6 ENGINEERED SAFETY FEATURES

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Appendix A, “Design Certification Rule for the U.S. Advanced Boiling Water Reactor,” to Title 10 of the *Code of Federal Regulations* (10 CFR) Part 52, “Licenses, Certifications, and Approvals for Nuclear Power Plants,” constitutes the standard design certification (DC) for the U.S. Advanced Boiling Water Reactor (ABWR) design. To document the U.S. Nuclear Regulatory Commission (NRC) staff’s review supporting initial certification of the ABWR, the staff issued a final safety evaluation report (FSER) in NUREG-1503, “Final Safety Evaluation Report Related to the Certification of the Advanced Boiling Water Reactor Design,” in July 1994 and NUREG-1503, Supplement 1, in May 1997.

The staff is documenting its review of the GE-Hitachi Nuclear Energy (GEH or the applicant) application for renewal of the ABWR DC in Supplement 2 to NUREG-1503. Chapter 1 of this supplemental FSER describes the staff’s review process for the ABWR DC renewal. This supplemental FSER section documents the NRC staff’s review specifically related to Chapter 6, “Engineered Safety Features,” Section 6.2.1.9, “Containment Debris Protection for ECCS Strainers,” of the GEH Design Control Document (DCD), Revision 7. Except as modified by this supplement to the FSER, the findings made in NUREG-1503 and its Supplement 1 remain in full effect.

6.2.1.9 Containment Debris Protection for ECCS Strainers

6.2.1.9.1 *Regulatory Criteria*

In the GEH ABWR DCD, Revision 7, the applicant proposed a design change to the emergency core cooling system (ECCS) pump suction debris strainers. This supplemental evaluation documents the staff’s review of the change to the ECCS strainer design described in DCD Tier 1, Tables 2.4.1, 2.4.2, and 2.4.4, and DCD Tier 2, Section 6C, “Containment Debris Protection for ECCS Strainers.”

In a letter dated July 20, 2012 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML12125A385), the NRC staff identified 28 items for GEH’s consideration as part of its application to renew the ABWR DC. In Item No. 09 of the letter, the staff asked the applicant to confirm that the ECCS suction strainer design complies with 10 CFR 50.46(b)(5), which included providing the net positive suction head (NPSH) margins determined using Regulatory Guide (RG) 1.82, “Water Sources for Long-Term Recirculation Cooling Following a Loss-of-Coolant Accident,” Revision 4, issued March 2012, addressing chemical, in-vessel, and ex-vessel downstream effects, providing a structural analysis, and updating the inspections, tests, analyses, and acceptance criteria (ITAAC) as necessary consistent with the new guidance. In a letter dated September 17, 2012 (ADAMS Accession No. ML12261A311), the applicant informed the staff that it would address all the items identified in the July 20, 2012, letter.

The proposed changes do not fall within the definition of a “modification.” Therefore, in accordance with 10 CFR 52.59(c), this design change is an “amendment,” as this term is defined in Chapter 1 of this FSER supplement and will correspondingly be evaluated using the regulations in effect at renewal. The applicable regulatory requirements for evaluating the design amendment to the ECCS strainers are given below.

The acceptance criteria for the performance of the ECCS following a loss-of-coolant accident (LOCA) are specified in 10 CFR 50.46, "Acceptance Criteria for Emergency Core Cooling Systems for Light-Water Nuclear Power Reactors." The acceptance criterion dealing with the long-term core cooling phase of the accident recovery is 10 CFR 50.46(b)(5), which states that:

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

As discussed in 10 CFR 50.46(a)(1)(i), the ECCS must be designed so that the calculated cooling performance in the event of a LOCA resulting from a break in the primary reactor coolant system is in accordance with an acceptable evaluation model, or alternately, a model in conformance with the features of 10 CFR Part 50, Appendix K, "ECCS Evaluation Models." The primary ECCS safety functions are comprehensively modeled and evaluated for breaks up to and including the double-ended severance of a reactor coolant pipe to show that the ECCS will limit the peak clad temperature to below 1204 degrees Celsius (°C) (2,200 degrees Fahrenheit (°F)) and ensure that the core will remain in place and substantially intact with its essential heat transfer geometry preserved.

The regulations in 10 CFR Part 50, Appendix A, "General Design Criteria for Nuclear Power Plants," (GDC) 1, "Quality Standards and Records," and 10 CFR 50.55a, "Codes and Standards," require that systems and components be designed, fabricated, erected, constructed, tested, and inspected to quality standards commensurate with the importance of the safety function to be performed. Regulations in 10 CFR 50.55a also incorporate by reference the applicable editions and addenda of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel (BPV) Code, which addresses pressure integrity of components. Application of 10 CFR 50.55a and GDC 1 provides assurance that established standard practices of proven or demonstrated effectiveness are used to achieve a high likelihood that these safety functions will be performed and that the codes and standards applied are commensurate with the importance to safety of these functions.

- GDC 4, "Environmental and Dynamic Effects Design Basis," requires that structures, systems, and components (including pumps, valves, and strainers) important to safety accommodate the effects of and be compatible with the dynamic effects and environmental conditions associated with postulated accidents.

- GDC 34, "Residual Heat Removal," requires that a system to remove residual heat be provided. The system safety function shall be to transfer fission product decay heat and other residual heat from the reactor core at a rate such that specified acceptable fuel design limits and the design conditions of the reactor coolant pressure boundary are not exceeded.

- GDC 35, "Emergency Core Cooling," requires that an ECCS be provided that is capable of transferring heat from the reactor core following a loss of reactor coolant, at a rate sufficient to ensure that the core remains in a coolable geometry and that the clad metal-water reaction is limited to negligible amounts.

- GDC 38, "Containment Heat Removal," requires that a system to remove heat from the reactor containment be provided. The system safety function shall be to reduce rapidly, consistent with the functioning of other associated systems, the containment pressure and temperature following any LOCA and maintain them at acceptably low levels.

The staff used the following guidance to determine whether the design of systems and components meets the regulatory requirements given above:

- RG 1.82, "Water Sources for Long-Term Recirculation Cooling Following a Loss-Of-Coolant Accident," Revision 4, issued March 2012 (ADAMS Accession No. ML111330278), as supplemented by the NRC-approved Boiling Water Reactor Owners' Group Utility Resolution Guidance (URG), NEDO-32686-A, "Utility Resolution Guidance for ECCS Suction Strainer Blockage," Volumes 1 through 4, Revision 0, issued October 1998 (ADAMS Accession Nos. ML092530482, ML092530500, ML092530505, and ML092530507), provide guidance for boiling-water reactor (BWR) debris evaluations.

- Safety Evaluation by the Office of Nuclear Reactor Regulation, for Topical Report (TR) WCAP-16406-P-A, Revision 1, "Evaluation of Downstream Sump Debris Effects in Support of GSI-191,' Pressurized Water Reactor Owners Group, Project No. 694," issued December 2007 (ADAMS Accession No. ML073520295).

- RG 1.100, "Seismic Qualification of Electrical and Active Mechanical Equipment and Functional Qualification of Active Mechanical Equipment for Nuclear Power Plants," Revision 3, issued September 2009, which endorses ASME Standard QME-1-2007, "Qualification of Active Mechanical Equipment Used in Nuclear Power Plants," (ADAMS Accession No. ML091320468).

- NUREG–0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition," (SRP), Section 6.2.2, "Containment Heat Removal Systems," Revision 5, issued March 2007 (ADAMS Accession No. ML070160661).

6.2.1.9.2 Summary of Technical Information

In the following requests for additional information (RAIs), the staff requested information on various aspects of the proposed amendment to the ABWR ECCS pump suction debris strainer design. The following is a chronological list of these staff requests and the GEH responses. Details of the requests and responses is addressed in the specific sections where the issues were evaluated in the technical evaluation Section of this supplemental FSER.

In RAI 06.03-1, dated March 10, 2015 (ADAMS Accession No. ML15068A227), the staff requested that GEH, in accordance with 10 CFR 52.59(a), provide information showing that the ECCS suction strainer design complies with 10 CFR 50.46(b)(5). The applicant responded by letters dated April 8 and July 17, 2015 (ADAMS Accession Nos. ML15098A484 and ML15198A332).

In RAI 06.03-2, dated December 15, 2015 (ADAMS Accession No. ML15343A408), the staff requested that GEH provide detailed information in three areas (design and analysis of ECCS strainers, chemical effects, and downstream effects) showing that the ECCS suction strainer design complies with 10 CFR 50.46(b)(5). The applicant responded by letters dated, May 27 and December 19, 2016, and February 23, 2017 (ADAMS Accession Nos. ML16148A101, ML16358A445, and ML17055C593 respectively).

On May 19, 2016 (ADAMS Accession No. ML16144A784), the staff had a public teleconference meeting with GEH regarding RAI 06.03-2 to provide clarification on the specific staff requests, which resulted in the GEH response on May 27, 2016.

On January 5, 2017, the staff had a public teleconference meeting with GEH regarding RAI 06.03-2 to provide clarification on the specific staff requests, which resulted in the GEH response on February 23, 2017.

In RAI 06.02.02-1, dated May 10, 2017 (ADAMS Accession No. ML17130A798), the staff requested the description of construction codes and classifications (safety class, ASME code class, seismic category and quality group) for the ECCS strainer design. The applicant responded in a letter dated June 16, 2017 (ADAMS Accession No. ML17167A161) and provided markups of the ABWR DCD, Revision 6, to the staff.

Following a public teleconference meeting with the staff on March 1, 2018 (ADAMS Accession No. ML18157A215), GEH provided an updated technical report (TR) NEDE-33878P, "ABWR ECCS Suction Strainer Evaluation of Long-Term Recirculation Capability," Revision 3, issued March 2018, by a letter dated March 28, 2018 (ADAMS Accession No. ML18092A303).

In RAI 06.03-3 a follow up to RAIs 06.03-2 B1, B2, and B3, dated March 28, 2017 (ADAMS Accession No. ML17087A290), the staff requested additional information regarding the containment material and chemical affects. GEH responded to RAI 06.03-3 in a letter dated April 25, 2017 (ADAMS Accession No. ML17116A071) and provided markups to the ABWR DCD, Revision 6, in its response dated August 23, 2017 (ADAMS Accession No. ML17236A062), to address the staff follow up questions to RAI 06.03-2.

In RAIs 06.03-4 through 9, dated July 10, 2017 (ADAMS Accession No. ML17187A127), the staff requested that GEH provide additional information regarding the settling velocity of potential debris and system operation for these conditions. GEH responded by a letter dated August 23, 2017, with a revised response to RAIs 06.03-3 and RAIs 06.03-4 through 9.

The final DCD changes as a result of all RAIs included changes to DCD Tier 1, Tables 2.4.1, 2.4.2, and 2.4.4 and changed inspections, tests, and analysis design commitments for NPSH available at residual heat removal (RHR) system pumps, high pressure core flooder (HPCF) system pumps, and reactor core isolation cooling (RCIC) system pumps from "50% minimum blockage of the pump suction strainers" to "analytically derived values for blockage of pump suction strainers based upon the as-built system."

In addition, GEH provided the changes to DCD Tier 2, Chapter 6, Appendix 6C in markups to the ABWR DCD, Revision 6, as follows:

- Replaced ABWR ECCS suction strainers from using a "'T' arrangement with conical strainers on the two free legs of the 'T'" to a General Electric (GE) optimized stacked disk design in accordance with GEH licensing TR NEDC-32721P-A, "Application Methodology for the General Electric Stacked Disk ECCS Suction Strainer," Revision 2, issued March 2003 (ADAMS Accession Nos. ML031010390 proprietary version and NEDO-32721-A Revision 2 ML031010388 public version). This strainer design was utilized in response to NRC Bulletin (BL) 96-03, "Potential Plugging of Emergency Core Cooling Suction Strainers by Debris in Boiling-Water Reactors," issued May, 1996, as a replacement of existing ECCS strainers with a large capacity passive strainer design. This design uses disks whose internal radius and thickness vary over the height of the strainer.

- Added evaluations of chemical effects and downstream effects, which were not considered during the original ABWR certification as these had not been discovered.

- Replaced RG 1.82, “Water Sources for Long-Term Recirculation Cooling Following a Loss-of-Coolant Accident,” Revision 1, issued November 1985 (ADAMS Accession No. ML003740236), for sizing ECCS suction strainers to RG 1.82, Revision 4.

- Replaced DCD Tier 2, Table 6C-1, providing input parameters used for debris analysis with a table of ECCS strainer debris loads and deleted DCD, Tier 2, Table 6C-2 providing ECCS strainers screen area and characteristic dimension.

6.2.1.9.3 Technical Evaluation

In FSER Section 6.2.1.9 of NUREG 1503, the staff discussed containment debris protection for the ECCS strainers (ADAMS Accession No. ML080670560). The FSER states that events at operating reactors involving the clogging of ECCS strainers led the staff to conclude that the guidance in RG 1.82, Revision 1, may not be conservative enough to eliminate this concern. The FSER mentions the issuance of Information Notice (IN) 92-71, “Partial Plugging of Suppression Pool Strainers at a Foreign BWR”; dated September 30, 1992; IN 93-34, “Potential for Loss of Emergency Cooling Function due to a Combination of Operational and Post-LOCA Debris in Containment,” dated April 26, 1993; Supplement 1 to IN 93-34; dated May 6, 1993; and BL 93-02, “Debris Plugging of Emergency Core Cooling Suction Strainers,” dated May 11, 1993. The staff indicated in the FSER that it was still working on resolving this issue for operating reactors. The staff stated that the issue regarding clogging of the ECCS strainers was resolved for the ABWR based on commitments made in Amendment 35 to the ABWR DCD. These commitments include:

- Sizing the RHR system suction strainers three times the area derived from NRC guidance for all breaks to account for uncertainty in the synergetic effects of strainer clogging from insulation, corrosion products, and other debris;

- Sizing the HPCF and RCIC system suction strainers according to guidance, but with conservatism in the mass of debris assumed to be deposited on the strainers; and

- Providing a 10-percent margin in the NPSH available from the static head of the suppression pool for conservatism.

However, because of lessons learned from BWR operating experience and during the review of Generic Safety Issue (GSI)-191, “Assessment of [Effect of] Debris Accumulation on PWR Sump Performance,” the staff determined that further review of the ECCS pump suction debris strainer design in the GEH ABWR DC renewal application was necessary to ensure continued compliance with the long-term cooling requirement of 10 CFR 50.46(b)(5). The RG generally used for the ECCS debris strainer design was RG 1.82, Revision 0, issued June 1974, which included a 50-percent debris blockage criterion as a means to establish sufficient NPSH margin for the ECCS pumps. This criterion allows only 50-percent of the ECCS suction debris strainer to be clogged by debris. The certified design relies on an ITAAC that verifies this criterion. The later revisions of RG 1.82 provided guidance for designing an ECCS that includes the use of mechanistically determined debris head loss across the suction strainers.

NRC BL 96-03, asked BWR licensees to address potential debris plugging of ECCS suction strainers that were designed to meet the 50-percent debris blockage criterion. In response, licensees with operating BWRs replaced ECCS pump suction strainers with large-capacity passive strainers. The ABWR DC did not address BL 96-03 because of the timing of BL issuance and completion of the original ABWR DC review.

Efforts to address GSI-191 have led the NRC staff and the industry to identify new issues, including the effects of chemical precipitates impacting the performance of ECCS suction strainers, and downstream effects on fuel impacting the ability of cooling the reactor core following a LOCA.

ECCS Suction Strainer Sizing Evaluation

In RAI 06.03-2, Part A, the staff asked the applicant to provide design and analysis information for the ECCS strainer because it was missing in the ABWR DC renewal application. The applicant's February 23, 2017, RAI response included a proprietary version of TR NEDO-33878, "ABWR ECCS Suction Strainer Evaluation of Long-Term Recirculation Capability," Revision 0 (ADAMS Accession Nos. ML17055C497, public version and ML17055C500 proprietary version), providing supporting technical information to show conformance with RG 1.82, Revision 4. The staff evaluation of the February 23, 2017, response to RAI 06.03-2 Part A, is given below. The staff's evaluation of the remaining parts of the response is given under separate headings in this section.

In RAI 06.03-2, Part A.1, the staff asked the applicant to provide its evaluation of ECCS strainer performance (e.g., head loss) and provide the results of any analysis and/or tests performed in support of its findings. In response, the applicant stated that the ABWR ECCS strainers will be the patented GE optimized stacked disk design in accordance with NEDC-32721P-A Revision 2. Along with NEDC-32721P-A Revision 2, the applicant used an updated strainer debris head loss correlation to address an issue identified in a letter to the NRC, dated March 24, 2008 (ADAMS Accession No. ML080850242). The applicant proposed to update the ABWR DCD, "to remove obsolete information related to the T-shaped conical strainer, and outdated information such as the guidance to design for 50% plugging." The applicant provided the markup for DCD Tier 1, Tables 2.4.1, 2.4.2, and 2.4.4 replacing the 50 percent plugging criteria for NPSH available for RHR, HPCF, and RCIC pumps in the original ABWR certification to, "analytically derived values for blockage of pump suction strainers based upon the as-built system." The staff evaluated the markup and finds that proposed DCD Tier 1 changes are appropriate and are consistent with guidance in RG-1.82, Revision 4, and are therefore acceptable.

The staff focused on the applicant's use of the methodology in TR NEDC-32721P-A, Revision 2, which was previously approved by the staff for BWR ECCS suction strainer design and developed using an updated head loss correlation. The staff reviewed the updated head loss correlation as provided in NEDO-33878, Revision 3 (ADAMS Accession Nos. ML18092A306, public version and NEDE-33878P ML18092A308 proprietary version) and audited its derivation as given in reference documents listed in NEDO-33878. The staff determined that similarities between BWR Mark II and Mark III and ABWR containment designs would warrant using NEDC-32721P-A methodology for debris generation and transport. Quantities and types of debris causing the ABWR ECCS strainer head loss will be bounded by those for BWRs, except for chemical precipitates which have not been fully evaluated for BWRs. Chemical effects for the ABWR are addressed below under separate heading in this section. As such the NEDC-32721P-A, Revision 2 methodology is also applicable for the ABWR ECCS strainer head loss evaluation.

The staff reviewed the supporting technical information for strainer performance presented in NEDO-33878, Revision 3 to show conformance with RG 1.82, Revision 4 and performed a regulatory audit from February 21, 2017 – June 20, 2017, on other supporting documents as discussed in a regulatory audit summary report dated January 24, 2019 (ADAMS Accession No. ML18354B167), to confirm that the applicant has used the NEDC-32721P-A, Revision 2 methodology. The applicant also proposed to update DCD Tier 2, Appendix 6C summarizing analysis performed for the ECCS debris strainer and provided the associated ABWR DCD, Revision 6, markup. Based on the staff review of the applicant's response supported by the staff regulatory audit (ADAMS Accession No. ML18354B167), the staff determined that the applicant's response to RAI 06.03-2, Part A.1, was acceptable.

In RAI 06.03-2, Part A.2, the staff asked the applicant to provide the types and quantities of insulation debris being transported to the ECCS suction strainers and to the core following a design basis accident. This information is needed for evaluating the ECCS and core design heat transfer capabilities. In response, the applicant listed in a table, types and quantities of debris, determined in accordance with staff approved URG NEDO-32686-A, Revision 0, Volumes 1 through 4, and provided DCD Tier 2, markups in Table 6C-1. The staff review found that for sludge/corrosion products, inorganic zinc (IOZ), epoxy coated IOZ, rust flakes, and dust/dirt debris, the applicant has used quantities as recommended in Sections 3.3.2.2.2.1.1 and 3.2.2.2.3 of the URG and therefore, the listed debris types and quantities specified for the ABWR are acceptable.

During the regulatory audit summarized in the January 24, 2019, audit report (ADAMS Accession No. ML18354B167), the staff confirmed that the applicant used reflective metallic insulation and Nukon fiber insulation quantities calculated for a reference ABWR plant using a methodology recommended in the URG. Therefore, considering that the applicant has a design commitment to use "analytically derived values for blockage of pump suction strainers based upon the as-built system" for ECCS pumps, the staff determined that the applicant's response to RAI 06.03-2, Part A.2, was acceptable.

In RAI 06.03-2, Part A.3, the staff asked the applicant to provide details of the ECCS debris strainer for assessing its performance under accident conditions because this information was not provided in the ABWR DC renewal application. In response, the applicant stated that the conical strainer design used in the original ABWR DC was obsolete and was updated to the GEH stacked disk strainer and design details related to the stacked disk strainer performance and sizing methodology can be found in the TR NEDC-32721P-A, Revision 2, which applies an updated head loss correlation. The applicant provided the following ECCS suction strainer configuration used for the ABWR application:

- Type: GEH stacked disk passive suction strainer

- Flow Area: Each strainer has perforated area 36 m^2 (388 ft^2) with 20 disks [combined surface area of 216 m^2 (2328 ft^2) for three (3) RHR, two (2) HPCF and one (1) RCIC strainer]

- Hole Size: 3.2 mm (0.125 inch) diameter.

As described in the January 24, 2019, regulatory audit report (ADAMS Accession No. ML18354B167), the staff reviewed the proposed new strainer drawing to confirm the above information and the supporting sizing calculations. The staff determined that the applicant's response to RAI 06.03-2, Part A.3, is acceptable because it provided requested information in conformance with RG 1.82, Revision 4.

In response to RAI 06.03-1, GEH in its letter dated April 8, 2015 (ADAMS Accession No. ML15098A487), proposed to delete DCD Tier 2, Tables 6C-1 and 6C-2, which provided debris analysis input parameters and results of ECCS debris strainer sizing analysis without providing alternate tables or references to calculation reports. The staff needed the referenced information provided in those tables in the ABWR DCD to support its review. Therefore, in RAI 06.03-2, Part A.4, the staff asked the applicant to provide the corresponding information. In its response letter dated May 27, 2016, the applicant proposed to add DCD Tier 2, Table 6C-1 providing design basis debris load (i.e., types and quantities of debris) used in sizing ECCS strainers. The applicant stated that the DCD Tier 2, Table 6C-1 information, combined with the methodology in NEDC-32721P-A, Revision 2, provides the necessary inputs to design a strainer that complies with 10 CFR 50.46(b)(5). The staff reviewed the applicant's response and supporting documentation during the staff regulatory audit (ADAMS Accession No. ML18354B167) and determined that the applicant has used the NEDC-32721P-A, Revision 2, methodology in conformance with RG 1.82, Revision 4, and therefore, the applicant's response to RAI 06.03-2, Part A.4, was acceptable.

In its response to RAI 06.03-1, dated July 17, 2015, the applicant provided references to guidance documents, for example, "Of the debris generated, the amount that is transported to the suppression pool shall be determined in accordance with [NEDO-32686-A] based on similarity of the Mark III upper drywell design." However, the response did not provide the ECCS debris strainer design input calculated using these guidance documents nor did it reference calculation reports providing such information. Therefore, in RAI 06.03-2, Part A.5, the staff asked the applicant to provide an analysis documenting the implementation of this guidance.

In the applicant's response to RAI 06.03-2, Part A.1, dated February 23, 2017, GEH provided a markup to DCD Tier 2, Appendix 6C adding a reference to NEDC-32721P-A, Revision 2 (with a note explaining the updated head loss correlation), which provides the strainer design methodology. As evaluated above the staff determined that the applicant provided information on analysis and implementation of NEDC-32721P-A, Revision 2 consistent with RG 1.82, Revision 4, and therefore, the applicant's response to RAI 06.03-2, Part A.5, is acceptable.

Based on the review of the applicant's submittal, including RAI responses and the staff regulatory audit summary (ADAMS Accession No. ML18354B167), the staff finds that the GEH ABWR ECCS suction strainer sizing evaluation conforms to the guidance in RG 1.82, Revision

4, NEDO-32686-A, Revision 0, and TR NEDC-32721P-A, Revision 2, and meets the requirements in 10 CFR 50.46(b)(5), and is, therefore, acceptable.

The applicant provided the necessary information from RAI 06.03-2, Part A.1, in the ABWR DCD, Revision 7, which incorporated the changes described in the applicant's response. Therefore, Confirmatory Item 6.2.1.9-1, from the staff advanced safety evaluation report (SER) with no open items for the ABWR DC renewal, is resolved and closed.

ECCS Suction Strainer Structural Evaluation

The staff reviewed TR NEDC-32721P-A, Revision 2, for conformance to RG 1.82, Revision 4. In this TR, the applicant addressed hydraulic performance design methods and provided procedures for the calculation of hydraulic loads for new strainer installations. Hydrodynamic loads in the suppression pool are directly caused by the movement of suppression pool water, driven by the oscillation of air and/or steam bubbles at either the locations of the main LOCA vents or the safety relief valve (SRV) discharge. The applicant states that the bubble source closest to the strainer will be the dominant source of hydrodynamic loads to the strainers. In all cases, a location scale factor is calculated based on the nearest bubble source. The scaled loads (resulting from multiplying a location scale factor to the load created from collapsing bubbles) are then multiplied by dynamic load factors (DLF) that are calculated from the natural frequencies of the new strainers. The new DLFs are based on the frequency ratio between the frequency of the bubble source and the natural frequency of the strainer assembly. The DLFs for suddenly applied loads (SRV Jet, LOCA Jet, and Fallback) are taken at 2.0. The product of the scale factors, DLFs, and the original loads is taken to be the load on the new strainer. The staff finds the methodology of assessing the hydrodynamic loads of the new strainers as provided in NEDC-32721P-A, Revision 2, meets the guidance of RG 1.82, Revision 4, and is therefore acceptable.

The staff reviewed design specifications and design documents of ECCS strainers during the staff's regulatory audit (ADAMS Accession No. ML18354B167), to verify that the component design meets the methodology and criteria described in DCD Tier 2, Section 6.2.2, and that the design of ECCS strainers conforms to RG 1.82, Revision 4, and the design requirements have been properly translated to the design documents. The structural analysis of the strainer is performed to ensure the structural adequacy of the strainer, and includes seismic, differential pressure, and hydrodynamic loads. This set of loading categories is consistent with those applied to ASME BPV Code Class 1, 2, and 3 components as described in DCD Tier 2, Section 3.9.3, "ASME Code Class 1, 2, and 3 Components, Component Supports, and Core Support Structures," and is therefore acceptable to the staff. During the regulatory audit (ADAMS Accession No. ML18354B167), the staff found that design specifications and design documents of ECCS strainers are consistent with the methodology and criteria described in the DCD Tier 2, Section 3.9.3, for ASME Code Class components and component supports.

During the regulatory audit (ADAMS Accession No. ML18354B167) of the ABWR ECCS strainer design, the staff noticed that, in GEH Document 24A5822, "ECCS Suction Strainers, Piping and Support," Revision 7, July 21, 1999 *(GEH Proprietary)*, the applicant specified the ECCS strainers are designed in accordance to ASME Code Section III. However, DCD Tier 2, Section 6C, does not provide the information of construction codes and standards of the ECCS strainers design and Table 3.2-1, "Classification Summary," did not include the component classifications of ECCS strainers (e.g., safety class, ASME code class, seismic category and quality group). In RAI 06.02.02-1, dated May 10, 2017 (ADAMS Accession No. ML17130A798), the staff requested the applicant provide in DCD Tier 2, the description of construction codes and classifications (safety class, ASME code class, seismic category and quality group) for the ECCS strainer design.

In the RAI response dated June 16, 2017 (ADAMS Accession No. ML17167A161), the applicant states that it added the component classification for the ABWR ECCS suction to DCD Tier 2, Table 3.2-1, as provided in the ABWR DCD, Revision 6, markups.

In the markups to DCD Tier 2, Table 3.2-1, the ECCS pump suction strainers in the ABWR suppression pool are classified to be Safety Class 2, Location C, Quality Group Classification B, Quality Assurance Requirement B, seismic Category I. The applicant added DCD Tier 2, Table 3.2-1, with the following notes (ii):

> ASME BPV Code Section III, Class 2 requirements are used as guidance for specification development of the design, fabrication, and inspection of the ECCS pump suction strainers, commensurate with the safety importance of the strainers. The strainers are not required to be ASME Code stamped and no ASME Certificate of Authorization is required (the strainers do not function as a pressure boundary and are attached to the end of the piping within the suppression pool). In addition, if required, the strainers may be supported from the suppression pool wall and floor.

The staff finds that the markup to DCD Tier 2, Table 3.2-1, is acceptable, since the component classification of the strainer design is appropriate to ensure the design, fabrication, erection, construction, testing, and inspection for the strainer will be commensurate with the importance of the safety function to be performed which is in accordance with GDC 1. Therefore, RAI 06.2.2-1 is closed.

The applicant provided the necessary information in the ABWR DCD Revision 7 which incorporated the changes described in the applicant’s letter dated June 16, 2017, to address RAI 06.2.2-1. Therefore, Confirmatory Item 6.2.1.9-2 from the staff’s advanced SER with no open items for the ABWR DC renewal is resolved and closed.

Based on the reviews of TR NEDC-32721P-A, Revision 2, on the proposed amended ABWR strainer design and the staff regulatory audit (ADAMS Accession No. ML18354B167) of ECCS strainer design, the staff finds that GEH ABWR ECCS suction strainer design includes the appropriate loads and is compatible with the environmental conditions associated with normal, operation, maintenance, testing, and postulated accident loads, including LOCAs and therefore meets GDC 4 requirements and conforms to the guidance in RG 1.82, Revision 4, and NEDC-32721P-A, Revision 2.

Chemical Effects Evaluation

Chemical Effects Introduction and/Background:

The term “chemical effects” refers to the possibility that interactions between materials and the post-LOCA containment environment will generate chemical precipitates that may contribute to blockage and head loss at the strainers and/or reactor core. For pressurized-water reactors (PWRs), the staff published detailed guidance in 2008 for evaluating plant-specific chemical effects (ADAMS Accession No. ML080380214). This includes guidance on using WCAP-16530-NP-A, “Evaluation of Post-Accident Chemical Effects in Containment Sump Fluids to

Support GSI-191," issued March 2008 (ADAMS Accession No. ML081150383). Conforming to this guidance provides one acceptable way to meet the requirements of 10 CFR 50.46, as they relate to the effect of chemical precipitates on the ECCS for PWRs.

The NRC has not issued comparable chemical effects guidance to BWR licensees or applicants. The generation of chemical precipitates in the water chemistry representative of a BWR post-LOCA environment has not been thoroughly studied. In RG 1.82, Revision 4, the staff Regulatory Position 3.3.1, states that post-LOCA containment conditions for BWRs may result in chemical interactions different than those considered for operating PWRs. The BWR Owners Group (BWROG) has performed testing to begin evaluating the chemical effects issues with operating BWRs.

The BWROG performed benchtop testing as an initial step to quantify material release rates, which refers to the release of elements into solution through corrosion of metallic materials and dissolution of non-metals. The BWROG report, "Review of Boiling Water Reactor Material Dissolution in Post-LOCA Containment Systems," issued November 2013 (ADAMS Accession No. ML14328A639), describes the results of the BWR testing. The NRC has not reviewed that testing to determine how it applies to new or operating reactors. To evaluate chemical effects for the ABWR DC renewal, the staff reviewed the information in the application and supplemental information in letters dated July 17, 2015, May 27, 2016, December 19, 2016, February 23, 2017, April 25, 2017, and August 23, 2017.

The complexity of evaluating chemical effects for BWRs is increased by the uncertainty in the post-LOCA chemical environment, which may be pH-buffered in the alkaline range or unbuffered, depending on the licensing basis of the plant and the conditions during the accident. Alkaline buffering is used by some plants, to prevent post-LOCA iodine re-evolution, and it is accomplished with addition of the borated chemical solution in the standby liquid control system (SLCS). Iodine re-evolution at acidic pH conditions is a potential consequence of acids generated by radiolysis of water, air, and organic materials (e.g., cable jacketing). However, even without an intentional buffer addition, the pH may become more alkaline if fiberglass is destroyed during the LOCA and subsequently undergoes chemical dissolution.

One possible difference for BWRs is that the lower pH range of an unbuffered post-LOCA fluid compared to the alkaline-buffered PWR fluid could lead to more corrosion of zinc (e.g., galvanized steel) and carbon and low-alloy steels. The ABWR containment has zinc in the form of galvanized steel and IOZ coatings, and some uncoated steel piping in the ECCS. It is not known whether zinc and iron form precipitates that clog fiber beds, other than the steel corrosion products ("sludge") that are included as part of the debris load in the resolution of BWR ECCS clogging in NEDO-32686, Revision 0, in response to NRC BL 96-03. The material called "sludge" is composed of iron oxide corrosion products in the suppression pool, and it was included as a type of debris in NEDO-32686, Revision 0, based on the observation of this material in operating plants and its role in the clogging events at Barseback Unit 2 (Sweden, 1992), Perry Nuclear Power Plant (1993), and Limerick Generating Station Unit 1 (1995). It may originate from exposed steel surfaces in the suppression pool or from connected piping systems.

Applicant's Approach to Addressing Chemical Effects

The applicant described its overall approach to chemical effects in DCD Tier 2, Section 6C.3.2, which states that the ABWR is designed to preclude the materials and environmental conditions most likely to generate chemical precipitates that may contribute to blockage and head loss. It also states that aluminum, phosphate, and calcium silicate will not be in containment. Both statements are based on the applicant's letter dated December 19, 2016, with corresponding ABWR DCD, Revision 6, markups and reflected in ABWR DCD, Revision 7.

The applicant considered IOZ and epoxy coatings in the particulate debris load (DCD Tier 2, Table 6C-1) but not for chemical effects. Other materials present in the containment that could potentially contribute to chemical effects are fiberglass, concrete, steel, and zinc as galvanized steel. The applicant did not identify any chemical effects associated exclusively with the post-LOCA environment. Therefore, sludge was the only corrosion product material assumed to be circulating in the post-LOCA fluid that potentially contributes to clogging of fiber beds.

The applicant described its treatment of carbon and low-alloy steel corrosion products in its letter dated August 23, 2017. The revised response to RAI 06.03-2 states that wetted surfaces are stainless steel or stainless-clad steel. The ABWR also uses stainless steel pipe in some connected systems. The design limits the surface area of bare carbon steel using protective coatings. The sludge is attributed to the corrosion of carbon steel piping and components in the ECCS during normal operation. For sludge, the design value of a net accumulation of sludge inside containment of 100 pounds mass (lbm) per year (45.4 kilograms (kg) per year during normal operation is between the median (88 lbm/39.9 kg) and mean (129 lbm/58.5 kg) values among BWRs surveyed for the URG. The applicant notes that assuming a net accumulation of 100 lbm sludge per year inside containment should be considered reasonable based on limiting the amount of carbon and low-alloy steel and the fact that the suppression pool clean-up system (SPCS) removes particulates and dissolved impurities to very low levels. Combined license (COL) Information Item 6.2.7.3, directs the COL applicant to address methods for maintaining the level of cleanliness assumed in the strainer debris evaluation.

The design of the GEH ABWR is based on 200 lbm (90.8 kg) of sludge, as listed in DCD Tier 2, Table 6C-1, which represents a two-year operating cycle. In the letter dated August 23, 2017, the applicant described the basis for assuming 200 lbm for the ABWR. The URG stated that each licensee should assume an initial sludge generation rate to be used in evaluating the ECCS suction strainers, since the actual rate requires measurements over a period of time. The URG suggested an assumed value of 150 lbm per year, about 1.7 times the median rate measured in the 1995 survey of BWR licensees. The applicant assumed 200 lbm for a two-year cycle as a reasonable assumption. It is less than the amount recommended in the URG but near the mean (258 lbm) and median (176 lbm). The ABWR has features designed to reduce the amount of sludge generation compared to older plants. For example, it includes a stainless steel lined suppression pool, less use of carbon steel piping connected to the suppression pool, and a SPCS that maintains water quality equivalent to the Fuel Pool Cooling and Cleanup System (e.g., less than 30 parts per billion corrosion product metals, less than 1.2 micro Sieverts (μS)/centimeter (cm) conductivity (a measure of the impurity level), and pH 5.6 – 8.6). In addition, COL Information Item 6.2.7.3, requires COL applicants to address acceptable methods for maintaining the level of cleanliness assumed in the ECCS strainer debris evaluation. According to DCD Tier 2, Section 6.2.1.7, the cleanliness methods will include removing, at periodic intervals, debris that might not be removed by the SPCS.

The applicant described the basis for including no chemical effects from concrete in its letter dated December 19, 2016. In response to RAI 06.03-2 B.1.e, the applicant stated that all concrete is coated and protected from jet impingement by a liner plate.

According to DCD Tier 2, Section 6.1, the ABWR design uses mostly metal-reflective thermal insulation in containment, but it includes 23.4 kg (51.6 lbm) of fiberglass insulation. This quantity is stated to be small relative to the amount reported in a survey of operating plants in 2015 (from information in Chapter 6 of the FSER for the COL application for South Texas Project, Units 3 and 4 dated September 29, 2015 (ADAMS Accession No. ML120830102)), which ranged from roughly 9 to 1600 kg (20 to 3600 lbm). In addition, the fiberglass is used only on small diameter piping and dispersed; therefore, no single break would affect all of it. The ABWR design was also identified by the applicatnt to exclude other types of non-metallic insulation found to contribute to strainer head loss and chemical effects in PWRs, such as calcium silicate and microporous insulation.

The applicant described its approach to zinc from galvanized steel in its letter dated August 23, 2017. The letter provided details of a corrosion calculation for galvanized steel surfaces in containment. The calculation includes estimated values of the surface area that would be wetted in a post-LOCA environment and the corresponding corrosion rate. The applicant concluded that the zinc released over the 30-day period would remain dissolved in the post-LOCA environment rather than form a precipitate.

The applicant described the pH and temperature conditions in its letter dated August 23, 2017, in response to RAI 06.03-2 B.1. The response states that the pH range will be maintained between 5.3 and 8.9 based on DCD Tier 2, Section 3I.3.2.3, "Water Quality and Submergence," which lists the pH and other reactor water quality characteristics for design basis LOCAs. It explains that the contents of the SLCS, although intended for beyond design basis accidents, could be added during the post-LOCA period to prevent pH below the design range. Such use of the SLCS requires operating procedures that would be developed by a COL applicant according to DCD Revision 6, Tier 2, Section 13.5.

The letter dated August 23, 2017, also described the suppression pool temperature. In response to RAI 06.03-2 B.2, the applicant stated that the temperature may increase to 77°C (170°F) at 30 minutes and may later reach a maximum of 89°C (192°F). The response refers to DCD Tier 2, Section 6.2.1.1.3.3, and Figures 6.2-7 and 6.2-15. Figure 6.2-15 extends to 28 hours, at which time the suppression pool temperature is decreasing and about 70°C (158°F).

Staff Evaluation of Chemical Effects

In its letter dated August 23, 2017, and in other responses, the applicant described maintaining this design basis pH range (5.3 – 8.9) as a "flat time history." Based on the corrosion rate variation for some ECCS materials over this range, the staff evaluated the applicant's proposed pH range and does not consider it to be a flat pH profile. For example, in the PWR chemical effects methodology, WCAP-16530-NP-A, the release (corrosion) rate of aluminum increases about five-fold from pH 5.3 to 8.9 at 82°C (180°F). Therefore, the evaluation below discusses the effect of the pH range where appropriate. The staff notes that for carbon steel and zinc, corrosion rates decrease as the pH increases within the range 5.3 to 8.9, assuming other factors are constant.

The applicant identified sludge as the only corrosion product material circulating in the post-LOCA fluid. Sludge has been included as a debris source for BWRs since the issue of ECCS strainer clogging was first identified. Sludge has not been identified as a "chemical effect" for BWRs, since the focus of chemical effects for PWRs has been on post-LOCA chemical reactions and because the industry and the NRC staff have reached no conclusions about BWR chemical effects. The staff evaluated 200 lbm (91 kg) of sludge as chemical debris in the ABWR standard design based on the following:

- ECCS strainer clogging events have been attributed to sludge combined with fibrous insulation.
- Characterization of sludge indicates it has properties similar to chemical precipitates studied for PWRs.
- Blockage of flow through fiber beds in laboratory testing has been attributed to steel corrosion products.
- BWROG strainer testing with a bed of fiberglass insulation and simulated sludge produced a sustained pressure drop. The staff's SER for the URG described the role of sludge in testing and in events at BWRs at certain operating conditions when the ECCS was in service. The "Background" section of the SER has the following observations and conclusions about strainer clogging:
  - Barseback Unit 2 (Sweden, 1992) – a pipe break can generate and transport insulation and other debris to the ECCS strainers and cause loss of NPSH.
  - Perry (1993) – fibrous debris combined with corrosion products in the suppression pool (sludge) can exacerbate the loss of NPSH.
  - Limerick Unit 1 (1995) – A diver found suction strainers covered with a thin mat of material consisting mostly of fibers and sludge (iron oxides).
  - Alden Research Laboratory – testing to support understanding of these BWR strainer events confirmed that fibrous debris filtering sludge greatly increases pressure drop across the ECCS strainer.

Studies of ECCS clogging included detailed characterization of BWR sludge. Results of these studies are documented in NUREG/CR-6367, "Experimental Study of Head Loss and Filtration for LOCA Debris," issued February 1996, and include the following:

- BWR suppression pool sludge as more than 99 weight percent steel corrosion particulate material. Some larger particles were postulated to result from agglomeration of an amorphous gelatinous component.
- The approximate sludge particle size based on characterization performed by the BWROG: 81 weight percent 0–5 micrometers (μm), 14 weight percent 5-10 μm, and 5 weight percent 10-75 μm. The smallest particles were approximately 0.1 μm diameter. (1 μm = 4×10^{-5} inch).
- The study proposed two mechanisms for blockage in the fiber beds-based on photomicrographs of the beds: smooth coating of fibers with small particles and blockage of passages by agglomerates.

The staff evaluated these results and they indicate that sludge has effects on fiber beds similar to the chemical effects recognized in testing in PWR environments. More recent studies suggest iron corrosion products formed in the post-LOCA environment (as opposed to the operating environment) can cause pressure drops in fiber beds. Testing performed by Framatome in Germany with galvanized steel in flowing, acidic boron-containing (boric acid) solutions at 50^{0}C (122°F) resulted in clogging of a mineral wool filtering bed with corrosion products of both zinc and steel (H. Ludwig and F. Roth, "Influence of Corrosion Processes on the Protected Sump Intake after Coolant Loss Accidents," Nuclear Technology Annual Convention 2006, English translation (ADAMS Accession No. ML083510156).

The staff also noted that for the tests with the liquid streaming onto the galvanized surface, the results indicated that the galvanized coating was physically removed, and the resulting steel corrosion products accumulated in the mineral wool caused a pressure drop. The significance of this testing for the ABWR is the suggestion that iron corrosion, which occurs under acidic conditions, may contribute to clogging of a fiber bed. Any specific effect of boron in these results would probably not be applicable to the ABWR since boron would only be present in the ABWR post-LOCA fluid as a result of adding sodium pentaborate from the SLCS. The sodium pentaborate would produce a mildly alkaline pH that inhibits iron corrosion.

In Japan, the Nuclear Electric Safety Organization (JNES) sponsored chemical effects testing, mostly in PWR environments but with one test in a BWR environment (see Section 4.3.1.3 of "Fiscal 2007 PWR Sump Screen Chemical Effect Test," Japan Nuclear Energy Safety Organization, issued May 2008 (ADAMS Accession No. ML090410318)). The test in the BWR environment, with a pH range between 3.2 and 6.5, produced a high concentration of iron in the test solution from corrosion of the carbon steel. When passed through a fiber bed, the iron-rich test solution produced a significant pressure drop. The pH range in the JNES test overlaps the design basis range (5.3 – 8.9) for the ABWR, and the pressure drop decreased as the pH increased from 3.2 into the ABWR range.

Pressure drops from precipitated iron, as well as from zinc and aluminum, in a fibrous bed were also observed in vertical loop tests sponsored by the NRC (NUREG/CR-6868, "Small-Scale Experiments: Effects of Chemical Reactions on Debris-Bed Head Loss," issued March 2005 (ADAMS Accession No. ML050900260)). The tests were conducted in boron-containing solutions at about 25 to 45^{0}C (77 to 113°F) and a room-temperature pH of approximately 7.

Based on the operating events, testing observations, and characteristics listed above, the staff finds that sludge can be considered a chemical effect for the ABWR design by the way it is formed by the reaction of containment materials and environment and can cause head loss by clogging flow paths in fiber beds. Sludge is different than the PWR chemical effects in the staff-approved PWR methodology in that it can be formed during both operation and post-LOCA. As noted above, characterization found that about 95 percent of sludge particles are less than 10 μm diameter. By comparison, LOCA-generated particulate debris and latent debris are expected to be mostly larger than 10 μm (4×10^{-4} inch) based on tests and sampling. The small size of sludge particles, combined with the conclusion in NUREG/CR-6367 (Appendix B) that sludge particles can both coat fibers and agglomerate to block larger gaps, makes sludge behavior similar to that of PWR chemical precipitates.

The design of the GEH ABWR is based on 200 lbm (90.8 kg) of sludge, which is listed in DCD Table 6C-1, and represents a two-year operating cycle. In its letter dated August 23, 2017, the applicant describes the basis for assuming 200 lbm for the ABWR. The URG stated that each licensee should assume an initial sludge generation rate to be used in evaluating the ECCS suction strainers, since the actual rate requires measurements over a period of time. The URG suggested an assumed value of 150 lbm per year, more than 1.5 times the mean rate measured in the survey of the BWR licensees in 1995. The applicant assumed 200 lbm for a two-year cycle as a reasonable assumption. It is less than the amount recommended in the URG but near the mean (258 lbm) and median (176 lbm). The ABWR has features designed to reduce the amount of sludge generation compared to older plants. For example, it includes a stainless steel lined suppression pool, less use of carbon steel piping connected to the suppression pool, and a SPCS that maintains water quality equivalent to the Fuel Pool Cooling and Cleanup System (e.g., less than 30 parts per billion corrosion product metals, less than 1.2 μS/cm conductivity (a measure of the impurity level), and pH 5.6 – 8.6). In addition, COL Information Item 6.2.7.3, directs COL applicants to address acceptable methods for maintaining the level of cleanliness assumed in the ECCS strainer debris evaluation. According to DCD Tier 2, Section 6.2.1.7, the cleanliness methods will include removing, at periodic intervals, debris that might not be removed by the SPCS.

During a LOCA, the ABWR SPCS would be isolated as part of containment isolation. Therefore, iron corrosion products formed on the surface of the carbon steel ECCS piping and components could potentially contribute to head loss if a fiber bed forms on the strainers and fuel inlet. Because of the design features for limiting accumulation of iron corrosion products (sludge) during operation, the staff considers it reasonable to expect there is margin in the 200 lbm of sludge to account for corrosion of carbon steel and low-alloy steel following a LOCA. COL Information Item 6.2.7.2 directs the COL applicant to provide confirmation that the 200 lbm limit can be achieved in the as-built plant. In its review of the COL application for South Texas Project, Units 3 and 4, the staff audited operating experience from ABWRs in Japan, and concluded that 200 lbm was a conservative assumption for the sludge quantity. This was documented in the corresponding STP 3 & 4 FSER Section 6.2.1.4 (ADAMS Accession No. ML120830102).

To address zinc, the applicant in its letter dated August 23, 2017, provided a detailed calculation of zinc corrosion from galvanized steel, and the corresponding zinc concentration in the post-LOCA fluid for 30 days. The applicant determined a zinc release (corrosion) rate was determined using the results of laboratory tests performed in demineralized water by the BWROG (R. W. Eaker and S. G. Sawochka, BWROG Report NWT 863, “Review of Boiling Water Reactor Material Dissolution in Post-LOCA Containment Solutions,” Revision 0, NWT Corporation, November 2013 (ADAMS Accession No. ML14328A635)). The applicant used a zinc release rate of 0.05 grams per square meter per hour, which is high relative to most of the measured values for test temperatures between 140 and 200^{0}F (60 and 93^{0}C). To estimate the galvanized surface area that would be exposed to the post-LOCA fluid, the applicant started with the highest value of galvanized steel in containment reported by an operating plant in an operating BWR survey [NRC Public Meeting Slides, “BWROG ECCS Suction Strainers Committee,” December 2, 2015 (ADAMS Accession No. ML15335A419)]. By multiplying this surface area by the estimated fraction of the area that would be wetted and the zinc release rate, the applicant calculated a total of 3.4 pounds of zinc released. Based on published values of zinc solubility [R. A. Reichle, K. G. McCurdy, and L. G. Helper, “Zinc Hydroxide: Solubility Product and Hydroxy-complex Stability Constants from 12.5-75 °C,” Canadian Journal of Chemistry, Vol. 53 (1975), pp. 3841-3845.], the applicant concluded all of the released zinc would remain in solution and not form a precipitate (3.4 lbm released compared to at least 4.8 lbm solubility) (1.5 kg compared to at least 2.2 kg).

At the time of publication of this supplemental FSER, the staff has not evaluated the BWROG testing and release rates to determine if the results are realistic or conservative. Higher corrosion rates are listed for solid zinc samples in aerated distilled water over the same temperature range [D. C. H. Nevison, “Corrosion of Zinc,” in Metals Handbook, 9th Edition, Vol. 13 (ASM International, Metals Park, Ohio, 1987), pp. 759-761]. In addition, no determination has yet been made by the BWROG, individual licensees, or the NRC staff, that zinc corrosion leads to a precipitate that causes strainer head loss. This level of uncertainty prevents the staff from concluding that released zinc would remain dissolved in the post-LOCA fluid and not contribute to chemical effects. However, because the applicant assumes a large quantity of sludge that is known to cause strainer head loss, which would provide margin in the event of zinc precipitation, and because it is not known if zinc precipitates cause head loss, the staff finds it acceptable to neglect incremental chemical effects from zinc corrosion for renewal of the ABWR DC.

The staff finds it acceptable to neglect chemical effects from concrete for the ABWR based on all concrete being either protected with a liner plate or coated and outside the zone of influence for the coating. In the suppression pool, the liner that separates the concrete from the water is stainless steel. In addition, the staff notes that the amount of chemical precipitate from concrete, calculated using the PWR chemical effects methodology for the ABWR temperatures over the pH range 5.3 – 8.9, is small (of the order of 0.01 kg per 100 square meters (m^2)) (0.02 lbm per 1,000 square feet (ft^2)). Based on the protection of concrete surfaces in the design and the small contribution to chemical effects, the staff concluded that it is acceptable for the ABWR to assume any chemical effects from concrete are negligible with respect to the overall quantity of chemical reaction products (i.e., 200 lbm sludge).

The ABWR design also includes 23.4 kg (51.6 lbm) of fiberglass insulation. As with zinc, for BWRs it is not known if fiberglass in the post-LOCA fluid contributes to chemical precipitates and strainer head loss. The BWROG chemical effects testing [R. W. Eaker and S. G. Sawochka, BWROG Report NWT 863, Revision 0], measured releases of silicon, calcium, sodium, and aluminum from fiberglass in demineralized water at BWR temperatures. This report was submitted for information, so the staff has used it for insights but has not formally endorsed it. The WCAP-16530-NP-A methodology for PWRs predicts chemical precipitate from fiberglass insulation, and the amount of precipitate from 23.4 kg of fiberglass is less than one kilogram (or 2.2 lbm) of sodium aluminum silicate at pH 5.3 to a few kilograms (or few pounds) at pH 8.9, using an estimated temperature profile. It is not yet known whether fiberglass insulation produces chemical effects for BWRs, but given the amount predicted for PWRs, the staff finds it acceptable for the applicant to neglect incremental chemical effects from fiberglass. The BWROG testing also showed fiberglass increased the pH of test solutions in the BWROG testing. A pH increase would be beneficial in terms of steel and zinc corrosion, although the amount of fiberglass insulation in the ABWR design may be too small to raise the pH significantly.

Based on the discussion above for the materials included in the design and those excluded, the staff concluded that 200 lbm (91 kg) of sludge is acceptable for the ABWR renewal. Since only iron corrosion products have been considered as chemical precipitates causing strainer head loss and reactor core pressure drop, this approach may not be suitable for other BWR designs and licensees. For example, BWRs with a combination of high pH and aluminum can be expected based on the PWR research to produce chemical precipitates, but the industry and the NRC staff have not yet determined how to conservatively quantify and evaluate them under BWR conditions.

Chemical Effects Evaluation Summary

Unlike for PWRs, chemical effects for BWRs have not been fully evaluated and defined in terms of staff-approved industry guidance. For PWRs, there is a methodology for quantifying and evaluating chemical effects in terms of $AlOOH$, $Na_2AlSi_3O_8$, and $Ca_3(PO_4)_2$. For BWRs, which have a lower pH without SLCS addition, the BWROG has studied zinc and iron corrosion products. The corrosion of galvanized steel and bare carbon or low-alloy steel can be higher or lower at unbuffered BWR conditions than at PWR conditions, depending on pH and temperature. The industry has not determined if this corrosion generates chemical reaction products that cause head loss. For the ABWR renewal, GEH included only iron corrosion product sludge in the ECCS suction strainer qualification. The staff considered the properties of sludge and operating experience with sludge causing clogging of suction strainers when combined with a fiber bed. The staff evaluated the applicant's sludge quantity and the basis for neglecting additional chemical effects and, based on the evaluation above, found it acceptable. In addition, COL Information Item 6.2.7.3 directs a future COL applicant to address acceptable methods for maintaining the level of cleanliness assumed in the ECCS strainer debris evaluation.

The applicant provided the necessary information from RAI 06.03-2 in the ABWR DCD, Revision 7, which incorporated the changes described in the applicant's response related to DCD Tier 2, Section 6C.3.2. Therefore, Confirmatory Item 6.2.1.9-3 from the staff advanced SER with no open items for the ABWR DC renewal is resolved and closed.

Ex-vessel Downstream Effects Evaluation

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 ECCS strainers in the suppression pool. By letters dated August 23, 2017 and March 28, 2018 (ADAMS Accession No. ML17236A060 & ML18092A293 respectively), GEH provided markups to ABWR DCD Tier 2, Revision 6, Section 6C.3.3, "Downstream Effects," and incorporated by reference NEDE-33878 Revision 3, to evaluate the impact of post-LOCA debris on the ABWR components downstream of the ECCS strainers. Areas of concern addressed for ex-vessel downstream effects include: (1) blockage of system flow paths at narrow flow passages (e.g., ECCS sparger spray nozzles, pump internal flow passages, and tight-clearance valves), and (2) wear and abrasion of surfaces (e.g., pump running surfaces) and heat exchanger tubes and orifices.

The NRC staff reviewed the applicant's evaluation of ex-vessel downstream effects for conformance to RG 1.82, Revision 4, to provide reasonable assurance that the ECCS components will function as designed under post-LOCA fluid conditions for the required mission time. The staff guidance in Section C.1.1 of RG 1.82, Revision 4, specifies regulatory positions common to all water-cooled reactors and Subsection C.1.1.10 states that the NRC considers the staff approved SER for WCAP-16406-P, "Evaluation of Downstream Sump Debris Effects in Support of GSI-191," dated December 20, 2007 (ADAMS Accession No. ML073520295), evaluation methods and criteria to be acceptable for components downstream of the sump strainers. Therefore, NRC staff applied the methodologies for the evaluation of the downstream ex-vessel components as approved in the staff SER for WCAP-16406-P to the GEH ABWR reactor design. The following sections of this FSER supplement, provide the staff's evaluation.

ECCS Systems and Components

NEDE-33878P, Revision 3, Section A.2, "ECCS System Descriptions and Mission Times," describes the ECCS systems in the scope of the downstream ex-vessel effects evaluation. The ABWR ECCS consists of the HPCF, the steam driven RCIC, and the RHR systems that take suction through the ECCS strainers. NEDE-33878P, Revision 3, Table A-1, "ECCS Mission Time and Description," identifies the ECCS long-term and short-term system operating lineups, conditions of operation, and mission times. NEDE-33878P, Revision 3, Tables A-4 through A8 identify and evaluate the effects of post-LOCA debris on the systems and components in the scope of the downstream ex-vessel effects evaluation. The NRC staff evaluated the revisions and found that the GEH NEDE-33878P, Revision 3, Section A.2, descriptions of mission time, systems and components is consistent with the guidance of RG 1.82, Revision 4 and, therefore, acceptable.

Post-LOCA Fluid Constituents

NEDE-33878P, Revision 3, Appendix A.3, "Debris Ingestion," and Table A-2, "ABWR Debris Source Term," describe the type, size, and quantity of debris that is small enough to pass through the holes of the ECCS suction strainer perforated plates. The ECCS suction strainer hole size is 0.125 inch. NEDE-33878P, Revision 3, Table A-3, "ABWR Debris Downstream Concentration," describes the debris concentration in the ECCS fluid. The NRC staff evaluated the revisions and determined that the type, size, and quantity of debris assumed to bypass the sump strainer is consistent with RG 1.82, Revision 4, and the staff SER for WCAP-16406-P and is therefore acceptable.

RHR, HPCF, and RCIC Pump Evaluation

ABWR DCD Tier 2, Section 3.9.6.1 specifies the design conditions under which pumps will be required to function but does not specifically address post-LOCA debris conditions under which pumps will be required to function. Therefore, the staff issued RAI 06.03-6 on July 10, 2017, requesting that GEH address design and qualification requirements for the pumps during post-LOCA operation in DCD Tier 2, Section 3.9.6.1. In its response to RAI 06.03-6, (ADAMS Accession No. ML17236A062) GEH provided a markup for revisions to DCD Tier 2, Section 3.9.6.1, to specify qualification of the ECCS pumps (including mechanical seals) under all design basis conditions including post-LOCA conditions is validated under ASME QME-1-2007, "Qualification of Active Mechanical Equipment Used in Nuclear Power Plants," as endorsed by RG 1.100, Revision 3, "Seismic Qualification Of Electrical and Active Mechanical Equipment and Functional Qualification of Active Mechanical Equipment for Nuclear Power Plants," issued September 2009.

In addition, GEH provided a markup for DCD Tier 1, Table 2.4.1, ITAAC 4.c, for the RHR pumps; Table 2.4.2, ITAAC 3.g for the HPCF pumps; and Table 2.4.4, ITAAC 3.j for the RCIC pump, to specify that the test result/report must confirm that the pumps perform their intended function during post-LOCA operation. The post-LOCA debris conditions in the ECCS fluid are specified in NEDE-33878P, Revision 3. The staff finds the GEH response acceptable because ASME Standard QME-1-2007 as endorsed in RG 1.100, Revision 3, provides an acceptable methodology for the functional qualification of pumps for post-LOCA operation and the ITAAC specify that the test result/report confirm that the pumps perform their intended function during post-LOCA operation. The staff determined that the pump evaluation confirms that the testing is adequate to ensure the pumps meet the regulatory requirements of GDC 4, to be compatible with the environmental conditions associated with LOCAs.

The applicant provided the necessary information from RAI 06.03-6 in the ABWR DCD, Revision 7, which incorporated the changes described in the applicant's response. Therefore, Confirmatory Item 6.2.1.9-4 from the staff advanced SER with no open items for the ABWR DC renewal is resolved and closed.

Heat Exchanger Evaluation

NEDE-33878P, Appendix A, Tables A-4 through A8, Revision 1, issued May 2017 (ADAMS Accession Nos. ML17132A029 proprietary version and NEDO-33878 ML17132A028 public version), describe the effect of post-LOCA debris on the operation of the RHR heat exchangers. The table column titled, "Auxiliary Equipment Evaluation," state that flow from the suppression pool is channeled through the shell side of the RHR heat exchangers and concludes that the heat exchangers will operate as designed during post-LOCA operation. However, GEH did not address the effects of post-LOCA debris on the shell side of the RHR heat exchanger. Therefore, in RAI 06.03-7, dated July 10, 2017, the staff requested that GEH address the effects of post-LOCA debris on the shell side of the RHR heat exchanger. In its response to RAI 06.03-7, GEH stated that ABWR DCD, Tier 2, Section 5.4.7.1, describes a design change that the ABWR RHR heat exchanger has reactor water flowing through the tube side of the heat exchanger. The primary purpose of the change was to reduce radiation buildup in the heat exchanger by providing a more open geometry flow path through the center of the tubes, as opposed to the shell side construction of spacers, baffles, and low flow velocity locations, which can provide places for radioactive sludge to accumulate. In the RAI response, GEH described that debris size, debris characteristics, and the flow velocities through the heat exchanger will preclude plugging, fouling, wear, and debris settling. GEH also stated that the RHR heat exchanger specifications require the vendor to meet performance requirements under design debris loading conditions that will be validated through the procurement process with a certificate of compliance. GEH revised the TR NEDE-33878P, Revision 2, issued August 2017 (ADAMS Accession Nos. ML17236A064 proprietary version and ML17236A063 public version), to clarify the reactor water (debris) flow path through the heat exchanger tubes.

The staff evaluated and determined that the GEH methodology to evaluate RHR heat exchanger plugging, fouling, wear, debris settling, and heat transfer performance in the presence of post-LOCA debris is acceptable because the effect of debris on the heat exchanger is consistent with the methodologies approved by the staff in the SER for TR WCAP-16406-P and the vendor will provide a certificate of compliance to verify conformance to performance requirements.

The staff confirmed that the applicant provided the necessary information from RAI 06.03-7, in the ABWR DCD, Revision 7, which incorporated the appropriate changes described in the applicant's response. Therefore, the staff determined that RAI 06.03-7, is closed and resolved.

Blockage Evaluation for Components Such as Valves, Orifices, Pipes, and Spray Nozzles/Spargers

NEDE-33878P, Revision 2, Appendix A, Tables A-4 through A8 describe the evaluation for blockage of valves, orifices, spray nozzles/spargers, and pipes during operation with post-LOCA fluids. GEH states that the ECCS piping and component flow area exceeds the maximum dimension of the debris particles and that blockage is not expected for valves, orifices, pipes, and spray nozzles/spargers during operation with post-LOCA fluids. However, GEH did not address the potential blockage for tight-clearance valves that may not be in the fully open position during post-LOCA operations. Therefore, the staff in its RAI 06.03-9, dated July 10, 2017, requested that GEH address the potential blockage for tight-clearance valves. In its response to RAI 06.03-9, dated August 23, 2017, GEH stated that the RHR, HPCF and RCIC systems do not have any throttle valves that are susceptible to blockage because all throttle valves will be in the open or closed position. GEH also stated that the check valves are installed on the suction and discharge of the pumps and due to valve opening clearances during operation are not susceptible to blockage.

The staff evaluated and determined that the GEH methodology of evaluation for blockage of valves, orifices, spray nozzles/spargers, and pipes during operation with post-LOCA fluids is acceptable because the flow diameters are larger than the maximum debris size and the evaluation is consistent with the methodology approved in the SER for TR-WCAP-16406-P.

The staff confirmed that the applicant provided the necessary information from RAI 06.03-9, in the ABWR DCD, Revision 7, which incorporated the appropriate changes described in the applicant's response. Therefore, the staff determined that RAI 06.03-9, is closed and resolved.

Instrument Tubing Blockage Evaluation

NEDE-33878 Revision 1, Appendix A, Tables A-4 through A-8 describe debris settling in instrument lines during post-LOCA operation for the ABWR design. In the column titled "Fluid Velocity Through Component," GEH states it is assumed that settling (instrument sensing lines/components) will occur when the flow velocity is less than the settling velocity for the debris type. Therefore, the staff in its RAI 06.03-5, dated July 10, 2017, requested that GEH provide additional information to address any instrument lines where debris settling, and blockage may occur. In its response to RAI 06.03-5, dated August 23, 2017, GEH stated that it revised NEDE-33878P Revision 2, to clarify that the ECCS instrument lines in service during post-LOCA operation are installed above the horizontal plane of the process piping and that no settling of debris in the instrument tubing is expected in this configuration.

The staff evaluated and determined that the GEH evaluation for instrument tubing is acceptable because the ECCS instrument lines in service during post-LOCA operation are installed above the horizontal plane of the process piping and no settling or ingestion of debris in an instrument line with this configuration is expected. The instrument tubing evaluation is consistent with the methodologies approved by the staff in the SER for TR-WCAP-16406-P.

The staff confirmed that the applicant provided the necessary information from RAI 06.03-5, in the ABWR DCD, Revision 7, which incorporated the appropriate changes described in the applicant's response. Therefore, the staff determined that RAI 06.03-5, is closed and resolved.

Wear Evaluation for Components Such as Pumps, Valves, Orifices, Pipes and Spray Nozzles/Spargers

NEDE-33878, Revision 2, Appendix A, Tables A-4 through A-8, states that the effect of post-LOCA debris on component and system wear for the mission time is insignificant. However, GEH did not describe a methodology to determine that wear for individual components is acceptable during post-LOCA operation. Therefore, in its RAI 06.03-8, dated July 10, 2017, the staff requested that GEH describe the methodology to determine that wear for individual components is acceptable for post-LOCA operation.

In the applicant's response to RAI 06.03-8, dated August 23, 2017, GEH stated that experimental data on the effects of particulates applied to ECCS type pumps show that degradation in pump performance is negligible for particulate concentrations less than 1 percent by volume as referenced in NUREG/CR-2792, "An Assessment of Residual Heat Removal and Containment Spray Pump Performance Under Air and Debris Ingesting Conditions," issued September 1982. NUREG/CR-2792 notes conservative estimates of the nature and quantities of debris show that fine abrasives may be present in the concentrations of about 0.1 percent by volume (about 400 parts per million by weight) and that very conservative estimates of fibrous material yield concentrations of less than 1 percent by volume. GEH stated that the debris concentrations specified in in NUREG/CR-2792 are less than the downstream debris concentrations during post-LOCA operation as specified in NEDE-33878P, Revision 2, Table A-3. The NRC staff evaluated the information provided and considers this response acceptable for the pumps because the wear methodology described by GEH indicates that pump internal component wear such as the impeller and bearings will not lead to pump performance degradation and that pump performance under all design basis conditions including post-LOCA debris loading conditions will be validated by qualification under ASME Standard QME-1-2007, as endorsed by RG 1.100, Revision 3.

The staff confirmed that the applicant provided the necessary information from RAI 06.03-8, in the ABWR DCD, Revision 7, which incorporated the changes described in the applicant's response. Therefore, the staff determined that RAI 06.03-8, is closed and resolved.

For non-rotating equipment such as piping, valves, heat exchangers, spargers, and instrumentation tubing, NEDE-33878P, Revision 3, Appendix A.1, states that wear and abrasion of surfaces in the ECCS during post-LOCA operation are evaluated based on the flow rates to which the surfaces are subjected and the grittiness or abrasiveness of the ingested debris. GEH concluded that the expected wear of non-rotating ECCS components such as piping, valves, heat exchangers, spargers and instrumentation tubing during the post-LOCA mission time under design basis debris loading will not adversely impact the ECCS performance. The NRC staff evaluated the information provided and considers this response acceptable for wear and abrasion of components in the ECCS flow path because the components are evaluated based on the abrasiveness of the debris and the ECCS flow rates and the expected wear will not impact ECCS performance. The staff, therefore, finds that the component wear evaluation is consistent with the methodologies approved by the staff in the SER for TR-WCAP-16406-P.

Debris Settling Evaluation for Valves, Orifices, Pipes, and Spray Nozzles

The staff SER for TR-WCAP-16406-P addresses debris settling and accumulation of debris in low flow areas that may occur when the settling velocity of the debris is less than the minimum flow velocity in the system piping and components. If the system/component flow velocity exceeds the debris settling velocity, it is assumed that the minimal settling of debris will occur and performance of the ECCS components will not be adversely impacted. Therefore, the staff in its RAI 06.03-4, dated July 10, 2017, requested that GEH provide additional information to identify any areas where settling velocity of the debris is less than the minimum flow velocity in system/components and provide the basis for acceptable system operation for these conditions. In the applicant's response to RAI 06.03-4, dated August 23, 2017, GEH stated that the flow through ECCS piping and components under design basis conditions exceeds the debris settling velocity with significant margin, therefore, debris settling is not expected to occur.

The staff evaluated and determined that the GEH response stating that flow through ECCS piping and components under design basis conditions exceeds the debris settling velocity with significant margin is acceptable because debris settling is not expected to occur when the system flow velocity exceeds the debris settling velocity and the evaluation is consistent with the methodologies approved by the staff in the SER for TR-WCAP-16406-P.

The staff confirmed that the applicant provided the necessary information from RAI 06.03-4, in the ABWR DCD, Revision 7, which incorporated the changes described in the applicant's response. Therefore, the staff determined that RAI 06.03-4 is closed and resolved.

Chemical Effects Evaluation for Ex-Vessel Downstream Components

The term chemical effects refer to the possibility that interactions of materials in the containment environment will generate chemical precipitate debris that may contribute to blockage in systems including downstream ex-vessel components. In RAI 06.03-2, dated December 15, 2015, the staff requested that GEH provide additional information regarding the chemical effects during post-LOCA operation. In its last revised response to RAI 06.03-2 dated February 23, 2017, GEH described the chemical effects evaluation and stated that the interaction of materials is not expected to generate chemical precipitation debris in the ABWR containment environment. GEH also stated that zinc chemical debris in very small quantities that could result from the corrosion of IOZ coating was assumed to transport to the suction strainer and that this debris is included as sludge in debris source term specified in NEDE-33878P, Revision 2, Table A-2.

The staff evaluated and determined that the applicant's evaluation that chemical precipitants have no effect on plugging or wear of downstream ex-vessel components is acceptable because it is consistent with staff positions documented in NRC memorandum, "Basis for Excluding Chemical Effects Phenomenon from WCAP-16406-P Ex-vessel Downstream Evaluations," issued January 21, 2010 (ADAMS Accession No. ML093160100), and the NRC TR, "Evaluation of Chemical Effects Phenomena Identification and Ranking Table Results," issued March 2011 (ADAMS Accession No. ML102280594).

The staff confirmed that the applicant provided the necessary information from RAI 06.03-2, in the ABWR DCD, Revision 7, which incorporated the changes described in the applicant's response. Therefore, the staff determined that RAI 06.03-2 is closed and resolved.

Ex-Vessel Downstream Effects Evaluation Summary

The NRC staff reviewed the provision in ABWR DCD and NEDE-33878P, Revision 3, for ex-vessel downstream effects and, verified the inclusion of the necessary information in the ABWR DCD, Revision 7, which incorporated the changes described in the applicant's response to RAI 06.03-2. Therefore, Confirmatory Item 6.2.1.9-3 from the staff advanced SER with no open items for the ABWR DC renewal is resolved and closed.

The NRC staff concludes that the provisions for mitigating downstream effects meet the regulatory requirements in GDC-4 for the components downstream of the ECCS strainer to be compatible with the environmental conditions associated with LOCAs. This conclusion is based on the applicant having specified provisions in the ABWR DCD and NEDE-33878P, Revision 3, that the ECCS design meets the staff approved methodology in the SER for TR-WCAP-16406-P, RG 1.82, Revision 4, and ASME Standard QME-1-2007, which contain approved methodologies for satisfying the GDC 4 requirements.

In-Vessel Downstream Effects Evaluation

Introduction/Background

The evaluation of in-vessel downstream effects of debris on long-term post-LOCA core cooling includes consideration of potential blockage at the core inlet, either at the core support plate structure or at the inlet nozzle of individual fuel bundles, collection of debris on bundle grid spacers, buildup of fibrous, chemical, and protective coating debris on fuel rod cladding surfaces, blockage of in-core bypass flow paths, and the phenomena associated with the various phases of LOCA, including blowdown, reflood, and post-reflood. The ABWR reactor vessel internals and fuel design are similar to those of conventional BWRs, so the studies and tests performed by the BWROG to address the effects of debris on ECCS performance, and the lessons learned from them, are generally applicable to the ABWR design. Numerous ABWR design enhancements serve to minimize the effects of debris on fuel cooling following LOCAs. These are described by GEH in DCD Tier 2, Chapter 6, and are evaluated in this FSER supplement.

The NRC has not formalized review guidance for the evaluation of in-vessel effects of debris. At the time the agency issued RG 1.82, Revision 4, in 2012, the review of in-vessel downstream debris effects in PWRs was in progress. The PWR Owners Group had submitted for review TR WCAP-16793-NP, “Evaluation of Long-Term Cooling Considering Particulate, Fibrous and Chemical Debris in the Recirculating Fluid.” As noted in RG 1.82, Revision 4, a method and reference for PWR licensees whose plants are bounded by its input assumptions to use in evaluating the downstream impact of debris on the performance of fuel following a LOCA, are subject to conditions and limitations specified in the NRC SER. The staff had not completed its review of WCAP-16793-NP when it issued of RG 1.82, Revision 4. Also, the applicability to BWRs had not yet been addressed, and no in-vessel testing with debris had been conducted for BWRs.

For BWRs, the staff has accepted the BWROG-sponsored URG for ECCS Suction Strainer Blockage, NEDO-32686-A. Volume 4 of that document contains a GEH generic SER that addresses the potential for fuel bundle flow blockage and consequent fuel damage. The staff SER for the URG (contained in Volume 1 of NEDO-32686-A) does not specifically address fuel blockage. Also, the URG does not specifically address ABWR ECCS design features, the certified ABWR fuel, or reactor vessel internals. However, since the ABWR fuel, core design, and ECCS are similar to those of currently operating conventional BWRs, the URG conclusions should generally be applicable. This is discussed further in the staff evaluation below.

Applicant’s Approach for Addressing In-vessel Downstream Effects

In RAI 06.03-2, Part C, dated December 15, 2015, the staff requested that GEH justify the acceptability of the ABWR core design and certified fuel with respect to core cooling in the presence of debris, including test results and/or analysis to support the design. GEH responded to this question on February 23, 2017, April 25, 2017, and August 23, 2017, with downstream effects evaluation described in Appendix A.5 of TR NEDE-33878P, Revision 0, submitted with the letter dated February 23, 2017. The applicant transmitted subsequent Revisions 1, and 2 to NEDE-33878P through separate letters April 25, 2017 and August 28, 2017. Following a public teleconference meeting with the staff on March 1, 2018 (ADAMS Accession No. ML18157A215), GEH provided an updated TR NEDE-33878P, Revision 3, by a letter dated March 28, 2018 (ADAMS Accession No. ML18092A303). The primary technical change between Revision 0, and subsequent revisions of the TR is the reduction of ECCS "mission time" from 100 days to 30 days following a LOCA. The staff typically considers 30 days to be an appropriate time period to demonstrate ECCS functionality, since beyond that time the decay heat loading will be small, such that alternative cooling will be possible should ECCS functionality be lost.

Appendix A.5, of GEH TR NEDE-33878P, Revision 3, discussed the in-vessel flow paths that could be blocked by debris following a LOCA. These include the normal and bypass flow paths between the reactor vessel lower plenum and upper plenum and through the fuel bundles. Table A-4 of the TR provides a qualitative evaluation of the effects of debris on reactor vessel internals and fuel, as well as on ECCS components. Since the minimum dimension of internal flow paths exceeds the largest debris particle dimension, GEH concludes that clogging is not considered credible. The TR references the URG, which qualitatively assesses fuel bundle inlet blockage. It is stated that if debris totally blocks the inlet to one or more fuel channels from below, these bundles would receive radiation cooling to the channel walls as the bypass refills, then direct cooling from water spill-over from above once the water level is restored above the top of the fuel channels.

NEDE-33878P, Revision 3, notes several ABWR design improvements from currently-operating BWRs that should minimize the effects of debris. The ABWR design eliminates the use of recirculation piping external to the reactor pressure vessel (typical of conventional BWRs) by use of reactor internal recirculation pumps. This reduces the likelihood of a large high-energy line break, which can be a significant source of debris for conventional BWRs, and, although not stated by GEH, eliminates a large coolant leakage path below the top of active fuel (TAF). In addition, main steam and feedwater piping connect to the RPV above the TAF. The possibility of a large break LOCA below the TAF is therefore eliminated. Also, the ABWR design has diverse ECCS delivery points, which helps reduce the consequences of downstream blockage.

Two HPCF loops deliver coolant to the region above the core within the core shroud. One of three low pressure core flooder loops (LPFL) provides coolant through one of the feedwater lines. The RCIC system delivers coolant to the other feedwater line. Two LPFL systems deliver coolant through separate spargers into the outer annulus region.

As noted in NEDE-33878P, Revision 3, tests with a small concentration of fibrous insulation material were performed to assess the potential blockage of coolant flow at the entrance to fuel assemblies. Modern GEH nuclear fuel (GNF2) was used for the tests. The evaluation concluded that significant BWR fuel bundle inlet clogging does not result in GNF2 heat up after the LOCA refill from ECCS injection. GEH states that this conclusion applies to other BWR fuel bundles (such as the ABWR GEH GE P8x8R nuclear fuel) with an equivalent degree of inlet resistance.

Staff Evaluation of In-vessel Downstream Effects

To evaluate the GEH response to RAI 06.03-2 and the accompanying TR NEDE-33878P, Revision 3, it is necessary to have a detailed understanding of ABWR design features and the similarities and differences from conventional BWRs. It is also important to note key differences from PWRs, for which the majority of in-vessel testing, and analyses has been done. BWRs use channeled fuel assemblies (bundles) which inhibit cross-flow, while PWR core designs allow open channel flow between fuel assemblies. Each ABWR fuel bundle has an independent flow path between the lower and upper plenum of the reactor vessel. BWR and PWR ECCS designs differ significantly with respect to diversity of injection locations. Both PWR and BWR fuel utilize grid spacers to maintain the relative position of fuel rods but differ in the number and size of fuel rods and number of spacers.

In DCD Tier 2, Figure 5.3-2a, “Reactor Pressure Vessel Key Features,” shows the relative locations of vessel internal components and indicates the various ECCS injection locations via HPCF, LPFL, and feedwater spargers (used for RHR core cooling Mode A1 and RCIC). DCD Tier 2, Table 4.4-1 “Typical Thermal-Hydraulic Design Characteristics of the Reactor Core,” provides relevant thermal-hydraulic design characteristics of the reactor core, including coolant flow area per assembly, core average and maximum inlet velocity, and total core pressure drop. DCD Tier 2, Table 4.4-5, “Reactor Coolant System Geometric Data,” provides average flow areas for the upper and lower plenum, core, and downcomer.

The applicant described the ABWR reactor pressure vessel internals in DCD Tier 2, Section 3.9.5, “Reactor Pressure Vessel Internals,” and the mechanical and nuclear design of the fuel and reactor core are described in DCD Tier 2, Chapter 4. The high and low-pressure systems which comprise the ECCS are described in DCD Tier 2, Chapter 5, and DCD Tier 2, Section 6.3 “Emergency Core Cooling Systems.” The ABWR design includes many features that will minimize the sources of debris and the mechanisms for transport into the ECCS and subsequently to the fuel. These are described in various places in the DCD and are summarized below.

The ABWR core and fuel are described in DCD Tier 2, Chapter 4. The core is comprised of 872 channeled fuel assemblies surrounded by a cylindrical core shroud. The annular (downcomer) region between the core shroud and the inner reactor vessel wall serves as the primary coolant flow path, both during normal operation and following a LOCA. During normal operation, feedwater flow and recirculation flow are directed downward to the lower plenum of the reactor vessel and then upward through the core. Flow enters each fuel assembly through a side entry orifice in the core support assembly, and then is directed upward to each channel through a transition (nose) piece to the lower tie plate (LTP). Fuel rods are held in place by the LTP, and spacing is maintained throughout the length of the channel box by grid spacers distributed over the bundle length. An upper tie plate is used at the bundle exit. Flow within the channel box is axial along the fuel rods in the open area between them. Alternate core flow paths include gaps between fuel bundles and between peripheral bundles and the inner reactor vessel wall. Each fuel bundle also includes two small channel-to-LTP bypass holes. Design details for the certified ABWR P8x8R fuel are provided in TR NEDE-31152P, "General Electric Fuel Bundle Designs Evaluated with GESTAR-Mechanical Analysis Bases (proprietary version)," issued December 1988 and Supplement 1, issued June 2000 (ADAMS Accession No ML003725063, Supplement 1 ML003725068 non-publicly available). Design parameters which affect the fuel cooling and potential capture of debris include the fuel rod cladding outer diameter, number of rods and rod pitch, channel box dimensions, and number and type of grid spacers.

To confirm the GEH assertion that the clogging of reactor vessel internals and fuel with debris is not credible, the staff reviewed the limiting dimensions of internal flow paths and fuel flow areas and compared them to the physical dimensions of the various types of debris that could be transported to the reactor vessel, as specified in the URG (NEDO-32686-A) and NUREG/CR-6367. Since any debris that can bypass the suction strainer must be smaller than 0.125 inches in diameter to pass through the strainer, this dimension was used for the assessment. Although some local clearances are less than this width, the staff agrees with GEH that complete blockage of a fuel bundle is not credible. This is because there are multiple possible ways in which ECCS water can reach the fuel rods within each channel. Even if the inlet to a fuel bundle is completely blocked, ECCS water can replace any liquid mass lost due to boiloff by downflow of spray droplets or spillover from the top of the channel box from the upper plenum. The upper plenum above the core serves as a common mixing region for all bundles, so even if one or several fuel channels are blocked, cooling liquid can be supplied from adjacent unblocked bundles.

The past BWR fuel bundle head loss test results show that the highest debris pressure drop occurs at the location of the first or the second spacer location if the fluid flows from the fuel bundle bottom to the top. The debris bed gradually forms at these two locations after the injected ECCS water from the strainer flow through these two spacers and the downward edge of the spacers captures the debris. Initially, the debris only accumulates along the edge of the spacers with the flow area away from the spacers open to the fluid. With more and more debris gradually piling up on the debris already captured by the spacers, a porous debris bed could form to bridge the gap between the spacers and the fuel pins. The porosity of the debris bed affects the pressure drop across the bed and is strongly affected by the number of spacers along the fuel bundle width. The more spacers included in the fuel bundle design, the denser the debris bed is, and the higher the pressure drop expected.

The staff compared the GNF2 fuel bundle design tested by Global Nuclear Fuel (GNF) to the ABWR fuel bundle design referenced by the DC renewal application, which is designated as GE P8x8R fuel, and noted two main differences. The GNF2 fuel bundle design has more fuel pins and an additional spacer to capture debris. Also, the GNF2 fuel bundle design incorporates a debris filtering LTP. The staff evaluated both of those differences to determine whether it agrees that the GNF2 testing results are applicable to the ABWR P8x8R fuel design.

With respect to the number of fuel pins and spacers, since the tested fuel bundle had a larger number of fuel pins, the debris captured in this configuration would tend to be greater than for the ABWR P8x8R design with fewer debris capture locations. Therefore, should the ABWR P8x8R fuel be tested for the same given amount of debris and fluid flow rate, the pressure drop across the debris bed would be expected to be less, so adequate cooling could be maintained.

With respect to the LTP design, the tested GNF2 fuel bundle would tend to capture more debris than the P8x8R fuel design without a debris filtering LTP. However, as previously stated, only debris with the size of 0.125” or less can pass through the strainer to get into the core region, and regardless of the LTP design, the holes in the debris filter of both the GNF2 and the P8x8R fuel are large enough to pass the debris bypassing the strainer. The GNF2 would capture more debris than the ABWR P8x8R design. As it was observed in the GNF2 fuel bundle head loss testing, the total measured pressure drops remained less than the available driving head.

Considering both major applicable design differences between the tested GNF2 fuel bundle and the ABWR P8x8R fuel design, the staff concludes that the hydraulic performance of the ABWR P8x8R fuel bundle is bounded by the results of fuel bundle head loss testing for the GNF2 fuel. Therefore, the staff concludes that debris blockage at the bundle inlet and lower grid spacers would not adversely affect the P8x8R fuel used by the ABWR.

It has been common nuclear industry practice to evaluate the effect of fuel cladding thermal resistance post-LOCA caused by the buildup of layers of oxide, crud, and chemical precipitates and the possible occurrence of a second peak cladding temperature during long-term cooling. Cladding oxidation in the ABWR design following a LOCA will be insignificant since the core remains covered. The high turbulence resulting from boiloff of liquid in the core region is expected to impede significant buildup of solid particulate, fiber and chemical precipitates on cladding surfaces. Because the ECCS injects water from both the top and bottom of the core, it is unlikely that a significant quantity of any solid particulate, fiber and chemical precipitate would be deposited on the fuel cladding surface. Therefore, the staff considers that an increase in thermal resistance from oxide, crud and chemical precipitates will be minimal, and occurrence of a second peak cladding temperature during post-reflood long-term cooling is unlikely.

For the reasons stated above, the staff finds the applicant’s approach for evaluation of in-vessel downstream effects for the ABWR design is sufficient to demonstrate that the long-term cooling requirement of 10 CFR 50.46(b)(5) is satisfied when considering the effects of debris.

6.2.1.9.4 *Conclusion*

Based on the above evaluation, the staff concluded that the design of the GEH ABWR ECCS suction strainer meets all applicable regulations including GDC 1, 4, 34, 35, and 38. Additionally, based on the above, the staff concluded that the design as described in the ABWR DCD, Revision 7, conforms to the guidance in RG 1.82, Revision 4, and TR NEDO-32686-A, Revision 0 and TR NEDC-32721P-A, Revision 2. The staff determined that the GEH ABWR ECCS suction strainer design complies with 10 CFR 50.46, specifically the requirements of 10 CFR 50.46(b)(5) and is, therefore, acceptable.

References

1. 10 CFR Part 50, Appendix A, “General Design Criteria for Nuclear Power Plants.”

2. 10 CFR Part 50, Appendix A, GDC 1, “Quality standards and records.”

3. 10 CFR Part 50, Appendix A, GDC 4, “Environmental and Dynamic Effects Design Basis,”

4. 10 CFR Part 50, Appendix A, GDC 34, “Residual heat removal.”

5. 10 CFR Part 50, Appendix A, GDC 35, “Emergency Core Cooling,”

6. 10 CFR Part 50, Appendix A, GDC 38, “Containment heat removal,”

7. 10 CFR Part 50, Appendix K, “ECCS Evaluation Models.”

8. 10 CFR 50.46, “Acceptance Criteria for Emergency Core Cooling Systems for Light-Water Nuclear Power Reactors.”

9. 10 CFR 52.47, “Contents of Applications; Technical Information.”

10. 10 CFR 50.55a, “Codes and Standards.”

11. 10 CFR Part 52, Appendix A, “Design Certification Rule for the U.S. Advanced Boiling Water Reactor.”

12. 10 CFR 52.59, “Criteria for Renewal.”

13. NRC, “U.S. Nuclear Regulatory Commission Regulatory Audit Summary Report: GE Hitachi U.S. Advanced Boiling-Water Reactor Design Certification Renewal Emergency Core Cooling System Strainer Design,” January 24, 2019 (ADAMS Accession No. ML18354B167).

14. NRC, NUREG-0800, “Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition,” Section 6.2.2, “Containment Heat Removal Systems,” Revision 5, March 2007 (ADAMS Accession No. ML070160661).

15. NRC, NUREG/CR-6367, “Experimental Study of Head Loss and Filtration for LOCA Debris,” dated February 1996.

16. NRC, NUREG-1503, “Final Safety Evaluation Report Related to the Certification of the Advanced Boiling Water Reactor Design,” July 1994 (ADAMS Accession No. ML080670592).

17. NRC, NUREG-1503, “Final Safety Evaluation Report Related to the Certification of the Advanced Boiling Water Reactor Design,” Supplement 1, May 1997 (ADAMS Accession No. ML080710134).

18. NRC, BL 96-03, “Potential Plugging of Emergency Core Cooling Suction Strainers by Debris in Boiling-Water Reactors,” May 6, 1996.

19. NRC, IN 92-71, "Partial Plugging of Suppression Pool Strainers at a Foreign BWR," September 30, 1992 (ADAMS Accession No. ML031200327).

20. NRC, IN 93-34, "Potential for Loss of Emergency Cooling Function due to a Combination of Operational and Post-LOCA Debris in Containment," April 26, 1993.

21. NRC, IN 93-34, "Potential for Loss of Emergency Cooling Function Due to a Combination of Operational and Post-LOCA Debris in Containment," Supplement 1, May 6, 1993.

22. NRC, BL 93 02, "Debris Plugging of Emergency Core Cooling Suction Strainers."

23. NRC, GSI-191, "Assessment of [Effect of] Debris Accumulation on PWR Sump Performance."

24. NRC, RG 1.82, "Water Sources for Long-Term Recirculation Cooling Following a Loss-Of-Coolant Accident," Revision 1, November 1985 (ADAMS Accession No. ML003740236).

25. NRC, RG 1.82, "Water Sources for Long-Term Recirculation Cooling Following A Loss-Of-Coolant Accident," Revision 4, March 2012 (ADAMS Accession No. ML111330278).

26. NRC, 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 (ADAMS Accession No. ML091320468).

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