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TOKYO, JAPAN

January 25, 2010

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-10016

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] "CFD Analysis for Advanced Accumulator", MUAP-09025.
[4] "Amended MHI's Responses to NRC's Request for Additional Information on Advanced Accumulator for US-APWR Topical Report MUAP-07001-P, Revision 2", UAP-HF-09450, dated September 16, 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. 30, 31, 32, 36, 37, 38, 39, 50 and 53 of the RAI (Reference 1)

These responses amend the previously transmitted answers submitted under MHI Reference UAP-HF-09239 on May 20, 2009 (Reference 2) in order to respond comments on the meeting dated June 18 and 19, 2009. These responses were revised based on CFD analysis which has been submitted to the NRC as technical report "CFD Analysis for Advanced Accumulator" (MUAP-09025) (Reference 3). The other amended responses to respond comments on the meeting dated June 18 and 19 have been submitted in Reference 4.

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

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Systems, Inc. if the NRC has questions concerning any aspect of the submittal. His contact information is below.

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-10016

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 January 2010, 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 25th day of January, 2010.

Y. Ogata

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

Enclosure 3

UAP-HF-10016
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

January 2010
(Non-Proprietary)

RAI 30.

The outlet nozzle throat area and the vortex chamber, during the high flow and the low flow periods, respectively, have low pressure regions. These low pressure regions are susceptible to evolving of dissolved gases and the production of vapor. This gaseous region may lead to increases in friction pressure drop and/or choking.

MHI's response to RAI 13 dated July 20, 2007, stated that it did not provide any detection system to observe cavitation in the ½ scale and 1/5 scale tests, but concluded that there must be some cavitation occurring in the tests. For small flow conditions, it also concluded that there cannot be cavitation at the exit nozzle throat. In its response to RAI 2 dated September 2008, MHI stated that under small flow rate conditions, there can be a stable cavitation cloud at the center of the vortex chamber and the size of the cavitation cloud is scale dependent.

(a) Will there be cavitation in the flow damper outlet nozzle/injection pipe during the large and small flow conditions, respectively? Is the cavitation a vaporous or gaseous (due to the dissolved nitrogen) cavitation? What is the critical cavitation factor when this type of cavitation first occur?

(b) Will there be cavitation in the vortex chamber during small flow conditions? Is the cavitation a vaporous or gaseous cavitation? What is the critical cavitation factor for vortex cavitation?

(c) In the ½ scale model experiments, at what times do you expect cavitation to occur during both the large flow and small flow conditions and where?

Response

The CFD analysis with the two-fluid model, MUAP-09025-P(R0), shows the flow conditions in the Advanced Accumulator.

(a) There is cavitation in the diffuser of the flow damper outlet nozzle for large flow injection. Cavitation in the diffuser for large flow injection will be vaporous cavitation. The inception cavitation factor is $\sigma_v \approx 8$ for large flow injection where the flow rate coefficient began to reduce as cavitation factor becomes smaller as shown in Fig. 5.1-1 in the topical report. It is supported by the CFD analysis.

(b) The CFD analysis shows there is not cavitation in the diffuser for small flow injection, but is at the center of the vortex chamber.

There exists a strong and steady vortex in the chamber so that the pressure at the center must be low enough to generate cavitation there during the early stage of the small flow injection.

[

]

Consequently, cavitation does not affect the critical flow at the throat nor flow rate coefficient. It can also deduce there is no flow choking for small flow injection.

The inception cavitation factor is between [ ] and [ ] from the CFD analysis.

(c) Please see the response mentioned above.

RAI 31.
How does the cavitation factor calculated with the flow damper outlet conditions represent cavitation in the vortex chamber?

Response
There is no way of representation of cavitation in the vortex chamber based on the cavitation factor defined by Equation (4-1) in the Topical Report MUAP-07001-P(R2). That is because the cavitation factor is used for evaluation of cavitation effect based on the flow rate coefficient, and not for cavitation state in the vortex chamber which does not affect the flow rate coefficient of the flow damper.

RAI 32.

Is there an estimate of void fraction in the vortex chamber and the flow damper outlet nozzle for the large and small flow conditions, respectively? Will the two phases separate and why? What is the effect of the voiding on the flow rate coefficient and any possible flow choking?

Response

The CFD analysis, MUAP-09025-P(R0), shows the void fractions in the Advanced Accumulator.

For small flow rate, please see the MHI's response to RAI30 of this document. Flow at the throat is single phase and free of void fraction. There may be cavitation at the center of a strong vortex in the vortex chamber and the reducer. There is no effect of voiding on the flow rate coefficient as mentioned above and no flow choking.

For large flow rate, cavitation occurs in the diffuser where pressure is a minimum due to the curvature of streamlines, or centrifugal force, by gradual expansion of the cross sectional area of the diffuser in addition to high velocity flow from the throat, and will be maintained at the critical pressure, or vapor pressure. (See the book:"Cavitation," by R.T. Knapp et. al., pp.280-281, McGraw-Hill, 1970) Therefore, pressure at the throat must be higher than the critical pressure, and flow will be single phase at the inception of cavitation. If cavitation fiercely occurs to fill the downstream of the throat, pressure there may reach the vapor pressure to choke the flow.

Fig. 32-1 shows the static pressure distribution in the outlet nozzle of the 1/2 scale model at [ ] seconds in Case 3 from the CFD analysis. The minimum scale is set at (the vapor pressure + 1Pa), [ ] Pa, in order to indicate the vapor pressure region in blue color. The cross section where the minimum pressure exists is shown on the right hand side in Fig. 32-1. The vapor pressure is restricted in the vicinity of the wall where cavitation occurs, and pressure in the most part of the cross section is higher than the vapor pressure. Thus, there is not choking flow in it. It is the severest case among all the operating conditions, so there must be no choking flow in the flow damper in the operating conditions.

RAI 36.

The accumulator characteristic correlations developed with the ½-scale accumulator test data indicate that the cavitation factor and flow rate coefficient are the only groups that represent important phenomena for high and low flow conditions.

(a) Are the cavitation factor and flow rate coefficient the only dimensionless groups that represent the important phenomena?

(b) In MHI's response to RAI 9-A (Sept, 2008), why is there no gravity term in the momentum equation? What are the boundary conditions (configuration)? What is the length scale (D) and the basis for being appropriate for all directions? Eq. 9-2 describes the local momentum balance. The statement below that Eq. states that the pressure loss is only function of Reynolds number. However, there is pressure loss beside the friction (viscous) loss that depends on the geometry. How is the pressure loss based on geometry preserved in different size facilities?

(c) Is the response for RAI 9-B (Sept, 2008) applicable to both large and small flow conditions? In case of gaseous cavitation (dissolved nitrogen), how do you calculate critical cavitation pressure.

(d) In the response to RAI 9-C, how are possible cavitation effects taken into account in the scaling assessment?

Response

The states of flow in the full-height 1/2-scale model of the flow damper and the standpipe are shown in Fig. 36-1. The scale of all dimensions is 1/2 except the height of the standpipe. For large flow injection, the ratio of cross sectional areas of the standpipe and the large flow pipe is [ ] so that there is no flow separation in the elbow between them to make a uniform velocity distribution in the large flow pipe. (See "Handbook of Hydraulic Resistance," by I.E. Idelchik, pp.400-401, 4th Revised and Augmented Edition, Begell House, Inc., 2007) In other words, the length of the standpipe does not affect the flow in the flow damper. In addition to that, the inlet of the standpipe below the anti-vortex cap is designed to have configuration without flow separation so that flow in the standpipe is uniform. The ratio of cross sectional areas of the accumulator tank and the standpipe is [ ], so the flow toward the inlet of the standpipe is rapidly accelerated for which the accumulator tank serves as a reservoir where water is almost at rest. Consequently, flow at the inlet of the standpipe is not affected by the flow conditions in the accumulator tank but only by the gas pressure. Friction losses in the standpipe for both the actual accumulator and the full-height 1/2 scale model are less than [ ] of flow resistance of the flow damper and negligible. Friction loss in the flow damper was evaluated with the data of 1/5 and 1/2 scale models, and the scale effect to friction loss was confirmed to be negligible for the operating conditions of the advanced accumulator. It is because the length of the flow path in the flow damper is less than that of the standpipe in addition to high Reynolds number.

For flow switching, a water column in the standpipe is in one dimensional motion as in water hammer analysis. Since it has actual velocity, actual amount of undershoot of water level happens in the full-height 1/2-scale standpipe so that simulation of water level transition in the standpipe can be realized. This is the reason the full height standpipe was chosen for the 1/2 scale model.

Froude number was used for the similarity of transition of water level in the standpipe during flow switching. A water column in the standpipe is in one dimensional motion as in water hammer analysis, where the height of the standpipe affects the motion of the water column but the hydraulic diameter does not. Please see the Response to RAI 18, UAP-HF-08174-P(R0). Therefore, the height of the standpipe should be used for the Froude number. The height of the standpipe for the full height 1/2 scale model is the identical as for the actual one.

For small flow injection, flow in the standpipe stops, so flow in the flow damper of 1/2 scale model is similar to that in the actual one. At very last stage of small flow injection, water level in the accumulator tank approaches the small flow pipe after the safety injection pumps start and the accumulator tank ends its role.

The minimum cross sectional area of the flow path is at the throat of the outlet nozzle. The cross sectional areas of the standpipe and the accumulator tank are [ ] and [ ] times the minimum cross sectional area respectively. Their dynamic pressures are less than [ ] of that at the throat and negligibly small. Consequently, the flow resistance of the advanced accumulator can be determined by the flow resistance of the flow damper.

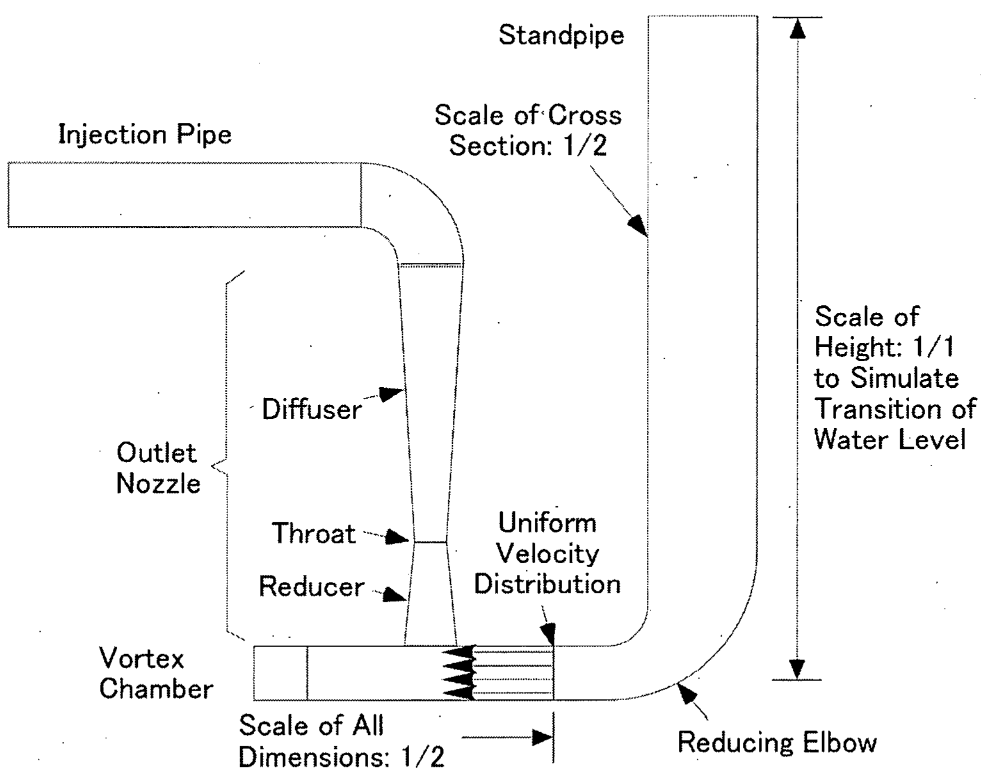

Fig. 36-1 1/2 scale Model of Flow Damper with full-height Standpipe

(a) Generally speaking, the dimensionless groups that represent the important phenomena are the cavitation factor, flow rate coefficient, Reynolds number and Froude number. Their roles are different from each other. Reynolds number represents effect of viscosity on flow resistance. Effect of viscosity is included in the flow rate coefficient which is less dependent on

Reynolds number in the plant operating conditions. Since water is isothermal, gravity affects only the boundary conditions at the free surface of water in the accumulator tank and the standpipe, and does not appear in the momentum equation. The cavitation factor directly affects the flow rate coefficient only when cavitation occurs.

(b) As mentioned in Response to RAI 9. UAP-HF-08174-P(R0), the boundary conditions are configurations of the model, inlet condition, namely, gas pressure in the accumulator tank, and outlet condition, namely, outlet pressure of the flow damper for the flow rate coefficient. The characteristic length (D) can be chosen as an arbitrary dimension except the heights of the standpipe and the accumulator tank. Then, the scale is 1/2 for all directions as shown in Fig. 36-1. The flow rate coefficient represents effects of the geometry and viscosity. The former is independent of Reynolds number, and constant for the flow damper with a given configuration for different size facilities. The latter is represented by Reynolds number which has less effect on the flow rate coefficient.

(c) Yes, the response for RAI 9-B (Sept, 2008) is applicable to both large and small flow conditions as mentioned above. Even in case of gaseous cavitation, effect of cavitation is evaluated in cavitation factor taken by the experiments. That is because local pressure is kept at vapor pressure where cavitaion occurs. This effect reflects on caviation factor.

(d) Please see the Response to RAI 33 for the effect of nitrogen on cavitation. If injection starts, cavitation nuclei rapidly grow as pressure decreases in the accumulator tank. The superficial density of water will be degraded only by pressure drop, which is independent of the scale of an accumulator.

RAI 37.
In MHI's response to RAI 10 (Sept 2008) to show similarity of the non-dimensional groups between the ½ scale test and the plant:

(a) What is the basis of assuming that reference velocities in the model and prototype will be equal (Um=Up)?

(b) Is it assumed that the losses in the flow path are preserved?

(c) What is basis of Eq. 10-9?

(d) What is scaloffing?

(e) Why is Cv for model and prototype in Eq. 10-11 the same?

(f) What is the basis for Eqs. 10-12 and 10-13?

Response
(a) Pressures in the accumulator tank and injection line and pressure difference across the flow damper of the full height 1/2 scale model were set to be equal to those of the actual accumulator. The friction of the flow damper is negligible, and form resistance is dominant as mentioned in the response to RAI 9 in this document. The configuration of the model was similar to those of the actual accumulator. Consequently, the velocity will be equal ($Um=U_p$).

(b) As mentioned above, the losses in the flow path will be preserved.

(c) During flow switching, motion of water column in the standpipe obeys the momentum equation, (18-1), cited in the response to RAI 18, UAP-HF-08174-P(R0). Making this equation in a dimensionless form yields a dimensionless parameter that is Eq. 10-9.

(d) The word "scaloffing" should be "scaling." It was mistyped. We apologize for it.

(e) Since friction loss is negligible and form resistance is dominant in the flow damper, Cv must be common both for model and prototype in Eq. 10-11.

(f) The data in Chapter 4.3 of the Topical Report shows flow rate coefficient is common both for 1/5 and 1/2 scale models. Then, it is also true for larger flow damper because of higher Reynolds number. This leads us to the conclusion that $C_{vm} = C_{vp}$ for $\sigma_{vm} = \sigma_{vp}$ both for large and small flow injections. Cavitation factor is an independent variable of the flow damper to get flow rate coefficient, and we can choose $\sigma_{vm} = \sigma_{vp}$.

RAI 38.

Table 11-1 in MHI's response to RAI 11 (Sept 2008) provides a comparison of various dimensions of the flow damper in the actual accumulator, and the 1/2 and 1/5 scaled models. MHI's response to RAI 14 (Sept 2008) stated that the flow rate coefficient depends on ratio of height to diameter for vortex damper, and that most of the energy loss depends on flow in vortex chamber but occurs in the injection pipe.

(a) What scaling rule is applied for determining vortex chamber height?

(b) What is the basis of claim that flow rate coefficient depends on ratio of height to diameter for vortex damper?

(c) Provide any quantitative estimate of losses in vortex chamber and the injection pipe.

Response

(a) The configuration of a model flow damper should be similar to that of an actual flow damper. If configuration of a model is modified, the characteristics of flow rate coefficient with respect to cavitation factor must be divagated from original one.

(b) The height is one of the very important dimensions of the vortex chamber. To understand its role, the flow structure in the chamber during small flow injection is explained first. If fluid were inviscid, there were no velocity boundary layers on the two disk walls of the chamber, then, two-dimensional vortex flow would appear in it. However, real viscous water generates velocity boundary layers on the two disk walls where centrifugal force is weaken and radially inward velocity is formed larger than that out of the boundary layers, or in the main flow where centrifugal force is preserved. Therefore, the height of the chamber determines the ratio of flow rate in the main flow with respect to that in the boundary layers. If the height becomes larger, the rate of the main flow will increase at the same velocity condition. If the thickness of the boundary layers is very small for large Reynolds number, the flow rate in the main flow will be dominant and dependency of flow rate ratio on Reynolds number can be negligibly small. But if the height of the chamber becomes further large for a given flow rate, tangential velocity from the small flow pipe reduces, and centrifugal force of a vortex in the chamber will be weaken. It will degrade the resistance of the flow damper. There is best height between them that is experimentally confirmed so that flow rate coefficients are common for 1/5 and 1/2 scale models and sufficient for the design requirement.

(c) Fig. 38-1 shows the pressure distributions in the flow damper and the outlet nozzle of the 1/2 scale model at [ ] seconds in Case 3 for small flow injection from the CFD analysis. The origin of the distance is at the radius equals to [ ] mm in the vortex chamber, while the radius of the outlet port is [ ] mm. The pressures are mean values in every cross sectional area.
The static pressure is transformed into the dynamic pressure in the vortex chamber and the reducer. The total pressure is, however, preserved in the vortex chamber, and is lost in the outlet nozzle. The amount of the pressure loss in the flow damper is [ ] kPa in this case, while the friction loss in the injection pipe of [ ] m in length is [ ] kPa.

[ ]

Fig. 38-1 Pressure distributions in the flow damper and the outlet nozzle of the 1/2 scale model at [ ] seconds in Case 3. The origin of the distance is at the radius equals to [ ] mm in the vortex chamber, while the radius of the outlet port is [ ] mm. The pressures are mean values in every cross sectional area.

RAI 39.
Referring to MHI's response to RAI 12 and 13 (Sept 2008):

(a) How is the frictional pressure drop preserved in different scale facilities?

(b) How much of the total pressure drop is contributed by the pressure drop in the vortex chamber?

(c) Is the flow field in vortex chamber controlled by the Reynolds number as defined in topical report MUAP-07001?

Response
(a) Please see Response to RAI 38(b).

(b) Please see Response to RAI 53.

(c) Generally speaking, the flow field in vortex chamber is controlled by the Reynolds number, and effect of viscosity on flow field decrease as Reynolds number goes large. Consequently, experimental investigation is necessary for the evaluation of effect of viscosity on the characteristics of flow rate coefficient of the flow damper.
The modified boundary layer coefficient, BLC*, are [ ] for the 1/2-scale model and [ ] for the actual flow damper, providing friction factor, *f* = [ ]. These values are close to [ ] for which the flow within the chamber conserves circulation. (J.W. Stairmand: Flow Patterns in vortex chambers for nuclear duties, Nucl. Energy, 1990, 29, No. 6, Dec., 413-418)

RAI 50.

MHI's response to RAI 20 (Sept 2008) explains why Case 1 have lower cavitation factors than Case 7 despite having higher pressures for small flow regime. It seems that cavitation factor does not represent any physics related to voiding in these tests. There can be choking in the diffuser section if voiding begins near the throat. In case of such choking, the cavitation factor becomes independent of the injection pipe exit pressure.
What is the purpose of using cavitation factor as one of the parameter?

Response

Cavitation factor is used for large flow injection, but not needed for small flow injection, since there is no effect of cavitation to flow rate coefficient. At the start of the development of the advanced accumulator, little information was available to substantiate the empirical estimation, but the results were later confirmed with experimental data.

There is no choking at the throat of the flow damper for small flow injection as mentioned in Response to RAI 30, and cavitation factor can be used as a parameter for flow rate coefficient. Please, see the location of cavitation calculated by CFD in MUAP-09025-P(R0).

RAI 53.

In the conference call on February 25, 2009, MHI indicated it has performed CFD calculations on the advanced accumulator.

Provide any final report about the CFD calculations, including the case and data files used to make the conclusions about the flow performance map (i.e. flow rate vs. time) as well as cavitation throughout the time of performance of the accumulator during both the large flow rate and small flow rate conditions.

Response

The CFD calculations have been submitted in the Technical Report, MUAP-09025-P(R0).