Enclosure 3

UAP-HF-18001
Docket No. 52-021

MHI's Response to NRC's Request for Additional Information 1098-9305

February 2018
(Non-Proprietary)

RAI 1.

On Page 3-3 of the topical report, it is stated: "Because the outlet piping is above the flow damper, the un-available "dead" water is less than that for an ACC design that has its outlet piping attached under the flow damper due to the need for increased installation space. The ACC main dimensions are shown in Fig. 3.2-1." From the dimensions given on Figure 3.2-1, the outlet piping is actually below the flow damper. This needs to be restated.

Response

MHI will revise the topical report by changing the word "flow damper" to "vortex chamber" to clarify the meaning of the statement.

(See the markup attached to this response)

RAI 2.

On Page 3-5, it is stated: "The equalizing pipe is provided to ensure prevention of a vortex formation during large flow injection." What is the effect of the equalizing pipe during small flow where the vortex formation is needed to achieve the desired flow rate?

Response

During small flow injection, a strong vortex is formed because only tangential flow enters into the vortex chamber. During this condition, the pressure distribution in the vortex chamber is dependent on the radial direction.
Circumferential forces are in equilibrium with the radial pressure gradient and are not affected by the end wall boundary layer.

The pressure difference between the points where equalizing pipe is attached is insignificant since these points are on the same circumference. Therefore, flow characteristics during small flow injection are not affected by the equalizing pipe since vortex formation is not interrupted. The flow in this short cylindrical vortex chamber depends on the intensity of the incoming tangential velocity and it is not impacted.

This flow behavior was confirmed during full-scale qualification testing when acceptance criterion for small flow injection was satisfied.

MHI will revise the topical report by adding a description regarding the effect during small flow injection.

(See the markup attached to this response)

RAI 3.

Table 3.3-1 provides the bases for all flow damper dimensions except for equalizing pipe. What are the dimensions of the equalizing pipe and what is the basis for these dimensions?

Response

The Inner diameter of the equalizing pipe installed across the vortex chamber is [ ].

The purpose of the equalizing pipe is to equalize the pressure across the vortex chamber during large flow injection. To efficiently accomplish this, a pipe with an inner diameter of [ ] was selected as the largest optimum size to connect to the vortex chamber wall. This size was shown to adequately cancel any pressure differential across the vortex chamber during full scale testing.

MHI will revise the topical report by providing the equalizing pipe inner diameter and the basis to Table 3.3-1 as new item numbered (11).

(See the markup attached to this response)

RAI 4.

On Page 4.2.1-22, it is stated: "the objective of the 1/5-sacle test is was to observe the flow in the flow damper during large and small flow, large to small flow switching, and to confirm the expected behavior of the flow." What is the basis for not repeating the confirmatory test with a modified vortex chamber with flow equalizer piping?

Response

Confirmatory tests were performed during the development phase. The purpose of the confirmatory tests was to observe the operational principles and function of each targeted part.

The operational principle of the equalizing pipe is simply to equalize pressure across the vortex chamber. The equalizing pipe does not affect any operational function such as direct flow to the outlet during large flow injection, sharp flow switching, and strong vortex formation during small flow injection. Therefore, confirmatory testing with a modified vortex chamber was not necessary.

MHI will revise the topical report by adding a description of the equalizing pipe and the basis for not repeating the confirmatory test with a modified vortex chamber.

(See the markup attached to this response)

RAI 5.

On Page 4.2.1-24, the 1/5-scale low pressure injection testing method which was included in Rev 5 as Item b is deleted without explanation anywhere in the document. The results of the low pressure injection test are also deleted on Page 4.2.1-26. What is the basis for the removal of this information?

Response

In topical report rev.5, the purpose of 1/5-scale low pressure injection testing was to confirm that the flow characteristics could be represented by dimensionless numbers, and these dimensionless numbers do not depend on the scale.

In topical report rev.6, experimental equations based on the full-scale test data were described. Therefore, the 1/5-scale low pressure injection test was deleted since it is no longer necessary in terms of above mentioned purpose.

MHI will revise the topical report as adding an appendix to explain the updates from topical report revision 5 to 6, including the above mentioned basis.

(See the markup attached to this response)

RAI 6.

On Page 4.2.2-4, there is no mention of a full-scale test case prior to the modification of the vortex chamber that added the equalizing pipe. If it is not a full-scale test without the equalizing pipe that necessitated the modification, what is the basis for changing the design?

Response

During full-scale testing, unstable flow during the large flow injection phase was sometimes observed. It was determined that this was due to swirl flow in the vortex chamber that was being caused by uneven pressure across the vortex chamber. In order to eliminate any unstable flow, it is necessary to prevent swirl flow in the vortex chamber during the large flow rate injection phase.

An effective method to prevent swirl flow is to equalize the pressure across the vortex chamber. Therefore, it was determined to install an equalizing pipe across the vortex chamber.

MHI will revise the topical report to add description of the equalizing pipe and an appendix to explain the updates from topical report revision 5.

(See the markup attached to this response)

RAI 7.

In Rev 5, Equations 4-8 and 4-9 were used for flow rate coefficient and cavitation factors, respectively as part of the now deleted 1/5-scale low pressure injection testing method. In Rev 6, the same equations were used on Page 4.2.2-6 (Equations 4-7 and 4-8) for full-scale qualification test with the addition of the Nitrogen contribution. What is the reason for inclusion of the Nitrogen contribution in Rev 6?

Response

In topical report rev.5, the nitrogen term was actually considered but was not included in the equation because the significance of the nitrogen term on the flow rate coefficient and cavitation factors was negligible (approx. 0.002% as Cv, comparing with and without the nitrogen term).

In topical report rev.6, it was included in the equation in order to precisely describe all factors considered regardless of their magnitude.

MHI will revise the topical report by adding an appendix to explain the updates from topical report revision 5, including above mentioned reason.

(See the markup attached to this response)

RAI 8.

In Rev 6, the correlation equation in the LOCA analysis computer code (Equations 5-9 and 5-10) are slightly different from Rev 5 (Equations 13 and 14). Will the Chapter 15 LOCA analysis be rerun with the new correlation equation? If not, provide a justification as to why the LOCA cases will not be rerun.

Response

The Chapter 15 LOCA analysis will be rerun with the new characteristics equations at future phase.

3.2 ACC Dimensions and Structure

An outline drawing of the ACC is shown in Fig. 3.2-1. The inner diameter of the tank is [ ] ft [ ] and total height is [ ]. The tank inner structure includes the flow damper and the standpipe. Because the outlet piping is above the ~~flow damper~~vortex chamber, the un-available "dead" water is less than that for an ACC design that has its outlet piping attached under the ~~flow damper~~vortex chamber due to the need for increased installation space. The ACC main dimensions are shown in Fig. 3.2-1. RAI 1 RAI 1

3.3 Structure of the Flow Damper

The structure of the flow damper is shown in Fig. 3.3-1 and Fig. 3.3-2. The flow damper consists of an anti-vortex cap, standpipe, vortex chamber, small flow pipe, and outlet pipe. The inlet of the standpipe is set at the water level at which the flow rate switches from large flow to small flow. The anti-vortex cap installed on the standpipe inlet prevents gas entrainment just before the flow switching and improves the flow-switching characteristics. The small flow piping is connected to the vortex chamber tangentially. An anti-vortex plate is also provided at the inlet of the small flow pipe and prevents the gas in the ACC gas space from being sucked into the standpipe when the water level is reduced to the small flow inlet. During large flow injection, the flows from the standpipe and the small flow pipe collide in the vortex chamber and the resulting water stream flows out of the chamber directly without forming a vortex. The equalizing pipe is provided to ensure prevention of a vortex formation during large flow injection. By pressure equalizing across the vortex chamber, swirl flow production during large flow injection is prevented. This design ensures that the performance of the flow damper during large flow injection will be stable and consistent with the characteristics equation as described in Chapter 5 of this report. On the other hand, the equalizing pipe does not interrupt the vortex formation during small flow injection because only tangential flow enters into the vortex chamber, and the pressure difference between the points where equalizing pipe is attached is insignificant. The throat portion and diffuser are provided on the outlet pipe to increase the flow resistance during small flow, recover the pressure during large flow, and provide a smooth transition for the pipe. The detailed dimensions, such as the inner diameters of the throat, and the vortex chamber, are determined from the tests using the ratio of Zobel diode. The basis for determining the dimensions is shown in Table 3.3-1.

RAI 2
RAI 6

Fig. 3.3-1 Overview of the Flow Damper

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Fig. 3.3-2 Outline Drawing of the Flow Damper

Table 3.3-1 The Basis for the Flow Damper Dimension

Regions	The bases of dimension
(1) Standpipe height	Specified to assure the required injection water volume during small flow injection is maintained between the inlet of the standpipe and the upper end of the vortex chamber, and to prevent the water level from reducing much below the upper end of the vortex chamber.
(2) Height of standpipe inner section	Specified to be consistent with the width of the large flow pipe connecting to the vortex chamber to assure the smooth flow from the standpipe to the vortex chamber.
(3) Width of standpipe inner section	Specified to limit the flow velocity just before the flow switching to prevent significant entrainment of gas during the water level transient in the standpipe.
(4) Inner diameter of the throat	The inner diameter of the throat is the dominant factor of the resistance of the flow damper during large flow. The inner diameter of the throat is specified to meet the required resistance of large flow.
(5) Inner diameter of the vortex chamber	The inner diameter of the vortex chamber is determined by tests using the ratio of Zobel diode.
(6) Height of the vortex chamber	The inner height of the vortex chamber is determined by tests using the ratio of Zobel diode.
(7) Width of small flow pipe	It is preferable that the width of the small flow pipe be as small as possible to increase the flow damper resistance during small flow. However, if the aspect ratio of the small flow pipe (height/width) is large, a stable jet flow is not formed. It is necessary that a stable jet flow is induced from the small flow pipe to the vortex chamber in order to form the stable vortex. Thus, the width of the small flow inlet pipe is specified with an aspect ratio of [ ] Note. Note: Max. aspect ratio for a stable jet flow is acquired from experience.
(8) Width of large flow pipe	It is preferable that the width of the large flow pipe is as large as possible to reduce the flow damper resistance during large flow. Therefore, the width of the large flow pipe is specified to make it as large as practical according to the structure considering the facing angle of the large flow and small flow pipe.
(9) Facing angle of large flow pipe and small flow pipe	The facing angle of the large flow and small flow pipe is specified to balance the angular momentum of each other so that no vortex is formed in the chamber during large flow considering the width of large flow pipe.
(10) Expansion angle of the throat	It is preferable that the flow area from the throat to outlet pipe increases gradually in order to return the kinetic pressure to the static pressure during large flow. However, if the expansion angle is too large, the flow may strip off the pipe and cause an energy loss. Therefore, the expansion angle is specified as [ ] degrees which is less than [ ] degrees, which prevents flow stripping based on experience.
(11) Inner diameter of the equalizing pipe	The purpose of the equalizing pipe is to equalize the pressure across the vortex chamber during large flow injection. To efficiently accomplish this, a pipe with an inner diameter of [ ] was selected as the largest optimum size to connect to the vortex chamber wall.

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4.2.1.3 1/5-Scale Test

1) Objectives

The objective of 1/5-scale test was to observe the flow in the flow damper during large and small flow, large to small flow switching, and to confirm the expected behavior of the flow.

(Note) RAI 4
The 1/5-scale test was performed without the equalizing pipe. This is because the equalizing pipe does not affect the operational principle because it is not directly related to any operational function such as direct flow to the outlet during large flow injection, sharp flow switching, or strong vortex formation during small flow injection.

2) Test Apparatus

The outline drawing of the test apparatus is shown in Fig. 4.2.1.3-1. The test facility consists of a test tank, flow damper, standpipe, injection piping, and exhaust tank. The flow damper is made of transparent acrylate to allow the fluid characteristics in the flow damper to be observed. A ball valve (nominal diameter is [ ]) is provided in the injection line as the isolation valve and a gate valve (nominal diameter is [ ]) is also provided in the injection line to control the flow resistance.

Appendix B RAI 5 RAI 6 RAI 7

Explanation about updates from rev.5

This appendix provides explanation about the basis for the design modification (installation of equalizing pipe), summary of updates based on the design modification, and explanation about each updates from revision 5 this report.

1. Basis for the design modification

During full-scale testing, unstable flow during the large flow injection phase was sometimes observed. It was determined that this was due to swirl flow in the vortex chamber that was being caused by uneven pressure across the vortex chamber.
In order to eliminate any unstable flow, it is necessary to prevent swirl flow in the vortex chamber during the large flow rate injection phase. An effective method to prevent swirl flow is to equalize the pressure across the vortex chamber.
Therefore, it was determined to install an equalizing pipe across the vortex chamber.

2. Summary of topical report update based on the design modification

Revision 6 of this report incorporates the design modification (installation of equalizing pipe) and qualification tests results performed in a full-scale test facility.
Description about Full-Height 1/2-scale model test, low pressure injection test with 1/5-scale test and discussion regarding scalability were deleted, and full-scale qualification test results were added in revision 6 of this report.

3. Explanation about each updates

Location	Explanation
ABSTRACT	Descriptions were updated incorporating the followings. - Change of the verification base to full-scale qualification test from scaled tests. - Deletion of 1/2-scale test, while 1/5-scale test was retained as a visualization test. - "significant" was added to precise description because gas entrainment, even such a slight quantity such that performance of the ACC was not influenced, is acceptable.
INTRODUCTION	Descriptions were updated incorporating that the ACC design verification base was changed to full-scale qualification test from scaled tests.
Fig. 2.1-2	Editorial modification.(Legend for RCP is added)
2.2.2	Contents of Section 4.3.1 and 4.3.2 of revision 5 were moved to Section 2.2.2 because they contain detailed explanation of phenomenological features and effects on flow characteristics. While, scalability and CFD related descriptions were deleted because these are no longer necessary.
2.3.2 2)	Editorial modification. (Capitalized)
3.0	Title was changed. ("as-installed" was removed since it is not needed to clarify)
Fig. 3.2-1	Fig. 3.2-1 was revised to reflect the design modification (equalizing pipe installation).
3.3	Further descriptions about equalizing pipe were added.
Fig. 3.3-1	Fig. 3.3-1 was revised to reflect the design modification (equalizing pipe installation).
Fig. 3.3-2	Fig. 3.3-2 is revised to reflect the design modification (equalizing pipe installation).
Table 3.3-1 Item (1)	"much" was added to precise description because gas entrainment, such a slight quantity that performance of the ACC was not influenced, is acceptable.
Table 3.3-1 Item (3)	"significant" was added to precise description because gas entrainment, such a slight quantity that performance of the ACC was not influenced, is acceptable.

Location	Explanation
4.0	Title was changed. ("confirmatory" was removed since this section describes both confirmatory and qualification testing) Description about joint study was deleted since it was related to scaled tests and no longer necessary to describe in this report. Description about scalability was deleted because it is no longer necessary.
4.1	Title was changed. ("scale" was removed since this section describes both scaled and full-scale testing) Descriptions were changed as clarifying confirmatory tests conducted during development phase and qualification tests conducted to verify the design. Confirmatory item (3) to (9) were deleted because these were related to scalability. Description about qualification test was added as identifying two verification items and one confirmatory item. Fig. 4.1-1 was deleted because of above mentioned reason.
4.2	Section structure is changed. 1/8.4, 1/3.5 and 1/5-scale test were included in 4.2.1 Confirmatory Testing. Full Height 1/2-Scale Test is deleted as replaced by 4.2.2 Qualification Testing. Table, Figure, Photo and Equation numbers were modified accordingly. Fig 4.2.4-12, The test results of water level reduction during flow rate switching, was deleted because they were Full Height 1/2-Scale tests results. Contents of Section 4.3.1 and 4.3.2 of revision 5 were moved to Section 2.2.2 because they contain detailed explanation of phenomenological features and effects on flow characteristics. The other part of Section 4.3 of revision 5 was deleted because these were no longer necessary since related to scalability and CFD. Section 4.4 of revision 5, Quality Assurance of the ACC Test Program, was deleted because the contents of section 4.4 was related to scaled tests. (Quality assurance of the full-scale qualification test was added on 4.2.2 7)

Location	Explanation
4.2.1.3	Descriptions about 1/5-scale low pressure injection test were deleted because the purpose of 1/5-scale low pressure injection testing was to confirm that the flow characteristics could be represented by dimensionless numbers, and these dimensionless numbers do not depend on the scale. These were no longer necessary since it was qualified by full-scale testing results.
Fig 4.2.2-1 Fig 4.2.2-2	Figures are changed to full-scale test facility. Comparison of Full Height 1/2-Scale and actual tank is deleted.
4.2.2 3) Test Conditions	Descriptions were modified precisely, while test condition itself was not changed from Full Height 1/2-Scale tests.
Table 4.2.2-1	Initial gas and water volume was changed to the full-scale tank values.
4.2.2 4) Parameters and Measuring Equipment	Equations for the flow rate coefficient and cavitation factor were added. Nitrogen term was added to describe precisely, although the significance of it was negligible.
4.2.2 5) Acceptance Criteria	Acceptance criteria for qualification testing were added.
4.2.2 6) Test Results and Conditions	Description about reproducibility was added because the reproducibility test results were also used for creation of characteristics equations and random error evaluations. Descriptions, tables and figures were updated with full-scale test results satisfying the acceptance criteria.
4.2.2 7) Quality Assurance	Description about quality assurance of the qualification test was added.
5.0	Description of 1/2-scale test and scaling effect was deleted. The uncertainty evaluations were updated with full-scale test results.
5.1.1	Characteristics equations were updated with the full-scale qualification test results.
Fig. 5.1-1	The figure was updated with full-scale qualification test results.
5.1.2	The basis of error evaluation was changed to GUM ISO/IEC Guide 98-3 because the full-scale qualification test was performed according to the quality manual of MHI Research & Innovation Center which refers GUM ISO/IEC Guide 98-3 as standard guidance of uncertainty evaluation.

Location	Explanation
5.1.2 (1)	Equation 5-4 was modified as considering reproducibility test results for each case.
Table 5.1-1	Case by case evaluation result was not described because comprehensive value is applied to safety analyses.
5.1.2 (2)	Descriptions related to ANSI/ASME PTC19.1 1985 were deleted because uncertainty evaluation was performed based on GUM ISO/IEC Guide 98-3. Values were updated with the full-scale qualification test results.
Table 5.1-2	Instrument uncertainty evaluation results were described simply because comprehensive value is applied to safety analyses.
5.1.2 (4)	Descriptions were modified based on GUM ISO/IEC Guide 98-3 methodology.
Table 5.1-3	Values were updated with the full-scale qualification test results.
5.2	Values were updated with the full-scale qualification test results.
Table 5.2-1	Evaluation was changed from root mean square to addition of flow switching level deviation and instrument error to have conservative value.
5.3	"2 seconds" and related description of time delay by dissolved nitrogen was deleted since it is not directly used in safety analyses model.
-	Section 5.4in revision 5, Estimation of Scaling Effect for Characteristic Equations, was deleted since it is no longer necessary.
5.4	Section 5.5 in revision 5 was moved to Section 5.4. Characteristics equations were modified based on the full-scale qualification test results.
6.0	Descriptions were changed because the basis was changed to full-scale qualification test and terms related to scalability were no longer necessary. Characteristics equations were modified based on the full-scale qualification test results.
7.0	Description was modified based on the full-scale qualification test results. Description about joint study was deleted since it was related to scaled tests and no longer necessary to describe in this report.

Location	Explanation
8.0	Reference 4.3-1, 4.3-4 and 4.3-5 of revision 5 were deleted since these were related to scalability. And the others were renumbered accordingly.
Appendices	This appendix was added as Appendix B. Attachment 1, test data of Full Height 1/2 Scale Tests, was deleted. Attachment 2, Flow Characteristics of Flow Damper with Full Height 1/2 Scale Tests results, was deleted.