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January 14, 2011

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-11006

Subject: MHI's Revised Response to US-APWR DCD RAI No. 311-2347 Revision 1 (SRP 15.04.06)

References: 1) "REQUEST FOR ADDITIONAL INFORMATION (RAI) 311-2347 Revision 1", dated April 2, 2009.
2) "MHI's Response to US-APWR DCD RAI No. 311-2347 Revision 1", MHI letter UAP-HF-09303, June 16, 2009.

Mitsubishi Heavy Industries, Ltd. ("MHI") transmits to the U.S. Nuclear Regulatory Commission ("NRC") the document entitled "MHI's Revised Response to US-APWR DCD RAI No. 311-2347 Revision 1 (SRP 15.04.06)".

The original response (Reference 2) to the NRC's US-APWR DCD RAI (Reference 1) was discussed during the US-APWR Boron Dilution Audit on December 14, 2010. The NRC requested that MHI revise the response to Question 15.4.6-5 of Reference 2 during the Audit. The enclosed material provides MHI's revised response to Question 15.4.6-5 to the NRC's RAI (Reference 1).

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 Revised Response to US-APWR DCD RAI No. 311-2347 Revision 1 (SRP 15.04.06) (non-proprietary)

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NRO

CC: J. A. Ciocco
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ENCLOSURE 1

UAP-HF-11006
Docket No. 52-021

MHI's Revised Response to US-APWR DCD RAI No. 311-2347
Revision 1 (SRP 15.04.06)

January 2011

(Non-Proprietary)

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

01/14/2011

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.: 15.4.6-5

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 Inadvertent Boron Dilution event is evaluated to determine the time available for the operator to detect the reactivity addition and take appropriate corrective actions. The MHI methodology is different for the various TS Modes of operation. In Modes 1 and 2, a fixed initial boron concentration is used to calculate the available time for operator action. On the other hand, in Modes 3, 4, and 5, the initial boron concentration is calculated from an assumed operator action time. The operator action time is an analysis input, based on the values in the SRP acceptance criteria. The operator action time corresponds to the time between a prompting alarm (the high source range neutron flux alarm) and the return to criticality. Then the end result of the calculation is the required initial boron concentration for that mode. In this methodology, the times reported for these modes are intentionally very close to the SRP acceptance criteria. The conservatism of the calculation is ensured by using the high source range neutron flux alarm as the prompting alarm, since this alarm occurs much later in the event than several other available prompting alarms.

These two calculation methodologies will be described in detail in the respective sections below. However, the same general boron and water mass equilibrium equations are utilized for these calculations.

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 equilibrium boron concentration can be determined:

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

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:

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

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

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

The critical boron concentration, C_c, is the boron concentration at which the core will be critical and shutdown margin (SDM) will be lost. Therefore, the total time available from event initiation to the critical boron concentration, t_{total}, is calculated based on Equation (5) as follows:

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

Modes 1 and 2

For these cases, the initial boron concentration, C_0, is based on the control rods being inserted to the insertion limits and the critical boron concentration, C_c, is based on the critical condition at HZP. For the at power case in automatic rod control, the rods will automatically insert as the boron concentration decreases. Eventually, the rods will reach their insertion limit. In this case, t_{total} is defined as the time between the rod insertion limit alarm and the return to criticality. For the at power in manual rod control and start-up case, t_{total} is defined as the time between the event initiation and the return to criticality. In this case, the time from the beginning of the event to the reactor trip is a small fraction of the time from the initiation of the transient to the return to criticality. This assures that the period of time available for operator actions (defined as the duration between the reactor trip and criticality) is in excess of the minimum required time of 15 minutes. Therefore, Equation (6) is used to calculate the times in DCD Table 15.4.6-1 for the at power and start-up cases.

Modes 3, 4, and 5

Figure 15.4.6-5.1 provides an illustration of the overall calculation methodology in these modes that will be useful for the following discussion.

As described previously, the methodology in these modes is to calculate the initial boron concentration based on an assumed operator action time. This operator action time is defined as the time between a prompting alarm and the loss of SDM. The US-APWR design includes the following alarms that are expected to annunciate and alert the operator to the occurrence of a dilution event in Modes 3, 4, or 5.

- Reactor makeup water flow rate deviation alarm
- Boric acid flow rate deviation alarm
- High primary makeup water flow rate alarm
- High volume control tank level alarm
- High volume control tank pressure alarm
- High source range neutron flux at shutdown alarm

As shown in Figure 15.4.6-5.1, several of the prompting alarms occur immediately at the time of event initiation. Although these alarms are available as prompting alarms, the Chapter 15 analyses conservatively assume the high source range neutron flux at shutdown alarm as the prompting alarm.

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.

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

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:

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

The values of A and B are not necessary since they will be substituted for as shown in the following steps. At criticality, k_{eff} is 1.0 and the boron concentration is C_c, so 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, C_a, is given as follows:

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

From Equations (5) and (10), the available time from the high source range neutron flux alarm to the return to criticality, t_{SR}, is given as follows:

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

The MHI methodology is to calculate the differential boron concentration, ΔC, required for each mode based on an assumed time. As indicated in Figure 15.4.6-5.1, ΔC is the difference between the initial boron concentration, C_0, and the critical boron concentration, C_c. [The SDM will be calculated based on this ΔC and is what will be specified in the COLR.] Since the critical boron concentration is known, the quantity of interest is the initial boron concentration, C_0. Equation (11) can be rearranged to solve for C_0 in terms of t_{SR} as shown in Equation (12) below.

$$C_0 = C_c \cdot \left\{ 10^{0.8} \cdot \left[\exp\left({t_{SR} \rho_{in} W}/{\rho V} \right) - 1 \right] + 1 \right\} \qquad \text{Eq. (12)}$$

In order to more clearly demonstrate, a sample calculation for Mode 5 is provided as follows. The following data are analysis assumptions:

C_c	=	1950 ppm
V	=	12370 ft^3
W	=	265 gpm
ρ_{in}	=	999.9 kg/m^3
ρ	=	963.0 kg/m^3
t_{SR}	=	16 min (15 min required by SRP plus additional margin)

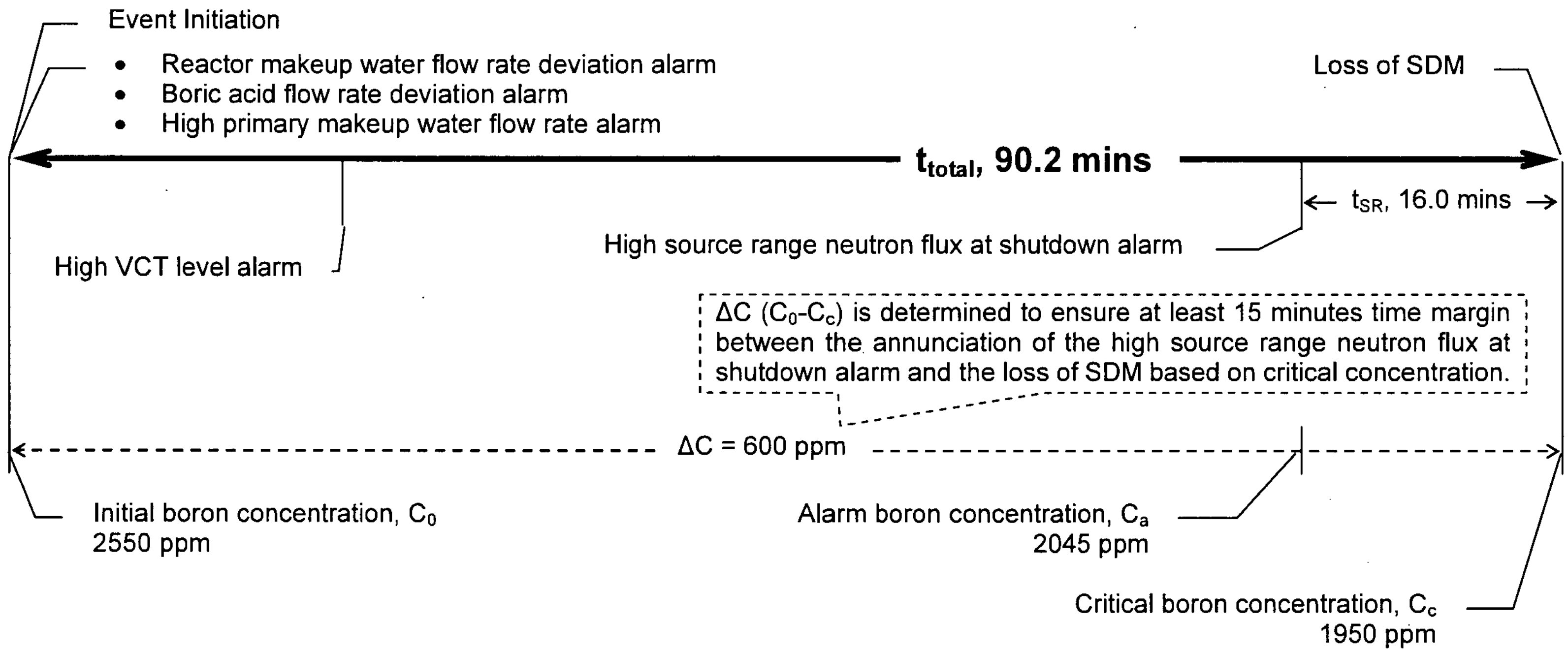
These input values are used to calculate C_0 using Equation (12) and C_a using Equation (10) as:

$$C_0 = 1950\ ppm \cdot \left\{ 10^{0.8} \cdot \left[\exp\left(\frac{16\,\text{min} \cdot 999.9 kg/m^3 \cdot 265 gal/\text{min}}{963 kg/m^3 \cdot 12370 ft^3 \cdot 7.48 gal/ft^3} \right) - 1 \right] + 1 \right\} = 2550\ ppm$$

$$C_a = 1950\ ppm + (2550\ ppm - 1950\ ppm)/10^{0.8} = 2045\ ppm$$

These values are also shown in Figure 15.4.6.-5.1. This calculation shows that an initial boron concentration of 2550 ppm (a differential boron concentration of 600 ppm) is required in Mode 5 to ensure adequate SDM.

The previous calculation was for Mode 5; similar calculations are performed for Modes 3 and 4. The results for these modes are provided in DCD Table 15.4.6-1. [Note that the required initial boron concentrations in DCD Table 15.4.6-1 are conservatively rounded up after calculation. The times in DCD Table 15.4.6-1 are then recalculated to correspond to these rounded values.]



The following indications are available throughout the event

- Reactor makeup flow rate indication
- Primary makeup flow rate indication
- Boric acid flow rate indication
- Charging flow rate indication
- Volume control tank level indication
- Source range neutron flux monitor
- Audible count rate meter

Note: The values are based on Mode 5 of DCD

Figure 15.4.6-5.1 Illustration of Boron Dilution Event

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.