UNITED STATES
NUCLEAR REGULATORY COMMISSION
ADVISORY COMMITTEE ON REACTOR SAFEGUARDS
WASHINGTON, DC 20555 - 0001

January 6, 2014

The Honorable Allison M. Macfarlane
Chairman
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

SUBJECT: SAFETY EVALUATION OF US-APWR TOPICAL REPORT MUAP-07001, REVISION 5, "THE ADVANCED ACCUMULATOR"

Dear Chairman Macfarlane:

During the 610th meeting of the Advisory Committee on Reactor Safeguards, December 4-7, 2013, we met with representatives of the NRC staff and Mitsubishi Heavy Industries, Ltd. (MHI or the applicant) to review the Safety Evaluation Report for Topical Report MUAP-07001, Revision 5, "The Advanced Accumulator," associated with the United States Advanced Pressurized Water Reactor (US-APWR) design.

Our US-APWR Subcommittee reviewed the advanced accumulator design during meetings on October 24, 2008; September 20, 2012; and September 17, 2013. We also had the benefit of the documents referenced.

CONCLUSIONS

1. The US-APWR advanced accumulator is an acceptable passive source of low pressure injection for emergency core cooling.

2. Accumulator injection performance can be characterized adequately by the applicant's defined flow rate coefficient and cavitation factor.

3. We concur with the staff's recommendations to increase the uncertainties that are used in loss of coolant accident (LOCA) analyses for the high-flow and low-flow injection regimes. The increased uncertainties account for the use of computational fluid dynamics (CFD) analysis models to extend the half-scale test results to predict full-scale accumulator performance.

BACKGROUND

The US-APWR is a four-loop pressurized water reactor with a large dry containment. In the US-APWR design, the emergency core cooling system (ECCS) injection functions are provided by the high head injection system (HHIS) and the advanced accumulator (ACC) system. The HHIS contains four divisions of pumps, which are normally aligned to deliver water from the refueling water storage pit (RWSP) to the reactor vessel. Four ACCs, one for each loop, passively provide the functions of both conventional accumulators and a low head safety injection system. Thus, in comparison to most conventional PWRs, the US-APWR ECCS does not contain a separate low head safety injection system.

The ACCs are designed to provide injection flow at a high rate to rapidly refill the reactor vessel lower plenum and the downcomer during the blowdown phase of a large break loss of coolant accident (LBLOCA). This initial large injection flow is followed by passive switching to a much lower injection flow rate needed to maintain downcomer level during the core reflood phase. The HHIS pumps provide injection flow for smaller breaks when pressure remains above the ACC shutoff head, and they provide long-term makeup after the ACC inventory is exhausted. The design is meant to ensure that the calculated peak cladding temperature and cladding oxidation level remain within acceptable regulatory limits in both the blowdown and reflood phases of any LOCA.

Passive switching between the high-flow and low-flow regimes is accomplished by an innovative ACC design in which the main initial outflow is guided through a vertical standpipe leading to a vortex chamber (or damper), which also has a much smaller side entrance duct. The vortex chamber is shaped like a flattened cyclone, with an outlet pipe that rises vertically from the center of its axis. The outlet pipe contains a throat region followed by a diffuser leading into piping that turns through a right-angled bend and then connects to the reactor coolant system.

Normal water level in the accumulator is well above the top of the standpipe. When safety injection commences, the water initially drains directly through the standpipe and flows through the damper in a manner such that no swirl is induced. The water then passes through the throat in the outlet piping just before the diffuser where it cavitates, developing a region of vapor-liquid flow where most of the flow-controlling pressure loss occurs. The system is designed to emulate the performance of a conventional accumulator during this period of high flow, which continues until the water level falls below the top of the standpipe. About two-thirds of the water in the accumulator is injected during this period at rates calculated to be sufficient to meet the acceptance criteria for the LBLOCA blowdown and refill phases.

Once the water level falls below the standpipe entrance, most of the outflow then enters directly into the damper through the much smaller side entrance, which is oriented to ensure that the inflow is tangential to the chamber wall. The flow then exits through the vertical outlet at the center of the damper with a strong swirl. The increased pressure loss in this swirling outflow reduces the injection flow rate to the significantly lower value needed to meet acceptance criteria for the LBLOCA core reflood phase. Little or no cavitation is calculated to occur at the outlet pipe throat at these lower flow rates.

The ACC injection flow switches from the high-flow mode to the low-flow mode without the need for active components. The stored water inventory is sufficient to ensure that ACC injection continues long enough (> 100 seconds) during the limiting LBLOCA for the emergency gas turbine-generators to supply power to the HHIS pumps, which then provide long-term makeup flow from the RWSP.

DISCUSSION

Because the US-APWR ACC incorporates a new passive design to control the safety injection flow rate, experiments at several scales and accompanying CFD analyses have been conducted to validate performance. Due to the expense of conducting full-scale testing at rated system pressure and temperature, the largest tests were full-height but were half-scale in vessel, pipe, and damper diameters.

Velocities in the half-scale tests were kept similar to those expected from calculations for the full scale, so the Reynolds numbers, which vary directly with pipe diameter and velocity (and inversely with kinematic viscosity), were about half the full-scale values. Smaller scale tests were also conducted to visualize flow in the damper and for evaluation of scaling effects on the flow and pressure loss characteristics of the system.

The test results were characterized by two dimensionless parameters: a flow rate coefficient and a cavitation factor. The flow rate coefficient is the inverse of the square root of the resistance coefficient, where the resistance coefficient is the ratio of the total pressure difference across the damper and the flow kinetic energy at the damper outlet. The cavitation factor is the ratio of the amount by which the damper outlet pressure exceeds vapor pressure and the total pressure difference across the damper.

In the low-flow regime, the flow rate coefficient is found to be essentially constant and independent of the cavitation factor for both the fifth-scale and half-scale tests. This behavior was also confirmed by CFD calculations where no cavitation is predicted. The pressure losses are dominated by the swirl induced in the damper, which persists through the outlet piping including the throat, the diffuser, and beyond. The swirl is so strong that the CFD calculations predict a region of reverse flow at the center of the discharge pipe.

On the other hand, in the high-flow regime for which no swirl is calculated, the flow rate coefficient shows a weak dependence on the cavitation factor. Both the fifth-scale and half-scale tests show similar behavior. In this flow regime, the CFD computations show cavitation being initiated at the throat of the damper outlet piping.

In the absence of full-scale tests, the applicant has conducted CFD analyses for comparison with the fifth-scale and half-scale test results. [

]

The results support the use of the CFD models to predict behavior at full scale, provided that uncertainties are properly applied. To quantify the uncertainties, a grid convergence study was undertaken with somewhat mixed results. [ ] As a consequence, the staff has recommended that the uncertainties related to injection flow be increased from the values proposed by the applicant. The staff's recommendation is to increase the scaling bias uncertainty in the flow coefficients from [ ] for the high-flow case, and to increase the uncertainty from [ ] for the low-flow case. In addition, [ ] is applied to account for the effect of dissolved non-condensable gases, resulting in a small reduction in the high-flow injection rate. We concur with the staff's recommendations.

Sincerely,

/RA/

J. Sam Armijo
Chairman

REFERENCES

1. Mitsubishi Heavy Industries, Ltd., MUAP-07001-P, Revision 5, "The Advanced Accumulator," July 1, 2013 (ML13196A157)

2. Mitsubishi Heavy Industries, Ltd., MUAP-09025-P, Revision 3, "CFD Analysis for Advanced Accumulator," June 21, 2013 (ML13198A031)

3. NRC Memorandum, Subject: United States – Advanced Pressurized Water Reactor Advanced Topical Report Safety Evaluation for MUAP-07001-P, Revision 5, "The Advanced Accumulator," August 15, 2013 (ML13169A087)

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4. Mitsubishi Heavy Industries, Ltd., MUAP-07001-P, Revision 5, "The Advanced Accumulator," July 1, 2013 (ML13196A157)

5. Mitsubishi Heavy Industries, Ltd., MUAP-09025-P, Revision 3, "CFD Analysis for Advanced Accumulator," June 21, 2013 (ML13198A031)

6. NRC Memorandum, Subject: United States – Advanced Pressurized Water Reactor Advanced Topical Report Safety Evaluation for MUAP-07001-P, Revision 5, "The Advanced Accumulator," August 15, 2013 (ML13169A087)

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