BORON DILUTION ANALYSIS AUDIT REPORT

NRC Audit Team:

- Andrew Bielen, NRO, Reactor Systems Engineer
- Jeffrey Schmidt, NRO, Sr. Reactor Systems Engineer (Audit Lead)
- Michael Takacs, NRO, Project Manager

1.0 SUMMARY

On December 14, 2010, the U.S. Nuclear Regulatory Commission (NRC) conducted an audit at the Mitsubishi Nuclear Energy Systems (MNES) offices located in Arlington, Virginia. The audit` pertained to the analysis methodology and results presented in the United States - Advanced Pressurized Water Reactor (US-APWR) Design Control Document (DCD) Section 15.4.6, "Inadvertent Decrease in the Boron Concentration of the Reactor Coolant System," (Reference 1) (referred to within this report as "Boron Dilution") and related Request for Additional Information (RAI) responses (Reference 2). Prior to conducting the audit, the NRC provided Mitsubishi Heavy Industries, Ltd. (MHI) with a list of five areas of discussion (Reference 3), in order to ensure clear direction to the conversation and to plainly and specifically highlight the remaining topic areas for which the NRC staff had concern. Upon arrival at the audit location, MHI provided the NRC staff with a handout of draft, proprietary responses to each of the areas of discussion. The audit primarily consisted of systematic discussion of each of these areas, supplemented by internal NRC discussions regarding the potential acceptability of each response. In addition, the NRC staff reviewed MHI-internal calculation documentation that supported one particular RAI response (RAI 15.4.6-5) contained within Reference 2. As a result of this review and subsequent discussion, MHI agreed to provide a revised response to RAI 15.4.6-5 that better captured the actual methodology utilized in analyzing Boron Dilution Events.

As a result of this audit, the NRC staff decided to provide three additional formal RAIs, very similar in nature to three of the five subject areas provided in Reference 3. Of the remaining two areas, the NRC staff decided to remove one from the discussion completely, due to the fact that MHI provided clear reference to its basis in existing documentation. The other area required more of a NRC internal discussion, and no commitments were made regarding the path forward.

2.0 BASIS

The Boron Dilution event is classified as an Anticipated Operational Occurance, and as such, is analyzed within Chapter 15, Section 15.4.6, of the US-APWR Final Safety Analysis Report. The event must be analyzed for all modes of operation as defined by the Technical Specifications (TS) to ensure that sufficient warning is available to the operators to mitigate the event before the reactor core either violates the Specified Acceptable Fuel Design Limits (SAFDLs) (while the reactor is at power or startup, Modes 1 and 2) or becomes critical (for higher modes of operation, Modes 3, 4, 5, and 6).

In the process of reviewing the RAI responses contained within Reference 2, the NRC staff came to the conclusion that MHI had not provided sufficient information to make a reasonable assurance conclusion on the acceptability of the analysis methods or results. This was

particularly true of the analysis results presented in Modes 3, 4, and 5, where the margin to the acceptance criteria stipulated by the Standard Review Plan (SRP), Section 15.4.6 (Reference 4), was the least.

The NRC staff decided to conduct an audit in order to maximize the efficiency of the review and ensure that the NRC's staff concerns were properly understood by the relevant MHI engineers and management. In order to define the specific areas where information was lacking, the NRC staff provided MHI with a list of five areas of concern, as documented in Reference 3 and summarized below:

1. Sufficient justification for the lack of analysis of the Boron Dilution event in Modes 4 and 5 with no Reactor Coolant Pumps (RCPs) running was not provided in either the DCD or RAI responses.

2. The use of two equations (Equations 7 and 8) presented within the response to RAI 15.4.6-5 was not adequately justified in the RAI response.

3. The NRC staff was not clear on the basis for the initial and critical boron concentrations used in the dilution analysis. Since the precise value of these quantities would vary for specific core designs, the NRC staff was unclear on how MHI could ensure that the analysis presented in Section 15.4.6 would bound all future core designs.

4. The NRC staff requested that MHI quantify the conservatism and uncertainty in each of the parameters input into the boron dilution analysis for Modes 3, 4 and 5 and provide a summary of how each parameter affected the calculated time to criticality.

5. The NRC staff requested that MHI verify that the dilution flow rate used in the boron dilution analysis bounded all possible flow rates for the higher modes of operation.

This list of questions was provided to MHI via e-mail on December 9, 2010, in preparation for the audit, conducted December 14, 2010.

3.0 OBSERVATIONS AND RESULTS

Upon arrival at the audit site, the MHI staff provided the NRC audit team with MHI's responses to each of the above five items of interest. The audit consisted primarily of discussion of both the questions and the responses, with time taken as necessary for the NRC staff to convene privately to discuss the provided responses and clarifications. A summary of the discussion points is provided below:

1. In response to Item 1, MHI explained that, while for certain conditions, they found it necessary to credit administrative controls in order to meet the acceptance criteria in the Design Certification stage, they would rather not impose conditions involving plant-specific procedures upon an eventual Combined License (COL) applicant without the involvement of said applicant. The NRC staff's position on this particular issue is as follows: a US-APWR plant will not be granted a COL

without proper disposition of the Boron Dilution event analysis in Modes 4 and 5 with no RCPs running. The NRC and MHI agreed that an RAI to this effect would be transmitted to MHI with the request that a COL action item be included to ensure that this plant condition received the required attention.

2. In response to Item 2, MHI took the position that while the equations utilized in the boron dilution event analysis in Modes 3, 4 and 5 may not be completely technically justifiable, there are sufficient additional alarms beyond the High Source Range Neutron Flux alarm to provide protection against inadvertent criticality. These alarms include alarms that come in upon event initiation (reactor makeup water flow rate deviation, boric acid flow rate deviation, and high primary makeup water flow rate), as well as additional protection from the Volume Control Tank overfill alarm, which is calculated to come in roughly 20 minutes from the event initiation. The basis for using the High Source Range Neutron Flux alarm is that it would be the last alarm to come in prior to criticality, and is thus the most conservative to credit for the licensing basis. MHI stated that they were prepared to seek credit for these additional alarms rather than refine the analytical model used for the High Source Range Neutron Flux alarm. They provided reference to Safety Evaluation Reports (SERs) in which current operating plants were permitted to credit these additional alarms to mitigate the Boron Dilution event. The NRC staff agreed to review the referenced SERs and to take a position after having sufficient time to consider the best path forward.

3. In response to Item 3, MHI explained that the initial boron concentration is selected in order to ensure that both the TS-required mode-specific shutdown margin is met, and that there is at least 15 minutes available between the High Source Range Neutron Flux Alarm and the loss of shutdown margin (i.e., criticality). This fact explains why the apparent margin to the SRP, Section 15.4.6 acceptance criteria appears to be so low, in fact, MHI determines the difference between initial and critical boron concentrations such that the 15-minute acceptance criteria is met. MHI referenced sections in the reload evaluation methodology that ensure that the analysis presented in Section 15.4.6 of the DCD bounds all future cores (or requires re-evaluation). Within the discussion of this item, MHI referenced internal calculation documentation which was reviewed by the NRC staff and discussed with the MHI engineers. During this discussion, it became clear that one major reason that the NRC staff had difficulty understanding MHI's methods was that the content of the response to RAI 15.4.6-5 (which requested specific details on the Boron Dilution event analysis methodology) was not clearly consistent with the methods actually employed by MHI to analyze this event. As a result of this discussion, the NRC staff decided to formally request Item 3 as an RAI, and the NRC staff requested that MHI amend the response to RAI 15.4.6-5 to more accurately explain the methodology they employ.

4. In response to Item 4, MHI provided a table that provided, for each operating Mode 3 through 5, for each input parameter, the best-estimate value of each parameter, the uncertainty in that value, and the impact on time-to-criticality between using a best-estimate input and the conservative input utilized for the DCD analysis. This table clearly demonstrates the impact that each parameter

has on the calculated results. The NRC staff decided to formalize Item 4 into a RAI, and informed MHI that the question would be supplemented by a request that MHI provide an explicit basis for all uncertainties considered in the analysis, as well as a request to quantify the total conservatism in the DCD approach.

5. In response to Item 5, MHI indicated that the makeup water flowrate utilized in the analysis is conservatively high for all modes of operation, to account for the nominal maximum flowrate plus uncertainty. If the flowrate does exceed the maximum allowable value, redundant interlocks isolate the primary makeup water flowpath. They provided reference to three different sections within the DCD and an internal document listing standard US-APWR design input data for safety analysis. Due to the numerous references provided by MHI, the NRC staff was satisfied that the information had already been provided and decided to not formally request a RAI.

To summarize, the NRC staff decided to pursue three additional RAIs (related to Items 1, 3 and 4) which will be routed through the normal approval and transmittal process. Item 2 requires additional evaluation by the NRC staff in order to determine the appropriate path forward. The information required for Item 5 has already been provided in other US-APWR DCD sections and additional information from MHI is not necessary. MHI will revise the response to an existing RAI (15.4.6-5) to better explain the methodology employed for the Boron Dilution event analysis.

4.0 CONCLUSION

The NRC staff audited MHI at the MNES offices on December 14, 2010, to facilitate the review of Section 15.4.6 of the US-APWR DCD. Prior to the audit, NRC provided five specific areas of concern to MHI, as summarized in Section 2.0 of this report. At the audit, the NRC staff reviewed MHI's responses to these items, as well as related MHI-internal documents. As a result of the audit, the following action items were agreed upon:

- MHI would revise the response to RAI 15.4.6-5 (Reference 2) to provide a more complete and accurate description of their analysis methodology.

- NRC would formalize three of the five items of interest into RAIs to be provided to MHI.

- NRC would consider the response to one of the remaining items of interest and then decide what path forward they would find acceptable.

With the completion of the above action items, and the acceptable response of the three new RAIs, NRC will move closer to closing out remaining issues with US-APWR DCD Section 15.4.6.

5.0 REFERENCES

1. US-APWR DCD Chapter 15, Transient and Accident Analyses, MUAP-DC015, Revision 2, dated October 2009.

2. MHI's Response to US-APWR DCD RAI No. 311-2347 Revision 1, UAP-HF-09303, dated June 2009.

3. NUREG-0800, Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition, Section 15.4.6, Revision 3, "Inadvertent Decrease in the Boron Concentration of the Reactor Coolant System," dated March 2007.