MITSUBISHI HEAVY INDUSTRIES, LTD.

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TOKYO, JAPAN

June 16, 2009

Document Control Desk
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

Attention: Mr. Jeffrey A. Ciocco

Docket No. 52-021
MHI Ref: UAP-HF-09303

Subject: MHI's Response to US-APWR DCD RAI No. 311-2347 Revision 1

Mitsubishi Heavy Industries, Ltd. ("MHI") transmits to the U.S. Nuclear Regulatory Commission ("NRC") the document entitled "MHI's Response to US-APWR DCD RAI No. 311-2347 Revision 1". The material in Enclosure 1 provides MHI's response to the NRC's "Request for Additional Information (RAI) 311-2347 Revision 1," dated April 2, 2009.

Please contact Dr. C. Keith Paulson, Senior Technical Manager, Mitsubishi Nuclear Energy Systems, Inc., if the NRC has questions concerning any aspect of this submittal. His contact information is provided below.

Sincerely,

Y. Ogata

Yoshiki Ogata
General Manager- APWR Promoting Department
Mitsubishi Heavy Industries, Ltd.

Enclosures:

1. MHI's Response to US-APWR DCD RAI No. 311-2347 Revision 1 (non-proprietary)

CC: J. A. Ciocco
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Contact Information

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ENCLOSURE 1

UAP-HF-09303
Docket No. 52-021

MHI's Response to US-APWR DCD RAI No. 311-2347 Revision 1

June 2009

(Non-Proprietary)

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

6/16/2009

US-APWR Design Certification

Mitsubishi Heavy Industries

Docket No. 52-021

RAI NO.:	**NO. 311-2347 REVISION 1**
SRP SECTION:	**15.04.06 – INADVERTENT DECREASE IN BORON CONCENTRATION IN THE REACTOR COOLANT (PWR)**
APPLICATION SECTION:	**15.4.6**
DATE OF RAI ISSUE:	**4/02/2009**

QUESTION NO.: 15.4.6-1

State whether the calculations for boron dilution events are done at the beginning or end-of-cycle. Explain why the other condition does not need to be considered.

ANSWER:

The calculations for boron dilution events are done at the beginning-of-cycle only. For end-of-cycle conditions, the RCS boron concentration is already low and, given the same dilution flow rate, it will take a much longer time to dilute the core boron concentration by an amount that will produce a reactivity effect similar to that at beginning-of-cycle. This increases the available time for operator action and makes the end-of-cycle case much less limiting than the beginning-of-cycle case.

Impact on DCD

There is no impact on the DCD.

Impact on COLA

There is no impact on the COLA.

Impact on PRA

There is no impact on the PRA.

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QUESTION NO.: 15.4.6-2

Provide additional information explaining why the probability of dilution during refueling is so sufficiently low that it does not need to be analyzed.

ANSWER:

US-APWR DCD Subsection 15.4.6.3.3.1 describes that for Mode 6, inadvertent boron dilution is prevented by the administrative controls in place to isolate the primary makeup water supply line (makeup isolation valves are secured in the closed position). By isolating the line with the valves locked closed, the unborated makeup water can not reach the reactor coolant system and therefore no boron dilution can occur. The US-APWR Technical Specification LCO 3.9.2 requires this administrative control for this Mode. MHI believes that the probability of an operator violating an administrative control associated with the Technical Specification is so low that it does not need to be analyzed.

Impact on DCD

There is no impact on the DCD.

Impact on COLA

There is no impact on the COLA.

Impact on PRA

There is no impact on the PRA.

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QUESTION NO.: 15.4.6-3

It is stated that the boron dilution event from power conditions is bounded by the analysis for the uncontrolled RCCA bank withdrawal at power. Provide detailed information on the rate of reactivity insertion for both events and explain how the rate of insertion is calculated for the boron dilution event.

ANSWER:

The reactivity insertion rate due to inadvertent dilution is calculated as follows. First, the boron dilution rate is calculated from the boron concentration equilibrium equation described in the response to Question 15.4.6-5 of this RAI. The boron dilution rate equation is:

$$\frac{dC}{dt} = \frac{W}{V}\frac{\rho_{in}}{\rho}(C_{in} - C)$$

For this calculation, the following conditions are assumed:

RCS boron concentration – C = 2150 ppm
Dilution boron concentration – C_{in} = 0 ppm
Dilution pure water flow rate – W = 265 gpm
Effective RCS volume – V = 12370 ft^3
Dilution pure water density – ρ_{in} = 999.9 kg/m^3
RCS density – ρ = 707.7 kg/m^3

Next, this boron dilution rate is multiplied by the boron reactivity coefficient to calculate the reactivity insertion rate. Although DCD Table 4.3-2 (sheet 2) gives a range of -9.3 to -8.0 pcm/ppm for the boron reactivity coefficient of the initial core, it is conservatively assumed to be -11.0 pcm/ppm for this calculation. The resultant reactivity insertion rate is approximately 1.6 pcm/sec.

As described in DCD Subsection 15.4.2, a range of reactivity insertion rates up to a maximum of

75 pcm/sec is analyzed for the uncontrolled RCCA bank withdrawal at power. Therefore, the assumed range of reactivity insertion rates for the uncontrolled RCCA bank withdrawal at power covers the reactivity insertion rate due to inadvertent boron dilution. As a result, the core parameters are bounded by the uncontrolled RCCA bank withdrawal at power. Therefore, for inadvertent boron dilution events initiated at power, the minimum DNBR remains above the 95/95 limit.

Impact on DCD

There is no impact on the DCD.

Impact on COLA

There is no impact on the COLA.

Impact on PRA

There is no impact on the PRA.

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QUESTION NO.: 15.4.6-4

Provide analysis of boron dilution events in Modes 4 and 5 with no RCPs running and Mode 6. Also, specifically state in detail the administrative controls in place that make boron dilution events in Mode 6 and Modes 4 and 5 with no RCPs running impossible.

ANSWER:

For administrative controls in place during Mode 6, refer to the response to Question 15.4.6-2 of this RAI.

For Modes 4 and 5 with no RCPs running, inadvertent boron dilution is prevented by administrative controls included in the procedures controlling planned dilution and makeup.

Planned makeup and dilution is carried out by setting a predetermined boron concentration using both a pure water flow rate setpoint and borated water flow rate setpoint corresponding to the predetermined boron concentration. When the predetermined amount of flow has been added, the makeup water valve is automatically closed, so that boron dilution beyond the predetermined limit will not occur. When carrying out a boron dilution, the operator performs two operations: (1) changing from the automatic makeup mode to the dilution mode and (2) operating the start switch. Dilution and makeup cannot start unless both of these steps are performed. The requirement for two distinct actions reduces the likelihood of inadvertent dilution caused by operator action.

Additionally, the reactor makeup control system has alarms to call the operator's attention to the following conditions:

- Deviation of reactor makeup flow rate from setpoint
- Deviation of boric acid flow rate from setpoint

The details of the reactor makeup control system are described in DCD Section 9.3.4.5.

Finally, the operator is procedurally required to monitor the following continuously available RCS makeup and dilution status signals during these modes with no RCPs running.

- Reactor makeup flow rate (boric acid flow plus primary makeup flow) indication
- Boric acid flow rate indication
- Charging flow rate indication
- Volume control tank level indication
- Source range neutron flux monitor
- Audible count rate meter
- High source range neutron flux at shutdown alarm

Based on these administrative controls, MHI does not postulate the occurrence of a boron dilution event in Modes 4 and 5 without the RCPs operating. Therefore, these cases are not analyzed.

Impact on DCD

There is no impact on the DCD.

Impact on COLA

There is no impact on the COLA.

Impact on PRA

There is no impact on the PRA.

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QUESTION NO.: 15.4.6-5

Provide details regarding the calculations done to determine the time available for operator action during the course of the event. Specifically, provide the boron and water mass equilibrium equations utilized.

ANSWER:

The boron and water mass equilibrium equations utilized are as follows:

a. Boron mass equilibrium equation

$$\frac{d\rho CV}{dt} = \rho_{in} W C_{in} - \rho W C \qquad \text{Eq. (1)}$$

b. Water mass equilibrium equation

$$\frac{d\rho V}{dt} = \rho_{in} W - \rho W \qquad \text{Eq. (2)}$$

where:

ρ = Density
V = RCS volume
W = Flow rate
C= Boron concentration
and the subscript "in" indicates the dilution parameters

From Equations (1) and (2), the following equation for the boron concentration equilibrium can be determined:

$$\frac{dC}{dt} = \frac{W}{V}\frac{\rho_{in}}{\rho}(C_{in} - C) \quad \text{Eq. (3)}$$

If the dilution boron concentration, C_{in}, is assumed to be zero ppm and the initial RCS boron concentration is C_0, this differential equation can be solved such that the RCS boron concentration as a function of time will be:

$$C = C_0 \exp\left(-\frac{W}{V}\frac{\rho_{in}}{\rho}t\right) \quad \text{Eq. (4)}$$

Therefore, the time interval from the initial RCS boron concentration, C_0, to a given concentration, C, is:

$$t = \frac{\rho V}{\rho_{in} W} \ln\left(\frac{C_0}{C}\right) \quad \text{Eq. (5)}$$

For the at power and start-up cases, the initial critical boron concentration, C_0, is based on the control rods being inserted to the insertion limits. The critical boron concentration, C_c, is based on the critical condition at HZP. Therefore, the available times shown in DCD Table 15.4.6-1 for the at power and start-up cases is calculated based on Equation (5) as follows:

$$t = \frac{\rho V}{\rho_{in} W} \ln\left(\frac{C_0}{C_c}\right) \quad \text{Eq. (6)}$$

For the hot standby and shutdown cases, the initial boron concentration is the mode specific concentration that will result in the Technical Specification required shutdown margin with all RCCAs fully inserted except for the most reactive single RCCA, which is assumed to be fully withdrawn. The critical boron concentration is based on the assumption that the reactor is critical with all RCCAs fully inserted except for the most reactive single RCCA, which is assumed to be fully withdrawn. The time from event initiation to criticality is given by Equation (6). However, the available times shown in DCD Table 15.4.6-1 for the hot standby and shutdown cases are from the time of the high source range neutron flux alarm to criticality.

The boron concentration at the high source range neutron flux alarm, C_a, can be calculated as follows. The analytical limit for the high source range neutron flux alarm is assumed to be 0.8 decades above background.

$$\frac{N_a}{N_0} = \frac{k_{eff}^0 - 1}{k_{eff}^a - 1} = 10^{0.8} \quad \text{Eq. (7)}$$

where:

N = Neutron flux level

k_{eff} = Effective multiplication factor

the subscript "0" indicates the initial parameters

and the subscript "a" indicates the parameters at the high source range neutron flux alarm

The boron concentration, C, can be given as follows:

$$C = A \cdot k_{eff} + B \quad \text{Eq. (8)}$$

The values of A and B are not necessary since they will be substituted for as shown in the following steps. At criticality, since k_{eff} is 1.0, then Equation (8) becomes:

$$C_c = A + B \qquad \text{Eq. (9)}$$

By combining Equations (7) through (9), the boron concentration at the high source range neutron flux alarm is given as follows:

$$C_a = C_c + \frac{C_0 - C_c}{10^{0.8}} \qquad \text{Eq. (10)}$$

From Equation (10), the available time from the high source range neutron flux alarm to the criticality shown in DCD Table 15.4.6-1 for the hot standby and shutdown cases is given as follows:

$$t = \frac{\rho V}{\rho_{in} W} ln\left(\frac{C_a}{C_c}\right) = \frac{\rho V}{\rho_{in} W} ln\left(1 + \frac{C_0/C_C - 1}{10^{0.8}}\right) \qquad \text{Eq. (11)}$$

Impact on DCD

There was a typographical mistake in the last bulleted item of Subsection 15.4.6.3.2 describing the analytical limit for the high source range neutron flux alarm that will be revised as follows:

- The analytical limit for the high source range neutron flux alarm (shutdown cases) is assumed to be 0.8 ~~times~~ decades above background.

Impact on COLA

There is no impact on the COLA.

Impact on PRA

There is no impact on the PRA.