AUDIT REPORT

1.0 SUMMARY

Mitsubishi Heavy Industries Ltd. (MHI) submitted to the U.S. Nuclear Regulatory Commission (NRC) Design Control Document (DCD) Revisions 1 and 2 for its United States - Advanced Pressurized Water Reactor (US-APWR) application in August, 2008, and October, 2009, respectively. After conducting a review of the information associated with net positive suction head (NPSH) in the US-APWR DCD and Technical Report MUAP-08001-P, Revision 2, "US-APWR Sump Strainer Performance," the NRC staff concluded that additional information was needed to make the determination that MHI meets the regulatory requirements for NPSH for emergency core cooling system (ECCS) pumps. An NPSH audit was initially conducted on January 21, 2010, and then re-performed on March 8, 2010, between Mitsubishi Nuclear Energy Systems, Inc. (MNES) staff and the NRC staff in their Arlington, Virginia offices.

An audit was conducted by the NRC staff at the MNES Arlington, Virginia office on March 8, 2010. The focus of the audit was to review and evaluate supporting NPSH calculations for the MHI DCD Section 6.2.2, Containment Heat Removal Systems, Table 6.2.2-1 and Section 6.3, ECCS, Table 6.3-5, and Figures 6.3-15 and 6.3-16, as well as related Technical Reports MUAP-08001-P, Revision 2, "US-APWR Sump Strainer Performance," and MUAP-08013-P, Revision 0, "US-APWR Sump Strainer Downstream Effects."

The purpose of this audit was to review, verify, and identify information and documentation that is related to NPSH calculations for containment spray/residual heat removal (CS/RHR) and safety injection (SI) pumps.

During the audit, the staff reviewed the NPSH calculation documentation and discussed the calculation steps with MNES personnel to evaluate whether MHI meets the regulatory requirements for NPSH for ECCS pumps. The following was reviewed:

1. A calculation showing parts of the elevation and piping losses head for the CS/RHR and SI systems. The calculation included drawings showing elevation changes, pipe diameter changes, elbows, branches or runs.

2. References for the values used in the calculations at each specific step of the calculation.

3. The assumed fluid conditions at the minimum water level in the Refueling Water Storage Pit in the accident analysis.

4. Determination of pump required head, and associated inspection, test, analysis, and acceptance criteria to demonstrate required head.

The analysis results identifying the percentage of allowed air ingestion and its associated head loss in the pump suction piping was not available for the audit.

2.0 BASIS

- General Design Criteria (GDC) 35 of Title 10 of the *Code of Federal Regulations* (10 CFR), Part 50, Appendix A, “Emergency Core Cooling”

- GDC 38 of 10 CFR, Part 50, Appendix A, “Containment Heat Removal”

- 10 CFR 50.46(b)(5), “Acceptance criteria for emergency core cooling systems for light-water nuclear power reactors”

- Regulatory Guide (RG) 1.82, “Water Sources for Long-Term Recirculation Cooling Following a Loss-of-Coolant Accident”

3.0 OBSERVATIONS AND RESULTS

The staff conducted the ECCS pump NPSH audit at the MNES office at Arlington, Virginia on March 8, 2010. The staff reviewed 4BS-UAP-100005, which describes the NPSH calculation procedure and the regulatory guidance used for the calculation. MHI included RG 1.82 Revision 3, in the calculation references. Also, the staff reviewed 4BS-UAP-100006, which contained the actual NPSH calculations. The safety injection system (SIS) pump B-train (or D-train) system was used for the NPSH calculation because the suction pipe length is longer and therefore the head loss is greater than the A-train (or C-train). For similar reasons, the CS/RHR pump A-train (or C-train) was used for the NPSH calculation.

The staff also reviewed Attachment 2 in calculation 4BS-UAP-100006, “Flow Rate of CS/RHR Pump,” which documents the minimum flow line flow rate in the suction line at the maximum pump flow rate operation, and 4CS-UAP-2007012, which contains the calculation for the refueling water storage pool water inventory.

The SIS and CS/RHR pump suction piping physical descriptions were reviewed and compared to the DCD P&IDs and to isometric drawings provided by MHI. The line lengths, number, type and location of elbows, valves and flow reducers were confirmed to be correct in the calculation. MHI used ZJS-UAP-2006001 as the reference to determine the physical dimensions of the pipes (namely the inside diameter).

MHI used the Crane manual to determine the equivalent resistance coefficient f(L/D) for the elbows. The pipe roughness values were typical values based on Japanese manufactured piping. No supporting documentation was available for review to confirm appropriate pipe roughness values. The flow coefficients (C_v) for the valves were taken as minimum typical values bases on Japanese valve designs. The minimum value is used in the calculation to conservatively maximize the equivalent pressure drop across the valve. No supporting documentation for the C_v values was available for review.

Two corrections were needed in 4BS-UAP-100006. The first was a typographical error on page nine, the table identified as “Table 6-5” should have been “Table 6-6.” The second concerned the descriptors for the viscosity. MHI was referring to the “dynamic” viscosity in its formulation for the calculation of the Reynolds number, when the actual value was, correctly, the “kinematic” viscosity. The calculation was correct, and the descriptors were revised to be consistent with the calculation. MHI had included the conversion factor, to convert from centipoise (the absolute (dynamic) viscosity value obtained from the Crane manual) to kg/m-sec, in the calculation, but its purpose and units were not stated. Dividing the "dynamic" (or absolute) viscosity by the specific volume of the fluid converts to the "kinematic" viscosity.

The calculation of the friction factor could only be confirmed by back substituting the value cited by MHI into the equation provided since the friction factor appears on both the left and right side of the equation.

The staff also reviewed the CS/RHR NPSH requirement and the pump configuration where the pump suction and discharge piping are located at markedly higher elevations than the pump centerline. MNES had estimated that the pump is about six feet tall; therefore, the midpoint of the pump is about three feet below the inlet of the pump. MNES assumes that the NPSH requirement should be applied at the center of the pump. The staff reviewed the pump design, and noted that it appeared that the flow of water goes to the center line before it enters the impeller. The staff questioned whether, therefore, the pump centerline is identified as the reference elevation where NPSH should be calculated. The staff plans to ask MHI a Request for Additional Information (RAI) related to this issue.

US-APWR DCD Table 1.9.1-1 shows that US-APWR conforms to RG 1.82, Revision 3. In DCD Table 6.2.2-2 MHI addresses RG 1.82 position 1.3.1.1 as follows:

> Post-LOCA containment pressure is not credited for US-APWR NPSH evaluation of ECC and containment heat removal systems.

However, in Technical Report MUAP-08001-NP, Revision 2, MHI states:

> For the minimum NPSH available calculation...containment pressure is assumed to equal the saturation pressure corresponding to the sump water temperature.

During the audit, it was confirmed that the NPSH calculations assume containment pressure is equal to the saturation pressure corresponding to the sump water temperature.

RG 1.82, Revision 3, position 1.3.1.1 states the following:

> ECC and containment heat removal systems should be designed so that sufficient available NPSH is provided to the system pumps, assuming the maximum expected temperature of pumped fluid and no increase in containment pressure from that present prior to the postulated LOCA.
>
> For sump pools with temperatures less than 212F, it is conservative to assume that the containment pressure equals the vapor pressure of the sump water. This ensures that credit is not taken for the containment pressurization during the transient.

NRC Standard Review Plan (SRP) 6.2.2, "Containment Heat Removal Systems" (NUREG-0800, Revision 5, dated March 2007) states that RG 1.82, Revision 3, describes methods acceptable to the staff for evaluating NPSH. SRP 6.3, "Emergency Core Cooling System," states that the design of the ECCS should conform to the recommendations of RG 1.1. (Note: RG 1.1 regulatory position is incorporated into RG 1.82, Revision 3.)

Given that US-APWR postulated post accident peak sump temperature is reported to be around 250F, the corresponding vapor pressure is close to 30 psia. RG 1.82 clearly indicates that equating containment pressure to vapor pressure is conservative for sump temperatures less than 212F. Given that US-APWR sump temperatures are well above 212F, equating containment pressure to vapor pressure does not meet regulatory guidance.

To conform to the referenced guidance it is necessary that the proper performance of emergency core cooling and containment heat removal systems be independent of calculated increases in containment pressure caused by postulated loss of coolant accidents. Expressed in another way, the guidance to limit pressure to what exists before the accident assured that in design-basis accidents the loss of containment accident pressure (CAP) for any reason would not affect the ability of the ECCS to maintain core cooling. The containment pressure generated by the accident is part of the safety margin against loss of NPSH. The use of CAP to provide adequate NPSHa introduces a dependency between the containment which controls and minimizes radiological consequences of the accident and the ECCS. If containment accident pressure is needed to prevent cavitation of the ECCS pumps, then inadequate containment pressure may lead to a core-damage accident. Therefore, oncept of defense-in-depth, the use of containment accident pressure in determining NPSHa introduces a dependency between the first barrier (fuel clad) and the third barrier (containment).

The alternative approach described by MHI in Technical Report MUAP-08001 (use of saturation pressure in NPSH analysis) is inconsistent with the US-APWR DCD commitment to follow RG 1.82, Revision 3 (for US-APWR, expect pressure around atmospheric pressure for NPSH analysis). MHI did not evaluate how their alternative to the SRP (RG) criteria provides an acceptable method of complying with NRC regulations. Additional information is needed to complete a safety finding that is clearly tied to 10 CFR 50.46(b)(5). Therefore, the NRC staff plans to ask an RAI requesting MHI to justify why the selected approach, use of CAP to support ECCS NPSH analysis is acceptable.

4.0 CONCLUSION

The physical descriptions of the SIS and CS/RHR suction piping and lines were found to be consistent with the DCD P&IDs and isometric drawings provided by MHI. The line lengths, number, type and location of elbows, valves and flow reducers were confirmed.

The pipe roughness and C_v values for the valves could not be verified. However, MHI is committed to updating the NPSH calculation for the “as-built” design. Critical parameters, such as the valve C_v values, may be included in the procurement specifications.

In general, the calculation method used in the NPSH calculations was found to be consistent with guidance and typical practices, except as noted in the discussion on CAP, and included conservative assumptions to maximize the head loss.