6.2 Containment Systems

6.2.2 Containment Heat Removal Systems

6.2.2.1 *Introduction*

This chapter assesses the U.S. EPR's capability to provide adequate long-term cooling water to the emergency core cooling system pumps in the presence of accident-generated and latent debris within containment. Additional impacts from accident-generated and latent debris discussed in this report include the effect of debris on the flow paths downstream of the emergency core cooling system (ECCS) strainers, such as pumps and fuel assemblies.

A concern regarding containment heat removal systems is that a high-energy line break in containment produces debris, that together with debris that exists before a line break, called latent debris, could transport to and accumulate on recirculation sump screens. The debris accumulation could potentially challenge the plant's capability to provide long-term cooling water to the containment heat removal system and emergency core cooling system pumps.

The U.S. EPR has limited post-accident debris relative to current pressurized-water reactors. The U.S. EPR reactor coolant system piping and components are insulated with reflective metal insulation. The U.S. EPR fibrous debris source is limited to latent debris sources. The U.S. EPR also uses a debris interceptor system consisting of weirs (curbs), trash racks, retaining baskets, and sump strainers to filter debris. The U.S. EPR does not use a containment spray system, which could contribute to debris transport, for design basis accident mitigation.

The ability of the U.S. EPR containment heat removal systems to reduce the containment pressure and temperature following a high-energy line break within the containment and maintain them at acceptable low levels is discussed in a separate safety evaluation report and will be combined with this report in a subsequent project review phase.

6.2.2.2 *Summary of Application*

The U.S. EPR design certification application information cited in this evaluation section is based on FSAR Revision 4, dated November 2012.

FSAR Tier 1: The Tier 1 information associated with this evaluation is found in Tier 1, Section 2.2.2, "In-Containment Refueling Water Storage Tank System," and Tier 1, Section 2.2.3, "Safety Injection System and Residual Heat Removal System." FSAR Tier 1, Sections 2.2.2 and 2.2.3 state that the IRWST and the ECCS are safety-related systems, and describe their safety-related functions and design features. FSAR Tier 1, Section 2.1.1.1, "Reactor Building," also describes the reactor containment building design features such as water flow paths to the IRWST, insulation materials, coatings, and the water-retention capacity of internal structures.

FSAR Tier 2: The Tier 2 information associated with this evaluation is found in Sections 6.2.2, "Containment Heat Removal Systems," and 6.3, "Emergency Core Cooling System." FSAR Tier 2, Sections 6.3.2.2.2, "System Components," and 6.3.2.5, "System Reliability," discuss debris and long term core cooling aspects of the U.S. EPR. FSAR Tier 2, Section 1.6, "Material

Referenced," incorporates by reference Technical Report ANP-10293P, "U.S. EPR Design Features to Address GSI-191," Revision 4, dated November 2011.

Technical Report ANP-10293P, Revision 4, November 2011, assesses the U.S. EPR design with respect to satisfying the guidelines in RG 1.82, "Water Sources for Long-Term Recirculation Cooling Following a Loss-of-Coolant Accident," Revision 3, November 2003 and Nuclear Energy Institute (NEI) Guidance Report NEI 04-07, "Pressurized Water Reactor Sump Pump Performance Evaluation Methodology," Revision 0, Volume 1, December 2004, and ensuring consistency with the associated NRC safety evaluation (SE), "Safety Evaluation by the Office of Nuclear Reactor Regulation Related to NRC Generic Letter 2004-02, December 2004. Technical Report ANP-10293P is the proprietary version of the report ("P" indicated proprietary). The applicant also issued a non-proprietary version of the technical report, that is ANP-10293NP ("NP" indicates non-proprietary). This evaluation refers to the non-proprietary version, ANP-10293NP, Revision 4, when sufficient, and the proprietary version, ANP-10293P, Revision 4, when necessary, unless noted otherwise. (Note: Revision 0 and Revision 1 of ANP-10293 contained non-proprietary information and had no "P" or "NP" letter designation.)

FSAR Tier 2, Section 6.3.2.5 states that the reactor coolant system piping and components, and other potentially insulated systems or components within a zone of influence, are insulated with reflective metal insulation (RMI), and no fibrous insulation is used.

FSAR Tier 2, Table 6.3-5, "Total Debris Source Term," indicates that insulation debris is limited to RMI and a very small amount of microporous insulating material.

FSAR Tier 2, Section 6.3.2.2.2, "System Components," under the heading for the In-Containment Refueling Water Storage Tank, specifies that latent debris is limited to 90.7 kilograms (kg) (150 lb). The latent fiber load comprises 4.6 kg (10.2 lb) of the 90.7 kg (150 lb) total.

ANP-10293NP, Section 2.0, "U.S. EPR Design Features," indicates that the U.S. EPR has four independent strainers that are located inside the IRWST. These strainers are installed on the floor of the IRWST and are designed to be fully submerged under loss-of-coolant accident conditions.

FSAR Tier 2, Table 1.8-2, "U.S. EPR Combined License Information Items," establishes COL Information Item 6.3-1 for instituting a containment cleanliness program. FSAR Tier 2, Section 6.3.2.2.2 provides a description of the cleanliness program.

The ITAAC associated with this evaluation are found in FSAR Tier 1, Section 2.2.2, Table 2.2.2-3, "In-Containment Refueling Water Storage Tank System ITAAC," and FSAR Tier 1, Section 2.2.3, Table 2.2.3-3, "Safety Injection System and Residual Heat Removal System ITAAC," (related to IRWST). ITAAC related to water flow paths to the IRWST and debris source term is provided in FSAR Tier 1, Section 2.1.1.1, Table 2.1.1-8, "Reactor Building ITAAC."

The Technical Specifications associated with FSAR Tier 2, Section 6.2.2 and associated sections of FSAR Tier 2, Section 6.3 (related to IRWST) are given in FSAR Tier 2, Chapter 16, "Technical Specifications," Section 3.5, "Emergency Core Cooling System."

Initial plant testing of the ECCS and IRWST is discussed in FSAR Tier 2, Section 14.2, "Initial Plant Testing Program," which specifies testing that is applicable to the ECCS (see Section 6.3

of this report for a list of tests). In addition, FSAR Tier 2, Section 14.2.12.2.10, "In-Containment Refueling Water Storage Tank System (Test #22)," specifies testing applicable to the IRWST.

6.2.2.3 *Regulatory Basis*

The relevant requirements of NRC regulations related to the evaluation of the water sources for long-term recirculation cooling following a LOCA are:

1. GDC 35, "Emergency core cooling," as it relates to providing abundant emergency core cooling to transfer heat from the reactor core following a LOCA

2. GDC 38, "Containment heat removal," as it relates to the ability of the containment heat removal system to rapidly reduce the containment pressure and temperature following a LOCA and to maintain these indicators at acceptably low levels

3. 10 CFR 50.46(b)(5), "Long-term cooling," as it relates to the requirements for long-term cooling, including analysis of available net positive suction head (NPSH) in the presence of LOCA-generated and latent debris

As directed by NUREG-0800, Section 6.2.2, "Containment Heat Removal Systems," Revision 5, the staff performed the review in accordance with RG 1.82, "Water Sources for Long-Term Recirculation Cooling Following a Loss-of-Coolant Accident," Revision 3, November 2003, as supplemented by NEI Guidance Report NEI 04-07, "Pressurized Water Reactor Sump Performance Evaluation Methodology," Revision 0, Volume 1, December 2004, and the associated NRC safety evaluation, "Safety Evaluation by the Office of Nuclear Reactor Regulation Related to NRC Generic Letter 2004-02," December 2004. RG 1.82 also describes methods acceptable to the staff for evaluating the NPSH margin. As directed by NUREG-0800, Section 6.2.2, if the containment accident pressure is credited in determining available NPSH, an evaluation of the contribution to plant risk from inadequate containment pressure should be made.

The review was also informed by WCAP-16406-NP,"Evaluation of Downstream Sump Debris Effects in Support of GSI-191," Revision 1, August 2007, as supplemented by "Final Safety Evaluation for Pressurized Water Reactor Owners Group Topical Report WCAP-16406-P," "Evaluation of Downstream Sump Debris Effects in Support of GSI-191, Revision 1," Revision 0, December 20, 2007; the March 28, 2008, NRC letter, "Revised Guidance for Review of Final Licensee Responses to Generic Letter 2004-02," with enclosures addressing the areas of chemical effects, coatings, and head loss testing; the final safety evaluation by the Office of Nuclear Reactor Regulation on TR WCAP-16530-NP, "Evaluation of Post-Accident Chemical Effects in Containment Sump Fluids to Support GSI-191," December 21, 2007; and the April 6, 2010, NRC letter, "Revised Guidance Regarding Coatings Zone of Influence for Review of Final Licensee Responses to Generic Letter 2004-02.

6.2.2.4 *Technical Evaluation for Long-term Recirculation Water Source*

FSAR Tier 2, Sections 6.2.2 and 6.3 describe the U.S. EPR systems and components that provide containment heat removal, emergency core cooling, and the long-term water source for recirculation cooling. The long-term recirculation flow is achieved through operation of the SIS. The SIS also removes post-accident decay heat from the reactor coolant system (RCS) and provides post-accident containment cooling via the low head safety injection heat exchanger. The water source for the SIS is the IRWST. The IRWST contains a large volume of borated water that is monitored for a homogeneous boron concentration, level, and temperature. The walls of the IRWST are lined with an austenitic stainless steel liner covering the immersed region of the building structure. The IRWST location inside containment is immediately below the RCS loop areas and permits integrating design features that address post-accident debris and ECCS sump blockage. The physical arrangement of these design features in containment creates a tiered strategy to address the potential for ECCS clogging. The design features that create this tiered strategy are shown in FSAR Tier 2, Figure 6.3-4, "SIS Debris Entrainment Prevention Features;" FSAR Tier 2, Figure 6.3-5, "IRWST Sump Level Plan View;" and FSAR Tier 2, Figure 6.3-6, "IRWST Heavy Floor Level Plan View," and include:

- Four independent weir and trash rack structures above the IRWST to retain large debris in the RCS loop floor area and prevent large debris from entering the retaining basket.
- Four independent retaining baskets located within the IRWST and directly below the weir and trash rack structures to catch and retain debris that is carried over the weirs and through the trash racks.
- Four independent three-dimensional flat screen strainers submerged within the IRWST, each protecting one of the four ECCS pump suction sumps located in the IRWST floor.

RG 1.8.2, Revision 3, as modified and supplemented for PWRs by NEI 04-07 and the associated NRC safety evaluation, provide guidance for PWR debris evaluations. The guidance is organized into several subject areas listed below. Each of these areas will be addressed as part of this technical evaluation.

6.2.24.1 6.2.2.4.2	break selection zone of influence (ZOI) /debris generation
6.2.2.4.3 6.2.2.4.4	debris characteristics latent debris
6.2.2.4.5 6.2.2.4.6	coatings evaluation debris transport
6.2.2.4.7 6.2.2.4.8	strainer head loss testing net positive suction head
6.2.2.4.9 6.2.2.4.10	upstream effects (water hold-up debris interceptor/strainer structural analysis
6.2.2.4.11 6.2.2.4.12	downstream effects on ex-vessel components and systems downstream effects on fuel and vessel
6.2.2.4.13	chemical effects

6.2.2.4.1 Break Selection

The objective of the break selection process is to identify the break location that produces the largest head loss across the sump strainer. RG 1.82, Regulatory Position C.1.3.2.3 and NEI 04-07, Sections 3.3 and 4.2.1 and the associated staff SE provide criteria to be considered in the overall break selection process to identify the limiting break.

The applicant's break selection information is provided in Technical Report ANP-10293NP, Appendix C, "Debris Generation Evaluation for the U.S. EPR." This technical report documents how the U.S. EPR meets the intent of RG 1.82 and NEI 04-07 guidance to determine the limiting break for the U.S. EPR.

In the U.S. EPR design, there are primarily three sources of debris that transport to the strainer and contribute to strainer head loss: Latent debris; post-accident chemical effects debris; and coatings debris. In addition, a small amount (0.028 cubic meters (m^3)) (one cubic foot (ft^3), of particulate insulation (microporous – Microtherm) is added to the overall debris source term for all break scenarios. In the U.S. EPR, the amounts of latent and chemical effects debris generated and transported to the strainers are independent of the break location. The coatings debris analysis also assumes a constant volume of coatings debris, based on using the largest break diameter, which is used to determine the coating ZOI. Coatings debris is presented in Section 6.2.2.4.5 of this report.

The largest ZOI is associated with breaks in the cold leg, cross over leg, and hot leg pipes as each of these pipes have the same inside diameter of 78 centimeters (cm) (30.71 in.). Due to the relatively small size of the pressurizer surge line and safety injection line, the debris amount generated by a break in these lines was substantially less than the debris associated with the hot-leg and cold-leg breaks.

NEI 04-07 and the associated SE indicate that main steam and feedwater lines need only be analyzed as potential break location in plants where ECCS recirculation is required to mitigate the effects of breaks in these lines. ANP-10293NP, Appendix C states that main steam line breaks or feedwater line breaks do not require recirculation; therefore, such breaks were not evaluated.

For the U.S. EPR design, seven break locations were evaluated for potential limiting insulation debris loads. ANP-10293NP identifies the limiting break to be the RCS hot leg 3 at the pressurizer surge line connection. FSAR Tier 2, Table 6.3-5, "Total Debris Source Term," presents the type and amounts of insulation debris generated at this break location. For all breaks, insulation debris is limited to RMI and a small, fixed amount of particulate insulation (microporous – Microtherm). There is no fiber insulation source the RCS hot leg 3 at the pressurizer surge line connection produces the most RMI insulation debris.

FSAR Tier 2, Section 6.3.2.5, "System Reliability," states that RMI is not susceptible to transport to the strainer and, therefore, does not contribute to strainer head loss. RMI debris transport is further evaluated in Section 6.2.2.4.6 of this report.

In the U.S. EPR, the amounts of latent debris, particulate insulation debris, and chemical debris generated and transported to the IRWST screen are independent of the break location; therefore, the consideration for break selection is limited to coatings debris.

The U.S. EPR design simplifies the break selection process through selection of insulation materials. As such, the staff finds the spectrum of breaks evaluated by the applicant to be consistent with RG 1.82, Regulatory Position C.1.3.2.3, Revision 3 and meet the intent of NEI 04-07 and the associated staff SE, and is therefore acceptable.

6.2.2.4.2 Zone of Influence/Debris Generation (Excludes Coatings)

The ZOI is the volume about the break in which the LOCA break jet forces would be sufficient to damage materials. Debris generation is the amount of debris generated by these forces.

NEI 04-07, Sections 3.4 and 4.2.2 and associated staff SE provide the methodology to assess ZOI and debris generation. The NEI 04-07 baseline methodology incorporated a spherical ZOI based on material damage pressures. The size of the spherical ZOI is based on experimentally deduced destruction pressures that were determined by applying ANSI/ANS 58.2-1988 standard het expansion models to correlate the damage to insulation blankets or cassettes by air and steam jets during debris generation testing to an equivalent spherical volume of destruction. The relationship between the ANSI/ANS 58.2-1988 standard and the staff SE-approved ZOIs was addressed in Appendix I of the staff SE for the NEI document. Once the ZOI is established for a selected break location, the types and location of all potential debris sources can be identified using plant-specific drawings, specification, or other such reference materials. The amount of debris generated is then calculated based on the amount of materials within the most limiting ZOI. NRC SE Section 4.2.2, for the NEI document discusses proposed refinements to the NEI 04-07 methodology that would allow application of debris-specific ZOIs. This refinement allows the use of a specific ZOI for each debris type identified. Using this approach, the amount of debris generated within each material-specific ZOI is calculated, and then these material-specific debris amounts are added to arrive at a total debris source term. The staff concluded in its SE on NEI 04-07 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 the staff SE, Section 4.2.2 on NEI 04-07, the staff accepted the application of these proposed refinements for PWR sump pump analyses.

The applicant's ZOI and debris generation evaluations and methods are presented in ANP-10293NP, Appendix C, "Debris Generation Evaluation for the U.S. EPR." The applicant uses the analytical refinements associated with debris-specific ZOIs, consistent with staff guidance. This refinement allows use of a specific ZOI for each debris type identified. The applicant selected a ZOI radius for RMO debris generation of two inside diameters, consistent with staff guidance. As discussed above, Microtherm insulation is limited to a small fixed amount, located in the RCS loop area, and all of it is assumed as transportable debris; therefore, a ZOI is not prescribed in the applicant's analysis.

In RAI 434, Question 06.02.02-74, the staff requested that the applicant clarify the selection of the ZOI used to assess the amount of fiber insulation generated during the accident. In a March 31, 2011, response to RAI 434, Question 06.02.02-74, the applicant indicated that the U.S. EPR design no longer incorporated Nukon insulation on piping subject to loss-of-coolant-accident jet blast effects. However, the applicant did not indicate the ZOI selected for the analysis and the staff considered the response to RAI 434, Question 06.02.02-74 incomplete. In follow-up RAI 488, Question 06.02.02-97, the staff requested that the applicant clarify the ZOI selected to address Nukon debris. In a November 11, 2011, response to follow-up RAI 488, Question 06.02.02-97, the applicant indicated there are three types of insulation used in containment: Nukon (or equivalent); Microtherm; and RMI. Only RMI and a minimum amount of Microtherm are used in the RCS equipment space. The applicant selected a ZOI radius of 17 inside diameters, consistent with staff guidance, to evaluate Nukon fiber insulation. In addition, ANP-10293NP, Appendix C was updated to specify 17D ZOI radius to assess Nukon insulation. Since the Nukon ZOI is consistent with the guidance contained in the staff SE on NEI 04-07 and ANP-10293NP has been verified to contain this information, the staff finds the applicant's response acceptable. Accordingly, the staff considers RAI 488, Question 06.02.02-97 resolved.

FSAR Tier 2, Table 6.3-5, “Total Debris Source Term,” lists the debris in containments and states the RMI amount is 196.7 m^2 (2119 ft^2) and microporous (Microtherm) insulating material is 0.03 m^3 (1.0 ft^3). The debris total for coatings is discussed in Section 6.2.2.4.5 of this report.

The staff reviewed the applicant’s insulation ZOI and debris generation evaluations, as presented in ANP-10293NP, relying on the approved methods documented in NEI 04-07, Sections 3.4 and 4.2.2 and the associated staff SE for NEI 04-07 as an acceptance guide. The staff finds that the applicant’s approach, which is consistent with staff guidance on insulation debris-specific ZOIs is acceptable.

6.2.2.4.3 Debris Characteristics

The objective of this section is to assess the applicant’s analysis related to the characteristics of post-accident debris. NEI 04-07, Section 3.4.3 and the associated staff SE provide guidance for debris characteristics. NEI 04-07 describes the debris characteristics in terms of size distribution, size and shape, and density.

The applicant’s discussion of debris characteristics is contained in ANP-10293NP, Appendix C, “Debris Generation Evaluation for the U.S. EPR.” The analyzed debris for the U.S. EOR includes RMI, Microtherm (microporous), coatings, and latent debris. This section describes the applicant’s assumptions regarding insulation debris characteristics. Latent debris, coatings, and chemical debris characteristics are discussed in Sections 6.2.2.4.4, 6.2.2.4.5, and 6.2.2.4.13 of this report, respectively.

The applicant’s size distribution assumed for RMI is 75 percent small pieces and 25 percent large pieces. The applicant’s size distribution for Microtherm is 100 percent small fines with a bulk density of 240 kg/m^3 (15 lb/ft^3).

The staff finds the applicant’s insulation debris characteristics analysis acceptable because it is consistent with the guidance contained in the staff SE associated with NEI 04-07.

6.2.2.4.4 Latent and Miscellaneous Debris

Latent debris is unintended debris present in containment prior to a postulated high-energy line break, which may be composed of various constituent materials including dirt, dust and other particulate, fiber, etc. The objective of the latent debris evaluation is to provide an estimate of the types and amounts of latent debris existing in containment for the purpose of assessing its impact on sump strainer head loss. The applicant performed an evaluation of the potential sources of latent debris within containment using the guidance provided in NEI 04-07 and the associated staff SE.

In ANP-10293NP, Appendix C, the applicant modeled latent fibrous debris as 100 percent small fines that are transportable to the debris screens. The applicant uses a density of 38.4 kg/m^3 (2.4 lb/ft^3) for latent fiber debris. The latent fiber size and bulk density are consistent the staff SE on NEI 04-07, and are acceptable. In addition, the applicant considers Nukon fiberglass to be a suitable surrogate to test latent fiber debris. The use of small fines from a low-density fiberglass, such as Nukon, as a surrogate debris for latent fiber in head loss analysis is acceptable because this practice is consistent the staff SE on NEI 04-07, Section 3.5.2.3, Appendix VII, “Characterization of Pressurized Water Reactor Latent Debris” of that document, and NUREG/CR-6877, “Characterization and Head-Loss Testing of Latent Debris from Pressurized-Water-Reactor Containment Buildings.” These documents indicate that hydraulic properties of latent fiber are similar to those of fiberglass (Nukon).

In RAI 434, Question 06.02.02-78, the staff requested that the applicant clarify their selection of latent particulate debris. In a March 31, 2011, response to RAI 434, Question 06.02.02-78, the applicant presented the latent particulate debris as a mix of dirt and dust (sand) covering a range of sizes consistent with guidance provided in the staff SE on NEI 04-07 and NUREG/CR-6877. Since the applicant's response is consistent the latent debris guidance on latent particulate size, size distribution, and density, the staff considers the response acceptable. Accordingly, the staff considers RAI 434, Question 06.02.02-78 resolved.

In FSAR Tier 2, Table 6.3-5, "Total Debris Source Term," and ANP-10293NP, Appendix C, the total latent debris amount is specified as 68 kg (150 lb). For the strainer head loss evaluation, the applicant assumes that fiber contributes 15 percent of the mass and particulate contributes 85 percent of the mass of the latent debris inventory. The staff considers the latent fiber contribution used for the strainer head loss evaluation acceptable because this practice is consistent with NEI 04-07 and the associated staff SE. While this distribution was acceptable for strainer head loss testing, the applicant's evaluation for fuel assembly testing used a lesser amount. For fuel testing the latent fiber amount was reduced to 6.8 percent and the particulate was increased to 93.2 percent. These values comprise the design basis distribution for latent debris for the U.S. EPR design. This yields a latent fiber amount of 4.6 kg (10.2 lb) and a latent particulate amount of 63.4 kg (139.8 lb). Fuel testing is addressed in Section 6.2.2.4.12 of this report.

In RAI 434, Question 06.3302.02-75, the staff requested that the applicant specify the latent debris design basis information in the FSAR cleanliness program description. In a March 31, 2011, response to RAI 434, Question 06.02.02-75, the applicant listed 68 kg (150 lb) as the latent debris design basis in a markup to FSAR Tier 2, Section 6.3.2, "System Design," which provides the containment cleanliness program requirements that a COL applicant is required to meet. The staff verified that the markup has been incorporated into FSAR Revision 3. Since the applicant clarified the COL applicant cleanliness requirements regarding latent debris, the staff finds the applicant's response to RAI 434, Question 06.02.02-75 acceptable. In addition, in RAI 511, Question 06.02.02-124, the staff requested that the applicant specify the design basis composition of the latent debris inventory in the FSAR. In a November 11, 2011, response to RAI 511, Question 06.02.02-124, the applicant committed to revise ANP-10293P and specify the latent fiber and particulate design basis debris amounts that a COL applicant is required to meet in their containment cleanliness program as 4.6 kg (10.2 lb) of fiber and 63.4 kg (139.8 lb) of particulate. The staff verified that this information was included in ANP-10293NP, Revision 4. The applicant also clarified the composition of latent debris in FSAR Tier 2, Section 6.3.2.2.2, "System Components," in a November 11, 2011, response to RAI 488, Question 06.02.02-91 (an RAI unrelated to latent debris). The FSAR Tier 2, Section 6.3.2.2.2 markup contained in the response to RAI 488, Question 06.02.02-91 reflects the same latent debris composition presented in the response in RAI 511, Question 06.02.02-124 and reflected in ANP-10293NP, Revision 4. Limiting the fiber inside the U.S. EPR containment to 4.6 kg (10.2 lb) equates to 6.8 percent of the total latent debris. The applicant explained that this is consistent with NUREG/CR-6877 which shows that the average percentage of fiber in four sample plants is 6.8 percent with two of the four sample plants less than 4 percent.

The staff finds that the assumption of 68 kg (150 lb) is a practical estimate of the total latent debris mass for the U.S. EPR containment. In accordance with the containment cleanliness program, applicants that reference the U.S. EPR must include a program to limit the amount of latent debris left inside containment following refueling and maintenance outages to the design basis amounts. The staff finds the 68 kg (150 lb) of total latent debris, consisting of 4.6 kg (10.2 lb) of fiber and 63.4 kg (139.8 lb) of particulate, inside the U.S. EPR containment acceptable because of the COL commitment to limit latent debris to these design-basis amounts. Given the discussion above, the staff finds the applicant's responses to RAI 511, Question 06.02.02-124 and RAI 488, Question 06.02.02-91 acceptable. The staff confirmed that FSAR Revision 4, dated November 15, 2012, contains the changes committed to in the RAI response. Accordingly, the staff finds that the applicant has adequately addressed this issue and, therefore, considers RAI 511, Question 06.02.02-124 and RAI 488, Question 06.02.02-91 resolved.

The objective of the miscellaneous debris evaluation is to provide an estimate of the types and amounts of miscellaneous debris existing in containment for the purpose of assessing its impact on sump strainer head loss. Miscellaneous debris is composed of items such as equipment tags, tape, labels, and placards. NEI 04-07, Section 3.5.2.2.2 and the associated staff SE provide guidance to be used to identify and evaluate potential sources of miscellaneous debris in containment. The guidance indicates that if transportability of miscellaneous debris or the capability of miscellaneous debris to remain intact cannot be determined, then it should be assumed that they remain intact and are transported to the sump screen, to preserve conservatism. In the absence of specific date that describes the behavior of miscellaneous debris, guidance states that the wetted sump-screen flow area be reduced by an area equivalent to 75 percent of the surface area of the debris.

In ANP-10293NP, Appendix C, the applicant assumes an amount of miscellaneous debris that could be generated in the U.S. EPR, representing items such as equipment tags, tape, and labels. The applicant assumption that the equipment tags, tape, and labels, etc., could generate debris and transport to the screens, under post-accident conditions, is consistent with the staff SE on NEI 04-07. In RAI 434, Question 06.02.02-70, the staff requested that the applicant clarify miscellaneous debris assumptions and treatment of miscellaneous debris during strainer design basis testing. In a March 31, 2011, response to RAI 434, Question 06.02.02-70, the applicant defined the miscellaneous debris source term as 9.3 m^2 (100 ft^2). ANP-10293NP, Appendix C, Section C.2.2, "Plant Specific Assumptions," also lists the miscellaneous debris source term as 9.3 m^2 (100 ft^2). The U.S. EPR testing program accounts for miscellaneous debris as reduced screen area equal to 75 percent of the original single-sided area of the miscellaneous materials are described in ANP-10293NP, Appendix E, "ECCS Strainer Performance Testing for the U.S. EPR." The staff finds the applicant's treatment of miscellaneous materials (i.e., as reduced screen area) acceptable because it is consistent with the guidance in the staff SE on NEI 04-07. Given the discussion above, the staff considers RAI 434, Question 06.02.02-70 resolved.

In addition, in RAI 434, Question 06.02.02-75, the staff requested that the applicant clarify the miscellaneous debris design basis requirements in the cleanliness program description. In a March 31, 2011, response to RAI 434, Question 06.02.02-75, the applicant added miscellaneous debris design basis information in a markup to FSAR Tier 2, Section 6.3.2 that provides the containment cleanliness program requirements that a COL applicant is required to meet. The staff verified that the markup has been incorporated into FSAR Revision 3.

The staff concludes that the 9.3 m^2 (100 ft^2) assumption is a practical estimate of the miscellaneous debris in the U.S. EPR containment. In accordance with the containment cleanliness program, applicants that reference the U.S. EPR design must include a program to limit the amount of miscellaneous debris in containment. The staff finds the 9.3 m^2 (100 ft^2) assumption of miscellaneous debris inside the U.S. EPR containment acceptable because of the COL commitment to limit miscellaneous debris to the design basis amount.

Given the discussion above, the staff finds that the applicant's method an approach to assess latent and miscellaneous debris acceptable because it is consistent with staff guidance and the FSAR has a COL commitment that limits debris to the design basis amounts. Accordingly, the staff considers RAI 434, Question 06.02.02-75 resolved.

6.2.2.4.5 Coatings Evaluation

To determine if the U.S. EPR design meets the requirements of GDC 35, GDC 38 and 10 CFR 50.46(b)(5) with respect to protective coatings (paint) in containment, the staff reviewed information in the FSAR and supporting documents listed in Section 6.2.2.3 of this report. The following are key guidance documents for coatings debris, and the first two are exclusive to coatings debris:

- "Revised Guidance Regarding Coatings Zone of Influence for Review of Final Licensee Responses to Generic Letter 2004-2, 'Potential Impact of Debris Blockage on Emergency Recirculation during Design Basis Accidents at Pressurized-Water Reactors,'" April 6, 2010

- Enclosure 2, "NRC Staff Review Guidance Regarding Generic Letter 2004-02 Closure in the Area of Coatings Evaluation," to "Revised Guidance for Review of Final Licensee Responses to Generic Letter 2004-20, 'Potential Impact of Debris Blockage on Emergency Recirculation during Design Basis Accidents ay Pressurized-Water Reactors," March 28, 2008

- NEI 04-07, Revision 0, December 2004, and the staff's accompanying safety evaluation

As stated in the staff SE on NEI 04-07 for protective coatings, it is acceptable for applicants to use a coatings ZOI spherical equivalent distance determined by plant-specific analysis or a default value of 10 pipe diameters. Subsequent to the guidance issued in the staff SE on NEI 04-07, additional coatings testing was completed and demonstrated that some coatings qualified for a ZOI reduction. The staff's March 2008 guidance regarding coatings zone of influence approved a ZOI of 4D (4 pipe diameters) for epoxy based coatings. The staff's April 2010 coatings guidance confirmed the March 2008 guidance remains valid for epoxy coatings.

Depending on the break location, coated components may or may not exist within this sphere. Where plant-specific data do not exist regarding the amount of coating within the ZOI, the NEI 04-07 guidance assumes that the area of coated structures and components within the ZOI volume, equivalent to the surface area of a sphere, will exist within this volume and generate fine particulate debris. The amount of coating debris generated is a function of the coating thickness and the surface area.

FSAR Tier 2, Section 6.1.2.1, "Description of Protective Coatings," provides a description of U.S. EPR protective coatings. Service Level I coatings are used inside containment in areas where coatings failure and subsequent transport to the IRWST sump screen could result in recirculation flow blockage. In addition, coatings are discussed in ANP-10293NP, Appendix C. Section 6.1, "Engineered Safety Features Materials," of this report provides additional analysis of protective coatings.

In ANP-10293NP, Section C.4.3.7, "Coatings Debris," the applicant applied a ZOI spherical equivalent of 10 pipe diameters in inorganic zinc (IOZ) coatings and a ZOI spherical equivalent of 4 pipe diameters for epoxy based coatings, consistent with staff guidance.

The coating debris volume is calculated based on the surface area of the ZOI sphere multiplied by the coating thickness. The sphere is ten times the largest main coolant pipe break diameter for IOZ and four times the largest main coolant pipe break diameter for epoxy coatings. Based on this analysis approach, the debris total for coatings is independent of the break location. In ANP-10293NP, Section C.4.3.7, the applicant states that the thicknesses of protective coatings in the U.S. EPR design are not yet specified. In ANP-10293NP, Section C.2.2, the applicant assumes a coating thickness of 0.0076 cm (3 mils (0.003 in.)) for IOZ coatings and 0.03 cm (12 mils (0.012 in.)) for the epoxy coatings to determine the amount of protective coatings generated from a postulated LOCA.

The applicant describes the U.S. EPR coatings assumptions in ANP-10293NP, Appendix C, Section C.2.2, "Plant Specific Assumptions." The qualified coatings within containment consist mainly of epoxy with an approximate density of 1506 kg/m^3 (94 lb/ft^3). In high temperature areas where epoxy coatings are not practical, IOZ coatings with an approximate density of 7320 kg/m^3 (457 lb/ft^3) are applied in lieu of epoxy coatings.

In ANP-10293NP, the applicant sized coatings debris as 100 particulate, consistent with NEI 04-07, Section 3.4.3 (e.g., 10 microns (0.4 mils)). The staff believes it is appropriate to treat the coatings in the ZOI as particulate for two reasons. First, all the coatings in the containment are qualified and only coatings within the ZOI will fail. Second, coatings within the ZOI are subjected to jet forces that are known to erode the coatings into a particulate form.

The applicant's strainer testing uses acrylic powder and tin powder as surrogates for epoxy and inorganic zinc coatings, respectively. Acrylic powder has similar density as epoxy and tin powder has a similar density as inorganic zinc. Based on the surrogate particle sizing and material density, the applicant's surrogate materials are considered comparable to the plant coating materials for strainer head loss testing purposes. Section 6.2.2.4.7 of this report discusses the head loss test program and results.

Since the applicant used a simplifying assumption to calculate the mass of coating debris (i.e., assuming a coating area equal to the surface area of the spherical ZOI and applying an assumed coating thickness), in RAI 429, Question 06.02.02-67, the staff requested that the applicant confirm that coatings in the as-built plant are bounded by the design analysis. In an October 24, 2011, response to RAI 429, Question 06.02.02-67, the applicant proposed ITAAC for coatings. The staff agrees with adding ITAAC analysis and inspection-related activities for coatings to confirm the as-built plant conforms to the design basis analysis. Therefore, the staff finds the applicant's response (FSAR markups) acceptable. The staff confirmed that FSAR Revision 4, dated November 15, 2012, contains the changes committed to in the RAI response. Accordingly, the staff finds that the applicant adequately addressed this issue and, therefore, considers RAI 429, Question 06.02.02-67 resolved.

In ANP-10293NP, Section C.4.3.7, the applicant affirms that unqualified coatings are not planned within the U.S. EPR containment. However, an amount of unqualified coatings is assumed to be present; all of which is assumed to fail as particulate and has a density consistent with epoxy coatings.

Based on the above guidance and assumptions, the applicant determined the qualified coatings amounts to be 57 kg (126 lb) for qualified epoxy coatings and 435 kg (250 lb) for qualified IOZ coatings. Unqualified coatings are assumed to make up 113 kg (250 lb) of the total debris source term. A summary of the coatings debris is found in FSAR Tier 2, Table 6.3-5, "Total Debris Source Term."

On the basis of the discussion above, the staff finds the applicant's qualified coating assessment is consistent with NRC guidance in RG 1.82, Revision 3; NEI 04-07 and the associated staff SE; and the March 2008 coating guidance and. therefore, is acceptable with respect to the coatings ZOI, quantity, characteristics, and the representation of coatings in screen testing. In addition, the U.S. EP has an ITAAC that verifies the coatings amount is consistent with the design basis.

6.2.2.4.6 Debris Transport

Debris transport analysis estimates the fraction of debris that would be transported from debris sources within containment to the sump suction strainers for postulated high energy line breaks requiring sump recirculation. Guidance is found in NEI 04-07, Section 3.6, "Debris Transport," as modified by the staff's SE. In general, debris transport in the containment can be considered to occur through four primary mechanisms:

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

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

- pool fill transport is the horizontal transport of debris by break flow and containment spray flow to areas that may be active or inactive during recirculation

- containment pool recirculation transport, which is the horizontal transport of debris from the active portions of the containment pool to the suction strainers through pool flows inducted by the operation of the ECCS and CSS in recirculation mode

For the U.S, EPR, debris transport in containment depends on blowdown, washdown due to fluid flowing from the break as well as condensation, and containment pool recirculation. Since the U.S. EPR has no containment spray actuation during design basis accidents, the associated washdown effect for debris transport is limited. Also, there is no pool fill because of the IRWST design.

The applicant describes debris transport in ANP-10293NP, Section 3.1.1, "Debris Transport." Although the U.S. EPR design incorporates multiple LOCA return flow paths and a tiered debris retention system, the applicant takes a conservative approach in the debris transport evaluation, in that credit is not taken for all design features. For strainer evaluation purposes, all LOCA related debris is transported to the IRWST and one of the four available retaining baskets. No credit is taken for debris settling prior to entering the retaining basket. In addition, all debris that bypasses the basket is assumed to collect on a single strainer. Transporting all the debris that bypasses the retaining basket to a single strainer is conservative because this assumption does not credit debris settling and minimizes the strainer area for debris accumulation (a minimum of two strainers would be in service during a postulated LOCA_. FSAR Tier 2, Section 6.3.2.5, "System Reliability," states that RMI, due to its high density, is not susceptible to transport tests with RMI. During testing, RMI was shown to sink and settle to the bottom of the retaining basket. RMI transport testing is discussed in Section 6.2.2.4.7 of this report.

Given the discussion above, the staff finds that assuming all the debris transports to the IRWST and is filtered by a retaining basket and strainer is consistent with guidance and is acceptable to evaluate strainer head loss.

6.2.2.4.7 Strainer Head Loss Testing

The objective of this section is to provide the staff's evaluation of the applicant's strainer head loss testing approach and results. The applicant conducted strainer head lost testing to demonstrate that the strainer head loss assumed in the emergency core cooling pump NOPSH evaluation is appropriate. The emergency core cooling pump NPSH review is discussed in Section 6.3 of this report. The staff review did not include any correlations developed to predict plant-specific strainer performance given the types of debris materials and plant parameters. Therefore, the staff's evaluation of strainer head loss is based on the applicant's plant-specific testing as the method to evaluate strainer performance inputs to the NPSH evaluation.

During a postulated LOCA inside containment, pipe and equipment insulation and coatings can be fragmented by the jet forces emitted from the break location. Chemical precipitate debris may be created from the coolant system fluid and the buffering agent solutions interacting with plant materials and the generated debris. Chemical debris is addressed in Section 6.2.2.4.13 of this report. This mixed debris potentially transports from the area of the break to the IRWST.

In the U.S. EPR, debris screens are located in the IRWST and upstream of the SIS pumps to minimize debris from entering the pump suction. Debris that transports to the IRWST must not cause a screen head loss that adversely impacts NPSH and satisfactory operation of the SIS pumps during a LOCA condition. The overall head loss attributable to the strainer is a combination of the head loss due to debris deposited on the strainer and the head loss associated with the clean strainer.

In FSAR Tier 2, Section 6.3.2.2.2, "System Components," under the heading for the In-Containment Refueling Water Storage Tank, the applicant indicates that the test program is summarized in ANP-10293P, "U.S. EPR Design Features to Address GSI-1914." In ANP-10293P, the applicant describes the U.S. EPR strategy to address ECCS sump suction clogging. The strategy includes a set of four protective weir/trash rack structures, four retaining baskets, and four strainers. The weir (curb) is located next to the heavy floor opening and is approximately 5 cm. (2 in.) high, to facilitate water pooling and debris settling in the RCS loop vault areas. The trash rack is a 4x4 heavy-duty screen that fully encompasses the floor opening and prevents large debris from entering the retaining basket below. The four retaining baskets are approximately 4.9 m (16 ft) tall and are located in the IRWST under each weir/trash rack port to catch and retain any debris that is carried through the trash racks by ECCS recirculation flow. The four retaining baskets are partially submerged during normal operations and during response to design basis accident conditions. The four sump strainers are about 2.1 m (7 ft) tall and are also located in the IRWST. The strainer and retaining basket have the same mesh size, 0.2 cm x 0.2 cm (0.08x0.08 in.), to filter debris.

The staff evaluated the applicant's strainer design basis testing using NRC guidance from "NRC Staff Review Guidance Regarding Generic Letter 2004-02 Closure in the Area of Strainer Head Loss and Vortexing," and "NRC Staff Review Guidance Regarding Generic Letter 2004-02 Closure in the Area of Plant-Specific Chemical Effect Evaluations," to "Revised Guidance for Review of Final Licensee Responses to Generic Letter 2004-02, 'Potential Impact of Debris Blockage on Emergency Recirculation during Design Basis Accidents at Pressurized-Water Reactors,'" March 28, 2008.

The applicant conducted a number of tests that informed the final approach selected to serve as the design basis for strainer head loss testing. The applicant's interaction with the staff regarding their initial testing is discussed in the next few paragraphs.

In a January 27, 2010, public meeting, the applicant summarized changes to their debris source term based on the results of sensitivity studies (head loss testing). These sensitivity studies let the applicant to reduce the particulate source term for Microtherm and coatings.

In a December 14, 2010, letter “AREVA NP, Inc., Closure Plan for Issues Associated with GSI-191 for the U.S. EPR Design Certification,” the applicant summarized additional changes based on the results of evaluations and GRI-191 testing. In the December 14, 2010, letter, in Table 2, “Summary of Sump Strainer Test Results,” the applicant summarizes the head loss results from Test 4 and 4a; both were thin bed tests. Although these tests did not end up serving as the applicant’s design basis tests, the staff considers that questions developed during the review of these two tests influenced the changes discussed in the December 14, 2010, letter. In RAI 378, Question 06.02.02-45, the staff requested that the applicant clarify the approach taken with regard to thin bed testing, which was selected in Test 4, conducted in February 2010. In an October 26, 2010, response to RAI 378, Question 06.02.02-45, the applicant revised how they approached thin bed testing. For example, the applicant’s fiber additions are now based on forming a thin bed on the wetted screen area of the retaining basket versus all the screen area available in the test flume. The staff finds this approach reasonable and consistent with staff guidance and, therefore, considers RAI 378, Question 06.02.02-45 resolved. This revised approach to thin bed testing was implemented in Test 4a in August 2010. During Test 4a, a large amount of floating debris covered the test flume surface. As a result, in RAI 434, Question 06.02.02-79, the staff requested that the applicant evaluate the floating debris that was unable to interact with the strainer (Note: No significant amount of floating debris was observed in the February 2010 testing). In a March 3, 2011, response to RAI 434, Question 06.02.02-79, the applicant changed the test protocol to carefully re-introduce any floating debris, thereby permitting the debris to interact with the strainer. Since the applicant adjusted the protocol to re-introduce floating debris, making it available to accumulate on the strainer and contribute to strainer head loss, the staff finds the applicant has adequately addressed this issue. Accordingly, the staff considers RAI 434, Question 06.02.02-79 resolved.

In the December 14, 2010, letter, the applicant committed to remove all fibrous insulation from the ZOI and replace it with RMI, thereby eliminating insulation from contributing to the fiber source term; leaving latent debris as the only fiber source. The December 14, 2010, letter further describes reducing the amount of latent debris from 113 kg (250 lb) to 88 kg (150 lb) (see Section 6.2.2.4.4 of this report for a discussion of latent debris). This reduction in the total amount of latent debris further reduced the fiber loading used to conduct strainer head loss tests. ANP-10293NP, Table E.2-2, “U.S. EPR Strainer Performance Tests – Phase 2,” provides a list of testing conducted in January and February 2011 that incorporated the design changes discussed in the December 14, 2010, letter. In ANP-10293NP, Appendix E, “ECCS Strainer Performance Testing for the U.S. EPR,” the applicant provides test results from Phase 1, Test No. 4 discussed above. The staff does not consider this test to be consistent with staff guidance with regard to the thin bed test approach. In addition, the staff notes the Phase 1 tests used a lower flow rate (non-conservative). Results from the Phase 1 strainer head loss tests are not relied upon in this report to reach a safety finding regarding strainer performance.

The U.S. EPR Phase 2 head loss testing was performed at Alden Research Laboratory (ARL). The scaled down test facility included a large steel tank that contained a retaining basket and strainer, which is representative of one of four ECCS trains in the U.S. EPR design. In the plant design, fluid from a postulated LOCA flows onto the heavy floor and then falls into the IRWST through four heavy floor openings. The test apparatus simulates the free-fall flow of water from one heavy floor opening by introducing the return flow at an elevation above the flume water surface. As the water enters the test flume, it flows through a retaining basket and towards the strainer. Downstream of the strainer, the water enters a recirculation loop and is pumped back to the top of the retaining basket to simulate the flow of water onto the heavy floor and through the floor opening.

For strainer testing the scaling approach, screen area, flow rate, strainer submergence, and debris amounts are important elements of the test setup and are discussed in the next few paragraphs.

In ANP-10293NP, Appendix E, the applicant adopted an area ratio-based geometrical scaling approach. The area ratio is a ratio of the test strainer area to the plant strainer area. The applicant refers to this area ratio as the scale factor. Based on this scaling approach, scaled down sections of the plant strainer and retaining basket were placed in a test loop. The test flow rate was determined by multiplying the design basis maximum sump flow rate by the area-ratio. In this way, the screen surface approach velocity was kept the same as the plant. The debris loading in the testing was also scaled based on the area ration. The area ratio-based scaling approach is consistent with staff testing guidance and, therefore, the staff finds this approach acceptable.

In the U.S. EPR there are two types of retaining baskets used to filter debris, a single compartment and a double compartment. The double compartment basket contains a large basket and a small basket which are separated by a screened panel. The double compartment large basket receives flow from the heavy floor and the double compartment small basket receives flow from the annular floor. The basket used for testing was scaled from the double compartment large basket. Since there are two basket designs (single and double), in RAI 488, Questions 06.02.02-95 and 06.02.02-98, the staff requested that the applicant justify the basket design selected for area scaling. In a November 11, 2011, response to RAI 488, Question 06.02.02-95, the applicant provided additional justification about how the area of the double compartment basket is limiting with regard to filtering area (smaller area) in comparison to the single compartment basket, because the single compartment basket will communicate with the other retaining baskets via the gutters and annular space in the event the basket clogs and causes a level rise. The staff notes that the applicant included this information in ANP-10293NP, Revision 4. The staff finds the applicant’s response to RAI 488, Question 06.02.02-95 acceptable because debris collection over a smaller area tends to increase head loss and is consistent with staff testing guidance. In a November 17, 2011, response to RAI 488, Question 06.02.02-98, the applicant provided a comparison between the double compartment large basket and double compartment small basket. The applicant clarified that the debris loading for the small basket is much less than that of the large basket and the small basket is expected to perform in a similar manner as the large basket, that is, similar head loss and bypass performance. Therefore, the applicant concluded that the small basket is bounded by the large basket testing. The staff notes that the applicant included this information in ANP-10293NP, Revision 4. Given the discussion above, the staff finds the applicant’s response to RAI 488, Question 06.02.02-98 acceptable. Accordingly, the staff considers RAI 488, Question 06.02.02-98 resolved.

In RAI 434, Question 06.02.02-69, the staff requested that the applicant clarify the basis for the plant flow rate used to calculate the scaled test flow rate. In a March 31, 2011, response to RAI 434, Question 06.02.02-69, the applicant adjusted the plant flow rate to the design basis maximum flow rate and, as a result, increased the test flow rate used for strainer testing. ANP-10293NP, Appendix E, shows that the increased flow rate was used during Phase 2 Tests 1D and 1E. The staff finds the applicant’s response to RAI 434, Question 06.02.02-69 acceptable because the test flow rate was scaled from the design basis maximum flow rate and any effect due to uncertainty in the flow rate used for strainer debris head loss testing is minimized given that the strainer debris head loss (discussed below) was minimal due to the presence of clean strainer during strainer testing.

ANP-10293NP, Section 3.0, “Applicable U.S. Design Bases,” indicates that the IRWST minimum water level is 3 m (10.0 ft) above the bottom of the IRWST and the strainer height is 2.4 m (7.8 ft). This results in a strainer submergence of 0.7 m (2.2 ft) under LOCA conditions. In ANP-10293NP, Appendix E, the applicant documents use of a one to one vertical scaling approach for water level and a strainer minimum submergence consistent with LOCA conditions. Therefore, because the strainer submergence used for testing is consistent with the design basis minimum submergence level, the staff finds the submergence used for testing acceptable.

ANP-10293NP, Appendix E documents several screen head loss tests. These tests were performed over a period of time, capturing difference evolutions of the design. In RAI 488, Question 06.02.02-96, the staff requested that the applicant specify which tests were credited with establishing the U.S. EPR strainer design basis tests. In a November 11, 2011, response to RAI 488, Question 06.02.02-96, the applicant included information in ANP-10293NP, Revision 4 that clearly identified Phase 2 Tests 1D, 1E, 2E, and 2F as comprising the design basis tests for the U.S. EPR. Since there were not changes in debris source term, test setup, test protocol, and flow rate over the course of the test program, only Tests 1D and 1E, which use the design basis source term, screen area, screen size, flow rate, and a protocol consistent with staff guidance, are considered representative of the U.S. EPR design for retaining basket and strainer head loss in this report. Tests 2E and 2F are fiber-only strainer bypass tests. These tests support the amount of fiber selected for downstream effects testing. Downstream effects testing is discussed in Sections 6.2.2.4.11 and 6.2.2.4.12 of this report for ex-vessel and in-vessel, respectively. Based on the discussion above, the staff finds that the applicant clearly identified the design basis tests. Therefore, the staff finds the applicant’s response to RAI 488, Question 06.02.02-95 acceptable. Accordingly, the staff considers RAI 488, Question 06.02.02-95 resolved.

The applicant conducted testing using plant-specific debris loads consistent with the debris generation and transport assumptions discussed previously. The debris consisted of non-chemical particulates (coatings, latent dirt and dust, and Microtherm), latent fiber, RMI, and chemical precipitates. The types and quantities of debris selected for the U.S. EPR strainer head loss testing program are shown in ANP-10293NP, Table E.5-2, “Debris Allocation and Flume Flow Rate for Head Loss Tests.”

The debris loads used in the tests were scaled down from the plant debris loads based on the area ratio discussed previously. The staff compared the characteristics of the surrogate test materials with the corresponding plant material to confirm prototypicality or conservatism. The surrogate insulation materials used by the applicant in head loss testing for the insulation debris were the same type as the plant material. Latent debris, coatings, and chemicals surrogate materials are discussed in Sections 6.2.2.4.4, 6.2.2.4.5, and 6.2.2.4.13, respectively, in this report. As discussed in these sections, the staff finds that the applicant’s surrogate materials used for head loss testing are acceptable because they are consistent with staff guidance.

RMI Debris Head Loss Assessment

The applicant conducted transport tests with RMI. During the Debris Transport Tests conducted in December 2009, RMI debris pieces of 0.05 mm (2 mil) thickness and various sizes from 6.4 mm x 6.4 mm (0.25 in x 0.25 in.) up to 10.2 cm x 10.2 cm (4 in. x 4 in.) were shown to sink and settle on the bottom of the retaining basket. Due to the non-transport characteristics of RMI under design flow conditions, RMI was not included in subsequent tests. Removing RMI from subsequent tests also prevents the possibility of RMI debris trapping fibrous debris and potentially limiting fiber transport to the strainer, thus resulting in conservative conditions. For the debris loads expected in U.S. EPR, it is considered acceptable by the staff to perform screen head loss testing without introducing RMI into the test flume along with the other debris.

Miscellaneous Debris (Tags, Tape, Label) Head Loss Assessment

Based on the U.S. EPR miscellaneous debris analysis, the applicant assumed 9.3 m^2 (100 ft^2) of miscellaneous debris (tags, tape, and labels, etc.) is available within containment to potentially obstruct portions of the screens. To account for miscellaneous debris, the applicant applied a 9.3 m^2 (100 ft^2) area reduction to the retaining basket screen because the flow into the IRWST is first filtered through the retaining basket. Since the applicant's treatment of miscellaneous debris is consistent with staff guidance found in the staff SE of NEI 04-07, the staff finds the applicant's treatment of miscellaneous debris acceptable.

Debris Preparation, Sequencing and Addition

All debris was prepared as fine and/or readily suspendable materials. The non-chemical debris were placed into buckets and mixed with water. The materials were well mixed with no agglomeration. The chemical products were formed outside the test loop consistent with staff guidance as discussed in Section 6.2.2.4.13 of this report.

All debris was poured into a tank and pumped into the test flume except for the latent particulate material (dirt and dust) and chemicals which were added directly into the test flume. The debris was sequenced into the flume in the following order: All non-chemical particulate then fiber. Chemical additions followed completion of all non-chemical particulate and fiber additions. Fibrous debris was added in small batches for Phase 2 Tests 1D and 1E. The amount of fiber in each small batch was based on forming a 1.6 mm (1/16 in.) theoretical bed on the wetted retaining basket screen area. Debris was added slowly into the test tank, in small batches, with the pump running.

The applicant's debris preparation, sequencing and additions were consistent with the staff's March 2008 testing guidance. For example, the debris was prepared as fine and readily suspendable material, the debris was sequenced with the most transportable debris first and the least transportable last, and the debris was introduced slowly into the test tank with the pump running and conservative hydraulic conditions (mixing, non-settlement test) established. Given the discussion above, the staff finds the applicant's debris preparation, sequencing and additions acceptable.

Strainer Head Loss Testing Assessment

As discussed above, the applicant's head loss testing approach is consistent with staff guidance and, as such, provides confidence that the test results reasonably bound the peak head loss. Two main tests are typically conducted to evaluate strainer head loss, a full load test, and thin bed test. For plants with minimal fibrous debris, a test with the upper bound fiber quantities may also serve to determine whether or not the thin bed configuration can occur. Since the U.S. EPR has minimal fiber debris, all design basis fiber debris was added during the thin bed test and satisfies the full load test.

The staff testing guidance indicates that an acceptable thin bed test should sequence the debris by adding 100 percent of the plant particulate load to the test flume and, subsequently adding fibrous debris in incremental batches of an approximate size to form a thin bed. Even if the plant has enough fiber to form a thick fibrous bed, the accumulation process should pass from zero accumulation to bed thicknesses greater than the typical thin bed thickness incrementally to ensure that the peak response is determined. A thin bed can be more challenging than thicker beds because a relatively small amount of fibrous debris can capture a relatively large amount of particulate debris resulting in a debris bed with relatively low porosity. The applicant's testing approach, documented in ANP-10293NP for Test 1D and 1E, was consistent with this guidance and, therefore, the staff finds this approach acceptable.

For Test 1D and 1E, after adding all the fiber material, the basket had negligible level change and the strainer head loss remained steady, consistent with a clean strainer head loss. The test demonstrated that the amount of fiber that bypassed the basket and collected on the strainer was not sufficient to cause an increase in strainer head loss. There was no observed change in sump strainer head loss after chemicals were added. After test termination, the test flume was drained and revealed that some of the strainer area was free of debris. Since there was strainer area free of debris, the measured total strainer head loss was similar to the measured clean strainer head loss. Test 1E was identical to Test 1D and confirmed repeatability.

The applicant investigated vortex formation as part of the strainer testing program. Strainer testing was conducted at the minimum water level and maximum strainer flow rate and showed no signs of vortex formation. Additionally, the applicant provided a vortex evaluation in ANP-10293NP, Section 3, "Applicable U.S. EPR Design Bases," that indicates that the available sump submergence is greater than the minimum required using the methodology from American National Standards Institute, ANSI 9.8-1998, "Pump Intake Design," and, therefore, vortex formation is unlikely. In addition, the applicant strainer test results showed that the maximum head loss across the screen is less than the strainer submergence. Therefore, flashing and deaeration are not expected to occur at the strainer during recirculation. Based on the discussion above, the staff finds that air ingestion due to vortex formation, flashing, and deaeration are unlikely to occur.

ANP-10293NP, Appendix E documents the results of Phase 2 strainer design basis head loss Tests 1D and 1E. Tests 1D and 1E show the measured strainer head loss did not appreciably change due to debris addition. Therefore, the strainer head loss is similar to the measured clean strainer head loss, which is no more than 0.15 m (0.5 ft) with a water temperature near 49 C (120 °F). This is consistent with visual observations of the strainer screen during draindown of the test flume. The tested strainer head loss is approximately one-tenth the design basis strainer head loss.

As discussed above, the applicant's strainer head loss testing approach is consistent with staff guidance and, as such, provides confidence that the testing bounds the peak head loss. The test result for the maximum head loss across the screen is less than the design basis strainer head loss assumed in the NPSH evaluation discussed in Section 6.3 of this report.

The staff finds that the applicant's strainer design basis testing is consistent with staff testing guidance and provides a reasonable approach to determine the effects of U.S. EPR plant-specific debris on strainer performance, and is therefore acceptable.

6.2.2.4.8 Net Positive Suction Head

The NPSH evaluation is presented in Section 6.3 of this report. The staff finds that the applicant's strainer head lost test result and IRWST inventory (minimum level) evaluated in Sections 6.2.2.4.7 and 6.2.2.4.9, respectively, support the NPSH evaluation discussed in Section6.3.

6.2.2.4.9 Upstream Effects

The purpose of the upstream effects review is to ensure that the applicant has accounted for potential holdup volumes, choke points, and other physical obstructions that could prevent water from draining to the sump. Water contained in holdup volumes would not be available in the IRWST to provide strainer coverage and would result in a reduction of available net positive suction head by impacting IRWST minimum water level analysis. NEI 04-07, Section 7.2 and the associated staff SE provide guidance to be considered in the upstream effects evaluation.

Early versions of ANP-10293P provided limited discussion on upstream effects. In RAI 434, Question 06.02.02-76, the staff requested that the applicant provide additional information related to upstream effects analysis. In a March 31, 2011, response to RAI 434, Question 06.02.02-76, the applicant provided information on water holdup in ANP-10293NP, Revision 3, Section 3.2.5, "Water Holdup." In a November 14, 2011, response to RAI 507, Question 06.02.02-121, the applicant stated that a summary of the upstream effects evaluation will be provided in ANP-10293NP, Revision 4, Section 3.2.6, "Upstream Effects." The staff verified that ANP-10293NP, Revision 4 contains Section 3.2.6 and provides a summary of the upstream effects evaluation. In a February 10, 2012, response to RAI 434, Question 06.02.02-72, the applicant also provided additional information on water holdup in ANP-10293NP, Revision 4, Section 3.2.5.

In ANP-10293NP, Revision 4, Section 3.2.5, water holdup in the Reactor Building is examined during various phases of the large break LOCA transient, including time of blowdown, refill/reflood, post-reflood, peak containment pressure, and half peak containment pressure. The different categories analyzed for water holdup include water as condensate on walls and ceiling, water retained in steam and droplet phase in the containment atmosphere, and water retained on floors. Water is also retained in a retaining basket, assumed to be clogged, and in the reactor coolant system. FSAR Tier 2, Section 6.2.1.1, "Containment Structure," indicates the U.S. EPR design does not have an automatic containment spray system for design basis accident mitigation. Therefore, the containment spray system does not contribute to water holdup.

In the applicant water retention analysis provided in the February 10, 2012, response to RAI 434, Question 06.02.02-72 and summarized in ANP-10293NP, Section 3.2.5, the dominant contributors to water holdup are water retained in the steam phase in the containment atmosphere and the water that collects on the floors with weirs (curbs) that directly drain to the IRWST (i.e., heavy floor and the annular floor). The amount of steam in the containment atmosphere is based on the containment vapor partial pressure and saturation temperature for the various LOCA phases described above. (Additional information related to the applicant's water holdup analysis can also be found in the December 15, 2011, response to RAI 340, Question 06.02.01-57, in which the applicant refers to the response provided in RAI 434, Question 06.02.02-72.)

The analysis for the heavy and annular floor considers water holdup behind weirs (curbs) that surround drainage openings, plus a dynamic head based on the floors water flow rate. The water flow on the heavy floor consists of condensation flow from rooms above the heavy floor and liquid break flow leaving the reactor coolant system. The heavy floor drains to the IRWST via four large floor openings that are surrounded by trash racks. In the heavy floor water holdup analysis, only three of the four large openings are credited to drain water as an added conservatism. In the March 31, 2011, response to RAI 434, Question 06.02.02-76, the applicant describes four wall openings that connect the steam generator blowdown (SGBD) tank room to the heavy floor (summarized in ANP-10293NP). These openings route fluid from a break in the pressurizer surge line out of the SGBD tank room and onto the heavy floor. In the water retention analysis, the SGBD tank room is considered to be flooded at the same depth as the heavy floor.

The water flowing into the annular floor consists of condensation flow (no break flow) from areas above the annular floor. Water collected on the annular area floor drains to the IRWST via seven wall openings that are situated just above the annular floor elevation. These seven wall openings are fitted with gutters that direct the water into the IRWST's retaining baskets. In RAI 488, Question 06.02.02-93, the staff requested that the applicant clarify in the FSAR the design basis function of the gutters. In a November 11, 2011, response to RAI 488, Question 06.02.02-93, the applicant provided markups to FSAR Tier 2, Section 6.2.2.2, "In Containment Refueling Water Storage Tank," that describes that gutters function to maintain separation between the RCS equipment space and the annular space during normal plant operation and permit flow between the annular space and each retaining basket during LOCA events. The applicant also provided markups that add the gutters to FSAR Tier 1, Table 2.2.2-1, "IRWST Equipment Mechanical Design" associated with the retaining basket. In addition, the applicant describes the gutters in ANP-10293NP, Sections 2.3.2, "Retaining Baskets," and 2.3.4, "Retaining Basket Gutter System." Similar to the FSAR, ANP-10293NP, Section 2.3.4 discusses how the gutters seal off the RCS equipment space from the service space (annular space) using a water seal in the IRWST to maintain the two-zone containments. The gutters are further described as being attached to the IRWST wall at the annular space openings and protruding from the wall approximately 0.3 m (12 in.) and then turning 90 degrees down into the IRWST water. The minimum IRWST level during normal operating conditions maintains the gutters submerged, keeping the service (annular) air space separated from the IRWST airspace (RCS equipment space). During a LOCA, it is possible for the pressure developed in the RCS equipment space, during RCS blowdown, to force water from the IRWST into the annular (service) area through the gutters. To account for this potential, the water holdup (retention) analysis described in ANP-10293NP assumes that the annular area would instantly fill to the wall opening height with IRWST liquid. Given the discussion above and the applicant's FSAR markups the staff finds response to RAI488, Question 06.02.02-93 acceptable. The staff confirmed that FSAR Revision 4, dated November 15, 2012, contains the changes committed to in the RAI response. Accordingly, the staff finds that the applicant has adequately addressed this issue and, therefore, considers RAI 488, Question 06.02.02-93 resolved.

The applicant's water holdup evaluation conservatively assumes the Technical Specification minimum ITWST water volume and maximum water temperature (prior to recirculation) to calculate the minimum initially available IRWST water mass inventory. ANP-10293NP, Figure 2-1, "U.S. EPR ECCS Sump Blockage Mitigation Design Features," and Table B.1, "GL 2004-02 Information Matrix," Item 2.(d)(iv), lists the minimum IRWST water level during a LOCA to be at elevation (-) 3.1 m (10.2 ft). This IRWST minimum level was used in the NPSH evaluation discussed in Section 6.3 of this report. The applicant's maximum water holdup analysis is summarized in ANP-10293NP, Table 3.2-1, "Maximum Water Holdup," and indicates there is positive margin, roughly 14 percent at a minimum, from the allowable IRWST water loss.

The staff review of the applicant's water holdup analysis (summarized in RAI 434, Question 06.02.02-72) identified two areas in containment that cannot return water to the IRWST and were not included in the IRWST water holdup analysis. These two areas are the core spreading area and the reactor cavity. Therefore, in RAI 475, Question 06.02.02-86, the staff requested that the applicant evaluate water holdup in these two regions. In a December 15, 2011, response to RAI 475, Question 06.02.02-86, the applicant revised the water retention analysis to include water holdup (condensed steam) associated with the core spreading area and the reactor cavity. The water retention analysis maintained positive margin above the design basis minimum IRWST inventory after including these rooms. Since the applicant revised the water retention analysis to include these rooms and demonstrated that positive margin remains in the water retention analysis, the staff finds the applicant's response to RAI 475, Question 06.02.02-86 acceptable.

In RAI 475, Question 06.02.02-87, the staff requested that the applicant provide information to justify that the large break LOCA evaluated in the IRWST water retention calculations was the most limiting for NPSH requirements. In a December 15, 2011, response to RAI 475, Question 06.02.02-87, the applicant provided information on other large and small pipe break cases, including at the pressurizer. The applicant concluded that the other break cases yielded lower retained water values than the most limiting value for the large-break case. The maximum amount of water holdup and, therefore, limiting NPSH level margin occurs early in the transient when there is a large steam mass in containment and a high dynamic head heights on the heavy floor and annular floor. The applicant included the maximum water retention results in ANP-10293NP, Table 3.2-1, "Maximum Water Holdup." The staff finds the applicant's response to RAI 475, Question 06.02.02-87 acceptable because it provides justification for the large break evaluation as the most limiting for the IRWST water retention analysis.

Based on the discussion above, the staff finds that water holdup is adequately addressed by the applicant. Accordingly, the staff considers RAI 434, Questions 06.02.02-72 and 06.02.02-76, and RAI 475, Questions 06.02.02-86 and 06.02.02-86 resolved.

In the 11/14/2011, response to RAI 507, Question 06.02.02-121, the applicant discusses upstream effects in ANP-10293NP, Section 3.2.6, "Upstream Effects." The applicant reviewed containment drawings and did not find areas where that the collection of debris could cause the narrowing of hallways or passages, with the exception of those identified in ANP-10293NP, Section 3.2.5, "Water Holdup." Given the containment design layout, no containment spray actuation, the debris source term, the four large heavy floor openings with trash rack and the seven openings at the annular floor area, the staff finds that blockage of flow paths is unlikely to occur. In the IRWST water retention analysis discussed above, the applicant assumed one of the four heavy floor drain paths was unavailable (clogged), resulting in higher water level on the heavy floor and increased water holdup. Based on the discussion above, the staff finds that upstream effects is adequately addressed by the applicant and, therefore, considers RAI 507, Question 06.02.02-121 resolved.

The staff finds that the applicant's evaluation of potential holdup volumes, choke points, and other physical obstructions that could prevent water from draining to the sump is consistent with NEI 04-07 and associated SE guidance and, therefore, is considered acceptable. In addition, the staff finds that the IRWST level assumed in the NPSH evaluation (discussed in Section 6.3

of this report) is acceptable, because there is positive margin between the minimum IRWST inventory calculation and the IRWST inventory used in the NPSH analysis.

6.2.2.4.10 Structural Analysis – Strainer, Retaining Basket, and Trash Rack

The structural review of debris interceptors (trash rack, retaining basket, and strainer) is located in Section 3.8.4 of this report.

6.2.2.4.11 Ex-Vessel Downstream Effects

The term "ex-vessel downstream effects" refers to effects of post-LOCA debris on the systems and components in the ECCS flow path (excluding the reactor vessel) located downstream of the recirculation sump strainer. Debris may be carried downstream of the ECCS strainer during post-LOCA operation, thus causing blockage or wear and abrasion in system components. Areas of concern for ex-vessel downstream components include (1) blockage of system flow paths at narrow flow passages (e.g., pump internal flow passages, and right-clearance valves) and (2) wear and abrasion of surfaces (e.g., pump running surfaces) and heat exchanger tubes and orifices.

Design parameters for the ECCS and its components are described in FSAR Tier 2, Section 6.3, "Emergency Core Cooling System." FSAR Tier 2, Section 6.3.2.5, "System Reliability," references Technical Report ANP-10293NP, Appendix G, "Ex-Vessel Downstream Effects Evaluation," for additional component design and evaluation parameters for ex-vessel downstream components exposed to post-LOCA fluids. The U.S. EPR design does not take credit for containment spray during a design-basis accident.

The staff reviewed the applicant's evaluation of ex-vessel downstream effects in Technical Report ANP-10293NP, Revision 4 to provide reasonable assurance that the ECCS and its associated components will function as designated under post-LOCA fluid conditions for the required mission time. ANP-10293NP, Appendix G contains the following subsections:

- ANP-10293NP, G.1 Introduction
    - Safety Injection Function
- ANP-10293NP, G.2 Assumptions and Design Information
    - Accident Scenarios Mission Time
    - Components of Interest
    - Post-LOCA Fluid Constituents
    - Summary of Assumptions and Conservatisms
- ANP-10293NP, G.3 ECCS Component Evaluations
    - LHSI (low head safety injection) and MHSI (medium head safety injection) Pump Evaluations
    - LHSI Heat Exchanger Evaluation
    - Evaluation of Valves, Orifices, Pipes and Instrument Tubing

- Conclusions

Introduction and Safety Injection Function

Technical Report ANP-10293NP, Section G.1 “Introduction,” states that ANP-10293NP, Appendix G documents the ex-vessel downstream effects evaluation for the U.S. EPR ECCS to verify that the system and its components function as designed under post-LOCA conditions. ANP-10293NP, Subsection G.1.1, “Safety Injection Function,” provides a general description of the ECCS. Each train of the ECCS delivers borated water to the RCS using MHSI, LHSI, and accumulator injection.

Accident Scenarios

Technical Report ANP-10293NP, Section G.2.1, “Accident Scenarios,” evaluates both the small break LOCA (SBLOCA) and large break LOCA (LBLOCA) to determine the most limiting accident scenario with the potential for debris transportation to the IRWST. The ECCS flows and debris generated during a SBLOCA will be less than those generated during a LBLOCA. Therefore, the bounding accident scenario for the ex-vessel downstream effects evaluation is a LBLOCA.

Mission Time

Technical Report ANP-10293NP, Section G.2.2, “Mission Time,” defines mission time as the amount of time that a given component is required to fulfill its safety function in a post-LOCA debris condition. For this evaluation, the mission time for ECCS components following a LBLOCA is 30 days of continuous operation.

Components of Interest

Technical Report ANP-10293NP, Section G.2.3, “Components of Interest,” lists the components in the ex-vessel downstream effects evaluation. The components in the ECCS flow path during SBLOCA and LBLOCA operations include pumps, heat exchangers, valves and orifices.

Post-LOCA Fluid Constituents

Technical Report ANP-10293NP, Section G.2.4, “Post-LOCA Fluid Constituents,” describes the debris generated during a LBLOCA and categorizes the debris according to type, size, and quantity in ANP-10293NP, Table G.2-3, “Total Quantity of Debris Generated during a LBLOCA.” The applicant’s evaluation assumes that the LBLOCA debris materials listed in ANP-10293NP, Table G.2-3 that are less than or equal to the mesh size of the sump screen 2 mm x 2 mm (0.08 in. x 0.08 in.)) will bypass the sump strainer and enter the ECCS. Based on the mesh size of the sump screen, the ECCS will ingest 100 percent of the Microtherm, coating particles, and latent particulate. Bypass testing of latent debris addressed in ANP-10293NP, Appendix E, yielded a fiber bypass percentage of less than 70 percent. The staff evaluation for bypass testing is documented in Section 15.6.5 of this report.

Latent debris as identified in ANP-10293NP, Table G.2-3 consists of both particulates (dirt and dust) and small fines (fibers). The applicant used two separate methodologies to determine the amount of particulates and small fines in the latent debris and used the more conservative value for each methodology. The result was 63.4 kg (139.8 pounds-mass (lbm)) of particulate and 10.2 kg (22.5 lbm) of fiber.

In RAI 552, Question 06.02.02-135, the staff requested that the applicant provide the basis for concluding that no RMI will bypass the sump screen and enter the ECCS during a LBLOCA. In a September 5, 2012, response to RAI 552, Question 06.02.02-135, the applicant stated:

> Section 3.2.2.4 of NUREG/CR-6808, “Knowledge Base for the Effect of Debris on Pressurized Water Reactor Emergency Core Cooling Sump Performance,” provides results of jet impact testing on RMI. NUREG/CG-6808, Figure 3-7, “Typical RMI Debris Generated by Large Pipe Break,” shows a size distribution at ¼ inch of 4.3 percent.
>
> Reference-4 of NUREG/CR-6808, “Safety Evaluation by the Office of Nuclear Reactor Regulation Related to NRC Bulletin 96-03 Boiling Water Reactor Owners Group Topical Report NEDO-32686, ‘Utility Resolution Guidance for ECCS Suction Strainer Blockage,’” Docket No. PROJ0691, August 20, 1998 (ADAMS Accession No. ML092530505) provides more detailed information in Appendix d of NEDO-32686 (pdf file pages 366 to 399), “Structural Properties of Reflective Metal Installed in U.S. BWRs”
>
> NUREG/CR 6808 Figure 3-7, Typical RMI Debris Generated by Large Pipe Break, can be found in NEDO-32686 Appendix D as Figure 6, Size vs. Percent by Weight. NEDO-32686 Appendix D test data analysis identifies Vattenfall/NRC test as a bounding case. Appendix D shows pictorially and states (ADAMS Accession No. ML092530505, pdf file page 387 of 399):
>
> > Photographs of a random sample of each size category are reproduced as Figure 7. Note that in the smallest sample size range, 0.25,” debris smaller than 0.25” is not observed.
>
> Therefore, the 4.3 percent of the RMI is 0.25 inches or larger.
>
> Testing described in AREVA NP Technical Report ANP-10293P, “U.S. EPR Design Features to Address GSI-191,” Revision 4, Section E.4.1 used RMI debris pieces of 2 mil thickness and various sizes from 0.25 inch x 0.25 inch up to 4 inch x 4 inch which were shown to sink and settle on the bottom of the retaining basket. The size distribution was based on NUREG/CR-6808 that shows that the RMI debris size distribution ranges from 0.25 inches to 6 inches.
>
> Furthermore, the U.S. EPR design takes advantage of the in-containment physical arrangement to develop a tiered “defense-in-depth” strategy. During a large break loss of coolant accident (LBLOCA), RMI would not only have to be transported to the retaining basket, but would also have to transport to the strainer and enter the strainer before being entrained in the pump suction. Other sources of debris that could pass through retaining basket screen size of 0.08 inch x 0.08 inch are tested to demonstrate the complete range of debris. Therefore, based on the test programs identified above, there is reasonable assurance that RMI will not enter the emergency core cooling system (ECCS) during a LBLOCA.

Based on the results of jet impact testing that no RMI debris smaller than 6.4 mm (0.25 in.) was observed, the staff concludes that there is reasonable assurance that RMI will not enter the ECCS because the size of RMI debris is greater than the mesh size 2 mm x 2 mm (0.08 in. x 0.08 in.)). Accordingly, the staff considers RAI 552, Question 06.02.02-135 resolved.

ECCS Flow Rate and Flow Velocity

Technical Report ANP-10293NP, Section G.2.5, "ECCS Flow Rate and Flow Velocity," describes the ECCS flow rates used to evaluate debris settlement and component wear during a LBLOCA.

For the evaluation of debris settlement in the ECCS, the LHSI and MHSI pumps provide minimum flow rates of 33 Kg/s (72.8 lbm/s (525 gpm)) and 10.4 Kg/s (22.9 lbm/s (165 gpm)) at shutoff head conditions. The debris settlement evaluation is detailed in Technical Report ANP-10293NP, Section G.3.3.2, "Blockage and Debris Settling Evaluation for Valves, Orifices, Pipes and Instrument Tubing."

For component wear evaluations in the ECCS, the LHSI and MHSI pumps provide maximum flow rates of 200 Kg/s (441.6 lbm/s (3220 gpm)) and 60 Kg/s (152.6 lbm/s (1110 gpm)), respectively, during runout conditions. The component wear evaluation is detailed in Technical Report ANP-10293NP, Section G.3.1, "LHSI and MHSI Pump Evaluations," using conservative flow rates of 206 Kg/s (454.8 lbm/s (3520 gpm)) for the LHSI pumps and 82 Kg/s (181.5 lbm/s (1320 gpm)) for the MHSI pumps.

The LHSI and MHSI pump shutoff and run-out flow rates are verified by the vendor during component procurement.

Summary of Assumptions and Conservatisms

Technical Report ANP-10293NP, Section G.2.6, "Summary of Assumptions and Conservatisms," describes the assumptions and conservatisms used in the ex-vessel downstream evaluation. These assumptions and conservatisms are summarized as follows:

1. 100 percent of all particulates (i.e., Microtherm, coating debris, and latent particles) and 70 percent of latent fiber are assumed to pass through the strainers and enter into the ECCS. RMI debris generated during a LBLOCA will be stopped by the retention basket.

2. The minimum LHSI and MHSI flow rates of 33 Kg/s (72.8 lbm/s (525 gpm)) and 10.4 Kg/s (22.9 lbm/s (165 gpm)), respectively, are assumed for the evaluation of debris settlement in the ECCS.

3. LHSI and MHSI pump flow rates of 206 Kg/s (454.8 lbm/s (3520 gpm)) and 82 Kg/s (181.5 lbm/s (1320 gpm)), respectively, are assumed for component wear evaluation.

Technical Report ANP-10293NP, Table G.2-5, "Post-LOCA Fluid Constituents Downstream of ECCS Screen," lists the amount of debris (including concentration, density, and size) in the post-LOCA fluid downstream of the ECCS screen that will be used for confirmatory tests of ex-vessel downstream components. The amount of latent debris in the ECCS during post-LOCA operation is based on Assumption #1. The amount of latent debris in ANP-10293NP, Table G.2-5 is conservatively based on the maximum amount of latent particulates and 70 percent of the maximum amount of fiber listed in ANP-10293NP, Table G.2-3.

The concentration of the post-LOCA fluid constituents listed in ANP-10293NP, Table G.2-5 is conservatively estimated based on the assumption that the IRWST contains 1.5 liters (L) (400,000 gal) of water during post-LOCA operation, which is less than the minimum IRWST water volume of 2.01 million L (500,342 gal). Estimating the debris concentration at less than the expected IRWST volume yields a more concentrated debris-laden fluid for confirmatory tests, and produces conservative test results. The applicant's methodology to determine the concentration of the post-LOCA fluid constituents it consistent with the methodology approved in the staff SE on TR-WCAP-16406-P for calculating debris concentration and, thus, the staff finds this acceptable.

LHSI and MHSI Pump Evaluations

Technical Report ANP-10293NP, Section G.3.1, "LHSI and MHSI Pump Evaluations," states that the LHSI and MHSI pumps and associated mechanical seals will be qualified to operate with the post-LOCA fluids for at least 30 days, using the qualification guidance of QME-1-2007 as endorsed by RG 1.100, "Seismic Qualification of Electrical and Active Mechanical Equipment and Functional Qualification of Active Mechanical Equipment for Nuclear Power Plants," Revision 3, September 2009. ANP-10293NP, Section G.3.1 identifies additional criteria to be met by the pump vendor during the qualification process. The post-LOCA fluids used for the design and qualification of pumps includes the debris that bypasses the containment sump strainer identified in ANP-10293NP, Table G.2-5.

RG 1.100, Revision 3, states that QME-1-2007 is a staff-approved methodology for the qualification of pumps and when an applicant or licensee commits to the use of QME-1-2007 for qualification of pumps and valves, the criteria and procedures become part of the basis for the qualification program. Therefore, the staff does not consider using QME-1-2007 as a guide to be acceptable. In RAI 569, Question 06.02.02-136, the staff requested that LHSI and MHSI pump qualification be "in accordance with" QME-1-2007. **RAI 569, Question 06.02.02-136 is being tracked as an open item.**

ITAAC 3.1 in FSAR Tier 1, Table 2.2.3-3, "Safety Injection System and Residual Heat Removal System ITAAC," confirms the design and functional qualification of pumps and valves under design basis accident conditions (this includes post-LOCA fluid operation for a 30-day mission time.

ITAAC 7.12 in FSAR Tier 2, Table 2.2.3-3 provides confirmation of the LHSI heat exchanger performance with post-LOCA fluids.

Evaluation of Valves, Orifices, Pipes and Instrument Tubing

Technical Report ANP-10293NP, Section G.3.3.1, "Blockage and Debris Settling Evaluation for Valves, Orifices, Pipes and Instrument Tubing," describes the evaluation for blockage and debris settling for valves, orifices, pipes, and instrument lines during operation with post-LOCA fluids. The applicant compares the minimum flow velocities of 0.375 m/s (1.23 ft/s) in the LHSI piping and 0.21 m/s (0.68 ft/s) in the MHSI piping to the terminal settling velocities of the debris listed in Technical Report ANP-10293NP, Table G.2-4. Based on this evaluation, the applicant concludes that settling will not occur because the lowest flow velocity in the LHSI and MHSI piping is greater than the terminal settling velocity debris. The staff considers the settling velocities identified in Technical Report ANP-10293NP, Table G.2-4acceptable based on staff evaluation of settling velocities in NEI 04-07, "PWR Sump Performance Evaluation Methodology," Section 4.2.4.

Technical Report ANP-10293NP, Table G.2-5 identifies latent particulate downstream of the ECCS screen as 63.4 kg (139.8 lbm) of sand. However, Technical Report ANP-10293NP, Table G.2-4 identifies the terminal settling velocity of both latent fibers and latent particulates as 0.244 cm/s (0.008 ft/s). In RAI 569, Question 06.02.02-137, the staff requested that the applicant provide justification for determining the settling velocity of latent particulate as 0.244 cm/s (0.008 ft/s). **RAI 569, Question 06.02.02-137 is being tracked as an open item**.

Technical Report ANP-10293NP, Section G.3.3.1 states that an analysis will be performed to confirm that post-LOCA debris will not clog the ECCS instrument lines during post-LOCA operation for at least 30 days. In a March 31, 2011, response to RAI 111, Question 06.02.02-13, which superseded the December 3, 2008, response, the applicant stated that instrument tubes are typically tapped off the top or side of the ECCS piping and will not be blocked by debris, which will settle on the bottom of the pipes. ITAAC 7.13 in FSAR Tier 1, Table 2.2.3-3 provides confirmation that post-LOCA debris will not clog the ECCS instrument lines.

In RAI 111, Question 06.02.02-13, the staff requested that the applicant address the effects of debris, chemicals, and gases in the ECCS recirculation water in instrument tubing connected to the ECCS piping and on the accuracy of instruments strapped to the outside of the ECCS piping. Instrument tubing will not function properly if plugged, and strapped-on instruments that make use of the velocity of sound through the fluid medium could be affected by the type and quantity of suspended debris, chemical composition, and presence of gases. In a March 31, 2011, response to RAI 111, Question 06.02.02-13 that superseded a December 3, 2008, response, the applicant stated the U.S. EPR design does not have strapped-on instruments on the ECCS piping. The staff finds the applicant's response acceptable because the ECCS system does not use strapped-on instruments that would be operationally affected by debris in the fluid medium.

Technical Report ANP-10293NP, Section G.3.3.2, "Wear Rate Evaluation for Valves, Orifices and Pipes," describes the wear rate evaluation for valves, orifices and pipes during operation with post-LOCA fluids. The wear rate evaluation is to be performed using the post-LOCA fluid constituents listed in Technical Report ANP-10293NP, Table G.2-5 and the flow velocities listed in Technical Report ANP-10293NP, Table G.3-1. The vendor will provide tests and/or analysis to support acceptable wear rates of valves, pipes and orifices. In addition, an analysis will be provided to confirm that the overall system resistance/pressure drop across the ECCS is consistent with the safety analysis results for the 30-day mission time. ITAAC 7.13 in FSAR Tier 1, Table 2.2.3-3 provides confirmation that LHSI and MHSI system flow and wear rates are acceptable during operation with post-LOCA fluids. In RAI 569, Question 06.02.02-138, the staff requested that the applicant further describe how the analysis described in Technical Report ANP-10293NP, Section G.3.3.2, will provide verification of acceptable ECCS operation at the end of the 30-day mission time when all components and piping reach their maximum wear. **RAI 569, Question 06.02.02-138 is being tracked as an open item.**

Technical Report ANP-10293NP, Section G.3.3.2 states that ECCS valves are to be qualified to operate with the post-LOCA fluids for at least 30 days using the qualification guidance of QME-1-2007 as endorsed by RG 1.100, Revision 3. The post-LOCA fluids used for the design and qualification of valves includes the debris that bypasses the containment sump strainer identified in ANP-10293NP, Table G.2-5.

RG 1.100, Revision 3, states that QME-1-2007 is a staff-approved methodology for the qualification of valves, and when a licensee commits to the use of QME-1-2007 for qualification of pumps and valves, the criteria and procedures become part of the basis for the qualification program.

Therefore, the staff does not consider using QME-1-2007 as a guide to be acceptable. Therefore, in RAI 569, Question 06.02.02-136, the staff requested that valve qualification be in accordance with QME-1-2007, as endorsed by RG 1.100. **RAI 569, Question 06.02.02-136 is being tracked as an open item.**

ITAAC 3.1in FSAR Tier 1, Table 2.2.3-3 confirms the design and functional qualification of pumps and valves under design basis accident conditions (this includes post-LOCA fluid operation for 30-day mission time).

Chemical Effects

In RAI 111, Question 06.02.02-13, the staff requested that the applicant address the effects of chemicals in the ECCS recirculation water. In a March 31, 2011, response to RAI 111, Question 06.02.02-13, the applicant stated that chemical precipitates do not significantly impact the ECCS functions. The staff finds the applicant conclusion that chemical precipitants have not significant impact on downstream ex-vessel components acceptable because it is consistent with staff positions in the NRC memorandum, “Basis for Excluding Chemical Effects Phenomenon from WCAP-16406-P Ex-Vessel Downstream Evaluation,” January 21, 2010, and Technical Report, “Evaluation of Chemical Effects Phenomena Identification and Ranking Table Results,” March 2011.

The staff reviewed the U.S. EPR application for compliance with NRC regulations for the evaluation of ex-vessel downstream effects. Due to the open items discussed above, the staff is unable to make a finding regarding ex-vessel downstream effects.

6.2.2.4.12 Downstream Effects – In-Vessel

The in-vessel downstream effects analysis is located in Section 15.6.5 of this report. Chemical effects related to in-vessel downstream effects testing is discussed in Section 6.2.2.4.13.7 of this report.

6.2.2.4.13 Chemical Effects

6.2.2.4.13.1 *Introduction*

To determine the compliance of the U.S. EPR design to the requirements of GDC 35, GDC 38, and 10 CFR 50.46(b)(5) with respect to chemical debris formed in the post-LOCA containment pool, the staff reviewed the information in the FSAR and supporting documents using the guidance listed in Section 6.2.2.3 of this report. Chemical effects could result from precipitation of corrosion products, leached inorganic substances that form gelatinous material, or other chemical reaction products that form as a result of interaction between the PWR containment environment and containment materials after a LOCA. These potential chemical effects may impede the flow of water through the sump strainers or affect downstream components in the emergency core cooling or reactor coolant systems. SRP Section 6.2.2 provides no specific guidance for chemical effects evaluations, but references RG 1.82, Revision 3, NEI 04-07, and the NEI 04-07 NRC SER for acceptable guidance for PWR sump debris evaluations.

For PWR plants, RG 1.82, Revision 3 contains the following guidance relative to chemical effects:

- Section 1.1.2.3 states that to minimize potential debris caused by chemical reaction of coolant with metals in the containment, exposure of bare metal surfaces (e.g., scaffolding) to spray impingement or immersion should be minimized either by removal or by using chemical-resistant protection (e.g., coatings or jackets).

- Section 1.3.2.6 states that in addition to debris generated by jet forces from the pipe rupture, debris created by the resulting containment environment (thermal and chemical) should be considered in the analyses. Examples of this type of debris would be disbondment of coatings in the forms of chips and particulates or formation of chemical debris (precipitants) caused by chemical reactions in the pool.

The following documents contain additional staff guidance for chemical effects evaluations:

- NEI 04-07, Revision 0, and the staff's accompanying SE.

- Enclosure 3, "NRC Staff Review Guidance Regarding Generic Letter 2004-02 Closure in the Area of Plant-Specific Chemical Effect Evaluations," to "Revised Guidance for Review of Final Licensee Responses to Generic Letter 2004-02, 'Potential Impact of Debris Blockage on Emergency Recirculation during Design Basis Accidents at Pressurized-Water Reactors," March 28, 2008.

- WCAP-16530-NP-A, "Evaluation of Post-Accident Chemical Effects in Containment Sump Fluids to Support GSO-191," May 2, 2008.

6.2.2.4.13.2 *Applicant Approach to Addressing Chemical Effects*

The U.S. EPR design addresses chemical effects primarily by selecting insulation and construction materials that are not expected to form a significant quantity of precipitate by reacting with the post-accident sump water. Where reactive materials are considered necessary, the quantities are limited in the plant design basis. This approach was first explained in ANP-10293NP, Revision 2, Section 3.3.1, "Chemical Effects," which stated that the chemical effects are expected to be minimal with respect to amount of precipitate formation, strainer head loss, and downstream effects. This is based on U.S. EPR using trisodium phosphate (TSP) as a post-accident buffering solution; the ZOI predominantly using RMI; limited amounts of encapsulated fiber insulation; a limited quantity of aluminum in containment, and little, if any, particulate-based insulation. Section 6.2.2.4.2 of this report describes debris generation from insulation materials.

The staff recognized that the proposed plant design would greatly reduce the potential for chemical precipitates compared to the current fleet of U.S. operating plants. However, given the evolving state of knowledge of sump chemical effects of industry-wide, the staff determined a more detailed justification was required in order to support a reasonable assurance finding. For example, the staff's March 2008 guidance provides a detailed methodology for performing chemical effects evaluations. Therefore, in RAI 90, Question 06.02.02-2, the staff requested that the applicant provide a detailed analysis to justify the chemical effects assumptions and conclusions using Figure 1, "Chemical Effects Evaluation Process Flow Diagram," of the staff's March 2008 guidance or other appropriate guidance. In a May 20, 2010, supplemental response, the applicant indicated that the chemical effects analysis is provided in ANP-10293, Revision 1, Section 3.1, "Technical Basis for the ECCS Sump Recirculation Design Features," and ANP-10293, Revision 1, Appendix D, "Chemical Effects Evaluation for the U.S. EPR."

ANP-10293NP, Revision 1 and subsequent revisions included Appendix D, which provides the detailed chemical effects analysis summarized in Section 3.1.3, "Chemical Effects," of the report. The analysis includes laboratory chemical effects testing and IRWST sump chemistry modeling to quantify the chemical debris potentially generated through the interaction of the sump pH buffer and materials in containment. The differences between ANP-10293NP, Revision 1 and ANP-10293NP, Revision 4 include changes based on the staff review of the chemical effects analysis, which is discussed below in Sections 6.2.2.4.13.3 – 6.2.2.4.13.7 (note: this evaluation refers to ANP-10293NP, Revision 4, the non-proprietary version of the technical report, when appropriate). The staff considers RAI 90, Question 06.02.02-2 resolved because the applicant performed testing and analysis to address the staff's guidance on chemical effects. Specifically, the staff did the following:

- Determined the chemical source term based on release-rate equations for containment materials. Used new laboratory autoclave testing and the existing knowledge base (previous testing) to determine and validate the release rates.

- Converted the calculated source term into a precipitate quantity for strainer and fuel assembly testing using a thermodynamic equilibrium code and assuming zero solubility for aluminum and calcium.

- Performed sump strainer tests that included scaled amounts of precipitates prepared outside the test loop using methodology previously approved by the staff.

- Performed fuel assembly tests with scaled amounts of precipitates prepared outside the test loop using a methodology previously approved by the staff.

6.2.2.4.13.3 *Chemical Effects Testing and Modeling – Chemical Source Term*

ANP-10293NP, Section 3.1.3 identifies the purpose of the chemical effects testing and modeling. The testing was performed under simulated post-LOCA conditions to identify chemical effects from the interaction of debris materials and the IRWST pH buffering agents. The sump chemistry modeling was performed to identify and quantify specific compounds that may precipitate in the sump pool following a LOCA. The staff notes that the analysis included materials that are known to be important to PWR chemical effects but are not necessarily in the form of debris inside containment (e.g., aluminum and concrete). The staff's review included audits to review test protocols, test facilities, test results, and modeling.

The applicant performed the chemical effects testing in a laboratory autoclave containing the materials listed in ANP-10293NP, Table 6.2-1, using the amount of material per unit volume expected in the plant. ANP-10293NP, Table 6.2-1 includes the amounts used in the WCAP-16530-NP-A testing to show that the source materials in the U.S. EPR design are significantly lower than in typical operating plants. The following test procedures were used:

- Weight-loss measurements

- Chemical analysis and electron microscopy of samples before testing

- Chemical analysis and electron microscopy of samples and deposits after testing

- Chemical analysis of the test solution

The aluminum coupon was electrically insulated from the autoclave to preclude galvanic corrosion. Screen supports of 80 mesh stainless steel were used to allow for adequate surface area of the fibrous and particulate material to be exposed. The chemical environment for the testing was 2,800 parts per million (ppm) boron, with an initial pH of 4.45. Once the test began, the TSP buffer was added over a period of about 2 hours, at which time the system pH stabilized at approximately 7.3 for the remainder of the test (total test time 158 hours). The temperature during the test was adjusted to simulate the calculated post-LOCA temperature profile in the IRWST. The nominal solution chemistry closely resembled that used in Integrated Chemical Effects Test #2 (ICET 2), NUREG/CR-6914, “Integrated Chemical Effects Test Project,” Volume 3, December 2006), which had 2,800ppm boron, TSP buffer, and a pH of approximately 7. Samples of the recirculating liquid were taken periodically to measure the water chemistry additives (boron, sodium, phosphorus) and the leaching/dissolution from the test materials (calcium, aluminum, silicon, potassium, magnesium).

In ANP-10293P, Revision 3, the applicant updated the calculated maximum IRWST temperature from 110 °C (230 °F) to approximately 121 °C (250 °F). Since the autoclave test was performed at 110 °C (230 °F) to simulate the maximum IRWST temperature, in RAI 490, Question 06.02.02-100, the staff requested that the applicant modify the report to discuss this change. The staff notes that the ANP-10293NP, Revision 4 was modified (Section D.2.2.2, “Test Procedure”) to state that the temperature difference does not affect the validity of the test because the time period is short (less than 3 hours) and because the test results were mainly used to validate this methodology. In a November 18, 2011, to RAI 490, Question 06.02.02-100, the applicant stated that the commercial modeling software used in the U.S. EPR analysis indicated the solubility and release rates of calcium and silicon can be extrapolated from 110 °C to 121 °C (230 °F to 250 °F). The staff finds the modification to the report acceptable because the test data were used to mainly to validate the methodology rather than determine release rates at the maximum temperature. The staff also finds this acceptable because other test data (e.g., WCAP-16530-NP_A) that bound the maximum temperature provide a basis for the staff to evaluate extrapolation and do not indicate an abrupt change in the corrosion rate between 110 °C and 121 °C (230 °F and 250 °F). In addition the predicted temperature is above the test temperature for about 2 hours (more corrosion), and this is followed by a period of more than 20 hours when the predicted temperature is below the test temperature (less corrosion). On this basis, the staff finds it reasonable to extend the methodology to the higher temperature. Accordingly, the staff considers RAI 490, Question 06.02.02-100 resolved.

Table 6.2-1: Comparison of Materials Radios in U.S. EPR and PWR Owners Group Testing

Material	Material to Post-LOCA Coolant Volume Ratio	
	U.S. EPR Testing	PWROG Testing
Fiberglass, Min K, Min-wool	N/A	0.18
Nukon fiberglass	0.000114	N/A
Cal-Sil, Interam, Durablanket	N/A	0.20
Microtherm	0.000691	N/A
	Surface area or Mass assumed	
Concrete	257 ft^2	All as latent debris
Aluminum	0.005179 ft^2/ft^3	5.42 ft^2/ft^3
Latent Debris	45 lb (0.000327 ft^3/ft^3 - Nukon 255 lb (0.00424 ft^2/ft^3 (concrete)	4.79 ft^2/ft^3 (concrete, sand and clay)

The U.S. EPR design features are principally responsible for the lower material ratios for the U.S. EPR design shown in Table 6.2-1 above. The most significant difference between the masses/surface areas of materials used in the WCAP testing versus the applicant testing is the reduced amount of the following:

- Fiberglass and blanket-type insulation materials in the ZOI (U.S. EPR uses RMI almost exclusively). This also significantly reduces the mass of aluminum leached for the fiberglass.

- Surface area for latent debris due to the design of the heavy floor and how water is transferred to the IRWST.

- Surface of concrete exposed (the IRWST is lined with stainless steel).

- Water that contacts the containment materials above the water line (only condensation and no containment spray).

Limiting of the types of nonmetallic materials and aluminum that can be in the ZOI and below the water line limits the concentrations of ionic contaminants (the chemical source term) for potential precipitates,

The applicant used publicly available sources with the GSI-191 literature to select release rates for solid concrete, Nukon insulation, Microtherm insulation, and commercially pure aluminum (Alloy 1100). The staff asked several questions to clarify the methodology and the technical details used to select the release rates. The staff did not make a safety finding on the release rates *per se*. Rather, the staff reviewed the release rate methodology and values to judge if they are reasonable given the current state of understanding of GSI-191 chemical effects. The staff safety finding on chemical effects debris quantity predicted from the release rates is discussed in the next section of this report.

The applicant used the solid concrete sample to validate release rates of aluminum, calcium, and silicon from concrete. The applicant used data from two sources corresponding to pH 8 and pH 10 (see below). These data included tests at pH 10 at temperatures of 60 °C, 90 °C, and 110 °C (140 °F, 194 °F, and 230 °F), and the data for pH 8 included tests at 88 °C (190 °F).

In RAI 401, Question 06.02.02-54, the staff requested that the applicant clarify how these release rates were used to derive a release rate for a pH of 7.4 (the U.S. EPR test condition). In an August 11, 2010, response, the applicant explained that they first derived linear expressions for calcium and silicon release rates as a function of temperature at pH 10. Then the rates were multiplied by the difference between the release rates for calcium and silicon at pH 10 and pH 8 at 90 °C (194 °F) to determine the higher release rate at pH 8 as a function of temperature for each element. These expressions were used to estimate the release rates in the pH 7.4 U.S. EPR autoclave test. The applicant considered the release of aluminum from concrete at pH 8 negligible based on the report by McMurry and He (below). As explained in ANP-10293NP, the applicant found that the concrete weight loss predicted from these release rates agreed reasonable well with the measured weight loss in the autoclave test.

- V. Vain, et al., “Corrosion Rate Measurements and Chemical Soeciation of Corrosion Products Using Thermodynamic Modeling of Debris Components to Support GSI-191,” NUREG/CR-6873, April 2005.

- J. McMurry and X. He, "Supplemental Leaching Tests of Insulation and Concrete for GSI-191 Chemical Effects Program," Technical Letter Report IM20.142130.01.001.320, Center for Nuclear Waste Regulatory Analyses (CNWRA), November 2006.

In RAI 490, Question 06.02.02-101, the staff requested that the applicant justify the linear extrapolation of the calcium release rate above 110 ° (230 °F). In a November 11, 2011, response, the applicant provided a series of figures showing that the linear fit yielded a higher cumulative calcium release than other fits (polynomial and exponential), making it conservative for debris generation. As noted above, the release rates were determined for solid concrete. The applicant assumed that pulverized concrete released its chemical constituents immediately, and ANP-10293NP lists the chemical composition of the sample used in the autoclave in ANP-10293NP, Table F.2-3, "Pre-Test EDS Data of Pulverized Concrete Sample." Since carbon was not included in the table, and the sample presumably contained calcium carbonate, in RAI 490, Question 06.02.02-102, the staff requested that the applicant explain the analysis and whether it had been normalized. In a November 18, 2011, response, the applicant confirmed that the pulverized concrete analysis was normalized to remove carbon because the analysis was performed with the sample mounted on carbon tape. In responses to RAI 401, Question 06.02.02-54 and RAI 490, Question 06.02.02-102, the applicant proposed changes to ANP-10293NP. The staff finds that these changes provide the information requested and confirmed that the changes were incorporated into ANP-10293NP, Revision 4.

The staff finds the applicant's determination and validation of concrete release rates reasonable because they are based on data from testing that the staff sponsored and reviewed previously, and they yielded a reasonable difference between measured and predicted results. The staff also finds it acceptable for the applicant to neglect aluminum release from concrete, since this is consistent with other chemical effects release rates the staff reviewed previously (WCAP-16530-NP-A). The staff's conclusion is also based on the supplemental information provided in the RAI responses. Accordingly, the staff considers RAI 401, Question 06.02.02-54 and RAI 490, Questions 06.02.01-101 and 06.02.02-102 resolved.

The applicant determined release rates for Nukon fiberglass based on the data reported in NUREG/CR-6873, "Corrosion Rate Measurements and Chemical Speciation of Corrosion Products Using Thermodynamic Modeling of Debris Components to Support GSI-191," April 2005, for pH 7, 2800 ppm boron, and temperatures of 60 °C, 90 °C, and 110 °C (140 °F, 194 °F, and 230 °F). The applicant derived an overall release rate as a composite of the release rate for each oxide constituent of the Nukon: SiO_2, Al_2O_3, CaO, MgO, Na_2O, and B_2O_3. Based on the analysis of the mass release versus time data at each temperature in NUREG/CR-6873, the applicant assumed that the release rate was negligible after 80 hours of exposure. In an August 11, 2011, response to RAI 401, Question 06.02.02-56, and in ANP-10293NP, Section D.3.3.3, "Nukon Fiber," the applicant summarized this procedure. In a November 17, 2011, response to RAI 490, Question 06.02.02-105, the applicant clarified that the assumption of negligible release after 80 hours was an assumption based on the mass release values reaching a plateau within about 100 hours. The response included proposed changes to ANP-10293NP, Section D.3.3.3 and ANP-10293NP, Figure D.3-3, "Mass Release Rate versus Time for Nukon Fiber at pH 7," caption. The staff confirmed that the changes were incorporated into ANP-10293NP, Revision 4.

The staff finds the approach described above acceptable, but had additional questions about the details. Therefore, in RAI 401, Question 06.02.02-53, the staff requested that the applicant clarify the effect of a deviation from the original test plan resulting in the testing only of Nukon heat treated at 316 °C (600 °F). The test plan included both heat-treated and untreated Nukon.

In an August 11, 2010, response, the applicant stated that using untreated Nukon would probably not affect the test results because the binder would have remained stable. The response included a proposed modification to ANP-10293P to address this issue. The staff finds the response acceptable because the applicant provided a reasonable argument for omitting the untreated Nukon and because the Nukon that was tested was heat-treated in a manner that simulates the expected service condition. This is the same heat treatment (316 °C (600 °F), 24 hours) used in the NRC-sponsored integrated chemical effects testing. The staff confirmed that the proposed changes were included in ANP-10293NP, Revision 4. Accordingly, the staff consider RAI 401, Questions 06.02.02-53 and 06.02.02-56, and RAI 490, Question 06.02.02-105 resolved.

Microtherm is a micorporous insulation composed of amorphous silica and titanium dioxide powders in a woven fiber blanket. The applicant included both the powder and fiber in the autoclave test and determined the release rated based on examination of the autoclave silicon concentration as a function of time. Since the CNWRA supplemental leaching tests (referenced above) previously identified Microtherm as the most reactive of the U.S. EPR insulation materials, and since the silicon content increased sharply over the first 20 hours of the test before changing to a gradual increase, the applicant assumed that all of the silicon in the Microtherm was released in the first 20 hours. After measuring the amount of silica in the Microtherm sample used in the test, the applicant calculated a release rate for silicon from Microtherm. Since the silica content of Microtherm varies over a range, the applicant's intent was to determine a generic releases rate. The applicant assumed the same release rate for aluminum for the alumina in the Microtherm, even though the sample contained a small amount that contributed little to the measured aluminum content of the autoclave liquid. The applicant applied these release rates to the design-basis Microtherm limiting quantity for calculating the amount of post-LOCA chemical debris.

The staff considered this approach acceptable, but requested additional information about the details. Therefore, in RAI 401, Question 06.02.02-59, the staff requested that the applicant justify including carbon in the Microtherm chemical analysis results, or revise the results if the carbon was an artifact of the measurement technique. In an April 11, 2010, response, the applicant provided a revised Microtherm chemical analysis showing no carbon. The staff confirmed that ANP-10293NP, Revision 4 included the revised table. In RAI 401, Question 06.02.02-58 and RAI 471, Question 06.02.02-84, the staff requested that the applicant explain why the chemical debris calculations did not assume the maximum silica and alumina values permitted by the Microtherm specification, since this would result in the maximum debris assumption. In a March 31, 2011, response to RAI 471, Question 06.02.02-84, the applicant explained that the debris generation calculations were revised by assuming the Microtherm installed in the plant would contain the maximum allowable silica (70 percent) and alumina (25 percent) contents. The staff finds this acceptable because it increases the calculated amount of chemical debris, which is conservative for a chemical effects analysis. The staff confirmed that the changes were incorporated into ANP-10293NP, Revision 4. Accordingly, based on the above discussion, the staff considers RAI 401, Questions 06.02.02-58 and 06.02.02-59, and RAI 471, Question 06.02.02-84 on Microtherm insulation, resolved.

The applicant determined a release rate for aluminum based on the weight-loss and solution chemistry measurements from the autoclave test. The weight loss provided an average corrosion rate over the entire test period, and the applicant found that the corrosion rate determined in this manner was significantly higher than expected based on comparison with other source of published data for aluminum in borated solutions. The solution chemistry measurements (aluminum concentration, in parts per million) indicated that aluminum was released from the test coupon rapidly during about the first 20 hours and then reached a nearly constant value for the remaining 138 hours of the test (low release rate). The applicant attributed the decrease to passivation (formation of a protective corrosion product) or saturation of the solution with dissolved aluminum.

Therefore, the applicant assumed the aluminum release in the plant would be made up of two parts. In RAI 490, Questions 06.02.02-106 and 06.02.02-107, the staff requested that the applicant clarify how the aluminum corrosion rate was divided into two parts and annotate ANP-10293NP, Figure D.3-5, "Corrosion of Aluminum A1100." In a November 18, 2011, response, the applicant provided this information. For the initial 20 hours, the calculated release rate was 3.95 g/m^2-hr based on the solution chemistry measurements. The staff's confirmatory calculation produced the same value. The second part was an exponential function of temperature determined by the OLI Corrosion Analyzer. The response also stated that the changes to ANP-10293NP, Figure D.3-4 would be made in a subsequent revision of the technical report. The staff verified that the applicant revised the figure in ANP-10293NP, Revision 4. Accordingly, the staff considers RAI 490, Questions 06.02.02-106 and 06.02.02-107 resolved.

The applicant compared the amount of corrosion predicted in 20 hours by the short-term corrosion rate (based on solution chemistry) to the measured weight loss of the coupon over the entire 158 hours. The predicted amount was about 13 percent less than measured. The applicant compared the longer term release rate (the exponential fit as a function of temperature) to aluminum corrosion rates reported from industry and NRC-sponsored GSI-191 testing. The applicant concluded that this comparison verified that the release rate function gave values consistent with the WCAP-16530-NP-A values for pH 7 and, as expected, the reported pH 9 rates were much higher than the pH 7 values. The staff performed a confirmatory calculation for the entire 158 hours of the test by combining the applicant's short-term and long-term release rates. For the long-term rate expression, which is dependent on temperature, the staff divided the test into time intervals and used the average temperature during that interval. The staff calculated about 12 percent more aluminum corrosion than the applicant measured, which indicates the applicant's release-rate expressions for aluminum, over the range of conditions tested, are conservative compared to the weight-loss measurement.

In an October 4, 2012, response to RAI 546, Question 06.02.02-133, the applicant clarified that a data point for pH 7, 66°C (150 °F) was misidentified in ANP-10293NP, Figure D.3-5. The temperature for that datum is actually 60 °C (140 °F), and the source is NUREG/CR-6912, "GSI-191 PWR Sump Screen Blockage Chemical Effects Tests: Thermodynamic Simulation," Table A-4, "Measured Corrosion Rate of Aluminum in Borated Containment Test Solutions." The response included a revision for ANP-10293NP, Figure D.3-5. The staff verified the source of the datum and that it coincides with the exponential fit as shown in the response. **RAI 546, Question 06.02.02-133 is being tracked as a confirmatory item**.

In reviewing the applicant's corrosion rate (release rate) for aluminum, the staff made several observations. First, the initial corrosion rate of 0.95 g/m^2-hr for the first 20 hours is equivalent to the cumulative release of aluminum using the WCAP-16530-NP-A, Equation 6.2 for the first 20 hours using the same pH, temperature, and aluminum surface area inputs as the applicant autoclave test. Second, for the longer term release rate, the low values measured in the applicant test and predicted in the OLI model are less than predicted by WCAP-16530 for the same conditions and time. This may be explained by the fact that the WCAP-16530-NP-A release rates at pH 7 were all based on short term tests (30, 60, 90 minutes). Third, the staff also observed that in ICET 2, which was a 30-day test at 60 °C (140 °F) with the same chemistry as the applicant test, there was no measurable aluminum in the solution and no visible precipitation in samples cooled to room temperature. The apparent corrosion rates of the aluminum in ICET 2 based on weight loss and in NUREG/CR-6912 (Table A-4) based on electrochemical polarization were approximately the same as that predicted by the applicant using the OLI model for pH 7 and 60 °C (140 °F).

The staff asked several questions related to clarification of measurement techniques and data presentation. In an August 11, 2010, response to RAI 401, Question 06.02.02-63, the applicant clarified the graphical presentation of measurements and detection limits, and explained that the calcium mass was not fully accounted for after the autoclave test because it appeared to be in the form of widely dispersed calcium phosphate. The applicant proposed adding this clarification to ANP-10293P. In a November 18, 2011, response to RAI 490, Questions 06.02.02-103 and 06.02.02-104, the applicant proposed modifying ANP-10293P to identify the amount of sodium and phosphate added to the autoclave test and clarify that the liquid samples were filtered through 0.45 micrometer (0.0177 mils) filters while the liquid was cooling. The staff verified that these changes were made in ANP-10293NP, Revision 4. Accordingly, the staff considers RAI 490, Questions 06.02.02-103 and 06.02.02-104 resolved.

After determining the release rates as described above, the applicant used them to calculate the amount of each species released under postulated post-LOCA conditions. The applicant then used the OLI Stream Analyzer commercial software to predict the identity and quality of the resulting chemical precipitates. The following sections discuss the staff review of the calculated debris amount and the application to strainer and fuel assembly testing.

6.2.2.4.13.4 *Type and Amount of Chemical Precipitates*

After determining release rates for the various materials as described above, the applicant calculated the total amount of release (e.g., kg of aluminum, calcium, and silicon) for 30 days according to the predicted temperature and pH transients. The applicant then used the OLI Stream Analyzer program to predict the type and amount of solids (i.e., chemical precipitates) that would form the solution. The methodology assumed that the dissolved calcium (in the presence of phosphate) and all dissolved aluminum spontaneously form the thermodynamically stable precipitates, regardless of any kinetic limitation. In WCAP-16530-NP-A, the staff concluded that there is a reasonable assumption for calcium and a conservative assumption for aluminum.

The staff previously investigated the use of OLI Stream Analyzer and other thermodynamic predictive codes in resolving GSI-191 chemical effects, as documented in NUREG/CR-6912. "The study concluded that the codes as tested were broadly useful in assessing whether precipitation of secondary solid phases was likely under the specified conditions and the quantify of material that was predicted to form." Although the staff concluded that thermodynamic programs may be broadly useful to inform chemical effects evaluations, the staff questions the ability of these programs to accurately predict the types and quantities of precipitates since the thermodynamic equilibrium conditions may not be reached in the time frame of interest. Predictions from thermodynamic equilibrium programs may be acceptable to the staff if the predicted type and quantity of chemical precipitates are conservative.

Using the calculated post-LOCA temperature and pH transients, along with the plant inputs for water volume and materials, the applicant predicted the following types and amounts of precipitates:

Applicant's Chemical Precipitate Calculation

Sodium aluminum silicate ($NaASI_3O_8$)	42.2 kg (82.8 lb)
Aluminum hydroxide ($Al(OH)_3$ and AlOOH)	13.7 kg (30.2 lb)
Calcium phosphate ($Ca_3(PO_4)_2$)	69.4 kg *153 lb)
TOTAL	**125 kg (276 lb)**

As part of its evaluation, the staff used the WCAP-16530-NP-A equations to independently calculate the amount of precipitates. Using the same inputs as the applicant for pH, temperature, TSP, aluminum, concrete, and insulation, the staff calculated the following types and amounts of precipitates:

Staff Chemical Precipitate Calculation

Sodium aluminum silicate ($NaASI_3O_8$)	2.83 kg (6.2 lb)
Aluminum oxyhydroxide (AlOOH)	102.6 kg (226 lb)
Calcium phosphate ($Ca_3(PO_4)_2$)	0.27 kg (0.59 lb)
TOTAL	**104 kg (233 lb)**

The overall amount of chemical precipitate calculated by the staff (104 kg (223 lb)) is less than that calculated by the applicant. Since the total mass of precipitated material is the critical factor in evaluating the potential for fouling filtering beds or sump strainers, the applicant's design basis (125 kg (275 lb)) is conservative with respect to a staff approved methodology (WCAP-16530-NP-A). However, a notable difference between the applicant and staff calculations is that the applicant's methodology predicted less aluminum precipitate and more calcium precipitate than the staff. The staff attributes the difference in aluminum precipitate quantity to the difference in long-term aluminum release rate. The applicant measured the aluminum release rate for the full 158 hours of the test, and found the rate decreased dramatically after approximately 20 hours. By contrast, the WCAP-16530-NP-A release rates are based on tests lasting no more than 90 minutes. Passivation of the aluminum could also explain the behavior observed in ICET 2, which is the ICET with conditions most similar to the U.S. EPR testing. In ICET 2, which had more submerged aluminum surface area per unit than the U.S. EPR test (0.175 vs. 0.053 ft^2/ftb^3), there was no measurable aluminum in solution after 30 days at 60 °C (140 °F) and pH 7 (TSP buffer), and no visible precipitation even at room temperature. Since the applicant's aluminum release rate reflects the testing performed specifically for the U.S. EPR, and since the applicant's proposed total chemical debris quantity exceeds that calculated by the staff using the methodology approved in staff guidance, the staff finds the applicant's proposed chemical debris acceptable. This finding is also based on the fact that all precipitates were assumed to be in forms that have been demonstrated to cause large pressure drops across filtering beds and were represented as such in the strainer and fuel assembly testing, as discussed below in Sections 6.2.2.4.13.6 and 6.2.2.4.13.7.

Another difference between the applicant's methodology and the WCAP-16530-NP-A methodology is that the applicant calculated a mixture of $Al(OH)_3$ an AlOOH for the aluminum hydroxide precipitate, with $Al(OH)_3$ dominate after about 50 hours. The WCAP calculations assume that all dissolved aluminum precipitates in the form of AlOOH. However, predicting a certain form of precipitate is not essential to meet the staff's chemical effects guidance, and the March 2008 staff guidance acknowledges an incomplete understanding of the type of precipitates that can from in the post-LOCA fluid. For this reason, and because the applicant used AlOOH in accordance with staff guidance as the surrogate chemical precipitate for aluminum in head-loss testing, the staff finds it acceptable that the applicant predicted the aluminum to be in the form of $Al(OH)_3$.

In RAI 401, Question 06.02.02-66, the staff requested that the applicant clarify if the initial pH and temperature for the plant transient were used to determine the chemical releases into solution and the amounts of solids formed. In an August 11, 2010, response, the applicant confirmed that the initial conditions were incorporated in the analysis and precipitation was assumed. The staff finds this acceptable because using the expected plant conditions, while assuming precipitation of the elements released, conforms to the March 2008 staff guidance. Accordingly, the staff considers RAI 401, Question 06.02.02-66 resolved.

6.2.2.4.13.5 *Control of Chemical Effects Source Materials*

The TSP is specified for pH control of the post-accident recirculating water, and it also contributes to the postulated chemical debris by reacting with dissolved calcium The March 2008 staff guidance recommends developing a thorough understanding of the post-accident environment, including the range of pH and temperature, prior to performing plant-specific chemical effects evaluations. Since the design and location of the baskets containing the TSP were not completely clear from ANP-10293, in RAI 90, Question 06.02.02-7, the staff requested that the applicant provide additional information on the potential for flow to bypass the TSP baskets and the possible impact on sump pH of such bypass flow. Additionally, since impurity content can alter the effectiveness of the TSP, the staff requested that the applicant provide information on the purity of the TSP. In a November 8, 2008, response to RAI 90, Question 06.02.02-7, the applicant provided diagrams that adequately addressed the issue of the bypass flow around the TSP baskets. The staff concluded that the information provided in this RAI response provide adequate guidance for the licensee for the TSP purity, and that the purity of the TSP identified is sufficient to meet the pH requirement (greater than pH 7 for 30 days). Since the applicant's response clarified the post-accident pH as requested, the staff considers RAI 90, Question 06.02.02-7 resolved. (The staff notes that the applicant also provided details of the predicted post-accident pH to FSAR Tier 2, Chapter 15, "Transient and Accident Analysis," in a July 14, 2010, response to RAI 394, Questions 15.00.03-7 and 15.00.03-8.)

The applicant's analysis showed that aluminum is a key contributor to the postulated chemical debris. Since the amount of aluminum-base chemical debris in the applicant's analysis is based on a limit of 278 m^2 (3,000 ft^2) submerged in the recirculating water, in RAI 483, Question 06.02.02-90, the staff requested that the applicant identify the inspections and controls in place to ensure plants do not exceed this limit. Without a specific limit for aluminum in the containment design (plus allowable excess) state in the FSAR, there is no correlation to the testing reported in ANP-10293. In a November 9, 2011, response, the applicant stated that this control is accomplished by COL Information Item 6.1-4 in FSAR Tier 2, Table 1.8-2, "U.S. EPR Combined License Information Items," and in FSAR Tier 2, Section 6.1.1.2, "ESF Fluids." However, the staff did not find this COL information item in the FSAR and in follow-up RAI 546, Question 06.02.02-129, the staff requested this information again, and closed RAI 483, Question 06.02.02-90. In an October 4, 2012, response to follow-up RAI 546, Question 06.02.02-129, the applicant stated that the aluminum limit would be limited directly in the FSAR rather than the COL application. The response included a draft revision to FSAR Tier 2, Section 6.1.12 with a statement limiting the amount of aluminum in containment that can potentially be submerged to 278 m^2 (3,000 ft^2). The staff finds this acceptable because this is the surface area assumed in the applicant's chemical effects analysis. The staff confirmed that the applicant included the aluminum limit, as stated in the RAI response in FSAR, Revision 4. Accordingly, the staff considers RAI 546, Question 06.02.02-129 resolved.

In RAI 90, Question 06.02.02-5, Part 2, the staff requested that the applicant clarify how they account for the chemical effects from materials in containment outside the ZOI, such as non-RMI insulation. In a May 20, 2010, response, the applicant stated that this information is provided in ANP-10293, Revision 1, Appendices C, D, and E. The staff determined that these appendices to ANP-10293 did not address all of the categories of materials. Therefore, in RAI 490, Question 06.02.02-108, the staff requested that the applicant confirm that the chemical effects analysis included insulation or other materials that will not necessarily be destroyed (i.e., are located outside the ZOI), but could be wetted and potentially contribute to the chemical effects. In a November 18, 2011, response to RAI 490, Question 06.02.02-108, the applicant indicated all such materials were addressed by the chemical effects analysis, including latent debris, an assumed amount of fiberglass insulation, and exposed aluminum. However, the staff examined ANP-10293, Revision 4, and determined that it did not clearly address non-RMI insulation outside the ZOI. Therefore, in RAI 546, Question 06.02.02-130, the staff requested that the applicant describe the effect of non-RMI insulation outside the ZOI on the chemical debris analysis and how the type and quantity of this insulation will be limited to the a mounts assumed in the analysis. RAI 546, Question 06.02.02-130 supersedes RAI 90, Question 06.02.02-5, Part 2, and RAI 490, Question 06.02.02-107, which are closed.

In an October 4, 2012, response to RAI 546, Question 06.02.02-130, the applicant explained that chemical debris from insulation materials outside the ZOI would be minimal because calcium silicate will be prohibited, and the contribution from Nukon and Microtherm will be negligible. Calcium silicate insulation has the highest potential for dissolution among the insulation materials (WCAP-16530-NP-A). In the presence of phosphate buffer it forms calcium phosphate, which has been found to have very low solubility over the temperature and pH range relevant to PWR sumps (WCAP-16530-NP, "Evaluation of Additional Inputs to the WCAP-16530-NP Chemical Model," May 2007 and NUREG/CR-6913, "Chemical Effects Head-Loss Research In Support of Generic Safety Issue 191," December 2006). In addition, the calcium phosphate precipitate has been shown to cause high pressure drops at low dissolved calcium levels in vertical loop tests with a fiber bed. Since the applicant did not include any calcium silicate insulation in the chemical effects analysis for the U.S. EPR, the staff's main concern in RAI 546, Question 06.02.02-130 was the possibility that calcium could leach out of wetted calcium silicate insulation outside the ZOI and produce calcium phosphate not accounted for in the applicant's analysis. However, because the response to RAI 546, Question 06.02.02-130 included an FSAR revision that states, "…calcium silicate insulation will not be used inside containment…," the staff finds that the applicant adequately addressed this concern.

For Nukon fiberglass, the applicant's analyses assumed to 10.2 kg (22.5 lbm) of Nukon fiber even though the plant design-basis fiber limit is 4.63 kg (10.2 lbm) latent fiber (no fibrous insulation inside the ZOI). For this reason, and because Nukon does not contribute greatly to chemical effects, the staff finds the applicant's treatment of Nukon outside the ZOI acceptable. Regarding Microtherm, the applicant's response indicated that dissolution of this material outside the ZOI would be negligible. The staff agrees that the potential incremental contribution of Microtherm outside the ZOI can be neglected since the environment would not be aggressive toward Microtherm. The staff also finds this response acceptable because the applicant treated Microtherm conservatively within the ZOI with respect to determining the release rate and assuming precipitation of the elements release. Therefore, the staff finds the FSAR modification to prohibit calcium silicate in containment addresses the staff's main concern about insulating materials outside the ZOI contributing to precipitate loading in the containment sump and RAI 546, Question 06.02.02-130 acceptable. **RAI 546, Question 06.02.02-130 is being tracked as a confirmatory item**.

With respect to the chemical effects from chlorides, nitrates, and organic materials, in a May 20, 2010, response to RAI 90, Question 06.02.02-4, Parts 4 and 7, the applicant stated that these effects are addressed by the details in ANP-10293, Appendices C, D, and E. However, the staff noted that chlorides, nitrates, and organic materials are not discussed explicitly in ANP-10293. Therefore, in RAI 546, Question 06.02.02-131, the staff requested that the applicant discuss how the chemical effects analysis addressed chlorides, nitrates, and organic materials. RAI 546, Question 06.02.02-131 supersedes RAI 90, Question 06.02.02-4, Parts 4 and 7, which are closed. In an October 4, 2012, response to RAI 546, Question 06.02.02-131, the applicant stated that the effects of chlorides, nitrates, and organic materials on the post-LOCA sump chemistry are fully addressed based on their effect on physical debris, hydrogen generation, and pH control, as analyzed in FSAR Tier 2, Sections 6.1.2, "Organic Materials," 6.2.5.3.1, "Post-LOCA Hydrogen Concentration," and 15.0.3.11, "Loss of Coolant Accident." The response indicated that the principal chemical effect of organic material would be radiolysis, which is addressed by the TSP sump buffer. The organic material found during the ICET 2 was due to decomposition of the phenol-formaldehyde resin-based resin that was a coating for the fiberglass fibers. The evaluation of the concentration of this material for that test was that it was small and would not adversely affect corrosion rates.

The response also stated that chlorine and nitrate would have a negligible effect with near-neutral pH buffering. The staff finds this acceptable based on reviewing the effects of organic materials in other sections and based on corrosion literature indicating low levels of chloride and nitrate have a small effect on the corrosion rate of aluminum at pH 7.5. Therefore, the staff considers RAI 546, Question 06.02.02 resolved. The staff notes that resolution of this question does not resolve issues related to organic materials that have been identified in the staff's evaluation of chemical effects phenomena identification and ranking table (PIRT) results for operating plants ("Evaluation of Chemical Effects Phenomena Identification and Ranking Table Results," March 2011.

6.2.2.4.13.6 *Chemical Debris in Strainer Head-Loss Testing*

This section describes the staff's review of the chemical debris component in the design-basis strainer testing for the U.S. EPR. The staff's review of the strainer testing is discussed mainly in Section 6.2.2.4.7 of this report. The applicant described the use of chemical debris in strainer performance testing in ANP-10293NP. The applicant performed the testing with the goal of all chemical debris eventually reaching the strainer (i.e., no settlement credit). The applicant added the debris in batches and finished adding the postulated 30-day debris load over a relatively short period and prior to the end of the event chronology. The staff finds this type of addition acceptable because it is an option in the staff's 2008 chemical effects guidance. ANP-10293NP, Table E.5-3, "Chemical Debris Additions and Flume Flow Rate for the Head Loss Tests, summarizes the calculations for the chemical debris quantity in the test. For each chemical debris component, the applicant multiplied the scaling factor of 9.37 percent by the calculated mass of that component for the plant, and then increased that value by 2.4 percent to set the amount of each chemical debris component for the testing. The 2.4 percent "bump-up" factor was comprised of 1 percent to account for chemical solubility plus 1.4 percent to account for possible losses in the system. Since the test was scaled according to screen area rather than water volume, the concentration of chemical debris in the test was much higher than that calculated for the plant conditions (i.e., kg debris per kg sump water).

For the strainer test program, the calculated mass of chemical debris for the plant (158 kg) (348 lb) total) was greater than the design-basis quantity documented in ANP-10293NP, Appendix D (125 kg (276 lb)). In each case, the total mass contained roughly equal portions of calcium-base debris and aluminum-base debris. In RAI 490, Question 06.02.02-109, the staff requested that the applicant explain how the chemical debris quantities listed in ANP-10293NP, Appendix D relate to the amount used in the strainer head-loss testing. In a November 18, 2011, response, the applicant stated that ANP-10293P, Section E.5.2 would be modified to include this explanation. The staff confirmed that ANP-10293P explains that the amount of chemical debris used in the testing was based on early calculations and bounds the amount in ANP-10293P, Appendix D. Accordingly, the staff considers RAI 490, Question 06.02.02-109 resolved.

The staff finds the quantity of chemical debris in the testing acceptable because including all of the calculated debris in the strainer testing conforms to the staff's 2008 guidance, the bump-up for solubility is reasonable, and there is additional margin by using the second bump-up and a plant chemical debris quantify that is greater than the design basis by about 26 percent (158 kg vs. 125 kg (348 lb vs. 275 lb) . The staff considers the 1 percent solubility bump-up reasonable because the surrogate is of the order of 0.01 to 0.1 percent. The staff did not evaluate the value of 1.4 percent for potential losses in the system (second bump-up), but the staff finds it reasonable given the other conservatisms in calculating the amount of chemical debris to use in the testing. The design-basis debris quantity using only the 9.37 percent scaling factor would be 11.7 kg (25.8 lbm). The amount actually used in the test was 15.2 kg (33.5 lbm). The calculated plant concentration for the design-basis debris quantity (76 ppm for 125 kg (276 lbm) of debris) is equivalent to approximately 1.2 kg (2.6 lbm) of chemical debris in the test.

The calcium phosphate debris ($Ca_3(PO_4)_2$) was generated outside the test loop in accordance with the applicant test plan. For the aluminum-base debris, the applicant used AlOOH as a surrogate for the sodium aluminum silicate calculated in the modeling. Like the calcium phosphate, this surrogate was generated outside the test loop based on the test plan. Sodium aluminum silicate was not prepared due to safety concerns with handling and using it. The debris was prepared in the laboratory under the applicant's supervision using procedures documented in the applicant's test plans. The staff reviewed the procedures. The staff notes that the procedures conform to staff guidance based on procedures industry developed and documented in WCAP-16530-NP-A. The staff accepted these procedures, with limitations and conditions, in its safety evaluation of the WCAP and included them in the March 2008 guidance. The applicant's procedures include the preparation of the chemicals and the settlement testing with the acceptance criteria. The staff finds this acceptable because research and testing has demonstrated that AlOOH and $Ca_3(PO_4)_2$ prepared and testing according to the WCAP cause head loss in strainer tests. The staff's SER on WCAP-16530-NP-A states that surrogate precipitate prepared in accordance with the WCAP provides adequate settlement and filterability characteristics to represent post-LOCA chemical precipitates in strainer head-loss tests.

The staff observed the preparation of the surrogate precipitates according to "Chemical Preparation Plan for U.S. EPR Strainer Test," U.S. EPR Engineering Information Record Document Number 51-7001869-000. The procedure included the mass of each chemical required for the test, the equivalent concentration in the solution for each, the volume of solution to be added in liters and gallons, and the number of 100 g (0.22 lbm) units of each product. The

AlOOH was prepared by reacting aluminum nitrate and sodium hydroxide for a solution concentration of 11 g/L (0.092 lb/gal). The $Ca_3(PO_4)_2$ was prepared by reacting calcium acetate and TSP for a solution concentration of 5 g/L (0.042 lb/gal). The staff accepted these debris generation methods in its safety evaluation report for WCAP-16530-NP-A.

To test the settlement properties of the prepared debris, the applicant used the standardized test procedures described in WCAP-16530-NP-A. In the settling test, prepared samples of each solution are shaken, put aside and allowed to settle for 1 hour. Settling is visually measured by the clarification of the liquid from the surface of the liquid down to the top level of cloudiness of the solution. The acceptance criteria are different for each precipitate. For the AlOOH, the applicant's acceptance criterion was less than or equal to 1 mL (0.03 fluid ounces) settling (10 percent). For the $Ca_3(PO_4)_2$, 50 percent settling was allowed. The staff notes these acceptance criteria meet the primary criteria approved by the staff in the SER for WCAP-16530-NP-A. The staff observed that both settling rests were acceptable when the surrogate was prepared the evening before adding it to the strainer test. The staff verified that the applicant's procedure required performing a second settling test the next morning to ensure the settling behavior did not change significantly, which conforms to a secondary criterion in WCAP-16530-NP-A.

The two different precipitates were added to the flume using separate pumps and hoses. The chemicals were added in batches to reach the calculated plant concentration of each chemical (AlOOH and $Ca_3(PO_4)_2$) after three additions at 14-minute intervals. The remaining additions of each chemical were smaller, and a total of about 40 batches were used to add the full debris load. The total time for chemical debris introduction was approximately 13.5 hours in the design-basis test, and the test continued for at least 15 flume turnovers after the final addition. The staff finds the applicant's preparation and use of the surrogate chemical debris acceptable because they conform to the staff chemical effects guidance documented in WCAP-16530-NP-A and the March 2008 guidance.

6.2.2.4.13.7 *Chemical Debris in Fuel Assembly Testing*

This section describes the staff's review of the chemical debris component of the design-basis fuel assembly testing performed to establish long-term core cooling for the U.S. EPR. The staff's review of the fuel assembly testing is located in Section 15.6.5 of this report. The applicant described the use of chemical debris in the fuel assembly testing in ANP-10293P, Appendix F, "Downstream Effects Evaluation for the U.S. EPR." The staff audited the test plan as part of its evaluation of the chemical debris component of fuel-assembly testing (AREVA EPR Fuel Assembly Downstream Effects Test Plan, Revision 7, CDI Test Plan 11-02, July 25, 2011).

ANP-10293P, Pages F-46 to F-55, describes how the quantity of chemical debris was calculated for the fuel assembly testing. For the design-basis tests, the amount of chemical debris used in the test was based on the calculated mass for the plant documented in ANP-10293P, Revision 3 (142 kg (313 lb)). This debris quantity was scaled for the testing by dividing by the number of fuel assemblies (241) for a total of 587 g (1.29 lbm). The staff performed a confirmatory calculation and finds this acceptable. The staff also notes that this quantity is greater than the final amount of postulated chemical debris (125 kg (276 lbm) in ANP-10293P, Revision 4), so the amount is conservative relative to the design basis. For hot-leg injection tests, 587 g (1.29 lbm) were added. The staff finds this acceptable because the debris was quantified based on conservative assumptions. In RAI 546, Question 06.02.02-132, the staff requested that the applicant clarify that the chemical debris quantity used in the fuel assembly testing was based on ANP-10293, Revision 3, rather than Revision 4. In an October 4, 2012, response to RAI 546, Question 06.02.02-132, the applicant stated that ANP-10293P, Table F3-7, "Quantify and Composition of Total Solids at 30 days" will be revised with a footnote to state that the fuel assembly test data presented in ANP-10293P, Appendix F is based on a larger debris source term than that used in the ANP-10293P, Appendix D analysis. The staff finds this acceptable because it clarifies why there is a difference between the design-basis chemical debris (ANP-10293P, Revision 4, Appendix D) and the amount used in the fuel assembly testing (ANP-10293P, Appendix F). **RAI 546, Question 06.02.02-132 is being tracked as a confirmatory item**.

For the design-basis cold-leg injection tests, the applicant reduced the amount of chemical debris by adding a quantity representing only the first hour following the break (since hot-leg injections begin within 1 hour). As shown in ANP-10293, Table F.3-4, "Quantify and Composition of Total Solids at One Hour," the first hour's portion of the chemical debris was determined from the amount of precipitates generated after 1 hour in ANP-10293, Table D.3-10 (total elements released and solids formed over 30 days). Since there is not a table entry at 1 hour, the applicant performed linear interpolation between 0.92 hours and 1.58 hours for each type of precipitate. The result was 169 g (0.372 lbm) total per fuel assembly as shown in ANP-10293, Table F.3-4 and in the test plan. The staff performed the calculation to confirm the result. In addition, the staff used the WCAP-16530-NP-A spreadsheet to determine that the amount of precipitate used in the testing is greater than calculated for the first hour after a LOCA using WCAP-16530-NP-A. As with the base case (addition of 30 days of chemical debris), this refinement uses the material release rates described above (Section 6.2.2.4.13.3 of this report) and assumes precipitation of all calcium and aluminum as they are released into solution. The staff finds this acceptable because the applicant determined the 1-hour debris quantify based on conservative release rates and assumed complete and instantaneous precipitation, consistent with the staff's March 2008 guidance.

For the fuel assembly tests, the applicant used AlOOH surrogate to represent all of the chemical debris. The staff finds this acceptable because of the demonstrated effect of this surrogate on head loss. As discussed above, using AlOOH surrogate also avoids the hazard associated with handling sodium aluminum silicate. The staff finds the use of AlOOH as a surrogate for $Ca_3(PO_4)_2$ acceptable because both caused head loss at relatively low concentration in laboratory studies to support GSI-191 (NUREG/CR-6913). One difference is addressed by assuming the surrogate forms immediately as the constituents (i.e., Ca, P, Al) are released into solution and adding the surrogate early in the test.

The test plan specified preparation and testing of AlOOH surrogate outside the test loop and in accordance with WCAP-16530-NP-A and the staff's corresponding SER. The surrogate was prepared at an initial concentration of 11 or 5.5 g/L (0.092 or 0.046 lb/gal), and the settling test requirement was a settled volume of at least 60 percent after 1 hour for a sample diluted to 2.2 g/L (0.018 lb/gal). As described above for strainer testing, the applicant's procedures include an additional settling test for surrogates stored overnight, and this conforms to the staff's guidance in WCAP-16530-NP-A. The staff finds these criteria acceptable because they conform to the guidance as stated in the test plan.

6.2.2.4.13.8 *Chemical Effects Summary*

Based on the staff review described in detail above and summarized below,

- The staff finds the applicant's chemical source term evaluation acceptable because it conformed to staff guidance or reasonable alternatives and resulted in a quantity greater than predicted by an approved staff methodology described in WCAP-16530-NP-A.

- The staff finds the applicant's consideration of chemical effects in strainer head-loss tests acceptable because the mass of precipitate included in the test was greater than that calculated from models and was represented by appropriate surrogates selected and prepared in accordance with the staff's March 2008 chemical effects guidance.

- The staff finds the applicant's consideration of chemical effects in fuel-assembly head-loss tests acceptable because the amount of precipitate included in the test was acceptable and was represented with a surrogate selected and prepared in accordance with the staff'

Accordingly, the staff finds the applicant's analysis of chemical effects acceptable.

<u>ITAAC</u>

The ITAAC associated with the containment and IRWST systems are given in FSAR Tier 1, Section 2.1.1 and Section 2.2.2, respectively. The staff's review of ITAAC related to these systems is found in FSAR Tier 2, Section 14.3.11, "Containment Systems – Inspections, Tests, Analyses, and Acceptance Criteria," of this report. The staff's review of ECCS-related ITAAC (including the IRWST) is discussed in Section 6.3 of this report. The staff's review of ITAAC applicable to ex-vessel downstream effects is discussed in Section 6.2.2.4.12 of this report and below.

FSAR Tier 1, Table 2.2.3-3, "Safety Injection System and Residual Heat Removal System ITAAC," contains the following ITAAC applicable to ex-vessel downstream components in post-LOCA debris conditions.

1. ITAAC Item 3.1 to confirm design and functional qualification of pumps and valves under design basis accident conditions (includes post-LOCA fluid operation for 30-day mission time).

2. ITAAC Item 7.12 to confirm LHSI heat exchanger performance in post-LOCA fluid.

3. ITAAC Item 7.13 to confirm that pressure drop/overall system resistance is consistent with safety analysis results for 30 days of post-LOCA operation; wear rates are acceptable for 30 days of post-LOCA operation; and post-LOCA debris will not clog the ECCS instrument lines.

The staff finds the ITAAC associated with the ex-vessel downstream effects review is acceptable as specified in FSAR Tier 1, Table 2.2.3-3 and summarized above

<u>TECHNICAL SPECIFICATIONS</u>

Technical Specifications for ECCS which includes the IRWST are presented in FSAR Tier 2, Chapter 16, Section 3.5. The Technical Specifications for ECCS items are reviewed in Section 6.3 of this report.

<u>TIER 2*</u>

Given the fuel assembly performance discussion provided in Technical Report ANP-10293, Appendix F, “Downstream Effects Evaluation for the U.S. EPR,” and containment debris limits discussed in response to RAI 511, Question 06.02.02-124 and RAI 488, Question 06.02.02-91 (discussed in Section 6.2.2.4.4 of this report), in RAI 552, Question 06.02.02-134, the staff requested that the applicant evaluate the appropriateness of applying Tier 2* designation it items associated with long-term core cooling. In a September 27, 2012, response to RAI 552, Question 06.02.02-134, the applicant provided markups to FSAR Tier 2, Section 6.3.2.2.2, “System Components,” that identified latent debris inside containment as Tier 2* information without expiration at fuel load. Since the applicant’s testing and analysis highlighted the significance of certain assumptions about debris in containment to the adequacy of long-term core cooling and its similarity to other 10 CFR Part 52 design certifications, the staff agree with the applicant’s approach to designating U.S. EOR containment latent debris as Tier 2* without expiration at fuel load. Given the discussion above, the staff finds the applicant’s September 27, 2012, response to RAI 552, Question 06.02.02-134 acceptable. The staff confirmed that FSAR Revision 4, dated November 15, 2012, contains the changes committed to in the RAI response. Accordingly, the staff finds that the applicant has adequately addressed this issue and, therefore, considers RAI 552, Question 06.02.02-134 resolved.

6.2.2.5 *Combined License Information Items*

The following is a list of item numbers and descriptions from FSAR Tier 2, Table 1.8-2, “U.S. EPR Combined License Information Items.”

Item No.	Description	Section
6.3-1	A COL applicant that references the U.S. EPR design certification will describe the containment cleanliness program which limits debris within containment.	6.3.2.2.2

FSAR Tier 2, Sections 1.8 and 6.3.2.2.2 describe COL Information Item 6.3-1, “A COL applicant that references the U.S. EPR design certification will describe the containment cleanliness program which limits debris within containment.” In RAI 139, Questions 06.02.02-18 through 06.02.02-21, the staff requested that the applicant clarify the cleanliness program objectives related to permanent and temporary modifications, foreign materials, maintenance activities, and coating materials, respectively. In a March 3, 2009, response to RAI 139, Questions 06.02.02-18 through 06.02.02-21, the applicant revised FSAR Tier 2, Section 6.3.2.2.2 to include a description for each of these cleanliness program objectives. Since a description of these elements was included in the FSAR and is consistent with staff guidance, the staff finds that the applicant has adequately addressed this issue. Accordingly, the staff considers RAI 139, Questions 06.02.02-18 through 06.02.02-21 resolved.

FSAR Tier 2, Section 6.3.2.2.2 originally did not present the latent and miscellaneous debris design basis analysis limits. As discussed in the latent debris section above, in RAI 434, Question 06.02.02-75, the staff requested that the applicant include design basis analysis limits for the amount of latent and miscellaneous debris within the COL cleanliness program description in FSAR Tier 2, Section 6.3.2.2.2. In a March 31, 2011, response to RAI 434, Question 06.02.02-75, the applicant revised FSAR Tier 2, Section 6.3.2.2.2 to include the design basis limits for the total amount of latent and miscellaneous debris. Accordingly, the staff considers RAI 434, Question 06.02.02-75 resolved. In RAI 511, Question 06.02.02-124, the staff requested that the applicant define the latent debris types and amounts that make up the total latent debris amount. In a November 11, 2011, response to RAI 511, Question 06.02.02-124, the applicant committed to revise ANP-10293NP and include the latent debris composition. The staff confirmed this information was included in ANP-10293NP, Revision 4. The applicant also clarified the composition of latent debris in FSAR Tier 2, Section 6.3.2.2.2 in a November 17, 2011, response to an unrelated RAI (RAI 488, Question 06.02.02-91). The FSAR Tier 2 markup contained in the November 17, 2011, response to RAI 488, Question 06.02.02-91 reflects the same latent debris composition presented in response to RAI 511, Question 06.02.02-124 and reflected in ANP-10293NP, Revision 4. Based on the above discussion, the staff finds that the applicant's response to RAI 511, Question 06.02.02-124 and RAI 488, Question 06.02.02-91 acceptable regarding latent debris composition. No additional COL information items were identified in this review.

6.2.2.6 *Conclusion*

Based on the open items discussed above, the staff cannot find the design acceptable as it relates to the effects of accident-generated and latent debris in accordance with the requirements of NRC regulations.