TESTING METHODS AND IMPLEMENTATION AUDIT REPORT

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1.0 SUMMARY

Mitsubishi Heavy Industries, Ltd. (MHI) submitted to the U.S. Nuclear Regulatory Commission (NRC) a Final Safety Analysis Report for its application of the United States - Advanced Pressurized Water Reactor (US-APWR) on December 31, 2007. MHI submitted Technical Report MUAP-08001-P, Revision 2, "US-APWR Sump Strainer Performance" in December 2008. This technical report summarizes the design and evaluation of the standard US-APWR sump strainer, and supports the US-APWR Design Control Document, Chapter 6, Subsections 6.2 "Containment Systems" and 6.3 "Emergency Core Cooling Systems" (ECCSs). Requests for Additional Information (RAIs) have been submitted by the NRC staff concerning sump strainer performance, to include testing. MHI then conducted US-APWR plant specific strainer head loss testing to qualify their strainer design. An audit was necessary to assess the adequacy of MHI's basis for determining its strainer head loss.

On June 8 - 9, 2010, the NRC staff conducted an audit of MHI's US-APWR suction strainer head loss testing at Alden Research Laboratory (ARL) in Holden, Massachusetts, to review, verify, and identify information and documentation that is related to containment sump strainer head loss testing associated with containment spray/residual heat removal and safety injection pumps. The audit reviewed and evaluated testing methods and implementation for the US-APWR Design Certification Section 6.2.2, "Containment Heat Removal Systems" and Section 6.3, "Emergency Core Cooling Systems" as well as related Technical Report MUAP-08001-P.

During the audit, the NRC staff observed the following testings:

- Thin Bed Head Loss Test
- Design Basis Head Loss Test

On June 7, 2010, MHI also conducted clean strainer head loss testing (CSHL) and bypass testing. MHI explained that they did not plan to submit the results of their bypass test, and planned to hold the results for future analysis. MHI does plan to submit the CSHL results.

When the NRC staff arrived on June 8, 2010, they witnessed the test setup prior to being filled with water, debris preparation, debris introduction, debris transport (to the extent possible), and head loss data collection. The NRC staff was also provided the opportunity to view the test procedure and an updated draft Performance Contracting Inc. (PCI – strainer vendor) document on the design input for the test plan. The documents reviewed by the NRC staff are included as Enclosure 3 of this package.

On June 9, 2010, during the design basis test, the NRC staff was notified by MHI that there had been an unexpected test result which would require re-evaluation of their design and input. The NRC staff concluded their audit upon notification of MHI's unexpected test result and need for further evaluation. Several weeks after the audit, the NRC staff was informed that MHI planned to use their test results.

Included in this audit report is the basis of the audit, observations, results, and the NRC staff's conclusion. The NRC staff has submitted draft RAI 4988 and plans to submit more RAIs as necessary, based on observations during the audit. RAIs will be submitted separate, from this audit report.

2.0 BASIS

To satisfy the requirements of Generic Design Criteria 38 and Title 10 of the *Code of Federal Regulations* Part 50.46(b)(5) regarding the long-term spray system and ECCS, the containment emergency sump in pressurized-water reactors (PWRs) should be designed to provide a reliable, long-term water source for ECCS and containment spray system pumps. The design of the sumps and the protective strainer assemblies is a critical element in ensuring long-term recirculation cooling capability. Therefore, adequate design consideration of potential debris generation and associated effects including debris screen blockage under postulated post Loss-of-Coolant Accident conditions and impacts of debris penetrating strainers on long-term coolability of the core is necessary. Regulatory Guide 1.82, Revision 3 (Reference 3), as supplemented for PWRs by the Nuclear Energy Institute (NEI) Guidance Report (GR) (Reference 4) and the NRC safety evaluation of the NEI GR (Reference 5), provide guidance for PWR debris evaluations. Other documents on which the regulatory audit is based, are included in the reference section.

3.0 OBSERVATIONS AND RESULTS

Overview

On June 8, 2010, and June 9, 2010, the NRC staff conducted an audit of MHI's US-APWR suction strainer head loss testing at ARL. MHI conducted this test in conjunction with PCI (strainer vendor), AREVA (QA Program), and ARL (test facility and implementation). During this time period the NRC staff witnessed the thin bed head loss test and the design basis head loss test. MHI conducted testing over a three day period (June 7 through June 9, 2010), of which the NRC staff was on hand for two of the three days (June 8 through June 9, 2010).

ARL has been conducting testing of PCI strainers with technical assistance from AREVA and PCI for several years. Several operating PWR's had previously conducted testing at ARL. The NRC staff determined that the previous operating plant testing was non-conservative due to near field settling in the test flume. The new test loops and test protocol are designed to remove the non-conservatisms previously identified by the NRC staff. ARL added mixing equipment and flow penetration through the bottom of the test tank to ensure debris reached the test strainer.

Clean Strainer Head Loss Testing

On June 7, 2010, MHI conducted CSHL testing. The CSHL test used no debris addition to the test flume, and head loss measurements were taken for the losses due to the clean strainer. During this testing MHI was able to show very small and steady head loss without significant change during the designated time period. This value is expected to be included in MHI's future test report. MHI informed the NRC staff that they did plan to use the CSHL results in their strainer head loss analysis.

Fiber Bypass Testing

MHI also conducted strainer fiber bypass testing. Data for this testing was not communicated to the NRC staff since MHI did not plan to submit this information as part of the docket for their strainer head loss analysis. MHI also explained that the data will be kept for their records for possible future use.

Thin Bed Testing - Pre-Test Review and Observations

On June 8, 2010, the NRC staff first observed and evaluated the unfilled test flume for any miscellaneous debris or fiber that could have potentially been left behind from earlier bypass testing. The NRC staff did not notice any debris or material that remained in the test setup from previous testing. Once tank/flume fill commenced, no leaks were observed. A video camera system was in place for the NRC staff to be able to view debris accumulation on the strainer. However, once the addition of particulate debris began, the NRC staff was not able to view anything on the video screen. Before filling the tank/flume, the NRC staff was briefed by AREVA/PCI/ARL personnel on how the testing would proceed and the necessary safety precautions. The NRC staff was informed that AREVA test procedures and a modified PCI test plan would be made available for the NRC staff to review. The NRC staff did not perform a detailed review of the procedures, but agreed that they were likely to result in a test that bounds the head loss for the strainers. The NRC staff also performed sample calculations based on the data provided to ensure test data was being processed appropriately.

Once the test tank/flume was filled, the NRC staff observed the head loss equipment measuring a differential pressure was consistent with the data recorded for the clean strainer head loss testing from the previous day.

Fiber and Particulate Debris Preparation

The NRC staff also witnessed debris preparation before the test began. Fibrous material was shredded at an off-site PCI facility and shipped to ARL. Both fine fiber and small fiber was shipped separately. The fiber appeared to be slightly clumpy and packed from transport, but the NRC staff found the material to be appropriately mixed once it was weighed and water was added. The small and fine fibrous debris was weighed as prescribed by the test plan and verified by the test director.

The NRC staff also observed the weighing of acrylic powder which represented qualified coatings (contrete-epoxy, and steel-epoxy). This debris was divided for introduction to the test

system. Both fiber and coatings debris were diluted with a prescribed ratio of water to debris. It was then stirred by the ARL staff. The NRC staff noted that the ARL staff thoroughly washed the debris that adhered to the stirring rod back into the solution.

Basis for Chemical Addition Amounts

The NRC staff also reviewed a data sheet that summarized the calculation of the amount of surrogate precipitate to be added during the head loss test. The predicted amount was obtained from experimental data provided to the NRC staff in Technical Report MUAP-08001-P.

The chemical added to the head loss test was Aluminum Oxyhydroxide (AlOOH). AlOOH was used as a surrogate for both the aluminum oxyhydroxide and sodium aluminum silicate, which are the only chemicals predicted to precipitate for the US-APWR. Using AlOOH as a surrogate conforms to the NRC staff's March 2008, guidance on Generic Safety Issue 191 (GSI-191), "Assessment of Debris Accumulation on PWR Sump Performance," chemical effects evaluations. However, the head loss testing assumes no chemical debris is present when the sump fluid is above 140 degrees Fahrenheit. The NRC staff is preparing a RAI on this subject.

Preparation of Surrogate Precipitates

It was not clear to the NRC staff how the amount of chemical debris incorporated the amount expected to be lost during water level management. An attachment to the test plan indicates the percentage of the debris that would be lost, but it was not apparent as to how that percentage was converted to a mass and included in the amount of chemical debris prepared. The NRC staff issued RAI 5056 on this subject.

The NRC staff observed the preparation of the surrogate precipitates. The procedure included the mass of each chemical required for the test, the equivalent concentration in the solution for each and the volume of solution to be added in liters and gallons. The AlOOH was prepared by reacting aluminum nitrate $Al(NO_3)_3$ and sodium hydroxide (NaOH).

The surrogate precipitate was prepared in a large plastic batching tank. The batching tank was equipped with a motorized stirrer to keep the precipitate in suspension. The chemicals were weighed on an industrial top-loading balance and added to the large plastic batching tank. The chemist ensured that the initial chemicals added were completely dissolved before proceeding to add the precipitating agent. The precipitating agent (NaOH) was then added to the tank while stirring. The precipitate was observed to form immediately, as evidenced by the solution becoming milky. The NRC staff noticed that before measuring the aluminum nitrate, the chemist discarded about 30 percent due to accumulated moisture. The discarded material had the appearance of slush. The chemist did not identify the reason for the accumulated moisture, but the NRC staff considered storage conditions a possibility. The NRC staff's concern is that the procedure depends on the chemist's judgment and may introduce variability in the amount of water added. However, the NRC staff also recognizes that the chemical debris must subsequently pass a settling test that indicates it has conservative properties with respect to head loss.

One hour after mixing each chemical in the batching tank, samples were drawn for a settling test. The test method and the acceptance criterion are standardized in WCAP-16530-NP, "Evaluation of Post-Accident Chemical Effects in Containment Sump Fluids to Support GSI-191," which was referenced in the test plan. In the settling test, 2 milliliters (mL) of each suspension is added to a 10-mL graduated cylinder. Eight mL of water is added to bring the volume up to 10 mL. The suspension is shaken, put aside, and allowed to settle for one hour. Settling is visually measured by the clarification of the liquid from the surface of the liquid down to the top level of cloudiness of the solution. The acceptance criteria is AlOOH is ≤ 1 mL settling or ≤ 10 percent. The NRC staff observed that the test was acceptable.

During the chemical preparation, it was not clear to the NRC staff that the level of quality control matched the level described in the procedure. For example, it was not clear that the quality assurance engineer verified the scale and pH meter calibration; and the copy of the procedure at the chemical preparation bench was an uncontrolled copy. The NRC staff communicated these observations to MHI in a phone call on July 1, 2010.

Fiber and Particulate Debris Introduction

The particulate debris was first introduced into a hopper. The qualified coatings debris was the first to be added, followed by the addition of fiber debris. The NRC staff saw very little change in head loss throughout the addition of surrogate coatings material.

Once the debris was added, the ARL staff used water that was heated to the temperature of the test setup to rinse the hopper and the trash cans to be certain all debris was placed into the system. To maintain the water level, the ARL staff drained the tank down and filtered using a filter. The filter would be rinsed off and the debris re-introduced into the system to ensure the appropriate amount of debris was being maintained in the test flume. The NRC staff verified that the debris was thoroughly rinsed off the filter and placed back into the test setup.

Fiber and Particulate Debris Transport and Accumulation

The NRC staff found that with the conclusion of particulate debris introduction, the water was opaque. The NRC staff could no longer view debris transport to the strainer. The water level was maintained by the ARL staff throughout the test. Overall, the NRC staff found debris preparation, sequencing, and addition for acrylic power, NUKON, and silica sand were in accordance with the NRC staff guidance.

Data and Observations

MHI and its contractors maintained a test criterion for adding more debris, or left it at the test director's discretion. When the ARL staff began to add fine fiber debris, the NRC staff saw small incremental increases in head loss. Only near the last addition of fine fiber material did the NRC staff see a slightly larger increase in head loss compared to other incremental increases.

Following the addition of the final batch of fines, MHI and its contractors discussed their observations of the data they were seeing. The NRC staff observed an incremental increase in head loss with each addition of fines. This increase in head loss did not appear to be indicative of a thin bed effect. MHI and its contractors decided that they were not seeing a thin bed effect.

PCI explained that if a thin bed effect was occurring then they should have seen a peak in head loss at some point with a decrease in head loss with each successive batch of fiber added. MHI informed the NRC staff that they did not believe they were seeing a thin bed effect and decided to move forward and add the remaining fibrous debris. It was also explained to the NRC staff that this would bound the design basis test and the results would become those expected for the design basis test. The NRC staff challenged MHI on what guidance explains how a thin bed should look since none of the NRC staff at the audit have experienced seeing a thin bed effect in past tests. PCI explained, that NRC staff not on hand for this audit explained to them at an earlier time, what a thin bed effect should look like, and that this data was not indicative of a thin bed effect. During MHI's final addition of fiber the NRC staff saw the largest increase yet in head loss, but still not impacting MHI's head loss criteria. The test was then run on recirculation for the remainder of the night.

The NRC staff also noted a significant amount of foam formation on the liquid surface of the test flume. This foam appeared to be the result of air ingestion from the hopper. The NRC staff is certain that at times there was air ingestion to the system due to efforts to ensure all debris entered the test system. The hopper would be flushed entirely and the trash pump would be permitted to draw from the hopper until it was drawing air. The concerns with the froth formation lie in guidance on near-field debris transport and accumulation. Particulate debris was coming out of the solution entrapped in the foam and froth. This debris was becoming somewhat of a crusted layer on top of the water, and appeared to be several inches high off the water surface. The NRC staff advised MHI and its contractors of their concern that this debris could capture fiber and prevent it from reaching the strainer.

On June 9, 2010, MHI conducted observations of the test from its overnight recirculation run. The ARL staff noted that there was air ingestion in one of the pressure tap lines. Once the air was cleared, head loss increased a small amount ARL staff explained to the NRC staff that although this air was trapped in the line the entire time, it did not change the fact that the head loss held steady overnight. The NRC staff also noted that in the high agitation region of the test flume, there was very little foam remaining. The rest of the test flume still had a layer of foam from the overnight run. It is very important to point out that due to the foam growing so high, the NRC staff did find that there was fiber entrapment. The NRC staff asked MHI and its contractor to quantify the amount of material remaining on the surface of the flume if possible, to determine the amount of material that did not make it to the strainer. MHI's contractor did explain that they would try to get a measurement of the foam and froth thickness and was unsure of the ability to quantify the debris removed from solution due to the foam.

Addition of Chemicals

Chemical debris was added within a span of two and a half hours on June 9, 2010. The precipitate was added to the flume using a pump and hose. The NRC staff verified this by walking down the hoses back to the source and checking the valve lineups before the addition. The full volume was divided into 4 additions of approximately 70 gallons each. After each addition, the main test tank was drained to maintain a constant water level. The water drain was filtered and the chemical recuperated were added back to the test. Additionally, head loss and pH were measured. At the end of the additions, the mix tank was rinsed to ensure all chemicals were added. Although nearly all of the chemical was rinsed from the filter bags and returned to the test, the NRC staff noticed that a small quantity was lost during this process.

Test Results

The NRC staff was informed by MHI that they had an unexpected test result. Upon the NRC staff's request for what the unexpected test result was, MHI explained that the head loss was too high with post temperature correction. MHI planned to reevaluate its current strainer head loss analysis.

Since the NRC staff was informed that MHI's testing was unexpected, the NRC staff decided to conclude the audit. The NRC staff also noted that it would be willing to discuss observations at a later date. The NRC staff was not present for the drain down of the test system and was thus not able to see the debris accumulation on the strainer or debris settlement.

4.0 CONCLUSION

MHI conducted testing over a three day period, June 7, 2010 through June 9, 2010. The testing conducted by MHI included CSHL, bypass test, thin bed head loss, and design basis testing. The NRC staff began their audit on June 8, 2010, and concluded on June 9, 2010. The audit observed thin bed head loss, and design basis head loss testing. The NRC staff observed and evaluated the test setup, debris preparation, debris introduction, debris transport, and head loss test data. The NRC staff had the opportunity to also view MHI's test procedures and a revised PCI test plan. The NRC staff saw no issues prior to the test being filled with water. Debris was appropriately weighed and mixed before introduction to the test system. Overall, introduction to the test system was adequate.

The NRC staff did have concerns over the amount of debris captured in the foam and froth formed at the surface of the test flume because this floating debris was not able to accumulate on the strainer and contribute to strainer head loss. The NRC staff requested to have this amount of debris quantified. The NRC staff also noted that there was air entrapment in the differential pressure transmitter lines, which led to an increase in head loss, once air was removed. The NRC staff submitted draft RAI 4988 on August 12, 2010, related to floating debris and air entrapment. With respect to the chemical debris preparation and delivery to the head loss testing, the NRC staff's preliminary conclusion is that these activities conformed to the test plan and the related NRC staff guidance. The NRC staff is preparing a RAI in order to complete the review. The NRC staff concluded their audit with the announcement by MHI of their unexpected test result and the need for further evaluation. Overall, the NRC staff found the testing implementation to be acceptable. The NRC staff independently confirmed that MHI's temperature corrected head loss value was well over their acceptance criteria. The NRC staff expects to hear from MHI on how this result will be handled in the future.