These insulations are: 1) Transco reflective metallic insulation (RMI), 2) mineral wool encased inside a Transco stainless steel (SS) cassette, and 3) Microtherm™ encased inside a Transco SS cassette. The licensee noted that mineral wool and Microtherm were not specifically identified in the SE as insulation types that were tested to provide established ZOIs.

Section 3.4.2.2 of the SE provides guidance for selection of a ZOI. The SE has approved the use of NUKON as a surrogate for other types of fibrous insulation based on its low destruction pressure and density. The entries in Table 3-2 of the SE relevant to the material types referenced for SONGS show the following:

Table 3.2-1: SE Table 3-2 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	6	17.0

For the Transco RMI insulation at SONGS, the licensee assumed a ZOI size in accordance with the guidance in the SE.

For the mineral wool and Microtherm at SONGS, the SE Table 3-2 does not provide specific guidance, so the licensee was required to develop ZOIs based on other information. The licensee noted that the mineral wool and Microtherm insulation that will remain in service at SONGS are contained in an engineered system comprised of cassettes that are constructed exactly the same as the Transco RMI used at SONGS. These cassettes are constructed of 24 gauge steel with the casing end seams seal welded. The licensee contends that, based on the robust nature of this encapsulation/jacketing system, the ZOI for the SONGS mineral wool would be closer to Transco RMI than unjacketed NUKON. To ensure conservatism, the licensee then doubled the ZOI from the Transco RMI (2D out to 4D). However, the licensee did not provide an analysis to support its conclusion that the jacketing system reduces the ZOI as asserted.

The Table 3-2 entries above show a single line entry for both unjacketed NUKON and jacketed NUKON with standard bands. This implies that credit should not be taken for jacketing with standard bands for reducing the size of the ZOI. However, directly under Table 3-2, the SE contains the following statements that are relevant to the position SONGS considers appropriate for their mineral wool and Microtherm insulation:

> Formal debris generation studies have confirmed that insulation products having outer casings, jackets, or other similar mechanical barriers resistant to jet impingement yield smaller quantities of debris than do less robust materials. Various studies have also demonstrated dependence between the orientation of the jacketing seam relative to the jet and the amount of debris generation. This suggests that the integrity of the jacket during impingement is an important feature for minimizing debris generation. Russell reports, for example, that double jacketing an insulation product with a second overcladding of stainless steel having a rotated, opposing seam was very effective at minimizing the distance from the jet to the onset of damage (OPG, 2001). As mentioned in Appendix I to this SE, any improvement in the mechanical resistance of the insulation product will help to avoid inflated ZOI volumes predicted by the ANSI jet model for very low damage pressures.

So, although the SE Table 3-2 entry does not directly support crediting insulation jacketing for NUKON with standard bands, the SE does recognize that jacketing configurations can be effective in reducing damage.

The justification for the SONGS position of 4D ZOI for their mineral wool and Microtherm insulation systems appears to be intuitively correct, but is not supported with a substantial engineering analysis or judgement. A more in-depth structural analysis of the cassette construction, and a direct comparison to established and accepted test data would strengthen the argument. The staff investigated the Transco RMI tested by the Boiling Water Reactor Owners Group (BWROG) as reported in the BWROG Utility Resolution Guide (URG) [20] and found that in seven tests (tests 01-1, 01-2, 01-3, 20-1, 20-2, 22-1, 22-2, and 22-3) of the Transco 0.024 inch stainless steel sheathed insulation with solid ends, no test showed penetration of the cassette (cassettes were blown off the pipe, deformed, but remained intact). It is not clear from the BWROG tests if the Transco cassettes tested had spot-welded or riveted seams, or were seal welded (URG test results, section 5.2.3 of [20]). In either case, the seal welded seams would be physically stronger; and would also provide a leak-proof barrier that would prevent the two-phased steam jet from penetrating, and subsequently expanding, inside the cassette. From this information it can be inferred that the SONGS 4D ZOI position is qualitatively correct, and the staff agrees that it is acceptable.

The physical location of the Microtherm insulation that will remain in use at SONGS after December 31, 2007, provides some unique analytical challenges. The Microtherm insulation remaining in use at SONGS will be a narrow band on the reactor vessel just below the nozzles. This insulation is located in an annular volume between two robust barriers (the reactor vessel and the biological shield wall), and the pipe break that destroys this insulation is in a location that will not allow full pipe separation (pipe separation prevented by the reactor vessel and biological shield). The licensee uses a spherical ZOI with this physical configuration in an evaluation [23] that credits the shadowing of the Microtherm on the back of the reactor vessel, as well as crediting the seal-welded structure of the Transco cassettes.

The licensee credits the reactor vessel as a robust barrier to provide shadowing of the Microtherm insulation on the opposite side of the reactor vessel from the postulated break, such that damage to the shadowed insulation need not be considered. Section 3.4.2.3 of the SE states:

> For the baseline analysis, the NRC staff position is that licensees should center the spherical ZOI at the location of the break. Where the sphere extends beyond robust barriers, such as walls, or encompasses large components, such as tanks and steam generators, the extended volume can be truncated. This truncation should be conservatively determined with a goal of +0/-25 percent accuracy, and only large obstructions should be considered. The shadow surfaces of components should be included in this analysis and not truncated, as debris generation tests clearly demonstrate damage to shadowed surfaces of components.

Note that the last sentence from this section of the SE contradicts the SONGS position on shadowing of the Microtherm insulation on the reactor vessel.

As stated above, for the Microtherm ZOI analysis, the two robust structures at SONGS (the reactor vessel and the biological shield wall) would prevent pipe movement after the break. The resulting configuration makes the assumption of a double-ended guillotine break (DEGB) unnecessary, and makes a spherical jet model inapplicable. As stated in the NRC SE :

> The staff has reviewed the use of a spherical model sized in accordance with the ANSI/ANS standard and finds this approach acceptable. The spherical geometry proposed encompasses a zone which considers multiple jet reflections at targets, offset between broken ends of a guillotine break, and pipe whip. The staff's confirmatory analysis (see Appendix I to this SE) verifies the applicability of the ANSI/ANS standard for determining the size of this zone. The staff found the use of a ZOI model to be an acceptable approach for analyzing debris generation in accordance with RG 1.82, Revision 3 ...

From these statements, it is clear that the spherical ZOI is applicable for modeling freely expanding jets from a DEGB. However, the staff believes this may not be an appropriate model for a restrained break that would not produce a freely expanding jet.

The ANSI/ANS standard (ANSI/ANS-58.2) referenced in the staff SE contains considerations for restrained breaks. It would be more appropriate for SONGS to apply the guidance in ANSI/ANS-58.2 for a restrained break when evaluating the potential for the destruction of the Microtherm insulation on the reactor vessel for a pipe break at the reactor vessel nozzle.

It should also be noted that the ANSI/ANS standard contains some considerations for jet shape factors that may also apply in the SONGS annulus region where full separation of the double-ended guillotine break could not occur. These may be considered as an allowable refinement in accordance with page 92/93 of the SE, which states:

> First, the application of worst-case thermal hydraulic conditions to every break location can be relaxed if there is supporting evidence to demonstrate that a particular break location or class of break locations exhibits substantially different conditions that can be conservatively calculated or measured.

In summary, for both mineral wool and Microtherm, the licensee is crediting the structural stability and strength of the Transco cassettes used at SONGS to define the ZOI, but did not provide analysis of the strength of the SONGS cassettes. Although this position can be inferred to be qualitatively correct, and is acceptable to the staff, a more in-depth analysis would strengthen the basis of this position.

For the Microtherm, an additional analysis to develop a ZOI for a restricted pipe break in the annular region was absent. Such an analysis could include revisiting assumptions made regarding shadowing, as well as the choice of ZOI. Multiple jet reflections and limited vent paths in the annular region could be addressed for their potential impact on the reactor vessel shadowing assumption. Because the licensee did not develop detailed analysis for a Microtherm ZOI for a restricted pipe break in the reactor vessel annular region, the staff designates this to be **Open Item 1**.

For the RMI, mineral wool, and Microtherm at SONGS, the debris-specific spherical ZOIs were superimposed by the licensee onto a SONGS computer-aided design (CAD) model at the applicable break location for each case analyzed. This model and insulation location data were used to determine the quantity of each type of insulation that would be in the ZOI. All of this insulation was then assumed to become debris. A summary of the SONGS insulation debris generation quantities is provided below:

SONGS Insulation Debris Quantities

Insulation	**Case 1 Loop 1 Hot Leg Break**	**Case 2 Loop 2 Hot Leg Break**	**Case 3 RV Nozzle Break**	**Case 4 Cooling Line Break**	**Case 5 Loop 1 Hot Leg Break After Mineral Wool Removal** (after SG replacement)

Transco RMI	7096 ft^2	7549 ft^2	7530 ft^2	815 ft^2	7096 ft^2
Mineral Wool	81 ft^3	81 ft^3	0	0	12 ft^3
Microtherm™	0	0	11.4 ft^3	0	0

For the Transco RMI insulation at SONGS, the licensee assumed a ZOI and volume of debris in accordance with the guidance in the SE. Additionally, the licensee assumed an RMI destruction size distribution that is conservative for the Transco RMI based on BWROG test results [20] . The staff finds the treatment of Transco RMI acceptable based on adherence to SE guidance and licensee-applied conservatism.

For the mineral wool insulation that will remain in service at SONGS, the licensee-proposed ZOI based on the cassette structure was used to evaluate insulation located on the shells of the steam generator secondary sides for its potential to generate debris, and to characterize the expected size distribution of the debris. The volume and size distribution of the debris were calculated in a manner similar to the guidance in the SE. The staff finds this acceptable. It should be noted that most mineral wool insulation will be replaced with RMI type insulation in the near future as part of the steam generator replacements planned for SONGS Unit 2 and Unit 3 in October, 2009 and October, 2010 respectively, resulting at that time in a lower debris source term. The Case 5 analysis was not credited for resolution of GL 2004-02 due to these corrective actions being scheduled beyond the December 2007 due date.

3.3 Debris Characteristics

The staff reviewed the debris characteristics presented in the licensee's debris generation calculation [13], debris transport calculation [14], debris head loss calculation [15], and insulation debris size distribution calculation [24]. During the onsite portion of the audit, from August 7–10, 2006, the staff also reviewed a slide presentation [6] provided by the licensee and discussed a number of technical issues with licensee and vendor personnel. The staff also reviewed two documents provided by Southern California Edison to amplify the licensee's position concerning issues discussed during the onsite portion of the audit which dealt with the 4D ZOI assumption for mineral wool [22] and the 50%-destruction assumption for Microtherm around the reactor vessel [23].

Several types of debris are present in the SONGS containment buildings, including stainless steel reflective metallic insulation (RMI), mineral wool, Microtherm, various types of qualified and unqualified coatings, and latent fibrous and particulate debris. The staff's review of the licensee's debris characterization assumptions for each debris type is provided below, except for coatings, which are discussed in Section 3.7 of this report.

3.3.1 Stainless Steel Reflective Metallic Insulation

According to documentation supporting the SONGS containment walkdowns [24], RMI is installed primarily on the reactor coolant system (including the pressurizer, primary side of the steam generators, and part of the reactor vessel), chemical and volume control system, liquid radwaste system, and shutdown cooling system. The RMI used at SONGS is produced by Transco and is encapsulated in 24-gauge 304 stainless steel jacketing.

The licensee applied the debris size distribution for Mirror RMI presented in NUREG/CR-6808 [8] to characterize the Transco RMI debris at SONGS. The licensee stated that the Mirror RMI debris size distribution is conservative for Transco RMI debris because the destruction pressure for Mirror RMI is significantly lower than that for Transco RMI.

:

The staff questioned the conservatism of applying the Mirror RMI debris size distribution for Transco RMI debris. While the two types of metallic foils may have similar properties, the staff notes that, presumably due to significantly different jacketing designs, testing performed in support of the Utility Resolution Guidance developed by the Boiling Water Reactor Owners' Group (BWROG) has shown that Mirror RMI and Transco RMI insulations have significantly different destruction zone of influence (ZOI) radii [20]. With its sturdier encapsulation, Transco RMI has a ZOI radius of only 2D, while the less robustly jacketed Mirror RMI with standard bands has a 28.6D ZOI. Damage to the inner insulation material occurs once the protective jacketing is breached. On the average, then, it is clear that exposed Transco RMI foils will experience significantly higher pressures than exposed foils of Mirror RMI. Since debris generated at increased jet pressures tends to be more finely fragmented than debris generated at lower pressures, it is not clear that the application of a size distribution from Mirror RMI debris to Transco RMI debris can be considered appropriate.

Furthermore, although the RMI debris size distribution from NUREG/CR-6808 [8] used by the licensee was based upon a sheet of RMI that was mounted close to the simulated break, NUREG/CR-6808 ultimately concludes that the pressures generated in this test were not sufficient to provide adequate results for RMI debris at local pressures from 120–1000 psig. As a result, NUREG/CR-6808 recommends that RMI debris subjected to pressures greater than 120 psig be conservatively considered as fragmenting into pieces of debris smaller than 2 inches. Since the destruction pressure corresponding to a ZOI of 2D is 114 psig, the staff noted that the majority of the RMI debris in the 2D ZOI used by SONGS could be exposed to pressures exceeding 120 psig. Because the licensee assumed that almost 30% of the Transco RMI is larger than 2 inches in size, the staff concluded that adequate technical justification was not provided to support the assumed RMI size distribution.

Nevertheless, after reviewing the licensee's debris transport and debris head loss calculations, the staff concluded that the assumed RMI debris size distribution did not have a non-conservative impact on the licensee's sump performance analysis. This conclusion is primarily based on the finding that in the licensee's transport model (reviewed in Section 3.5 of this report), large pieces (i.e., greater or equal to 4 inches in size) of RMI debris transported more readily than did small pieces (i.e., less than 4 inches in size).

Although the increased transportability of large pieces of RMI debris relative to small pieces of RMI appears counterintuitive, NUREG/CR-6772 [9] documents that the incipient tumbling velocity metric of 0.28 ft/s applies to both 1/2-inch and 2-inch crumpled pieces of RMI under uniform flow. Since the tumbling velocity metric of 0.28 ft/s was applied to both large and small pieces of RMI debris, the primary distinction between the transport of these two sizes of RMI debris in the SONGS model is that larger pieces were assumed not to be launched into the upper containment during the blowdown phase due to the presence of intervening gratings. Instead, large pieces of RMI were conservatively assumed to drop into the containment pool in areas between the break and the sumps, which generally had higher flow velocities than the rest of the containment pool. On the other hand, a significant fraction of the small pieces of RMI debris lofted into the upper containment was assumed to enter the pool at other locations (described in more detail in Section 3.5.4.1 of this report) that had significantly lower flow velocities, which ultimately led to a lower transport fraction for this size category.

Based upon the discussion above, the staff believes that, while the licensee may have overestimated the RMI size distribution in its analysis, the possible overestimation likely has a conservative overall effect, given the present set of analytical assumptions. Therefore, the staff concluded that the set of characteristics assumed for RMI debris is acceptable as applied to the SONGS replacement strainer design.

3.3.2 Mineral Wool

According to documentation supporting the licensee's containment walkdowns [26], mineral wool is installed primarily on secondary side components, including main steam and feedwater piping, and the secondary side of the steam generators. The mineral wool used at SONGS is produced by Transco and is encapsulated in 24-gauge 304 stainless steel jacketing.

In lieu of following Section 3.4.3.3.1.9 of the GR, which conservatively recommended that, absent applicable experimental data, a debris size distribution of 100 percent small fines be generically assumed for mineral wool within the ZOI, the licensee adopted a mineral wool debris size distribution that was derived using a proprietary Alion methodology for characterizing fibrous debris. In fact, the licensee's debris generation calculation presents two mineral wool size distributions, one assuming that the radius of the mineral wool ZOI is 17D and the other assuming a radius of 4D. While the assumption of a 17D ZOI for mineral wool insulation was carried through the licensee's analytical calculations, head loss testing was only performed based on the assumption of a 4D ZOI for mineral wool. Therefore, the staff did not review the licensee's mineral wool debris characterization for the assumed 17D ZOI.

3.3.2.1 Debris Size Distribution for 4D Mineral Wool ZOI

The size distribution for the 4D mineral wool ZOI was based upon a proprietary Alion methodology that essentially subdivides the applicable ZOI into several regions based upon radius from the break, according to the principle that insulation exposed to the highest pressures in the regions nearest the break tend to be fragmented most finely. Using this Alion methodology, which is based upon a technique applied in Appendix II of the staff's SE [2], the licensee considered mineral wool debris within the 4D ZOI to be destroyed into 20% fines and 80% small pieces less than 6 inches per side.

The derivation of the licensee's mineral wool debris size distribution assumed that mineral wool debris has a size distribution identical to that of Nukon low-density fiberglass debris. The licensee stated that mineral wool is a fibrous insulation that is denser than fiberglass (8 lbm/ft^3 as opposed to 2.4 lbm/ft^3), which has been analyzed via scanning electron microscope (SEM) and determined to have constituent fibers of similar diameter to fiberglass fibers. The licensee further stated that mineral wool fibers are bonded with an organic or inorganic binder, or both, similar to fiberglass insulation. As a result of these similarities, the licensee considered the expected debris size distribution for Nukon low-density fiberglass insulation to be applicable to mineral wool.

The staff agrees with the general principle underlying the licensee's approach of subdividing the mineral wool ZOI into regions based upon radius from the break, which is that insulation debris generated nearer the break location will tend to consist of finer fragments than insulation generated nearer the edge of the ZOI. However, the staff noted that the debris size distribution applied to the 4D mineral wool insulation ZOI (i.e., 20% fines and 80% small pieces) was actually derived using data intended for a 7D ZOI. Given the general principle that increased destruction is expected nearer the break location, it is not clear to the staff how a debris size distribution intended for a 7D ZOI could conservatively characterize debris generated solely within the confines of a 4D ZOI. That is, the higher volume-averaged pressure associated with a 4D ZOI would seemingly be capable of creating a larger percentage of fines than the lower volume-averaged pressure associated with a 7D ZOI. The staff further identified that the mineral wool debris size distribution used for the 4D ZOI was based on rough, best estimate values from air-jet testing, and that an allowance had not been made to account for uncertainties associated with the potential for increased fragmentation from a two-phase steam/water jet.

During the onsite portion of the audit, the licensee's assumed size distribution for mineral wool debris (in conjunction with the applicability of a 4D ZOI to the encapsulated Transco mineral wool) was discussed at length without resolution. Following the onsite portion of the audit, the licensee provided an additional calculation to justify the assumed mineral wool size distribution in ALION-REP-SONGS-3987-01 [22]. In this calculation, the licensee noted that there is no mineral wool within 2.56D of the limiting break location for generating mineral wool (Case 1). Since the pressure of a LOCA jet decays with increasing distance from the break location, this statement implies that no mineral wool insulation will be exposed to the most severe destruction pressures directly adjacent to the break. The licensee also performed calculations of mineral wool debris generation and transport assuming that the fraction of fines and small pieces (i.e., 0.007) is identical to the value associated with Transco RMI. This calculation was intended to show that the assumed mineral wool debris size distribution is conservative, and was apparently based upon the assumption that similar debris size distributions can be assumed for different types of insulations that are covered with identical jacketing material.

While the staff's concerns with the mineral wool size distribution were lessened by the information that no mineral wool insulation is within 2.56D of the most limiting pipe rupture, the staff's overall concern was not fully addressed because the maximum jet pressures within a spherical shell between 2.57D and 4D from the break location are still expected to be at least double the pressure at 7D. While further insight was also provided by the licensee's calculations of debris generation for fines and small pieces of mineral wool assuming a Transco RMI size distribution, the staff considered them to be of limited value for characterizing mineral wool because an appropriate correlation between insulation jacketing material and debris size distribution has not been adequately demonstrated to be applicable independent of the underlying insulation type.

Finally, additional review of several non-SCE-provided references following the onsite portion of the audit uncovered evidence of a heightened fragility for mineral wool relative to Nukon fiber. One reference, an international compilation of knowledge concerning research on post-accident debris blockage issues at boiling-water reactors published by the Organization for Economic Co-operation and Development (OECD) and titled NEA/CSNI/R (95)11,"Knowledge Base for Emergency Core Cooling System Recirculation Reliability," [28] identified that mineral wool seems to disintegrate more quickly under jet impact than fiberglass. This report also states that mineral wool has shown evidence of deteriorating into fines as the result of exposure over time to operational temperature levels. Another reference, NUREG/CR-6224, “Parametric Study of the Potential for BWR ECCS Strainer Blockage Due to LOCA Generated Debris,” [50] also reports that plant-aged mineral wool tends to be destroyed into a larger fraction of fines than Nukon low-density fiberglass insulation. This experimental evidence that mineral wool tends to be more easily fragmented than Nukon (which could lead to increased transport and potentially different head loss behavior) was not addressed in the material presented by the licensee for audit review. As a result of this information and the staff concerns discussed above, the lack of an adequate licensee justification for the assumed size distribution of 20% fines and 80% small pieces for the 4D mineral wool ZOI is considered to be **Open Item 2**.

3.3.2.2 Mineral Wool Bulk and Material Densities

The staff also followed up on issues concerning the bulk and material densities assumed for mineral wool. Note that the bulk density represents the density of the as-fabricated insulation blanket, which contains considerable voiding or “air space” between the microscopic individual insulation fibers. The material density represents the density of the microscopic insulation fibers themselves, or, in macroscopic terms, the density of an insulation blanket if it could be perfectly compressed such that all internal voids were eliminated.

In Table 2.4.1 of the debris head loss calculation [15], the licensee assumed that the material density of mineral wool is 180 lbm/ft^3. The basis for this potentially non-conservative assumption was not clear to the staff, since Table 3-2 of NEI 04-07 indicates that the material density of mineral wool is 90 lbm/ft^3. During the onsite portion of the audit, Alion personnel stated that the assumption of 180 lbm/ft^3 as the mineral wool material density was based upon information in a report compiled by the OECD [28]. The staff’s review of the OECD report subsequently confirmed Alion’s statement. As a result, the staff considered the licensee’s assumed material density for mineral wool to be acceptable.

Table 3-2 of NEI 04-07 [1] indicates that mineral wool may be fabricated at a range of bulk densities, commonly between 4 and 10 lbm/ft^3. The licensee’s debris generation calculation assumed that the bulk density for mineral wool at SONGS is 8 lbm/ft^3 based upon a recommended bulk density specified in American Society for Testing and Materials (ASTM) C612 [118]. Since the origin of the SONGS mineral wool is not known with certainty, the staff concluded that, while 8 lbm/ft^3 is within in the range of expected density values, uncertainty is associated with applying this value to SONGS. However, given that (1) the density value assumed by the licensee is near the upper end of the range of expected values, (2) the surrogate mineral wool debris has a density of 8 lbm/ft^3, and (3) the licensee is expected to address several open items in this audit report to ensure that the overall treatment of mineral wool debris is conservative (e.g., regarding debris size distribution (2), flotation (Open Item 5), and susceptibility to erosion (Open Item 6)), the staff concludes that additional conservatism is not necessary regarding the assumed bulk density of mineral wool. The staff further noted that the licensee is planning to replace the mineral wool on the steam generators with RMI when new steam generators are installed in 2009.

Therefore, with the exception of Open Item 2 associated with the debris size distribution for the 4D ZOI (described above), the staff concluded that the set of characteristics assumed for mineral wool debris is acceptable as applied to SONGS.

3.3.3 Microtherm

According to the debris generation calculation [13], Microtherm is installed primarily inside the reactor cavity, in a 3-foot band below the reactor vessel loop nozzles. However, the staff also noted that an engineering drawing presented during the audit indicated that Microtherm is also installed on the lower part of the vessel as well. In the debris generation calculation, the licensee also noted that, in addition to the 3-foot band, there is Microtherm installed at 4 discrete locations on the vessel. As part of its planned activities in response to GL 2004-02, the licensee stated during the onsite portion of the audit that all other Microtherm currently in containment that is located in potential LOCA ZOIs will be removed prior to December 31, 2007. The licensee specified that the Microtherm used at SONGS is encapsulated in 24-gauge 304 stainless steel jacketing similar to that used for RMI and mineral wool insulation [13].

The licensee assumed that the destruction pressure for Microtherm is 2.4 psig (i.e., a ZOI of 28.6D), based upon its similarity to Min-K insulation. A destruction pressure of 2.4 psig for Min-K insulation with Mirror jacketing fastened by standard bands is stated in Table 3-2 of the NRC staff's SE on NEI 04-07 [2]. The licensee's assumptions regarding the ZOI for Microtherm insulation credited the "shadowing" effect of the reactor vessel, assuming that only half the insulation around the reactor vessel would be destroyed by a reactor vessel nozzle break. This issue was discussed extensively during the onsite portion of the audit, and it was recognized that the approved spherical ZOI methodology for computing insulation damage is difficult to implement in the confined reactor cavity annulus. The staff declared the issue of the Microtherm ZOI in the reactor cavity to be an open item at the end of the onsite portion of the audit (see **Open Item 1** above). Subsequently, the licensee submitted additional justification for the assumption that 50% of the Microtherm installed on the reactor vessel will be destroyed [23]. The staff's review of the licensee's ZOI assumptions for Microtherm insulation is presented in Section 3.2 of this report.

Microtherm debris, as a microporous material, has a significant potential to adversely impact head loss in a manner comparable to or worse than calcium silicate debris. Like calcium silicate, Microtherm contains both particulate and fibrous materials that may contribute to the formation of a thin debris bed on a sump strainer without the presence of significant quantities of additional fibrous debris.

In the absence of specific destruction test data for Microtherm, the licensee assumed that the Microtherm destroyed in the shadowed ZOI within the reactor cavity annulus would all become fine particulate. The licensee further identified the specific composition and material properties assumed for Microtherm debris as follows:

Table 3.3-1: Assumed Material Properties of Microtherm Debris

Material	Weight Percent	Particle/Fiber Size	Density
Fiber	3%	6 μm	165 lbm/ft^3
Fumed Silica (SiO_2)	58%	Varies, centered at 20 μm	137 lbm/ft^3
Titanium Dioxide (TiO_2)	39%	2.5 μm	262 lbm/ft^3
Microtherm	100%	2.5 – 20 μm	187 lbm/ft^3

In particular, the licensee stated that the fumed silica (SiO_2) particle size is considered to be 20 μm based upon information provided by the insulation vendor. The particle size assumed by the licensee is based upon the fumed silica breaking into three-dimensional branched chain aggregates that are mechanically tangled into approximately spherical agglomerates. Information provided by the insulation vendor estimated that a fundamental particle size for Microtherm of approximately 20 μm is appropriate because an amount of dispersion energy typically provided by a high-shear mixer along with the use of chemical dispersants is necessary to reduce the particle size further.

It was not feasible during the course of the audit for the staff to compare in detail the degree to which Microtherm is fragmented by a high-energy line break as opposed to a high-shear mixer and dispersants. As discussed further in Section 3.5.3.2 of this report, the staff believes that the general range of particle sizes assumed by the licensee is acceptable for computing debris transport.

However, when considering the potential head loss contribution from Microtherm, the assumed particle size distribution is potentially non-conservative (i.e., the assumed minimum particle sizes may be too large). The staff believes that an actual LOCA jet may be capable of inducing some fragmentation of SiO_2 into submicron-range particles, and Appendix A to the licensee's head loss calculation further indicates that 2.5 μm is the center of the size distribution range for TiO_2, rather than a minimum value [15]. While it is possible that the assumed particulate size range could be representative of the particles that may be effectively filtered out in fibrous debris beds having typical porosities, a validated technical basis for making this conclusion was not provided.

Since smaller particulate sizes may result in increased head loss by packing tightly together in a fibrous debris bed matrix, the licensee's head loss test procedures should be capable of ensuring that an adequately conservative size distribution is achieved for Microtherm. The staff's review of SONGS' head loss test program in Section 3.6.3.1.5 of this report provides assurance that the Microtherm surrogate test debris has acceptably representative characteristics to the actual debris expected for the plant. The staff did not perform a detailed review of the Microtherm material characteristics used in the analytical debris head loss calculation (e.g., specific surface area) because this calculation was not being used to support the replacement strainer design basis.

On the basis of the observations described above, the staff concluded that the set of transport characteristics assumed for Microtherm debris (see Table 3.3-1 above) is acceptable as applied to the SONGS replacement strainer design. The staff's review results for the SONGS head loss test program in Section 3.6.3.1.5 of this report concludes that the licensee's assumed head loss characteristics for Microtherm are acceptable.

3.3.4 Latent Fiber

The licensee generally adopted the recommendations from the NRC-sponsored study of containment latent debris collected from four PWR containments as documented in NUREG/CR-6877 [27] and the staff's SE [2]. NUREG/CR-6877 concluded that it was conservative to assume that latent fibers have similar hydraulic properties to those of Nukon low-density fiberglass. The study examined dry bulk densities for collected latent fibers and recommended assuming a bulk density of 2.4 lbm/ft^3, which is the nominal bulk density of Nukon low-density fiberglass insulation.

The staff noted one minor theoretical deficiency in the discussion of the SONGS latent fiber characteristics in the licensee's debris generation calculation [13]. In this calculation, the licensee noted that a value of 175 lbm/ft^3 would be applied for the material density of Nukon, and that this assumption would provide conservative results relative to the Nukon material density assumed in the staff's SE (i.e., 159 lbm/ft^3) for the purpose of calculating head loss. During the onsite portion of the audit, the staff noted that the lower value for material density used in the SE would actually provide a more conservative result (i.e., a higher head loss), which can be inferred from Equation B-23a in NUREG/CR-6224 [50]. Vendor personnel present during the audit acknowledged this fact. Although this point is worthy of recognition, due to the fact that the licensee used testing rather than analytical calculations in formulating the sump strainer head loss design basis, it did not result in a non-conservative effect on the licensee's strainer design.

In light of the above discussion, the staff concluded that the licensee has followed the recommendations of NUREG/CR-6877 and assumed acceptable characteristics for latent fibrous debris.

3.3.5 Latent Particulate

The licensee adopted recommendations from the NUREG/CR-6877 study of containment latent debris collected from four PWR containments [27], which were further examined in Appendix V to the staff's SE [2]. In this study, a surrogate latent particulate was formulated from sand and dirt to simulate the density and size distributions of samples of containment latent particulate debris. This surrogate particulate was tested in a closed loop head loss test apparatus to determine a specific surface area for the mixture. The specific surface area (essentially a ratio of surface area to volume) identified for the latent particulate debris was 106,000/ft (i.e., ft^2/ft^3), which corresponds to an equivalent particle diameter of 17.3 microns. The licensee adopted this diameter and the material density of 169 lbm/ft^3, but did not specify a particulate bulk density, which is necessary for head loss calculations.

Instead of directly specifying a bulk particulate density for latent particulate debris, the licensee specified a mixed debris bed porosity, which is a function of the bulk particulate density. The licensee performed the debris head loss calculations with the Alion HLOSS code using a porosity value of 0.8 for bulk particulate in beds with a significant quantity of fibrous debris [15]. It is not clear to the staff whether this assumption is valid, since porosity is debris-type dependent, and a specific justification was not presented to support the assumed value. Otherwise, the licensee's characteristics for latent particulate are acceptable. Furthermore, because the licensee's strainer qualification for head loss is based upon testing rather than analysis, the staff does not consider the resolution of the issue concerning the assumed value of latent particulate bulk porosity to be necessary for demonstrating the acceptability of the SONGS replacement strainer design.

3.3.6 Miscellaneous Debris

The licensee's debris generation calculation assumed that tape, tags, and labels are not present in the containment building [13]. As a result, the licensee's debris head loss calculation did not set aside any sacrificial area to account for the existence of miscellaneous debris [15]. These calculations noted that SONGS procedures do not permit tags, labels, and tape to be left inside the containment. During the onsite portion of the audit, the staff also learned that SONGS was in the process of replacing all equipment tags inside the containment building with ceramic tags that were not considered a threat to sump performance.

The staff's overall review of the licensee's assumptions concerning miscellaneous debris is described in Section 3.4 of this report. However, it should be noted here that many types of miscellaneous debris, such as tape, tags, and labels, can be nonporous. Furthermore, as some nonporous miscellaneous debris has relatively low densities, it may have the capability of blocking off part of the available strainer area if present in containment during a LOCA. Since the characteristics of these types of miscellaneous debris are not adequately represented by any of the other types of debris currently analyzed by the licensee, any future discoveries of significant quantities of miscellaneous debris inside containment could necessitate post-discovery analyses to verify the adequacy of the strainer design. Further discussion of the licensee's treatment of miscellaneous debris is provided in Section 3.4 of this report.

3.3.7 Debris Characteristics Conclusion

The licensee generally used accepted guidance in characterizing potential debris sources. Several exceptions to this statement are described in detail in Section 3.3 of this report, including the size distribution assumed for RMI debris, the size distribution assumed for mineral wool, the particle size distribution assumed for Microtherm, the material density assumed for latent fiber, and the lack of characteristics applicable to miscellaneous debris. Other than the assumed size distribution of mineral wool, the staff concluded that these issues did not require resolution to ensure the design adequacy of the SONGS replacement strainer for the reasons described in Section 3.3. Because the size distribution assumed for mineral wool was considered to have the potential to affect the replacement strainer design in a non-conservative manner, the staff designated it as an open item (see **Open Item 2** above).

3.4 Latent Debris

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

SONGS Calculation RPA02-0080 “Quantification of Containment Latent Debris” [16] documents the assumptions and methodology the licensee applied to determine the amount, type, and impact on sump screen head loss from latent debris.

The staff reviewed the licensees latent debris evaluations and the methodology applied. Specifically, the staff reviewed SONGS Calculation RPA02-0080 against the approved methodology documented in Section 3.5 of the SE. The evaluation for Latent Debris at SONGS was performed in a manner considered by the NRC to be similar to the SE approved methodology. During the audit, in response to staff questions, the licensee provided additional information in the form of procedure SO 123-0A4, Rev. 1 “Configuration Control” [61], SONGS Weblink 0401 “Preparation and Installation of Equipment Identification Tags and Labels” [62], and SO23-XV-23.1.1 “Containment Cleanliness/Loose Debris Inspection” [63].

The total source term was determined through the collection of debris samples from multiple locations throughout the SONGS Unit 3 containment. From this, a calculation was performed to provide an estimate of the total amount of latent debris in containment. Conservatisms were added to the calculated source term to account for uncertainties and provide a bounding estimate for screen evaluation purposes. The characterization of latent debris followed the guidance in the SE. At the time of this audit, this activity was completed for SONGS Unit 3. The licensee plans to completed a similar sampling/evaluation activity for SONGS Unit 2 in February, 2007, and determined that the debris quantities found in Unit 3 were bounding. The licensee therefore plans to use the Unit 3 values in both unit’s evaluations and calculations, and revise [16] accordingly.

During the audit, the staff identified that SONGS did not make any allowances for tags and labels, or provide sacrificial screen area for any miscellaneous debris in containment. For tags and labels, SONGS has an ongoing program to replace all equipment tags, labels, signs, and placards in containment with ceramic-lined metal. A number of samples of these new tags and signs were provided to the staff for inspection during the audit. They are very robust, and quite heavy. Because of this, they have no probability of transport to the sump strainer, and are not considered in the sump strainer evaluation. The SE identifies that construction characteristics can be used to evaluate tags, labels, and signs for the potential to be destroyed or transported. Based on the construction of the tags, labels, and signs being used at SONGS, the staff finds the licensee position of no transport acceptable.

SONGS originally took the position that their containments were kept very clean, and that there was no need for a sacrificial screen area to account for some miscellaneous debris. The staff pointed out that while this may be possible, it is probably not prudent or realistic. The staff noted that Attachment 1 of SO23-XV-23.1.1 [63] identifies some actual miscellaneous debris items left in containment. The licensee could not verify during the audit whether these items were accounted for in calculation RPA02-0080 [16]. Based on the number, size, and descriptions, it is not expected that these items would result in the actual latent debris source term exceeding the value assumed for the strainer design, but this should be confirmed through licensee analysis for both SONGS units. Without allowance for miscellaneous debris in the form of extra latent debris source term or sacrificial strainer area, the licensee would be required to perform an operability determination every time some new miscellaneous debris is identified to be in the containment when the sump strainer was required to support ECCS operation.

In conclusion, the NRC staff found that the evaluation for latent debris was performed in a manner consistent with SE approved methodology. However, miscellaneous debris that was left in the Unit 3 containment, as identified in Attachment 1 of SO23-XV-23.1.1 [63], needs to be further evaluated by the licensee. Also, since the licensee had not conducted a Unit 2 specific evaluation for latent debris, the value assumed for the SONGS Unit 2 latent debris source term needs to be confirmed by the licensee. These two final Unit 2 and Unit 3 latent debris evaluation and documentation activities are designated as **Open Item 3**.

3.5 Debris Transport

Debris transport analysis estimates the fraction of debris that would be transported from debris sources within containment to the sump suction strainers. Debris transport would occur through four major processes:

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

2. washdown transport, which is the downward transport of debris in containment by the containment sprays and break flow,

3. 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 (i.e., experiencing significant flow during sump recirculation) or inactive (i.e., not experiencing significant flow) during the recirculation phase of an accident, and

4. containment pool recirculation transport, which is the horizontal transport of debris from active portions of the containment pool to the sump strainers through pool flows induced by the operation of the emergency core cooling system and containment spray system taking suction on the recirculation sumps in recirculation mode.

Through the blowdown transport process, debris would be transported throughout the lower and upper containment. Through the washdown transport process, a fraction of the debris in the upper containment would be washed down to the containment floor. Through the pool fill-up transport process, debris on the containment floor would be scattered around, and some debris could be washed into inactive volumes, such as the reactor cavity, which do not participate in recirculation. Thus, any debris that enters an inactive pool would be considered to stay there, rather than being transported to the sump strainers. Through the containment pool recirculation transport process, a fraction of the debris in the active portions of the containment pool would be transported to the sump strainers.

The licensee analyzed debris transport in ALION-CAL-SONGS2933-03, Revision 2 [14]. The licensee stated that the debris transport methodology used for SONGS is based on the methodology in Nuclear Energy Institute 04-07 (NEI 04-07), “Pressurized Water Reactor Sump Performance Evaluation Methodology,” [1] as modified by the associated NRC Safety Evaluation (SE) [2]. The licensee used logic trees to calculate the transport of debris from the zone of influence (ZOI) to the sump strainers by the blowdown, washdown, pool fill, and recirculation transport processes [14]. The licensee's logic trees were based on the generic model recommended by NEI 04-07, but divided debris into four size distributions (fines, small pieces, large pieces, and large pieces with intact jacketing). Other modifications to the baseline logic tree structure included branches for modeling (1) the erosion of small and large pieces of fragile debris, (2) the washdown of debris after the filling of inactive containment pool volumes, (3) the direct transport of debris to the sump during pool fill-up, and (4) the transport of large pieces of debris. The licensee proceeded to quantify the logic trees to calculate transport of the following types of debris: stainless steel reflective metallic insulation (RMI), mineral wool insulation, Microtherm insulation, latent fibrous debris, latent particulate debris, and epoxy paint debris inside the ZOI [14]. For unqualified coatings outside the ZOI, an assumption of 100% transport was conservatively applied in lieu of a logic tree approach [14].

The licensee stated that the four postulated breaks listed below in Table 3.5-1 have been evaluated for debris transport based upon the determination in the debris generation calculation that these breaks are bounding [13]. The staff reviewed the licensee's break selection analysis in Section 3.1 of this audit report.

Table 3.5-1: Analyzed Break Locations

Case	Break Location
1	Loop 1 Hot Leg
2	Loop 2 Hot Leg
3	Reactor Vessel Nozzle Break Inside Reactor Cavity
4	Shutdown Cooling Line Break Outside Bioshield Wall

Due to its proximity to the recirculation sumps, the overall transport fraction for debris generated by the Case 4 shutdown cooling line break was assumed to be 100% in lieu of performing detailed analysis. As a result of the licensee's conservative transport assumption for this break, the staff will focus on the three other cases in this evaluation.

The licensee's approach generally followed guidance from NEI 04-07, using assumptions from both the baseline methodology and analytical refinements. In particular, the licensee applied an analytical refinement to analyze debris recirculation transport by using the FLOW-3D computational fluid dynamics (CFD) code to assist in calculating the fraction of debris in the containment pool that transports to the sump strainers during recirculation. The following subsections discuss the licensee's transport methodology in detail, noting any issues the NRC staff identified during the audit review.

3.5.1 Blowdown and Washdown Transport

The licensee computed blowdown transport using a relative volume approach, as described in Section 5.4 of the debris transport calculation [14]. Since 74% of the overall containment volume is considered to belong to the upper containment, the licensee assumed that 74% of vertically transportable debris generated in the ZOI would be blown upward, with the remaining 26% being assumed to be blown downward. A strong technical basis was not provided in support of this assumption. The staff's conclusion regarding the relative significance of this assumption is provided at the end of this section.

For Cases 1 and 2 (large hot-leg breaks), fines and small pieces were considered vertically transportable [14]. Large pieces of debris were not considered vertically transportable due to the presence of gratings between the analyzed break locations and the upper containment [14]. For Case 3 (reactor vessel nozzle break), only fines were considered vertically transportable, while small and large pieces of debris were considered to be ejected directly to the containment floor [14]. The licensee stated that this assumption is conservative, since no credit was taken for the hold-up of debris inside the reactor cavity or incore instrumentation tunnel.

In Section 5.5 of the debris transport calculation, the licensee conservatively assumed that all of the debris blown into the upper containment would be washed back down to the containment pool [14]. The licensee also conservatively assumed that all failed coatings in the upper containment would be washed down. According to the licensee's analysis, spray drainage from the upper containment would lead to 78% of the washed-down debris entering the containment pool along the periphery of one side of the containment (based upon the containment spray flow drainage pattern created by the containment geometry) and 22% of the washed-down debris entering the pool via the refueling canal drain line. The licensee stated that minimal debris will enter the containment pool through the steam generator compartments and a small curbed equipment hatch area because these locations will not receive containment spray draining from a large debris-collecting area such as the operating deck or refueling canal.

Since the licensee did not credit debris retention in the upper containment, the primary significance of the blowdown and washdown transport analysis is its effect on the spatial distribution of debris entering the containment pool. Since a large fraction of the small pieces of debris were assumed to be affected by blowdown and washdown, the licensee's assumptions concerning these transport processes are important in determining the quantity of debris that reaches the sump strainers. Overall, notwithstanding the licensee's 74%/26% vertical blowdown assumption, the staff considers the licensee's blowdown and washdown assumptions to be reasonable based upon the physical phenomena governing these transport processes and the plant-specific information provided in the licensee's debris transport calculation. While inherent uncertainties exist in the licensee's methodology for analyzing chaotic blowdown flows and the subsequent washdown of debris, the staff concludes that they are balanced by the conservative assumption that no debris is retained in the upper containment.

3.5.2 Pool-Fill Transport

As the containment pool fills up prior to the initiation of sump recirculation, shallow, high-velocity sheeting flows may scatter debris along the containment floor. In addition, the potential exists for debris to be transported directly to the recirculation sumps or into inactive pool volumes such as the normal sump. The licensee assumed that pool-fill transport will occur for debris falling directly into the containment pool, but not for debris that was first blown into the upper containment and later washed down by the containment sprays [14]. The staff considered this assumption to be reasonable for SONGS based upon the fact that rapid sheeting flows and the filling of the recirculation sumps and inactive normal sump occur very early in the accident, contemporaneous with the blowdown and washdown transport processes for debris initially directed into the upper containment.

The licensee computed the fractions of debris transporting directly to the recirculation sumps and the inactive normal sump during pool fill-up by taking the volume ratio of each of these sumps to the overall volume of the containment pool when the containment water depth is 4 inches [14]. Since the recirculation sumps have a 4-inch curb surrounding them, the licensee stated that the containment pool water level would have to rise above this level to enter the recirculation sumps. Although the normal sump does not have a curb, in the interest of conservatism, the licensee similarly did not credit debris retention in the normal sump prior to the containment water level reaching 4 inches. The licensee further stated that only fine debris would be considered for direct transport to the normal sump or recirculation sumps during pool fill-up, since small or large pieces of debris would be stopped by curbs that would only be passing a thin sheet of water over them as the sump pits fill with water. Using this methodology, the licensee computed that 40% of the fine debris initially located in the recirculation pool would transport directly to the recirculation sumps during pool fill-up, and that 4% of the fines initially located in the recirculation pool would transport directly to the inactive normal sump.

In Section 5.1 of the debris transport analysis, the licensee stated that, while the computer-aided design (CAD) model of the SONGS containment building assumes that the containment floor is flat at a nominal elevation of 17'6", it actually has a significant slope, with elevations ranging between 16'10" and 18'3" [14]. While this effect was not analyzed in detail, the licensee noted that the floor inside the steam generator compartments (where the majority of debris will initially be located) is located at a lower elevation than the recirculation sumps. As a result, debris would have to tumble slightly uphill in order to reach the recirculation sumps.

While the licensee generally used conservative assumptions in analyzing pool-fill transport, the staff notes that several significant uncertainties exist in the methodology. Foremost, the licensee did not consider the relocation of small and large pieces of debris during pool fill-up. The licensee concluded that these debris pieces would not be able to pass over curbs when only a thin layer of water is flowing over. The staff does not consider this assumption to have a strong technical basis, since the characteristics of the flow during pool fill-up (e.g., velocity, turbulence, and complex phenomena such as surface waves) were not explicitly analyzed. These flow characteristics cannot be determined without explicit analysis, and are expected to vary with break location. Furthermore, small and large pieces of mineral wool debris may not be fully saturated with water during the pool fill-up phase and could pass over curbs by floating on the pool surface by virtue of retaining trapped air. Beyond the transport of small and large pieces of mineral wool, the staff further notes that the licensee's pool-fill transport model is not geometrically representative. For example, although the licensee noted that the SONGS containment floor is sloped, the methodology for computing pool-fill transport is essentially based on the assumption that the containment floor is flat. In addition, the layout of the containment, including the relative positions of the sumps and the break location, were not explicitly evaluated. The licensee has not determined the cumulative effect of neglecting these physically important details.

However, since all fine debris in active pools was considered to transport during the recirculation phase (as discussed below), the overall effect of the licensee's pool fill transport methodology is to remove a maximum of 4% of all types of fine debris (other than unqualified coatings outside of the ZOI) from the debris source term reaching the containment recirculation sumps. Despite the lack of physicality in the licensee's model, the staff notes that there are two important considerations that suggest that the results of the calculation are reasonable overall:

(1) physically modeling the pool-fill transport of small and large pieces of debris could lead to a significant fraction of this debris being spread into low-velocity areas of containment where the debris would be considered to settle rather than reaching the strainers during the recirculation phase, and (2) while assuming full transport of all fine debris to the sump screens is conservative, some fraction of this debris may realistically settle or transport to an inactive pool volume. Therefore, although the staff considers the licensee's model of pool-fill transport to be nonphysical and inappropriate for general application, based upon the small fraction of settling assumed, the plant-specific characteristics of the SONGS containment design, and the two considerations noted above, the staff considers the results of the licensee's pool-fill transport analysis to be acceptable.

3.5.3 Containment Pool Recirculation Transport

The licensee computed flow velocity and turbulence fields in the containment pool during the recirculation phase of a design-basis loss-of-coolant accident (LOCA) with the aid of computational fluid dynamics (CFD) and a computer-aided design (CAD) model of the SONGS containment [14]. The licensee then compared the results of the CFD simulation to experimentally derived debris transport metrics to compute the quantities of debris reaching the containment recirculation sumps [14]. The staff's discussion below evaluates the licensee's assumptions, analytical models, and calculations associated with determining the containment pool recirculation debris transport percentages.

3.5.3.1 Debris Spatial Distribution

The locations at which debris is assumed to enter the containment pool can have significant impact upon the recirculation transport results. The licensee noted that the distribution of debris at the beginning of recirculation could vary widely due to chaotic blowdown from the break and from sheeting flows along the containment floor during pool fill-up [14]. Acknowledging these uncertainties, the licensee attempted to make conservative assumptions with respect to the initial debris spatial distribution, which are summarized in Table 3.5-2 below:

Table 3.5-2: Assumed Debris Spatial Distribution at the Beginning of Recirculation

Debris Type	Assumed Initial Spatial Distribution
Latent Debris	Uniformly distributed on the containment floor
Unqualified Coatings in Lower Containment	Uniformly distributed in the containment pool
Unqualified Coatings Washed Down from Upper Containment	Distributed where containment spray drainage enters pool (i.e., between the bioshield wall and outer containment wall and at the refueling canal drain)
Fine Debris in Lower Containment	Uniformly distributed in the containment pool
Fine Debris Washed Down from Upper Containment	Distributed where containment spray drainage enters pool (i.e., between the bioshield wall and outer containment wall and at the refueling canal drain)
Small and Large Pieces of Debris in Lower Containment	Uniformly distributed along the flowpath between the location where it was generated and the recirculation sumps
Small and Large Pieces of Debris Washed Down from Upper Containment	Distributed where containment spray drainage enters pool (i.e., between the bioshield wall and outer containment wall and at the refueling canal drain)

As explained below, the staff considers the assumed debris spatial distribution to be appropriate for SONGS. First, for latent debris, unqualified coatings, and fine debris, the licensee calculated essentially 100% transport to the sump strainers (as noted in Section 3.5.2, a small fraction of latent and fine debris in the lower containment was considered to be trapped in the inactive normal sump). As a result of this observation and the staff's review of the licensee's CFD analysis, the staff concluded that varying the assumed spatial distribution of latent debris, unqualified coatings, and fine debris will not significantly affect the overall debris transport results for SONGS. With respect to small and large pieces of insulation, the staff considers it conservative for SONGS to assume that debris in these categories is distributed uniformly along the flowpath between its destruction location and the recirculation sumps. Assuming that small and large pieces of debris enter the containment pool in this region ensures that their transport potential will be conservatively evaluated, since the containment pool flows between the break and the recirculation sumps will generally be faster than the average containment flow velocity. Finally, the staff considers the licensee's assumption that small and large pieces of debris washed down from the upper containment enter the pool with spray drainage to be an approximation that is physically reasonable. Therefore, the staff considers the licensee's assumptions regarding the distribution of debris at the beginning of sump recirculation to be acceptable.

3.5.3.2 Debris Transport Metrics

A summary of the debris transport metrics used by the licensee to analyze transport during containment pool recirculation is provided in the Table 3.5-3 below:

Table 3.5-3: Assumed Metrics for Debris Transport During Recirculation

Debris Type	Size	Terminal Settling Velocity (ft/s)	Incipient Tumbling Velocity (ft/s)	Minimum Curb Lift Velocity (ft/s)	
				2 in.	6 in.
Stainless Steel RMI	Small Pieces	0.37	0.28	0.84	1.0
	Large Pieces	0.48	0.28	0.84	1.0
Mineral Wool	Individual Fibers	0.0074*	N/A	N/A	N/A
	Small Pieces	0.15*	0.16*	0.25*	0.3*
	Large Pieces	0.41*	0.9	0.25*	0.28*
Microtherm	20 μm SiO_2 Agglomerate	0.0015†	N/A	N/A	N/A
	2.5 μm TiO_2 Particulate	6.4×10^{-5}†	N/A	N/A	N/A
Latent Fiber	Individual Fibers	0.0074*	N/A	N/A	N/A
Latent Particulate	17.3 μm Particulate	0.0016†	N/A	N/A	N/A
Various Coatings	10 μm Particulate	1.7 – 3.3 × 10^{-4}†	N/A	N/A	N/A

* Denotes that test data for Nukon low-density fiberglass was used in lieu of material-specific data

† Denotes that Stokes' Law was used in deriving this value rather than test data

With several exceptions discussed in detail below, the staff generally found the tabulated metrics the licensee applied for analyzing terminal settling velocity (i.e., the limiting vertical velocity at which debris sinks in a calm pool of water), incipient tumbling velocity (i.e., the horizontal velocity at which debris begins to tumble across a containment floor), and curb lift velocity to be acceptable for evaluating debris transport to the SONGS replacement strainers. The staff's basis for accepting these metrics (with the exceptions noted below) is that they are based upon validated test data. In particular, since the RMI debris metrics will not be discussed further below, the staff notes that the licensee obtained the empirical metrics applied to RMI debris in Table 3.5 from NUREG/CR-6772 [9].

3.5.3.2.1 Mineral Wool Transport Metrics

In the debris generation calculation, mineral wool insulation was evaluated for two cases, a 4D ZOI and a 17D ZOI [13]. However, the licensee did not carry the 17D-ZOI assumption completely through its analysis (i.e., head loss testing was only performed based on the quantity of mineral wool debris generated assuming a 4D ZOI). The staff's review of the licensee's ZOI assumptions for mineral wool is presented in Section 3.2 of this report.

As described in Section 3.3.2.1 of this report, the licensee assumed that individual fibers comprise 20% of the debris within the 4D ZOI for mineral wool, and that small pieces (i.e., less than 6 inches) comprise the remaining 80% of the debris (see **Open Item 2** above). Since large pieces of mineral wool (i.e., greater than 6 inches) were only assumed to be generated under the 17D-ZOI assumption, the staff did not review the transport metrics for this debris size category in detail during the audit. In evaluating debris transport, it is conservative to assume that no large pieces of debris are formed within the 4D ZOI, since large pieces of debris tend to be less mobile than small pieces and fines.

The terminal settling velocities assumed for individual fibers and small pieces of mineral wool are based upon values for Nukon low-density fiberglass [14]. Since mineral wool is denser than Nukon, the staff expects these velocity values to be bounding for mineral wool debris that does not float on the surface of the containment pool.

The staff questioned the value of 0.16 ft/s used as the incipient tumbling velocity metric for small pieces of mineral wool. The licensee's debris transport calculation [14] states that this incipient tumbling velocity metric is applicable to Nukon, but it subsequently indicates that this value was actually the result of testing conducted on shredded pieces of Thermal Wrap low-density fiberglass, as documented in NUREG/CR-6772. However, because NUREG/CR-6772 indicates that (1) the incipient tumbling velocity for shreds of Nukon is 0.12 ft/s and (2) the incipient tumbling velocity for 4-inch by 6-inch pieces of Thermal Wrap is 0.12 ft/s, the staff found that the licensee did not adequately justify the use of 0.16 ft/s as the incipient tumbling velocity for small pieces of mineral wool. The staff notes that, while the increased density of mineral wool may support choosing the higher incipient tumbling velocity metric of 0.16 ft/s associated with Thermal Wrap shreds, the licensee did not appear to address this point adequately in the debris transport calculation [14]. Since the licensee did not adequately justify the assumption of 0.16 ft/s as the incipient tumbling velocity metric for small pieces of mineral wool, the staff considers this to be **Open Item 4**.

3.5.3.2.2 Mineral Wool Buoyancy

Mineral wool has been shown to have the propensity for trapping air, which was not adequately addressed by the licensee. The licensee's debris transport calculation assumes that mineral wool is incapable of remaining buoyant long enough to transport to the sump strainers by floating on the containment pool surface and subsequently sinking atop the strainers [14]. The primary justification provided for this conclusion was that fibrous insulation tends to sink more readily as the water temperature is increased. While hot water does tend to penetrate the mineral wool fibers more quickly than cold water, thus displacing trapped air that results in buoyancy, the staff does not consider this comparison to be an adequate basis for neglecting mineral wool transport by floatation for SONGS. In particular, NUREG/CR-6808 states that "[m]ost mineral wool does not readily absorb water and can remain afloat for several days" [8]. Based upon the information presented by the licensee, it is not clear that the mineral wool at SONGS will sink prior to transporting to the sump strainers. During the onsite portion of the audit, the staff learned that a cover plate will be installed over the SONGS sump strainers. However, the potential impact of the cover plate on buoyant transport of mineral wool was not discussed during the staff's interactions with the licensee regarding mineral wool buoyancy and was also not described in the debris transport calculation. Thus, while the presence of the cover plate may to a significant degree prevent floating mineral wool from sinking on top of the sump strainers, sufficient documentation and analysis was not presented in the transport report or during the onsite portion of the audit to allow the staff to confirm this conclusion (in a post-audit week communication, the staff learned that the planned cover plate is not in all post-LOCA scenarios below the sump pool water level, and therefore may not always be significantly effective in preventing floating mineral wool from reaching the Enercon strainers). Mineral wool transport by flotation has significant potential to affect the design adequacy of the SONGS replacement strainers. Therefore, because the staff could not confirm the licensee's mineral wool bouyancy conclusions, the staff considers the adequacy of the licensee's analysis of mineral wool transport by flotation in the presence of the SONGS sump strainer cover plates to be **Open Item 5.**

3.5.3.2.3 Stokes' Law Approach for Computing Terminal Settling Velocity

The licensee's calculations resulted in very high transport percentages for individual fibers and micron-sized particulate debris (i.e., at least 96%) [14]. The small fraction of these various types of fines not considered as transporting to the recirculation sumps was assumed to be captured in the inactive sump during pool fill-up. As a result of the conservative transport results for fines, the precision of the assumptions made by the licensee regarding the transport metrics for fine debris was not considered to be of great significance, and these assumptions were not reviewed in detail by the staff during the audit.

However, the staff noted that the licensee used an analytical methodology based on Stokes' Law to derive terminal settling velocities for various fine particulate debris (flagged in Table 3.5-3 with †). This methodology was based upon the assumption that all of the particulate debris of a given type is (1) perfectly spherical and (2) of a size equal to the mean value of the associated size distribution. Since real debris particles are not perfectly spherical and vary in size, reliance upon terminal settling velocities computed by the Stokes' settling methodology to reduce the quantity of transported debris would depend upon questionable and/or unvalidated assumptions. The staff did not request that the licensee validate these questionable assumptions since no credit was taken for in the SONGS analysis for debris settling using this approach.

3.5.3.2.4 Turbulent Kinetic Energy Re-suspension Modeling

The licensee applied a turbulent kinetic energy (TKE) resuspension metric to determine whether various types of debris would be capable of remaining in suspension with the flow in the containment pool during recirculation [14]. The licensee derived the metric according to the definition of TKE, arriving at a debris-specific value equal to 3/2 times the square of the terminal settling velocity for the given debris type. The licensee subsequently compared the TKE metric for each type of debris to TKE values predicted by the FLOW-3D CFD code (using the re-normalized group theory [RNG] modeling option) to determine whether a given debris type would remain suspended or would settle onto the containment pool floor.

A similar TKE metric approach was evaluated by the staff in both the Fort Calhoun Station [29, 30] and Crystal River Unit 3 pilot audit reports [11]. In both reports, the staff identified concerns with this technical approach, noting that (1) using TKE and vertical flow velocity separately as independent metrics may nonconservatively neglect the potential for a correlation between these quantities, and (2) the TKE metric has not been benchmarked against experimental data to verify its validity. As these concerns have not been resolved and were not addressed during the SONGS audit review, the staff considers the TKE metric to lack adequate technical justification for use in debris transport analyses. Nevertheless, the staff does not consider the resolution of the issue necessary for the SONGS audit because (1) the licensee did not credit any settling of fine fibrous and particulate debris based upon the TKE metric and (2) the licensee's assumption that larger pieces of debris will not remain suspended at velocities typical of the SONGS containment pool (excluding several localized areas, such as where break flow and heavy drainage from containment spray enter the pool) is justified by previous test data and consistent with the staff's engineering judgment.

3.5.3.3 Debris Erosion

The licensee's transport calculation discusses debris erosion in Section 5.11 [14] . Of the types of debris analyzed for SONGS, the licensee stated that stainless steel RMI, microtherm, latent fiber, and latent particulate debris would not be subject to erosion following initial generation. As a result, erosion was considered only to apply to mineral wool debris. The staff considers this assumption to be reasonable based upon the facts that (1) pieces of RMI debris are sufficiently robust to preclude further degradation after the initial shockwave and jet impingement from the break and (2) microtherm, latent fiber, and latent particulate debris are assumed to be broken into 100% fines at the time they are generated, leaving no potential for subsequent erosion.

With respect to the erosion of mineral wool debris, the licensee stated that erosion applies only to the small-piece and large-piece categories because individual fibers and intact jacketed blankets would not be subject to erosion mechanisms [14]. The licensee further stated that 1% erosion would be assumed for small and large pieces of mineral wool retained in the upper containment, based upon the results of NUREG/CR-6369, Volume 2, "Drywell Debris Transport Study: Experimental Work," September 1999 [31], and the pilot plant analysis presented in Appendix VI of the staff's SE on NEI 04-07 [2]. To address erosion in the containment pool, the licensee assumed that 10% of the small and large un-jacketed pieces of mineral wool would be eroded into fines. The licensee used an equation and erosion rate provided in Appendix III of the staff's SE under the assumption that erosion tapers off after one day to compute an erosion percentage of 7%, which was subsequently rounded up to 10%. The basis for the licensee's assumption was that significant uncertainties are associated with the SE erosion data and the licensee interpretation that the observed erosion consisted primarily of small, loosely attached pieces of fiber breaking off from larger pieces.

Based upon previous testing and guidance in the staff's SE, the staff found the licensee's determination that erosion need only be considered for small and large pieces of mineral wool to be acceptable. With regard to the licensee's assumption of 1% erosion of the small and large pieces of mineral wool retained in the upper containment, the staff notes that this assumption did not affect the debris transport calculation because debris retention in the upper containment was not credited (i.e., 100% of the debris blown into the upper containment was assumed to be washed down). Therefore, the staff did not review the acceptability of the 1%-erosion assumption for fibrous debris retained in the upper containment.

The staff believes that sufficient basis has not been presented for the assumption that the erosion of small and large pieces of mineral wool in the containment pool would cease after one day. Specifically, Appendix III to the staff's SE [2] recommended that, in lieu of test data, the erosion of fibrous debris in the containment pool should be assumed to occur over the mission time of the recirculation sumps (considered to be 30 days in Appendix III). Under this assumption, a debris erosion percentage of approximately 90% was calculated. While the assumption of continued debris erosion at the rate assumed in Appendix III over a 30-day period may overestimate erosion in an actual containment pool, the staff notes that there are several significant sources of uncertainty associated with the licensee's calculation of 10% erosion of mineral wool. First, as discussed in Section 3.3.2 of this audit report, there is evidence that mineral wool may be more fragile than Nukon low-density fiberglass. As a result, it may erode more readily than Nukon, for which the licensee's erosion rate was derived. Second, a significant fraction of small pieces of mineral wool debris are predicted by the licensee's debris transport calculation [14] to enter the containment pool as part of the containment spray washdown. As discussed below, a significant fraction of the containment spray drainage could be in the form of continuous streams rather than spray droplets. Concentrated streams of spray drainage could create local turbulence levels greater than assumed in the licensee's calculation, which could lead to an increased rate of erosion for a significant fraction of the small pieces of mineral wool currently assumed to settle. The staff notes that, based upon data provided in the debris transport calculation, assuming 90% erosion for a 4D ZOI could result in the additional transport of approximately 20 ft^3 of mineral wool to the sump strainers. The staff considers the potential effects of concentrated spray drainage, including its effect on the local velocity and turbulence fields, and whether 10% erosion of washed-down debris is a valid estimate, to be significant issues. In light of these concerns, the staff concluded that adequate justification had not been presented in the course of the audit review to justify the assumption that only 10% of the small and large pieces of mineral wool in the containment pool would be subject to erosion and designates this issue be **Open Item 6**.

3.5.3.4 Debris Interceptors and Curbs

The licensee's debris transport analysis did not discuss the installation of debris interceptors as part of its modifications in response to Generic Letter 2004-02. However, a 4-inch curb currently exists around the recirculation sumps. Lacking specific test data, the licensee's debris transport calculation assumed that a loose pile of debris would form with an angle of repose of 34°, apparently based upon the characteristics of sand [14]. The licensee's CFD analysis indicated that a 4-inch curb would not be effective in interdicting small pieces of mineral wool, but would be effective at stopping some RMI debris.

Using the licensee's assumption of a 34° angle of repose, the staff performed a rough calculation showing that capacity exists for only about 5 ft^3 of debris to accumulate at the base of the curb around the sumps. This volume is small compared to the quantity of RMI debris the licensee calculated as transporting to the recirculation sumps. The staff's review of the licensee's debris transport results found that credit did not appear to be taken for the debris curb to reduce the quantity of RMI transporting to the strainers. Therefore, the staff considered the licensee's treatment of the debris curb to be acceptable.

3.5.4 Computational Fluid Dynamics Analysis

The licensee used computation fluid dynamics (CFD) to simulate the flow field in the SONGS containment pool during sump recirculation as an input to the debris transport calculation [14]. For the staff's audit review, the licensee provided two FLOW-3D input decks that were intended to predict the steady-state containment pool flow field during the recirculation phase of a large-break LOCA. The Case 1 input deck modeled a hot-leg break in Loop 1. Case 2 modeled a hot-leg break in Loop 2. Case 3 (reactor vessel nozzle break) and Case 4 (shutdown cooling line break outside bioshield wall) were not modeled using CFD. The licensee used the Case 2

CFD flow field to compute debris transport for Case 3, and a conservative 100%-transport assumption was made for Case 4. The CFD analysis for SONGS was performed by Alion.

The objective of the staff's review was to evaluate the adequacy of the physical assumptions and numerical approaches used in the CFD analysis to ensure that it predicted flow velocity, turbulence, and other containment pool parameters in a manner that would lead to conservative debris transport results. The staff's review focused on two main aspects: (1) examining the assumptions and explanations provided in the licensee's debris transport calculation concerning the CFD analysis and (2) executing the FLOW-3D code using the input decks provided by the licensee (with small changes to the input decks to determine whether perturbations to the input conditions and modeling assumptions would significantly affect the calculation results). The staff's CFD sensitivity simulations are discussed in more detail in Appendix IV to this report.

As described below, the staff identified several issues concerning the licensee's CFD analysis.

3.5.4.1 Containment Spray Modeling

In modeling the drainage of containment spray fluid, the licensee consulted various drawings and a computer-aided design (CAD) model of the SONGS containment [14]. Under the assumption that the containment spray flow is uniform through the horizontal cross-sections of upper containment, the licensee's model calculated the fraction of spray flow landing on any given surface to be the fraction of that surface's exposed area to the total cross-sectional area of the containment. The flow rate of containment spray drainage running off of a solid surface where it had previously landed was calculated according to ratios of the lengths of the open/unblocked peripheral boundaries of the solid surface. Using this methodology, the licensee computed the following containment spray drainage pattern:

Table 3.5-4: Assumed Containment Spray Drainage Pattern

Spray Drainage Location	Flow Rate	Percentage
Containment Periphery	3,165 gpm	63.3%
Refueling Canal Drain	911 gpm	18.2%
Steam Generator Compartments	900 gpm	18%
Curbed Area on Containment Floor	24 gpm	0.5%
Total	5,000 gpm	100%

Because sufficient information was not available in the documents provided by the licensee, the assumed containment spray drainage pattern was not reviewed in detail. Based upon the limited information provided, including the CAD model and CFD input decks, the staff concluded that the licensee's general methodology for computing the containment spray drainage pattern and the assumed surface area ratios appears reasonable. However, the staff also noted that significant uncertainty surrounds the licensee's resulting estimates.

To assess potential uncertainties in the assumed spray drainage pattern, the staff performed several sensitivity simulations using the FLOW-3D CFD code. One simulation increased the total containment spray flow by 20% for the Case 1 break location, distributing it proportionately among the drainage locations in Table 3.5-4 above. Another simulation (which was performed for both the Case 1 and Case 2 break locations) increased the proportion of spray drainage through the refueling canal drain by 30% (while maintaining total containment spray flow constant) to examine the potential for increased debris transport from the pool area surrounding the refueling canal drain line if the flow through this line were increased. The results of these simulations, which are discussed further in Appendix IV to this report, indicated that the results of the debris transport calculation would not be likely to be affected by perturbations of this magnitude. Therefore, the staff considered the licensee's assumed containment spray drainage pattern to be appropriate.

3.5.4.1.1 Containment Spray Drainage Kinetic Energy Influx to Containment Pool

As a point source, the refueling canal drain was representatively modeled in FLOW-3D by locating a mass source at the drain line termination point [14]. However, for the other distributed spray drainage locations in Table 3.5-4 above, a physically representative model including numerous water droplets and streams was considered computationally infeasible [14]. Instead, within the CFD model, the licensee cut holes in the containment floor at these locations and introduced the associated spray flows into the computational domain from the bottom of the containment pool.

In Section 5.8.3 of the debris transport calculation, the licensee derived the velocity components for the simulated containment spray flow entering from the holes in the containment floor. The vertical velocity component was modeled based upon the assumption that the flow rate at each spray drainage location was spread uniformly over the associated floor surface area; horizontal velocity components of constant magnitude but periodically alternating direction were chosen for the incoming flow in an attempt to accurately model the influx of kinetic energy to the containment pool without artificially imparting a preferred direction to the overall containment pool flow pattern. The staff previously reviewed an identical methodology for introducing containment spray drainage during a pilot audit review for Fort Calhoun Station (FCS) that had also been performed by Alion, identifying that the methodology actually underestimated the kinetic energy influx to the containment pool [29, 30]. Following the staff's identification of this issue for FCS, the SONGS licensee performed a revised CFD run of the worst-case break with respect to debris transport (Case 1) using an improved version of the FLOW-3D code to address the kinetic energy flux issue by introducing spray with a more physically representative model. The revised SONGS Case 1 input deck, which requires a customized proprietary version of the FLOW-3D code to run, was not provided for the staff's audit review. However, plots were appended to the transport calculation that compare the flow velocity and turbulence in the containment pool for the original Case 1 CFD run and the revised Case 1 run [14]. The overall containment pool flow patterns for the two cases do not appear to have significant qualitative differences. In addition, selected transport percentages computed from the revised CFD analysis also appear similar to the original calculation (see Section 3.5.4.3 for a comparative discussion of the original and revised Case 1 FLOW-3D runs).

The staff's previous pilot audit review considered FCS' application of an identical conceptual methodology for modeling containment spray drainage as entering through the containment floor with alternating horizontal velocity components, concluding that the associated underestimation of kinetic energy influx to the containment pool did not have a non-conservative effect on the debris transport results [29, 30]. However, there are several pertinent plant-specific differences between FCS and SONGS with regard to implementing the spray modeling methodology, including differences in pool height (the SONGS containment pool (1.58 ft deep) is somewhat shallower than that of FCS (3.96 ft)) and differences in localized spray flow drainage rates and velocities.

To consider the impact of these differences, the staff assessed the results of previous staff calculations described in the proprietary version of the FCS pilot audit report [29] considering the reduced pool height at SONGS. The staff's assessment indicated dispersed drainage flow introduced from the top of the SONGS containment pool would not significantly penetrate through 1.58 ft of water to perturb the flow conditions near the pool floor that influence tumbling transport and resuspension. In light of this analysis and the results of the revised simulation conducted by the licensee, the staff concluded that the licensee's non-physical modeling of the kinetic energy influx of the spray from the containment floor did not have a non-conservative impact on the debris transport results. However, as discussed in the following section, the staff has unresolved questions on a related aspect of the containment spray model, specifically, the assumption that spray drainage enters the pool in a dispersed and uniform manner.

3.5.4.1.2 Dispersed Modeling of Containment Spray Drainage

In both the original CFD runs and the revised CFD run with enhanced containment spray modeling, the licensee assumed that spray drainage flow would enter the pool with a dispersed and uniform flow at each of the spray drainage locations in Table 3.5-4 other than the refueling canal drain line. This assumption implies that the spray drainage is essentially in the form of droplets rather than concentrated, continuous streams with the potential to penetrate significantly below the containment pool surface and influence the turbulence and velocity fields near the containment floor. In Section 5.8.3 of the debris transport calculation, the licensee provided justification for the dispersed spray drainage assumption by stating that spray drainage at the containment periphery and in the steam generator compartments would be broken up by grating, equipment, steel beams, and other structures and components before reaching the containment pool [14].

Based upon a review of the licensee's CAD model and diagrams included in the debris transport calculation [14], the staff questioned whether the dispersed spray drainage assumption is physically reasonable. For example, Figures 5.1.7 and 5.8.2 in the transport calculation [14] suggest that a substantial fraction of the spray drainage that enters the pool around the containment periphery would first land on concrete floors at higher elevations, from which it would presumably cascade down to the containment pool in concentrated, continuous streams. Although the assumption of dispersed, uniform spray drainage flow does not appear likely to have a significant impact upon the overall containment flow field, local effects could be significant. Specifically, as concentrated streams falling ten feet or more may penetrate through several feet of water, the staff identified the potential for increased velocity and turbulence along the containment pool floor in the regions directly exposed to containment spray drainage. Since a significant fraction of debris is assumed to be washed down to the containment pool with spray drainage, and a sizeable fraction of this washed-down debris is assumed to settle promptly, this issue has the potential to affect the overall transport results, both by influencing the local flow field and by potentially increasing the erosion rate for washed-down debris that is not susceptible to pool transport.

To provide insight into the possible flow field perturbations that could result from explicitly modeling the containment spray drainage as concentrated, continuous streams, the staff created a simplified model using the FLOW-3D CFD code that was loosely based upon information in the licensee's debris transport report concerning spray drainage flow rates and containment physical geometry. While the staff's simplified model was not sufficiently representative to make a conclusion with respect to SONGS, the results of the simplified model suggested that significant increases in containment pool turbulence and velocity could be experienced in the local flow field if concentrated spray drainage is explicitly modeled. The staff's simplified calculation is discussed further in Appendix IV to this report.

In light of the discussion above, the staff concluded that the licensee's debris transport report did not adequately address the potential effects of concentrated spray drainage, including its effect on the local velocity and turbulence fields, and whether 10% erosion of washed-down debris is a valid estimate (see **Open Item 6** above).

3.5.4.2 Graphical Determination of Debris Transport Fractions

In calculating the transport fractions for various types of debris, the licensee used plots of the velocity and turbulent kinetic energy fields in the containment pool to determine the spatial areas where these parameters exceed the debris-specific transport metrics discussed above in Section 3.5.3.2 [14]. The licensee then overlaid the initial debris spatial distributions (discussed above in Section 3.5.3.1) onto these plots, highlighting regions where the initial debris spatial distributions and areas of exceeded transport metrics overlap. A debris transport fraction was then obtained by dividing the highlighted, overlapping areas by the total area over which debris was initially distributed. The licensee's debris transport calculation refers to this process as the graphical determination of debris transport fractions [14].

The staff considered the licensee's method of graphically determining debris transport fractions to be reasonable overall based upon the previous discussions in Sections 3.5.3.1 and 3.5.3.2; however, two instances were identified where the staff questioned its implementation. First, on Figure 5.9.26 of [14], which was used to calculate the transport of small pieces of washed-down RMI for the Case 2 break, the staff questioned why an area in the southeast quadrant of the containment pool that exceeded the transport metric had not been highlighted. Part of this area overlaps a containment spray washdown zone outside the bioshield wall, and any debris washed down in this area would appear to have a continuous transport path to the recirculation sumps. Second, on Figure 5.9.32 of [14], which was used to calculate the transport of small pieces of mineral wool for the Case 2 break, the staff questioned why an area in the Loop 2 compartment (near the curb separating the Loop 1 and Loop 2 compartments) that exceeded the transport metric had not been highlighted. The staff noted that the metric for curb lift velocity appeared to be exceeded by the flow, and that debris in the affected area appeared to have a continuous transport path to the recirculation sumps.

The licensee did not address the two questions identified above regarding the graphical determination of debris transport fractions and therefore did not ensure that the debris transport results presented for the audit review werre conservative. The staff considers the absence of adequate justification for the graphically determined debris transport fractions obtained from Figures 5.9.26 and 5.9.32 in the debris transport analysis report to be **Open Item 7**.

3.5.4.3 Staff CFD Sensitivity Simulations

In addition to performing baseline runs of the as-received CFD input decks and performing several sensitivity simulations referred to in the previous section regarding containment spray modeling, the staff conducted a series of additional CFD sensitivity simulations for both the Case 1 and Case 2 input decks to verify that credible perturbations to assumptions and modeling conditions would not significantly affect containment pool flow parameters of importance to debris transport, such as velocity and turbulence. Overall, the staff's sensitivity simulations demonstrated that the licensee's CFD input decks were relatively robust and were not significantly altered by credible perturbations to the input assumptions. However, the staff identified several areas where the general methodology used to conduct the CFD simulations could lead to non-conservative results if applied in an analogous way to other expected plant configurations. The staff's sensitivity simulations are described in more detail in Appendix IV to this report.

3.5.4.4 Overall Transport Results and Revised CFD Methodology

The licensee's debris transport calculation [14] provides the results of the original debris transport calculation for Cases 1 through 4, which are summarized in Table 3.5-5 below. (Table 3.5-1 identifies the break location corresponding to each case.)

Table 3.5-5: Original Debris Transport Results

Debris Type	Transport Percentage Case 1	Transport Percentage Case 2	Transport Percentage Case 3	Transport Percentage Case 4
Stainless Steel RMI	59%	51%	82%	100%
Mineral Wool (4D ZOI)	72%	68%	N/A	100%
Epoxy Paint (Inside ZOI)	99%	99%	99%	100%
Unqualified Coatings (Outside ZOI)	100%	100%	100%	100%
Latent Particulate	96%	96%	96%	100%
Latent Fiber	96%	96%	96%	100%
Microtherm	N/A	N/A	99%	N/A

However, as noted above in Section 3.5.4.1, the licensee revised the original CFD model and performed an additional simulation of the bounding case (Case 1) with a revised input deck. As noted, the revised input deck incorporated an enhanced model for containment sprays that introduced the spray flow from the top of the containment pool at a representative velocity, rather than introducing the flow from the bottom of the pool and employing alternating horizontal velocity vectors in an attempt to represent the kinetic energy flux into the containment pool. In addition, the revised Case 1 input deck incorporated a more realistic model for simulating the pipe break flow entering the containment pool, which was expected to reduce the pool turbulence in the vicinity of the break [14]. Selected debris transport results computed using the revised Case 1 CFD input deck are compared to the results using the original input deck in Table 3.5-6 below (transport results for all debris types using the revised input deck were not provided during the audit).

Table 3.5-6: Comparison of Original and Revised Case 1 Transport Percentages

Debris Type	Original Case 1 Total Transport Percentage	Revised Case 1 Total Transport Percentage
Stainless Steel RMI	59%	59%
Mineral Wool (4D ZOI)	72%	74%
Mineral Wool (17D ZOI)	44%	45%
Particulate Debris *	99%	99%

* Unspecified in analysis, but presumably this is particulate from epoxy paint from within the ZOI

The selected revised transport percentages calculated by the licensee are within about 2% of the original results. This result is not surprising based upon (1) the revised Case 1 plots appended to the transport calculation, which did not appear to have significant qualitative differences in the overall containment flow pattern as compared to the original Case 1 results and (2) a staff sensitivity simulation, described in Appendix IV to this report, which suggest that dispersed sprays do not substantially affect the containment velocities along the floor of the pool. As a result, the licensee concluded that the original transport results remain valid [14].

The staff noted that the head loss testing conducted by the licensee used debris quantities derived from the original transport results [31], despite the fact that a slightly increased mineral wool transport percentage was calculated based upon the revised CFD simulation. However, based upon the staff's experience, the slight increase in the mineral wool transport percentage appears to be within the uncertainty band associated with using CFD as an input to the debris transport calculation. The staff further notes that CFD simulations ideally provide best-estimate (rather than conservative) predictions of fluid behavior, and that the overall conservatism of debris transport results is dependent upon analytical assumptions used in applying CFD predictions and other results. The licensee's decision to perform head loss testing with the original percentage of mineral wool rather than the revised percentage non-conservatively neglects approximately 1.5 ft^3 of fibrous debris. However, in light of conservative assumptions made in the licensee's transport calculation (described further in Section 3.5.5, below) and the licensee's plan to replace the mineral wool on the steam generators, the staff considers the use of the original debris quantities as inputs to the head loss testing to be acceptable.

3.5.5 Conservatisms in the Debris Transport Analysis

In addition to various conservatisms previously identified in the above discussion, the staff noted several substantive sources of conservatism in the licensee's debris transport analysis.

- The licensee assumed that large and small pieces of insulation would be uniformly distributed along the flowpath between the locations where they would be destroyed and the sump strainers [14]. In actuality, the staff expects that the multi-directional flows occurring during the blowdown and pool fill-up phases would tend to disperse this debris throughout containment, including areas with reduced transport potential. Therefore, by distributing the debris only over areas between the location where it is destroyed and the sump strainers, the conservatism of the debris transport analysis is enhanced.

- The licensee assumed that all debris in the upper containment would be washed down to the containment pool [14]. As such, no credit was taken for capturing debris on gratings or other structures and equipment in upper containment. Although a large fraction of small pieces of debris may eventually be washed back down to the containment pool, assuming 100% washdown is conservative.

- The licensee adopted the conservative baseline assumption that 100% of the small fines of fibrous and particulate debris in active volumes of the containment pool would transport to the sump strainers [14]. 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 present in active pools is conservative.

- The licensee assumed that 100% of the debris generated during an small-break LOCA was assumed to transport to the sump strainers [14]. The most limiting small-break LOCA analyzed by the licensee is located in the vicinity of the sump strainers. Although large debris transport fractions are expected to result from the shortness of the transport path and the turbulence that the break flow would cause in the pool near the sump strainers, assuming complete transport is conservative.

- The licensee performed CFD simulations for the two large-break LOCA cases assuming the more bounding small-break LOCA minimum water level [14]. For the large-break LOCA case, the water level is slightly increased (i.e., roughly 0.6 ft) due to the contribution from the safety injection tanks. This additional water will decrease the flow velocities in the pool and reduce the impact of containment spray drainage, both of which may tend to slightly reduce debris transport.

- The licensee did not credit holdup in the reactor cavity [14]. Settling in the reactor cavity may be particularly significant for the Case 3 break on the reactor vessel nozzle, but would occur to some extent for all analyzed cases.

- The licensee performed CFD simulations for the two large-break LOCA cases assuming that one of the low-pressure coolant injection pumps fails to automatically stop running after the injection phase [14]. This single-failure assumption increases the normal post-accident sump flow by almost 80%. As a result, predicted flow velocities are significantly increased throughout the containment pool, which is conservative with respect to predicting debris transport.

- The licensee performed the debris transport analysis assuming that the containment floor is flat [14]. However, the debris transport calculation noted that the recirculation sumps are actually at a slightly higher elevation than the steam generator loop compartments. As a result, some debris may have to tumble slightly uphill in order to transport to the recirculation sumps. The licensee did not credit this effect in the transport analysis, which may have reduced the quantity of debris reaching the sump strainers.

While the overall impact of these conservatisms is difficult to quantify, the staff believes that, provided that the licensee acceptably addresses the open items identified in this report, sufficient conservatism has been incorporated into the debris transport analysis to address the impact of any remaining issues identified in the preceding discussion as potential non-conservatisms.

3.5.6 Debris Transport Summary

The NRC staff reviewed the licensee's debris transport analysis (including the CFD model) to determine its consistency with the sump performance methodology approved in the staff's SE. 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.

The staff's CFD sensitivity cases described in Appendix IV further demonstrate that, while several concerns were identified with respect to the general methodology, the licensee's computational transport model generally appeared robust in response to the perturbations introduced by the staff.

Among the potentially significant non-conservative assumptions made by the licensee with respect to debris transport were the following open items:

- **Open Item 4**: The licensee had not justified using 0.16 ft/s as the incipient tumbling velocity metric for small pieces of mineral wool.

- **Open Item 5**: The licensee had not justified neglecting the transport of mineral wool by flotation.

- **Open Item 6** : The licensee had not justified the assumption that containment spray enters the containment pool as a dispersed flow rather than concentrated, continuous streams, and the related assumption of 10% erosion for small and large pieces of mineral wool in the containment pool

- **Open Item 7**: The licensee had not justified the graphically determined debris transport fractions obtained from Figures 5.9.26 and 5.9.32 in the debris transport analysis report.

The licensee also made a number of conservative assumptions in the debris transport analysis. A partial list of these items is provided in Section 3.5.5 above. The staff determined that these conservatisms are sufficient to address any non-conservatisms identified in this report that were not designated as open items. Therefore, provided that the open items described above are appropriately resolved, the staff concluded that the licensee's methodology for analyzing debris transport is acceptable.

3.6 Head Loss, Vortexing and Net Positive Suction Head Available

3.6.1 Head Loss and Vortexing

3.6.1.2 Head Loss and Vortexing Audit Scope

The new sump design proposed by the licensee uses Enercon vertical Top-Hat strainer modules installed within the existing two separate containment sump pits. The water enters the inner and outer perforated plate surfaces of each strainer module and flows through the annulus created between these two surfaces. The total surface area of perforated plate for each sump is 976 ft^2. The total strainer array volume for each sump is 233.4 ft^3 [6]. Based on the debris transport calculation, 58.3 ft^3 of mineral wool is assumed to be transported to the sump for the RCS Loop 1 break case and 169.5 lb Microtherm material for the reactor cavity nozzle break case.

The licensee employed the HLOSS computer code 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 single and multiple Top-Hat-hat strainer modules. As part of the prototypical head loss testing program, the licensee evaluated the susceptibility of the strainers to vortex formation.

The NRC staff focused the audit effort in the following technical areas:

1. System characterization and the design input to the head loss evaluation;
2. Prototypical head loss test module design, scaling, surrogate material selection and preparation, testing procedures, results and data extrapolation;
3. Vortex testing procedures and the vortex formation test results.

3.6.1.2 System Characterization and Design Input to the Head Loss Evaluation

The licensee performed a LOCA scenario evaluation and identified events that may lead to ECCS recirculation through the containment sumps. SONGS 2&3 utilizes a group of systems known collectively as Engineering Safety Features (ESF) systems to mitigate the effects of design basis accidents. The systems requiring containment sump operation can be divided into to two subgroups: the Safety Injection Systems (SIS), which provided borated water injection to the reactor coolant system in the event of primary system breaks, and the containment heat removal systems. The SIS at SONGS 2&3 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. According to the design, the LPSI pumps are tripped when transfering SIS from the initial injection mode from the RWST to the recirculation mode through the containment sumps, and therefore are not supposed to take suction from the containment emergency sump during a LOCA event.

3.6.1.2.1 Flow Rate

The two containment emergency sumps provide a reservoir for an adequate source of water for the HPSI and containment spray pumps following a Recirculation Actuation Signal (RAS). The licensee indicated in its LOCA event characterization document [33] that for the most limiting LOCA scenario with a single failure assumption (one LPSI pump failure to stop at RAS), one train of HPSI, Containment Spray and LPSI pumps takes water from one sump, while another train of just a HPSI and a Containment Spray pump (with a secured LPCI pump) takes water from the other sump. Assuming that one sump strainer and/or its associated pumps fail during the accident due to excessive flow and head loss caused by the running LPSI pump, the other sump would need to supply 3500 gpm of flow to one train of HPSI and CS pumps. Therefore, the design flow rate input for the new strainer in each sump is 3500 gpm.

Staff Evaluation

The staff reviewed the report of the LOCA event characterizations [33] and found that the assumptions used in the report appear to be reasonable and can be supported by licensing basis documents and other technical information collected on site. Specifically, the staff examined the LPSI pump suction line piping system, the LPSI pump curve data and the LPSI control signal requirements. It was indicated in UFSAR Section 6.3.2.9.4 [68] that two LPSI pumps are secured after RAS. Therefore, applying at SONGS a LPSI pump failure-to-stop assumption to determine the sump design flow rate is reasonable.

3.6.1.2.2 Sump Water Temperature

It was indicated on Page 5 of [6] that the calculated sump water temperature ranges between 110 °F and 270 °F. In [33] it was determined that the containment sump temperature at the initiation of recirculation varies, based on the event duration and the amount of cooling available. The SIS pump NPSH calculation assumed a conservative temperature of 270 °F for the NPSH available calculation, which is conservative for minimizing the static head. However, for the head loss calculation, the higher the temperature, the lower the head loss. Therefore, the licensee chose the minimum saturated containment water temperature of 208.84 °F as the bounding temperature for the head loss calculation based on the minimum containment pressure of -0.9 psig specified by [75].

Staff Evaluation

The staff reviewed the analysis determining the bounding sump water temperature for the strainer head loss calculation. The determination of the bounding sump water temperature of 208.84 °F for head loss appears to be reasonable because it bounds the head loss calculation based on the current licensing basis minimum containment pressure for LOCA scenarios. However, the licensee needs to approve the 208.84 °F bounding sump water temperature for the strainer head loss evaluation.

3.6.1.2.3 Containment Pool Water Level

The licensee has performed a calculation that determines the volume of water transferred to the containment from the SITs (Safety Injection Tanks) prior to transfer to re-circulation mode and determined that the minimum containment flood level is at 19.08 ft elevation [33]. The minimum water level was determined based on small break LOCA analysis and does not include the 50,200 gallon volume of water potentialy introduced into the containment from the SITs. If the total SIT volume is included, the level will increase by approximately 0.61 ft. However, the 19.08 ft is used in the new strainer head loss analysis [15] without taking the credit of the additional 0.61 ft margin. The minimum strainer submergence is therefore 12", which is greater than the maximum corrected head loss across the screen (0.887 ft from Table 5.8.1 of [74]), and therefore no water vapor flashing is expected to occur inside the strainer during the long-term recirculation phase.

Staff Evaluation

The staff reviewed the analysis determining the minimum containment water level. Since it is based on the previous licensing basis water level calculation excluding total SIT volume, it appears that the minimum water level defined for the strainer design is conservative. No flashing is expected to occur inside the strainer during the long-term cooling phase of a LOCA.

3.6.1.3 Prototypical Head Loss Testing

In order to demonstrate that the new strainer head loss for the most limiting LOCA cases is less than 5.0 ft, the licensee contracted with Alion to perform prototypical head loss testing. As shown in Figure 3.1, the prototype strainer was placed in a large test tank approximately 6.0 ft tall, 6.0 ft wide, and 10.0 ft long. The 3x3 Top-Hat strainer array was installed near the center of the tank and was mounted in a plenum assembly placed on the floor of the test tank. The flow was routed from the tank inlet, through the strainer/plenum assembly, and out through one of the tank's two flow outlet channels. The outlet channels are located on the suction side of the tank near the bottom of that side. All the tests were performed with 4 plywood walls enclosing the Top-Hat strainer array as shown in Figure 3.1. Pressure transmitters, a flow meter and thermocouples were installed to measure the head loss, total flow rate and the water temperature. A total of three test series (twelve test runs) were performed to measure the head loss across the "thin bed effect" regime and capture the head loss with the maximum debris loading [74].

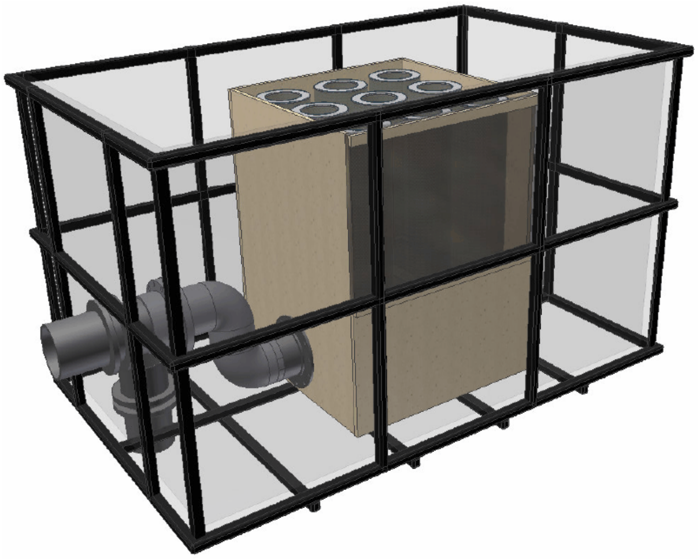

Figure 3.1 Isometric View of Alion Test Tank with SONGS Prototype Strainer Installed

3.6.1.3.1 Debris Types, Quantities, and Characteristics

The type of debris that may be generated during a LOCA in the SONGS Units 2 & 3 containment buildings include RMI, mineral wool, Microtherm, qualified and unqualified coatings (epoxy, enamel, alkyd), and latent debris (dirt, dust, latent fiber) [74].

3.6.1.3.1.1 Fiber Debris

The amount of Mineral Wool fiber debris transported to the sump is estimated to be 468.8 lb for the RCS Hot Leg Break case based on the licensee's transport analysis. The licensee performed a debris characteristics evaluation and identified that the SONGS specific mineral wool material has a microscopic density of 180 lb/ft^3 and a fiber diameter of 4.9 microns. The surrogate mineral wool used in the head loss tests was studied using a scanning electron microscope (SEM) and the surrogate mineral wool was determined to have a fiber diameter of 3.7 microns. The microscopic density of the surrogate mineral wool was found to be 180 lb/ft^3. The material was baked before the test to remove the binding force between the fibers.

The latent fiber material was simulated by Nukon low-density fiberglass manufactured by Industrial Insulation Group, LLC. The Nukon fiber surrogate material was shredded into small pieces, boiled and then rinsed to simulate the destruction associated with a LOCA break condition.

Staff Evaluation

The Nukon fiber material was used as the surrogate material to represent the latent fiber. This approach was acceptable because it is consistent with requirements of GR and SE. The mineral wool surrogate material has the same microscopic density as that of plant material. In addition, it has a smaller fiber diameter than the mineral wool in service and therefore would tend to cause higher head loss. Therefore, the use of the surrogate mineral wool material with the current preparation procedure is acceptable.

3.6.1.3.1.2 Coating Debris

A total of 939.2 lbs and 650.7 lbs [74] of epoxy coating, unqualified alkyds and enamels were estimated to be transported to the sump for the RCS Loop 1 Break case and Reactor Cavity Nozzle Break case respectively. For testing purposes, all the coating debris arriving at the sumps were assumed to be in the form of particulate with a particle size of 10 microns. SIL-CO-SIL 53 ground silica was used as a surrogate for all coatings. Based on observation with a scanning electron microscope (SEM), the licensee stated that the ground silica material has a density of 165 lb/ft^3 with a size distribution between 1 μm and 100 μm, and an average diameter of 10 microns based on the sizing evaluation of the ground silica material. The licensee used the same volume of ground silica as that of the coating material even though the ground silica's density was much higher than that of coating debris. This is conservative because higher density for the same volume means that the amount of debris tested was greater than that expected to actually occur in the plant. During the test, the agitation was introduced to prevent the settlement of the ground silica powder.

Staff Evaluation

The GR conservatively recommends assuming 10 µm spheres for unqualified coating debris due to substantial uncertainty regarding its debris size. The selection of ground silica met this criteria. In addition, the volume of the ground silica was kept the same as the volume of the coating debris. Therefore, using ground silica in this manner is considered conservative and acceptable.

3.6.1.3.1.3 Other Particulate Material

Silica sand prepared by Performance Contracting, Inc. was used as a surrogate material for latent dirt and dust debris. Similar to the discussion in Section 3.6.3.1.2 above, the size distribution of the silica sand was prepared to be consistent with latent dirt/dust size distribution provided in the SE.

Staff Evaluation

The use of silica sand of the size distribution chosen by the licensee to represent the latent debris dirt and dust is acceptable because the size distribution of the surrogate material is consistent with the latent dirt/dust size distribution defined in the SE.

3.6.1.3.1.4 RMI

Based on the licensee's debris transport analysis [14], a significant amount of RMI debris would be transported to the sump. For example, for the Reactor Cavity Nozzle Break case, 82% of the stainless steel RMI debris generated inside the ZOI is transported to the sump. Therefore, the RMI is expected to occupy a certain fraction of the interstitial volume inside the sump pit. The licensee performed the strainer head loss tests without using RMI debris surrogate material. It was assumed by the licensee that the presence of RMI in the sump pit would disperse the fiber and particulate over a large volume and prevent the formation of the fiber and particulate debris bed. Therefore, the licensee concluded that introducing RMI debris into the test would have the effect of reducing strainer head loss. Based on this assumption, the licensee decided to exclude the RMI debris from the head loss tests, and the licensee believed that the measured head loss was conservative.

Staff Evaluation

In general, the staff agrees with the licensee that RMI debris tends to disperse the fiber and particulate debris and may reduce the head loss if all the debris arrives at the sump pits at the same time. However, for SONGS's new strainer design case, it is not clear whether the RMI would have this effect. The dispersion of the fiber and particulate debris within the RMI depends on the arrival sequence of the debris, which is not known. Although certain portion of the fiber and particulate debris may arrive at the sump pit at the same time as the RMI debris, fiber debris (especially the fiber debris caused by erosion) may arrive at the sump pit after the RMI. If the fraction of fiber amount arriving later is sufficiently large, the fiber may form a debris bed on the top of the RMI debris in the sump pits. Such a debris bed would reduce the effective strainer surface area, and could cause higher head loss than the head loss value measured during the tests. Without sufficient information regarding the debris arrival sequence, the industry practice for this consideration has been to develop bounding combinations of debris with the worst-case arrival sequence. For the SONGS' sunken pit design, one such bounding test case could be RMI arriving first, filling to some level of the strainer array interstitial volume, followed by fiber and particulate.

The licensee had not addressed the potential head loss change from RMI debris entering the interstitial volume of the sump pit. Since the staff has not seen sufficient evidence to support the assumption that excluding RMI from head loss testingwould result in conservative head loss measurement, the staff designates this issue as **Open Item 8**.

3.6.1.3.1.5 Microtherm Material

For the Reactor Cavity Nozzle Break case, a total amount of 169.5 lbs of Microtherm material is estimated to arrive at the sump. Reference [73] indicated that Microtherm material produced by U.S. Silica company was used as the Microtherm surrogate material during the head loss tests. Since it is known that Microtherm material changes its properties with temperature and the head loss tests were conducted at room temperature, during the onsite audit the staff questioned the temperature dependency of the material and its possible impact on the head loss test results extrapolated to representative SONGS recirculation sump pool temperatures. On October 3, 2006, the staff held a teleconference with the licensee and its contractors regarding this issue. The staff was given the following information: (1) the primary constituent of Microtherm is the fumed silica, which changes its properties and material behavior at different temperatures; (2) at temperatures greater than 235 °C, fumed silica loses its hydrophobic behavior and becomes permanently hydrophilic; (3) because the SONGS reactor vessel has operated for many years at temperatures greater than 235° C, it is very likely that the Microtherm insulation is hydrophilic; (4) the viscosity of aqueous suspensions containing hydrophilic Microtherm will decrease with increasing temperature.

Staff Evaluation

The staff reviewed the licensee’s response documented in the teleconference summary (Appendix III) and concluded that the licensee properly evaluated the temperature dependence of Microtherm material properties for neutral pH (pH 7) solutions because the viscosity of aqueous suspensions containing hydrophilic Microtherm decreases with increasing temperature. However, the licensee had not resolved Microtherm temperature-dependent material behavior for the pH value or values expected in the post-LOCA sump pool. This resolution, essentially an environmental variation (scaling) of the information contained in Appendix III to this report, would be officially approved by the licensee and included as part of the SONGS design basis documents. The lack of such a resolution is designated as **Open Item 9**.

3.6.1.3.2 Scaling Methodology, Testing Procedures And Test Results Interpretation

3.6.1.3.2.1 Geometrical Scaling Methodology

The SONG strainer array consists of Top-Hat modules with different heights. The height varies between 24" and 65". Alion performed scaled prototypical head loss testing using 3x3 Top-Hat modules with a height of 42". The selection of 42" was largely determined by the test loop maximum water level and the minimum submergence values based on minimum calculated containment water level. The licensee believed that the strainer vendor’s approach was conservative because most of the modules are longer than 42", and, shorter Top-Hat modules tend to promote more uniform debris loading on the screens and therefore result in higher head loss measurements. The testing array setup provides an accurate simulation of the actual strainer assembly in that the walls of the sump pit are simulated by the plywood walls within the tank. During the test, all the debris (except, as discussed above, the expected RMI debris) was introduced into the confined space between the plywood walls. Therefore, no credit was taken for near-field debris settlement. Alion scaled the total debris loading with a scaling factor of 0.146 based on the ratio between the total testing module surface area and the actual screen surface area. The screen approach velocity was scaled one to one.

Staff Evaluation

The testing module was scaled assuming no near-field debris settlement. The shorter Top-Hat module is believed to result in conservative head loss measurement by eliminating some potential clean screen surface area. In addition, the screen approach velocity was kept the same. Therefore, the licensee's geometrical scaling methodology is considered acceptable.

3.6.1.3.2.2 Testing Procedures

Prototypical head loss testing was performed by Alion following generic testing procedures along with specific debris addition procedures,and testing implementation procedures. Portions of this testing were observed by the NRC staff. The generic testing procedures included the following:

Test Equipment Verification Procedure
Test Lab Safety Procedure
Debris Preparation Procedure
Test Tank Fill Procedure
Test Tank Draining and Cleaning Procedure
Test Tank Debris Head Loss Measurement Procedure

The mineral wool surrogate and NUKON insulation were prepared in accordance with the generic debris preparation procedure. The procedure includes shredding and boiling of the NUKON fiber. Boiling NUKON fiber for 10 minutes was intended to remove the binding force that exists in the NUKON surrogate material. The boiled fiber was then mixed thoroughly with a paint mixer attached to an electric drill until a homogeneous slurry was formed. The mineral wool was baked to remove the binder and mixed with water uniformly to form the slurry.

All the surrogate material was added at the top of the testing module directly over the strainer array. This ensured the maximum amount of debris transported to the strainers thereby ensured the conservative head loss measurement. For some test cases, the debris was introduced in calculated increments of 1/8" and 1/4" of fiber bed thickness (assuming the worst head loss case of even distribution of the fiber on the strainer surfaces, which is not necessarily the case). Between each batch of debris load, the head loss was allowed to stabilize at either less than a 1% increase over a 10 minute period or for at least 5 tank turnovers.

During the tests, the temperature, the total flow rate and the head loss were continuously monitored. It was observed that the water temperature slightly increased as the test progressed due to the energy addition from the pump.

Staff Evaluation

The staff reviewed the key testing procedures affecting the head loss measurement and concluded that they were properly applied to SONGS strainer head loss tests because the SONGS-specific debris introduction procedure resulted in minimum near field settlement and conservatively increased the measured head loss as compared to head loss testing using a long testing flume with upstream debris introduction. Therefore, the testing procedures are considered acceptable for this particular plant.

3.6.1.3.2.3 Test Results Interpretation

The SONGS prototypical test program consisted of 4 separate series of tests [74]. Test series #1 and #2 were performed to determine the head loss due to debris generation from a RCS Loop 1 Break. Test series # 3 was performed to measure the head loss due to debris generated during the postulated Reactor Cavity Nozzle Break LOCA event. The #4 series was performed to evaluate the possibility of vortex formation and is discussed in Section 3.6.4.

Because all of the test series were performed around the design basis flow rate and the strainer design target temperature is 208 ^{o}F, Alion decided to develop a data extrapolation scheme to convert the ambient temperature head loss measurement data to that at 208 ^{o}F with the design flow rate. On Page 93 of [74], the last two formulas were used to demonstrate the concept of flow split into the laminar and the turbulent components. These two formulas are incorrect due to several typographical errors. In addition, the staff has not seen a sound theoretical or empirical basis to adopt the concept of flow split. However, the final equations for temperature extrapolation (Equation 6 and 7 on Page 94 of [74]) appear to be conservative and result in conservative head loss prediction at 208 ^{o}F with the rated flow. Because the fractional decrease of dynamic viscosity is much greater than the fractional water density reduction at the design temperature, Equation 6 and 7 yields a higher head loss prediction than that of the standard industry practice derived from accepted fluid mechanics principles. The predicted maximum head loss was determined to be 0.887 (ft-water) under the design temperature condition of 208 ^{o}F based on the maximum room temperature tested head loss of 2.2 feet, while the SONGS NPSH margin is 5 (ft-water).

Staff Evaluation

Not considering potential chemical effects, Alion developed a temperature and flow rate correction methodology to interpret the measured strainer head loss. Although the staff has not seen sufficient evidence to support the concept of flow split into the laminar and turbulent components, and the sample demonstration had some errors, the final head loss predictions are considered conservative because they provide higher head loss than equations that follow the standard industry approach. Therefore, the final results of the test data extrapolation regarding the temperature appear to be acceptable for SONGS.

3.6.1.4 Vortexing

3.6.1.4.1 Vortex Evaluation

In response to NRC's RAI regarding the evaluation of possible vortex formation on the surface of the new strainer, the licensee investigated the possibility of vortex formation as part of the strainer array testing program. The licensee identified the most limiting condition for possible vortex formation, using a clean 24" Top-Hat strainer module on the collector box with the highest flow at the onset of recirculation. The licensee did not perform any analytical evaluation based on empirical correlations. Instead, it relied on the testing of a full size strainer module with only the upper one third of the strainer surface open and the lower two thirds blocked.

Test series #3 was conducted to investigate how water level and flow rate influence the formation of vortices on top of the SONGS 3x3 prototypical Top-Hat array. The bottom two-thirds of the exterior surface of the Top-Hats in the array was covered with plastic to prevent the flow through the lower outside surface. This approach is conservative with respect to the vortex formation because it forces the majority of the flow through the upper portion of the Top-Hat strainers and into the inner surface of each Top-Hat module. It bounds possible non-uniform debris bed formation and the flow condition of 24" Top-Hat strainers on top of the collector box During the test, the water level and the total flow rate were adjusted to capture the initiation of the vortex formation. Based on [73] (Page 10 of 31), 511 gpm for the testing module is equivalent to 3,500 gpm designed sump flow rate. The total flow rate of the testing module was controlled between 904 gpm and 1478 gpm (Table 4.5.1 of [73]). The submergence of the strainers varied between 12" and 4". After the flow rate reached 1478 gpm and the submergence was adjusted to 4", a noticeable intermittent vortex was observed at the top of the strainer array. However, with a submergence of 8.5" and 1470 gpm flow rate, no vortex was observed.

In addition to the full-scale strainer module vortex test, the licensee also calculated the water level depression above the sump pit. Reference [73] indicated that the calculated water level depression is less than one inch. Therefore, with 12" minimum submergence, the licensee concluded that the formation of a vortex was unlikely.

Staff Evaluation

The licensee performed Top-Hat strainer array vortex tests to evaluate the possible vortex formation on top of the SONGS Top-Hat strainer array. The staff concluded that the licensee's test practices were acceptably conservative because the full size Top Hat strainer modules were used with a conservative blockage of the bottom two-thirds of the strainers. The test results showed that vortices were not observed until the submergence dropped to 4 inches with with a flow rate higher than design flow rate, and the calculated minimum submergence of the strainers is 12 inches. Therefore, the staff considers the licensee's conclusions regarding vortex formation acceptable.

3.6.1.5 Head Loss and Vortex Evaluation Conclusions

The licensee performed plant-specific prototypical strainer head loss testing to measure the head loss across the top hat strainer with the SONGS plant-specific debris loading. The testing matrix, the testing procedures and the system input evaluation were reviewed during the audit. Because the predicted head loss is 0.887 ft under the design temperatures conditions, based on the maximum room temperature tested head loss of 2.2 ft, is significantly less than the 5.0 ft NPSH margin, the staff considers the licensees head loss evaluation adequate, excluding **Open Item 8** and **Open Item 9** above, as well as any potential head loss change due to chemical effects (Table 5.8.1 of [74]).

Vortex tests were conducted using conservative testing approaches. The results showed that the SONGS new strainer would not be subject to vortex formation on top of the strainer array with the designed flow rate and the minimum submergence. The staff considers the test results acceptable.

3.6.2 Net Positive Suction Head Available

3.6.2.1 Net Positive Suction Head Available (NPSHA) Audit Scope

The licensee's engineered safety feature (ESF) systems include two trains of emergency cooling pumps. Each train consists of one high pressure safety injection (HPSI) pump, one low pressure injection pump (LPSI) and one containment spray (CS) pump. An additional HPSI pump can be switched to one train or the other as maintenance operations require. During the recirculation mode of decay heat removal following a loss-of-coolant accident (LOCA), the individual trains independently take suction from one of two independent containment emergency sumps (a structural barrier divides the sump into two redundant sumps) [15]. The licensee performed net-positive suction head (NPSH) calculations to establish the ECCS pump NPSH margins during recirculation heat removal in the absence of the proposed sump debris strainers and collected debris. These margins were used by the licensee to determine the head-loss adequacy of the emergency containment sump screens during the recirculation mode of emergency core cooling following a postulated LOCA (i.e., the final ECCS pump NPSH margins will be calculated by subtracting the NPSH available without proposed sump strainers and debris from the NPSH required by the ECCS pumps).

The calculations were performed by the licensee using hydraulic models that were evaluated using Microsoft Excel spreadsheets. The models and calculations are presented in references [76-80].

The NRC staff reviewed the models and calculations of references [76, 77] prior to the onsite audit period, and reviewed assumptions, models and calculations with the licensee staff during the onsite audit. References [78-80] were provided by the licensee during the onsite audit as additional background documentation. The review included guidance provided by Regulatory Guide (RG) 1.82, Revision 3 [4], NRC Generic Letter 97-04 [81], NRC Audit Plan [5], NEI 04-07, the industry methodology report for sump performance [1] and the NRC Safety Evaluation of NEI-04-07 [2].

3.6.2.2 NPSH of the ECCS and CSS Pumps

3.6.2.2.1 Summary Presentation of NPSH Results

The licensee performed two sets of calculations, presented separately in two calculation documents [76, 77]. Reference [76] presents NPSH calculations assuming a sump water temperature of 270°F, while reference [77] presents the calculations for sump water temperatures of 110°F, 160°F and 208°F. Results are summarized below, and discussed in greater detail in the following sections.

Ref. [76] presents eight NPSH calculation cases performed for the recirculation mode of decay heat removal. The safety injection mode of heat removal cases are also presented, but are not discussed here since they do not impact the sump debris strainer clogging issue. The sump water temperature is taken as 270°F for these cases, and the NPSH margin value represents the difference between the water pressure and the liquid vapor pressure at the pump suction. The sump water temperature of 270°F was established based, as discussed in [78], on wording in Regulatory Guide 1.1 “Net Positive Suction Head for Emergency Core Cooling and Containment Heat Removal System Pumps (Safety Guide 1)” dated November, 1970 [123]: “no credit may be taken for the containment pressure which is above atmospheric pressure during an accident, and the highest atmospheric temperature during an accident must be used in the determination of NPSHA...” The sump pool temperature of 270°F (the highest temperature expected during the injection phase) is not representative of the sump pool temperature at the initiation of recirculation, which would be close to 208°F. However, it does represent a bounding case calculation conducted by the licensee.

Four of these cases assume train and pump lineup combinations of one HPSI pump and one Containment Spray (CS) pump during recirculation, with no single failure assumed. The remaining four cases assume a single active failure that results in failure to switch off the LPSI pump during the transition from injection to recirculation heat removal, resulting in a pump lineup of one HPSI, one LPSI and one CS pump during recirculation. Table 3.6.2.2.1-1 below summarizes the results of the NPSH calculations and presents the available and required net positive suction heads (NPSHA and NPSHR, respectively) and the NPSH margins for the worst case for each pump type. The pumps are identified by number, and only the recirculation pumps are included in Table 3.6.2.2.1-1 below. The results show that in the recirculation mode of decay heat removal, the design basis (no single failure assumed) NPSH margin for the HPSI pumps is a minimum of 5.02 ft of water, while for the CS pumps the margin is a minimum of 13.97 ft. The most limiting pump from the point of view of NPSH is the HPSI pump P018A.

Reference [76] also presents results for the assumed case involving a single active failure, in which an LPSI pump is included in the pump lineup. Table 3.6.2.2.1-1 below shows that, for this case, the LPSI pump NPSH margin is 0.94 ft of water, the minimum value based on all the calculation cases. In addition, the HPSI pump NPSH margin is reduced to 2.65 ft. The licensee concluded that even in the event of such a single failure on one pump train, a second fully functional train, taking suction from an independent sump, is still available without a LPSI pump operating. The single failure assumption case (failure of LPSI to stop) was included in the analysis for conservatism [78], and shows that even for this high flow case the HPSI pump in the faulted train continues to have adequate, if small, NPSH available.

The assumptions, modeling and results presented in Reference [76] are discussed in further detail in the following sections.

The licensee has performed NPSH calculations for a range of sump water temperatures of 110°F, 160°F and 208°F, with the rationale that the pressure losses across the sump screen (with and without debris) are a function of water temperature, and that 110°F is a conservative estimate of the coldest fluid temperature that would occur at the end of a postulated LOCA event. The 208°F fluid temperature corresponds to the saturation temperature corresponding to the initial pressure in containment for LOCA accident analysis. The assumptions, model and calculations for these cases are presented in [77].

Table 3.6.2.2.1-1: Calculated NPSHA and NPSH Margins[1] for 270°F Sump Water Temperature (Delta P across any future debris screen is not considered.)

Pump Function	NPSHR (ft)	RECIRC Mode Design Basis		RECIRC Mode Single Failure	
		NPSHA (ft)	Margin (ft)	NPSHA (ft)	Margin (ft)
HPSI	23	28.02 (Pump P018A)	5.02 (Pump P018A)	25.65	2.65
LPSI	23	-	-	23.94	0.94
CS	14[2]	27.97 (Pump P013)	13.97 (Pump P013)	25.52	11.52

1 Table entries are from [2]. Calc. M-0012-01D. Table 1, Sheet 6.
2 For CS pump P012 only. NPSHR-13' is for the rest of CS pumps.

The limiting suction heads in this series of calculations are computed on the basis of two physical models. The first is based upon the difference between the water and saturation pressures at the pump suction. The second model is based on the release of dissolved air as the water, assumed saturated with air at containment pressure, is transported from the sump to the pump suction, with an assumed limit of 2% volume fraction of air at the pump suction. The margin to the required NPSH based on gas release is termed “Off Gas Pressure Margin.”

The results of the temperature sensitivity of NPSH margin is shown in Table 3.6.2.2.1-2 below. For each fluid temperature the NPSH margins are presented based upon vapor pressure and upon gas release. The minimum of the two is presented in the last column as “NPSH Margin.” The results show that the margins are substantial at low temperature, and are limited by gas release. At higher temperature, the margins are controlled by the vapor pressure, but at 208°F the margin is greater than that computed at 270°F.

Table 3.6.2.2.1-2: Calculated NPSH Margins[1] as Function of Sump Water Temperature (Delta P across any future debris screen is not considered)

Pump	Sump Fluid Temp (°F)	NPSH Vapor Pressure Margin (ft)	NPSH Off Gas Pressure Margin (ft)	NPSH Margin (ft)
CS P-012	110	43.08	31.97	-
HPSI P-018	110	34.38	**23.27**	**23.27**
CS P-012	160	35.37	32.97	-
HPSI P-018	160	26.58	**24.18**	**24.18**
CS P-012	208	14.53	33.01	-
HPSI P-018	208	**5.68**[2]	24.15	**5.68**

1 Ref. [3]. Calc. M-0012-01D, Table, Page 6.
2 Compare with 5.02 ft at 270°F.

The assumptions, modeling and results presented in [77] are discussed in further detail in the following sections.

3.6.2.2.2 Consideration of Possible ECCS Modes of Operation

The licensee ECCS design consists of two redundant trains of ESF pumps that take suction from two emergency containment sumps during the recirculation mode of heat removal. The configuration that is used for the licensee's design basis cases consists of 1 HPSI pump and 1 Containment Spray pump taking suction during recirculation from the Containment Emergency Sump.

The licensee provided documentation to show that the two sumps and the two trains are redundant [San Onofre 2&3 UFSAR, Section 7.3.1.1.1]. Each train consists of a HPSI, a LPSI, and a CS pump. A third HPSI (swing) pump exists that can be switched to one or the other train in the event of maintenance of one HPSI pump. The licensee provided documentation to show that the "...third [HPSI] pump is an installed spare and has its power isolated electrically by the use of a Kirk Key Interlock" [San Onofre 2&3 UFSAR, Section 6.3.2.5.2]. In the original NPSH Calc [78], it was assumed that operator error resulted in alignment of the swing HPSI pump along with one of the other HPSI pumps. In the current NPSH Calc [76] the licensee assumes that the Kirk Key Interlock and associated procedures mitigate the potential for the operator error, and the scenario was judged by the licensee to be improbable and was not included to support the current analysis. In [78] the licensee provided a conservative estimate of the NPSH margin with two HPSI pumps in a train in the original NPSH calculation, with a resulting NPSH margin for the 270°F sump water case of 3.50 ft compared with 5.02 ft for the single HPSI pump case in [76] - but again, this information was not included to support the current analysis.

The licensee assumed, for its base case calculations, that both LPSI pumps are stopped in response to a Recirculation Activation Signal (RAS) signal during the switchover from safety injection mode to the recirculation cooling mode. The licensee also considered a single active failure case in which a LPSI pump in one of the trains fails to stop (LPSI pump breaker fails to open) in response to the RAS. This assumption leads to a small LPSI pump NPSH margin (0.94 ft) and a reduced HPSI pump NPSH margin for one train, resulting from increased pressure losses due to the addition of the relatively large flow rate of a LPSI pump. However, these reduced NPSH margin values remain adequate to support proper pump performance. In addition, even if the LPSI pump fails to stop in one train, a second train is assumed to be available with its LPSI pump stopped, and the HPSI and CS pumps in this redundant train would operate with their full base case NPSH margin values.

Because of the small NPSH margin (0.94 feet) associated with the LPSI pump failure-to-stop single active failure case, the NRC questioned the potential for failure to stop a LPSI pump in both trains from a single failure. The licensee provided documentation to demonstrate that the two trains are redundant, and that the RAS signal would only fail to stop the two LPSI pumps in the event of three simultaneous failures of the 2-out-of-4 logic RWST level signals [San Onofre 2&3 UFSAR, Section 7.3.1.1.1]. The failure to stop two LPSI pumps is thereby judged to be highly unlikely and the staff determined that it need not be considered. The licensee's ECCS pump configuration consisting of one HPSI pump and one CS pump for the purpose of NPSH margins calculation is acceptable because (1) the interlock system mitigates the potential for operation of the HPSI "swing" pump, and (2) because the failure of one LPSI pump to turn off upon initiation of recirculation is considered the worst case single failure, and also leaves the second train fully functional with the LPSI pump off.

3.6.2.2.3 Review of the Applied NPSH Margin Methodology

The standard definition of NPSH margin, the difference between the available (NPSHA) and required (NPSHR), was applied. The NPSHR is the required difference between the fluid pressure at the eye of the pump impeller and the limiting pressure of the fluid at its assumed temperature. NPSHR is data provided by the pump manufacturer. The limiting pressure is either the fluid vapor pressure at the assumed temperature, or the pressure at which the volume fraction of released dissolved air is 2%. Both of these physical models are considered in references [76,77].

The basic NPSH margins methodology is described in [76]. NPSHA was computed on the basis of a single-phase fluid hydraulic model that was constructed using plant isometrics and piping diagrams (examples of which were discussed at the onsite audit), and that was encoded into Excel spreadsheets. For each case considered, a schematic diagram was provided that simplifies the plant drawings. The hydraulic model consists of a collection of pipe segments, elbows, valves, tees, pumps and the sump. Pump flow rates were presented, and the flow resistance factors were presented for the pipe segments and components using standard single phase hydraulics methodology. Hydraulic resistance values were obtained from Crane ("Flow of Fluids," Technical Paper No. 410). Reference [76] does not state the assumption regarding pipe condition friction factors (smooth vs. rough). However, the friction factors used in the head loss calculations are typical of commercial (relatively rough) piping.

Given the assumed flowrates and fluid density, the water level in containment and component elevations, the pressure drops along each segment and across each component were computed. The fluid pressure drop from the water level to each pump was also computed. NPSHA was computed for each pump. The (no screen or debris) NPSH margin was computed in feet of liquid head as the difference between available and required NPSH, as described above.

A question was raised by the auditors at the on-site audit concerning the consistency of the assumed sump water temperature when calculating the NPSH available with the temperature associated with the NPSHR value provided by the pump manufacturer. The issue was not resolved at the time of the audit. The standard analysis procedure is found in the Centrifugal Pumps ANSI Standard [82]. The NPSH available is computed based upon the system operating temperature at accident conditions. The NPSH required (NPSHR) is provided by the pump manufacturer, and is usually presented for room temperature conditions. The ANSI standard provides instructions for a reduction in the NPSHR for high-temperature water. NRC, however, does not allow this temperature correction to maintain a significant amount of conservatism in view of the NPSH calculational uncertainties in areas such as quantities and characteristics of the debris laden fluid, pump flow rates, and temperature changes during the post-LOCA period [4]. In addition, the ANSI Standard itself recommends either making no correction or using no more than 50% of the NPSHR correction for temperature. The licensee calculation procedure, which does not use the NPSHR correction for temperature, is therefore judged to be conservative and consistent both with the ANSI standard and the NRC guidance.

In the NPSH calculations for the 270°F sump temperature presented in [76], the licensee makes the conservative assumption that the containment pressure is equal to the saturation pressure corresponding to the sump water temperature. Credit is not taken for the containment pressure above the saturation pressure of the sump liquid, thus underestimating the expected containment pressure when computing NPSH. This satisfies the guidance of [4].

For the cases of the lower sump temperatures of [77], the licensee conservatively assumes that the containment pressure is below the minimum operating containment pressure, and credit is not taken for any gas pressure above the initial pressure in containment prior to the LOCA. This satisfies the guidance of [4]. The methodology for computing the effect of sump temperature on NPSH margins uses the results of [76], and applies derived temperature corrections to the spreadsheet results of [76]. Case 10 from [76] is used as the baseline calculation, since the results of Case 10 provide the largest piping and component head losses. It is noted by the staff that the vapor pressures at the lower temperatures are below the assumed containment pressure, and the pressure difference provides added NPSH margin above that due to fluid head alone.

The licensee's NPSH margins methodology follows standard engineering approaches [see for example reference 82], and principle assumptions regarding conservative treatment of containment pressure are considered reasonable. The methodology, therefore, is acceptable.

3.6.2.2.3.1 Consideration of Main Parameters Influencing the Available NPSH Margin

The main parameters that influence the available NPSH margins are: ECCS configuration, water level in containment, sump water temperature, pump flow rates, containment pressure, NPSHR and hot fluid correction factor for NPSHR, and decay heat.

ECCS Configuration

The ECCS configuration is discussed above in Section 3.6.2.1. The presence of a second running HPSI pump as a result of operator error involving use of the Kirk Key Interlock would lead to a reduction in NPSHA of approximately 1.5 ft of liquid. The analysis of this scenario is presented as a case that had been previously analyzed, but was not included to support the licensee's new analyses. This operator error was viewed by the licensee as being of low probability and it was not considered in establishing NPSH margins.

The single active failure to stop an LPSI pump in one ECCS train during switchover to recirculation leads to a reduction of the LPSI pump NPSHA of approximately 4.1 ft of liquid, and to a reduction of the HPSI pump NPSHA of 2.37 ft of liquid, as a result of losses resulting from the high capacity of the LPSI pumps. However, the second ECCS train is available with no reduction of NPSHA, and common multiple failures to stop LPSI on both trains are very improbable. Also, the licensee base case configuration for NPSH margins calculations of one HPSI pump and one containment spray (CS) pump is considered to be reasonable as discussed in Section 3.6.2.2.

Minimum Water Level

The minimum water level in containment during recirculation was calculated to be the plant elevation of 19.08 feet (1.58 ft above containment floor as specified in the SONGS RWST Technical Specifications document [79]). High water level increases the NPSHA as a result of the additional available liquid head. Reference [4], Section 1.3.1.6, provides guidance that "...the calculation of available NPSH should minimize the static head of water above the pump suction..." The SONGS RWST Technical Specification document [79] conservatively accounts for the sources of water on the containment floor and for the water holdup mechanisms. This document was reviewed and calculations were spot-checked. The documentation is clear and complete, the calculation models are physically reasonable, and the spot-checked calculations are correct. The use of the small LOCA minimum water level for all cases is conservative because it used the minimum amount of water transferred to the containment floor. For these reasons, the value utilized by the Licensee for the minimum water height in containment is considered to be acceptable.

Sump Water Temperature

NPSHA calculations were performed for sump water temperatures of 270°F in [76], 110°F, 160°F and 208°F in [77]. Limiting conditions at the pumps were calculated based upon vapor pressure considerations, and also based on dissolved gas release. The most limiting condition with respect to NPSH margin was shown by the licensee to occur at a sump water temperature of 270°F.

The licensee adopted the maximum containment sump temperature during recirculation as being 270°F based upon LOCA calculations presented in [80]. These LOCA transient calculations were run for inclusion in the UFSAR, and predict a peak sump temperature of 264°F. The licensee stated that 270°F was selected as a conservative estimate based upon the transient calculation result of 264°F.

The NPSHA calculations at lower temperatures were bounded at the high end by 208°F, the saturation temperature at the assumed conservative (with respect to NPSH margin) initial containment pressure of 13.8 psia, and at the low end by 110°F, an estimate of the sump water temperature 116 days post-LOCA [77]. The 160°F temperature was taken as intermediate between the limits.

The staff considered it appropriate that the licensee performed NPSHA calculations for a bounding range of sump water temperatures, including intermediate temperature values.

Pump Capacities

NPSHA calculations are presented for HPSI, LPSI and CS pumps, based upon the hydraulics model of the system and the pump capacities. The larger the pump flow rates, the larger the line hydraulic losses, and the smaller the computed values of the NPSHA. The pump capacities presented in [76] are the pump run-out flowrates. The same capacities are quoted in [78], and are presented in the plant UFSAR (Section 6.2.1.1.2.4). Since the run-out flowrates are the maximum operating flowrates for the pumps, they are considered acceptable assumptions for the calculations.

Containment Pressure

The NPSHA calculations were performed with assumptions following the guidance in [4] for minimizing the effect of containment over-pressure on the NPSH calculation results. For the minimum NPSH margin case of 270°F sump water temperature, it was conservatively assumed, following the guidance, that the containment pressure is equal to the vapor pressure of the sump water, thereby eliminating containment air pressure as a driving force that would increase the NPSHA. Table 2.1.1-1 of [80] presents the peak pressure in containment as 45.8 psig (60.5 psia), when the sump temperature is 264°F. The vapor pressure corresponding to 264°F would be approximately 38 psia. This pressure difference of 22 psia, which represents the partial pressure of air, is conservatively neglected in the NPSHA and margins calculation for this case.

For the low temperature cases, the containment pressure was conservatively assumed to be 13.8 psia, below the minimum operating containment pressure of 14.4 psia. No credit was given for elevated containment pressure resulting from the LOCA. This follows the guidance of [4].

NPSHR and Hot Fluid Correction

The room-temperature pump NPSHR specifications of the HPSI, LPSI and CS pumps are presented in [76] as conservative quantities, and are found in the plant UFSAR (Section 6.2.1.1.2.4). Reference [4], Section 1.3.1.5, provides guidance that "...the hot channel (more commonly known as "hot fluid") correction factor specified in American National Standard for Centrifugal Pumps for Nomenclature, Definitions, Application and Operation, ANSI/HI

1.1-1.5-1994, should not be used in determining the margin between the available and required NPSH ....” Neglecting the hot fluid factor is conservative, and it was appropriately neglected in the licensee margins calculations.

Decay Heat

Reference [4] provides guidance that “The decay and residual heat produced following accident initiation should be included in the determination of the water temperature. The uncertainty in the determination of the decay heat should be included in this calculation...” Reference [80], Section 4.9, indicates that this guidance was adhered to in the NPSHA calculations.

3.6.2.2.3.2 NPSH Margin Safety Relevance

The NPSH margins methodology used by the licensee for the NPSH margins calculations is a standard single-phase hydraulics methodology and is acceptable. The licensee’s base case for the NPSH calculation considers an ECCS pump lineup of one HPSI pump and one CS pump. This selection is judged reasonable because (1) the third available (swing) HPSI pump is used only for maintenance purposes and is normally interlocked using a “Kirk Key” interlock (so that only one HPSI pump per train is normally available), and (2) a LPSI pump that has failed to stop in one of the two trains at recirculation actuation is considered to be the “worst-case” single failure. For this case, one HPSI pump, one LPSI pump, and one CS pump are included in the NPSH analysis. While this case leads to a significantly reduced NPSH margin in the faulted train relative to the base case, SONGS concluded that the second train would still be available with its LPSI pump stopped, with the unfaulted train’s NPSH margin computed on the basis of one HPSI and one CS pump operational. This argument is acceptable because the ECCS system consists of two independent redundant trains, and a single failure only reduces the performance of the faulted train, leaving the second train to perform normally.

The values of the NPSH calculation input parameters are documented, follow the guidance provided by NRC for NPSH margins calculations [4], and are conservative. For these reasons they are deemed acceptable. As a result of this review, the computed NPSH margins are considered to be conservative.

3.7 Coatings Evaluation

3.7.1 Coatings Zone of Influence

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

As stated in the NRC SE, for protective coatings, the staff position is that the licensees should use a coatings ZOI spherical equivalent determined by plant-specific analysis, based on experimental data that correlate to plant materials over the range of temperatures and pressures of concern, or 10 L/D. The NRC staff has not reviewed WCAP-16568-P to verify the use of a 5L/D coatings ZOI at SONGS. NRC staff's review of the WCAP-16568-P jet impingement test data for applicability to the specific conditions and coating types at SONGS was therefore unable to be conducted. Resolution of the coatings ZOI issue is Open Item 10. The licensees final supplemental response should justify coatings ZOIs chosen, considering results of NRC staff's review of WCAP-16568-P.

3.7.2 Coatings Debris Characteristics

As discussed in section 3.7.1 of this report, the licensee applied a ZOI of 5 L/D, in which all coatings were assumed to fail as 10 μm particulate. For coating debris outside of the ZOI, the licensee assumes that all of the unqualified coatings will fail as 10 μm particulate.

The NRC staff's SE addresses two distinct scenarios for formation of a fiber bed on the sump screen surface. For a thin bed case, the SE states that all coatings debris should be treated as 10 μm particulate and assumes 100% transport to the sump screen. For the case in which no thin bed is formed, the staff's SE states that the coating debris should be sized based on plant-specific analyses for debris generated from within the ZOI and from outside the ZOI, or that a default chip size equivalent to the area of the sump screen openings should be used. Because the plant specific debris loading for SONGS results in a fiber bed across the strainer surface, the staff agrees with the treatment of all coatings debris as 10 μm particulate.

During interaction with PWR licensees for resolution of GSI-191, the NRC staff has questioned the current industry method of assessing qualified coatings. The staff has asked licensees to either prove that their assessment techniques can accurately identify the amount of degraded qualified coatings in containment, or assume all of the coatings fail. The licensee assumes that all of qualified coatings outside of the ZOI will remain adhered under DBA conditions. The licensee stated that they will rely on the results of an ongoing test program conducted by EPRI (Electric Power Research Institute) and the Nuclear Utilities Coatings Council (NUCC) to validate their assessment techniques at SONGS. The referenced testing will subject visually sound and visually degraded coatings to physical testing (i.e. adhesion tests) in an attempt to show that visual assessments are capable of identifying coatings that would not remain adhered during a DBA. This testing has not been performed and therefore has not been reviewed by the NRC staff. Assessment of qualified coatings will remain an open item pending industry validation testing and NRC staff review of the results. The licensee's final supplemental response to GL 2004-02 should include an evaluation of the applicability of the EPRI/NUCC coatings test data and provide the basis for the licensee's treatment of qualified coatings in its evaluation of sump performance; this issue is designated as **Open Item 23.**

4.0 DESIGN AND ADMINISTRATIVE CONTROLS

4.1 Debris Source Term

Section 5.1 of the GR and SE discuss five categories of debris design and operational refinements which could affect the debris source term through the SONGS operational period:

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

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

The licensee addressed these candidate refinements as follows:

1. Housekeeping and foreign material exclusion programs

   SONGS Procedure SO23-XV-23.1.1 “Containment Cleanliness/Loose Debris Inspection” [63] currently provides instructions to inspect the reactor building following a maintenance outage. This procedure provides instructions to ensure no loose debris is present which can be carried to the containment sump, ensure post LOCA recirculating water flow paths are open and unobstructed, and addresses other containment cleanliness items. Inspections are performed at the end of each outage, prior to plant restart.

2. Change-out of Insulation

   The licensee has committed to removing some Microtherm insulation that would be included inside the ZOI for some large breaks. This insulation will be replaced by RMI. Removal of this portion of the Microtherm insulation will be done during U3C14 and U2C15 refueling outages prior to the December 31, 2007 GL 2004-02 corrective action completion date. The mineral wool that will remain in service at SONGS will be replaced with RMI type insulation in the near future as part of the steam generator replacements planned for SONGS units 2 and 3 in 2009 and 2010, respectively. Since this is after the date required for corrective actions in GL 2004-02, replacement of the mineral wool insulation is not credited in the sump strainer analysis.

   Guidance contained in the Design Criteria Requirements checklist 26-182 and the associated Engineering Change Package guidance document 26-182-1 [64] have been revised to monitor changes to insulation systems used within the containment. These changes will document the evaluation and monitoring of insulation types and amounts to verify the containment ECCS suction strainers will continue to be capable of performing their intended function.

3. Modify Existing Insulation

   Modification of existing insulation was not proposed in the detailed licensee evaluations.

4. Modify Other Equipment or Systems

   Modification of other equipment or systems was not proposed in the detailed licensee evaluations.

5. Modify or Improve Coatings Program

   See Section 3.8 of this report.

4.2 Screen Modification Package

Section 5.3 of the approved 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 SE [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 design and performance information regarding the proposed SONGS sump modifications. The information provided is documented in Engineering Change Package (ECP) #040301974-11 (draft Rev. 00 with partial approval signatures dated 7/17/2006) "Modify the Containment Emergency Sump S32426CSUMP in accordance with Generic Letter 2004-02" [65]. The objective of the SONGS reactor building sump design changes is to improve long-term sump recirculation capabilities by addressing post-LOCA debris. The design is intended to partially address the above performance objectives. Certain aspects of attaining those objectives are not yet addressed (e.g., chemical effects). Some other aspects are discussed in other sections of this audit report.

The planned modifications include several physical changes inside the containment building. The steel mesh on bottom portion of all gates located at bioshield pathways on elevation 17 will be removed, and the grating trash racks surrounding each containment emergency sump (CES) pit enclosure will be removed and replaced with vertical steel rods 10" on center. The licensee expects the gate modifications to reduce potential debris blockage at elevation 17 bioshield pathways, and the modified trash racks to allow sufficient fluid flow to the containment emergency sump (CES) screens. The CES level (float) instruments will be relocated to the opposite side of each sump train to avoid interfering with the screen assembly, and will be surrounded with a screen cage to prevent debris from affecting the float level capability. The existing cover plate above the sump will be cut to facilitate relocation of the level instruments. The two fine mesh screens surrounding each CES pit enclosure will be removed and replaced with a strainer screen assembly (SA). The SA, to be located inside the concrete CES pit, will contain multi-tube (top hat) modules fabricated from perforated plate and mounted in a vertical orientation. The top-hats are attached to rectangular flow plenums which are anchored to the sump concrete floor. The flow plenums allow only filtered fluid to reach a box collector at the safety injection pipe intake. The SA maximizes the screen surface area, improves handling capability for large debris and small particulates, and ultimately is expected to reduce head loss across the increased screen surface area.

The ECP discusses two incomplete items associated with the guidance of the SE. First, the ECP states that confirmatory testing for SONGS-specific debris types (e.g., microtherm insulation) and vortex formation will be documented in a final test report. Second, the impact of chemical effects on the final screen assembly head loss will be compared to the assumed 25% bump-up factor in the licensee's NUREG/CR-6224 [50] correlation calculation ALION–REP-

SONGS-2933-004 [15] (see listing of calculations immediately below). The ECP further states that there is a third incomplete item related to the impact of the screen assembly on the passive heat sink calculation C-257-01.06.01 and the corresponding UFSAR Table 6.2-13, page 6 of 18.

The safety evaluation for the ECP notes that the containment emergency sump screens are designed to remain functional during post-LOCA containment recirculation. The primary safety concerns for the screens are the potentially adverse blockage effects that can result from LOCA-generated debris. The engineering evaluations intended to ensure the containment emergency sumps will not suffer from excessive post-LOCA screen blockage and that other debris-related issues are addressed are composed of the following separate calculations:

- Characterization of events
- Debris generation
- Debris transport
- Debris accumulation and head loss
- Downstream effects - vessel blockage
- Downstream effects - heat exchanger, nozzles and pump plugging and wear
- Downstream effects - ECCS and CS valve plugging and wear
- Downstream effects - debris ingestion evaluation
- Downstream effects - fuel evaluation

The NRC staff has reviewed these calculations and documented those reviews in other sections of this audit report.

The ECP describes the design criteria and standards for the SA, including:

- Structural steel standards
- Welding standards
- Input parameters (design temperature of 300F, sump ambient temperature post-LOCA of 266F, static pressure exerted by water on the sump screens of 7 psi based on the containment flood level of 19.08 feet)
- Seismic response curves and damping values
- Interface requirements
- Material requirements
- Plant layout and arrangement requirements:
- Quality class and seismic category [the containment emergency sump, liner plate, trash rack, grating cage, top-hat plenum, and top-hat screens are all quality class II and seismic category I (Q-list section 6.3)]
- Electrical requirements
- Instrumentation within the scope of Regulatory Guide 1.97, “Criteria for Accident Monitoring Instrumentation for Nuclear Power Plants”

The ECP also describes operating experience used in development of the design. Operating experience identified includes the need to enforce detailed debris removal and inspection after installation of strainer assemblies in the containment emergency sump (Brunswick 1 - 1993) and discovery that the minimum gap in the centrifugal charging pump cold leg injection throttle valves was less than the fine mesh size in the containment recirculation sump screens (Comanche Peak - 1997). Another item noted was improper application of a correlation that was used to derive head loss across a screen that was assessed to be partially fouled with debris, and incorrect application of the results to a partially submerged screen that would be susceptible to air intrusion (Point Beach - 2005). The ECP also notes that the screen assembly supplier, Enercon Services, provided to the licensee an Installation Lessons-Learned report for Enercon's project at Indian Point 2.

The ECP also describes acceptance criteria for the new installation. These are:

- At a maximum flow rate of 3500 gpm, the tested head loss is less than the required head loss limits (based on net positive suction head requirements of the ECCS pumps) at each sump water temperature. This test shall incorporate the Appendix A debris loadings, impact of filling the interstitial volume (spaces between the vertically-oriented cylindrical strainers bounded by the sump walls) of the screen assembly with this debris loading, and the contribution of the head loss because of chemical effects within the containment. This test shall validate a debris capture efficiency of at least 99.5% of the fine fibrous debris.

- At a maximum flow rate of 3500 gpm and a containment flood level of 19.08 feet, the SONGS-specific SA scheme (design) will not be susceptible to vortex formation. Additionally, testing shall establish the expected elevation above the SA scheme at which vortex formation is expected to occur (the minimum depth between the containment flood level and the top of the SA scheme).

- All aspects of chemical effects testing for SONGS-specific loadings shall comply with the recommendations of Westinghouse Owners Group (WOG) document PA-SEE-0275, "Method for Evaluating Post-Accident Chemical Effects in Containment Sump Fluids" [119]. Supplier [Enercon] shall be responsible for reviewing the WOG testing results and determining if sufficient WOG testing was performed. Additional bench testing may be performed for certain SONGS specific materials to encompass all potential reactants. Supplier shall develop a chemical effects bump-up factor to be applied to a screen head loss determined independent of chemical effects. The supplier is responsible for the plan, procedure and performance of the SA mock-up testing including the recording.

Staff Evaluation

The NRC staff reviewed the ECP to assess the overall SONGS sump blockage resolution approach. The NRC staff observed that the licensee's overall screen modification approach appears reasonable. However, because the adequacy of the new screen design is highly dependent on the acceptability of the various analyses that establish the screen design and its required performance (i.e., debris generation, debris transport, debris accumulation and head loss), further design changes could be necessary as the licensee finalizes the various ongoing aspects of the sump performance evaluation. These items are discussed 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 in-vessel downstream effects analysis (awaiting Westinghouse methodology report). The analyses of these individual aspects of the sump evaluation will form the technical basis for confirming adequacy of the new sump screen design and other proposed modifications to address GL 2004-02.

The NRC staff's evaluations of specific aspects of the ECP and associated documents related to the various sub-issues of GSI-191 are found elsewhere in this report.

10 CFR 50.59 Screening Evaluation

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

1. The change causes a large increase in sump screen surface mechanical components.

2. Structural and seismic calculations have been performed and have shown satisfactory results.

3. Screen assembly hydraulic calculations have been performed and show no vortexing or air ingestion at minimum recirculation containment water level.

4. Changes in head loss as sump temperature decreases have been evaluated and found to not adversely affect the containment emergency sump design function.

5. Revised pipe support loading for the 24" safety injection piping does not adversely impact the design function of the piping system and the concrete common wall that supports the piping and struts from the screen assembly.

The evaluation concludes that the screen assembly replacement does not adversely affect the sump design function.

The evaluation notes that the 1:1 scale model testing of the sump screen described in the Updated Final Safety Analysis Report (UFSAR) was not performed because the new configuration is not susceptible to air ingestion or vortexing.

Staff Evaluation

The NRC staff reviewed the licensee’s 10 CFR 50.59 screening evaluation of its sump modification. The staff noted that the 10 CFR 50.59 evaluation did not explicitly address the compliance of the new screen with the existing licensing basis (50% screen blockage). It is unlikely that the licensee would have a new, mechanistic analysis and corresponding licensing basis in place by the end of the fall 2006 outage for SONGS Unit 3. Licensee staff stated that they intended to start up SONGS 3 based on the new strainer's compliance with the existing licensing basis. However, the licensee has not demonstrate that the new design complies with the existing licensing basis to the extent that it functions satisfactorily at 50% screen blockage, and this is designated as **Open Item 11**.

The evaluation also states that "the vertical bar trash racks surrounding the [sic] prevents large debris from reaching the screen assembly, see UFSAR Section 6.2.2.1.2.5." The referenced UFSAR section states: "Sump intakes are protected by an outer trash rack and two inner screens..." The previously installed trash racks consisted of a mesh (similar to floor grating), while the new trash racks will be vertical bars mounted 10" on center with no mesh between the bars. The new trash racks clearly will not impede passage of "large" debris (defined in NEI 04-07 as debris larger than 6") to the same extent as do the existing trash racks. The 10 CFR 50.59 evaluation did not address this reduction in protection for the sump screen. The licensee had not documented an evaluation of this change and the ability of the new screens to continue to function and withstand damage from relatively large debris that bypasses the new trash racks, and this is designated as **Open Item 12**.

The NRC staff found that, though the evaluation does not so state, the licensee has performed scale testing and validated that vortexing does not occur in the new sump strainer configuration under conditions expected in the plant post-LOCA. Reference is made to this testing in the ECP though not in the 10 CFR 50.59 evaluation.

Environmental Qualification (EQ)

In the ECP the licensee screened the sump change for equipment qualification (EQ) impacts. The sump level transmitters are within the scope of the EQ program. A licensee staff member performed an EQ review and made several comments.

Staff Evaluation

The NRC staff reviewed the licensee's comments on EQ and found them to be indicative of a thorough review. However, the NRC staff was unable to locate a direct conclusion in the ECP or related documentation that the movement of the transmitter as part of the ECP causes no concern regarding the changes in the environment to which the transmitter is subjected. The licensee had not documented in its engineering change package a direct conclusion regarding transmitter functionality in its new location, and this omission is designated as **Open Item 13**.

Maintenance

SONGS Procedure SO23-I-2.53, "Containment Emergency Sump Inspection Surveillance," Rev. 7 dated March 16, 2005 [120] provides requirements for periodic inspection of the emergency sumps. This procedure satisfies Technical Specifications (TS) surveillance requirements 3.5.2.10 and 3.5.3.1.

Staff Evaluation

The NRC staff reviewed the applicable TS requirements. The required tests, conducted on a 24-month frequency, call for verification by visual inspection that each ECCS train containment sump suction inlet is not restricted by debris and that the suction inlet trash racks and screens show no evidence of structural distress or abnormal corrosion.

Procedure SO23-I-2.53 implements these requirements by requiring the following checks:

1. No restrictions or debris at the ECCS suction inlets

2. No loose debris in the sump interior

3. No loose debris in and around accessible areas of the top cover

4. No debris, structural distress, or abnormal corrosion on trash racks and screens

5. No missing screens or breaks in screen integrity

6. No missing or loose fasteners

7. Maximum penetrations or gaps 0.090"

In conjunction with the ECP, the licensee has an open Site Program/Procedure Impact (SPI) Analysis #040301974-56 [121] that calls for review of Repetitive Maintenance Orders (RMOs). The NRC staff verified that these in turn reference Procedure SO23-I-2.53.

The licensee staff stated that the SPI process would result in revision of SO23-I-2.53 before turnover of the ECP. Such revision is needed because the much larger and more complex SA configuration will make access to the interior of the sump challenging. The new SA configuration will create the need for specific guidance involving removal of the top of a "top-hat" strainer that will be required to perform an adequate inspection of the sump.

5.0 ADDITIONAL DESIGN CONSIDERATIONS

5.1 Sump Structural Analysis

5.1.1 Flow Plenum Structural Qualification

Dynamic and static structural analysis were performed by the licensee to structurally qualify the Containment Emergency Sump Strainer (CESS) flow plenum. The CESS flow plenum was qualified for loading associated with dead weight, seismic (including hydrodynamic mass) and the differential pressures due to head loss, all in accordance with the AISC Manual of Steel Construction 9th Ed. [34], Regulatory Guide 1.92 [35], and ASME Section III, Appendix I, 1989 Ed [36].

The criteria for qualification of the CESS flow plenum, Calculation No. SCSN001-CALC-002 [39], are contained in Specification S023-205-07 Rev. 1 "Containment Emergency Sump Replacement Screen"[38]. The methodology and results of these calculations were based on the following assumptions by the licensee:

- Per the SONGS design basis document for LOCA, containment maximum temperature is 270 °F. Conservatively for additional margin, the containment strainer top hat supporting structure/flow plenum was designed for 300 °F.

- The effect due to buoyancy has been conservatively neglected since it is small and in opposite direction of the dead weight.

- A conservative value of 10 psid differential pressure loading corresponding to a fully debris loaded strainer is used in the supporting structure design. Structural steel and anchorage were qualified for a combination of dead load, seismic load (SSE) and a differential pressure of 10 psid, using normal allowable stresses.

- ASME Section III [36] was used to evaluate the specific material properties at elevated temperatures. Studs and bolts were qualified using ASME Section III Div. 1 [36].

- Stainless steel weld filler metal was assumed to have a minimum tensile strength of 70 ksi.

- A 5% damping value was conservatively used for the Design Basis Earthquake analysis.

All of these assumptions were evaluated and verified by the NRC staff to determine whether they were based on sound engineering principles and practices.

Staff Evaluation

The basic CESS flow plenum structural analysis methodology used by the licensee was reviewed by the NRC staff to evaluate the adequacy of the calculation for the Flow Plenum Structural Qualification. The NRC evaluation of each plenum structure was based on criteria given by SRP Section 3.8.4, "Other Seismic Category I Structures" [37]. The licensee used structural analysis software to find maximum stress and deflection values that were supplemented by hand calculations using applicable design codes called out in the SRP. Each strainer supporting structure was modeled using GTSTRUL. This analysis was based on the licensee's assumptions previously mentioned. All assumptions used in this analysis by the licensee were reasonably conservative and referenced codes and standards adopted by the NRC.

In general, each analysis (computer and hand calculation) was conducted using seven different load combinations of dead weight, differential pressure, and seismic loads (including hydrodynamic mass). These combinations were based on Design Basis Earthquake (DBE) and Loss of Coolant Accident (LOCA) conditions. The maximum stress values for each plenum were found to be within allowable limits. The location and magnitude of maximum stress values correspond to those found through hand calculations. Each anchor bolted connection was designed for shear and tension interaction, which were also within allowable limits.

The GTSTRUDL calculations submitted by licensee to the NRC staff adequately describe and reflect the as-built geometry of the flow plenum support system. Each plenum was modeled as a structural steel tube section which conservatively yields maximum stresses well below those allowed by design criteria contained in Specification S023-205-07 Rev. 1[38]. The NRC staff has concluded, based on the considerations discussed above, that the concepts and procedures used in this analysis are acceptable.

5.1.2 Top Hat Assembly Qualification

Structurally, each cylindrical top hat assembly is rigidly connected to the flow plenums and is basically a free-standing hollow post free to rotate and translate in any direction at the opposite end from the rigid connection. Each top hat assembly contains an inner and outer perforated plate strainer element used to keep the ECCS pumps free of debris. Each top hat assembly also includes a wire mesh filter downstream of the perforated strainer elements to catch fiber bypassing the strainer elements. The top hats were checked using the same assumptions and design criteria as the flow plenums. Hand calculations and GTSTRUL software was used to qualify the top hat assemblies. The Top Hat Assembly Qualification calculations (Calc. No. SCSN001-CALC-001) [40] submitted by the licensee were reviewed by the NRC staff.

Staff Evaluation

The Top Hat structure was examined by the licensee using a dynamic analysis and damping values given in Regulatory Guide 1.61 [41]. This analysis provides frequency, modal and response spectrum results considering the structures hydrodynamic mass for all relevant loading combinations. A written and graphical description of the GTSTRUL computer model was submitted by the licensee. The input data provided by the licensee accurately mimics the design geometry of the unit. The output results of each element of GTSTRUL model are in good agreement with the hand calculation provided by the licensee. The analysis results are compared to the allowable stresses in tabular form. These results clearly show all stress values are within allowable limits. Therefore, the staff concludes that the Top Hat structure is qualified to handle all expected LOCA hydrodynamic loads.

5.1.3 Analysis of Instrument Support, Temporary Strainer, and Vent Strainer

The instrument support, temporary strainer and vent strainer of the CESS system were qualified in calculation SCSN001-CALC-005 [43] using the same assumptions mentioned in section 1.0 with the exception of differential pressure being neglected.

5.1.3.1 Instrument Support

The level instrument support is made up of 3x3x1/4” tube steel and various size plates. The tube steel provides two points of support for the instrument shell. The shell around the level instrument is constructed of perforated stainless steel plates supported by ¼” thick base plates. The perforated plates are welded to 3/16” x 3” plate clamps. The clamps are connected via vertical plates which are bolted to each other with 8 – 3/8” diameter bolts. These structural components were qualified using a combination of hand calculations and the GTSTRUDL computer modeling software.

The level instrumentation support components mass and section properties were calculated by hand using conventional engineering principles and practices. These properties were used in the computer model developed by the licensee. This model was used to perform a dynamic frequency and modal analysis to develop the response spectrum for the supporting structure. Each connection device, anchor and weld was qualified by hand calculations. To accommodate the thermal expansion of structure, bolted connections with 1 ¼” slotted holes were used in the trash rack cover plate.

5.1.3.2 Temporary Strainer

A 24” diameter, 14 gauge thick perforated plate was used as a temporary strainer. The strainer plate was qualified in the same manner as described in section 3.1 with several different assumptions. Differential pressure for this strainer qualification was considered at 0.57 rather than 10 psi. The horizontal seismic acceleration values were taken from specification S023-205-07 Rev. 1 [38]. The perforated steel plate mass and section properties were calculated based on a reduction of gross section properties. To simplify bending stress calculations the strainer geometry was considered rectangular with approximately the same surface area and simply supported on each side.

5.1.3.3 Vent Strainer

The vent strainer is a 2” x 1” reducer with a perforated plate welded at each end. Like the temporary strainer, the assumed design conditions for the vent strainer are the same as those mentioned in section 3.2 with one exception. Since the mass and area of this component is small, the seismic load is neglected.

Staff Evaluation

Each component of the design analysis was evaluated on a individual basis. In general, the methods and loads used to qualify all three components of this section are in accordance with SRP section 3.8.4 [37]. For this reason the NRC staff finds that the concepts and procedures used in this analysis are acceptable and that they provide an adequate level of quality and safety.

5.1.4 Sump Strainer Collector Box

The Sump Strainer Collector Box frame is made up of 3 x 3 x ¼” tube steel and is covered by 3/8” thick plates on four sides including the top. The bottom of the box is covered by a ½” plate welded to 8" deep channels. These channels are connected to the vertical legs of the box structure via 3 x 3 x 3/8” clip angles (bent plates). The top of the box structure also houses an arrangement of small wide flange sections and hot-rolled steel angles which support strainer top hats.

The collector box structure qualification was based on the same assumption and methodology explained in section 1.0. The connection components such as threaded studs, bolts, and welds were qualified using hand calculations. The space frame structural members and cover plates were qualified via GTSTRUDL computer software. A combination of dead weight, seismic (including Hydrodynamic mass) and differential pressure loads were considered. To accommodate thermal expansion, oversized and slotted bolt holes were used to relieve the frame from thermal loads.

Staff Evaluation

The NRC staff has evaluated the Sump Strainer Collector Box calculation (Calc. No. SCSN001-CALC-003) [41] submitted by the licensee based on SRP section 3.8.4 [37]. Each assumption, method of analysis, and code requirement used reflects the position taken by this section of the SRP. All studs, bolts, welds and anchors were designed using hand calculations. Each bolt, weld and anchor force reactions were taken from results of the global GTSRUDL model. The global model includes the entire collector box structure, which includes all applicable load combinations. Each collector box member force was enveloped to yield maximum stresses based on each load combination. The resulting maximum stress values for frame members, base plates, bolts, and welds are within allowable limits set forth by the applicable code. Based on the evaluation of submitted calculations by the licensee, the NRC staff concludes the Sump Strainer Collector Box structure qualification is acceptable.

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

The licensee was asked whether the licensee had addressed possible high energy line breaks (HELBs) in the vicinity of the recirculation sumps. The licensee responded by providing a drawing, a figure, and UFSAR Appendix 3.6A, “High Energy Pipe Break.”

Section 3.6 of the San Onofre 2&3 Updated Final Safety Analysis Report (UFSAR), “Protection Against Dynamic Effects Associated with Postulated Rupture of Piping,” describes design bases and protective measures to ensure that containment, essential equipment, and other essential structures are adequately protected from the dynamic effects associated with the postulated rupture or break of high-energy reactor coolant pressure boundary piping. The Safety Injection System, including both pre- and post-recirculation actuation signal lineups, is addressed in

Section 3.6 of the SONGS UFSAR, and potential dynamic effects on containment recirculation sumps are specifically addressed.

SONGS drawing 40400-16 (partial) is a plan drawing of the piping in the vicinity of the recirculation sumps. Figure 3.6A-8 from the SONGS UFSAR is an isometric drawing that shows all postulated breakpoints and restraints for the shutdown cooling line in containment.

The SONGS UFSAR states that the shutdown cooling line is of stainless steel seamless construction, and consists of 10", 16" and 18" piping, that it is routed from the nozzle on the bottom of the reactor coolant hot leg 2 through the steam generator compartment wall, and outside of that wall the line tees into 16" and 10" lines that terminate at two normally closed motor-operated valves.

The SONGS UFSAR continues that the only postulated breakpoint in the vicinity of the recirculation sumps is breakpoint 7 in shutdown cooling line 1201-016 (breakpoint 7 being at the physical connection between the high energy shutdown cooling line and two normally closed isolation valves). The SONGS UFSAR continues “two restraints are provided in the [shutdown cooling] line to prevent [pipe whip] impact on essential components.” The location of the two restraints is shown in Figure 3.6A-8, and the restraint nearest the postulated breakpoint 7 is shown as being between breakpoints 22 and 13, in a direction away from both breakpoint 7 and the recirculation sumps.

Staff Evaluation

It is clear by inspection of the provided drawings that the portion of shutdown cooling line 1201-016 exposed to operating RCS pressure can not physically reach the recirculation sumps if whipping from the pipe restraint nearest to breakpoint 7.

With respect to jet impingement, section 3.6A.2.5.3 the UFSAR states that pipe breaks in the vicinity of the emergency sump are postulated at breakpoint 7 in the shutdown cooling line, and that:

- the jet may impinge on the conduit to the containment emergency sump outlet valve, HV-9304, but that the conduit has been reinforced to preclude damage;
- the jet does not impinge on the sump structure; and
- jet impingement on the containment pool water surface, that may result in vortices, is not a concern because the RCS will be depressurized prior to initiation of recirculation.

Based on the above considerations, the staff concludes that the licensee has appropriately addressed possible high energy line breaks in the vicinity of the recirculation sumps.

5.2 Upstream Effects

The objective of the upstream effects assessment is to evaluate the flowpaths upstream of the containment sump for holdup of inventory which could reduce flow to and possibly starve the sump. Section 7.2 of the GR [1] and the SE [2] provide the guidance to be considered in the upstream effects process to evaluate holdup or choke points which could reduce flow to and possibly cause blockage upstream of the containment sump. 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 ZOI.

In [33], the licensee determined the post-LOCA containment water level during the recirculation phase. The minimum water level cases were calculated to ensure there is enough water on the containment floor from the standpoint of vortexing and air ingestion. Also, minimum water level was calculated to ensure adequate NPSH available for the ECCS and CSS pumps.

Staff Evaluation

The SONGS Debris Transport Calculation [14] and San Onofre document N-0240-006, “RWST Technical Specification Requirement,” [79] were used in the review of upstream effects. The staff reviewed these documents to determine that the licensee evaluated the flow paths from the postulated break locations and from containment spray washdown to identify and take measures to mitigate potential choke points in the flow field upstream of the sump. The staff also reviewed the above documents and interviewed licensee personnel to verify that the licensee considered water holdup in the placement of any curbs or debris racks intended to trap debris before reaching the sump.

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 refueling canal drain. The staff reviewed the containment evaluation to determine whether the licensee evaluated all possible locations regarding flow path clearance or blockage specifically for the minimum flood elevation cases. The staff found that the licensee’s evaluation of the flow path leading to the sump which result in the minimum volume in the sump pool was performed in a manner consistent with the approved methodology. Alion found three possible blockage points: four grated gates that leads to the steam generator compartments, the 10-inch refueling canal drain, and one of two passages blocked by an heating, ventilation and air conditioning (HVAC) plenum. The refueling canal drain as well as the two passages are not considered actual choke points because the canal drain inlet has a screen designed to prevent blockage in the canal. As for the walkway located at the northwest corner of the containment blocked by a HVAC plenum, since there is another open passageway in the same area, this blockage point would not change the transport results. Since the four grated gates are considered possible choke points, San Onofre plans to remove the mesh from the bottom portion of the gates to eliminate the probability of blockage.

The staff concludes that the licensee's upstream effects evaluation was performed in a manner consistent with the approved methodology. Based on discussions with the licensee, and review of the cited documents, the staff concludes that the licensee has adequately reviewed the flow paths leading to the emergency sump screen for choke points, has considered the entrapment of debris upstream of the sump screen with regard to the holdup of water, and has considered the effect of water holdup in planned sump modifications. Therefore, the staff finds the licensee's treatment of upstream effects to be acceptable.

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.

Staff safety evaluation (SE) [2] of GR Section 7.3 amplified the GR statements regarding the potential safety impact of LOCA generated debris on components downstream of the containment sump. In the SE 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 ECCS or CSS 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 [122]).
>
> 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 [NRC Information Notice 96-27 “Potential Clogging of High Pressure Safety Injection Throttle Valves During Recirculation”]) 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 CS system evaluation integrating limiting or worst-case pump, valve, piping, and heat exchanger conditions should be performed and include the potential for reduced pump/system capacity resulting from internal bypass leakage or through external leakage. Internal leakage of pumps may be through inter-stage supply and discharge wear rings, shaft support, and volute bushings (NUREG/CP-1052 Vol. 5, 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.”

SONGS provided five calculations to address downstream effects [45, 48, 89, 90, 91]. These calculations were developed in accordance with PWROG WCAP-16406-P, Rev. 0 [83].

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 inconsistencies between some of the documents and references. Additional conversations with SONGS were needed to clarify these inconsistencies. The inconsistencies were minor in nature and had no significant impact on the overall downstream effects conclusions. P&ID’s (piping and instrument diagrams), UFSAR passages, and operations procedures supporting the calculations were reviewed with no design discrepancies identified.

In accordance with SE Section 7.3, the staff reviewed mission times and system lineups to support LOCA critical systems. System line-ups, mission times, flows and pressures used to bound downstream evaluations were not clearly identified or incorporated explicitly into the various downstream effects calculations reviewed. However, through review of available plant documents the staff was able to determine that the information exists and is reflective of actual plant operations.

The staff reviewed all LOCA scenarios (i.e., small-break LOCA, medium-break LOCA, and large-break LOCA) to assess system operation. ECCS operation during small-break LOCA, medium-break LOCA, and large-break LOCAs appeared to be adequate in that flows and pressures achieved for the 30-day mission time meet the requirements of the SONGs accident analysis.

The staff reviewed the licensee's analysis of the extent of air entrainment (apart from vortexing), and concurs that there is no significant air entrainment with the ECCS that would either impact ECCS pump operation or cause air pockets in ECCS piping. The potential for waterhammer and slug flow was adequately addressed.

Based on review of the downstream effects debris ingestion calculation [48] the staff concluded that the licensee characterization and properties of ECCS post-LOCA fluid (abrasiveness, solids content, and debris characterization) were appropriate, complete and conservative.

The staff reviewed design documents to verify opening sizes and running clearances. Minor, non-significant discrepancies were discovered that had no impact on licensee evaluations. The SER identifies the potential for the high-pressure safety injection (HPSI) throttle valves to clog during ECCS operation. The SONGS HPSI throttle valves are normally open, minimizing the potential for clogging. Procedures and instrumentation are in place such that if an operator chooses to throttle these valves, there is adequate indication and alarm for low flow and differential pressure. Cycling open a throttle valve will effectively clear debris and allow flow. The SONGS HPSI System was designed such that operation with full open throttle valves is acceptable.

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 Section 7.3 of the SE notes the potential to clog or degrade equipment strainers, cyclone separators, or other components. SONGS has cyclone separators in its HPSI, CS and LPSI pumps. Licensee reviews of installation and operation of these cyclone separators were not complete at the time of audit, and this lack of reviews is designated as **Open Item 14**.

The SE Section 7.3 states that a review and assessment of changes in system or equipment operation caused by wear (i.e., pump vibration and rotor dynamics) should be performed. Also an assessment of whether the internal bypass flow increased, thereby decreasing performance or accelerating internal wear, should be completed. The lack of an evaluation of pump hydraulic degradation due to internal wear is designated as **Open Item 15**.

In addition, although the licensee evaluated the pumps for other conditions such as vibration, bypass flow, plugging, etc., the range of pressures and flows utilized in these analyses may not be adequate to predict pressure, flow, vibration, mechanical operation, and stage-to-stage or seal leakage degradation, or to assess system and component operability. Minimum pump flows per equipment operating instructions (EOIs), or best efficiency points of pump operation

(BEPs), or normal operating or design basis flows were not considered. These pump related issues are designated as **Open Item 16**.

The licensee did not quantify HPSI Pump debris-induced seal leakage into the Auxiliary Building. An evaluation of the resultant affects on equipment qualification and room habitability was not performed. These analytical omissions are designated as **Open Item 17**.

The licensee defined the range of fluid velocities within piping systems. SONGS 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.

Based on review of the licensee's five calculations to address downstream effects [45, 48, 89, 90, 91], the staff concurs with the licensee conclusion that there is a negligible change in system flow resistance due to accumulation of debris or wearing of piping components. Therefore, flow balances and current analysis are unaffected. Based on this information the staff also concurs that the are no adverse affects on or concerns with ECCS system heat exchangers.

Based on review of the licensee's five calculations to address downstream effects [45, 48, 89, 90, 91], the staff concurs with the licensee conclusion that there is a negligible change in flow-induced system vibration due to accumulation of debris or clogging of system components.

5.3.2 Downstream Effects - Fuel and Vessel

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

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

At the request of the industry, the NRC staff provided additional interpretation for 1) the requirements and acceptance criteria for long-term core cooling once the core has quenched and re-flooded and 2) for the mission time that should be used in evaluating debris ingestion effects on the reactor fuel. The NRC staff provided these clarifications in [44].

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

Generic Letter 2004-02 [3] requires that holders of operating licenses for pressurized-water reactors perform evaluations of the ECCS and the containment spray recirculation functions. These evaluations are to include the potential for debris blockage at flow restrictions within the ECCS recirculation flow path downstream of the sump screen. Examples of flow restrictions which should be evaluated are the fuel assembly inlet debris screens and the spacer grids within the fuel assemblies. Debris blockage at such flow restrictions could impede or prevent the recirculation of coolant to the reactor core leading to inadequate long term core cooling. SCE provided evaluations for the purpose of demonstrating that debris blockage of the reactor core during the long-term cooling period is not of concern for SONGS [45]. The potential for blockage of reactor vessel flow paths other than the core was evaluated in [46]. The NRC staff review of this material is described herein.

Staff Evaluation

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

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

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

For the evaluation of potential core blockage following a hot leg or a cold leg break, the licensee used the methodology of WCAP-16406-P, Rev. 0 [83]. The WCAP describes how particulate debris with a density that is heavier than water will settle in the reactor vessel lower plenum and not be passed into the core for a sufficiently low flow velocity. The WCAP also describes how fibrous debris with a density approximately the same as water would be carried along with the recirculated sump water but would be filtered by the sump screens and by screens located at the inlet to the fuel bundles. WCAP-16406-P, Rev. 1 [84] was recently submitted as a topical report for NRC staff review. The staff plans to complete the review of this topical report in 2007. During a meeting with the PWR Owners Group (PWROG) on April 12, 2006, to discuss issues associated with downstream effects on reactor fuel, the PWROG presented plans to develop another topical report with a more detailed fuels evaluation methodology. Conclusions from the review of both these topical reports may affect the staff's conclusions for SONGS compliance with Generic Letter 2004-02 [3].

The licensee provided a generic methodology for the amount of particulate debris which might flow into the reactor vessel with the ECCS water [45]. The generic methodology discussed the settling potential for RMI, concrete debris, latent containment debris and coating particulates. The licensee believes that any small particles of RMI, concrete debris, latent containment debris and all but the smallest coating particulates that pass through the sump screen and reach the reactor vessel will settle in the lower plenum of the reactor vessel. The staff agrees based on review of the licensee's evaluation of the force balance on particulate debris. The licensee has performed an evaluation which determined that the total volume of particulate and coatings debris which may pass into the reactor vessel to be approximately 31 cubic feet [48]. The volume of the reactor vessel lower plenum below the core is much larger (approximately 900 cubic feet). Thus the staff concludes that there is insufficient particulate and coating debris at SONGS to cause lower plenum blockage.

The licensee determined that 28.7 cubic feet of mineral wool and latent fibrous debris might be formed within the containment of a SONGS unit following a large LOCA. The licensee conservatively assumed that 100% of the fibrous debris is transported to the containment sump. Most of the fibrous debris would be retained on the sump screens, but the licensee assumes that all such debris passing through the screen would reach the core.

Using the methodology of WCAP-16406-P, the licensee calculated the size of a debris bed which might form at the core entrance. A sump screen efficiency of 97% for filtration of fibrous debris was used based on scale model screen testing described in reference 6. The SONGS sump screen testing program was based on the screen velocity which would occur for a flow rate of 3500 gpm. This flow rate would be appropriate for operation of one high pressure ECCS pump and one containment spray pump in each engineered safety features train. In the event that the low pressure ECCS pump for that train were inadvertently not tripped, the sump strainer flow would be 9000 gpm. This condition, and it's associated bypass flow debris quantities, was not included in the licensee's tests [73, 74]. The licensee needs to evaluate sump bypass debris quantities at 9000 gpm. See Open Item 18 below.

The licensee used an acceptance criterion of a fibrous debris bed thickness of no more than 0.125 inches across the core inlet. This acceptance criterion is based on pressure drop studies for BWR strainer blockage concerns in NUREG/CR-6224 [50]. Additional justification is provided by the licensee starting on page 37 of [45]. Based on the low, non-uniform flow rates which are expected to exist at the core inlet during the post-LOCA long-term cooling period, the staff considers the formation of a uniform compact fiber bed at the core inlet to be unlikely. The staff therefore agrees that the licensee's acceptance criterion is conservative. Using the methodology of WCAP-16406-P, the licensee calculates a fiber bed thickness at the core inlet of 0.019 inches following a postulated cold leg break and 0.069 inches following a hot leg break [45]. These thicknesses are for the latest time of switchover from cold leg recirculation to hot leg recirculation, which is 4 hours at SONGS. The staff has not finished reviewing WCAP-16406-P, but notes that with a 97% assumed sump screen efficiency, even if all the fibers that might pass through the sump screen were collected at the bottom of the core, the licensee's acceptance criterion of 0.125 inches thickness would not be exceeded. When the licensee analyzes bypass flow debris quantities associated with 9000 gpm, as discussed in the previous paragraph, the staff will reach a conclusion as to whether the inlet of the core might be blocked by debris following a LOCA at SONGS. The lack of a licensee analysis of bypass flow debris quantities for a 9000 gpm operating condition (one low pressure ECCS pump for an operating train inadvertently not tripped) is designated as **Open Item 18**. It should be noted that the staff's concern regarding the flow velocities used in the sump screen testing does not affect the staff's conclusion that the licensee's acceptance criterion of a uniform fiber bed of 0.125" across the core inlet is conservative.

As part of its review for another plant, the staff performed audit calculations of core inlet blockage using the RELAP5 and TRACE computer codes. The staff evaluations concluded that following a break of a reactor system cold leg, adequate core cooling would still be maintained for an excess of 99% core blockage during the long-term cooling period. The staff believes that similar results would be obtained for a SONGS core blockage analysis.

To prevent excessive concentration of boric acid within the core following a large cold leg break, the existing emergency procedures at SONGS instruct operators to manually align the high pressure injection pumps to redirect water to the hot legs between 2 and 4 hours after a loss of coolant accident. If sufficient water is added to the hot legs, a net down flow will be established in the reactor core which will flush out the concentrated boric acid and prevent further concentration from occurring. Since the location of the break will not be known to the plant operators, hot leg recirculation would begin between 2 to 4 hours after the accident at SONGS regardless of break location.

The initiation of flow to the reactor hot legs may be a source of debris to the top of the core. Since hot leg injection will not begin until at least two hours after the pipe break occurs, there is the opportunity for a considerable amount of the debris to be filtered out or to settle from the water that flows to the top of the core. The licensee has provided an analysis (Ref. 2) based on the methodology of WCAP-16406-P, which indicates that after a time of two hours, the concentration of fibrous debris in the recirculating fluid will be about one half of the initial value. The NRC staff has not approved the methodology in WCAP-16406-P. The staff notes however that with a sump screen efficiency of 97% there will insufficient fiber admitted into the reactor vessel at any flow rate to block the top of the core even if it were evenly spread at that location. When the licensee analyzes bypass flow debris quantities associated with 9000 gpm, the licensee will be capable of reaching a conclusion as to whether the top of the core might be blocked by debris following a LOCA at SONGS. The lack of a licensee conclusion regarding potential blockage at the top of the reactor core is designated as **Open Item 19**.

In addition to locations at the core inlet and exit, the licensee also addressed other possible locations for blockage within the reactor vessel internals which might affect core cooling (Ref. 3). The smallest clearance was found to be 0.87 inches. This dimension is approximately a factor of 10 greater than the dimension of the strainer holes in the containment sump screen. Given this difference, the staff agrees with the licensee that debris blockage of non-core reactor vessel internals is unlikely at SONGS.

Although the licensee addressed blockage at the core inlet during cold leg recirculation and at the top of the core during hot leg recirculation, other issues remain unresolved. These issues involve the potential for core internal heat transfer degradation between the fuel rods and the coolant in the presence of debris and chemicals in the recirculated sump water. Following a large cold leg break, continued boiling in the core will act to concentrate the debris and chemicals in the water between the core coolant channels. Chemical reaction of the debris with the containment spray buffering agents and boric acid from the ECCS water in the presence of the core radiation field might change the chemical and physical nature of the mixture. Heat transfer might be affected by direct plate-out of debris on the fuel rods and by accumulation of material within the fuel element spacer grids. The licensee has stated that they will rely on an ongoing program by the PWROG to investigate the effects of local blockages within fuel elements and the effect of plate out of substances on fuel rod surfaces during the long term cooling period (this document is to undergo NRC topical review). The completed PWROG document will enable the licensee to reach a conclusion on the various potential effects of debris blockage of the fuel assembly support grids and chemical concentration through boiling in the SONGS reactor. The lack of a licensee conclusion regarding debris blockage of the fuel assembly support grids is designated as **Open Item 20**.

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 GSI-191 SE [2]. In support of the chemical effects portion of the audit, the NRC staff reviewed the following licensee documents:

- M-0012-037, Rev. 1. - "Data Input for WOG Chemical Testing - Emergency Containment Sump Strainer Replacement" [51]
- S023-205-7-M40, Rev. 1 - "Head Loss Testing in Vertical Loop of SONGS Units 2&3 Chemicals and Debris [52]
- S023-205-7-C55, Rev. 0 - "The SONGS Chemical Product Generation Report" [53]

The NRC staff also observed two chemical effects tests for SONGS conducted in the vertical head loss loop at the Alion Science and Technology Hydraulics Laboratory in Warrenville, Illinois on August 17-18, 2006. NRC staff observations from these tests are documented in a trip report dated November 6, 2006 - "Staff Observations of Testing for Generic Safety Issue 191 During August 17 and August 18 Trip to the Alion Hydraulics Laboratory" (ADAMS Accession No. ML063110561) [54]. One of the staff observations in the trip report relates to the performance of chemical precipitates in test environments that are not representative (e.g., no boron, no pH buffer) of post-LOCA containment pool conditions. Ongoing chemical effects evaluations must validate that this approach does not alter the precipitates in a non-conservative manner relative to head loss (see first open item for this section below). A summary of additional staff observations from these two tests is provided below.

The SONGS containment materials include galvanized steel, aluminum, carbon steel, concrete, mineral wool insulation and Microtherm insulation. The insulation materials are encased in stainless steel cassettes. Trisodium phosphate (TSP) is located in the lower level of containment to buffer the post-LOCA containment pool pH.

The August 17-18, 2006 chemical effects tests for SONGS were performed in the small scale multi-function test loop. This vertical test loop includes a horizontal, 5.5-inch diameter flat perforated plate to facilitate bed formation. The horizontal test plate is located within a clear plastic section to enable visual observation of the test bed. The test loop has a 16-gallon capacity, is constructed with materials intended to be compatible with representative sump environments, and is capable of operating at a maximum 160°F temperature. The Alion Hydraulics Laboratory also has the chemicals and equipment needed for generating precipitates using the methodology outlined in WCAP-16530-NP, "Evaluation of Post-Accident Chemical Effects in Containment Sump Fluids to Support GSI-191 [55]." Note: the NRC staff is currently reviewing WCAP-16530-NP and has issued a request for additional information to the PWR Owners Group to resolve technical questions about the chemical model and particle generator contained in the WCAP.

The technical approach employed by Alion to evaluate SONGS chemical effects consists of several test steps. Prior to the vertical head loss loop testing, Alion performed a plant-specific determination of the chemical products expected to be formed using the chemical model spreadsheet developed in WCAP-16530-NP. These precipitates were prepared using the directions provided in WCAP-16530-NP, with the exception that reverse osmosis water was used instead of potable water. After the precipitates were mixed for longer than the minimum mixing time specified in the WCAP, the solutions were diluted to a specific concentration and settling rates were measured in standard centrifuge tubes and compared to the acceptable settling rates defined in the WCAP.

Once the chemical precipitates were generated, a scaled amount of non-chemical debris (e.g. fibers and particulate) from a postulated loss of coolant accident (LOCA) break location was introduced into the vertical test loop and a stable baseline head loss was established across the debris bed. After the baseline head loss was established and documented, incremental percentages of chemical precipitate are introduced to the test loop and the head loss associated with these precipitates was determined. Given the results from vertical head loss loop tests, a "bump-up" factor due to chemical effects would then be applied in an appropriate manner to other tests (e.g., large scale tank tests with multiple strainer sections) with the same test conditions.

As stated above, NRC staff observed chemical effects tests for two SONGS LOCA break scenarios that generate limiting (non-chemical) debris loads with different types of insulation. The non-chemical debris for Test 1 was based on a postulated break in the reactor coolant system hot leg that generates a maximum debris load including mineral wool, NUKON latent fiber, dirt/dust, and coatings debris. The non-chemical debris for Test 2 was based on a postulated break at a reactor vessel nozzle that generates high particulate loading including Microtherm insulation, NUKON latent fiber, dirt/dust, and coatings debris. All coating debris was treated as particulate (this results in higher head loss for plants with fiber debris beds). The debris types and quantities were obtained from the SONGS debris generation and transport calculations. Chemical precipitate loading is obtained from the SONGS chemical generation report that applies the WCAP-16530-NP chemical model. All plant-specific loadings were scaled from the modified plant screen area to the vertical test loop screen area (0.165 ft^2). The flow rate in the test loop was set to achieve the 0.008 ft/sec plant screen approach velocity. The test loop fluid was potable water.

On August 17th, the staff observed SONGS Chemical Effects Test 1. The ratio of total particulate mass-to-total fiber mass was approximately 2:1 for Test 1. After all non-chemical debris had been added to the vertical head loss loop, pressure drop stabilized after 2 hours and the bed thickness at that time was approximately 0.5 inch. The stable pressure drop was approximately 7.4 feet of water. Based on the heat input from the pump and the ambient conditions in the lab, the temperature of the fluid in the test loop during testing was approximately 85°F. Test loop fluid pH was approximately 7.3. Once the baseline pressure drop in the vertical head loss loop was stable, an aliquot equal to 1% of the total chemical product load for the SONGS hot leg break was introduced into the top of the loop. Within minutes, the pressure drop started to rapidly increase. When the test was stopped approximately 10 minutes after the introduction of the chemical precipitate, a gas pocket was visible under the debris bed. By the time the pump was turned off to terminate the test, the debris bed had compressed to about 0.25 inch thickness and the pressure drop across the debris covered test screen had increased to 13 feet of water.

The staff observed the start of Chemical Effects Test 2 on August 18th. The non-chemical debris load for this test was based on a postulated break at the reactor vessel that generates high particulate loading. The ratio of total particulate mass-to-total fiber mass was 34:1 for Test 2. All of the Microtherm insulation was added as particulate. After all debris had been added to the loop, the baseline pressure drop (without chemical precipitates) remained low, approximately 0.02 feet of water. Due to the limited fiber in Test 2, the bed did not effectively filter the particulate and only the outermost portion of the debris bed was visible through the clear test section due to the high turbidity of the test fluid. After approximately 2 hours, the pressure drop across the screen section remained stable at 0.02 feet of water, and an aliquot equal to 1% of the total chemical product load for this break was introduced into the top of the loop. After approximately one-half hour, the pressure drop remained at 0.02 feet and an additional 4% of the total chemical product load was added. Within minutes, the pressure drop started to slowly increase. Approximately one hour after the 4% chemical product addition, the pressure drop was 0.48 feet and increasing. Approximately 3.5 hours after the 4% SONGS chemical product addition, the pressure drop was 1.7 feet and increasing at an approximate rate of 1 foot every 90 minutes. At that point, an additional 15% of chemical product (or a cumulative 20% of the total chemical product) was added to the loop. Pressure drop exceeded 14 feet of water five minutes later and the test was terminated.

On September 27, the NRC staff and representatives from SONGS participated in a conference call to discuss the licensee's plans for addressing chemical effects given the results from the vertical head loss loop tests at Alion. During the call, the licensee indicated that they were evaluating several options but had not decided on the next steps for addressing plant-specific chemical effects. Therefore, licensee resolution of chemical effects is designated as **Open Item 21**. As part of the chemical effects resolution, NRC staff expect any chemical effects testing that uses surrogate chemical precipitate or that is performed in environments not representative of postulated plant conditions will have a technical basis that demonstrates why the test results are acceptable.

Both qualified coatings within the ZOI and unqualified coatings (e.g., alkyds) are included in the generated debris that will be transported to the containment pool following a LOCA. With the exception of inorganic zinc coatings, that were tested within the joint NRC/Industry Integrated Chemical Effects Test program, the licensee needs to provide justification that these coatings will not produce significant chemical effects. Potential interactions could include the leaching of chemicals from coatings, softening, or other changes to the coating (e.g., become gelatinous) that could produce greater head loss compared to the particulate that was tested in ambient temperature water at Alion. The licensee should justify that leaching from coatings or changes in the form of coatings has been adequately addresses in the head loss testing; this is designated as **Open Item 22**.

In summary, the staff reviewed several documents related to the licensees chemical effects evaluations and observed chemical effects tests performed in a vertical head loss loop at a vendor's facility. Since simulated chemical precipitates in these tests resulted in head loss greater than the acceptance criteria, and the licensee's evaluation of chemical effects is ongoing, chemical effects resolution is an open item. A second open item relates to the evaluation of the potential for coatings to produce a chemical effect in the post-LOCA containment pool.

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 Southern California Edison 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 SONGS 2 and SONGS 3.

Appendix I

Open Items

Open Item 1: The licensee did not develop detailed analysis for a Microtherm ZOI for a restricted pipe break in the reactor vessel annular region.

Open Item 2: The licensee did not justify the assumed size distribution of 20% fines and 80% small pieces for the 4D mineral wool ZOI.

Open Item 3: Miscellaneous debris that was left in the Unit 3 containment, as identified in Attachment 1 of SO23-XV-23.1.1 [63], needs to be further evaluated by the licensee. Also, the value assumed for the SONGS Unit 2 latent debris source term needs to be confirmed by the licensee.

Open Item 4: The licensee did not adequately justify the assumption of 0.16 ft/s as the incipient tumbling velocity metric for small pieces of mineral wool.

Open Item 5: The licensee should establish the adequacy of mineral wool transport by flotation in the presence of the SONGS sump strainer cover plates.

Open Item 6: The license also had not resolved the potential effects of concentrated spray drainage, including its effect on the local velocity and turbulence fields in the sump pool, nor justified the assumption that only 10% of the small and large pieces of mineral wool in the containment pool would be subject to erosion.

Open Item 7: The licensee did not provide adequate justification for the graphically determined debris transport fractions obtained from Figures 5.9.26 and 5.9.32 in the debris transport analysis report.

Open Item 8: The licensee had not addressed the potential head loss change from RMI debris entering the interstitial volume of the sump pit, and did not provide sufficient evidence to support the assumption that excluding RMI from head loss testing would result in conservative head loss measurement.

Open Item 9: The licensee had not resolved Microtherm temperature-dependent material behavior for the pH value or values expected in the post-LOCA sump pool.

Open Item 10: The licensee was unable to provide documentation justifying use of a 5L/D ZOI for coatings.

Open Item 11: The licensee has not demonstrate that the new design complies with the existing licensing basis to the extent that it functions satisfactorily at 50% screen blockage.

Open Item 12: The licensee had not documented an evaluation of the ability of the new screens to continue to function and withstand damage from relatively large debris that bypasses the new trash racks.

Open Item 13:	The licensee had not documented in its engineering change package a direct conclusion regarding transmitter functionality in its new location.
Open Item 14:	Licensee reviews of installation and operation of HPSI pump cyclone separators had not been completed at the time of the audit.
Open Item 15:	The licensee had not evaluated pump hydraulic degradation due to internal wear.
Open Item 16:	The licensee had not evaluated the range of pressures and flows used by SONGS to evaluate pump wear rates in order to properly predict degradation or assess operability.
Open Item 17:	The licensee did not quantify HPSI Pump debris-induced seal leakage into the Auxiliary Building, and did not perform an evaluation of the resultant affects on equipment qualification and room habitability.
Open Item 18:	The licensee did not perform an analysis of bypass flow debris quantities for a 9000 gpm operating condition (one low pressure ECCS pump for an operating train inadvertently not tripped).
Open Item 19:	Due to lack of a licensee analysis of bypass flow debris quantities associated with a one train 9000 gpm operating condition, the licensee was unable to reach a conclusion as to whether the top of the core might be blocked by debris following a LOCA at SONGS.
Open Item 20:	The licensee did not form a conclusion on the various potential effects of debris blockage of the fuel assembly support grids and chemical concentration through boiling in the SONGS reactor.
Open Item 21:	The licensee had not resolved the chemical effects issue at SONGS at the time of the audit.
Open Item 22:	The licensee had not justified that leaching from coatings or changes in the form of coatings will not produce greater head loss than was observed in head loss testing.
Open Item 23:	The licensee had not conducted a full evaluation of the applicability of the EPRI/NUCC coatings test data at SONGS.

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97. Drawing 40111BS03, P&ID Reactor Coolant System, System No. 1201, Unit 3, Rev. 37

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111. Emergency Operating Instruction SO23-12-3, Loss of Coolant Accident, Rev. 19.

112. Emergency Operating Instruction SO23-12-5, Excess Steam Demand Event, Rev. 20

113. Emergency Operating Instruction SO23-12-10, Safety Function Status Checks, Rev. 2

114. Emergency Operating Instruction SO23-12-11, EOI Supporting Attachments, Rev.4

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120. SONGS Procedure SO23-I-2.53, "Containment Emergency Sump Inspection Surveillance," Rev. 7 dated March 16, 2005

121. SONGS Site Program/Procedure Impact (SPI) Analysis #040301974-56, July 31, 2006

122. NUREG/CP-0152 Vol. 5, TIA 2003-04, “Proceedings of the Eighth NRC/ASMR Symposium on Valve and Pump testing,” July 2004

123. Regulatory Guide 1.1 “Net Positive Suction Head for Emergency Core Cooling and Containment Heat Removal System Pumps (Safety Guide 1)” dated November, 1970

Appendix III. Teleconference Minutes On Microtherm Material

Teleconference Summary

Background:

During the NRC on-site audit exit meeting on 28-SEP-06, the NRC audit team suggested that there may be temperature-related behavior of Microtherm that could have an effect on sump recirculation head loss, and that this temperature-related effect might not have been reflected in analyses and/or testing that was available during NRC's audit. NRC indicted that this could be a potential open item from the audit.

Dr. Shanlai Lu (NRC Staff) subsequently contacted Mr. Gilbert Zigler (Alion) and informed him that a teleconference could be held to further discuss the issue.

Mr. Zigler proceeded to contact appropriate personnel within Alion and SONGS resulting in a telecon with the NRC on 3-OCT-06, 3:30 EST.

Participants:

Ed Kimoto	SCE, SONGS
Shanlai Lu	NRC
Matt Yoder	NRC
Leon Whitney	NRC
Aaron Smith	Enercon
Eric Hixson	Alion Science and Technology
Gil Zigler	Alion Science and Technology
Greg Guliani	Alion Science and Technology
Rob Choromokos	Alion Science and Technology
Andy Roudenko	Alion Science and Technology

Summary of Discussion:

Mr. Eric Hixson (Alion) provided an overview discussion of physical characteristics and behavior of fumed silica, a primary constituent of Microtherm, in various temperature, pH regimes and concentrations, including the materials' hydrophilic or hydrophobic tendencies in aqueous solutions. Mr. Hixson indicated that at temperatures greater than 235 °C, fumed silica loses its hydrophobic behavior and becomes hydrophilic. Because the SONGS reactor vessel has operated for several years at temperatures greater than 235° C, it must be assumed that the Microtherm insulation is hydrophilic.

Mr. Greg Guliani (Alion) then confirmed that the hydrophilic variety of Microtherm material (which is the more problematic of the two forms of Microtherm from a head loss perspective) was used in SONGS array head loss testing.

Mr. Rob Choromokos (Alion) also confirmed that the head loss testing for the SONGS replacement screen was performed at room temperature using tap water. It was agreed that any issues associated with pH or chemical effects and the impact on head loss remain an open item under the broad and recognized issue of “chemical effects.”

Action Items:

SCE-SONGS agreed to provide NRC with a summary of its conclusions on temperature-related Microtherm effects on predicted head loss. The summary is provided below.

Summary of Discussion:

Mr. Eric Hixson (Alion) provided an overview discussion of physical characteristics and behavior of fumed silica, a primary constituent of Microtherm, in various temperature, pH regimes and concentrations, including the materials' hydrophilic or hydrophobic tendencies in aqueous solutions. Mr. Hixson indicated that at temperatures greater than 235 °C, fumed silica loses its hydrophobic behavior and becomes hydrophilic. Because the SONGS reactor vessel has operated for several years at temperatures greater than 235° C, it must be assumed that the Microtherm insulation is hydrophilic.

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Action Items:

SCE-SONGS agreed to provide NRC with a summary of its conclusions on temperature-related Microtherm effects on predicted head loss. The summary is provided below.

Conclusion on Temperature-Related Microtherm Effects on Headloss:

1. Of the major constituents of Microtherm, the only one that exhibits viscous colloidal phase properties when suspended in water is fumed silica. The other constituents, (e.g., fiber and titanium dioxide), have not been observed to alter the rheological properties of water. Therefore, aqueous suspensions containing Microtherm will tend to respond in a manner similar to aqueous suspensions containing fumed silica, (e.g., the viscosity of such suspensions will decrease with increasing temperatures).

2. The headloss tests conducted by Alion Science and Technology for SONGS used the hydrophilic variety of Microtherm. The hydrophilic variety of Microtherm is the more problematic of the two varieties of Microtherm from a head loss perspective.