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November 21, 2013

Document Control Desk
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

Attention: Mr. Perry Buckberg

Docket No. 52-021
MHI Ref: UAP-HF-13271

Subject: MHI's Amended Response to US-APWR DCD RAI No. 998-7025 (SRP Section 05.04.07)

References:
1) "Request for Additional Information No. 998-7025, SRP Section: 05.04.07, dated February 27, 2013.
2) MHI Letter No. UAP-HF-13074, "MHI's Response to US-APWR DCD RAI No. 998-7025 (SRP Section 05.04.07)", dated March 27, 2013

With this letter, Mitsubishi Heavy Industries, Ltd. ("MHI") transmits to the U.S. Nuclear Regulatory Commission ("NRC") a document entitled "Amended Response to Request for Additional Information No. 998-7025."

Enclosed is the amended response to Questions 05.04.07-16 contained within Reference 1. The response was revised to reflect the staff feedback requesting clarification of the technical justification provided in the first response (Reference 2).

Please contact Mr. Joseph Tapia, General Manager of Licensing Department, Mitsubishi Nuclear Energy Systems, Inc. if the NRC has questions concerning any aspect of this submittal. His contact information is provided below.

Sincerely,

Joseph Tapia for

Yoshiki Ogata,
Executive Vice President
Mitsubishi Nuclear Energy Systems, Inc.
On behalf of Mitsubishi Heavy Industries, Ltd.

Enclosure:

1. Amended Response to Request for Additional Information No. 998-7025

D081
NRD

CC: P. Buckberg
J. Tapia

Contact Information

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Enclosure 1

UAP-HF-13271
Docket No. 52-021

Amended Response to Request for Additional Information No. 998-7025

November 2013

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

11/21/2013

US-APWR Design Certification

Mitsubishi Heavy Industries

Docket No. 52-021

RAI NO.:	**NO. 998-7025**
SRP SECTION:	**05.04.07 – RESIDUAL HEAT REMOVAL (RHR) SYSTEM**
APPLICATION SECTION:	**5.4**
DATE OF RAI ISSUE:	**2/27/2013**

QUESTION NO.:05.04.07-16

This RAI (7025) is a follow-up to RAI 6413. RAI 6413 questions the susceptibility of the US-APWR RHR system to potential vortex induced air ingestion and the impact to RHR pump performance and reliability. An on-site audit was held on Oct 9th, 2012 which reviewed 1/2 scale RHR inlet pipe test results. The staff stated during the audit that the information was insufficient and in subsequent telecons discussed potential options that MHI could follow to provide the needed information. The audit report documented that insufficient information was provided for the staff to make a safety determination. In response to this follow-up question, MHI should determine what option to follow and provide the related information.

ANSWER:

The body text of this revision supersedes Revision 0 of this response in its entirety. Revision 0 impacts to US-APWR DCD Revision 3 remain valid unless impacts to DCD Revision 4 are noted.

1.0 CS/RHR Pump Mid-Loop Performance and Reliability Confirmation

MHI's intent is to rely on pre-operational testing of the as-built plant to confirm acceptable RHR mid-loop performance of the as-built US-APWR RHRS. MHI does not intend to construct a full scale test apparatus to conduct "bench top testing" of the intended RHRS configuration. To mitigate the associated risks of relying solely on pre-operational testing, a mitigation and corrective strategy will be employed in the unlikely event that the as-built RHRS fails to meet pre-operational test acceptance criteria for mid-loop operations.

2.0 RHRS Pre-Operational Test Objectives

The following onsite tests will be performed to confirm acceptable operation of the US-APWR RHRS during mid-loop conditions:

1. Verify operation of the automatic let-down isolation interlock
2. Verify operation of the SFP gravity injection lines
3. Verify the accuracy of the RCS water level instrumentation
4. Verify RHR pump operation and RHR nozzle performance at RCS Low water level

This RAI response is focused on test objective number 4 which is testing at the RCS Low water level.

3.0 CS/RHRS Pump Vendor Test Data

The CS/RHR pump for the US-APWR is planned to be a single stage centrifugal pump that is qualified in accordance with ASME QME-1-2007 prior to procurement. The pump vendor will provide type-test data for pump performance characteristics such as pump discharge head, pump flow rate, and pump vibration at maximum rated mid-loop flow for the maximum allowable steady-state, transient, and instantaneous void fractions specified in RG 1.82, Rev. 4, Table A-2. Hydraulic testing (discharge head and flow rate) will determine the reduction in performance due to void fraction ingested. Vibration monitoring during will indicate if there is mechanical instability and, if so, how much. Instrument accuracy for measured parameters will be equal to better than what is specified in ASME OM Code Table ISTB-3510-1 for Comprehensive and Preservice Tests. Pump motor current will be monitored, but will only be used as a gross indicator of pump distress.

Vibration spectral analysis in particular will be used to assess pump operation before, during, and after air void testing. The vibration analysis will be used to monitor for and to aid in the determination of degradation or abnormal performance throughout the test program. Acceptance Criteria will be in accordance with the ASME OM Code Subsection ISTB for Group A Pumps. Spectral analysis techniques will further be used to assess pump distress. Failure to meet ASME OM Code criteria is considered test failure. A review of the spectral data may be cause for failure if it is determined that the pump is in distress or degrading.

In addition to measurement of pump performance characteristics during pump operation, the pump oil will be periodically sampled during the test program to inspect for degradation or wear of bearing surfaces.

At the conclusion of pump testing, the pump will be disassembled and visually inspected for abnormal wear or degradation. Cavitation wear is a long term phenomena (weeks, months, years) except under extreme conditions. If other testing does not indicate pump distress or degradation, then visual examination is not expected to indicate observable damage to pump internals. Therefore, for purposes of MHI's pump testing program, visual examination will be used to qualitatively examine for obvious severe damage to pump internals using the un-aided eye following completion of type testing. Severe damage will be cause for failure of the test and qualification. The pump will only be disassembled at the conclusion of testing in order to reduce the risk of pump damage during the disassembly/assembly process.

It should be emphasized that even though there will be some uncertainty in the individual analyses due to instrument error, multiple test parameters are being observed to increase the overall level of confidence in the pump qualification.

As mentioned, pump performance under transient and instantaneous void fractions will be tested to include the corresponding RG 1.82 limits. Corresponding to the regulatory guide, the pump qualification will include at least to a 5% void fraction over 20 seconds for continuous air ingestion (corresponding to a bubbly flow regime). The qualification will also include an instantaneous 8.5% void fraction test (corresponding to a slug flow regime). The size of void fraction will be controlled and measured either by controlled continuous air injection or by creating a fixed volume within the test loop at the start of the test. The precise air volumes and detailed procedure for air injection and establishment of required flow regime will be determined by the pump vendor and verified through MHI's pump procurement testing program.

4.0 Pre-Operational Test Pre-requisites

As mentioned in Section 3.0, prior to plant construction, the CS/RHR pumps will be qualified per ASME QME-1-2007. To meet the requirements and intent for NRC GL 08-01, these pumps will be qualified for air ingestion to include the limits specified in NRC Regulation Guide 1.82, Rev. 4. Additionally, the RHR pump vendor shall provide type-test data for air ingestion for the pump performance parameters specified in this pre-operational testing regime.

For the RHRS as-built, in-situ plant testing, testing will follow the requirements of the Code Subsection ISTB for Preservice Testing for Group A Pumps starting with a high RHR water level (loops filled) for baseline testing.

The pre-operational test for mid-loop performance will be performed after the standard RHR pre-operational test with loops filled (and its associated pre-requisites). Water level instrumentation operation (Objective #3 above) will be verified prior to the pump and RHR nozzle performance tests (Objective #4 above). Isolation interlock and SFP gravity injection (Objectives #1 and #2 above) may be performed separately from the pump and RHR nozzle performance testing.

The loops-filled testing will be used as a reference or control case to determine nominal pump operation performance characteristics (i.e. expected pump flow rate, expected differential pressure range, expected pump vibration) for as-built plant conditions and provide direct verification of the vendor-supplied QME-1 qualification data. Subsequent testing at the RCS Low water level will be conducted while monitoring hydraulic performance of the pump and performing the same (or equivalent) vibration spectral analysis as that used by the pump vendor during the pump qualification and type-testing. The baseline results and vendor void testing data from the pump qualification will be used to determine if any air is ingested by the RHRS and, if so, whether the void fraction entering the pump is within the pump qualified limits (i.e. observing whether any detected pump vibration is within limits observed during pump qualification). Vibration testing data will be the first and primary indicator of unacceptable pump air ingestion if it occurs.

5.0 Pre-Operational Test Conditions & Parameters

The test conditions to verify acceptable system operation for the RHR pump and connected piping at Low RCS water level shall consist of the following:

1. RCS Water Level
    a. Testing shall be performed at the minimum expected mid-loop water level which is the Low RCS Water Level minus installed instrument uncertainty (MCP Center + 0.44 ft) which is the most conservative water level.
    b. No tests below the RCS Low Water Level will be required. This is because the US-APWR PRA assumes that operating pumps will fail if RCS water level falls below the Low water level. Therefore there are no acceptance criteria below RCS Low Water Level. Utilities may still choose to conduct testing below the Low RCS Water Level to evaluate margin to the RCS level at which RCS level vortex formation and air ingestion actually starts to occur.
2. RHR Flow Rate
    a. A general Pre-Service Test for Group A pumps shall be performed at RCS Low water level per the ASME OM Code to measure pump differential pressure and flow rate at a minimum of 5 points ranging from minimum pump flow to maximum rated mid-loop flow. The maximum rated mid-loop flow shall be designated the reference point for comparisons to future tests for mid-loop performance as a bounding case (however, no additional in-service testing for mid-loop is planned at this time). (Note: A Pre-service Test with loops filled will have already been performed per Section 4.0 above)
    b. Specific testing to evaluate RHR nozzle performance (and the associated pump performance acceptance criteria) will be performed at the maximum rated mid-loop design-basis flow rate which is 2,650 gpm (or approx. 600 m^3/hour). Testing at maximum flow rate is most favorable to vortex formation and therefore is the most conservative condition for this test.
3. Test Duration
    a. The OM Code Pre-service Tests will, at a minimum, meet the test duration requirements for Group A tests. The pump shall be run at each flow point for a minimum of 2 minutes after flow becomes stable.
    b. The Low level test duration at maximum mid-loop flow used to evaluate RHR nozzle performance will be sufficiently long to identify any intermittent and/or periodic vortex

formation and air ingestion. A testing duration of one hour at maximum flow rate is assumed to be sufficient.

Measured test parameters shall include:

1. RCS Water Level*
2. RCS Temperature
3. Pump Performance Parameters for Air Ingestion Performance
   a. Pump Intake and Discharge Head
   b. Pump Intake and Discharge Flow Rate
   c. Pump Vibration (complete spectral analysis – identical or equivalent method and equipment used for vendor type-testing)
4. Other system parameters or inspections (for information only)
   a. Inspection of accumulated air in piping and/or pump casing at completion of mid-loop test. The procedures employed for inspection of accumulated non-condensable gas in the RHRS will be developed by the COL applicant as part of the plant operating and maintenance procedures in US-APWR DCD Section 13.5.2.

   *RCS water level measurement shall be monitored using temporary differential pressure transducers with a minimum accuracy of +/- 0.5%.

Note: RCS draining for mid-loop operations is accomplished through the difference between charging pump flow (adding RCS volume) and the CVS letdown isolation line flow (removing RCS volume). The minimum RCS water level is based on the RCS Low-Level alarm setpoint and the associated instrument uncertainty of the letdown isolation valve interlock. Upon actuation of the interlock, water level may continue to decrease slightly during the valve closure time for the letdown isolation line. However, during this time, the charging pump flow continues to add RCS water volume and the rate of RCS drainage immediately begins to decrease upon the start of letdown valve actuation. As soon as letdown line flow decreases below charging pump flow, RCS water level will begin to increase. This transient minimum water level due to isolation valve closure time is not considered significant for pump operation, and its effect is neglected in the RCS water level for pre-operational testing. Based on the expected valve closure time and calculated drain flow rate, the RCS water level is expected to decrease only slightly before letdown isolation is completed.

6.0 Pre-Operational Test Acceptance Criteria

The acceptance criteria for acceptable mid-loop pump and RHR nozzle performance shall be based on pump performance at RCS Low water level. Pump parameters monitored to check for air ingestion will include pump discharge head, pump discharge flow rate, and pump vibration. At the low levels of air ingestion anticipated during mid-loop conditions, no readily measurable impact on pump performance (such as discharge head) is expected. Therefore, the following acceptance criteria will be used to measure air ingestion performance by comparison to vendor type-test data with representative void fractions and sizes.

Acceptance criteria at RCS Low water level shall be:

a. Discharge head does not degrade beyond the pump qualification test results obtained during vendor qualification for air void ingestion at any time.
b. Pump vibration does not exceed beyond the pump qualification test results obtained during vendor qualification for air void ingestion at any time.
c. Pump motor current does not indicate gross signs of pump distress at any time.

7.0 Pre-Operational Test Termination Criteria

If RHR pump measured parameters meet the acceptance criteria for the given test, the test shall continue for a duration sufficient to identify any intermittent and/or periodic vortex formation and air ingestion (from Section 5 above, a 1 hour test duration at each test point is assumed to be sufficient at this time).

However, if observed parameters (e.g., vibration, pump discharge head, motor current) exceed vendor limits at any point during the testing, then the test will be immediately terminated. Exact test termination criteria will be defined prior to testing based on vendor-supplied operating range data for the given pump performance parameter.

8.0 Mitigation and Corrective Strategy

Should initial RCS Low level RHR mid-loop testing not meet acceptance criteria, a systematic approach will be taken to ascertain the cause of the failure.

In the unlikely event that pre-operational testing for mid-loop RHR operation fails to meet acceptance criteria due to air ingestion, the decision on specific corrective actions will be based on the severity of the observed air ingestion. Possible solutions may include raising the alarm set point for the RCS Low water level and / or reducing the RHR pump flow rate. Margin has been built into the RHRS design to allow use of both mitigation strategies.

9.0 References

1. "NRC Staff Criteria for Accessing Gas Movement in Suction Lines and Pump Response to Gas—Revision 1; For NRC Staff Review of Responses to GL 2008-01." January 7, 2009, attached to an NRC Public Meeting Notice under ADAMS Accession Number ML090150637.
2. EPRI Report 1026498, "Report of the Expert Panel on the Effect of Gas Accumulation on Pumps," August 2012.
3. Code for Operation and Maintenance of Nuclear Power Plants. American Society of Mechanical Engineers (ASME OM Code), 2004 Edition through 2006 Addenda.
4. "Water Sources for Long-Term Recirculation Cooling Following a Loss-Of-Coolant Accident." Regulatory Guide 1.82, Rev. 4, March 2012.

Impact on DCD

DCD Revision 4, Section 14.2.12.1.22 will be revised as shown in the attached markup.

Impact on R-COLA

There is no additional impact on the R-COLA as a result of this RAI response.

Impact on PRA

There is no impact on the PRA.

Impact on Topical/Technical Reports

There is no new impact on any of the referenced technical reports as a result of this RAI response.

This completes MHI's response to the NRC's question.

3. Test instrumentation is available and calibrated.

4. Required support system are available.

5. Required system flushing/cleaning is completed.

6. Required electrical power supplies and control circuits are energized and operational.

7. The CCW system is available to supply water to the CS/RHRS heat exchangers, pump seal coolers, and CS/RHRS pump motors.

C. Test Method

1. System component control and interlock circuits and alarms are verified, including the operation of the CS/RHRS pumps and RHRS valves.

2. CS/RHRS pump and RHRS performance characteristics are verified during RCS circulation.

3. RHRS operation is verified during RCS heatup and cooldown in conjunction with the hot functional test. This includes operation of reactor coolant cooling with only two of four subsystems.

4. Operation of the RHRS during RCS mid-loop hot leg water level is verified, including testing at the RCS Low water level in which discharge head, ~~and~~ pump ~~motor current~~ vibration, and pump motor current are monitored for air ingestion.. DCD_05.04.07-16 S01

5. Operation of the SFP gravity injection to the RCS during mid-loop operation is verified.

D. Acceptance Criteria

1. RHRS components respond properly to normal control and interlock signals (see Subsection 5.4.7).

2. CS/RHRS pump and RHRS performance characteristics are within design specifications.

3. RHRS functions as designed during RCS heatup and cooldown.

4. Reactor coolant temperature can be cooled down with only two of four subsystems.

5. The RHRS functions as designed during RCS mid-loop hot leg water level.

6. The RHRS relief valve operation to provide low temperature overpressure protection for RCS is verified by in-service testing specified in subsection 3.9.6.