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TOKYO, JAPAN

March 29, 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-11083

Subject: MHI's Response to US-APWR DCD RAI No. 706-5339 Revision 0 (SRP 15.06.05)

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. 706-5339 Revision 0". The enclosed materials provide MHI's response to Question 15.06.05-80 of the NRC's "Request for Additional Information (RAI) 706-5339 Revision 0," dated March 1, 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.

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NRO

Enclosures:

1. Affidavit of Yoshiki Ogata
2. MHI's Response to US-APWR DCD RAI No. 706-5339 Revision 0 (proprietary)
3. MHI's Response to US-APWR DCD RAI No. 706-5339 Revision 0 (non-proprietary)

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

<u>Contact Information</u>

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ENCLOSURE 1

Docket No. 52-021

MHI Ref: UAP-HF-11083

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 "MHI's Response to US-APWR DCD RAI No. 706-5339 Revision 0" dated March 2011, 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 29th day of March, 2011.

Y. Ogata

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

ENCLOSURE 3

UAP-HF-11083
Docket No. 52-021

MHI's Response to US-APWR DCD RAI No. 706-5339 Revision 0

March 2011

(Non-Proprietary)

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

3/29/2011

US-APWR Design Certification

Mitsubishi Heavy Industries

Docket No. 52-021

RAI NO.:	**NO. 706-5339 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:	**3/1/2011**

QUESTION NO.: 15.06.05-80

Provide the results from comparing the predictions from the level swell model, used in the US-APWR two-phase mixture level assessment during the LOCA long term cooling phase, against low-pressure level swell test data of relevance for the plant analysis.

ANSWER:

The core side mixture level is maintained above the hot leg bottom elevation, which was provided in ref-[1]. From the viewpoint of boric acid concentration, the volume of liquid in the mixing volume (MV) is important. For a given evaporation rate in the core, a smaller volume of liquid in the MV results in a higher boric acid concentration. As described in DCD Section 15.6.5.3.1.3, the void fraction in MV is calculated with the modified Yeh's correlation. The liquid volume of MV is calculated directly from this correlation. The calculation procedure is described in ref-[2].

As discussed above, the modified Yeh's correlation is utilized directly to calculate the void fraction which is used to calculate the volume of liquid in the MV. A comparison of the void fraction predicted by the correlation and the measured void fraction in several tests is shown in original paper (ref-[3]). The good agreement shows the appropriateness of the void fraction correlation including its use in the low-pressure condition (P=20 psia (0.14 MPa)). Fig-1 shows the comparison of the predicted and the measured void fraction which is described in ref-[3].

The modified Yeh's correlation for void fraction is given by,

$$\alpha = C\left(\frac{\rho_g}{\rho_f}\right)^{0.239}\left(\frac{V_g}{V_{bcr}}\right)^{m}\left(\frac{V_g}{V_g+V_f}\right)^{0.6}$$

Where

α	void fraction
ρ_f	liquid density
ρ_g	vapor density
V_f	superficial liquid velocity
V_g	superficial vapor velocity
V_{bcr}	critical bubble rise velocity,

and C and m are piece wise functions of V_g/V_{bcr}.

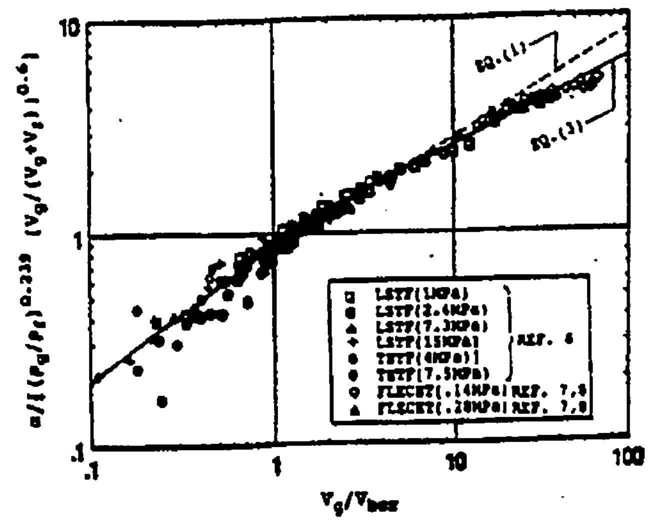

Fig-1 Comparison of the Predicted and the Measured Void Fraction (Excerpt from figure-3 of ref-[2])

In addition, the following conservative assumptions are made in the post-LOCA long term cooling evaluation from the viewpoint of calculation of liquid volume in the MV.

- Atmospheric pressure is assumed as the lowest possible system pressure during a large break LOCA. In actually, core pressure is likely higher than the containment back pressure by at least 3 psi due to the downcomer head. Higher system pressure results in a lower void fraction and consequently higher liquid volume in the MV, but this effect of higher core pressure is not considered in the evaluation.
- The ECC injection temperature is assumed to be at the saturation temperature at atmospheric pressure for large break LOCA. This assumption results in a higher void fraction as well as the maximum core evaporation rate.

To confirm the applicability of the modified Yeh's correlation to the post-LOCA long-term cooling evaluation, a comparison of the calculated and measured void fraction in LSTF void fraction distribution test (ref-[4]) was performed. This test is includes in ref-[3].

There are fourteen test cases in ref-[4]. A summary of the test cases and conditions are described in Table-1. In terms of system pressure, the four low pressure cases were selected, where the pressure is at 145 psia (1.0 MPa). Using the calculation procedure described in ref-[2], the average core void fraction in each case was evaluated. The calculation results for each case are presented in Table-2. As shown in Table-2, for each case the void fractions calculated by modified Yeh's correlation are in good agreement with or slightly higher value than indicated in the test data, which shows this correlation can estimate a conservative lower liquid volume. An example calculation of void fraction is provided in <Addendum> of this answer.

Table-1 Summary of Test Case and Condition
(Excerpt from table-2 of ref-[3])

Test	Pressure (MPa)	Power (MW)	Heat Flux (kW/m2)	Jg,exit (m/s)
ST-VF-01A	1.0	0.5	4.5	0.425
ST-VF-01B	1.0	1.0	9.1	0.851
ST-VF-01C	1.0	2.0	18.2	1.702
ST-VF-01D	1.0	3.5	31.8	2.978
ST-NC-08E	2.4	1.426	13.0	0.566
ST-NC-01	7.3	3.57	30.7	0.553
ST-NC-06E	7.3	3.95	34.0	0.612
SB-CL-16L	7.3	5.0	43.0	0.774
ST-SG-04	7.35	7.17	61.7	1.104
ST-VF-01E	15.0	1.0	9.1	0.091
ST-VF-01F	15.0	0.5	4.5	0.045
ST-VF-01G	15.0	2.0	18.2	0.182
ST-VF-01H	15.0	4.0	36.3	0.363
TR-LF-03	17.2	0.94	7.2	0.080

Table-2 Comparison of measured and calculated void fractions

Test Case	Bundle Power(MW)	Measured Void Fraction(-)[*]	Calculated Void Fraction(-)
ST-VF-01A	0.5	0.21	
ST-VF-01B	1.0	0.32	
ST-VF-01C	2.0	0.43	
ST-VF-01D	3.5	0.54	

[*] estimated value from fig. 3 of ref-[4]

Fig-2 Comparison of measured and calculated over-all bundle void fraction, 1 MPa
(Excerpt from fig.3 of ref-[3])

<Addendum> Calculation Example of void Fraction

An example calculation of void fraction for one case in Table-2 is described in this addendum.

Test case: ST-VF-01D

Symbol	Term	Value	Reference
Q_{core}	Core Power	3317 Btu/s (3.5 MW)	
J_g	Superficial steam velocity	9.770 ft/s (2.978 m/s)	Table 2 of ref-[4] (rows Q_{core}, J_g, P_{sys})
P_{sys}	System pressure	145 psia (1.0MPa)	
A_{core}	Core flow area	1.22 ft^2 (0.1134 m^2)	Table 1 of ref-[4]
Z_{core}	Core length	12 ft (3.66 m)	Table 1 of ref-[4]

The following physical quantities are estimated from the system pressure (145 psia).

Symbol	Term	Value
T_{sat}	Saturated temperature	355.8 F
ρ_f	Saturated liquid density	55.38 lbm/ft^3
ρ_g	Saturated vapor density	0.3212 lbm/ft^3
h_f	Saturated liquid enthalpy	327.9 Btu/lbm
h_g	Saturated vapor enthalpy	1193.9 Btu/lbm
σ	Surface tension	9.307x10^{-2} lbm/sec^2

Steady-state reflux condensation conditions were achieved in this test and its mixture flow level was kept constant at slightly below the hot leg bottom. [

]

The following calculation procedure is described in ref-[2].

The modified Yeh's void fraction correlation is expressed as follows:

(BB-5) of ref-[2]
$$\alpha = K \times \left(\frac{\rho_g}{\rho_f}\right)^{0.239} \times \left(\frac{j_g}{u_{rb}}\right)^{m} \times \left(\frac{j_g}{j_g + j_f}\right)^{0.6}$$

where,

- α : Void fraction (-)
- K : Coefficient (-)
- ρ_g : Density of saturated steam (lbm/ft^3)
- ρ_f : Density of saturated water (lbm/ft^3)
- j_g : Superficial rising velocity of steam (ft/s)
- j_f : Superficial rising velocity of water (ft/s)
- u_{rb} : Critical rising velocity of void (ft/s)
- g : Gravitational acceleration (ft/s^2)

The values of K and m are as follows.

$j_g/u_{rb} \leq 1$: K=0.925, m=0.67 ⇨ Region-[1]

$1 < j_g/u_{rb} < 4.31$: K=0.925, m=0.47 ⇨ Region-[2]

$4.31 \leq j_g/u_{rb}$: K=1.035, m=0.393 ⇨ Region-[3]

Critical rising velocity of void (u_{rb}):

From (BB-8) of ref-[2], $$u_{rb} = 1.53\left[\frac{\sigma \times (\rho_f - \rho_g)g}{\rho_f^2}\right]^{\frac{1}{4}}$$ = 0.737 ft/s

Average linear power density (q):

From (BB-7) of ref-[2], [ ]

Region-[1]

Upper elevation of Region-[1] (Z_1):

From (BB-17) of ref-[2] [ ]

Coefficient A in Region-[1] (A_1):

From (BB-12) of ref-[2] [ ]

Then, collapsed level in Region-[1] (Z_{c1}):

From (BB-14) of ref-[2] [ ]

Region-[2]

In the same way, Upper elevation of Region-[2] (Z_2):

From (BB-18) of ref-[2] [ ]

Coefficient A in Region-[2] (A_2):

From (BB-12) of ref-[2] [ ]

Then, collapsed level in Region-[2] (Z_{c2}):

From (BB-15) of ref-[2] [ ]

Region-[3]

Upper elevation of Region-[3] (Z_3) is core top elevation (Z_{core}).
Coefficient A in Region-[3] (A_3):

From (BB-12) of ref-[2] [ ]

Then, collapsed level in Region-[3] (Z_{c3}):

From (BB-16) of ref-[2] [ ]

Total core collapsed level (Z_c) can be calculated as,

[ ]

Finally core average void fraction (α) is obtained.

[ ]

References:

1. UAP-HF-09384 "MHI's Response to US-APWR DCD RAI No. 352-2369 Revision 1" (July 2009) RAI Question 15.6.5-48.
2. UAP-HF-09384 "MHI's Response to US-APWR DCD RAI No. 352-2369 Revision 1" (July 2009) RAI Question 15.6.5-44 Appendix B Attachment.
3. H. C. Yeh, "Modification of Void Fraction Calculation," Proceedings of the Fourth International Topical Meeting on Nuclear Thermal-Hydraulics, Operations and Safety, Volume 1, Taipei, Taiwan, April 5-9, 1994.
4. Y.Anoda, Y.Kukita, and K.Tasaka, "Void Fraction Distribution in Rod Bundle under High Pressure Conditions", HTD-Vol.155, An. Soc. Mech. Eng., Winter Annual Meeting, Dallas, Nov. 25-30, 1990.

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.