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September 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-09453

Subject: Amended MHI's Responses to NRC's Requests for Additional Information on Advanced Accumulator for US-APWR Topical Report MUAP-07001-P, Revision 2

Reference: [1] "Request for Additional Information Topical Report The Advanced Accumulator MUAP-07001-P Rev. 2" dated April 7, 2009.
[2] "MHI's Responses to NRC's Requests for Additional Information on Advanced Accumulator for US-APWR Topical Report MUAP-07001-P, Revision 2", UAP-HF-09239, dated May 20, 2009
[3] "Modified RAI for Advanced Accumulator- Topical Report MUAP-07001-P", dated August 7, 2009

With this letter, Mitsubishi Heavy Industries, LTD. ("MHI") transmits to the U.S. Nuclear Regulatory Commission ("NRC") the document entitled "Amended MHI's Responses to NRC's Requests for Additional Information on Advanced Accumulator for US-APWR Topical Report MUAP-07001-P, Revision 2".

Enclosed are the responses to No.33, 34, 35, 41, 42, 43, 47, 48 and 52 of the RAI (Reference 1) and the modified RAI (Reference 3)

These responses amend the previously transmitted answers submitted under MHI Reference UAP-HF-09239 on May 20, 2009 (Reference 2) in order to respond the modified RAI (Reference 3) and comments on the meeting dated June 18 and 19, 2009.

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 with the information identified as proprietary redacted and replaced by the designation "[ ]".

This letter includes a copy of the proprietary version (Enclosure 2), a copy of the non-proprietary version (Enclosure 3), and the Affidavit of Yoshiki Ogata (Enclosure 1) which identifies the reasons MHI respectfully requests that all materials designated as "Proprietary" in Enclosure 2 be withheld from public 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 the submittal. His contact information is below.

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NRO

Sincerely,

Y. Ogata

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

Enclosures:
1 – Affidavit of Yoshiki Ogata

2 – Amended MHI's Responses to NRC's Requests for Additional Information on Advanced Accumulator for US-APWR Topical Report MUAP-07001-P, Revision 2 (proprietary)

3 – Amended MHI's Responses to NRC's Requests for Additional Information on Advanced Accumulator for US-APWR Topical Report MUAP-07001-P, Revision 2 (non-proprietary)

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

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ENCLOSURE 1

Docket No. 52-021
MHI Ref: UAP-HF-09453

MITSUBISHI HEAVY INDUSTRIES, LTD.

AFFIDAVIT

I, Yoshiki Ogata, 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 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.

2. In accordance with my responsibilities, I have reviewed the enclosed document entitled "Amended MHI's Responses to NRC's Requests for Additional Information on Advanced Accumulator for US-APWR Topical Report MUAP-07001-P, Revision 2" dated September 2009, and have determined that portions of the document contain 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 information identified as proprietary in the enclosed document has in the past been, and will continue to be, held in confidence by MHI and its disclosure outside the company is limited to regulatory bodies, customers and potential customers, and their agents, suppliers, and licensees, and others with a legitimate need for the information, and is always subject to suitable measures to protect it from unauthorized use or disclosure.

4. The basis for holding the referenced information confidential is that it describes the unique design of the Advanced Accumulator developed by MHI and 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.

5. The referenced information is being furnished to the Nuclear Regulatory Commission ("NRC") in confidence and solely for the purpose of information to the NRC staff.

6. The referenced information is not available in public sources and could not be gathered readily from other publicly available information. Other than through the provisions in paragraph 3 above, MHI knows of no way the information could be lawfully acquired by organizations or individuals outside of MHI.

7. Public disclosure of the referenced information would assist competitors of MH in their design of new nuclear power plants without incurring the costs or risks associated with the design and testing of the subject systems. Therefore, disclosure of the information contained in the referenced document would have the following negative impacts on the competitive position of MH in the U.S. nuclear plant market:

A. Loss of competitive advantage due to the costs associated with development and testing of the Advanced Accumulator. Providing public access to such information permits competitors to duplicate or mimic the Advanced Accumulator design without incurring the associated costs.

B. Loss of competitive advantage of the US-APWR created by benefits of enhanced plant safety, and reduced operation and maintenance costs associated with the Advanced Accumulator.

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 16th day of September, 2009.

Y. Ogata

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

Enclosure 3

UAP-HF-09453
Docket No. 52-021

Amended MHI's Responses to NRC's Requests for Additional Information

on

Advanced Accumulator for US-APWR Topical Report MUAP-07001-P, Revision 2

September 2009
(Non-Proprietary)

RAI 33.

It will take time for accumulator to become saturated with nitrogen. The upper layer will saturate but thereafter, the dissolved gas will diffuse to the rest of the accumulator liquid. If there are any convection currents in the liquid, the mixing will be even faster. The response to RAI 5b dated September 2008, regarding the dissolved ratio of nitrogen in terms of diffusion period of 2 years through 10 years, does provide the actual concentration of the dissolved gas, and the dissolution of the gas as the fluid particles move to the lower pressure. The amount of gas that will evolve depends on the nucleation sites and interfacial area.

Why are the effects of nucleation sites, interfacial area density and convection not addressed, in addition to the diffusion process?

Response

About the effect of convection currents:

Temperature difference between water and the wall can induce convection currents in an accumulator tank. We have no data showing temperature variation in accumulator tanks at operating plants, so we cannot evaluate convection currents affecting on nitrogen dissolution. The maximum effect of dissolved nitrogen on cavitation will be at the saturated condition. That is why we carried out Case 5 with water saturated with nitrogen. If enough nitrogen is supplied, some nitrogen will be dissolved in the water to reach the saturation condition, and excess nitrogen that forms as tiny bubbles in water which may act as cavitation nuclei. If there are too many nuclei, some will combine to form larger bubbles and escape out of water. Therefore, there must be maximum density of cavitation nuclei. Convection currents in an actual accumulator tank may increase dissolution of nitrogen in water, but will not affect the number of cavitation nuclei. In Case 5 Study, bubbling and showering of nitrogen were supplied to water until the pressure in the tank stopped its variation and became sedentary. This case represents the maximum or conservative approach to estimate the number of cavitation nuclei in saturated water in Case 5. Consequently, Case 5 was the critical condition of nitrogen to cavitation.

About nucleation sites and interfacial area density:

Numerous cavitation nuclei are generally contained in water. There are also some cavitation nuclei on the walls of the vortex chamber and the throat. The size of nuclei seems to be in the order of 10^{-3}inch in water.

The pressure drop in the actual accumulator tank is slow. However, let's consider a nitrogen bubble that experiences abrupt depression from the storage pressure of 5.33MPa to an atmospheric pressure of 0.101MPa at time t=0 sec as a stepwise to be able to examine the growth of the bubble as the most conservative. The bubble at first rapidly expands due to gas expansion, then nitrogen slowly permeates in water due to diffusion of saturated nitrogen. Bubble dynamics due to gas expansion in inviscid fluid is given by the following equation (L.D. Landau and E.M. Lifshitz: Fluid Mechanics, Pergamon Press, 1975):

$$P(t) = p_0 + \frac{1}{2}\rho\left[\frac{d^2\left(R^2\right)}{dt^2} + \left(\frac{dR}{dt}\right)^2\right] \qquad (33\text{-}1)$$

Where R is radius of the bubble, $P(t)$ pressure on the surface of the bubble, t time, ρ density of fluid, and p_0 ambient pressure.

The distension of a spherical bubble with an initial radius 2×10^{-3}in (0.05mm) due to gas expansion is shown in Figure 33-1. Surface tension on the bubble was taken into account in the calculation. Bubble distension due to gas expansion is very rapid. For adiabatic change, or specific heat ratio γ=1.4, the bubble is distended in 9×10^{-6} sec, and for isothermal change, or γ=1.0, the bubble is distended in 1.6×10^{-5} sec. An actual bubble will be abruptly distended in time between them.

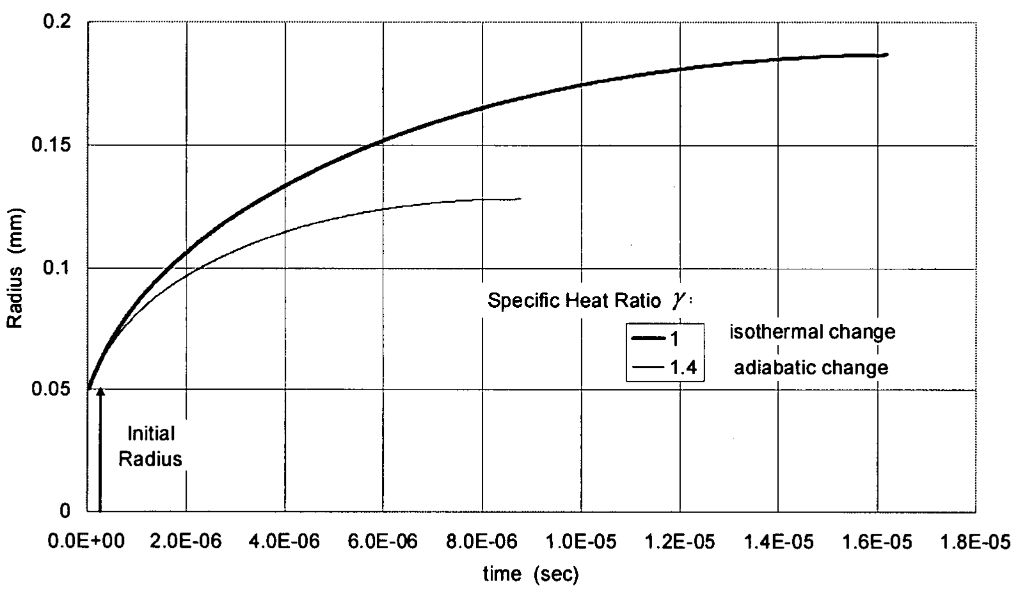

Fig. 33-1 Example of Distension of a Nitrogen Bubble due to Gas Expansion

Nitrogen diffusion affects the growth of a bubble. For simplicity, the solution of one dimensional diffusion of nitrogen in the water around the bubble is shown as

$$c = c_R + (c_\infty - c_R)\,erf\frac{x}{2\sqrt{Dt}} \qquad (33\text{-}2)$$

where c is concentration of nitrogen, c_R and c_∞ concentrations at radii $r = R$ and $r \to \infty$ respectively, $x = r - R$, D diffusion coefficient of nitrogen in water, and an error function

$$erf\eta = \frac{2}{\sqrt{\pi}}\int_0^\eta \exp(-\xi^2)d\xi\,. \qquad (33\text{-}3)$$

The distension of the spherical bubble due to nitrogen diffusion after the gas expansion is shown in Figure 33-2. The Henry's law was applied to calculate the balance of pressure in the bubble and density of nitrogen in water around the bubble. It is shown that the distension due to the diffusion of nitrogen is very small for about 0.15sec which is the duration a bubble in water passes through the vortex chamber and the throat. The diffusion around a bubble depends on its radius, and it is nonlinear. The diffusion of nitrogen is very slow.

The speed of nitrogen diffusion is the same for nuclei on the walls as for bubbles in water. The former are sedentary on the walls and the bubbles expand to a certain size at which superjacent flow carries them away. The growth rate is controlled by slow diffusion of nitrogen in water.

Consequently, the effect of nitrogen is the abrupt distension of bubbles, or cavitation nuclei, in the form of gas expansion, and diffusion of nitrogen is negligible.

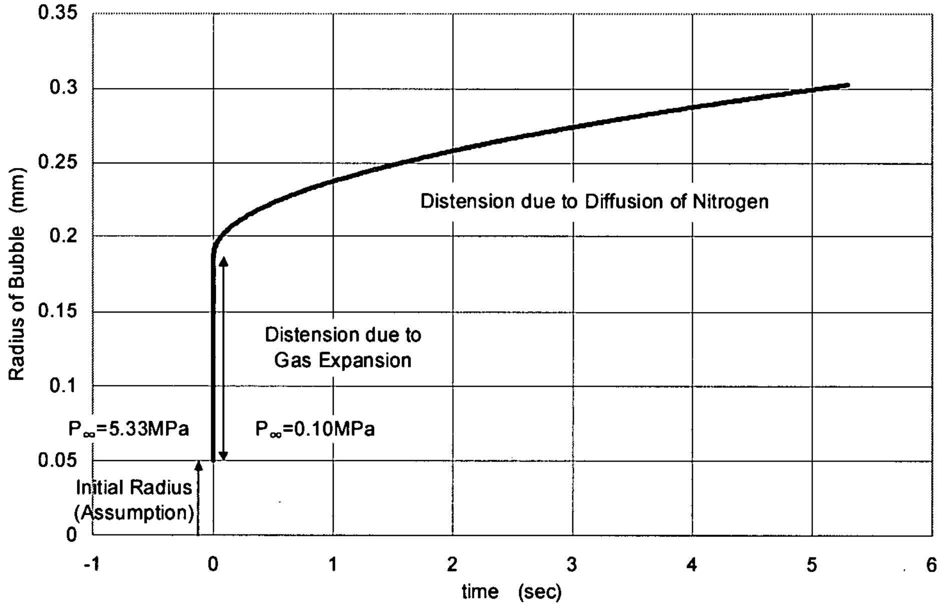

Fig. 33-2 Example of Distension of a Nitrogen Bubble due to Diffusion

RAI 34.

Figure 4.2.4-9 in the topical report (MUAP-07001) compares Case 1 and Case 5 of the ½ scale tests with same accumulator tank and exhaust tank pressures. In Case 5, the liquid was saturated with nitrogen. A comparison of data from two tests indicates that the data for cavitation factor and flow rate coefficient are shifted to lower values for Case 5. In response to RAI 16-B, dated July 20, 2007, on why Case 5 was not included in developing correlations, MHI stated that "using the Case 5 test data will result in evaluating flow rate coefficient smaller than that of the actual accumulator because the test condition in test Case 5 with nitrogen gas compulsorily saturated by bubbling and showering is much more critical than the actual accumulator". However, disregard of Case 5 test result would completely ignore the effect the dissolved nitrogen, though not saturated, in the actual accumulator.

(a) Explain why Case 5 has lower values of the flow rate coefficient and cavitation factor relative to Case 1.

(b) How do the proposed accumulator flow rate characteristic correlations for flow rate coefficient account for dissolved nitrogen?

(c)
How is the effect of nitrogen accounted for in implementing accumulator characteristic equations? Is there any delay in accumulator flow to account for nitrogen effect? How is this delay estimated? How is this delay validated to full scale accumulator?

Response

(a) Please see the response to RAI 33. In the Case 5 test, it seems that the maximum number of cavitation nuclei existed in the nitrogen-saturated water by bubbling and showering. The generation of microbubbles was observed in the tank along the test initiation in the Case 5 test, and this fact supports the above description. The cavitation nuclei seem to grow rapidly due to gas expansion induced by pressure drop, and change effective density of water to increase pressure loss at throat portion. This is the reason for cavitation factor and flow rate coefficient in the Case 5 test being lower than those in the Case 1.

(b) Flow coefficient reduction for dissolved nitrogen is not considered in the proposed accumulator flow rate characteristic correlations. Because it is not expected, as described in the response to RAI 33, that dissolved nitrogen diffusion accelerates the growth of bubbles to increase pressure loss at the outlet of throat portion.

(c) In Large Break LOCA analysis, the accumulator injection line piping resistance uncertainty is treated as a statistical parameter, and the resistance which is sampled randomly from uniform distribution within the range of $\pm$10% is used for the analysis. For the cases with maximum and minimum piping resistance, duration of large flow injection period is different by approximately 2.4 seconds (Figure 34-1). Therefore, the large flow injection completion time delay induced by the effect of nitrogen is bounded by considering piping resistance uncertainty.

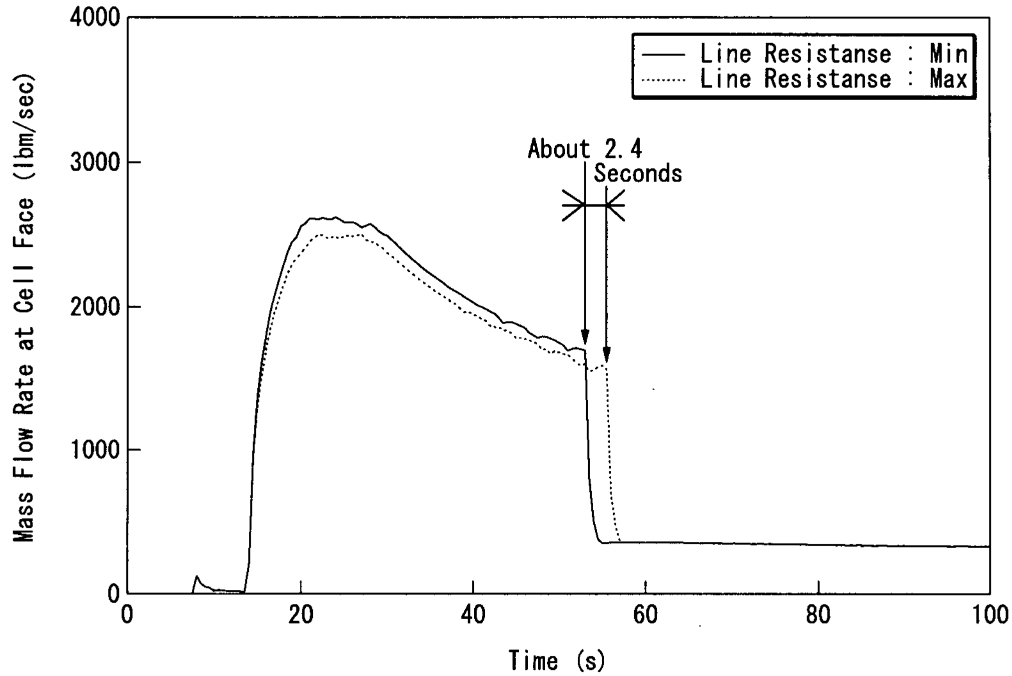

Figure 34-1 Accumulator flow rate during Large Break LOCA

As above description, 2.4 seconds of large flow injection completion time delay considering piping resistance uncertainty encompasses 2 seconds of delay in full height 1/2 scale test case 5. The large flow injection completion time delay in test case 5 is expected to be applicable to full-scale accumulator for the following reasons:

- Since the Full-height 1/2 scale model is used in the actual pressure condition, time axis of injection characteristic (time vs. injection flow rate) is the same in the test model and actual accumulator. Therefore, with the initial tank pressure and back pressure equivalent to the actual condition, the injection time of test and actual accumulator will be the same.
- The large flow injection completion time delay in test case 5 is assumed to be induced by expansion of microbubbles formed by compulsory bubbling and showering before the test initiation by depressurization, which decreased effective density of water and increased pressure drop in the flow damper and injection pipe. Since bubbles grow very fast according to pressure change as described in the response to RAI 33, decrease of effective density of water does not depend on the scale of accumulator tank and flow damper if the amount of microbubbles in the tank water and tank pressure are the same. It is very conservative to consider large flow injection completion time delay which is comparable with the delay time in the test case 5 as the worst case in safety evaluation because the initial pressure of test case 5 is equal to the pressure in the actual ECCS performance analysis, and microbubbles more than test case 5 do not exist in the actual accumulator since compulsory bubbling and showering is not conducted.

RAI 35.

The results of 1/2 - scale test cases presented in Figures 4.2.4 of topical report MUAP-07001-P, indicate that the flow rate coefficient starts to decrease around cavitation factor of 4 for the large flow phase. The analysis, presented in response to RAI 21 (Sept 2008), is not clear. It assumes that the wall pressure as throat pressure (i.e., Pw = Pt, Eq. 21-2). It is not obvious how pressure at the throat could be equated to pressure along the wall especially when cavitation occurs at the throat. It is also not clear why dp, instead of dt, is used in the term (Pt π/4 dp^2) in Eq. 21-8. The original conservation of momentum projected along the axis of the nozzle is represented by Eq. 21-1, where the first term is Pt π/4 dt^2, not Pt π/4 dp^2.

The critical cavitation factor computed from MHI's analysis, in the responses to RAI 13-B (July 2007) and RAI 21 (Sept 2008), will be too low to have any cavitation during both the large and small flow rate conditions. As such, these derived equations are not helpful to predict cavitation.

Using simple Bernoulli equation with loss coefficient, we can get an equation:

$$\sigma_v = \frac{(P_2 - P_v)}{\zeta_d \rho V_2^2/2} = \frac{(P_t - P_v)}{\zeta_d \rho V_2^2/2} - \frac{\zeta_p}{\zeta_d} + \frac{\left(\left(\frac{d_2}{d_t}\right)^4 - 1\right)}{\zeta_d} \qquad (35\text{-}1)$$

This indicates that the critical cavitations inception for large flow will be around (-1+15/ ζ d), or approximately 2 (since ζ d= ζ p =5 for large flow). Therefore, there will be cavitation for large flow phase. For the small flow, the total loss coefficient, ζ d, is around 250 but the injection pipe loss coefficient ζ p will be close to 5. So the cavitation inception expression will be (-(p/ ζ d) +15/ ζ d). That will imply a critical cavitation factor value of 0.04, which is much smaller than the data (Fig. 5.1-1, MUAP 07001-P).

(a) Explain why the correlation starts to predict a decrease in flow rate coefficient at cavitation parameter around 4.0 for the large flow condition (Figure 5.1-1, MUAP-07001)?

(b) How will this critical cavitation factor of 0.04 explain cavitation in the vortex chamber for the small flow condition as was stated in the MHI's response to RAI 2 of Sept 2008?

Response

P_w=P_t is an assumption which was used as a rough estimation. A more rigorous expression of cavitation factor is Equation (21-9) for which mean pressure coefficient, $\overline{C}_p$, must be given.

Equation (35-1) derived from the Bernoulli equation will be useful to examine the values of cavitation factor.

d_p is correct in the first term in equation (21-8).

Equation (21-1) is

[ ] (21-1)

Equation (21-6) is

[ ] (21-6)

Equation (21-7) is

[ ] (21-7)

where the diameter of the exit of the diffuser, d_2, is equal to that of the injection pipe, d_p.

Using equations (21-6) and (21-7), the second term on the left hand side of equation (21-1) becomes

[ ] (21-a)

Substituting this equation into the second term of equation (21-1) gives equation (21-8) as

[ ] (21-8)

Namely, the first term on the right hand side of equation (21-a) combines with the first term of equation (21-1) to yield the first term of equation (21-8).

Equation (21-9) cited in the previous Response to RAIs No.2, UAP-HF-08174-P(R0), was derived from the control volume approach, where P_2 is pressure at the exit of the outlet nozzle as shown in Figure 21-1, while P_2 cited in equation (35-1) is pressure at the exit of the injection pipe. It causes the second term on the right hand side of equation (35-1).

[ ] (21-9)

The last term of equation (35-1) is slightly different from that of equation (21-9), which might come from the difference of the assumptions of no pressure loss in the diffuser for equation (35-1) and of pressure distribution on the wall of the diffuser for equation (21-9).

(a) The theoretical value of cavitation factor is relatively close to the experimental value for large flow injection. Also, the pressure at the throat is close to the minimum value in the diffuser. Figure 5.1-1 of the Topical Report indicates degradation of flow rate coefficient for cavitation factor of $\sigma_v \approx 7$ or less for large flow injection. Cavitation might occur around this range. The cavitation factor defines pressure at the exit of the outlet nozzle as the characteristic pressure for the flow damper, not pressure at the exit of the injection pipe.

As mentioned in Response to RAI 32, cavitation may occur in the diffuser where local pressure is a minimum for large flow injection. If cavitation occurs in the diffuser, flow passing through the throat separates from the wall of the diffuser and forms a vena contracta. Since pressure of the vena contracta is the minimum along the axis of the outlet nozzle of the flow damper and kept close to vapor pressure when cavitation occurs on the wall of the diffuser, the pressure at the throat is higher than the vapor pressure. To keep the pressure of the vena contracta close to vapor pressure causes degradation of flow rate coefficient of the flow damper when flow rate increases.

(b) The cavitation factor of 0.04 is used to evaluate cavitation in the diffuser. We agree that there is no cavitation at the throat or diffuser during small flow injection, but the pressure at the center of the vortex in the chamber is smaller than that at the throat, and it is possible that there is cavitation at the center of the vortex chamber for small flow injection. Please see Response to RAI 53.

RAI 41.

With respect to the uncertainties associated with the accumulator flow characteristic equations, instrumentation, manufacturing, and the flow rate switching water level:

(a) What contributes to bias (systematic) and standard deviation (precision or random) part of uncertainty in the flow rate coefficients of the large- and small-flow characteristic correlations of the flow damper?

(b) What are the other contributors to uncertainty beside instrument uncertainty, dispersion or regression analyses error and manufacturing uncertainties? How are these combined? How is the scaling uncertainty determined and accounted for in the characteristic correlations?

(c) What is the relationship between the diversion of correlations listed in Table 3.5-5 (in MUAP-07011 Large-Break LOCA Methodology) and listed in Table 5.2-1 in MUAP-07001)?

Response

(a) Contributors to bias and random part are as follows:

Bias part

1) To measuring uncertainty:
   - Test tank diameter
   - Specific weight of water
   - Height of injection pipe
   - Injection pipe diameter
2) To manufacturing errors
   - Manufacturing tolerance
3) To uncertainty of water level for switching flow rates
   - Level instrument error (guaranteed value by vender)

Random part

1) To measuring uncertainty:
   - Test tank diameter
   - Water Level in Test Tank
   - Pressure drop (pressure loss)
   - Height of injection pipe
   - Injection pipe diameter
2) To experimental equation
   - Dispersion of experimental equation and test data
3) To uncertainty of water level for switching flow rates
   - Deviation between flow switching level and standpipe inlet level

(b) There is no other possible uncertainty. The combinations of uncertainties described above are shown in Reference 41-1, Section 3.5.1.4, item (1), Total Uncertainty of Experimental Equation Applicable to US-APWR (Page 3-27, and 28).

Scaling Uncertainty

As shown below, the manufacturing errors are considered as the scaling uncertainty:

- Instrumental uncertainty; The instrumental uncertainty is considered as experimental equation uncertainty, therefore, another consideration is not needed for scaling.
- Dispersion of the data from the experimental equations; Since the same phenomenon is assumed to be occurred in 1/1 and 1/2 models, scaling effect is not possible to be exist in the dispersion of the data from the experimental equations.
- Manufacturing errors; Manufacturing errors are considered using actual dimension tolerance.

(c) The values in Table 5.2-1 (MUAP-07001) shows dispersion of the test data from experimental equations in each test case (Case 1, 2, 3, 4, and 6). The values in Table 3.5-5 (MUAP-07011, Large-Break LOCA Methodology) shows dispersion of the test data bounding all of Case 1, 2, 3, 4, and 6, from experimental equations. Experimental equations are developed for all of experimental data bounding Case 1, 2, 3, 4, and 6, thus values shown in Table 3.5-5 are used for estimation of experimental equations uncertainty in LOCA analyses.

The uncertainty of experimental equations (Dispersion Deviation) shown in Table 3.5-5 (MUAP-7011 Large-Break LOCA Methodology) is based on numerous data. On the other hand, the instrumental uncertainty shown in Table 3.5-4 (MUAP-07011 Large-Break LOCA Methodology) is based on data from only 15 cases test data for each of large and small flow. Thus, in the case of instrumental uncertainty, the uncertainty in the worst case is adopted conservatively, since the number of data is few.

Reference

41-1 "Large Break LOCA Code Applicability Report for US-APWR", MUAP-07011-P(R0), July 2007

RAI 42.

In MHI's responses to RAI 17 (July 2007) related to instrumentation uncertainties:

(a) How are the bias limits for the six parameters estimated?

(b) Why the biases are zero for the accumulator tank water level, pressure drop and flow rate (Tables 17-1 and 17-2)?

Response

(a) The following is the detailed description of how bias limits of 6 parameters (i.e., test tank diameter, specific weight of water, flow rate, height of injection pipe, injection pipe diameter, flow rate coefficient) are obtained:

1) Test tank diameter: A half of minimum scale value of slide gauge is used as bias limit for test tank diameter. (Reference 42-1, page 32, response 3), (1) to question 17-B.)
2) Specific weight of water: The guaranteed value for instrument accuracy of thermocouple provided by manufacturer is[ ]°C. Temperature difference of[ ]°C corresponds to density difference of[ ]kg/m^3 at normal temperature and pressure. Thermocouples have characteristic bias of [ ]°C, thus this value is treated as the bias limit. Note that the effect of pressure instrument error was neglected since the sensitivity of density is very small as compared with pressure gauge error. (Reference 42-1, page 33, response 3), (3) to question 17-B.)
3) Flow rate: As a relative bias limit, it was calculated from (B_Q/Q) in the 1st. equation in response 5) to question 17-B. (Reference 42-1, page 34.)
4) Height of injection pipe: Please see Reference 42-1, page 33, response 3), (5) to question 17-B.
5) Injection pipe diameter: Bias limit is[ ]mm, which is a half of minimum scale value of micrometer. (Reference 42-1, page 33, response 3), (6) to question 17-B.)
6) Flow rate coefficient: As a relative bias limit, it was calculated from (B_{cv}/Cv) in the 6th. equation in response 5) to question 17-B. (Reference 42-1, page 35.)

(b) Here is the detailed description of how the deviation of test tank water level, pressure drop, and flow rate is treated:

Test tank water level: Normally, a half of minimum scale value of manometer should be used as a bias limit, however, this value is neglected since this bias limit is very small as compared with precision index.
Bias limit is[ ]mm which is a half of minimum scale value of[ ]mm. Averaged value of measurements is[ ]m and relative bias limit is[ ], which is as small as approximately[ ]of relative precision index of[ ]that we neglected this value.

Pressure drop (pressure loss): Bias limit is neglected since it tends to be controlled by random part from the result of comparison of deference measured by pressure transducer in test tank and injection pipe with the method shown in the response 3), (4) to question 17-B, Reference 42-1, page 33. (Refer to Table 42-1)

Table 42-1 Comparison of deference measured by pressure transducer in test tank and iniection pipe Unit (kg/cm^2)

Flow rate: Biases (relative bias limit) are considered as described in the response to RAI 42(a). Biases are indicated as relative bias limit in Reference 42-1, Table 17-1, and 17-2.

<u>Reference</u>

42-1 Response to NRC's Questions for Topical Report MUAP-07001-P(R1) The Advance Accumulator, UAP-HF-07086-P(R0), July 2007

RAI 43.

Citing ANSI/ASME PTC19.1-1985 in the response to RAI 17 (July 2007), MHI uses the square-root-sum-of-squares (RSS) method to combine bias with precision (standard deviation) in the uncertainty analysis as shown in Eqs. 17.5 and 17.6. The USNRC staff has accepted the RSS methodology for combining the uncertainties that are random, normally distributed, and independent, whereas the algebraic method is used to combine uncertainties that are not random, not normally distributed, or are dependent.

(a) Provide justification of combining bias with precision (standard deviation) through the RSS method.

(b)In the case of instrument uncertainty, why is the standard deviation of the mean used? Why the standard deviation of the distribution not used?

Response

(a) Bias limit and precision index of flow coefficient are calculated using bias limits and precision indexes of pressure drop, test tank water level, water density, height of injection pipe, flow rate, injection pipe diameter, and their relative influence coefficients. Each of bias limits and precision indices of above parameters, based on which the bias limit and precision index of flow coefficient are calculated, is independent. Therefore, each of bias limit and precision index of flow coefficient is also independent. Thus, it is valid to apply RSS method.

(b) Since the experimental equations are regression formula, it represents mean of measured data. The standard deviation of the mean is used to evaluate instrument uncertainty, since the effect of instrument uncertainty to experimental equation (mean value) should be evaluated. Standard deviation of data distribution is used for Dispersion Deviation from Experimental Equation to obtain the data cover ratio of the experimental equation.

RAI 47.

In topical report MUAP-07001, Table 5.2-1, "Dispersion of the Data from Experimental Equations," provides the standard deviation of the flow rate coefficient of the large- and small-flow characteristic correlations. These standard deviations are different for different test cases. Tables 5.2-2(1/2) and 5.2-1(2/2), provide the instrumentation uncertainties for the large and small flow conditions, respectively, which are different for different test cases and different injection periods. The Manufacturing Error associated with the flow rate coefficient described in the report uses a bounding value (proprietary).

Describe how these uncertainty values are combined and how they are accounted for in the safety analyses?

Response

The combined value of each uncertainty (for instrument: Equation 3.5.1-8[47-1], for dispersion: Equation 3.5.1-9[47-1] and for manufacturing: Equation 3.5.1-10[47-1]) based on their relative standard deviations is obtained by the treatment of root mean square (R.M.S).

The instrument uncertainties shown in Table 3.5-5 of Reference 47-1 are defined by 95% coverage in two-side test. Therefore, the instrument uncertainties are equivalent to 1.96 times the "relative standard deviation of instrument uncertainty", if the instrument uncertainties are derived from the parent population assumed as a normal probability distribution. The relative standard deviation of instrument uncertainty is shown in Equation 3.5.1-8 in Reference 47-1. For the detailed basis for the calculation of the combined value of each uncertainty, please refer to the Subsection 3.5.1.4 in Reference 47-1.

Reference

47-1 "Large Break LOCA Code Applicability Report for US-APWR," MUAP-07011-P(R0), Mitsubishi Heavy Industries, Ltd., July 2007.

RAI 48.

MHI's response to RAI 18 (Sept 2008) explains the reason for the variation in the standpipe water level from case to case in the ½ scale tests right after the switch from large flow to small flow phase (Figures 4.2.4 of MUAP-07001) as due to the variation of the velocity in the standpipe right before the switch of flow rate. However, physical arguments have not been presented. In addition, there is a sharp drop in the tank outlet pressure at the time of flow switch that is related to the level in the stand pipe.

(a) Explain this sharp drop in the tank outlet pressure.

(b) Provide a physical argument for the variation in the standpipe water level at the time of switch.

(c) Explain how Eq. 18-1 was obtained, and how it is solved to get the results in the Figure 18-1.

Response

(a) The sharp drop in the outlet pressure of the flow damper is engendered by large diminution of flow rate in the injection pipe. Flow rate plummets down to about 1/5 that before flow switching, and pressure in the exhaust tank is kept constant at the experiments. Consequently, the pressure drop over the injection pipe reduces to about 1/25 that before flow switching. It is why the sharp drop appears in the outlet pressure of the flow damper at flow switching.

(b) At the beginning of flow switching, the standpipe is filled with water at large velocity. Then, the water level in the standpipe decrease with the velocity. Pressure at the outlet of the large flow pipe is equal to the static pressure in the small flow pipe, which is lower than the total pressure in the accumulator tank at the amount determined by the dynamic pressure of the small flow pipe. The static pressure stops the motion of water column in the standpipe as follows:
If the water level in the standpipe reduces below the balance level equivalent to the static pressure, the velocity of the water column decreases and stops. Then, the static pressure pushes the water column back to the balance level, and the flow switching comes to an end.

(c) The sign of the last term of Equation (18-1) should be "+" instead of "-" As:

$$\frac{d}{dt}(lV) = -\frac{Q_l}{A}V_2 + g(l_v - h) - (\zeta + Cd)\frac{1}{2}|V|V + (1 - Cp)\frac{1}{2}V_l^2 \qquad (18\text{-}1)$$

Water hammer analysis discusses one-dimensional momentum balance of a water column in a pipe. Similar discussion leads us to Equation (18-1) as follows:
Momentum change of the water column is expressed by the term on the left hand side of Equation (18-1). Momentum flowing out from the large flow pipe into the vortex chamber is given by the first term, (a), on the right hand side of Equation (18-1). Gravitational force acting on the water column is given by the second term, (b), on the right hand side, flow resistance of the standpipe and the large flow pipe by the third term, (c), and pressure recovery of small flow by the fourth term, (d). There is no pressure recovery of small flow of the flow damper for US-APWR, and the fourth term, (d), turns to null.
It was solved numerically. Pressure drop in the injection pipe is caused by the large flow resistance of the flow damper, and the pressure in the exhaust tank was kept constant at the tests. So there is no pressure effect to the dynamics of water column in the standpipe.

RAI 52.

In MHI's response to RAI 26 dated September 2008, how was mass flow rate uncertainty?

Response

The same flow rate calculation method is used for both small and large flow injection as described in the answer to RAI-26 in Reference 52-1. [ ] of uncertainty is expected.

Tables 52-1 is example list of the parameters, average or planned values, absolute bias limits, absolute precision indices, relative bias limits, relative precision indices and relative influence coefficients, and used for the calculation of uncertainties of flow rates in small flow injection in test case 1. For detail of calculation method, please see the answer to question 17-B in Reference 52-2.

Table 52-1 Uncertainty of Flow Rate at the Initial Stage of Small Flow of Case 1

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Reference

52-1 MHI's Responses to NRC's Requests for Additional Information on Advanced Accumulator for US-APWR Topical Report MUAP-07001-P, Revision 1, UAP-HF-08174-P(R0), September 2008

52-2 Response to NRC's Questions for Topical Report MUAP-07001-P(R1) THE ADVANCED ACCUMULATOR, UAP-HF-07086-P (R0), July 2007