DRAFT SAFETY EVALUATION BY THE OFFICE OF NEW REACTORS

TOPICAL REPORT MUAP-07001, REVISION 7

"THE ADVANCED ACCUMULATOR"

MITSUBISHI HEAVY INDUSTRIES, Ltd

DOCKET NO. 52-021

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Enclosure

1.0 INTRODUCTION

In support of the application for the design certification (DC) for the United States - Advanced Pressurized Water Reactor (US-APWR), Mitsubishi Heavy Industries, Ltd. (MHI), hereinafter referred to as the applicant, submitted Topical Report MUAP-07001-P, Revision 7, "The Advanced Accumulator" (ML18178A267). The US-APWR design uses advanced accumulators (ACC) as a part of the emergency core cooling system (ECCS) design. The US-APWR ACC design is built on the operating experience of a conventional accumulator used for mitigating the consequences of loss-of-coolant accidents (LOCAs) in pressurized water reactors (PWR). Similar to the conventional accumulators used in the operating PWR plants, the ACC is an accumulator tank partially filled with borated water and pressurized with nitrogen. The ACC is attached to the primary system with a series of check valves and an isolation valve and is aligned during operation to allow flow into the primary coolant system if the primary system pressure drops below the pressure of the accumulator. The US-APWR ACC design differs from the conventional accumulators in that it incorporates a flow damper in the accumulator tank to provide a passive flow control. The flow damper is an inherently reliable passive fluidic device to achieve a desired reactor coolant injection flow profile without the need for any moving parts.

Emergency core cooling during a LOCA is one of the primary functions of the ECCS. In a conventional PWR, the ECCS consists of accumulators, high-head safety injection system (SIS), and low-head SIS to accomplish these ECCS functions. During a large break LOCA (LBLOCA), the fuel cladding temperature increases due to a lack of liquid in and around the core. An LBLOCA generally includes blowdown, refill, reflood, and long-term cooling phases. After the initial blowdown, the ECCS is required to inject water into the core to limit the rise of fuel temperature in three steps. In the refill phase, the accumulators quickly inject water at a high flow rate to fill the lower plenum and downcomer of the reactor vessel. Subsequently, the core is reflooded by the water head in the downcomer, and the high-head and low-head SIS inject flow to keep high water level in the downcomer to reflood the core. In the long-term cooling phase after core reflood is completed, the low-head injection system provides water to remove decay heat and maintain the core in a flooded state.

As described in more detail in the technical evaluation section of this report, in the US-APWR ECCS design, the ACC switches its flow rate from large-flow injection to small-flow injection automatically and passively after the ACC injection reduces the water level in the tank below the top entrance of the large-flow standpipe. According to the applicant, the combination of the ACC and the high-head injection system performs the function of the low-head injection system in the reflood and long-term cooling phases, and therefore, eliminates the need for the low-head injection system. Also, during an LBLOCA, it is necessary to start the ECCS pumps prior to the end of accumulator injection to the reactor vessel. The ACC injects water longer than a conventional accumulator, thereby allowing more time to start the ECCS pumps. The applicant asserts that this will allow the US-APWR to use gas turbine generators as opposed to the emergency diesel generators.

The ACC design simplifies the ECCS design by the elimination of low-head safety injection (SI) pumps and increases the amount of time available to start backup emergency power system. The applicant expects that the use of ACCs rather than the low-head SI pumps in the US-APWR design will reduce the net maintenance and testing workload at nuclear facilities.

Topical Report MUAP-07001-P, Revision 7, describes the ACC design, the principles of operation and important design features of the ACC, the empirical characteristic correlations of the ACC, and experimental programs to prove the concept and develop the correlations. The application indicates that the flow characteristics of the ACC have been verified by a full-scale qualification testing and can be fully described as a function of dimensionless numbers. Empirical flow rate coefficients have been developed from the test results and will be used in an integrated thermal hydraulic model of the US-APWR Reactor Coolant and ECCS systems to assure the US-APWR meets or exceeds all regulatory requirements.

2.0 REGULATORY EVALUATION

The staff's review of MUAP-07001-P, Revision 7, evaluates the applicant's compliance with the following regulatory requirements:

- General Design Criterion (GDC) 35, "Emergency core cooling," in Appendix A to Title 10 of the *Code of Federal Regulations* (10 CFR) Part 50, "Domestic Licensing of Production and Utilization Facilities," as it relates to the requirement for a system to provide abundant emergency core cooling to satisfy the ECCS safety function of transferring heat from the reactor core following any loss of reactor coolant at a rate such that (1) fuel and clad damage that could interfere with continued effective core cooling is prevented, and (2) clad metal-water reaction is limited to negligible amounts.

- Section 50.46 (10 CFR 50.46), "Acceptance criteria for emergency core cooling systems for light-water nuclear power reactors," as it relates to the requirement for an ECCS designed with a calculated cooling performance for a spectrum of postulated piping breaks within the reactor coolant pressure boundary to assure that cooling performance for the most severe postulated LOCAs is calculated. The ECCS cooling performance following postulated LOCAs must be calculated in accordance with an acceptable evaluation model to demonstrate conformance to the following acceptance criteria set forth in 10 CFR 50.46(b):

  - The calculated maximum fuel element cladding temperature does not exceed 1200 ^{o}C (2200 ^{o}F).

  - The calculated total local oxidation of the cladding does not exceed 17 percent of the total cladding thickness before oxidation.

  - The calculated total amount of hydrogen generated from the chemical reaction of the cladding with water or steam does not exceed one percent of the hypothetical amount that would be generated if all of the metal in the cladding cylinders surrounding the fuel, excluding the cladding surrounding the plenum volume, were to react.

  - Calculated changes in core geometry are such that the core remains amenable to cooling.

- After any calculated successful initial operation of the ECCS, the calculated core temperature is maintained at an acceptably low value and decay heat is removed for the extended period of time required by the long-lived radioactivity remaining in the core.

- Section 50.46 (10 CFR 50.46(a)(1)(i)) also requires that for the realistic analysis of the ECCS cooling performance, the uncertainties in the analysis method and input must be identified and assessed so that the uncertainty in the calculated results can be estimated and accounted.

The US-APWR ECCS design, including the ACCs, must comply with GDC 35, and the cooling performance will be evaluated through the safety analyses of LOCAs for the full spectrum of break sizes (including LBLOCA and small-break LOCA (SBLOCA)) to demonstrate that the above acceptance criteria are met.

The staff's evaluation of the ACC topical report includes the evaluation of the ACC characteristic equations and uncertainties and applicability of the characteristic equations to US-APWR as part of the LOCA evaluation models for the calculation of the US-APWR ECCS capability, as required by 10 CFR 50.46 and GDC 35.

3.0 TECHNICAL EVALUATION

The US-APWR ECCS system configuration includes four ACCs connected to the reactor coolant system (RCS) cold legs. In addition, four high head injection subsystems inject directly into the reactor vessel downcomer following accumulator injection.

The ACC topical report describes the system as consisting of a tank partially filled with borated water and pressurized with nitrogen, and a flow damper inside the tank. The flow damper consists of a vortex chamber located near the bottom of the accumulator tank, a standpipe connected to a large-flow pipe attached radially to the vortex chamber, a side entry small-flow pipe tangentially connected to the vortex chamber, and a reducer-diffuser nozzle connected to the outlet port of the vortex chamber and the injection pipe. A pressure equalizing pipe is connected across the vortex chamber. The standpipe and the small flow inlet pipe also include anti-vortex caps. The configuration and operation principle of the ACC design is shown in Figure 2.2.1-1, "Principle of Advanced Accumulator Operation," and the detailed structure of the flow damper is shown in Figure 3.3-1, "Overview of the Flow Damper," of the Topical Report MUAP-07001-P, Revision 6, Agencywide Document Access and Management System (ADAMS) Accession No. ML17040A160. The staff noted an inconsistency in the description of the outlet piping on Page 3-3 of the topical report and Figure 3.2-1 and requested the applicant to clarify the location of the outlet piping in its request for additional information (RAI) 9305, Question No. 1. In its response to RAI 9305, Question No.1, dated February 1, 2018 (ML18037A649), the applicant corrected the location description of the outlet piping relative to the flow damper. The staff finds the above response acceptable because the revised description is consistent with Figure 3.2-1 and based on this response, RAI 9305, Question No. 1 was previously tracked as a Confirmatory Item. The staff verified that the markups have been incorporated into Revision 7 of the topical report. Therefore, the staff considers RAI 9305, Question No. 1, resolved and closed.

If a LOCA occurs and pressure in the reactor vessel decreases below the ACC pressure, the check valves in the injection pipe open to permit the injection of the ACC cooling water into the reactor vessel. With the initial water level in the accumulator tank higher than the elevation of the inlet of the standpipe, water flows into the vortex chamber through both the large-flow rate and small-flow rate pipes. These flows collide with each other at a design facing angle between the large flow and small flow inlet pipes at the vortex chamber to cancel angular momentum. This prevents vortex formation in the vortex chamber as the staff observed in a video of the test as described in more detail below. The ACC topical report indicates that the equalizing pipe is provided to ensure prevention of vortex formation during large flow injection. Consequently, the flow resistance in the vortex chamber is small, resulting in a large flow rate. The flow through the flow damper is essentially the usual pipe flow without a strong vortex. The flow through the outlet nozzle dominantly experiences a pressure reduction in the reducer and a pressure recovery in the diffuser. The throat of the outlet nozzle is the critical section to determine the ACC flow rate.

The staff noted that Table 3.3-1, provides the bases for all flow damper dimensions, except for the equalizing pipe. In RAI 9305, Question No. 3, the staff requested the applicant to provide the dimensions of the equalizing pipe and its basis. In response to RAI 9305, Question No. 3 dated February 1, 2018 (ML18037A649), the applicant stated that the purpose of the equalizing pipe is to equalize the pressure across the vortex chamber during large flow injection. The pipe size was selected to efficiently accomplish this, by canceling any pressure differential across the vortex chamber and this was demonstrated during full scale testing. The applicant proposed to revise the topical report to add the equalizing pipe dimension and the basis for the selection in Table 3.3-1, "The Basis for the Flow Damper Dimension." The staff finds the above response and the revision to the topical report acceptable because it provides a complete list of all flow damper dimensions, including the equalizing pipe and based on this response, RAI 9305, Question No. 3, was previously tracked as a Confirmatory Item. The staff verified that the markups have been incorporated into Revision 7 of the topical report. Therefore, the staff considers RAI 9305, Question No. 3, resolved and closed.

The large-flow injection phase continues until the water level in the accumulator tank falls below the inlet level of the standpipe, and the flow in the standpipe almost comes to a stop. The flow from the small-flow pipe enters the vortex chamber tangentially, which creates a strong vortex in the vortex chamber. The vortex flow in the chamber creates a large pressure drop, and therefore, results in a small-flow injection rate. The switching from the large-flow to small-flow injection phase is thus accomplished passively without any moving parts. The topical report stated that "[t]he equalizing pipe is provided to ensure prevention of a vortex formation during large flow injection." In RAI 9305, Question No. 2, the staff requested the applicant to discuss the effect of the equalizing pipe during small flow where the vortex formation is needed to achieve the desired flow rate. In its response to RAI 9305, Question No. 2, dated February 1, 2018 (ML18037A649), the applicant stated that 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 the acceptance

criterion for small flow injection was satisfied. The applicant proposed to revise the topical report to address the effect of the equalizing pipe during small flow injection consistent with its response. The staff finds the above response and the revision to the topical report acceptable because the design and qualification testing demonstrated that the equalizing pipe does not affect small flow injection and based on this response, RAI 9305, Question No. 2, was previously tracked as a Confirmatory Item. The staff verified that the markups have been incorporated into Revision 7 of the topical report. Therefore, the staff considers RAI 9305, Question No. 2, resolved and closed.

The US-APWR ACC is designed with two performance objectives: (1) immediately after the reactor coolant blowdown during an LBLOCA, the ACC injects water at a large flow rate for a limited duration to refill the reactor vessel lower plenum and downcomer, and (2) after the refill period, it injects water at a relatively small flow rate to establish the core reflooding condition by maintaining the downcomer water level. To achieve these performance objectives, Section 2.3.4, "Design Requirements for the ACC," of the report describes the determination of the design parameters for the large flow and small flow injection phases, respectively, based on an LBLOCA sensitivity analysis. The water volume above the top of the standpipe in the ACC is the large flow injection water volume needed to refill the reactor vessel lower plenum and downcomer during the refill phase of a LOCA. The injection flow rates for the large-flow and small-flow injection phases, respectively, are to refill the lower plenum and downcomer as rapidly as possible and to provide sufficient reflood rate to assure the peak cladding temperature is within the acceptance criteria during the worst case LOCA.

The flow resistance coefficient of the ACC injection flow path for the large flow phase is calculated based on the refill injection rate, the ACC pressure, and the characteristics of the RCS depressurization transient. The application used the flow rate ratio at the point the flow regime switches from large flow to small flow to determine the ratio of the flow resistance coefficients of the total ACC system injection line during the large-flow and small-flow injection phases. The flow damper flow resistance coefficients for the large-flow and small-flow phases, respectively, are obtained by subtracting the injection pipe resistance coefficient from the corresponding total ACC system injection line resistance coefficients. In the application, the ratio of the flow damper flow resistance coefficient for the small flow injection to the large flow injection is calculated to be [redacted] The application indicates further that the small flow injection water volume is determined based on the need for the duration of small flow injection from the ACC, followed by the injection from the SI pump, in the reflood phase to maintain the downcomer water level through the core quench. In all, the LBLOCA sensitivity study establishes the target flow damper flow resistance coefficients, and water injection volumes for the large-flow and small-flow injection phases, respectively. The design specifications of the ACC as summarized in Table 3.1-1, "Specifications for the ACC," of the topical report include additional margins from the results of the sensitivity analysis. Section 3.1, "ACC Design Basis and Specifications," of the topical report presents the detailed design of the "as installed" ACC with the structure of the flow damper depicted in Figure 3.3-1, "Overview of the Flow Damper," and Figure 3.3-2, "Outline Drawing of the Flow Damper," of the topical report.

Although the ACC topical report does not include the Chapter 15 accident analysis, it should be noted that the LBLOCA sensitivity analysis used in establishing the ACC design requirements

was performed using the 10 CFR Part 50, Appendix K, “ECCS Evaluation Models,” with the Japanese decay heat model. The decay heat level of the Japanese model is different from that of the American Nuclear Society (ANS) 1971 decay heat model required in the Appendix K model, and therefore the core reflood rate would be different from the results if the ANS-1971 decay heat model was used. However, the sensitivity analysis was performed solely for the purpose of establishing the values of the ACC design parameters. There are margins added to the final design specifications of the ACC. The applicant’s analysis of the ECCS acceptance criteria is presented in the LOCA safety analyses described in US-APWR Design Control Document (DCD) Section 15.6.5, “Loss-of-Coolant Accidents Resulting from Spectrum of Postulated Piping Breaks within the Reactor Coolant Pressure Boundary.” The adequacy of the credited injection flow rate will ultimately be confirmed by the ECCS performance analysis using the WCOBRA/TRAC code with ASTRUM methodology for the LBLOCA, and the M-RELAP5 code with the Appendix K requirements, including the ANS-1971 decay heat model, for the SBLOCA. The applicant used the Japanese decay heat model in the LOCA sensitivity analysis solely to establish the ACC design parameters. Since the Japanese decay heat model was not used in the safety analysis in the US-APWR DCD, its use in the sensitivity analysis is acceptable.

3.1 Evaluation of Accumulator Performance

The applicant conducted three types of scaled tests: 1/8.4, 1/3.5 and 1/5-scale model tests. These tests used visualization to confirm flow rate switching, vortex formation, and the prevention of significant gas entrainment into the vortex chamber at the end of the large flow stage of injection. The injection test provides the performance data needed for quantitative evaluation of ACC flow. The applicant verified the flow characteristics of the ACC by full-scale qualification testing, and these flow characteristics can be fully described as a function of dimensionless numbers. The applicant developed empirical flow rate coefficients from the test results and these coefficients will be used in an integrated thermal hydraulic model of the US-APWR Reactor Coolant and ECCS systems to assure the US-APWR meets or exceeds all US safety standards. The full-scale qualification test included a modification to the flow damper that installed a pressure equalizing pipe across the vortex chamber. The details of the test objectives, test apparatus, and test results for these tests are described in Section 4, “Testing Program for the ACC,” of the topical report.

The 1/8.4 scale tests were flow visualization tests conducted to examine the basis of operation of the ACC and to understand the injection flow characteristics. The tests confirmed the basic operational characteristics of the flow damper in the ACC, and showed the flow switching from the large flow injection to small flow injection. The vortex chamber for this test was in an upright position, compared to a horizontal vortex chamber in the actual design. Since the sole purpose of the test was to demonstrate vortex cancellation and flow switching, the test configuration does not affect the results.

The 1/3.5 scale tests were visualization tests conducted to confirm that the anti-vortex cap at the top of the standpipe prevents vortex formation at the standpipe inlet and promotes quick and smooth flow switching at the end of the large-flow injection. For the test, the anti-vortex cap that is at the top of the standpipe was made of transparent acrylate such that the flow can be observed at the standpipe inlet.

The 1/5 scale visualization tests were conducted to confirm the operational characteristics of the flow damper by observing the flow in the flow damper during large-flow injection, flow switching, and small-flow injection. The flow damper with a wall made of transparent acrylic resin was installed outside the test tank. The flow in the vortex chamber was recorded with a video camera. The characteristics in the vortex chamber were observed using blue ink as a flow tracer. The 1/5 scale test was not repeated with the modified flow damper, which included a pressure equalizing pipe across the vortex chamber. In RAI 9305, Question No.4, the staff requested the applicant to discuss the basis for not repeating the confirmatory test with a modified vortex chamber with flow equalizer piping. In its response to RAI 9305, Question No. 4, dated February 1, 2018 (ML18037A649), the applicant stated that confirmatory tests were performed during the development phase to observe the operational principles and function of each targeted part. The applicant indicated that the operational principle of the equalizing pipe is simply to equalize pressure across the vortex chamber. The applicant also indicated that 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, the applicant concludes that confirmatory testing with a modified vortex chamber was not necessary. The applicant proposed to 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. The staff finds the above response and the revision to the topical report acceptable because it clarifies that the equalizing pipe does not affect any operational function and based on this response, RAI 9305, Question No. 4, was previously tracked as a Confirmatory Item. The staff verified that the markups have been incorporated into Revision 7 of the topical report. Therefore, the staff considers RAI 9305, Question No. 4, resolved and closed. Additionally, in its responses to RAI 9305, Question Nos. 5, 6, and 7, dated February 1, 2018 (ML18037A649), the applicant addressed the staff's observation of various changes in Revision 6 of the topical report, and proposed an appendix to explain the updates from topical report Revision 5 to Revision 6. The staff finds the above responses and the revision to the topical acceptable in clarifying the changes in the latest revision of the topical report and based on this response, RAI 9305, Question Nos. 5, 6, and 7, were tracked as Confirmatory Items. The staff verified the markups have been incorporated into Revision 7 of the topical report. Therefore, the staff considers RAI 9305, Question Nos. 5, 6, and 7, resolved and closed.

In addition, the applicant conducted a qualification test using a full-scale test facility to verify the following items:

1. ACC performance during large flow and small flow phases,
2. Flow switching in the ACC without need of any moving parts, and
3. The effect of dissolved nitrogen gas on the performance of the ACC.

The staff observes that the three-small scale confirmatory tests described above measure separate effects that are not affected by the scale of the tests. Accordingly, the staff finds that these tests are adequate for their intended purposes, which the staff evaluates below. For the tests where the validity of the results depends on scale, the applicant used a full-scale facility, and the staff therefore finds that there were no scaling effects on the test results.

3.1.1 Principle of Flow Damper

The flow damper is designed to act as a diode where flow decreases rapidly as the water level in the tank decreases below the standpipe entrance, leading to a vortex formation in the vortex chamber. The applicant performed tests at three scales, i.e., 1/8.4, 1/3.5 and 1/5, to demonstrate the intended operation.

As described in the topical report, the results of these tests showed that a vortex is not formed when the tank water level is above the standpipe. When the water level in the tank falls below the inlet of the standpipe, a vortex is formed in the vortex chamber, leading to a large pressure drop in the vortex chamber and a rapid decrease of flow rate. This is the intended characteristic of the ACC and the staff finds that these tests support the principle of passive flow switching from a large flow rate to a small flow rate.

3.1.2 Performance of Anti-Vortex Cap

An anti-vortex cap is installed at the entrance of the standpipe, as shown in Figure 3.3-1, "Overview of the Flow Damper," of the topical report. The purpose of the anti-vortex cap is to prevent any ingress of nitrogen from the top of the tank into standpipe. Without an anti-vortex cap at the entrance, it is possible to have vortex formation near the standpipe entrance where nitrogen can be entrained as the level in the tank decreases. The anti-vortex cap will prevent this mechanism. There is another anti-vortex cap at the inlet of the small flow pipe, which is connected to the vortex chamber near the bottom of the ACC. However, by the time the water level approaches the level of the small flow pipe inlet, the ACC water is close to the dead volume, and the high head SI provides needed ECCS flow. Therefore, the effectiveness of the anti-vortex cap at the small flow entrance is not of particular interest.

The results of the tests at three test scales, 1/8.4, 1/3.5 and 1/5 scales, respectively, showed the effectiveness of the anti-vortex cap in preventing ingress of nitrogen through the standpipe. The 1/3.5 scale test results showed that in the case of the standpipe inlet without an anti-vortex cap, there was a creation of vortex at the standpipe entrance as the water level decreased to the standpipe entrance, and subsequent entrainment of nitrogen as the water level further decreased. In the case of standpipe with the anti-vortex cap, a slight disturbance appeared on the water surface as the water level decreased from just above the upper end of the cap to the lower end of the cap. However, no vortex occurred, and the flow rate switched from high to low much more quickly than the case without the anti-vortex cap.

3.1.3 Water Level Transient in Standpipe during Flow Switching

During the switching of flow from the large-flow to the small-flow injection phase, the water level in the standpipe undergoes a transient due to inertial effects. Water level goes down and then recovers. If the level goes down too much, there is a possibility of entrainment of nitrogen from the standpipe to the vortex chamber. The staff reviewed the data from the full-scale test and confirmed that when the test tank water level was reduced to the flow switching level, the standpipe water level temporarily dropped, recovered, and then continued to drop gradually during the small flow injection period but remained high enough to preclude any entrainment of

nitrogen into the vortex chamber. (Refer to MUAP-07001-P, Revision 7, Fig. 4.2.2-3(1/2) "Full Scale Test Results (Case 1) (1/2)).

3.1.4 Performance of Flow Damper during Large Flow and Small Flow Phases

During a LOCA, there is initially large flow injection from the accumulator when the check valve in the injection pipe opens in response to the fall of the RCS pressure below the accumulator pressure. The flow decreases as the water level in the accumulator tank decreases and the level reaches near the entrance to the standpipe. In the large flow injection phase, the flow is the combination of flow from the standpipe and the flow from the small-flow side entry. The net flow is radial in the vortex chamber, and there is no vortex so that the flow resistance is small. As the flow in the standpipe decreases, there is vortex formation in the vortex chamber with a large increase in flow resistance and correspondingly lower flow. This small-flow phase is equivalent to operation of the low head injection pump in the ECCS of a conventional PWR. The safety analysis credits the ACC design with a large flow injection phase for approximately [redacted] of operation, and then an order of magnitude less flow in the small-flow phase. The head losses in the small-flow phase should be about a factor of [redacted] (as discussed in Section 3.0, "Technical Evaluation," of this report) greater than in the large-flow phase.

The applicant used the full-scale tests to confirm that the flow magnitude and timing of switching between the large flow and the small flow credited in the safety analysis can be achieved. A total of seven test cases were conducted with various test accumulator tank pressures and exhaust tank pressures. The staff verified that that test conditions, including the injection pipe resistance, initial water level in the accumulator tank, and the initial accumulator pressure are comparable to the actual plant values. However, Test Case 7 was a low-pressure test for anticipated preoperational test conditions. Test Case 5 was conducted with water saturated with nitrogen to evaluate the effect of dissolved nitrogen gas. During the tests, the applicant measured the water levels in the tank and the standpipe; pressures in the accumulator, injection pipe, and exhaust tank; and water temperatures in the test tank. The applicant used these data, excluding data from Test Cases 5 and 7, to develop the flow characteristic equations.

The applicant used commonly accepted statistical methods to develop the characteristic equations from the test data, specifically, the least squares fit method. The staff finds that application of the least squares fit method to the data is an appropriate use of that method, and accordingly, the characteristic equations are acceptable. The staff's evaluation of the applicant's treatment of uncertainty is in Section 3.3 of this safety evaluation (SE).

3.1.5 Water Level at Flow Switching

The ACC is designed such that the flow switching from the large-flow rate to the small-flow rate takes place when the water level drops to the lower end of the anti-vortex cap at the entrance of the standpipe. For the full-scale tests, the applicant plotted the accumulator flow rates and the accumulator water level for each test as a function of time. The water level at the switching of flow rates from large-flow to small-flow was defined as the intersecting point of two curves of water levels for large flow injection and small flow injection. As shown in Table 4.2.2-2, "Flow Switching Water Level," of the topical report, the data from the full-scale tests showed that the water level for the flow rate switching is within a small range of uncertainty of [redacted]

[redacted] from the expected flow-switching water level at the lower end of the anti-vortex cap installed at the inlet of the standpipe. In view of the above, the staff concludes that flow switching occurs as predicted within the measured uncertainties. The uncertainty in the switching level and its treatment in the safety analysis are described in Section 5.2, "Estimation of Potential Uncertainties of Water Level for Switching Flow Rates," of the topical report and in Section 3.3.2, "Uncertainty in Switching Level," of this report.

3.1.6 Effect of Dissolved Nitrogen

Fluid in the accumulator is in contact with nitrogen and, over time, nitrogen will dissolve into and diffuse throughout the liquid phase. In the limiting case, water could be saturated with nitrogen and there could be equilibrium between gas phase and liquid phase. There could be a potential impact of dissolved gas on the performance of the flow damper. As the fluid particles move through the flow damper, subject to decreasing pressure, the dissolved nitrogen gases will emerge and potentially affect the flow resistance of the flow damper.

To evaluate the effect of dissolved nitrogen gas in the accumulator water, the applicant conducted a test (Test Case 5) with nitrogen-saturated water in the full-scale facility. In Test Case 5, water in the ACC tank was forced to be saturated with nitrogen by compulsorily bubbling and showering with nitrogen. The applicant conducted this nitrogen-saturated water test case with boundary conditions similar to those of Test Case 1, in which nitrogen gas was passively charged so that it was not in equilibrium. A comparison of the test results between Test Cases 1 and 5, as shown in Figure 4.2.2-7 of the topical report, showed lower cavitation factor and flow coefficient for the large flow phase and a delay of approximately [redacted] in the switchover from the large-flow rate to small-flow rate phase for Test Case 5. Lower flow coefficient, or higher flow resistance, during the large flow injection phase due to the effect of the dissolved nitrogen resulted in a lower accumulator flow rate, and a longer period of the large flow injection phase.

The applicant did not consider the flow coefficient data points from Test Case 5 in developing the accumulator characteristic equations as documented in Section 5.1, "Flow Rate Characteristics for Safety Analysis," of the topical report. This is because the test condition in Test Case 5 with saturated nitrogen is much more limiting than the actual conditions in the accumulators, and therefore, using the Test Case 5 data will result in evaluating a flow coefficient smaller than that of the actual accumulator. Rather, the Test Case 5 result of a [redacted] delay of flow rate switching was used to address the effect of the dissolved nitrogen. As discussed in Section 3.3.3 of this report, the applicant will incorporate an increase in the accumulator injection pipe flow resistance coefficient in the LOCA analyses.

3.1.7 Summary

Based on the foregoing, the staff finds that the three sets of different scaled confirmatory tests and the full-scale qualification test conducted by the applicant demonstrated the ACC performance principles. The tests confirmed the principle of the flow damper performance to switch the ACC flow from large flow injection to small flow injection caused by vortex formation in the vortex chamber during the small flow injection phase. The tests demonstrated that installation of an anti-vortex cap at the standpipe inlet prevents nitrogen ingress through the

standpipe at the end of the large-flow injection phase, and that, at the time of flow rate switching, the water level in the standpipe remains high enough above the vortex chamber to preclude any entrainment of nitrogen into the vortex chamber. The tests also showed that the flow rate switch water level is within a small uncertainty range of the standpipe inlet, and that the dissolved nitrogen has minimal effect on the ACC flow injection. Both the uncertainties of the flow rate switching water level and dissolved nitrogen effect are accounted for in the safety analysis. Accordingly, the staff concludes that the applicant's use of the full-scale tests results to develop the ACC characteristic equations for the large-flow and small flow injection phase is acceptable, as further discussed in the following section.

3.2 Characteristics Equations for Advanced Accumulator (ACC)

The ACC provides SI in response to pressure drop in the primary system. For the calculation of the ACC flow rate, the applicant developed two ACC flow characteristic equations, Equations 5-1 and 5-2, for the large-flow and the small-flow injection phases, respectively, as described in Section 5.1.1, "Characteristic Equations of Flow Rates for the Safety Analysis," of the topical report. These characteristic equations describe the flow coefficient, C_v, as a function of cavitation factor, σ_v, which are defined below. The transition from the large-flow characteristic equation to the small-flow characteristic equation takes place based on the water level in the accumulator. When the water level decreases below the inlet of the standpipe, no flow enters the large flow standpipe and a vortex is formed in the vortex chamber thereby decreasing flow rate.

The applicant developed these characteristic equations, along with switching criteria between the two equations, based on data from the full-scale ACC tests. [redacted] Test Case 7 was conducted with lower tank pressure of [redacted] and not representative of reactor operating conditions. The water temperature varied [redacted] as shown in Figures 4.2.2-3 to 4.2.2-9 of the topical report and discussed in response to Question No.1 of the U.S. Nuclear Regulatory Commission (NRC) RAI 9448, dated April 26, 2018 (ML18121A126). The effect of water temperature is included in the cavitation factor since it is defined as a function of vapor pressure. In addition, the cavitation factor and flow coefficients also include density in the dynamic pressure terms, although this term is less temperature dependent than vapor pressure.

The flow rate coefficient, C_v, and the cavitation factor, σ_v, as defined below, for each test are obtained from the test data.

$$K_D = \frac{\left(P_A + \rho g H\right) + \rho_{N2} g(H_1 - H)) - \left(P_D + \rho_w V_D^2 / 2 + \rho_w g H'\right)}{\rho V_D^2 / 2}$$

$$C_v = \frac{1}{\sqrt{K_D}}$$

$$\sigma_v = \frac{P_D + P_{atm} - P_v + \rho_w g H' + \rho_w V_D^2 / 2 - \rho_w V_m^2 / 2}{\left(P_A + \rho_w g H + \rho_{N2} g(H_1 - H)\right) - \left(P_D + \rho_w V_D^2 / 2 + \rho_w g H'\right)}$$

Where,

C_v	Flow rate coefficient
σ_v	Cavitation factor
K_D	Resistance coefficient of flow damper
P_A	Test tank pressure [gage]
ρ_w	Density of water
ρ_{N2}	Density of nitrogen gas
g	Acceleration of gravity
H	Vertical distance between test tank water level and vortex chamber
H_1	Vertical Distance between test tank pressure gage and vortex chamber
H’	Vertical distance between outlet pipe and vortex chamber
P_{at}	Atmospheric pressure
P_v	Vapor pressure of water
P_D	Static pressure of flow damper outlet piping [gage]
V_D	Velocity in the flow damper outlet piping
V_m	Velocity at the model piping diameter

The applicant plotted the test data (flow coefficient vs. cavitation factor) in a log-log curve. The data for the large-flow and small-flow phases collapse into two distinct curves as shown in Figure 5.1-1, “The Flow Characteristics of the Flow Damper,” of the topical report. The ACC characteristic equations shown in Equations 5-1 and 5-2 of the topical report for the large-flow and small-flow phases, respectively, are obtained by the least square fits of the test data.

The flow switches from low resistance to high resistance flow path when the level in accumulator reaches the entrance of the standpipe. When the flow resistance becomes high, the ACC characteristic equation changes from the large-flow to the small-flow equation.

Uncertainties in the characteristic equations are addressed in Section 5.1.2, “Estimation of Uncertainty of the Characteristic Equations of Flow Rates,” of the topical report and in Section 3.3, “Uncertainty in ACC Characteristic Equations,” of this report.

3.3 Uncertainty in ACC Characteristic Equations

The characteristic equations developed from the full-scale test data will be used in the safety analyses. There are uncertainties in the characteristics equations that have to be factored into the safety analyses either as conservative bias or as a distribution in statistical analyses for determining overall uncertainty.

The overall uncertainties of the ACC characteristic equations are attributed to experimental uncertainty that includes the manufacturing error (tolerances) of the test model, instrumentation uncertainty for data acquisition, and the dispersion uncertainty of the least-square fit equation to the test data. Section 5.1.2, "Estimation of Uncertainty of the Characteristic Equations of Flow Rates," of the topical report provides an analysis of the full-scale test characteristic equation uncertainties, and the staff evaluation is described in Section 3.3.1, "Experimental Uncertainty in Characteristic Equations," of this report.

In the large break LOCA analysis, the total uncertainty is treated as a statistical parameter in the Automated Statistical Treatment of Uncertainty Method (ASTRUM), WCAP-16009-P-A (ML050910157) analysis and the value is randomly sampled from the normal distribution within 4 standard deviations. In the small break LOCA analysis and the mass and energy release analyses, the total uncertainty is treated as a negative bias of one-sided 95% confidence level.

There are additional uncertainties in the modeling parameters such as water level for the switchover from the large-flow to small-flow injection phase, and the dissolved nitrogen effects. The uncertainties of the ACC water level for switching flow rates is described in Section 5.2, "Estimation of Potential Uncertainties of Water Level for Switching Flow Rates," of the topical report, and the staff evaluation is described in Section 3.3.2, "Uncertainty in Switching Level," of this report. The treatment of the dissolved nitrogen effect is discussed in Section 5.3, "Treatment of Dissolved Nitrogen Gas Effect in the Safety Analysis," of the topical report, and the staff's evaluation is described in Section 3.3.3, "Uncertainty due to Dissolved Nitrogen Effect," of this report.

3.3.1 Experimental Uncertainty in Characteristic Equations

As discussed above, the applicant predicted the ACC flow rate coefficient using two characteristic equations: one for the early large flow phase when the water level is above the entrance of the standpipe, and the other for the small flow phase when the water level is below the standpipe entrance. These two characteristic equations were derived from the data obtained from the full-scale test facility. In addition, information about the water level in the tank at the time of switch is also obtained from these tests. This section describes the evaluation of the uncertainties associated with the full-scale test characteristic equations.

3.3.1.1 Estimate of Experimental Uncertainty

There are three sources of uncertainty. The first source of uncertainty is dispersion deviation, which is the uncertainty due to curve fitting the data to obtain the characteristic equations. The second is instrument uncertainty, which is the uncertainty in the measurement of different

parameters that are used to compute flow rate coefficients and cavitation factors. The third is the manufacturing error in different components of the test setup.

Section 5.1.2, "Estimation of Uncertainty of the Characteristic Equations of Flow Rates," of the topical report, identifies these sources of uncertainties and the values associated with dispersion deviations, instrument uncertainties, and manufacturing errors. In quantifying the uncertainty associated with the full-scale test, the applicant has employed a methodology according to the Guide to the Expression of Uncertainty in Measurement (GUM) found in the International Organization for Standardization / International Electrotechnical Commission (ISO/IEC) Guide 98-3 (Reference 5). This methodology is different from the methodology used in Revision 5 of the topical report; i.e., ANSI/ASME PTC19.1-1985 (Reference 6). In RAI 9448, Question No. 1, the staff requested the applicant to discuss the differences between the methodologies, to justify the change in its approach, and to discuss the overall impact of the full-scale test on the estimation of uncertainty of the characteristic equations of flow rates. In its response to RAI 9448, Question No.1, dated April 26, 2018 (ML18121A126), the applicant stated that GUM ISO/IEC Guide 98-3 was incorporated into the MHI's current quality manual as an uncertainty evaluation standard. The applicant further explained that in recent years, GUM ISO/IEC Guide 98-3, is recognized as the standard method for uncertainty evaluations, and it is accepted by several international standardization authorities such as IEC and ISO. With the exception of the methodology change, the staff finds that the uncertainties of the full-scale test are appropriately evaluated according to the GUM ISO/IEC Guide 98-3 because they are essentially the same as those obtained in the full height 1/2 scale test. The staff approved the uncertainties obtained in the full height 1/2 scale test in its SE for Revision 5 of the topical report (ML14030A383). There the applicant evaluated the uncertainties with ANSI/ASME PTC19.1-1985 which is acceptable to the NRC staff.

The dispersion deviation is computed by estimating departure of the characteristic equation from the measurement as described in Section 5.1.2 of the topical report. For the full-scale tests, the applicant calculated the relative difference between the flow coefficients from the test data and the flow coefficient calculated with the characteristic equation, and the dispersion deviation of the test is the standard deviation of the relative differences of the data points in the tests. Equation 5-4 of the topical report is used to calculate the dispersion deviation of all full-scale tests used in the development of the flow characteristic equation. Table 5.1-1, "Dispersion of the Data from the Experimental Equations," summarizes the standard deviation of the relative differences of the flow rate coefficient calculated from the test data and the characteristic equations, respectively, of individual tests and combined over all the five tests. The standard deviation for the dispersion deviation for the large-flow phase equation is [redacted] and is [redacted] for the small-flow equation when averaged over all the five tests. The staff finds this to be a standard curve fitting procedure and acceptable.

The instrument uncertainty relates to the uncertainties associated with the measurement of those parameters in the experiment pertaining to the determination of the flow characteristics of the accumulator. Table 5.1-2, "Instrument Uncertainties," of the topical report summarizes the standard deviation of the relative differences of the flow rate coefficient calculated from the test data and the characteristic. In RAI 9448, Question No. 3, the staff noted that the results in Revision 6 of the topical report are different from the results in Revision 5 and requested the

applicant to explain the difference in approach and resulting instrument uncertainty associated with the flow rate coefficient. In its response to RAI 9448, Question No.3, dated April 26, 2018 (ML18121A126), the applicant explained the difference between the method used to calculate the instrument uncertainty for the full height 1/2 scale test and full-scale test as follows….

[redacted]

[redacted]

[redacted]

[redacted]

The staff finds the instrument uncertainty values acceptable because the values represent accurate maximum uncertainty values within the respective cavitation ranges.

The third source of uncertainty is due to manufacturing tolerance of the flow damper dimensions. In its response to RAI 9448, Question No.1, dated April 26, 2018 (ML18121A126), the applicant confirmed that the manufacturing error remains the same for both the full height 1/2 scale test and the full-scale test because this estimation is independent of test data and utilizes the same methodology. In its response to Question No. 18, dated July 20, 2007 (ML070280342), the applicant described that the effect for flow rate coefficient due to manufacturing error is considered separately for the large-flow and small-flow injection phases. The applicant explained as follows:

> For the large-flow injection phase, the parameters with dominant effect on the flow rate coefficient are the vortex chamber outlet nozzle throat diameter and the facing angle between the large-flow and small-flow inlet pipe at the vortex chamber. The outlet nozzle throat has the minimum flow area in the flow damper and is therefore the dominant dimension for flow damper performance. The facing angle of the large and small flow inlet pipes is the angle at which flows from the large and small flow inlet pipe collide. Since a goal of the design is to set this angle such that angular momentum of the two flows cancel each other and eliminate any vortex in the vortex chamber, the error in this collision angle would cause some

vortexing during large-flow injection and affect the flow damper performance.

[redacted]

3.3.1.2 Combining Uncertainties

The characteristic equations are incorporated into the computer codes such as WCOBRA-TRAC as best estimate values. However, there is a need for estimates of the aggregate of all uncertainties as bias and distribution. This is described in Section 5.1.2 of topical report MUAP-07001, Revision 7.

The standard deviation of the combined uncertainty is calculated by the SRSS of the standard deviations for instrument, dispersion and manufacturing error, respectively.

The total experimental uncertainty in the characteristic equation is expressed in terms of standard deviation for the flow rate coefficient and is summarized in Table 5.1-3, "Total Uncertainty of Flow Rate Coefficient (Experimental Equations) for Safety Analysis of US-APWR," of MUAP-07001, Revision 7. In the LBLOCA analysis (ML111230038), the total uncertainty is treated as a statistical parameter in the ASTRUM analysis and the value is randomly sampled from the normal distribution within four standard deviations. In the SBLOCA analysis (ML13346A162) and the mass and energy release analyses, the total uncertainty is treated as a negative bias of the one-sided 95 percent confidence level. The staff has determined that these uncertainty treatment approaches to be acceptable in the above cited SBLOCA and LBLOCA analyses.

3.3.2 Uncertainty in Switching Level

The ACC model implementation uses the logic of switching from the large flow characteristic equation to the small flow characteristic equation. The uncertainty in this model is described in Section 5.2 of the topical report. The data from the full-scale tests, excluding Test Case 5, indicate that switching level deviation with respect to the standpipe entrance varies

[redacted]. Consideration of the "+" side error is equivalent to a decrease in the volume available for large flow injection. Thus, the maximum flow switching level is taken into account for the safety analysis to result in the shortest duration of the large flow injection. The applicant conservatively chose the bounding value of Test Case 3 as the flow switch level uncertainty, and the staff verified that this case represents the highest level of switchover. The staff finds this to be conservative. With addition of instrument uncertainty, the uncertainty in the switchover water level is [redacted]

The water level uncertainty is accounted for in the safety analyses by converting it into the initial ACC water volume uncertainty; i.e., decreasing the initial water volume in the accumulator by the "+" side error of the water level uncertainty range. This will result in earlier switching to the small-flow phase and will result in shorter duration of the large flow injection phase. Since the important function of the ACC is to fill up the reactor vessel lower plenum promptly during the refill period, and then simultaneously raise the water level in the downcomer, the shorter duration of the large flow injection phase will result in a slower increase in the downcomer water level. Thus, the staff finds that it is conservative and acceptable to treat the switchover water level uncertainty by reducing the initial water level in the accumulator.

For the LBLOCA analysis, which uses the realistic analysis with the ASTRUM statistical treatment of uncertainties methodology, the flow rate switching water level uncertainty is included in the initial ACC water volume uncertainty and used in the ASTRUM analysis, as described in Section 3.5.1.4, "Uncertainty," of Topical Report MUAP-07011-P, "Large Break LOCA Code Applicability Report for US-APWR," (ML111230038). For the SBLOCA analysis, which uses the Appendix K to 10 CFR 50 approach, the switching water level uncertainty will be treated as a bounded value to reduce the initial water volume in the accumulator, as described in Section D.4, "Treatment of Uncertainty," of Topical Report MUAP-07013-P, "Small Break LOCA Methodology for US-APWR, Revision 3" (ML13346A162). The staff has determined that these uncertainty treatment approaches to be acceptable in the above cited analyses.

3.3.3 Uncertainty due to Dissolved Nitrogen Effect

As stated in Section 3.2 of this report, the characteristic equations were developed from the full-scale test data. The data from Test Case 5, was not included in the database for the characteristic equations because it was performed with accumulator water saturated with nitrogen. Section 3.1.6, "Effect of Dissolved Nitrogen," of this report describes the effect of dissolved nitrogen on the ACC performance. The liquid in the actual accumulators will have dissolved nitrogen, which may be less than liquid saturated with nitrogen as in Test Case 5. However, as a conservative approach, the applicant proposed to increase the accumulator injection line piping resistance to compensate for the dissolved nitrogen effect.

In its response to RAI 34, dated September 16, 2009 (ML092650198), the applicant performed a sensitivity analysis of LBLOCA with the accumulator injection line resistance varied within [redacted]. The results showed that a change of the injection pipe loss coefficient [redacted] will delay the onset of transition from the large-flow injection phase to the small-flow phase by [redacted], which encompasses the [redacted] delay observed in Test Case 5. In Section 5.3 of the topical report, it is stated that although the dissolved nitrogen in Test Case 5 greatly exceeds that expected in the actual accumulator tank,

the slightly longer flow switching delay due to the dissolved nitrogen effect is included in all the LOCA safety analysis by increasing the injection piping resistance by [redacted]. The staff finds that the increase of the ACC injection line piping resistance in the LOCA analysis adequately account for the [redacted] flow switching delay caused by the dissolved nitrogen effect, and is, therefore, acceptable.

3.4 Pre-Operational Test of Accumulator Performance

Section 6.0, "Characteristic Equations in the Pre-Operational Test," of the topical report provides the calculation for acceptable ranges of the flow resistances of the flow damper. The accumulator flow resistance is the inverse of the square of the flow damper flow coefficient. The acceptable flow resistance ranges for the large-flow and small-flow injection phases, respectively, are therefore based on the flow coefficients calculated from the characteristic equations and the uncertainties associated with the flow characteristic equations. The staff evaluation of the uncertainties in the characteristic equations is described in Section 3.3 of this report.

In the US-APWR DC application DCD Tier 1 information, Section 2.4.4, "Emergency Core Cooling System (ECCS)," Table 2.4.4-5, "Emergency Core Cooling System Inspections, Tests, Analyses, and Acceptance Criteria [ITAAC]," lists ITAAC items for the ECCS system. Item 7.b.i.b requires that tests and analyses of the as-built accumulator system be performed for the as-built accumulator system to calculate and demonstrate the resistance coefficient of the as-built accumulator system meets the acceptance criteria shown in Table 2.4.4-6, "Requirement for Accumulator System Resistance Criteria." The acceptance criteria specified in Table 2.4.4-6 are consistent with the acceptable resistance ranges of the large-flow and small-flow injection modes of the accumulator flow damper described in Section 6.0 of the topical report. Therefore, the staff finds that the ITAAC test provides acceptable verification that the performance of the as-built advanced accumulator system is within the ACC flow characteristic equations within the acceptable uncertainty range, as will be credited in the safety analysis.

4.0 SUMMARY OF EVALUATION

The staff reviewed US-APWR Topical Report MUAP-07001, Revision 7, "The Advanced Accumulator" (ML18178A267), along with the responses to the staff's requests for additional information. As a result of its review and for the reasons stated above, the staff concludes as follows:

a) The applicant's data and analysis are sufficient to support the concept of a vortex damper to passively switch the accumulator injection flow from a large flow to a small flow injection.

b) The applicant's data and analysis are sufficient to establish that an anti-vortex cap will prevent formation of a vortex at the entrance of the standpipe.

c) The applicant's data is sufficient to validate the two characteristic equations that correlate flow rate coefficient with cavitation factor for the large flow and small

flow injection phases, which will be used to estimate the accumulator flow rate coefficient for the safety analysis.

d) The characteristic equations developed from the full-scale test facility are applicable to the full-scale accumulator with additional uncertainties and bias, which are described in Section 3.3.1 of this report.

e) Cavitation is predicted in the outlet nozzle for both large and small flow phases. The location and impact of losses have been correctly addressed.

f) The effect of dissolved nitrogen will be accounted for through an increase in the loss coefficient by [redacted] in the accumulator discharge pipe. Accounting for dissolved nitrogen in the analysis will be an additional loss to the already existing loss coefficient for the accumulator injection pipe.

5.0 REFERENCES

1. “The Advanced Accumulator”, MUAP-07001-P, Revision 7, May 31, 2018 (ADAMS Accession No. ML18178A267).

2. Response to NRC’s Questions for Topical Report MUAP-07001-P, Revision 6, “The Advanced Accumulator (Proprietary)”, UAP-HF-18001, February 1, 2018 (ADAMS Accession No. ML18037A649).

3. Response to NRC’s Questions for Topical Report MUAP-07001-P, Revision 6, “The Advanced Accumulator (Proprietary)”, UAP-HF-18003, April 26, 2018 (ADAMS Accession No. ML18121A126).

4. “Realistic Large Break LOCA Evaluation Methodology Using the Automated Statistical Treatment of Uncertainty Method (ASTRUM)”, WCAP-16009-P-A, Revision 0, March 11, 2005 (ML050910157).

5. ISO/IEC Guide 98-3: 2008 Uncertainty of measurement – Part 3, Guide to the expression of uncertainty in measurement (GUM: 1995).

6. ANSI/ASME PTC19.1-1985.

7. United States Advanced Pressurized Water Reactor Final Topical Report Safety Evaluation for Topical Report MUAP-07001-P, Revision 5, “THE ADVANCED ACCUMULATOR,” February 5, 2014 (ADAMS Accession No. ML14030A383).

8. “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, May 20, 2009 (ADAMS Accession No. ML091420551).

9. “Large Break LOCA Code Applicability Report for US-APWR”, MUAP-07011-P-A, Revision 4, March 2014 (ML111230038).

10. “Small Break LOCA Methodology for US-APWR,” MUAP-07013-P-A, Revision 3, December 5, 2013 (ML13346A162).

11. “Amended 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-09453, September 16, 2009 (ADAMS Accession No.ML092650198).

12. “Response to NRC’s Questions for Topical Report MUAP-07001-P, Revision 1, “The Advanced Accumulator (Proprietary)”, UAP-HF-07086, July 20, 2007 (ADAMS Accession No. ML072080342).

6.0 LIST OF ACRONYMS

ACC	Advanced Accumulator
ANS	American Nuclear Society
ASTRUM	Realistic Large Break LOCA Evaluation Methodology Using Automated Statistical Treatment of Uncertainty Method
BLC	Boundary Layer Coefficient
BPG	Best Practice Guidelines
CFR	Code of Federal Regulations
DCD	Design Control Document
ECCS	Emergency Core Cooling System
GCI	Grid Convergence Index
GDC	General Design Criteria
GUM	Guide to the Expression of Uncertainty in Measurement
ISO/IEC	International Organization for Standardization / International Electrotechnical Commission
LOCA	Loss-of-Coolant Accident
MHI	Mitsubishi Heavy Industries, LTD
NRC	U. S. Nuclear Regulatory Commission
PCT	Peak Cladding Temperature
PWR	Pressurized Water Reactor
RAI	Request for Additional Information
RCS	Reactor Coolant System
RSM	Reynolds Stress Model
SRSS	Square-Root-Sum-of Square
SS	Schnerr and Sauer
US-APWR	United States-Advanced Pressurized Water Reactor

ZGB	Zwart-Gerber-Belamri