Response to NRC's Questions for Topical Report MUAP-07001-P(R1) THE ADVANCED ACCUMULATOR

Non-Proprietary Version

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Introduction

An advanced accumulator (ACC) that MHI has proposed to apply for the US-APWR has unique features to simplify the emergency core cooling system design and the low head safety injection pumps of a conventional nuclear pressurized water reactor (PWR) design. The design of the ACC was described in a topical report, Reference MUAP-07001-P(R1), which was submitted to the NRC on January 26, 2007. The topical report will be referred in the Design Control Document for the US-APWR. Since the submission of the reports, MHI has been asked questions by the NRC staffs. This report summarizes our response to those questions regarding the ACC.

QUESTION-1

Figure 3.3-2 in the Topical Report MUAP-07001-P provides an outline drawing of the geometry and specific dimension values of the flow damper for the US-APWR advanced accumulator, and Table 3.3-1 provides information regarding the aspect ratio, and the expansion angle of the diffuser. The flow damper geometry includes standpipe height and flow area dimensions, large flow inlet pipe dimensions, small flow inlet pipe width and aspect ratio, facing angle between the large and small flow pipes, offset of the large and small flow pipe from the vortex chamber diameter, dimensions and locations of the anti-vortex caps at the standpipe and small flow pipe, and diameters of vortex chamber, outlet port, throat, and injection pipe, respectively, as well as the diffuser angle.

Question 1-A

Is the flow damper geometry information specified in Figure 3.2-2 and Table 3.3-1 preliminary or final?

Response

The flow damper geometry specified in Figures 3.3-2 and Table 3.3-1 is the final geometry that will be used in the US APWR. Since the geometry of a fluidic device such as the flow damper is essential to determine its functions and performance, we have collected the appropriate quantitative data for the specified final geometry. This geometry will be controlled throughout the design, fabrication and installation of the component consistent with Section 5.2 in the Topical Report, Manufacturing Error, and as discussed below in response to RAI 18-A.

Question 1-B

Are the scaled test models described in the Topical Report scaled in accordance with the dimension values of the flow damper geometry?

Response

The scaled models of 1/3.5, 1/5 and 1/2 are scaled in accordance with the dimension values of the flow damper geometry, while 1/8.4 scaled model is not. As described

At the Objectives in the Section 4.2.1 in the Topical Report, this is because the 1/8.4 scaled model was built only for the demonstration of the basic functions of the Advanced Accumulator. But the other three models, as described bellow, have been used for quantitative evaluations of the ACC and necessary to be scaled with the final geometry.
1/3.5 scaled test was to demonstrate that a smooth flow switching behavior from the high flow to the lower flow as the tank level would decrease with the vortex cap.
1/5 scaled test and 1/2 scaled test were to confirm the operational characteristics of the flow damper and the performance characteristics during large and small flow.

As shown in Figure 1-1 (refer to Figures 4.2.4-3 and 4 in the Topical Report), the full height 1/2 scaled model has the full height accumulator tank and standpipe, and 1/2 scale dimensions of all the other parts. In other words, the flow damper and anti-vortex cap are completely 1/2 scale those of the actual accumulator. Since the flow friction of the standpipe is negligible, flow in the 1/2 scaled model is similar to that in the actual accumulator from the anti-vortex cap through the damper to the injection pipe. At the same time, since pressure and velocity are same as those in the actual accumulator, water level transients both in the accumulator tank and standpipe are just same as those in the actual accumulator. Hence, the 1/2 scale tests can evaluate the minimum remnant of water level in the standpipe that prevents gas entrainment at flow switching.

From the results of 1/5 and full height 1/2 scale tests, it was confirmed the flow characteristics of flow damper can be represented dimensionless number and were independent with the scaling. Therefore, the similarity law that evaluates the actual flow damper can be applied.
The performance of the actual accumulator will be confirmed in a pre-operational test.

Fig.1-1 Schematic Comparison of Actual Tank and Full Height 1/2 Scale Test Tank

Question 1-C

What are the dominant parameters that affect the flow rate characteristics of the flow damper? What would be the validity of the scaled tests results, especially the flow rate characteristics of the flow damper, if the final design values of the US-APWR advanced accumulators deviate from the values of these dominant parameters that are the bases for the scaled models?

Response

There are three dominant parameters. The first one is the ratio of the diameters of the vortex chamber and throat; the second one is the ratio of the areas of the large and small flow pipes, and the last one is the collision angle of large and small flows. With respect to the validity of the scaled test results, the final design values of the US-APWR advanced accumulators have employed the same diameter ratios and collision angles that have been examined in the scaled tests. Therefore, the scaled test results are valid to the US-APWR.
As discussed response to Question 18, the effects of the manufacturing tolerance to flow rate characteristics are small. This geometric dimension will be controlled throughout the design, fabrication and installation of the component.

Question 1-D

What are the top level flow damper design values to be specified in the Tier 1 information of the US-APWR Design Control Document?

Response

The dominant values that affect the flow rate characteristics and the required injection volume are throat diameter, vortex chamber inner diameter, collision angle (facing angle) between the large and small flow pipes, the height and width of the small flow inlet pipe, the height and width of the large flow inlet pipe, standpipe height and standpipe installation level in the tank.
We are discussing which values we will specify as the top level design values in the Tier 1.

As discussed above, throat diameter, vortex chamber inner diameter, facing angle between the large and small flow pipes, the height and width of the small flow inlet pipe are the dominant parameters that affect the flow rate characteristics of the flow damper. The standpipe height and standpipe installation level in the tank are necessary to determine the required injection volume for large and small flow injection periods.

A drawing of ACC with key dimensions will be included in the tier 1 documentation.

QUESTION-2

Section 2.2.1 indicates that the angle of collision (or facing angle) of the vortex chamber between the large and small flow rate pipes is determined so that the flow from the large flow rate pipe cancels the angular momentum of the flow from the small flow rate pipe.

Question 2-A

Describe in detail how this angle of collision was determined or calculated.

Response

The angular momentum will be null when the following equation is satisfied.

(2.1)

The collision angle is determined to satisfy the above equation.

Fig.2-1 Control of angular Momentum

Question 2-B

Is the collision angle specified in Figure 3.3-2 a fixed value for the flow dampers used in the US-APWR accumulators regardless of the geometry variation? Or will the collision angle vary on a plant specific basis depending on the geometry of the flow damper design, such as the ratio of the flow areas of large and small flow inlet pipes, the offsets of the large and small flow pipes from the vortex chamber diameter, the vortex chamber diameter, and the outlet port diameter?

Response

The collision angle is a fixed value regardless of the geometry variation. The collision angle is one of the parameters to be specified as one of the standard design values in DCD.
Since the geometry is fixed for the US APWR, then the collision angle is also fixed, and will be specified as a standard design value in the DCD. This fixed geometry including the collision angle was used in the scaled tests which showed the intended large flow without a vortex when flow was from both large and small inlet pipes.

Question 2-C

What is the sensitivity of angle of collision on the elimination of vortex in the vortex chamber, and the effect on the flow coefficient of the large flow injection?

Response

As far as the confluence of large and small flows goes straight to the throat, there is no vortex in the chamber and no effect on the flow coefficient as mentioned in the answer for Question 2A. If the angle of collision slightly changes form[ ]
[ ] remnant of the angular momentum is

[ ] (2.2)

The notations are shown in Fig.2-1.
If we neglect the loss across the chamber, conservation of the angular momentum yields tangential velocity at an arbitrary radius r as;

[ ] (2.3)

Equations (2.1) to (2.3) yield

[ ] (2.4)

where A_1 and A_2 are cross sectional areas of the large and small flow pipes respectively. Therefore, the tangential components of the velocities of the confluence at the inlet of the vortex chamber, r=R, and the throat, r=d/2, are respectively as follows:

[ ] (2.5)

[ ] (2.6)

The radial momentum balance at the collision point is;

[ ] (2.7)

Neglecting $\Delta\theta$, this equation gives the radial velocity component at the collision point as

[ ] (2.8)

On the other hand, the axial velocity component at the throat is

[ ] (2.9)

or

[ ] (2.10)

Substituting Equations (2.5), (2.6), (2.8) and (2.10) into the following Bernoulli's equation (2.11) gives static pressure drop across the vortex chamber.

[ ] (2.11)

If there is no remnant momentum, or $\Delta\theta = 0$, this equation reduces to

[ ] (2.12)

Hence, the change of the pressure drop is

[ ] (2.13)

Consequently, the rate of the pressure drop change is given by the following equation;

[ ] (2.14)

Assume the change of the collision angle is [ ], Equation (2.14) gives the rate of the pressure drop change to be [ ] Therefore, change of the flow rate coefficient is theoretically [ ] that is a half of the rate of the pressure drop change, because flow rate coefficient is the inverse of a square root of the resistance coefficient.

QUESTION-3

Section 2.2.2(3) states that if the influence of friction is negligible, flow rate coefficients (at small flow rate) will be common for any size of flow damper. However, Section 2.2.1 indicates that the strength of vortex in the vortex chamber depends on the ratio of the diameter of the vortex chamber and that of the outlet port.

Is the small flow rate dependent on the vortex strength, and therefore on the diameter ratio of the vortex chamber and the outlet port? What is meant by the statement that flow rate coefficients will be common for any size of flow chamber?

Response

Yes, the small flow rate depends on the ratio of the diameters of the vortex chamber and the throat. Flow rate coefficients will be identical for any size of flow chamber as long as the ratio of the diameters of the vortex chamber and throat is kept constant.

QUESTION-4

Confirm if Equation 2-1 is correct. It appears that the dynamic head term, ρU2/2, at the injection point is missing from the right hand side of the equation.

Response

Equation 2-1 in the Topical Report was verified to be correct. It is noted that K that is an overall resistance coefficient of accumulator injection system during large flow, in the right hand side of the equation, is addressed as the resistance coefficient to the overall pressure drops of flow damper, piping, and valves, and dynamic head loss at the injection point.

Equation 2-1 was led as following:

$$(Pgas + Ht\rho g) - (Pinj + Hp\rho g) = \frac{\rho K_1 U^2}{2} + \frac{\rho U^2}{2}$$

$$Pgas - Pinj = \frac{\rho(K_1 + 1)}{2} U^2 - \rho g(Ht - Hp)$$

$$= \frac{\rho K U^2}{2} - \rho g(Ht - Hp)$$

K_1	:	Resistance coefficient of accumulator injection system during large flow
K	:	Overall resistance coefficient of accumulator injection system during large flow ($=K_1+1$)
Pgas	:	Accumulator gas pressure
Pinj	:	Pressure at the injection point
Ht	:	Water level elevation of accumulator tank
Hp	:	Elevation of the injection point
U	:	Velocity in the injection pipe
ρ	:	Density of water
g	:	Gravity acceleration

QUESTION-5

Section 3.3 states that the detailed dimensions, inner diameters of the throat and the vortex chamber are determined from the tests using the ratio of Zobel diode. Table 3.3-1 also indicates that the inner diameter of the throat is the dominant factor of the resistance of the flow damper during large flow, the throat inner diameter is specified to meet the required resistance of the large flow, and that the inner diameter and height of the vortex chamber, respectively, are determined by tests using the ratio of Zobel diode.

Describe the tests, using the ratio of Zobel diode, for determining the dimensions of the vortex chamber and the throat.

Response

We have examined the configurations of the flow damper and chosen the design parameters for the US-APWR. The tests mentioned here are the tests conducted for those examinations.
The ratios of the inner diameter and height of the vortex chamber to the throat inner diameter of the US-APWR advanced accumulator are equal to those of Zobel diode respectively.
Refer to following URL site as Basics of Fluidics;
"http://www.tippettsfountains.com/fluidicsbasics.php?width=1020&heght=604"

QUESTION-6

Table 3.3-1 specifies a value for the height/width aspect ratio of the small flow inlet pipe to induce a stable jet flow in the vortex chamber. The footnote indicates that this aspect ratio is the maximum aspect ratio for which a stable jet flow is acquired from experience.

Describe the experience and how this aspect ratio was determined.

Response

The aspect ratio was determined by expert judgment.
We have applied expert judgment to the vortex damper that was shown to work well to achieve the functions.

QUESTION-7

Table 3.3-1 specifies an expansion angle degree for the flow area from the throat to the outlet pipe, which is indicated to be based on experience to prevent flow strip-off.

Describe the experience or any confirming tests, and clarify whether the expansion angle is dependent on the throat diameter and other parameters.

Response

We established the optimal expansion angle relying on established Boundary Layer theory. For example, in H. Schlichting's Text, "Boundary Layer Theory" (McGraw-Hill), it is shown that diffuser efficiency attains a maximum at the optimum zenith angle of between 3 and 8 degrees and that the velocity profiles for channels with a divergent angle greater than 8 degrees cease to be symmetrical. The data in Schlichting's text is valid for Reynolds numbers of $2.5\text{-}5.2 \times 10^5$ and is independent of the diameter of the throat.

QUESTION-8

In the 1/8.4 scale test (section 4.2.1) to confirm the operating principle of the flow damper, the test apparatus has an upright vortex chamber and a horizontal injection pipe, compared to the horizontal vortex chamber and a vertical outlet in the actual flow damper of the advance accumulator design.

Question 8-A

Explain how the offsets of the large and small flow pipes, respectively, from the vortex chamber diameter, and the angle of collision between the large and small flow pipes in flow dampers in the US-APWR accumulators are incorporated in the 1/8.4 test apparatus.

Response

The large and small flow pipe offsets and collision angle in the 1/8.4 model are geometrically similar to the full size accumulator. The only difference between the model and the full scale design is the horizontal vs. vertical orientation.

Question 8-B

Explain the effects or the distortions of the flow characteristics of the vertical vortex chamber and horizontal injection pipe from the prototype flow dampers.

Response

The influence of the vertical orientation of the chamber is considered to be negligible because of a higher flow velocity compared with the earth rotational speed.

The offsets of the flow pipes and the angle of collision in the vertical vortex chamber are identical with those in horizontal one respectively. Since the earth rotates 360° in 24 hours, or 0.0042 degree/sec, while flow in the vortex chamber rotates( )degree/sec. Hence, the effect of the earth's rotation on the flow in the vortex damper is negligible, and there is no difference of formation of a vortex in a vertical chamber from that in a horizontal one.

The gravitational terms can be included into the static pressure terms.

QUESTION-9

The accumulator flow damper uses an anti-vortex cap at the top of the standpipe to prevent the formation of a vortex as the flow drains from the tank, such that the flow will only switch from a high flow to a lower flow when the level in the accumulator tank drops below the top of the standpipe. Without the anti-vortex cap, as the water level is reduced close to the upper end of the standpipe, it is possible for supercritical flow to form at the inlet of the standpipe and gas could be entrained, and the flow rate would not shift smoothly. The 1/3.5 scale anti-vortex test was performed to test the anti-vortex cap at the top of the standpipe to confirm the prevention of forming a vortex at the large flow inlet at the end of large flow.

Question 9-A

Describe the mechanism by which the anti-vortex cap suppresses the formation of supercritical flow at the inlet of the standpipe so as to prevent gas entrainment.

Response

Supercritical flow exists in an open channel or a stream with a free surface, the anti-vortex cap prevents a free surface from being formed at the top of the standpipe until the very moment of flow switching. Hence, supercritical flow and associated gas entrainment can be suppressed.

Question 9-B

Explain how the design (dimension and shape) of the anti-vortex cap, and the position of the anti-vortex cap relative to the standpipe affect the phenomena of vortex formation or suppression at the standpipe inlet. Confirm with explanation whether the 1/3.5 scale test apparatus represents the actual anti-vortex cap design and installation.

Response

The anti-vortex cap at the top of the standpipe is composed of a cruciform plate and a flat plate with a skirt around it as shown in Figures.3.3-1 and 2 in the Topical Report. The cruciform plate prevents the formation of a vortex and works as a support of the flat plate at the same time. The minimum area of the flow path between the standpipe and the flat plate is much larger than the cross-sectional area of the standpipe not to increase flow resistance. The lower end of the skirt around the flat plate is slightly lower than the top of the inlet of the standpipe to attain a sharp switching of the flow. Since the diameter of the test tank was 1/3.5 that of the US-APWR accumulator tank, the scale of the model of the standpipe and the anti-vortex cap was chosen to be 1/3.5 in order to simulate the behavior of the free surface and flow. Hence, it represents the actual anti-vortex cap design and installation.

The inlet of the standpipe of full height 1/2 scale model is shown in figure 9-1.

Figure 9-1 Inlet of the standpipe of Full Height 1/2 scale model

Question 9-C

Explain why there is not a confirming test to demonstrate the anti-vortex function of the anti-vortex plate at the small flow pipe inlet.

Response

As some of you have seen the video tape at the pre-application review meeting on November 29 last year, vortex formation appears at the water level above about only the pipe opening length from the inlet port of the standpipe. When the accumulator ends its role, the free water surface in the accumulator tank is around [ ]above the small flow pipe, that is far larger than the size of the pipe opening length (around[ ]). Therefore, there is sufficient water height not to form a vortex at the inlet of the small flow pipe. However, since the flow injection continues afterward, the anti-vortex plate is placed at the small flow inlet just to provide a margin. Our conclusion is that there is no need to additionally demonstrate functional tests of the anti-vortex plate.

QUESTION-10

Figure 4.2.4-5 (2/2) shows the full height ½ scale Test Results (Case 1) of flow rate coefficient versus cavitation factor with cavitation factors ranging from about[ ]to [ ](Table 5.2-2 shows the range of cavitation factor for large flow injection between [ ]for instrumentation error associated with flow rate coefficient). Using the test data provided in Attachment 1 of Topical Report MUAP-07001-P and the flow rates from Figure 4.2.4-5 (1/2), the NRC staff performed a few calculations with the results showing a cavitation factor of about[ ]for the time at[ ]second.

Explain why the larger cavitation factor at the early part of the test is not included.

Response

An isolation valve that is not employed in the US-APWR, was used for the full height 1/2 scale test. The valve needs about[ ]seconds for its opening. Therefore, the data in this duration were not considered in the assessment. It is noted that flow rate coefficients vs. cavitation factors were determined by quasi-static tests, as mentioned at the note on page 4.2.4-8 of the Topical Report.

QUESTION-11

Attachment 1 of Topical Report MUAP-07001-P provides the test data of the full height 1/2 scale tests. These data include test tank pressure, flow damper outlet pressure, test tank level, tank water temperature, and standpipe water level as a function of time.

Attachment 2 of Topical Report MUAP-07001-P provides summarized flow characteristics (i.e., flow coefficients vs. cavitation factors) from the 1/2 scale test results.

The same information is provided in Figures 4.2.4-5 through 4.2.4-11, but they can not be easily discerned for any specific time.

Question 11-A

For Attachment 1 of Topical Report MUAP-07001-P, Mitsubishi Nuclear Energy Systems (MNES) is requested to provide the flow rate and corresponding calculated cavitation factor and flow coefficient at each time step. (Time steps larger than the 0.04 seconds currently used in Attachment 1 can be used.)

Response

In attachment A, the test tank pressure, flow damper outlet pressure, test tank level, tank water temperature, flow rate, and corresponding calculated cavitation factor and flow coefficient at each time step in full height 1/2 scale tests are summarized.

The test tank pressure, flow damper outlet pressure, test tank level, tank water temperature are same as in "Attachment 1 of Topical Report MUAP-07001-P(R1)"

Question 11-B

MNES is also requested to provide a similar table for the 1/5 scale test.

Response

In attachment B, the test tank pressure, flow damper outlet pressure, test tank level, tank water temperature, flow rate, and corresponding calculated cavitation factor and flow coefficient at each time step in 1/5 scale tests are summarized.

QUESTION-12

In the Full Height 1/2 Scale tests, Test Results (Case No. 5) were conducted with water containing dissolved nitrogen, and the results show that the flow rate coefficient, during large flow, was smaller than that of Case No. 1 without dissolved gas, and essentially the same for small flow with or without dissolved gas. However, it appears that Case No. 5 has lower tank water temperature than Case No. 1 (about 83°F vs. 87°F).

Explain how this water temperature difference affects the test results.

Response

Water temperature difference may affect density of water and solubility of nitrogen gas into water. The density of water varies only 0.07% and the solubility only 3% by a temperature change from 87°F to 83°F. The effect of the density difference has been included in a flow rate coefficient, Cv, and cavitation factor, σ_v. Concerning the solubility of nitrogen, cavitation originates not from dissolved gas but from tiny gas bubbles in water. Therefore, the nitrogen gas solubility does not contribute the test results. With respect to the cavitation effect due to gas bubbles, we will discuss cavitation nuclei at the question 16B.

QUESTION-13

Section 4.3 states the trend that the flow rate coefficient lessens as the cavitation factor becomes smaller for the large flow rate injection is reasonable, because cavitation is stronger for a smaller cavitation factor, and that the flow rate coefficient approaches a constant value as the cavitation factor gets larger, because cavitation is reduced and vanishes for larger cavitation factors.

Question 13-A

Discuss whether cavitation occurred in the Full Height ½ scale tests and the 1/5 scale tests, and how cavitation was detected in the tests.

Response

We didn't provide any detection system to observe cavitation in the Full High 1/2 scale tests and the 1/5 scale tests.
It is generally known that if there is no cavitation, the dimensionless parameter of internal flow is governed by only a Reynolds number. The experimental data indicated that the flow rate coefficient of the flow damper is independent of a Reynolds number, but depends on cavitation factors. Furthermore, the velocity at the throat reached up to[ ]ft/s (or[ ]m/s) with a back pressure of[ ]psia ([ ] MPa) at the end of the injection pipe. The momentum theory tells that without any cavitation, the pressure at the throat must be[ ]psia ([ ]MPa) at this large flow condition. This value is not only less than the vapor pressure of water, which is[ ]psia ([ ]kPa absolute), but also a negative absolute pressure. Consequently, we have concluded that there must be some cavitation occurring in the tests.

Question 13-B

Since the cavitation factor is calculated at the flow damper exit, rather than at the throat where cavitation most likely occurs, discuss whether there is a threshold number for the cavitation factor below at which cavitation would occur at the throat for large flow injection.

Response

It is not necessary to define a cavitation factor at the location where cavitation most likely occurs. That is because pressure distribution can be normalized along the diffuser from the throat to the injection pipe by the reference dynamic pressure at the damper exit, and you can define a cavitation factor either at the throat or at the exit. Both the cavitation factors can be directly converted to each other. In our calculation, we used the one at the exit for our convenience.

There must be a critical cavitation factor that indicates cavitation inception at the throat for large flow injection. The cavitation factor used in the Topical Report, or Thoma's sigma, is

$$\sigma = \frac{P_2 - P_v}{\Delta P},$$

where P_2 is pressure at the exit of the flow damper, P_v vapor pressure of water and ΔP pressure loss across the flow damper. Let the flow resistance coefficient of the flow damper be ζ_{damp}, then

[ ]

where ρ is density of water and V_2 mean velocity in the injection pipe. Combining these two equations and the momentum theory yield

[ ]

where P_t is pressure at the throat, d_p and d_t are the diameters of the injection pipe and the throat respectively. We used the one-dimensional momentum balance described as

[ ]

and the equation of continuity to get the above equation.
If the critical pressure at which cavitation can occur is the vapor pressure of water, this equation gives the threshold number, σ_{th}, below at which cavitation can occur, and

[ ]

We use $d_p/d_t \approx$[ ]for the US-APWR accumulator here.

Question 13-C

Since the small flow injection occurs after switching from large flow injection, the accumulator tank pressure and the injection point pressure during the small flow injection are lower than those during the large flow injection. In addition, the formation of a steady vortex in the vortex chamber would further generate a pressure gradient. Discuss why cavitation would not occur for small flow injection.

Response

For small flow injection, the mean velocity in the injection pipe is only up to[ ] ft/s (or[ ]m/s). Swirl flow in the diffuser may generate a reversed flow around the axis of the diffuser to transfer the pressure at the exit to the throat. This pressure prevents cavitation at the throat. On the other hand, a strong vortex flow at the outlet port of the vortex chamber may generate a steady vacuum core at the center of the vortex that will not reach the throat because of the reducer from the outlet port of the vortex chamber to the throat. Consequently, the flow rate coefficient is independent of a cavitation factor. This conclusion is confirmed by the data shown in Chapter 4 in the Topical Report.

QUESTION-14

Figure 4.3-1 shows that the flow coefficients versus cavitation factors of the flow damper for the full-height ½ Scale and 1/5 Scale Models that collapsed into the same lines for large and small flow rates. Therefore, Section 4.2 concludes that the flow rate characteristics with respect to cavitation factor shown in Figure 4.3-1 are the flow characteristics applicable to the actual accumulator.

Question 14-A

Explain how the ½ and 1/5 Scale Models preserve the same geometry relationship of the actual flow damper design in the US-APWR accumulator.

Response

All flow path dimensions for the full scale flow damper will be double those of the 1/2 scale model. Only the 1/2 scale test data was used to obtain the flow coefficient-cavitation factor relationship.

Question 14-B

Explain how the flow coefficient-cavitation factor relationships shown in Figure 4.3-1 are applicable to other flow damper designs that deviate from the basic geometry that is used for 1/5 and 1/2 scale model?

Response

The relationship between the flow coefficient and cavitation factor as shown in Figure 4.3-1 in the Topical Report is valid only for the flow damper shown in Figure 3.3-2 in the Topical Report and the same configuration with scaled-up and -down sizes. If some modification is applied to the basic geometry, the characteristics of flow coefficient for the new geometry must be developed. The flow damper is final geometry. The dominant dimensions of the flow damper will be controlled throughout the design, fabrication and installation of the component.

Question 14-C

What are the conditions or restrictions of the flow damper design to maintain the applicability of these relationships?

Response

The same configuration of the flow damper is required to maintain the applicability of the relationships. The scales of the flow damper should be equal to the 1/5 scale model or larger. This is because we have not had any data that shows Reynolds number or viscosity may not affect these relationships for a damper smaller than that of the 1/5 scale model.

QUESTION-15

Equations 5.1 and 5.2, respectively, describe the relationship between the flow rate coefficient and the cavitation factor for large and small flow rate injections.
The cavitation factor, defined in equation 5-4, is a function of both the outlet pressure and flow velocity (or pressure drop) of the injection pipe.
The cavitation factor is a function of the flow damper outlet pressure and injection flow rate, and the flow injection rate depends on the flow rate coefficient, which is correlated with the cavitation factor.

Describe the methodology for solving equations 5.1, 5.2, and 5.4.

Response

A detailed methodology will be discussed in a separate topical report of "Safety analysis methodology (LBLOCA and SBLOCA)," not in this ACC topical report. In the report, the applicability of WCOBRA/TRAC code will be described. This topical report will be submitted in this July.

QUESTION-16

Section 5.2 describes an estimation of uncertainty of the flow damper characteristic equations based on the full-height 1/2 diameter scale tests. Table 5.2-1 presents the dispersion of data from the characteristic equations of the flow rate coefficient for the large and small flows, respectively. This represents the goodness of the curve fitting to the test data from each test case.

Question 16-A

Explain why the test results from 1/5 scale test are not included in the development of the flow damper characteristics equation and the estimation of uncertainties of the damper flow characteristic equations.

Response

Inclusion of the 1/5 scale test data will not improve or even may degrade the accuracy of the flow characteristic equations, because Reynolds numbers of the 1/5 scale tests is much smaller than those of the 1/2 scale tests. The full height 1/2 scale tests are the most representative of the actual accumulator flow damper because geometric scaling is preserved, and the Froude numbers for the test facility and the actual accumulator match. Reynolds numbers of the full-height 1/2 scale tests are only a half of those of the actual flow damper and have less effect to the flow rate coefficients.

Question 16-B

Since Test Case No. 5 from Full Height 1/2 scale tests simulated the tank water with dissolved gas, which appears to be representative of the advanced accumulators that are covered with pressurized nitrogen, explain why test Case No. 5 is excluded from Table 5.2-1.

Response

In this test, nitrogen gas is compulsorily saturated by bubbling and showering which are not in the actual accumulator. Therefore, the test condition is much more critical than the actual accumulator. Consequently, using the case 5 test data will result in evaluating flow coefficient smaller than that of the actual accumulator.

Question 16-C

Explain why Test Case No. 7 from Full Height 1/2 scale tests is excluded from Table 5.2-1.

Response

The purpose of Case 7 of full height 1/2 scale test was to confirm if the test data covering the regions of cavitation factors during large break LOCA could be obtained by testing at low pressure. Since for Case 7 of full height 1/2 scale test, the initial tank pressure was set at 213 psig (1.5 MPa gage) and deviated largely from the actual operating condition, the flow characteristics obtained from this test could have large uncertainties. Therefore, the data of Case 7 were eliminated from the Table 5.2-1 in the Topical Report.

Question 16-D

Describe how the data dispersion results shown in Table 5.2-1, as well as other uncertainties and bias errors described in Section 5.2, will be accounted for in the application of the flow damper flow characteristics for the design basis loss-of-coolant accident (LOCA) analysis.

Response

The uncertainties, such as the data dispersion, instrument errors, and manufacturing tolerances, will be accounted for the design basis loss-of-coolant accident (LOCA) analysis.
Additional information will be provided in a separate topical report of "Safety analysis methodology (LBLOCA and SBLOCA)."

QUESTION-17

Tables 5.2-2 (1/2 and 2/2) provide the instrument errors associated with the flow rate coefficients for large and small flow rates, respectively, from the full height ½ scale test cases.

Question 17-A

Define the early, middle, and last injection stages from the tests for the large and small flow rates, and describe how these stages are related to LOCA event sequences.

Response

For a large flow rate, the early injection stage corresponds to the point in time when the isolation valve is fully open and the maximum flow rate occurs in LOCA, while the last injection stage corresponds to the timing just prior to the flow switching. The middle injection stage is an intermediate time between the early and last injection stages.
Relation to LOCA event sequences;
The early, middle, and last injection stages from the tests for the large flow rate are corresponding to the early, middle, and last injection stages of Blow Down & RV Refill.

For a small flow rate, the early injection stage corresponds to the time just after the flow switching, while the last injection stage corresponds to the timing just prior to the end of injection. The middle injection stage is an intermediate time between the stages.
Relation to LOCA event sequences;
The early, middle, and last injection stages from the tests for the small are corresponding to the early, middle injection stages of Core Re-flooding, and end of small flow injection.

Question 17-B

Provide a detailed description of how the instrument errors for each injection stage and each test case are obtained. The description should include (1)the instrument string including, sensor, process rack, analog/digital converter, process computer, and readout devices for each parameter measured in the tests, i.e., temperature, pressure, water level, and flow rate;(2)the accuracy or allowance associated with each instrument component, such as sensor reference, calibration, and measurement accuracies, respectively; rack calibration and measurement accuracies; sensor pressure and temperature effects; rack pressure and temperature effects; drift; process measurement accuracy; instrument range, span, and operating limits, etc.;(3)the methodology for combining the uncertainties, allowances, or errors of the instrument components associated with each parameter to arrive at the overall uncertainty of each measured parameter and (4) the methodology used to arrive at the total uncertainty for the flow rate coefficients for the large and small flow rates.

Response

We have followed the procedure mentioned below to estimate the uncertainty according to ANSI/ASME PTC19.1-1985 translated into Japanese by JSME.

- Decision of measuring process,
- Listing factors of elemental errors,
- Prediction of each elemental error and calculation of precision index and bias limit for each parameter,
- Calculation of total precision index and bias limit based on the propagation theory of errors,
- Calculation of uncertainty interval of each result, and
- Report of uncertainty, coverage, bias limit, precision index and degree of freedom.

1) Decision of Measuring Process

The measuring system is shown in Figure 17-1. The instrument strings for flow rate coefficients and cavitation factors are:

(1) Gas pressure in the test tank: pressure transducer for the test tank to amplifier to A/D converter to process computer,

(2) Water level in the test tank: differential pressure transducer for the water level to amplifier to A/D converter to Process Computer,

(3) Pressure in the injection pipe: pressure transducers for the injection pipe to amplifiers to A/D converter to process computer, and

(4) Specific weight of water, or water temperature in the test tank: thermocouple to amplifiers to A/D converter to process computer.

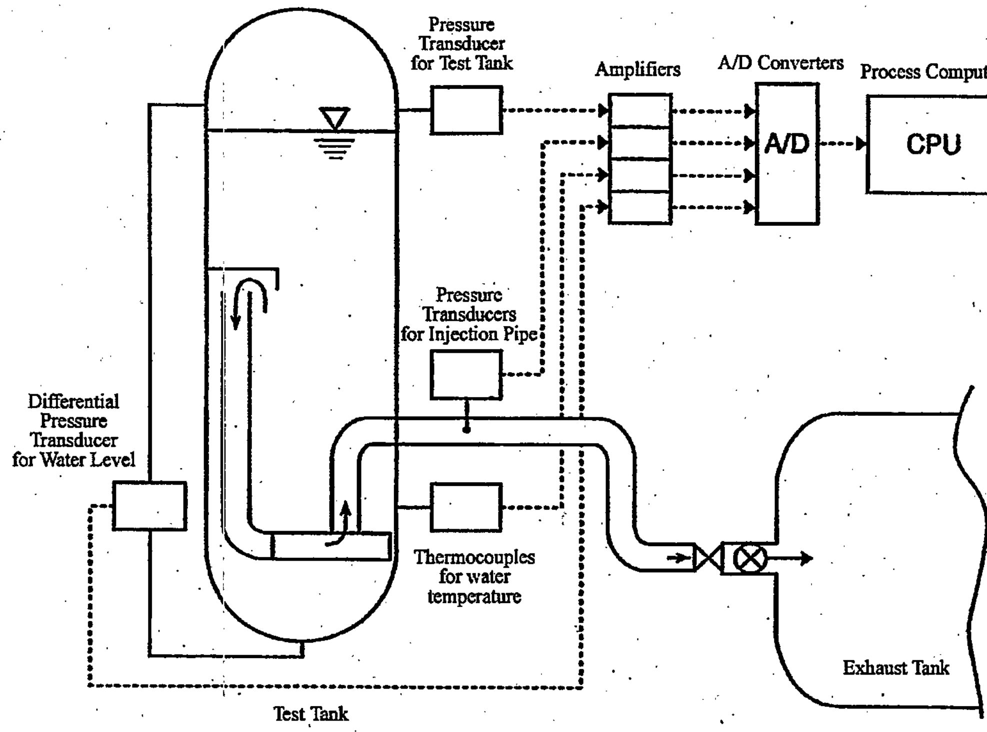

Figure 17-1 Measuring system of the Full Height 1/2 Scale Tests

Similar instrument strings for water level in the standpipe and pressure in the exhaust tank were installed, but not shown in this figure.
The sensor maker, Yamari Sangyo Co., supplied thermocouples whose accuracy was within [ ]F ([ ]K) guaranteed. The systems of the thermocouples connected to the amplifiers were calibrated at room temperature at the beginning of the tests.

2) Listing Factors of Elemental Errors

Flow rate is calculated from water level change in the test tank and the measured diameter of the test tank by using the following equation:

Flow rate:

$$Q=\frac{\pi}{4}D^2\frac{\Delta h}{\Delta t}, \quad \Delta h=\frac{\Delta P}{\gamma} \qquad (17.1)$$

where D is the diameter of the test tank, Δh the variation of water level in the test tank during time duration Δt and ΔP indication of pressure transducer for the water level in the test tank.

Flow rate coefficient is calculated from pressure difference over the flow damper, water level in the test tank, flow rate, specific weight of water, the measured diameter and the elevation of the injection pipe by using the following equation:

Flow Rate Coefficient:

$$C_v = \left[\frac{(P_t + \gamma H_t) - \left\{ P_p + \frac{\gamma}{2g}\left(\frac{4Q}{\pi d_p^{\,2}}\right)^2 + \gamma H_p \right\}}{\frac{\gamma}{2g}\left(\frac{4Q}{\pi d_o^{\,2}}\right)^2} \right]^{-\frac{1}{2}} \tag{17.2}$$

where P_p is pressure in the injection pipe, P_t gas pressure in the test tank, H_t water level in the test tank, H_p level of the injection pipe, d_p the inner diameter of the model injection pipe, d_o the inner diameter of the actual injection pipe, γ specific weight of water and g gravitational acceleration.
All the parameters used in these equations but gravitational acceleration, g, were assumed as factors of elemental errors.

3) Prediction of Each Elemental Error and Calculation of Precision Index and Bias Llimit for Each Parameter

(1) The elemental error of the diameter of the test tank was predicted with[ ] measured values every[ ] degree in circumference direction by a slide caliper calibrated with a standard gauge. The bias limit was predicted as a half of the mark interval, [ ] inches ([ ]mm), of the caliper. The absolute precision index was calculated to be[ ]inches ([ ]mm) from the[ ] measured values.

Absolute Precision Index: $$S_x = \left[\frac{\sum_{k=1}^{N} (X_k - \overline{X})^2}{N-1} \right]^{1/2} \tag{17.3}$$

Relative Precision Index: $$\frac{S_x}{\overline{X}} \tag{17.4}$$

where X_k is a measured value at k-th trial, $\overline{X}$ mean value and N total number of trials.

(2) The elemental error of water level was predicted with[ ]sets of values measured by the differential pressure transducer against the manometer attached to the test tank as a standard gauge. The measured values scattered independent of water levels, so we used Equation (17.4) to get the relative precision index as[ ]

(3) Specific weight of water was given by the Steam Table for measured temperature. The elemental error of specific weight was taken as ([ ]kg/m^3) that corresponds to[ ]degree Celsius of the maker warranty of the thermocouples. This error was treated as a bias limit.

(4) The elemental error of the pressure drop across the flow damper was predicted with[ ]sets of differential values measured by the pressure transducers in the test tank and injection pipe under common static pressures. The true value of the pressure drop was zero for any common pressures. The measured values scattered independent of the common pressures, and we used Equation (17.3) to get the absolute precision index as[ ] psi ([ ] kg/m^2).

(5) The elemental error of the height of the injection pipe was predicted with the data measured by the following procedures;
(a) A centerline was marked off at the pressure taps of the injection pipe,
(b) The level of the ceiling of the vortex chamber was marked off on the outside wall of the flow damper in the test tank,
(c) Strings with plummets were set at every[ ]degrees along the circumference of the vortex chamber,
(d) With a level gauge made of a transparent flexible tube with water inside, the level of the centerline of the injection pipe was marked off on every string with a plummet, and
(e) The height of every mark indicating the centerline on the string was measured from the mark on the outside wall of the flow damper with a steel ruler.
The error for Step (a) was predicted to be[ ] inches ([ ] mm) as a half of the mark interval of the steel ruler that was calibrated by a standard ruler. The error for Step (b) was also predicted to be[ ] inches ([ ] mm), because the procedure was same as that for Step (a). NO error occurred for Step (c). The error for Step (d) was predicted to be[ ] inches ([ ] mm) that was a half of the meniscus of the water surface in the tube, about[ ]mm. The error for Step (e) was predicted to be[ ] inches ([ ] mm) as a half of the mark interval of the steel ruler that was calibrated by a standard ruler. The linear summation of these errors yielded[ ] inches ([ ] mm) as the bias limit. [ ]sets of the measured values were scattered, and Equation (17.3) gave the absolute precision index as[ ] inches ([ ] mm).
(6) The elemental error of the diameter of the injection pipe was predicted with[ ] values measured every[ ]degrees in a selected section with a micrometer caliper calibrated with a standard gauge. The bias limit was predicted to be +/- [ ]inches ([ ]mm) of the reading error only because the measured values were derived from the read values minus the gauge error. The absolute precision index was calculated to be[ ]inches ([ ]mm) from the[ ] values.

4) Calculation of Total Precision Index and Bias Limit based on the Propagation Theory of Errors

Tables 17-1 and 17-2 are example lists of the parameters, average or planned values, absolute bias limits, absolute precision indices, relative bias limits, relative precision indices, relative influence coefficients and degrees of freedom in addition to the bias and precision errors estimated in Item 3) and used for the calculation of uncertainties of flow rates and flow-rate coefficients respectively.

5) Calculation of Uncertainty Intervals

Propagation equations of bias limit and precision index of each parameter were derived by Taylor expansion, and the uncertainties of flow rates and flow-rate coefficients were calculated.
Flow rate is given by Equation (17.1), and independent variables are D the diameter of the test tank, Δh the variation of water level in the test tank during time duration Δt and ΔP indication of pressure transducer for the water level in the test tank.

The propagation equations for flow rate are as follows;

Relative Bias Limit :

[ ]

Relative Precision Index:

[ ]

Relative Influence Coefficient of Diameter of Test Tank:

[ ]

Relative Influence Coefficient of Water Level of Test Tank:

[ ]

Relative Influence Coefficient of Specific Weight:

[ ]

Flow-rate coefficient is given by Equation (17.2), and independent variables are P_p pressure in the injection pipe, P_t gas pressure in the test tank, $H_t = \Delta P/\gamma$ water level in the test tank, H_p level of the injection pipe, d_p the inner diameter of the model injection pipe, d_o the inner diameter of the actual injection pipe and γ specific weight of water.

Relative Bias Limit :

Relative Precision Index:

Relative Influence Coefficient of Pressure Drop:

Relative Influence Coefficient of Water Level in Test Tank:

Relative Influence Coefficient of Height of Injection Pipe:

Relative Influence Coefficient of Specific Weight:

Relative Influence Coefficient of Flow Rate:

Relative Influence Coefficient of Diameter of Injection Pipe:

where

We used the following equation for the uncertainty of 95% coverage.

$$U_{RSS} = \sqrt{B_r^{\,2} + \left(t\frac{S_r}{\sqrt{N}}\right)^2}\,, \tag{17.5}$$

where B_r is relative bias limit, S_r relative precision index, N sampling number of flow rate or flow-rate coefficient and t Student t value which is given to degree of freedom at a table in ANSI/ASME PTC19.1-1985. Degree of freedom is

$$\nu_r = \frac{(S_r/r)}{\sum_{i=1}^{t}\left[\frac{\left(\theta_i S_{\bar{p}_i}/\bar{p}_i\right)^4}{\nu_i}\right]},$$

where $\bar{p}_i$, $S_{\bar{p}_i}$, θ_i, ν_i are the mean value, the relative precision index, the influence coefficient and the degree of freedom of i-th parameter.
Since if degree of freedom is 6 or larger, sampling number, N, is 7 or larger, $t/\sqrt{N}$ becomes less than 1. Hence, Equation (17.5) can be reduced as

$$U_{RSS} = \sqrt{B_r^{\,2} + \left(t\frac{S_r}{\sqrt{N}}\right)^2} < \sqrt{B_r^{\,2} + S_r^{\,2}}\,, \tag{17.6}$$

We used this equation for uncertainty of flow rate coefficients for conservative assessment and simplicity of calculation.

6) Report of Uncertainties, Coverages, Bias limits, Precision Indices and Degrees of Freedom

As explained above, the total uncertainties for the flow rate coefficients were according to ANSI/ASME PTC19.1-1985.

Table 17-1 Uncertainty of Flow Rate at Initial Stage of Large Flow of Case 1

	Parameter	Notation	Unit	Average (Planned) X	Bias Limit Bx	Precision Index Sx	Relative Bias Limit Bx/X	Relative Precision Index Sx/X	Relative Influence Coefficient θ	Degree of Freedom v

Table 17-2 Uncertainty of Flow-Rate Coefficient at Initial Stage of Large Flow of Case 1

	Parameter	Notation	Unit	Average (Planned) X	Bias Limit Bx	Precision Index Sx	Relative Bias Limit Bx/X	Relative Precision Index Sx/X	Relative Influence Coefficient θ	Degree of Freedom v

Question 17-C

As the heading of the section "bias errors" indicates, clarify whether the instrument errors will be treated as bias errors, rather than random errors.

Response

The title "bias errors" is incorrect. The instrument uncertainties cited in this section include both bias and random errors. Hence, the title should be "Instrument Uncertainties" as follows:

Instrument Uncertainties

A true value may be different from the experimental equations. This difference is defined as an experimental error. However, the true value is not known and needs to be estimated. Each string of a sensor, an amplifier, an A/D converter and a process computer was calibrated one by one. Instrument uncertainties consist of accuracy of each instrument string as a bias error and sampling error of each calibration as a random error and were calculated by root-sum-square of them. Instrument uncertainties associated with flow rate coefficients is shown for each test case in Table 5.2-2.

Table 5.2-2(1/2) Instrument Uncertainties at Large Flow

Test Case	Range of Cavitation Factor	Instrument Uncertainties Associated with Flow Rate Coefficient (95% Coverage)		
		Early Injection	Middle Injection	Last Injection

Table 5.2-2(2/2) Instrument Uncertainties at Small Flow

Test Case	Range of Cavitation Factor	Instrument Uncertainties Associated with Flow Rate Coefficient (95% Coverage)		
		Early Injection	Middle Injection	Last Injection

Question 17-D

Describe how the instrument errors of various injection stages of each and all of the seven test cases in Tables 5.2-2 are accounted for in the application of the flow damper flow characteristics equations in the safety analysis.

Response

As previously mentioned in Question 16-D, the uncertainties, including the instrument uncertainties will be accounted for the design basis loss-of-coolant accident (LOCA) analysis. Additional information will be provided in a separate topical report of "Safety analysis methodology (LBLOCA and SBLOCA)."

QUESTION-18

In the section under "Manufacturing Errors" in Section 5.2, it is stated that the manufacturing error associated with the flow rate coefficient will be less than a percent.

Question 18-A

Describe in detail how this value was obtained.

Response

The affect for flow rate coefficient by the manufacturing error is considered in two parts which are during large flow and during small flow. The affects for flow rate coefficient by the manufacturing tolerance during large flow and small flow are described respectively.

(1) During large flow

Dimension of each part of flow damper which affects the performance of flow damper during large flow and these errors for flow rate coefficient are described as follows:

(a) Throat diameter

The throat in outlet pipe has the minimum flow area among that of every part in flow damper and therefore this is the dominant dimension to the flow damper performance during large flow.
The manufacturing tolerance is[ ]inch ([ ]mm) for actual throat diameter[ ]inch ([ ]mm). Under the same pressure condition, the flow rate "Q" during large flow is proportional to the throat flow area "A", thus, the relation between throat error ratio, "ΔB/B" and the flow rate error ratio is

$$\frac{(Q \pm \Delta Q)}{Q} = \frac{A \pm \Delta A}{A} = \frac{\frac{\pi}{4}\{(1 \pm \Delta B/B)B\}^2}{\frac{\pi}{4}B^2} = (1 \pm \Delta B/B)^2$$

$$= 1 \pm 2\Delta B/B + (\Delta B/B)^2 \cong 1 \pm 2\Delta B/B \qquad (18\text{-}1)$$

$$\frac{Q \pm \Delta Q}{Q} = 1 \pm \Delta Q/Q = 1 \pm 2\Delta B/B \qquad (18\text{-}2)$$

Thus,

$$\Delta Q/Q = 2\Delta B/B[\qquad\qquad] \qquad (18\text{-}3)$$

Since the flow rate coefficient ratio and the flow ratio are equivalent, the flow rate coefficient error of flow damper during large flow due to manufacturing tolerance of the throat is[ ].

(b) Facing angle (i.e. collision angle) of large and small flow inlet pipe

The facing angle of large and small flow inlet pipe is[ ], which is the angle that flows from large and small flow inlet pipe collide together and vanishes the angular momentum to eliminate the vortex in the flow chamber during large flow injection. Therefore, the error of this collision angle would cause vortex during large flow injection and affect the damper performance. This effect of collision angle tolerance during large flow injection on the flow rate coefficient of flow damper (i.e. flow rate coefficient error) is evaluated [ ] based on the development test data.

The ratio of the dimension of large and small flow pipes may affect the flow rate coefficient. However the affect of the ratio can be negligible since the manufacturing tolerance is much smaller than actual dimension. Therefore this error is not considered in this evaluation.

As discussed above, the flow rate coefficient error of flow damper during large flow injection by manufacturing tolerance is[ ]using the following root-mean-square value with margin.

$$[\qquad] \tag{18-4}$$

(2) During small flow

Dimension of each part of flow damper which affects the performance of flow damper during small flow and these errors for flow rate coefficient are described as follows:

(a) Throat diameter

The relation between the throat dimension error ratio and the flow rate error ratio during small flow injection is represented in "$\Delta B/B = \Delta Q/Q$" Note1, which is defined as follows considering the manufacturing tolerance[ ] inch ([ ]mm) for the actual throat diameter[ ] inch ([ ]mm).

$$\Delta Q/Q = [\qquad] \tag{18-5}$$

Therefore, the flow rate coefficient error of flow damper during small flow due to manufacturing tolerance of the throat is[ ].

(b) Vortex chamber diameter

The relation between the vortex chamber diameter error ratio and the flow rate error ratio during small flow injection is represented as (a) above in "$\Delta B/B = \Delta Q/Q$" Note1, which is defined as follows considering the manufacturing tolerance[ ]inch ([ ]mm) for the vortex chamber diameter [ ]inch ([ ]mm).

$$\Delta Q/Q = \left[\qquad \right] \tag{18-6}$$

Therefore, the flow rate coefficient error during small flow due to manufacturing tolerance of vortex chamber diameter is[ ].

Note 1: Assuming free vortex, the pressure drop is the square function of the ratio of vortex chamber diameter and throat diameter.

(c) Small flow pipe width

The relation between the error ratio of small flow pipe width "S" and that of flow rate is represented in "ΔQ/Q = ΔS/S", which is defined as follows considering the manufacturing tolerance[ ]inch ( ]mm) for the actual small flow pipe width[ ]inch ( ]mm).

$$\Delta Q/Q = \left[\qquad \right] \tag{18-7}$$

Therefore, the flow rate coefficient error during small flow due to manufacturing tolerance of small flow pipe width is[ ].

(d) Small flow pipe height

The relation between the error ratio of small flow pipe height G and that of flow rate is represented in "ΔQ/Q = ΔG/G", which is defined as follows considering the manufacturing tolerance[ ]inch( ]mm) for the actual small flow pipe width [ ]inch ( ]mm).

$$\Delta Q/Q = \left[\qquad \right] \tag{18-8}$$

Therefore, the flow rate coefficient error during small flow due to manufacturing tolerance of small flow pipe width is[ ].

As discussed (a), (b), (c) and (d) above, the flow rate coefficient error of flow damper during small flow injection by manufacturing tolerance is[ ] using the following root-mean-square value with margin.

$$\left[\qquad \right] \tag{18-9}$$

(3) Summary

As stated above, the flow rate coefficient of flow damper during large flow by manufacturing tolerance is[ ] and during small flow is[ ]. However, the flow rate coefficient error is set to[ ] during both large flow and small flow in accordance with that of during large flow.

The dimensions of the test model were controlled very precisely, so the manufacturing errors of the test model were negligible small to that of the actual flow damper.

Question 18-B

Clarify whether the manufacturing error will be treated as a bias or random error, and why.

Response

Manufacturing errors are treated as bias errors. This is because manufacturing errors of the flow damper are based on the dimensional tolerances specified in the manufacture drawings.
In the estimation of manufacturing errors, we assumed the worst case which is that the flow damper is manufactured with the upper/lower tolerance limits.

Question 18-C

Describe how this manufacturing error will be applied in the application of the flow damper flow coefficients equations in the safety analysis.

Response

This was previously discussed in Question 16-D

QUESTION-19

Section 5.3 describes an estimation of potential uncertainties of the accumulator tank water level for switching from large to small flow rate. Table 5.3-1 provides the instrument errors and deviation for flow switching level for the seven test cases from the full height ½ scale tests. The overall uncertainties of flow switching level were obtained using the square root of sum of the squares method.

Question 19-A

Clarify what each value under Instrument Error and Deviation for Flow Switching Level represents.

Response

The instrument error indicates error of the differential pressure transducer that measures water level in the test tank. The deviation for flow switching level indicates the difference of measured water level at flow switching from the lower end of the skirt of the anti-vortex cap.

Question 19-B

Describe how each of these values were obtained. (Refer to RAI No. 17.B)

Response

The instrument error B is the total error of the measuring string shown in the Figure 19-1.
The calibration of the differential pressure transducer for water level in cooperate with the amplifier was done by the sensor maker. The resolution of the A/D converter and the process computer was given as a 1/2 of minimum resolution.

Figure 19-1 Instrument Error of Water Level

The deviation for flow switching level S is the difference of measured water level at flow switching from the lower end of the skirt of the anti-vortex cap. The measured water level at switching of flow rate was taken at the intersecting point of large and small gradients of the water level transient. The lower end of the skirt of the anti-vortex cap was the planned level.

Question 19-C

Describe how the switching water level uncertainties in Table 5.3-1 are accounted for in the LOCA safety analysis.

Response

The switching water level uncertainties will be accounted for the design basis loss-of-coolant accident (LOCA) analysis, assuming a smaller water volume for the large flow rate periods. Detailed information will be provided in a separate topical report of "Safety analysis methodology (LBLOCA and SBLOCA)."

Attachment A

Full Height 1/2 Scale Tests
Test Data and calculated cavitation factors and flow rate coefficients

Full Height 1/2 Scale Test (Case 1)

time(sec)	test tank pres. (kg/cm^2)	flow damper outlet pres. (kg/cm^2)	test tank level (m)	tank water temperature (℃)	flow rate (m^3/s)	cavitation factor σ_v	flow rate cosfficient C_v

Full Height 1/2 Scale Test (Case 1)

time(sec)	test tank pres. (kg/cm^2)	flow damper outlet pres. (kg/cm^2)	test tank level (m)	tank water temperature (°C)	flow rate (m^3/s)	cavitation factor σ_v	flow rate cosfficient C_v

Full Height 1/2 Scale Test (Case 1)

time(sec)	test tank pres. (kg/cm^2)	flow damper outlet pres. (kg/cm^2)	test tank level (m)	tank water temperature (°C)	flow rate (m^3/s)	cavitation factor σ_v	flow rate cosfficient C_v
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Full Height 1/2 Scale Test (Case 1)

time(sec)	test tank pres. (kg/cm^2)	flow damper outlet pres. (kg/cm^2)	test tank level (m)	tank water temperature (℃)	flow rate (m^3/s)	cavitation factor σ_v	flow rate cosfficient C_v

Full Height 1/2 Scale Test (Case 2)

time(sec)	test tank pres. (kg/cm^2)	flow damper outlet pres. (kg/cm^2)	test tank level (m)	tank water temperature (℃)	flow rate (m^3/s)	cavitation factor σ_v	flow rate cosfficient C_v

Full Height 1/2 Scale Test (Case 2)

time(sec)	test tank pres. (kg/cm^2)	flow damper outlet pres. (kg/cm^2)	test tank level (m)	tank water temperature (℃)	flow rate (m^3/s)	cavitation factor σ_v	flow rate cosfficient C_v
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Full Height 1/2 Scale Test (Case 2)

time(sec)	test tank pres. (kg/cm^2)	flow damper outlet pres. (kg/cm^2)	test tank level (m)	tank water temperature (°C)	flow rate (m^3/s)	cavitation factor σ_v	flow rate cosfficient C_v

Full Height 1/2 Scale Test (Case 2)

time(sec)	test tank pres. (kg/cm^2)	flow damper outlet pres. (kg/cm^2)	test tank level (m)	tank water temperature (℃)	flow rate (m^3/s)	cavitation factor σ_v	flow rate cosfficient C_v

Full Height 1/2 Scale Test (Case 3)

time(sec)	test tank pres. (kg/cm^2)	flow damper outlet pres. (kg/cm^2)	test tank level (m)	tank water temperature (°C)	flow rate (m^3/s)	cavitation factor σ_v	flow rate cosfficient C_v

Full Height 1/2 Scale Test (Case 3)

time(sec)	test tank pres. (kg/cm^2)	flow damper outlet pres. (kg/cm^2)	test tank level (m)	tank water temperature (℃)	flow rate (m^3/s)	cavitation factor σ_v	flow rate cosfficient C_v

Full Height 1/2 Scale Test (Case 3)

time(sec)	test tank pres. (kg/cm^2)	flow damper outlet pres. (kg/cm^2)	test tank level (m)	tank water temperature (℃)	flow rate (m^3/s)	cavitation factor σ_v	flow rate cosfficient C_v

Full Height 1/2 Scale Test (Case 3)

time(sec)	test tank pres. (kg/cm^2)	flow damper outlet pres. (kg/cm^2)	test tank level (m)	tank water temperature (℃)	flow rate (m^3/s)	cavitation factor σ_v	flow rate cosfficient C_v

Full Height 1/2 Scale Test (Case 4)

time(sec)	test tank pres. (kg/cm^2)	flow damper outlet pres. (kg/cm^2)	test tank level (m)	tank water temperature (℃)	flow rate (m^3/s)	cavitation factor σ_v	flow rate cosfficient C_v

Full Height 1/2 Scale Test (Case 4)

time(sec)	test tank pres. (kg/cm^2)	flow damper outlet pres. (kg/cm^2)	test tank level (m)	tank water temperature (°C)	flow rate (m^3/s)	cavitation factor σ_v	flow rate cosfficient C_v

Full Height 1/2 Scale Test (Case 4)

time(sec)	test tank pres. (kg/cm^2)	flow damper outlet pres. (kg/cm^2)	test tank level (m)	tank water temperature (℃)	flow rate (m^3/s)	cavitation factor σ_v	flow rate cosfficient C_v

Full Height 1/2 Scale Test (Case 4)

time(sec)	test tank pres. (kg/cm^2)	flow damper outlet pres. (kg/cm^2)	test tank level (m)	tank water temperature (°C)	flow rate (m^3/s)	cavitation factor σ_v	flow rate cosfficient C_v

Full Height 1/2 Scale Test (Case 4)

time(sec)	test tank pres. (kg/cm^2)	flow damper outlet pres. (kg/cm^2)	test tank level (m)	tank water temperature (°C)	flow rate (m^3/s)	cavitation factor σ_v	flow rate cosfficient C_v

Attachment B

1/5 Scale Tests

Test Data and calculated cavitation factors and flow rate coefficients

1/5 Scale Test (T. No. 1/5-2-1)

time(sec)	test tank pres. (kg/cm^2)	flow damper outlet pres. (kg/cm^2)	test tank level (m)	tank water temperature (℃)	flow rate (m^3/s)	cavitation factor σ_v	flow rate cosfficient C_v

1/5 Scale Test (T. No. 1/5-2-1)

time(sec)	test tank pres. (kg/cm^2)	flow damper outlet pres. (kg/cm^2)	test tank level (m)	tank water temperature (℃)	flow rate (m^3/s)	cavitation factor σ_v	flow rate cosfficient C_v

1/5 Scale Test (T. No. 1/5-2-2)

time(sec)	test tank pres. (kg/cm^2)	flow damper outlet pres. (kg/cm^2)	test tank level (m)	tank water temperature (℃)	flow rate (m^3/s)	cavitation factor σ_v	flow rate cosfficient C_v

1/5 Scale Test (T. No. 1/5-2-2)

time(sec)	test tank pres. (kg/cm^2)	flow damper outlet pres. (kg/cm^2)	test tank level (m)	tank water temperature (℃)	flow rate (m^3/s)	cavitation factor σ_v	flow rate cosfficient C_v

1/5 Scale Test (T. No. 1/5-2-2)

time(sec)	test tank pres. (kg/cm^2)	flow damper outlet pres. (kg/cm^2)	test tank level (m)	tank water temperature (°C)	flow rate (m^3/s)	cavitation factor σ_v	flow rate cosfficient C_v

time(sec)	test tank pres. (kg/cm^2)	flow damper outlet pres. (kg/cm^2)	test tank level (m)	tank water temperature (℃)	flow rate (m^3/s)	cavitation factor σ_v	flow rate cosfficient C_v

1/5 Scale Test (T. No. 1/5-2-3)

time(sec)	test tank pres. (kg/cm^2)	flow damper outlet pres. (kg/cm^2)	test tank level (m)	tank water temperature (℃)	flow rate (m^3/s)	cavitation factor σ_v	flow rate cosfficient C_v