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TOKYO, JAPAN

May 18, 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-11139

Subject: 3rd MHI's Response to US-APWR DCD RAI No. 719-5352 Revision 0 (SRP 15.06.05)

Mitsubishi Heavy Industries, Ltd. ("MHI") transmits to the U.S. Nuclear Regulatory Commission ("NRC") the document entitled "3rd MHI's Response to US-APWR DCD RAI No. 719-5352 Revision 0". The enclosed materials provide MHI's response to Question 15.06.05-87 and Question 15.06.05-89 of the NRC's "Request for Additional Information (RAI) 719-5352 Revision 0," dated March 17, 2011.

As indicated in the enclosed materials, this document contains information that MHI considers proprietary, and therefore should be withheld from public disclosure pursuant to 10 C.F.R. § 2.390 (a)(4) as trade secrets and commercial or financial information which is privileged or confidential. A non-proprietary version of the document is also being submitted in this package (Enclosure 3). In the non-proprietary version, the proprietary information, bracketed in the proprietary version, is replaced by the designation "**[ ]**".

This letter includes a copy of the proprietary version of the RAI response (Enclosure 2), a copy of the non-proprietary version of the RAI response (Enclosure 3), and the Affidavit of Yoshiki Ogata (Enclosure 1) which identifies the reasons MHI respectfully requests that all material designated as "Proprietary" in Enclosure 2 be withheld from disclosure pursuant to 10 C.F.R. § 2.390 (a)(4).

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.

D081
NRO

Enclosures:

1. Affidavit of Yoshiki Ogata
2. 3rd MHI's Response to US-APWR DCD RAI No. 719-5352 Revision 0 (proprietary)
3. 3rd MHI's Response to US-APWR DCD RAI No. 719-5352 Revision 0 (non-proprietary)

CC: J. A. Ciocco
C. K. Paulson

Contact Information

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ENCLOSURE 1

Docket No. 52-021

MHI Ref: UAP-HF-11139

MITSUBISHI HEAVY INDUSTRIES, LTD.

AFFIDAVIT

I, Yoshiki Ogata, being duly sworn according to law, depose and state as follows:

1. I am General Manager, APWR Promoting Department, of Mitsubishi Heavy Industries, Ltd. ("MHI"), and have been delegated the function of reviewing MHI's US-APWR documentation to determine whether it contains information that should be withheld from disclosure pursuant to 10 C.F.R. § 2.390 (a)(4) as trade secrets and commercial or financial information which is privileged or confidential.

2. In accordance with my responsibilities, I have reviewed the enclosed document entitled "3rd MHI's Response to US-APWR DCD RAI No. 719-5352 Revision 0," and have determined that the document contains proprietary information that should be withheld from public disclosure. Those pages containing proprietary information are identified with the label "Proprietary" on the top of the page and the proprietary information has been bracketed with an open and closed bracket as shown here "[ ]". The first page of the document indicates that all information identified as "Proprietary" should be withheld from public disclosure pursuant to 10 C.F.R. § 2.390 (a)(4).

3. The basis for holding the referenced information confidential is that it describes the unique design of the safety analysis, developed by MHI (the "MHI Information").

4. The MHI Information is not used in the exact form by any of MHI's competitors. This information was developed at significant cost to MHI, since it required the performance of research and development and detailed design for its software and hardware extending over several years. Therefore public disclosure of the materials would adversely affect MHI's competitive position.

5. The referenced information has in the past been, and will continue to be, held in confidence by MHI and is always subject to suitable measures to protect it from unauthorized use or disclosure.

6. The referenced information is not available in public sources and could not be gathered readily from other publicly available information.

7. The referenced information is being furnished to the Nuclear Regulatory Commission ("NRC") in confidence and solely for the purpose of supporting the NRC staff's review of MHI's application for certification of its US-APWR Standard Plant Design.

8. Public disclosure of the referenced information would assist competitors of MHI in their design of new nuclear power plants without the costs or risks associated with the design and testing of new systems and components. Disclosure of the information identified as proprietary would therefore have negative impacts on the competitive position of MHI in the U.S. nuclear plant market.

I declare under penalty of perjury that the foregoing affidavit and the matters stated therein are true and correct to the best of my knowledge, information, and belief.

Executed on this 18th day of May, 2011.

Y. Ogata

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

ENCLOSURE 3

UAP-HF-11139
Docket No. 52-021

3rd MHI's Response to US-APWR DCD RAI No. 719-5352 Revision 0

May 2011

(Non-Proprietary)

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

5/18/2011

US-APWR Design Certification

Mitsubishi Heavy Industries

Docket No. 52-021

RAI NO.:	**NO. 719-5352 REVISION 0**
SRP SECTION:	**15.06.05 – LOSS OF COOLANT ACCIDENTS RESULTING FROM SPECTRUM OF POSTULATED PIPING BREAKS WITHIN THE REACTOR COOLANT PRESSURE BOUNDARY**
APPLICATION SECTION:	**15.6.5**
DATE OF RAI ISSUE:	**3/17/2011**

QUESTION NO.: 15.6.05-87

If fluid mixing between coolant in the US-APWR lower plenum and in adjacent reactor core regions can take place, assess the effects of possible localized coolant temperature variations in the lower plenum and core inlet areas in the US-APWR boric acid precipitation analysis. Due to the strong dependence of the boric acid solubility limit on the solution temperature, precipitation can first be triggered by such local coolant temperature distributions in areas where colder coolant can reside.

Provide a calculation for the boric acid solubility limit at a solution temperature that conservatively bounds expected coolant temperature variations in the reactor vessel lower plenum during post-LOCA long term cooling. Provide a plot showing the determined precipitation limit as a function of time after the LOCA initiation. Provide relevant data and/or equations used to compute the result as well as those used to compute any other boric acid precipitation limits applied in the US-APWR precipitation analysis. List all assumptions made in calculating the precipitation limits and discuss the impact of each individual assumption on the limiting concentrations obtained. If a parameter that changes in time is represented by a single value, explain how this value was computed and the point in time or time period for which it is representative of. Also, if a volume average quantity is used to represent the conditions in a certain region modeled by a control volume, explain how the spatial distribution effects associated with this parameter have been accounted for in obtaining the volume average value. In considering possible effects related to time and space variations, show that the results applied led to conservative predictions.

ANSWER:

During the post-LOCA long-term cooling phase, the boric acid solution in the core where the concentration and temperature are high mixes with the solution in the lower plenum where the concentration and temperature are lower, due to the destabilization of the vertical density gradient. In this scenario, it is possible that when the more highly concentrated borated water from the core mixes with the cooler water in the lower plenum the resulting mixed borated water may be cooled to below the solubility limit. The boric acid concentration is also decreased by mixing, a more detailed analysis shows that no boric acid precipitation in the lower plenum will occur in practice.

The temperature dependency of boric acid saturation concentration presented in reference-(1) is shown in Figure-1.

The condition in which the mixed water is at the lowest temperature is assumed to occur when the mixing flow begins between the saturated borated water of the core and the cooler less borated water in the lower plenum. Once the mixing flow begins, the temperature of the lower plenum increases, hence the possibility of the precipitation due to low temperature would decrease.

For the ECC water from the downcomer, it is assumed that some heat transfer would occur from the core to the downcomer through the core barrel. The downcomer water would then be heated, and the liquid density would decrease. Consequently, the density of the water in the downcomer would become lower than the water in the lower plenum. The heated downcomer (ECC) water is able to flow into the core without traveling down to the bottom of the lower plenum. This was observed in the BACCHUS tests presented in the reference-(2). For this scenario the following calculation is derived without considering the ECC water from the downcomer.

Based upon the above discussion, the possibility for boric acid precipitation at the time when the mixing flow begins between the core and the lower plenum is presented.
As shown in reference-(3), the mixing flow between the core and the lower plenum begins when the boric acid concentration in the core exceeds 15.69 wt.% even if the lower plenum liquid temperature is assumed to be conservatively low at 39 °F. Therefore, the following initial mixing conditions for the borated water of the two regions are conservatively assumed.

Region	Temperature (°F)	Boric Acid Concentration (wt.%)
Core	212 (saturated)	16.0
Lower Plenum	39	2.402 (maximum initial concentration)

In practice, it is difficult to predict which proportion of the core water and the lower plenum water are mixed; therefore the mixing fraction of lower plenum water to core borated water is defined as 'R_{mix}'.

$$R_{mix} = \frac{M_{mix-LP}}{M_{mix-CORE}}$$

where;

$M_{mix\text{-}LP}$: Lower plenum water mass involved the mixing

$M_{mix\text{-}CORE}$: Core borated water mass involved the mixing

Atmospheric pressure is assumed. The liquid temperature and the boric acid concentration of mixed water can be calculated as follows.

- Boric acid concentration (Cb_{mix})

$$Cb_{mix} = \frac{M_{mix-CORE} \cdot Cb_{CORE} + M_{mix-LP} \cdot Cb_{LP}}{M_{mix-CORE} + M_{mix-LP}} = \frac{Cb_{CORE} + R_{mix} \cdot Cb_{LP}}{1 + R_{mix}}$$

where;

Cb_{CORE}: Boric acid concentration of the core= 16.0 wt.%

Cb_{LP}: Boric acid concentration of the lower plenum = 2.402 wt.%

- Liquid temperature (T_{mix})

  The specific enthalpy of the mixed water (h_{mix}) is calculated by the following equation.

$$h_{mix} = \frac{h_{CORE} + R_{mix} \cdot h_{LP}}{1 + R_{mix}}$$

where;

h_{CORE}: Liquid specific enthalpy of the core = 180.13 (Btu/lbm)

h_{LP}: Liquid specific enthalpy of the lower plenum = 16.45 (Btu/lbm)

The liquid temperature of the mixed water (T_{mix}) can be obtained by referring to the steam table.

Figure-2 shows the variation of the mixed water temperature (T_{mix}) in case the mixing fraction (R_{mix}) is varied from 0.1 to 100. Figure-3 shows the relationship between the mixing fraction (R_{mix}) and the boric acid concentration of the mixed water (Cb_{mix}). The relationship between the mixing fraction (R_{mix}) and the boric acid solubility limit can be obtained from Figure-1 and Figure-2, which is also presented in Figure-3.

As shown in Figure-3, the mixed water boric acid concentration remains below the solubility limit for all values of the mixing fraction (R_{mix}).Therefore, no boric acid precipitation would occur because of the mixing between the core and the lower plenum due to the destabilization of the vertical density gradient. Note that the assumption that the initial water temperature in the lower plenum is at 39 °F is conservative. In practice the lower plenum water would be heated by the stored heat in the reactor vessel metal during the reflood and early post-reflood phase and water temperature would increase accordingly.

Figure-4 shows the relationship between the boric acid concentration of the mixed water and the boric acid solubility limit for the case where the lower plenum temperature is assumed to be at 60 °F. The mixed water temperature will be high if the water temperature in the lower plenum is also high. Consequently the margin between the boric acid concentration of the mixed water and the boric acid solubility limit would be large. In the US-APWR the mixing ratio is about 0.5. In Figures 3 and 4 there is a good margin relative to the solubility limit at a mixing fraction of 0.5 for both lower plenum initial temperatures.

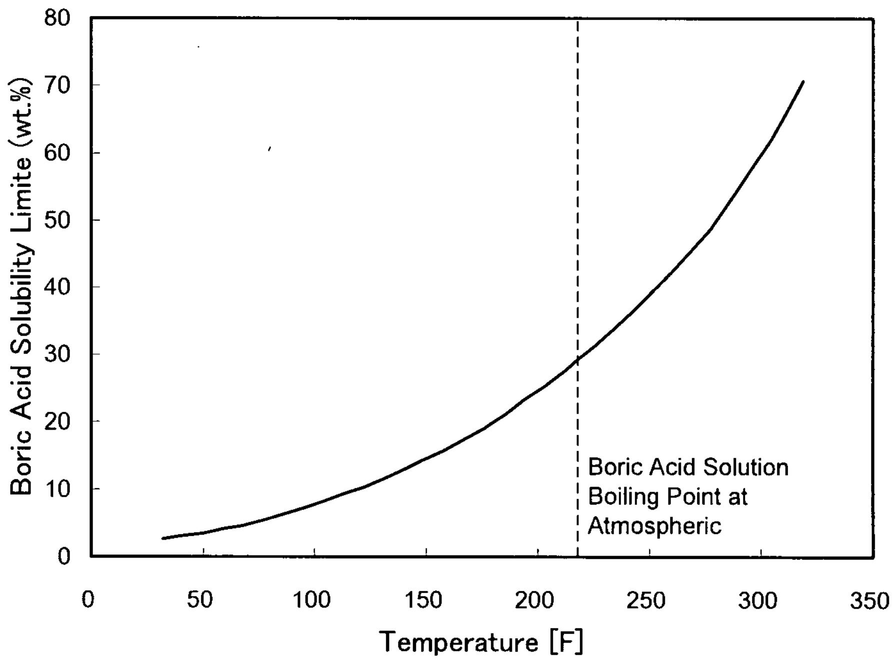

Figure-1 Boric Acid Solubility Limit vs. Solution Temperature

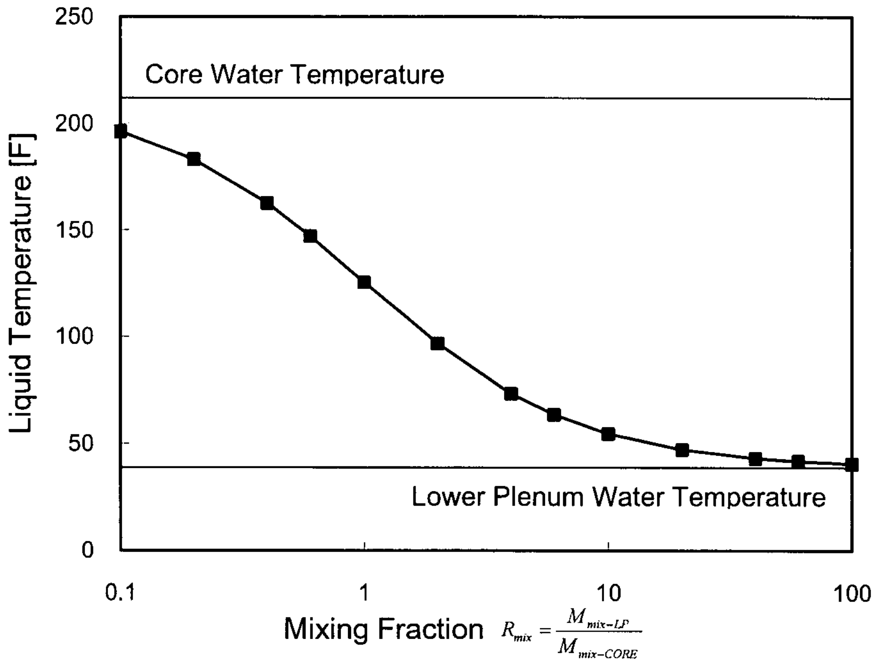

Figure-2 Liquid Temperature vs. Mixing Fraction (R_{mix})
- Lower Plenum Temperature = 39 °F Case

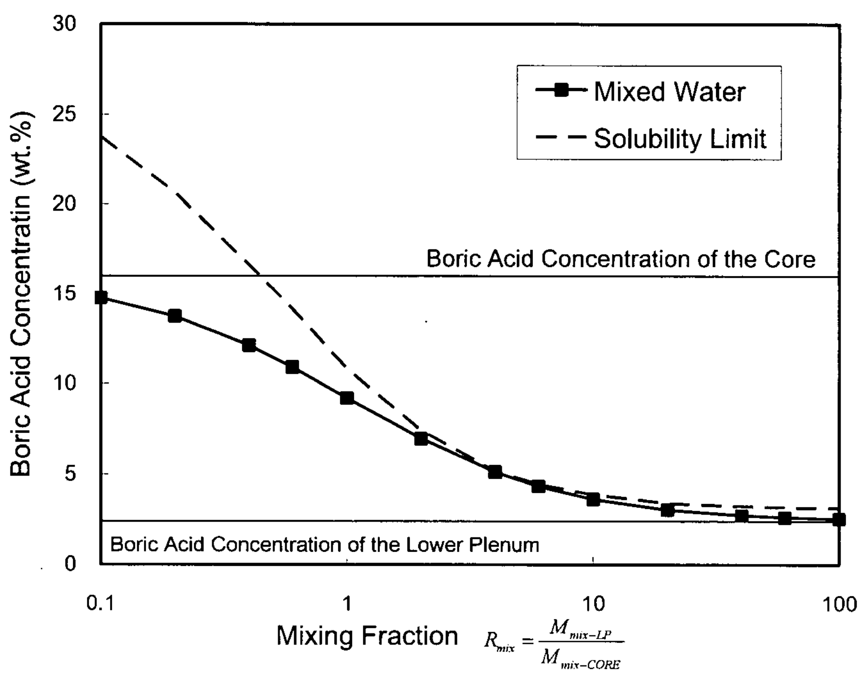

Figure-3 Boric Acid Concentration vs. Mixing Fraction (R_{mix})
- Lower Plenum Temperature = 39 °F Case

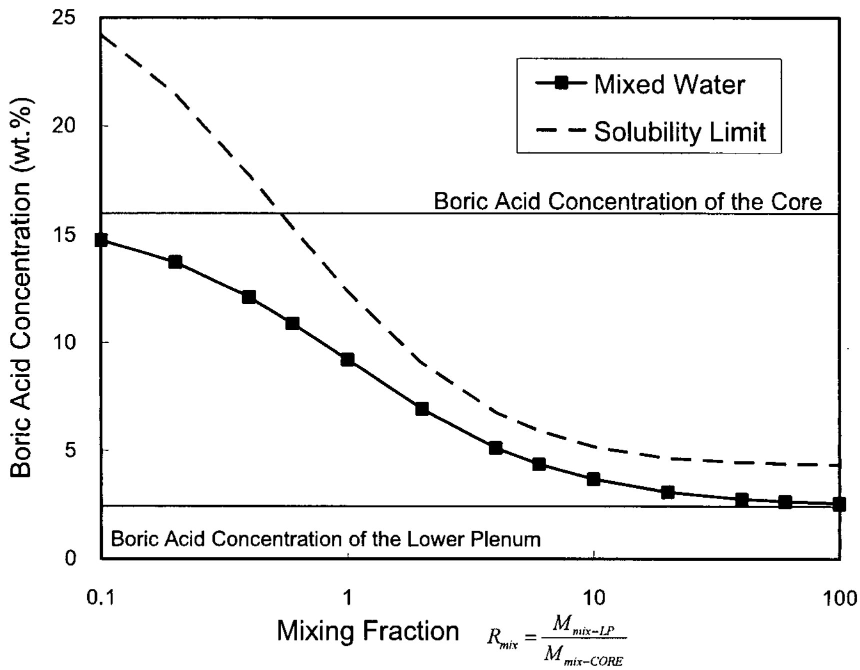

Figure-4 Boric Acid Concentration vs. Mixing Fraction (R_{mix})
- Lower Plenum Temperature = 60 °F Case

References:
1. Cohen, P., 1969, Water Coolant Technology of Power Reactors, Chapter 6, "Chemical Shim Control and pH Effect," ANS-USAEC
2. UAP-HF-11130 "MHI's Response to US-APWR DCD RAI No. 706-5339 Revision 0" (March2011) RAI Question 15.6.5-81.
3. UAP-HF-11130 "MHI's Response to US-APWR DCD RAI No. 706-5339 Revision 0" (March2011) RAI Question 15.6.5-82.

Impact on DCD

There is no impact on the DCD.

Impact on R-COLA

There is no impact on the R-COLA.

Impact on S-COLA

There is no impact on the S-COLA.

Impact on PRA

There is no impact on the PRA.

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

5/18/2011

US-APWR Design Certification

Mitsubishi Heavy Industries

Docket No. 52-021

RAI NO.:	**NO. 719-5352 REVISION 0**
SRP SECTION:	**15.06.05 – LOSS OF COOLANT ACCIDENTS RESULTING FROM SPECTRUM OF POSTULATED PIPING BREAKS WITHIN THE REACTOR COOLANT PRESSURE BOUNDARY**
APPLICATION SECTION:	**15.6.5**
DATE OF RAI ISSUE:	**3/17/2011**

QUESTION NO.: 15.6.05-89

Fibrous debris, in combination with other types of debris, can bypass the US-APWR sump strainer and reach the reactor core region where fuel blockage can take place. Debris can cause fuel blockage near the reactor core inlet region in a direct vessel ECCS injection mode and, in a simultaneous ECCS injection mode, fuel blockage in the top core regions becomes possible. Discuss effects from fuel blockage by debris in the reactor coolant on the US-APWR boric acid precipitation evaluation. If fluid mixing between the reactor lower plenum and adjacent core regions has been credited in the precipitation analysis, demonstrate that fuel blockage at the core inlet will not preclude or adversely impact coolant mixing between the lower plenum and the core. In addition, show that fuel blockage by debris in the top core area will not interfere with downwards coolant penetration into the core region during the core flushing process.

ANSWER:

The possibility of the core inlet blockage due to debris is in discussed in the reference-(1) as follows.

From section 4.4.1 (3) of ref-(1),

Core inlet blockage due to accumulated sump debris may slightly effect the predicted rate of boric acid concentration accumulation in the core, depending on the specific mixing volume assumptions used in a given boric acid precipitation analysis. However, significant core inlet blockage will not be expected since it is quite unlikely that the downstream debris may pile up at the fuel assembly bottom nozzle described in section 4.1.1. Although it is unlikely that bypass debris accumulates exactly in the core inlet region to predict, only entire or severe core inlet blockage would effectively isolate the lower plenum from the core region. Core inlet blockage that would be expected for cold leg large break scenarios evaluated would not impede flow between the lower plenum and the core region since there will not be sufficient core inlet flow rate and the amount of bypass debris that clog the core inlet in such a break case.

As significant core inlet blockage is not expected, the core region liquid inventory would not be significantly affected, and the core region mixing volume used in the US-APWR analyses would remain effective.

The limiting scenario for boric acid precipitation is a cold leg break where the core is stagnant with core inlet flow corresponding to the core boil off. In this scenario, most of injected water through the DVI lines spills from the cold leg break point, and the rest of which makes up for the core boil off goes downward in the downcomer to the core. The liquid flow velocity through the downcomer is estimated to be less than 0.4 inch per second at about one hour after a double end guillotine break occurs.

For this scenario, the debris with density less than that of the borated water spills from the break, bypassing the core without going down through the downcomer. The debris with density larger than that of the borated water precipitates at the bottom of the lower plenum. Only debris with density comparable to the borated water has a possibility to reach the core inlet and cause fuel blockage, but its quantity is estimated to be very small as described above.

In this RAI response, the boric acid mixing flow rate between the core and the lower plenum is calculated. As discussed in reference-(2), there is reason to believe that some heat transmission occurs from the core to the downcomer liquid through the core barrel and this heating lowers the density of the downcomer liquid.. Consequently the density of the downcomer becomes smaller than the lower plenum, and the heated downcomer water is able to flow into the core without traveling down to the bottom of the lower plenum. In this scenario the following calculation regarding mixing flow is derived without considering the ECC water from the downcomer.

From the post-LOCA long-term cooling evaluation assumption regarding the range of mixing volume described in DCD section 15.6.5.3.1.3, the following equation is assumed.

$$Cb_{LP} = \frac{1}{2} Cb_{CORE} \qquad \text{(eq-1)}$$

where,

Cb_{LP}: averaged boric acid concentration of the entire lower plenum (wt.%)

Cb_{CORE}: averaged boric acid concentration of the core (wt.%)

Boric acid mass in the lower plenum is obtained.

$$Mb_{LP} = \left(\frac{Cb_{LP}}{1.0 - Cb_{LP}} \right) V_{LP} \rho \qquad \text{(eq-2)}$$

where,

Mb_{LP}: Boric acid mass in the lower plenum (lbm)

V_{LP}: Volume of lower plenum = [ ]

ρ: Liquid density of lower plenum = 62.43 (lbm/ft^3)

(conservatively assumed as 39 °F at atmospheric pressure)

The calculated time-history of the boric acid concentration is presented in Figure-1 which is the same as presented in DCD Figure 15.6.5-42. Figure-1 (dashed line) also shows the lower plenum boric acid concentration based on the assumption of (eq-1).

To calculate the boric acid influx rate to the lower plenum, boric acid mass in the lower plenum is differentiated. Figure-2 shows the time history of the boric acid mass and boric acid influx rate of the lower plenum.

$$Wb_{in} = \frac{d}{dt} Mb_{LP}$$ with Wb_{in}: boric acid influx rate to the lower plenum (lbm/sec) (eq-3)

Mixing flow rate can be obtained by the following equation

$$Wb_{in} = \left(\frac{Cb_{CORE}}{1.0 - Cb_{CORE}} \right) W_{mix} - \left(\frac{Cb_{LP}}{1.0 - Cb_{LP}} \right) W_{mix}$$

$$W_{mix} = \left\{ \frac{Cb_{CORE}}{1.0 - Cb_{CORE}} - \frac{Cb_{LP}}{1.0 - Cb_{LP}} \right\}^{-1} Wb_{in} \qquad \text{(eq-4)}$$

where,

Wb_{in}: boric acid influx rate to the lower plenum (lbm/sec)

W_{mix}: boric acid mixing flow rate between the core and the lower plenum (lbm/sec)

Figure-3 shows the calculated time-history of the boric acid mixing flow rate between the core and the lower plenum by (eq-4). Mixing flow velocity calculated by the following equation is also presented in Figure-3.

$$v_{mix} = 12 \times \frac{W_{mix}}{\rho \cdot \frac{1}{2} A_{LP}}$$

where,

v_{mix}: Mixing flow velocity (inch/sec)

A_{LP}: Core inlet flow area (Lower plenum support plate) (ft^2)

As shown in Figure-3, the required mixing flow rate and velocity to maintain the boric acid concentration in the lower plenum is quite low. This means that the pressure loss will not significantly increase even if partial clogging in the core inlet happens. Therefore, it is believed that the impact of accumulated sump debris on mixing flow behavior between the core and the lower plenum is very limited.

Effects of sump debris on hot leg Injection

The effects of sump debris on hot leg injection are discussed in the reference-(1) as follows.

From section 4.4.3 of ref-(1),

The US-APWR design uses ECCS hot leg injection no sooner than about four (4) hours after occurrence of the postulated LBLOCA. At this switchover time, the coolant in the RWSP is expected to have been circulating through the ECCS and CSS several times. Therefore particulate and fibrous debris, which is generated by the initial RCS break flow and CS water flow back into the RWSP, is expected to be depleted either by capture on the strainer or by settle-out in low flow rate regions, such as the lower plenum. Thus, the amount of debris injected during the hot leg injection mode is expected to be small enough that the core cooling will not be significantly affected by the debris.

Furthermore, core flow rate would be maintained high enough to remove decay heat since the core power at hot leg switch over (HLSO) decreases to around one third of that at the time core quench is completed.

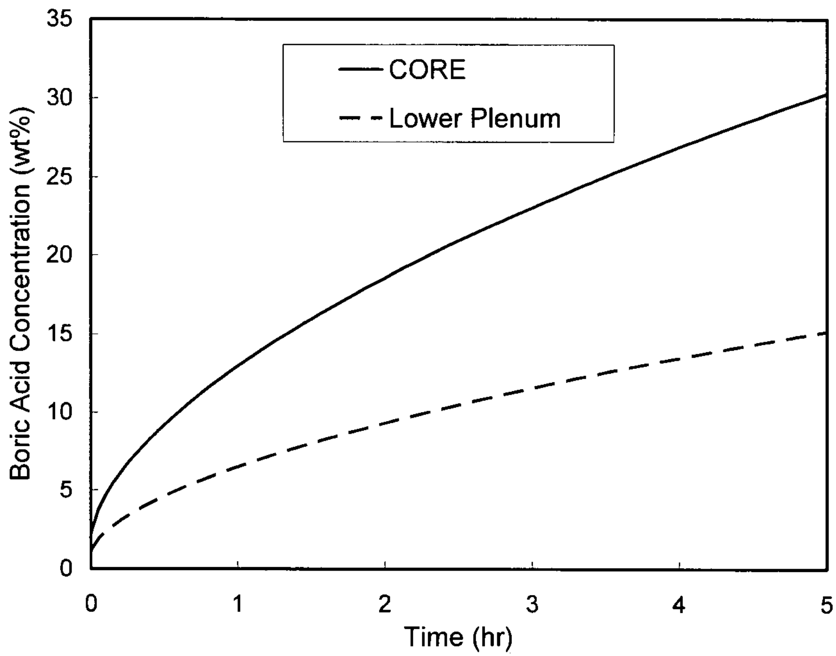

Figure-1 Boric acid Concentration during post-LOCA Long-term Cooling

Figure-2 Boric acid mass in the lower plenum and boric acid influx rate to the lower plenum during post-LOCA long-term cooling

Figure-3 Mixing mass flow rate and mixing flow velocity between the core and the lower plenum during post-LOCA long-term cooling

References:
1. MUAP-080013-P(R0), "US-APWR Sump Strainer Downstream Effects", December 2008
2. UAP-HF-11130 "MHI's Response to US-APWR DCD RAI No. 706-5339 Revision 0" (March2011) RAI Question 15.6.5-81.

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