Safety Evaluation Report on General Electric Hitachi Nuclear Energy Topical Report NEDO-33373: "Dynamic, Load-Drop and Thermal-Hydraulic Analyses for ESBWR Fuel Racks"

1.0 Introduction

GE Hitachi Nuclear Energy (GEH) issued Revision 5 of Topical Report NEDO-33373, "Dynamic, Load-Drop and Thermal-Hydraulic Analyses for ESBWR Fuel Racks," in October 2010 (Ref. 1). (Unless otherwise noted, references to NEDO-33373 refer to Revision 5.) NEDO-33373 documents the results of the structural and thermal-hydraulic analyses for the design of spent fuel racks located in the spent fuel pool and buffer pool, as well as new fuel racks in the buffer pool. Section 2 of this safety evaluation report (SER) discusses the U.S. Nuclear Regulatory Commission (NRC) staff's evaluation of the technical adequacy of GEH's structural analyses to determine the capability of the fuel racks to protect the housed fuel assemblies, as documented in Sections 1, 2, 3, and 4 of NEDO-33373. (Structural evaluation of the pools and stored fuel assemblies is not within the scope of NEDO-33373.)

Section 3 of this SER discusses the staff's evaluation of the technical adequacy of the applicant's thermal-hydraulic analysis on decay heat removal from the spent fuel assemblies during all anticipated operating and accident conditions, documented in Section 5 of NEDO-33373. Section 3 also discusses the staff evaluation of the technical adequacy of the applicant's thermal-hydraulic analysis on adequate natural circulation of the coolant during all anticipated operating conditions, including full-core offloads during refueling, to prevent nucleate boiling for all fuel assemblies.

2.0 Dynamic Load and Load-Drop Analyses

2.1 Regulatory Criteria

The staff reviewed the economic simplified boiling-water reactor (ESBWR) dynamic load and load-drop analyses of the new and spent fuel storage racks in accordance with NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition" (hereafter referred to as the SRP), Section 3.8.4, "Other Seismic Category I Structures," Appendix D, "Guidance on Spent Fuel Pool Racks," Revision 2, issued March 2007 (Ref. 2). The staff's acceptance of the dynamic load and load-drop analyses of the new and spent fuel storage racks is based on applicant compliance with the following requirements:

- Title 10 of the *Code of Federal Regulations* (10 CFR) Part 50, "Domestic Licensing of Production and Utilization Facilities," (Ref. 3) specifically, 10 CFR 50.55a, "Codes and Standards," as they relate to codes and standards

- General Design Criterion (GDC) 1, "Quality Standards and Records," of Appendix A, "General Design Criteria for Nuclear Power Plants," to 10 CFR Part 50, as it relates to structures, systems and components being designed, fabricated, erected, constructed, and tested to quality standards commensurate with the importance of the safety function to be performed

- GDC 2, "Design Bases for Protection against Natural Phenomena," as it relates to structures, systems, and components important to safety being designed to withstand appropriate combinations of the effects of normal and accident conditions with the effects of earthquakes.

- GDC 4, "Environmental and Dynamic Effects Design Bases," as it relates to structures, systems and components important to safety being appropriately protected against the dynamic effects of discharging fluids.

- Appendix B, "Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants," to 10 CFR Part 50, as it relates to design control.

2.2 Summary of Technical Information

Sections 1, 2, and 3 of NEDO-33373 supply the dynamic analyses used for the design of the spent fuel racks located in the spent fuel pool and buffer pool, as well as new fuel racks in the buffer pool. Section 4 of NEDO-33373 gives a load-drop analysis to demonstrate that the functionality of the spent fuel racks and the new fuel racks is not affected by the postulated accidental drops. The subsections below give a summary description of each of these analyses. (The respective sections of NEDO-33373 provide detailed descriptions of these analyses.)

Dynamic Load Analysis for Spent Fuel Racks in the Spent Fuel Pool

Section 1 of NEDO-33373 describes the dynamic load analysis for spent fuel racks in the spent fuel pool, which is located in the fuel building. The spent fuel racks give structural support to and protection of the stored spent fuel assemblies, and are designed by analysis in accordance with the requirements for American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel (B&PV) Code Class 3 plate and shell type supports (Ref. 4). The racks are plate-type structures constructed using stainless steels and borated stainless steels. These racks are permanently submerged in the pool water but are not structurally fastened to the pool walls or base. The fuel assemblies are inserted and removed through the access at the top of the racks. NEDO-33373, Section 1.4, gives the detailed layout and dimensions of the racks.

Section 1.4 of NEDO-33373 also describes the dynamic load analysis for the spent fuel racks in the spent fuel pool. The description includes (1) the dead weight plus buoyancy load, (2) fuel handling loads (upward force by postulated stuck fuel assembly), (3) the thermal effect, (4) the safe-shutdown earthquake (SSE), (5) the safety relief valve discharge (SRVD) load, and (6) the loss-of-coolant accident (LOCA) load. These loads were combined in accordance with the service limits given in Table 1 of Appendix D to SRP Section 3.8.4. The stress limits were based on ASME B&PV Code (2001 edition with 2003 addenda), Section III, Division I, Subsection NF and Appendix F, (Ref. 4) for Class 3 plate and shell type supports.

The applicant performed a response spectrum analysis to calculate the dynamic response of the spent fuel racks to SSE, SRVD, and LOCA loads. A finite element model for an individual rack was developed, with the hydrodynamic coupling between adjacent racks and between racks and the walls through water around them conservatively disregarded. Section 1.5 of NEDO-33373 describes the details of the finite element modeling and also documents the analysis results, including maximum deformations in critical locations and stress checks in the critical sections of the different plates and welds of the rack against the stress limits in accordance with ASME B&PV Code, Section III, Division I, Subsection NF and Appendix F, for Class 3 plate and shell type supports.

Because the spent fuel racks are not structurally connected to the walls and base of the spent fuel pool, the racks could slide against and lift off the pool base. In addition, the fuel assemblies housed in the racks can rattle against the racks. The topical report characterized these dynamic effects through a simplified global coupled fluid structure model. The applicant carried out a transient analysis to determine the dynamic response of the racks subjected to SSE ground motions. NEDO-33373, Section 1.6, gives the details of the fluid structure model, and Sections 1.7 to 1.9 document the analysis results, including maximum deformations in critical locations and stress checks in the critical sections of the different plates and welds of the rack against the stress limits in accordance with ASME B&PV Code, Section III, Division I, Subsection NF and Appendix F, for Class 3 plate and shell type supports.

The applicant concluded in NEDO-33373, Section 1.10 that the design of the spent fuel racks in the spent fuel pool meets the requirements of ASME B&PV Code, Section III, Division I, Subsection NF and Appendix F, for design by analysis of Class 3 plate and shell type supports.

Dynamic Load Analysis for Spent Fuel Racks in the Buffer Pool

Section 2 of NEDO-33373 describes the dynamic load analysis for spent fuel racks in the buffer pool located in the reactor building. The spent fuel racks give structural support to and protection of the stored spent fuel assemblies and are designed by analysis as ASME Code Class 3 plate and shell type supports. The racks are structures fabricated from stainless steel and borated stainless steels plates similar to the spent fuel racks in the spent fuel pool located in the fuel building, except that the spent fuel racks in the buffer pool are designed with different storage capacity and are anchored to the pool structure at the base. The connection of the anchor bolts to the buffer pool base is not within the scope of NEDO-33373. These racks are permanently submerged in the pool water. The fuel assemblies are inserted and removed through the access at the top of the racks. NEDO-33373, Section 2.4, provides the detailed layout and dimensions of the racks.

Section 2.4 of NEDO-33373 describes the dynamic load analysis for the spent fuel racks in the buffer pool. The applicant performed a response spectrum analysis to calculate the dynamic response of the spent fuel racks to SSE, SRVD, and LOCA loads. The load combinations were performed in accordance with the service limits in Table 1 of Appendix D to SRP Section 3.8.4. Section 2.5 of NEDO-33373 describes the stress checks for the critical sections of the plates and welds. The stress limits were based on ASME B&PV Code, Section III, Division I, Subsection NF and Appendix F, for Class 3 plate and shell type supports.

The applicant performed a nonlinear transient analysis to estimate the impact of the fuel assemblies on the racks during an SSE event. On the basis of this dynamic analysis, the applicant checked stresses in the critical sections of the different plates and welds of the racks against the ASME Code stress limits in accordance with ASME B&PV Code, Section III, Division I, Subsection NF and Appendix F, for Class 3 plate and shell type supports. NEDO-33373, Section 2.5.4, provides the detailed analysis and results.

The applicant concluded in NEDO-33373, Section 2.6 that the design of the spent fuel racks in the buffer pool meets the requirements of ASME B&PV Code, Section III, Division I, Subsection NF and Appendix F, for design by analysis of Class 3 plate and shell type supports.

Dynamic Load Analysis for New Fuel Racks in the Buffer Pool

Section 3 of NEDO-33373 describes the dynamic load analysis for new fuel racks in the buffer pool located in the reactor building. The new fuel racks give structural support to and protection of the stored new fuel assemblies. The racks are structures fabricated from stainless steel plates that are anchored to the buffer pool base. These racks are permanently submerged in the pool water, with the fuel assemblies free to be moved in and out of the racks through the lateral entrances. NEDO-33373, Section 3.4 gives detailed layout and dimensions of the racks.

Section 3.4 of NEDO-33373 also describes the dynamic load analysis for the spent fuel racks in the buffer pool. The applicant performed a response spectrum analysis to calculate the dynamic response of the new fuel racks to SSE, SRVD, and LOCA loads. The load combinations were performed in accordance with the service limits in Table 1 of Appendix D to SRP Section 3.8.4. The stress limits were based on ASME B&PV Code, Section III, Division I, Subsection NF and Appendix F, for Class 3 plate and shell type supports.

The analysis results in NEDO-33373, Section 3.5, include maximum deformations in critical locations and stress checks in the critical sections of the different plates and welds of the rack against the stress limits in accordance with ASME B&PV Code, Section III, Division I, Subsection NF and Appendix F, for Class 3 plate and shell type supports.

The applicant performed a nonlinear transient analysis to estimate the impact of the fuel assemblies on the racks during an SSE event. On the basis of this dynamic analysis, the applicant checked stresses in the critical sections of the different plates and welds of the racks against the ASME Code stress limits in accordance with ASME B&PV Code, Section III, Division I, Subsection NF and Appendix F, for Class 3 plate and shell type supports. NEDO-33373, Section 3.5.4, gives a detailed analysis and results.

The applicant concluded in NEDO-33373, Section 3.6 that the design of the new fuel racks in the buffer pool meets the requirements of ASME B&PV Code, Section III, Division I, Subsection NF and Appendix F, for design by analysis of Class 3 plate and shell type supports.

Load-Drop Analysis

Load-drop analysis is required in the design of fuel storage racks for new and spent fuel assemblies. The racks must be capable of withstanding operational and accidental load drops of the fuel assemblies and handling tools. NEDO-33373, Section 4, describes the load-drop analysis for both spent fuel racks and new fuel racks. For the spent fuel racks, the analysis considered two drop scenarios because the fuel assemblies are inserted and removed through the access at the top of the racks: (1) a dropped element may fall through to the bottom of a cell and impact the base plate of the rack, and (2) the dropped element may be arrested at the top of the rack cells. For the new fuel racks that accommodate the fuel operations through lateral entrances, the drop scenarios include the impact of a dropped element on the base plate and the cell walls. NEDO-33373, Section 4.2, describes the geometry and the behavior of the falling fuel elements and the accident drop scenarios associated with the spent fuel racks and new fuel racks.

Sections 4.3 and 4.4 of NEDO-33373 give detailed drop analyses (based on the finite element models of the spent fuel racks) to assess the effects of the postulated drop scenarios on the spent fuel racks. The objectives of these drop analyses were to demonstrate that these postulated drops will not damage the fuel assemblies stored in the rack cells and that the dropped object would not penetrate through the base plate and thereby damage the pool liner. To achieve these objectives for the drop analyses, the applicant used plastic material properties and the analysis algorithm permitting large deformations to make realistic assessments of the consequences of these postulated accidental drops of fuel elements.

The applicant performed similar drop analyses for the new fuel racks, given in NEDO-33373, Section 4.5.

The applicant concluded in NEDO-33373, Section 4.6 that the drop analyses for both spent fuel racks and new fuel racks demonstrated that the stored fuels and the pool liners were not affected by these postulated drop scenarios.

2.3 Staff Evaluation

The NRC staff reviewed (1) the dynamic analyses of the spent fuel storage racks in the spent fuel pool located in the fuel building and in the buffer pool in the reactor building, and (2) the dynamic analysis of the new fuel storage racks in the buffer pool. The staff also reviewed the drop analyses performed for both spent fuel racks and new fuel racks.

The staff's review included applicable codes and standards for the design of the racks by analysis, material properties, the analysis procedures used to perform the dynamic analyses for the fuel storage racks, load combinations, and structural acceptance criteria for conformance with GDC 1, 2, and 4, as well as other regulatory requirements identified in Section 2.1 of this SER. The staff carried out its technical review of the structural analyses for the fuel storage racks in accordance with Appendix D to SRP Section 3.8.4.

The ESBWR standard design includes facilities for the storage of spent and new fuel. The fuel storage facilities include fuel storage racks that store and protect the fuel, the fuel storage pools that contain the storage racks, and the associated auxiliary components. The scope of this topical report includes the structural dynamic and thermal-hydraulic analyses for the fuel storage racks. This staff evaluation pertains to the technical adequacy of the structural analyses of the ESBWR fuel storage racks.

Fuel storage racks are designed as the storage and structural protection for the spent and new fuel assemblies. The ESBWR fuel storage racks are designed as stainless steel plate type structures. NEDO-33373 designates these racks as ASME Class 3 plate type supports and applies ASME B&PV Code, Section III, Division I, Subsection NF and Appendix F, corresponding to the design by analysis for Class 3 plate and shell type supports. The classification of the fuel storage racks as Class 3 plate and shell type supports and the design of the racks by analysis approach based on the ASME B&PV Code are consistent with 10 CFR 50.55a and with the guidance in Appendix D to SRP Section 3.8.4. On this basis, the staff concludes that the classification and the design-by-analysis approach for the fuel storage racks in NEDO-33373 are acceptable.

According to NEDO-33373, Revision 5, the fuel storage racks are designed and analyzed using stainless steels with material properties consistent with ASME B&PV Code, Section II, Part D (Ref. 5). However, the staff found that the material properties given in NEDO-33373, Revision 0 (Ref. 6) were associated with a temperature that was lower than the accident temperature given in the ESBWR Design Control Document (DCD), Revision 4 (Ref. 7). ESBWR DCD, Revision 4, Tier 2, Section 9.1.2.5, gives the thermal-hydraulic design for the fuel storage racks, which states, "In the event of loss of FAPCS cooling trains, boiling can occur. The structural acceptance criterion for the fuel storage racks is that the storage rack design does not exceed the allowable stress level given in the ASME B&PV Code, Section III, Subsection NF during boiling." The staff was concerned that the applicant used material properties for the fuel storage racks from below the boiling or accident temperatures. In Request for Additional Information (RAI) 9.1-54 (Ref. 8), the staff asked GEH to justify not using the accident temperature in determining the steel material properties.

In its response dated November 10, 2008 (Ref. 9), the applicant stated the following:

> Due to the depths of the spent fuel storage racks in both the Buffer Pool and Spent Fuel Pool, re-analysis of all racks has been performed using ASME code material limits for [121 degrees C] 250° F. Tables 1-3, 2-3, and 3-3 shall be revised to update the material limits to [121 degrees C] 250°F. Sections 1.4.5.3, 2.4.6.3, and 3.4.6.3 of LTR NEDC-33373P, "Dynamic, Load Drop and Thermal-Hydraulic Analysis for ESBWR Fuel Racks," November 2007, shall be revised to reference [121 degrees C] 250° F. In addition, a reference to the ASME Steam Tables shall be added to Sections 1.8, 2.7, and 3.7 as a source for the [121 degrees C] 250°F at the depths of the fuel storage racks.

The staff finds the applicant's response to be acceptable because the applicant has updated the selection of material properties based on the accident temperature of 121 degrees C (250 degrees F), as specified for the buffer pool and spent fuel pool in DCD, Tier 2, Revision 7, Section 9.1.2.5. On this basis, the staff concludes that the material properties used by the applicant for performing dynamic and drop analyses of the fuel storage racks are acceptable. On the basis of the applicant's response, RAI 9.1-54 is resolved.

The applicant used the response spectrum method described in Appendix D to SRP Section 3.8.4 to perform the dynamic analyses of the fuel storage racks under SSE, LOCA, and SRVD loads. Upon reviewing the procedure that the applicant applied to determine the dynamic response of the fuel storage racks based on the response spectrum method, the staff identified a number of technical issues:

(1) NEDO-33373, Revision 0, described the response spectrum analyses for fuel storage racks under a SSE using a higher damping value than the damping value for welded steel structures given in Table 1 of Regulatory Guide (RG) 1.61, Revision 1, "Damping Values for Seismic Design of Nuclear Power Plants," issued March 2007 (Ref. 10). The fuel storage rack structures are welded steel construction and, according to RG 1.61, the SSE damping should be 4 percent. In RAI 9.1-60 (Ref. 8), the staff asked GEH to justify using a damping value higher than 4 percent in the SSE response analyses.

    In its response dated November 10, 2008 (Ref. 9), the applicant stated the following:

    > Higher damping values are allowed under Regulatory Guide 1.61, Paragraph C.2, and Standard Review Plan Section 3.8.4, Appendix D, Section 3, Paragraph 4, which states that submergence in water can be taken into account. Based on a review of the work by Lawrence Livermore laboratory, "Effective Mass and Damping of Submerged Structures," Report UCRL-52342, by R. G. Dong (1978) [Ref. 11], damping values higher than 4 percent and 6 percent damping were justified for the spent fuel racks located under water with close tolerance fit-up to the fuel assembly. A conservative approach within the industry

showed most racks evaluated with this allowance were using an additional 2 percent damping.

The staff found the applicant's justification inadequate because the study in Lawrence Livermore National Laboratory Report UCRL-52342, "Effective Mass and Damping of Submerged Structures," dated April 1, 1978 (Ref. 11), was based on submerged structures that had different structural configurations from the fuel storage rack structures described in NEDO-33373, Revision 0. Furthermore, the data compiled in Report UCRL-52342 do not support the 6 percent damping value to account for the submergence effect. In RAI 9.1-60 S01 (Ref. 12), the staff asked the applicant to supply adequate and supportable justification for the use of a higher damping value.

In its response to the RAI, dated May 14, 2009 (Ref. 13), GEH agreed to "re-perform the fuel storage rack seismic analysis with a 4 percent damping value as prescribed in Table 1 of RG 1.61." The staff finds the applicant's response acceptable because the applicant redid the seismic analysis of the racks with a damping value consistent with the guidance in Regulatory Guide (RG) 1.61. The staff also reviewed NEDC-33373P[1], Revision 3 (Ref. 14), and confirmed that the applicant has implemented the 4 percent damping value in the seismic analysis of the racks. On the basis of the applicant's response, RAI 9.1-60 is resolved.

(2) Employing the response spectrum method to determine the dynamic response of fuel racks to SSE, LOCA, and SRVD loads, the applicant stated in NEDC-33373P, Revision 3, Sections 1.5.3, 2.4.8, and 3.4.8, that the modal responses are combined in accordance with the grouping method established in RG 1.92, "Combining Modal Responses and Spatial Components in Seismic Response Analysis." The staff noted that the NRC established the grouping method in RG 1.92, Revision 1, issued February 1976 (Ref. 15) however, the NRC did not include this method in RG 1.92, Revision 2, issued July 2006 (Ref. 16). The staff also noted that in NEDC-33373P, Revision 3, Sections 2 and 3 referred to RG 1.92, Revision 2, while NEDC-33373P, Revision 3, Section 1 did not identify which revision of RG 1.92 was used. In RAI 9.1-148 (Ref. 17), the staff asked the applicant to address this apparent inconsistency.

The staff recognizes that, although RG 1.92, Revision 2, provides some new methods for combining modal responses, the methods established in RG 1.92, Revision 1, are still applicable because they are conservative. However, as described in Sections C.1.4.1 and D of RG 1.92, when applicants use the methods in RG 1.92, Revision 1, they need to include the missing mass contribution, which is particularly important for an adequate estimate of support reactions. The applicant used the 10 percent rule for including the missing mass, which the staff considers nonconservative based on the guidance in RG 1.92, Revision 2. Using the 10 percent rule, the applicant excluded the missing mass effect in NEDC-33373P, Revision 3, Sections 1 and 2, and included the missing mass in NEDC-33373P, Revision 3, Section 3. In RAI 9.1-148, the staff asked the applicant to consider the missing mass effect for modal combinations based on the grouping method in NEDC-33373P, Revision 3, Sections 1 and 2.

[1] Prior to Revision 4, NEDO-33373 was treated by the applicant as a proprietary document and thus designated NEDC-33373P. With Revision 4, the applicant determined that NEDO-33373 did not contain proprietary information, resulting in a new designation.

In its response dated March 11, 2010 (Ref. 18), the applicant revised NEDO-33373, Sections 1.5.3, 1.10, 1.11, 2.4.8, 2.6, 2.7, and 3.7, to assess the effect of the neglected missing masses on the seismic analysis results. The applicant also clarified that it used RG 1.92, Revision 1, in NEDO-33373, Sections 1, 2, and 3, and applicable sections of DCD Tier 2, Chapter 9. According to the applicant's assessment, because of the sizeable design margins in the stress ratios (stress demand to ASME stress allowable) for the fuel storage racks' design, adding the contribution of the neglected missing masses results in a small increase to the stress ratios. However, the resulting stress ratios are still limited to within 1.0, therefore meeting the ASME B&PV Code design requirement. The staff finds that the applicant's response has adequately addressed the missing mass effect and has established that the fuel storage racks design is still adequate when the missing masses are incorporated into the seismic analysis results, which is consistent with the staff position in Sections C.1.4.1 and D of RG 1.92, Revision 2. The staff reviewed NEDO-33373, Revision 4 (Ref. 19), and confirmed that the applicant has supplied detailed descriptions of this assessment. On the basis of the applicant's response, RAI 9.1-148 is resolved.

On the basis of the discussions above, the staff concludes that the response spectrum method used by the applicant for establishing the seismic demands for the fuel storage racks is consistent with RG 1.92, Revision 2, and is therefore acceptable.

In NEDO-33373, Revision 0, the applicant designed the fuel storage racks in the spent fuel pool to be anchored to the pool base. The applicant changed the design in NEDC-33373P, Revision 1 (Ref. 20), so that the fuel storage racks in the spent fuel pool are not structurally fastened to the spent fuel pool, which means that the racks remain freestanding on the base of the pool. To reduce the movement of racks under a SSE, the racks are connected to each other at the bases as well as at the tops. To follow the guidance in Appendix D to SRP Section 3.8.4, the applicant performed a nonlinear transient seismic analysis for the fuel storage racks in the spent fuel pool under SSE ground motions to demonstrate that these racks can withstand sliding and overturning effects associated with the freestanding design. The staff reviewed the nonlinear model that the applicant developed for the nonlinear transient seismic analysis and identified a number of technical issues:

(1) The applicant developed one nonlinear model in NEDC-33373P, Revision 1, for a north-south (N-S) row of fuel storage rack array and another for an east-west (E-W) row of the rack array. Both models were built with two-dimensional (2-D) beams and point masses. These models are adequate for capturing vibrations in both E-W and N-S directions because the dynamic characteristics of the beam and mass model were developed from the detailed finite element model, which was developed for the response spectrum analysis. However, the staff was concerned that the 2-D models were not able to capture the three-dimensional (3-D) effect of vibrations of the freestanding racks where the racks may be supported at only a corner and pivot about that point. Past studies (NUREG/CR-5912, "Review of the Technical Basis and Verification of Current Analysis Methods Used to Predict Seismic Responses of Spent Fuel Storage Racks," issued October 1992 (Ref. 21)) showed that the pivotal effect may induce large horizontal displacements of the racks. In RAI 9.1-117 (Ref. 12), the staff asked the applicant to either show that the 2-D analyses envelop the pivotal vibration effect or provide an assessment of pivotal effect on the seismic responses.

In its response, dated April 22, 2009 (Ref. 22), GEH agreed to "perform a dynamic analysis of fuel storage rack array. This analysis will include an evaluation of the pivotal effect due to the seismic responses of the fuel storage rack structure using a 3-D model of the racks." The staff finds the applicant's response adequate because the applicant performed the nonlinear transient seismic analysis of the racks using a 3-D model of the racks. Furthermore, the staff reviewed NEDC-33373P, Revision 3, and confirmed that the applicant developed a 3-D model based on the dynamic characteristics of the detailed finite element model, which was developed for the response spectrum analysis. On the basis of the applicant's response, RAI 9.1-117 is resolved.

(2) Many factors affect the seismic response of the freestanding racks. Among these factors, the friction coefficient between the bearing pads and the pool floor is important in determining whether the racks will be subject to sliding or overturning. NEDC-33373P, Revision 3, Section 1.6.5.1, gives a scenario study of various combinations of factors and establishes a bounding case for the seismic response of racks. The staff noticed that Case C-5 showed that a friction coefficient equal to 0.5 controls the relative displacements of racks with the pool floor at the bottom and the pool wall at the top in the E-W direction. However, the lower bound for the friction coefficient is 0.2. In RAI 9.1-146 (Ref. 23), the staff asked the applicant to demonstrate that the relative horizontal displacements between rack foot and pool floor and fuel storage rack top and pool wall will not exceed the prescribed gaps when Case C-5 is analyzed with a 0.2 friction coefficient.

In its response to RAI 9.1-146 dated March 11, 2010 (Ref. 24), the applicant stated that "[a] new case (Case C-6) will be added…. This new case evaluates the seismic response of the fuel racks assuming a coefficient of friction of 0.2 for the bearing pads on the pool floor…." The staff reviewed the analysis results in NEDC-33373P, Revision 3, Table 1-16, and finds that Case C-6 controls the relative displacements in the E-W direction between the fuel storage racks and the pool liner. In its response to RAI 9.1-144 (Ref. 25) dated March 11, 2010, the applicant changed the design to increase the gap between the fuel storage racks and the pool liner to ensure no impact of fuel storage racks on the liner because of seismic and thermal loads. The staff evaluated the design changes and determined that the large relative displacements induced by Case C-6 are less than the gap between the fuel storage racks and the liner, ensuring no impact of fuel storage racks on the liner. On the basis of the discussion above, the staff concludes that the applicant has adequately considered the seismic load in its nonlinear analysis of fuel storage racks. On the basis of the applicant's response, RAI 9.1-146 is resolved.

(3) To determine the global stresses for the freestanding racks, the applicant used a ratio coefficient to scale the fixed-based response spectrum stress results. Because the maximum global bending moments acting at the level of the base plate control the global stresses in plates and welds, the ratio coefficient was determined as the ratio of the maximum bending moment of the freestanding model to the maximum bending moment of the fixed-base response spectrum model. However, the staff noticed that the maximum bending moment of the freestanding model was determined by the SSE motion, while the maximum bending moment of the fixed-base response spectrum model was calculated based on the SSE plus the LOCA plus the SRVD, resulting in a smaller ratio coefficient than if the calculation were done based on the SSE for both models. Given that some stresses provided in NEDC-33373P, Revision 3, Table 1-19, are very close to the ASME stress limit, in RAI 9.1-147 (Ref. 23), the staff asked the

applicant to demonstrate that the ASME stress limit will not be exceeded if the ratio coefficient is calculated using SSE for both models.

In its response dated December 5, 2009 (Ref. 26), the applicant provided an analysis to justify use of the reduction factor. The staff's evaluation finds that the applicant's justification included a mathematical error and is inadequate. However, the applicant indicated that even if the reduction factor is not used, the resulting stresses are within the allowable limits, The applicant specifically stated that "[i]n reviewing NEDC-33373P, Revision 3, Table 1-19 and assuming an f_M factor of 1.0, the resulting stresses are still less than the allowable…." The factor f_M is the applied reduction factor.

The staff reviewed NEDC-33373P, Revision 3, Table 1-19, which provides the stress results for the fuel storage racks and the corresponding ASME stress limits. The staff has confirmed the applicant's position that, if no credit is taken for the reduction factor (set f_M = 1.0), the resulting stress demand in all fuel storage rack components is within the ASME stress allowable limits. On the basis of the applicant's response, RAI 9.1-147 is resolved.

On the basis of the discussions above, the staff concludes that the nonlinear transient seismic analysis of the fuel storage racks in the spent fuel pool under SSE motions is consistent with the guidance of Appendix D to SRP Section 3.8.4 and therefore is acceptable.

The applicant followed Appendix D to SRP Section 3.8.4 for load combinations consistent with ASME B&PV Code, Section III, Division I, Subsection NF and Appendix F, corresponding to the design-by-analysis approach for Class 3 plate and shell type supports. However, the staff's review of the implementation of the load combinations concluded that the applicant did not include the thermal load with the SSE in the ASME Service Level D load combination. The staff estimated that, based on the configuration of the rack arrangement in the spent fuel pool, the rack could expand laterally and impact the pool liner if the applicant had appropriately performed its analysis using the Service Level D load combination and included both the temperature and SSE loads. In RAI 9.1-144 (Ref. 27), the staff asked the applicant to demonstrate that when the Service Level D load combination calculations are performed using both the accident temperature and SSE loads, the racks will not impact the liner and the effect of the thermal gradient will not impact the functionality of the racks in accordance with the guidance in Section 1.4 (in particular, the 3rd sentence of the 1st paragraph) of Appendix D to SRP Section 3.8.4.

In its response, dated March 11, 2010 (Ref. 25), the applicant increased the minimum clearance to the fuel pool wall from 42 mm to 92 mm in the N-S direction as a result of the Service Level D reanalysis to include both the accident temperature and SSE loading. The applicant stated that this increase can be accommodated since the tolerance in the N-S pool dimension has been decreased by 100 mm (the minus tolerance was changed from 300 mm to 200 mm per Table 2.16.7-1 in Tier 1 of DCD Rev. 6). The applicant clarified that in the E-W direction, the racks will be placed with a minimum gap of 60 mm to accommodate seismic and thermal expansion.

The staff evaluated the design changes and concludes that the newly established gaps between the fuel storage racks and the pool liner can adequately accommodate the loads resulting from the Service level D load combination. Therefore, this issue is resolved.

In addition, the applicant considered the worst case temperature differential, which results in the maximum temperature gradient between a full cell and an adjacent empty cell, and performed a structural evaluation to determine the impact of the temperature gradient on the functionality of the racks. The applicant stated that "[t]he result of the calculation is that the decrease in the gap between the fuel bundle and the fuel cell walls is less than 44 percent of the nominal gap (…22 mm nominal gap size). Therefore, the distortion of the fuel racks associated with this thermal gradient would not cause the rack walls to contact the stored fuel bundles...." On the basis of the applicant's evaluation, the staff finds that the functionality of the racks will not be compromised because there remains a gap between a fuel bundle and the racks under the maximum thermal gradient conditions. This is consistent with the guidance in Section 1.4 of Appendix D to SRP Section 3.8.4, which states that the temperature gradient across the rack structure that results from the differential heating effect between a full and an empty cell should be indicated and incorporated in the design of the rack structure. Therefore, on the basis of the evaluation above and the applicant's response, RAI 9.1-144 is resolved.

The staff concludes that the load combinations are consistent with the guidance of Appendix D to SRP Section 3.8.4 and ASME B&PV Code, Section III, Division I, Subsection NF and Appendix F, and therefore are acceptable.

The applicant used the structural acceptance criteria in Appendix D to SRP Section 3.8.4 to conform to GDC 1, 2, and 4. The applicant chose the design acceptance limits for the rack designs in accordance with ASME B&PV Code, Section III, Division I, Subsection NF and Appendix F, corresponding to the design-by-analysis approach for Class 3 plate and shell type supports. The staff reviewed the applicant's implementation of the design checks of the structural demands from various load combinations with the ASME B&PV Code's specified acceptance limits for the critical plate sections and welds and identified a number of technical issues:

(1) When the stress limits based on F-1332 of Appendix F to ASME B&PV Code, Section III, Division I, are used for plate type supports, a sizeable contribution from bending stress should be present in the plate in addition to the membrane stresses. Therefore, the stress limits per F-1332.2 for membrane plus bending are characterized as peak stresses (recognizing the effect of bending on stress distribution across the plate section) and are much higher than the membrane stress limits provided per F-1332.1. The applicant stated in NEDC-33373P, Revision 3, Sections 1, 2, and 3, that bending plate stresses are negligible; however, the allowable stresses for Service Level D were chosen from F-1332.2. The staff believes that, if the bending effect is negligible, then the plate stress state should be controlled by the membrane stresses. Therefore, the stress allowable per F-1332.1 should be applied. In RAI 9.1-149 (Ref. 17), the staff asked the applicant to make appropriate corrections to the allowable stresses based on F-1332.1 if the bending stress is determined to be secondary to the membrane stress.

    In its response dated March 11, 2010 (Ref. 28), the applicant clarified that when the bending stresses are secondary, they are not included in the stress calculations. However, the primary bending stresses are included in the analysis results, in which case the allowable limits will include both membrane and bending components. The applicant also revised the NEDO-33373, Revision 4 sections that provide the stress results to include this statement:

    > Bending stresses across the plate thickness are negligible and are classified as secondary stresses; however, other directions of the plate

contain primary bending stresses that are included in the stress analysis results.

Because the bending stresses that are identified to be the primary stress have been included in the stress results consistent with F-1332.2, the staff finds that the applicant has appropriately applied the ASME B&PV Code allowable limits. The staff also confirms that NEDO-33373, Revision 4, has incorporated the above statement in the sections documenting the stress results. On the basis of the applicant's response, RAI 9.1-149 is resolved.

(2) The applicant stated in NEDC-33373P, Revision 3, that the stress limits for Service Level D were based on F-1332 of Appendix F to ASME B&PV Code, Section III, Division I, and provided the stress limits for various stress conditions. However, the staff's review noted that the requirements for compressive stresses are provided under F-1332.5, which then refers to the rules of F-1331.5(a). The staff also noted that the applicant did not evaluate the racks subject to compressive stresses in accordance with the rules of F-1331.5(a). Without such evaluation, the staff considers the applicant's Service Level D analysis to be incomplete. In RAI 9.1-145 (Ref. 27), the staff asked the applicant to provide an evaluation of the rack plates subjected to compressive loads induced during the Service Level D load combination against the buckling limits per F-1331.5(a) of Appendix F to ASME B&PV Code, Section III, Division I.

In its response dated January 29, 2010 (Ref. 29), the applicant stated that "NEDO-33373 will be revised to include an evaluation of the compressive loads induced during the Service D load combination against ASME Code buckling limits. The evaluations will be contained in Appendices B1 and D of NEDO-33373…." The staff confirms that Appendices B1 and D have been added to NEDO-33373, Revision 4. The staff also evaluated the buckling analysis and finds that the buckling analysis based on detailed finite elements, including potential manufacturing imperfections, is consistent with the requirements per F-1331.5 of Appendix F to ASME B&PV Code, Section III, Division I. The results of the buckling analysis show that the allowable buckling limits are much larger than the membrane stresses, and that the buckling loads do not control the design of the fuel storage racks' plates. On the basis of the applicant's response, RAI 9.1-145 is resolved.

(3) Sections 2.5.4 and 3.5.4 of NEDC-33373P, Revision 3 analyze fuel assemblies impacting the rack cells. The applicant first used simplified beam mass models to develop impact forces on the rack cells, then applied these forces to detailed finite element models for the racks and performed plastic analyses to determine the stresses in the cell plates. The applicant referred to NF-1342.2, which the staff could not locate in Subsection NF. In RAI 9.1-150 (Ref. 17), the staff asked the applicant to clarify the apparently incorrect reference. The staff also asked the applicant to identify applicable and specific ASME Code requirements that were based on plastic analyses.

In its response dated March 11, 2010 (Ref. 28), the applicant clarified that a typographical error was made and that the correct ASME Code requirements applied for the plastic analysis are included in F-1341.2 of Appendix F to ASME B&PV Code, Section III, Division I. The applicant stated that the plastic analysis results showed a localized plasticity that does not lead to any global plastic deformation, therefore not impacting the functionality of the racks. The applicant also stated that the stress results are much lower than the ASME Code allowable limits. On the basis that the applicant applied Appendix F, F-1341.2 in performing the plastic analysis, the staff concludes that the applicant meets the ASME Code requirements for using plastic analysis methods. The staff has confirmed that the analysis methods and results are appropriately documented in NEDO-33373, Revision 4. The staff also confirmed that the identified typographical error has been corrected in NEDO-33373, Revision 4. On the basis of the applicant's response, RAI 9.1-150 is resolved.

On the basis of the discussions above, the staff concludes that the applicant has appropriately applied the structural acceptance criteria, consistent with the guidance of Appendix D to SRP Section 3.8.4 and ASME B&PV Code, Section III, Division I, Subsection NF and Appendix F, and therefore is acceptable.

For the load-drop analyses, the applicant followed the guidance in Appendix D to SRP Section 3.8.4 to demonstrate the functional capability of the fuel racks to protect the stored fuel during postulated operational accident drops of fuel assembly and associated tools. The applicant postulated several operational accident scenarios that the staff considered acceptable because the determination of the accident drop scenarios was based on the configuration of fuel storage racks and the lift height of fuel assemblies above the racks during the installation and removal operation of the fuel assemblies. The applicant also used detailed finite element models with fine meshes to capture the localized impact effects. The applicant employed a commercial code with the explicit algorithm that is typically used for assessing structural performance associated with impact phenomena. The applicant also demonstrated that, for the various load-drop scenarios, the impact of the accidental drops does not affect the regions of the fuel storage racks that house the fuel assemblies; therefore, the stored fuel assemblies remain in a safe and stable configuration. The staff's review of the applicant load-drop analyses did not identify any technical issues. On the basis of the above assessment of the applicant's load-drop analyses, the staff finds that the applicant's load-drop analyses are consistent with the guidance in Appendix D to SRP Section 3.8.4 and are acceptable.

2.4 Conclusions

This report gives the NRC staff's review and assessment of the dynamic and drop analyses for the ESBWR fuel storage racks in NEDO-33373, Revision 4. The staff's review included applicable codes for the design of the racks by analysis, material properties, analysis procedures used to perform the dynamic analyses for the fuel storage racks, load combinations, and structural acceptance criteria to conformance with GDC 1, 2, and 4, and other regulatory requirements listed in Section 2.1 of this report.

The staff concludes that the ESBWR fuel storage racks meet the relevant requirements of 10 CFR 50.55a and GDC 1, 2, and 4. This conclusion is based on the following:

(1) The applicant has met the requirements of 10 CFR 50.55a and GDC 1 to ensure that the fuel storage racks are structurally analyzed and designed to the quality standard commensurate with the safety function of protecting the stored fuel assemblies by meeting the guidelines of Appendix D to SRP Section 3.8.4 and ASME B&PV Code, Section III, Division I, Subsection NF and Appendix F.

(2) The applicant has met the requirements of GDC 2 by structurally analyzing and designing the fuel storage racks to withstand the most severe earthquake that has been established for the ESBWR certified design, with sufficient margin and combinations of the effects of normal and accident conditions with the effects of earthquake loading.

(3) The applicant has met the requirements of GDC 4 by ensuring that the structural analysis and design of the fuel storage racks are capable of withstanding the dynamic effects associated with accidental load drops and discharging fluids such as those associated with LOCAs and SRVD.

Therefore, the staff concludes that the dynamic and load-drop analyses, as well as the structural design of the ESBWR fuel storage racks, are acceptable.

3.0 Thermal-Hydraulic Analyses

3.1 Regulatory Criteria

The staff reviewed the ESBWR thermal-hydraulic analyses of the spent fuel storage racks in accordance with SRP Section 9.1.2, Revision 4, "New and Spent Fuel Storage," issued March 2007 (Ref. 30). The staff's acceptance of the spent fuel storage facility is based on compliance with GDC 61, "Fuel Storage and Handling and Radioactivity Control," as it relates to the facility design provisions for safe fuel storage and handling of radioactive materials (1) with a residual heat removal capability having reliability and testability that reflects the importance to safety of decay heat and other residual heat removal, and (2) to prevent significant reduction in fuel storage coolant inventory under accident conditions.

The SRP acceptance criteria are also based on conformance to the guidelines in Regulatory Positions C.9 and C.11 in RG 1.13, Revision 2, "Spent Fuel Storage Facility Design Basis," issued March 2007 (Ref. 31), which provide guidance on pool cooling and fuel cooling, respectively.

3.2 Summary of Technical Information

NEDO-33373 Section 5, Appendix G, and Appendix H describe the thermal-hydraulic analyses for spent fuel cooling in the spent fuel pool in the fuel building. NEDO-33373 does not provide thermal-hydraulic analyses for spent fuel cooling in the buffer pool in the reactor building, stating that it is bounded by the spent fuel pool analyses. NEDO-33373 Section 5, Appendix G, and Appendix H describe the calculation of the peak temperatures at the exit of the fuel racks using a computational fluid dynamics (CFD) methodology to determine the temperature distribution throughout the fuel pool.

NEDO-33373, Revision 5, Section 5.1.1, describes the normal and abnormal conditions evaluated in the thermal-hydraulic analyses. For the normal condition, a configuration with the accumulation of 10 years of spent fuel was modeled. For the abnormal condition, a configuration with the accumulation of 10 years of spent fuel and a full-core offload was modeled. In NEDO-33373, Revision 4 (Ref. 19), the abnormal condition was based on a heat load of 17.3 megawatts (MW). The applicant subsequently determined that an alternative abnormal condition heat load of 19.0 MW was bounding. Instead of performing a new CFD analysis for the 19.0 MW heat load condition, the applicant uses the results from the 17.3 MW CFD analysis in NEDO-33373, Revision 4 (Ref. 19) (which is retained in NEDO-33373, Revision 5, Section 5), a previous CFD analysis of a 29 MW heat load condition (in Appendix H), and application of their results to a 19.0 MW heat load condition (in Appendix G).

NEDO-33373, Appendix G, Section 1.0 describes the bases for the 17.3 MW, 19.0 MW and 29.0 MW heat load. NEDO-33373, Appendix G, Section 2.0 describes the key parameters considered in the evaluation of the 19.0 MW heat load condition. NEDO-33373, Appendix G, Section 3.0 identifies the differences between the 17.3 MW and 29.0 MW CFD analyses and corresponding adjustments made to the 19.0 MW analysis.

The maximum pool inlet temperature from the fuel and auxiliary pools cooling system (FAPCS), for both normal and abnormal conditions, is computed from the first law of thermodynamics for a steady-state, steady-flow process and is described in NEDO-33373, Section 5.2. During normal conditions, the bulk fuel pool temperature will be maintained below 48.9 degrees C (120 degrees F). During abnormal conditions, the bulk fuel pool temperature will be maintained below 60 degrees C (140 degrees F). The applicant imposed a local coolant temperature limit of 121 degrees C (250 degrees F) to maintain favorable material stress properties used in rack fabrication. NEDO-33373 Sections 5.3 and 5.5 and Appendix H describe the results of the CFD analyses. NEDO-33373 Section 5.5 and Appendix G conclude that adequate margin exists to the local coolant temperature limit for the normal condition (7.626 MW) and the abnormal condition (19.0 MW), respectively. NEDO-33373, Section 5.3.6, also describes the determination of the maximum coolant temperature with an 80 percent blockage of the rack channel outlets.

3.3 Staff Evaluation

The staff verified that the design of the ESBWR spent fuel pool racks complies with the requirements of GDC 61 regarding the decay heat removal of spent fuel in the storage racks. The guidelines in SRP Section 9.1.2, Revision 4, specify that the applicant's thermal-hydraulic analysis of the flow through the spent fuel racks should show that there is adequate decay heat removal from the spent fuel assemblies during all anticipated operating and accident conditions. Furthermore, the analysis should show adequate natural circulation of the coolant during all anticipated operating conditions, including full-core offloads during refueling, to prevent nucleate boiling for all fuel assemblies.

The staff notes that the design basis for spent fuel pool cooling during accident conditions allows for the spent fuel pool water to boil. Spent fuel pool cooling during accident conditions is addressed in the Design Certification Document and is outside the scope of NEDO-33373.

SRP Section 9.1.2 does not prescribe specific areas of review for the thermal-hydraulic analyses. The staff carried out its review consistent with standard engineering calculation practice. The method selected and the assumptions and inputs used in the applicant's analyses were independently evaluated.

The analyses provided by the applicant in NEDO-33373 reference design specifications and drawings that are the bases for the CFD model geometry and boundary conditions input.

The staff conducted an audit at the applicant's Washington, DC, office on February 11–12, 2009 (Ref. 32), to review these documents. The staff finds that the CFD model appropriately represents the spent fuel pool and storage rack geometry, as well as FAPCS flow rates and temperatures. The staff also reviewed supporting design calculations for decay heat load and rack pressure drop as a function of flow rate. The staff finds that the calculations used conservative assumptions and standard engineering practice. The 29.0 MW condition was added to NEDO 33373, Revision 5, Appendix H after the staff conducted its audit. As discussed below, the applicant has made adjustments to the results of the 29.0 MW heat load condition (in NEDO-33373, Appendix G, Section 3.0) to account for FAPCS flow temperatures and loss coefficient assumptions that could not be confirmed.

The staff also reviewed the CFD program documentation during the audit to assess the theoretical development, the inherent assumptions, the solution method, and the qualification of the code predictions by comparison to experimental benchmarks and hand-calculated solutions. The staff finds that the CFD program is consistent with other industry-standard finite element fluid dynamics computer programs in theoretical development, assumptions, and solution technique and is therefore acceptable. The CFD code is appropriate for application to spent fuel pool flow and temperature calculations.

Acceptance Criteria

NEDO-33373, Revision 5, Section 5.1, defines the purpose of the thermal-hydraulic analyses as to determine the maximum peak temperatures at the exit of the fuel racks. Section 5.1 defines the acceptance criteria in the form of maximum bulk pool temperatures under normal (48.9 degrees C, 120 degrees F) and abnormal conditions (60 degrees C, 140 degrees F) as well as the maximum local coolant temperature (121 degrees C, 250 degrees F). The staff finds that these acceptance criteria are acceptable because they are consistent with RG 1.13, Regulatory Position C.9, which states that the spent fuel storage facility should include a system for cooling the pool water in order to maintain a bulk temperature below 60 degrees C (140 degrees F) for all heat load conditions. In NEDC-33373P, Revision 2 (Ref. 33), the applicant changed the maximum pool bulk temperatures from acceptance criteria to input assumptions. The staff finds the applicant's approach acceptable since it still ensures that the bulk temperature of the pool remains below 60 degrees C (140 degrees F) for the conditions analyzed in the thermal-hydraulic analyses consistent with RG 1.13, Regulatory Position C.9.

Section 5.1 of NEDO-33373 includes an acceptance criterion that the design of the racks shall allow adequate natural circulation to prevent nucleate boiling within the fuel assemblies. Section 5.1 also includes an acceptance criterion of 121 degrees C (250 degrees F) for the local coolant temperature exiting the spent fuel storage racks. As discussed in Section 2 of this SER, 121 degrees C (250 degrees F) is used for material properties in the dynamic load and load-drop analyses and therefore is acceptable for these purposes.

The staff evaluated whether the temperature limit of 121 degrees C (250 degrees F) could be used as a criterion for nucleate boiling, because nucleate boiling may occur at temperatures below this value. A higher temperature is nonconservative as a criterion to avoid nucleate boiling.

Using NEDO-33373, Figure 5-1, the staff estimated the depth of the pool as 12.5 meters. Assuming that the top of the heated fuel is 3.5 meters from the bottom of the pool, the depth of the highest part of a fuel rod is 9 meters. For water that is 60 degrees C (140 degrees F), the density is 983 kilograms per cubic meter (kg/m^3) (from the ASME Steam Tables, Ref. 34) and the pressure at the 9-meter depth is 1 atmosphere + (density) x (acceleration due to gravity) x (depth) (P = 101,325 pascals (Pa) + 983 kg/m^3 * 9.8 meters per second squared (m/s^2) * 9 meters = 188,026 Pa) or 1.86 atmospheres. The saturation temperature at this pressure (interpolated from the ASME Steam Tables, Ref. 34) is 117.8 degrees C (244 degrees F). This indicates that boiling could occur for temperatures below the 121 degrees C (250 degrees F) criterion set by the applicant.

Another consideration relates to the bulk fluid flow at the top of the rack and fluid temperatures along the fuel rods. The CFD methods used by the applicant do not compute a thermal boundary layer on a fuel rod because of their simplified modeling assumptions. Only a bulk fluid temperature is computed. If the bulk fluid temperature at the top of the rack is determined to be 121 degrees C (250 degrees F), the temperature of the flow adjacent to a fuel rod will be slightly higher. The local temperature near the fuel rod, not the bulk temperature, governs nucleate boiling. However, the staff finds the use of the bulk fluid temperature acceptable based on the applicant's approaches for determining the maximum cladding temperature and nucleate boiling. In NEDO-33373, Section 5.3.5, Appendix G, and Appendix H, the applicant uses the bulk fluid temperature and not a boundary layer temperature to determine the maximum cladding temperature. The staff finds the maximum cladding temperature determination acceptable below. In NEDO-33373, Section 5.5 and Appendix G, the applicant considers the maximum cladding temperature in the determination of nucleate boiling so the boundary layer temperature does not need to be considered. Based on the above, the staff finds the use of the bulk temperature acceptable.

In RAI 9.1-120 (Ref. 35), the staff asked the applicant to clarify the basis for the temperature limit of 121 degrees C (250 degrees F) in NEDC-33373P, Revision 1, for the maximum coolant temperature allowable exiting the top of the racks. The staff also asked the applicant to explain (1) what criterion it established to prevent boiling within the bundles, (2) what assumptions it used to determine this value, and (3) how the local conditions at the fuel rod are determined from the bulk flow predictions. In its response dated June 30, 2009 (Ref. 36), the applicant stated that the purpose of the limit of 121 degrees C (250 degrees F) is to maintain consistency with the dynamic analyses within NEDO-33373, not to prevent boiling. For nucleate boiling, the applicant added an acceptance criterion in NEDC-33373P, Revision 2, consistent with RG 1.13, Regulatory Position C.11, Revision 2, to demonstrate that the design of the racks allows adequate natural circulation to prevent nucleate boiling for all fuel assemblies. The applicant further stated that the results show that there is substantial margin to boiling. The staff concludes that the RAI response is acceptable because the temperature limit of 121 degrees C (250 degrees F) is used consistently for the structural and thermal-hydraulic analyses in NEDO-33373. The staff also finds the nucleate boiling criterion acceptable because it is consistent with RG 1.13. The staff confirmed that the changes were incorporated into NEDC-33373P, Revision 2. Accordingly, on the basis of the applicant's response and NEDO-33373 revisions, RAI 9.1-120 is resolved.

On the basis of the discussion above, the staff finds the acceptance criteria for the thermal-hydraulics analysis to be acceptable.

<u>Maximum Pool Inlet Temperature Determination</u>

Section 5.2 of NEDO-33373 describes the calculation of the maximum pool inlet temperature condition, which is computed from the First Law of Thermodynamics for a steady-state, steady-flow process. The staff finds this approach acceptable because it is based on basic thermodynamics. The staff also finds the use of a maximum pool inlet temperature acceptable because it maximizes the outlet temperature calculated by the CFD model. For the normal conditions, the heat load is based on 10 years of spent fuel and is identified as 7.626 MW. The staff finds this value acceptable because it is consistent with the design basis of the FAPCS for the cooling of the 10 years of spent fuel accumulation. For abnormal conditions, NEDC-33373P, Section 5.2, Revision 1, specified the heat load as 29.0 MW. This is higher than the heat removal capability of the FAPCS at design conditions (19.2 MW) discussed in the applicant's response to RAI 9.1-10 S02 (Ref. 37). In addition, the applicant reported that the maximum heat load for the pool with 20 years of fuel and one full-core offload is 18 MW. These numbers are inconsistent.

If the maximum inlet temperature for the abnormal case is computed using 18 MW instead of 29 MW, the maximum inlet temperature will be 45.7 degrees C (an increase of almost 9 degrees C). This increase in the pool temperature would increase the rack inlet temperatures for each rack in the pool.

In RAI 9.1-121 (Ref. 35), the staff asked the applicant to clarify the heat load during abnormal conditions. In its response dated July 1, 2009 (Ref. 38), the applicant stated that it would revise the heat load to be consistent with the design basis of the FAPCS for the cooling of the 10 years of spent fuel plus one full-core offload. The heat load is determined to be 17.3 MW. The staff concludes that the RAI response is acceptable because the revised heat load is consistent with the design basis of the FAPCS. The staff confirmed that the changes were incorporated into NEDC-33373P, Revision 2. On the basis of the applicant's response and NEDO-33373 revision, RAI 9.1-121 is resolved.

The applicant subsequently determined that an alternative abnormal condition heat load of 19.0 MW was bounding in NEDO-33373 Revision 5. With the addition of higher abnormal heat load of 19.0 MW and a bounding heat load condition of 29.0 MW in NEDO Revision 5, the staff is further addressing the concern in RAI 9.1-121. In NEDO-33373, Appendix G, Section 1.0, the applicant describes the basis for the 17.3 MW, 19.0 MW, and 29.0 MW heat load conditions. In addition, NEDO-33373, Appendix H identifies that FAPCS is designed for heat load of 20.1 MW. The FAPCS and the spent fuel racks have different design basis heat loads since FAPCS is designed for twenty years of spent fuel with a full-core offloaded at the end of a fuel cycle with 5 days of decay while the spent fuel racks are analyzed for ten years of spent fuel with a full-core offloaded at the end of a fuel cycle with 5 days of decay.

As discussed in Section 3.2 of this report, the applicant is using the results of the CFD analyses for 17.3 MW and 29.0 MW heat load conditions to bound the fuel rack conditions for a 19.0 MW heat load condition instead of performing a new CFD analysis for the 19.0 MW heat load condition. Since the 29.0 MW heat load condition exceeds the design basis heat load of the FAPCS (20.1 MW heat load condition), the results of the CFD analysis for the 29.0 MW heat load condition cannot be directly compared against the fuel rack acceptance criteria. Accordingly, NEDO-33373, Appendix H treats the 29.0 MW condition as a bounding case and does not compare the results of its CFD analysis against the fuel rack acceptance criteria. As discussed below, the applicant has identified in NEDO-33373, Appendix G, Section 3.0 adjustments made to the results 29.0 MW heat load condition regarding the Maximum Pool Inlet Temperature Determination and the CFD Model Loss Coefficient so that the 29.0 MW heat load condition can serve as a bounding case for the 19.0 MW heat load condition and the adjusted results can be compared against the fuel rack acceptance criteria. Because the applicant has identified (1) the basis for the 17.3 MW, 19.0 MW, and 29.0 MW heat load conditions, (2) the relation of the 17.3 MW, 19.0 MW, and 29.0 MW heat load conditions to the 20.1 MW FAPCS design basis heat load condition, and (3) how the 29.0 MW heat load condition serves as a bounding heat load condition through the use of adjusted results, RAI 9.1-121 remains resolved.

In RAI 9.1-122 (Ref. 35), the staff asked the applicant to justify that the SFP inlet temperatures are consistent with the design of the FAPCS. The staff asked this question because the pool inlet temperatures calculated in NEDO-33373 were marginally higher (2.0 degrees C) than the maximum FAPCS heat exchanger shell inlet temperatures specified in DCD Tier 2, Table 9.1-8. In its response dated July 1, 2009 (Ref. 38), the applicant stated that the FAPCS is operated as necessary to remove the heat load in the spent fuel pool. The applicant's response did not directly address the staff concern. However, using the realistic heat loads discussed in its response to RAI 9.1-121, the applicant in NEDC-33373P, Revision 2, calculated higher allowable SFP inlet pool temperatures. These higher SFP inlet temperatures result in a temperature difference between the pool inlet temperatures and the maximum FAPCS heat exchanger shell inlet temperatures of at least 11.0 degrees C, which addresses the staff concern. On the basis of the applicant's changes in NEDC-33373P, Revision 2, RAI 9.1-122 is resolved.

With the addition of higher abnormal heat load of 19.0 MW and a bounding heat load condition of 29.0 MW in NEDO-33373, Revision 5, the staff is further addressing the concern in RAI 9.1-122. In its October 4, 2010 submittal (Ref. 39), the applicant revised DCD Tier 2, Table 9.1-8, to add the thermal-hydraulic analysis input assumptions and SFP inlet temperatures to ensure that the design of the FAPCS heat exchangers can support the cooling assumed in NEDO-33373, Revision 5. This includes adding performance data for a 20.1 MW heat load condition with two trains of FAPCS running and adding a maximum allowable heat exchanger outlet temperature. The applicant also added a note to DCD Tier 2, Table 9.1-8 to clarify that the maximum allowable tubeside outlet temperature, or SFP inlet temperature, is the value that the fuel rack thermal hydraulic analysis is based upon. These changes address the concern that FAPCS is designed to support the SFP inlet pool temperatures calculated in NEDO-33373, Revision 5.

NEDO-33373, Appendix G, Section 2.1 states that the maximum SFP inlet temperature is calculated for the 19.0 MW using the same methodology as described in NEDO-33373, Section 5.2.2.2. As discussed above, the staff finds this calculation methodology acceptable. For the 29.0 MW case, the applicant used the same methodology to calculate the maximum inlet pool temperature. However, the 29.0 MW condition is outside the performance data for the FAPCS heat exchangers added to DCD Tier 2, Table 9.1-8 in the October 4, 2010 submittal (Ref. 39). The calculated maximum SFP inlet temperature for the 19.0 MW heat load condition is 45.0 degrees C while the calculated maximum SFP inlet temperature for the 29.0 MW heat load condition is 37.0 degrees C. An increase in the SFP inlet temperature for 29.0 MW heat load condition would result in an increase in the SFP bulk temperature and the peak rack exit temperature, which is an acceptance criteria value.

To address the concern of whether the FAPCS can maintain the SFP inlet temperature and bulk temperature at the values assumed in NEDO-33373, Appendix H, the applicant in NEDO-33373, Appendix G, Section 3.0 adjusted the calculated peak rack exit temperature of the 29.0 MW heat load condition by the difference in the calculated maximum SFP inlet temperatures, or 8 degrees C (45.0 degrees C - 37.0 degrees C). In NEDO-33373, Appendix H, the applicant calculated a peak rack exit temperature of 80.9 degrees C for the 29.0 MW heat load condition. Considering only the adjustment for the maximum inlet pool temperature, this would increase the peak rack exit temperature from 80.9 degrees C to 88.9 degrees C. NEDO-33373 Section 5.2.5 documents the results of sensitivity studies performed by the applicant, which indicate that the peak rack exit temperature changes by 0.4 - 0.6 degrees C for each degree C inlet pool temperature change. This sensitivity is reasonable since some of the bulk water in the pool is expected to mix with the water coming into the pool at the entrance to the fuel racks, thus moderating the effect of the inlet pool temperature. Since the applicant conservatively increased the peak rack exit temperature by a full degree for each degree C change in the inlet pool temperature, the staff finds the adjustment for the lower SFP inlet temperature used in the CFD analysis 29.0 MW heat load condition acceptable. On the basis of the above, RAI 9.1-122 remains resolved.

On the basis of the discussion above, the staff finds the maximum pool inlet temperature determination for the thermal-hydraulics analysis to be acceptable.

Computational Fluid Dynamics Model Calculation of the Temperatures and Velocities within the Spent Fuel Pool

NEDO-33373 Section 5.2 and Appendix H describe generally the CFD methods used in the thermal-hydraulic analyses. The CFD-based methods are a common technique for estimating quantities such as the maximum fuel pool coolant temperatures. The results can give assurance when the margin is significant, because CFD methods are generally used to predict ranges of variables rather than precise results. On the basis of the margin discussed in the results below, the staff finds the use of CFD methods acceptable.

NEDO-33373 Section 5.2 and Appendix H describe the model used to perform the thermal-hydraulic analyses. The same model was used for both the 17.3 MW and 29.0 MW heat load conditions with the exception of the limited variances described in NEDO-33373, Appendix G. The ANSYS CFX CFD program (Ref. 40) is used to calculate temperatures and velocities in the fuel pool and rack regions. ANSYS CFX is a high-performance, general purpose CFD program that has been applied to solve wide-ranging fluid flow problems in many industrial applications for over 20 years. To model the ESBWR storage racks and spent fuel pool, a porous medium approach using no physical rack structures is employed to represent the rack regions. This approach simply defines a region that has a loss coefficient applied to slow down or direct the flow. The fluid volume and flow area of this region is unaffected (i.e., region is wide open), and the wide-open region does not affect the velocity of the fluid as a physical rack structure would. For a given rack mass flow, the velocity in the wide-open region is lower than what would be expected in a rack. In addition, fluid residence time in this region is affected. The heat from the fuel is treated as a uniform source term over this region. This method gives only the bulk temperatures. Details such as local temperatures along a fuel rod are not computed. In the staff discussion of the acceptance criteria above, the staff accepted the use of the bulk temperature approach based upon how the maximum cladding temperature and nucleate boiling are determined. In addition, in the staff discussion of the maximum cladding temperature determination, the staff confirmed that the maximum cladding temperature is below the boiling temperature of water at the level of the racks even if a reduced overall heat transfer coefficient is assumed, which also supports the applicant's use of a bulk temperature.

The staff determined that it needed additional information about the CFD model and geometry as described in NEDC-33373P, Revision 1. In RAI 9.1-124 (Ref. 35), the staff asked the applicant to provide the dimensions of the fuel pool model components, information related to loss coefficients, and the locations of the FAPCS inlets and outlets. In its response dated July 31, 2009 (Ref. 41), the applicant provided information on how the pool and rack geometry, and the pool inlets and outlets are modeled. The response also clarified rack assumptions and loss coefficients. The staff concludes that the applicant's response is acceptable because it clarifies the rack assumptions and loss coefficients and how the CFD model as described in the NEDO-33373, Revision 4 is consistent with the ESBWR spent fuel pool design. On the basis of the applicant's response and NEDO-33373 revisions, RAI 9.1-124 is resolved.

On the basis of the discussion above, the staff finds the CFD model calculation of the temperatures and velocities within the spent fuel pool for the thermal-hydraulics analysis to be acceptable.

CFD Model Loss Coefficient

NEDO-33373, Section 5.2 and Appendix H describe the empirical basis for the loss coefficients in the CFD model and their representation in NEDO-33373, Figure 5.2 (repeated in Figure H5-

2). In RAI 9.1-126 (Ref. 34), the staff asked the applicant to clarify NEDC-33373P, Revision 1, Figure 5.2, which is the plot of loss coefficient in the racks and presents the pressure drop as a function of mass flow. In its response dated July 31, 2009 (Ref. 41), the applicant explained that these data are calculated and that the mass flow refers to a single bundle. The applicant also explained that the pressure drop was bounding, because it was based on fuel for existing reactors rather than the shorter ESBWR fuel. The staff concludes that the response is acceptable because the response clarified the information in NEDO-33373, Figure 5.2, and how it is used in the cooling analysis. Therefore, the staff finds the loss coefficient of the CFD model to be acceptable. On the basis of the applicant's response and NEDO-33373 revisions, RAI 9.1-126 is resolved.

With the addition of higher abnormal heat load of 19.0 MW and a bounding heat load condition of 29.0 MW in NEDO Revision 5, the staff is further addressing the concern in RAI 9.1-126. In NEDO-33373 Revision 5, Appendix G, Section 3.0, the applicant states that different loss coefficients were used for the 17.3 MW and 29.0 MW heat load conditions. Appendix G states that the loss coefficient for the 29.0 MW heat load condition was calculated using area and length characteristics for fuel other than the GE14E fuel modeled in NEDO-33373. Appendix G identifies that the loss coefficient is non-conservative and notes that the loss coefficient for the 17.3 MW heat load condition is based on the fuel characteristics of GE14E fuel. NEDO-33373, Section 5.2.5 describes an analysis of this loss coefficient sensitivity and determined that a 20 percent increase in loss coefficient equates to no more than a 6 percent increase in rack exit temperature. NEDO-33373, Appendix G, Section 3.0 identifies that the loss coefficient used for the 29.0 MW heat load condition should be increased 42 percent (to be consistent with the loss coefficient used for the 17.3 MW heat load condition), which represents a total rack exit temperature increase of 12.6 percent, or 10.2 degrees C. The staff finds this adjustment acceptable since the applicant applied the bounding sensitivity results to determine the rack exit temperature correction. On the basis of the above, RAI 9.1-122 remains resolved.

On the basis of the discussion above, the staff finds the loss coefficient of the CFD model for the thermal-hydraulics analysis to be acceptable.

Key Computational Fluid Dynamics Model Assumptions

NEDO-33373 Section 5.2 and Appendix H give tables of the key assumptions about the model characteristics and boundary conditions used in the CFD models for the 17.3 MW and 29.0 MW heat load conditions. For example, it states that the k-epsilon model is used to model turbulence. The treatment of density and buoyancy are addressed by the use of a constant density with a Boussinesq-type (density gradient) approximation for the buoyancy term. The staff determined that additional information was needed about the basis for the modeling assumptions described in NEDC-33373P, Revision 1.

In RAI 9.1-125 (Ref. 35), the staff asked the applicant to describe what sensitivity studies it performed to support its CFD modeling assumptions. In its response dated July 31, 2009 (Ref. 41), the applicant described a series of related sensitivity studies of the CFD model. NEDC-33373P, Revision 2, included a comparable description of sensitivity studies. The specific mesh density studies cited are for an unspecified model of a boiling-water reactor spent fuel pool and are only considered to be qualitative. The staff concludes that the response is acceptable because the margin in the peak temperature predictions bounds the range of CFD model variability shown in the sensitivity studies. The staff also finds that the sensitivity studies support the use of the applicant's selected model characteristics and boundary conditions. On the basis of the applicant's response and NEDO-33373 revisions, RAI 9.1-125 is resolved.

NEDO-33373, Appendix G, Section 3.0 describes the differences between the CFD models for the 17.3 MW and 29.0 MW heat load conditions. As discussed and evaluated above, different loss coefficients are used for the two heat load conditions. Another difference is the orientation of the SFP inlets, which are described in NEDO-33373, Section 5.2.3 and Appendix H. For the 17.3 MW heat load condition, the inlet locations are modeled at the bottom of each corner of the west wall with a 20º offset towards the middle. For the 29 MW case, the inlet locations are modeled at the bottom of each corner of the west wall with no offset. NEDO-33373, Section 5.2.3 and Appendix H state that the actual inlet locations will be inboard from the corners, equally spaced between the pool walls. The applicant determined that the modelling differences have negligible impact on analysis results; therefore, neither model was modified to reflect actual inlet locations and no adjustments to the results are needed in order to compare these cases with the 19.0 MW heat load condition. The staff finds the applicant's approach acceptable since both models have the SFP inlets at the limits of the SFP and bound the distance to the hottest fuel.

On the basis of the discussion above, the staff finds the key CFD model assumptions for the thermal-hydraulics analysis to be acceptable.

Maximum Cladding Temperature Calculation

NEDO-33373, Section 5.3, Appendix G, and Appendix H describe the maximum cladding temperature calculation, which is computed using an analytical model for the water and cladding temperature. The staff determined that the key assumptions in this model are the heat transfer coefficient and the thermal resistance of the crud layer.

To confirm the validity of the results from this approach, the staff performed a confirmatory calculation based on the applicant's data in NEDC-33373P, Revision 1. This calculation used a peak heat flux and a peak temperature, along with Newton's law of cooling and the GEH-provided heat transfer coefficients. The maximum bulk temperature in the rack computed by the CFD code is 80.9 degrees C (177.6 degrees F). Heat flux is determined from the values provided in the table on page 1,021 of the report. An average heat flux at the fuel surface is found to be 2,263 watts per square meter (W/m^2) (717.367 British Thermal Units per hour per square foot ($BTU/hr\text{-}ft^2$)). A peak heat flux is estimated by assuming a simple cosine distribution. A peak value, estimated to be a factor of 1.57 higher than the average, is determined to be 3,555 W/m^2 (1126.93 $BTU/hr\text{-}ft^2$). Assuming an overall heat transfer coefficient (U) of 270 watts per square meter-degree Kelvin ($W/m^2\text{-}K$) (47.582 British Thermal Units per hour per square foot per degree F ($BTU/hr\text{-}ft^2\text{-}F$)) ($1/U = 1/283.9 + 1/5673$), the peak cladding temperature is estimated to be 94 degrees C (201 degrees F). This is close to the value of 97 degrees C (207 degrees F) estimated by GEH.

These results depend on the values of the heat transfer coefficient and the fuel rod heat flux. It is assumed that fuel rod heat flux can be established. Heat transfer coefficients, on the other hand, typically have a high uncertainty. If the overall heat transfer coefficient were half of the value used above ($U = 135\ W/m^2\text{-}K$), the peak cladding temperature would be estimated to be 107.3 degrees C (225.1 degrees F).

In RAI 9.1-127 (Ref. 34), the staff asked the applicant to clarify the basis for the peak cladding temperature prediction in NEDC-33373P, Revision 1. In its response dated July 31, 2009 (Ref. 41), the applicant cited references validating the selection of the heat transfer coefficient and performed sensitivity studies on the heat transfer coefficient to demonstrate that the value could be reduced by 75 percent and still maintain temperatures below the limit. The applicant also discussed the flow rates, experimental data, and the crud layer resistance and their impact on the peak cladding temperature prediction. The staff concludes that the response is acceptable because the applicant cited standard references for its data and the staff was able to confirm the crud layer resistance sensitivity reported by the applicant. On the basis of the applicant's response, RAI 9.1-127 is resolved.

As described in NEDO-33373 Section 5.3.5, Appendix G and Appendix H, two values in the maximum cladding temperature calculation depend on the CFD analysis, the water temperature at rod inlet and rack flow rate. Since the applicant has not performed a CFD analysis for the 19.0 MW heat load condition, the applicant has used limiting values from the 17.3 MW heat load condition (rack flow rate) and the 29.0 MW heat condition (water temperature at rod inlet), otherwise using the same methodology to calculate the maximum cladding temperature.

As discussed with the maximum pool inlet temperature determination, the 29.0 MW heat load condition is outside the performance data for the FAPCS heat exchangers added to DCD Tier 2, Table 9.1-8 in the October 4, 2010 submittal (Ref. 39). Therefore, the applicant in NEDO-33373, Appendix G, Section 3.0 adjusted the peak rack exit temperature to account for the lower SFP inlet temperature used in the CFD analysis 29.0 MW heat load condition, as described above. In its October 15, 2010 submittal (Ref. 42), the applicant proposed a modification to be included in the accepted version of NEDO-33373, Appendix G, Section 2.3, to justify not making a corresponding adjustment to the maximum rod inlet water temperature calculated for the 29.0 MW heat load condition in NEDO-33373, Appendix H. This justification is based on the heated water exiting the racks having little if any influence on the rod inlet water temperature and maintaining the SFP bulk water temperature below 60 degrees C for the 19.0 MW heat load condition. The applicant states that the heated water exiting the racks has little if any influence on the pool water entering the racks because the heated water from the racks is more buoyant and rises to the SFP surface and the outlets. In addition, the cooler SFP inlet water enters at the SFP bottom, and being the least buoyant, enters the rack inlet plenum with limited mixing with the warmer bulk water, which is maintained below 60 C for 19.0 MW heat load condition. The applicant states that these arguments are supported by the results of the CFD analyses presented in NEDO-33373 Figures 5-6, 5-12, 5-12a, H5-6 and H5-12, which show the temperatures of the water in the SFP and the paths the water travels as it passes through the racks. The applicant concludes that these observations provide assurance that the calculated rod inlet temperature for the 29.0 MW heat load condition is bounding and the actual rod inlet temperature for the 19.0 MW heat load condition is expected to fall below the value of 60.39 degrees C that is used to calculate the bounding peak cladding temperature.

The staff confirmed that NEDO-33373 shows that the rack inlet temperature for the hottest fuel for both the 17.3 MW heat load condition and the 29.0 MW heat load condition are both near the SFP bulk water temperature of 60 degrees C used in these analyses. In addition, the figures identified by the applicant show little interaction between the water exiting the racks and the water entering the racks. Therefore, the staff finds the calculation of the maximum cladding temperature for 19.0 MW heat load condition using the rack inlet temperature calculated for the 29.0 MW heat load condition in NEDO-33373, Appendix H acceptable. The staff also finds proposed modification in the October 15, 2010 submittal (Ref. 42) acceptable for inclusion in the accepted version of NEDO-33373.

On the basis of the discussion above, the staff finds the maximum cladding temperature calculation to be acceptable.

Maximum Fluid Temperature Calculation with 80-Percent Blockage of Rack Outlets

Section 5.3 of NEDO-33373 describes the maximum fluid temperature calculation with 80-percent blockage of rack outlets. However, NEDC-33373P, Revision 1 is not clear about what the 80-percent blockage represents. In RAI 9.1-119 (Ref. 35), the staff asked the applicant to clarify what 80-percent blockage means and how it is represented in the CFD model. The staff noted that this type of analysis is needed only if the spent fuel pool liner is not seismic Category I. In its response dated June 30, 2009 (Ref. 43), the applicant clarified that the spent fuel pool liner is seismic Category I and made corresponding changes to the DCD. The applicant also stated that the 80-percent blockage is modeled by reducing the flow area through the channel of each fuel assembly. All channels would therefore be partially blocked. The staff concludes that the response is acceptable because the designation of the spent fuel pool liner as seismic Category I makes the analysis optional and because the applicant clarified the modeling assumption. On the basis of the applicant's response and DCD and NEDO-33373 revisions, RAI 9.1-119 is resolved.

NEDO-33373, Appendix G does not contain a calculation of the maximum fluid temperature calculation with 80-percent blockage of rack outlets for the 19.0 MW heat load condition. As noted above, this calculation is not needed since the SFP liner is seismic category 1.

On the basis of the discussion above, the staff finds the maximum fluid temperature calculation with 80-percent blockage of rack outlets to be acceptable.

Results

The staff compared the results of the calculations documented in NEDO-33373, Section 5.5 and appendix G, against the acceptance criteria. The maximum local coolant temperature at the rack exit for normal conditions is 65 degrees C (149 degrees F). The maximum rack exit temperature for abnormal conditions (19.0 MW heat load condition discussed in Appendix G) is 99.1 degrees C (163.4 degrees F). The maximum peak cladding temperature is 101.0 degrees C (192.6 degrees F). The maximum local coolant temperature at the rack exit for the reactor building buffer pool is 67 degrees C (153 degrees F). These results indicate that there is substantial margin to boiling at the exit of the racks (boiling temperature was previously calculated to be 117.8 degrees C (244 degrees F) at the depth of the top of the racks) and meets the applicant's materials property criteria of 121 degrees C (250 degrees F). The staff notes that the maximum rack exit temperature includes data adjustments from the 29.0 MW heat load condition and that if an actual CFD analysis were performed, lower results would be expected. The staff further notes that if the maximum peak cladding temperature were adjusted upward by 8.0 degrees C to account for the lower inlet pool temperature used in the 29.0MW heat load condition CFD analysis, the cladding would still remain below the boiling point for water at the depth of the top of the racks. Therefore, the staff finds that the results show that acceptance criteria for temperature are met.

The staff assessed the CFD results for demonstration of natural circulation through the storage racks. In NEDO-33373, Figures 5-9, 5-12, and 5-12a show streamlines from inlets to outlets under normal and abnormal conditions, respectively. The figures show that the pools are well mixed and provide evidence of flow through the racks. This supports the conclusion that there is natural circulation through the racks; therefore, the staff finds that the natural circulation criterion is met.

On the basis of the discussion above, the staff finds that the thermal-hydraulic analysis of the flow through the spent fuel storage racks is appropriate to demonstrate adequate decay heat removal from the spent fuel assemblies during all anticipated operating conditions. Furthermore, the analysis shows that adequate natural circulation of the coolant is provided during all anticipated operating conditions, including full core-offloads during refueling, to prevent nucleate boiling for all fuel assemblies. Therefore, the staff finds that the thermal-hydraulic analyses demonstrate that the spent fuel storage racks meet the requirements of GDC 61 and the guidelines of RG 1.13 for the decay heat removal of spent fuel in the storage racks.

3.4 Conclusions

On the basis of the discussions above, the staff finds that the thermal-hydraulic analyses demonstrate that the spent fuel storage racks meet the requirements of GDC 61 and the guidelines of RG 1.13 for the decay heat removal of spent fuel in the storage racks. Therefore, the staff finds that the thermal-hydraulic design of the ESBWR fuel storage racks is acceptable.

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