MITSUBISHI HEAVY INDUSTRIES, LTD.
16-5, KONAN 2-CHOME, MINATO-KU
TOKYO, JAPAN

February 3, 2014

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

Attention: Mr. Perry Buckberg

Docket No. 52-021
MHI Ref: UAP-HF-14010

Subject: **MHI's 2nd Amended Response to US-APWR DCD RAI No. 998-7025 (SRP Section 05.04.07)**

References:
1) "Request for Additional Information No. 998-7025 Revision 0, 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
3) MHI Letter No. UAP-HF-13271, "MHI's Amended Response to US-APWR DCD RAI No. 998-7025 (SRP Section 05.04.07)", dated November 21, 2013

With this letter, Mitsubishi Heavy Industries, Ltd. ("MHI") transmits to the U.S. Nuclear Regulatory Commission ("NRC") a document entitled "Response to Request for Additional Information No. 998-7025 Revision 2."

Enclosed is the amended response to Question 05.04.07-16 contained within Reference 1. The response was revised to reflect the staff feedback requesting further clarification of the technical justifications provided in the first two responses (References 2 and 3).

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,

Y. Ogata

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

D081
NRO

Enclosure:

1. Response to Request for Additional Information No. 998-7025 Revision 2

CC: P. Buckberg
    J. Tapia

Contact Information

Joseph Tapia, General Manager of Licensing Department
Mitsubishi Nuclear Energy Systems, Inc.
11405 N Community House Road, Suite 300
Charlotte, NC 28277
E-mail: joseph_tapia@mnes-us.com
Telephone: (704) 945 – 2740

Enclosure 1

UAP-HF-14010
Docket No. 52-021

Response to Request for Additional Information
No. 998-7025 Revision 2

February 2014

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION, REVISION 2

02/03/2014

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 1 of this response in its entirety. Impacts to US-APWR DCD Revision 3 remain valid. 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. Volume(s) of Accumulated Gas Voids in the RHRS Following CS/RHR Pump Shutdown
    A survey of accumulated air in the RHRS piping and/or pump casing is performed at the completion of RHR mid-loop testing at low RCS water level to verify operability of the system. This surveillance will be performed consistent with the Bases of TS SR 3.9.6.4 (Mode 6 – Low Water Level). The exact procedures and acceptance criteria employed for surveillance 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. DCD Section 5.4.7.2.3.6 will be clarified using similar language to the bases of TS SR 3.9.6.4 to more clearly define the meaning of "sufficiently full of water" (i.e. that accumulated gas at susceptible locations does not exceed set acceptance criteria for establishing system operability). Additionally, DCD Section 14.2.12.1.22 will include a specific requirement, following CS/RHR pump testing at Low Water level, to survey the RHRS for accumulated gas to verify system operability.
    *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.
d. The volume of accumulated gas in the RHRS following CS/RHR pump shutdown does not exceed established acceptance criteria for RHRS operability.

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 or accumulation. 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 5.4.7.2.3.6 will be revised as shown in the attached markup.

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.

5.4.7.2.3.5 Refueling

The RHRS utilizes one or more CS/RHR pumps during refueling to transfer borated water from the RWSP to the refueling cavity. During this operation, one RHR train is selected for water transport with the CS/RHR pump hot leg isolation valves being closed and the CS/RHR pump RWSP isolation valves opened. The refueling cavity is prepared for flooding and the vessel head is removed to its storage pedestal using the containment polar crane. The refueling water is transferred through the CS/RHR pumps into the reactor vessel through the RHR return lines and into the refueling cavity through the open reactor vessel flange. The reactor vessel head is unbolted to begin refueling operation and the head is lifted as the refueling water increases. After the water level reaches the normal refueling level the CS/RHR pumps are stopped, the RWSP isolation valves are closed, the CS/RHR pump hot leg suction isolation valves from the RCS are re-opened and the pumps restarted to initiate the RHR operation.

During refueling, the RHRS is maintained in-service with the number of pumps and heat exchangers in operation as required by the heat load.

Following refueling, the CS/RHR pumps are used to drain the water in the refueling cavity to the top of the reactor vessel flange. This is done by pumping water from the RCS through the pump full-flow test lines to the RWSP as the reactor vessel head is lowered into place. The vessel head is then replaced and the normal RHRS flow path is re-established. The refueling cavity can also be gravitationally drained to the RWSP without the operation of pumps.

5.4.7.2.3.6 Mid-loop and Drain Down Operations

The RHR system is used to provide core cooling when the RCS must be partially drained to allow maintenance or inspection of the reactor head, SGs, or reactor coolant pump seals.

Mid-loop operation is a residual heat removal (RHR) operation where the RCS water level is brought to the middle portion of the main coolant piping (MCP) during outage for oxidation operation and installation/removal of steam generator (SG) nozzle dams.

When the RCS water level abnormally decreases, air may be ingested into the residual heat removal system with the possibility of affecting the RHRS. The RCS level should be maintained higher than the RCS Low water level of 0.47 feet higher than loop center and a RHRS flow rate of 1,550 gpm to 2,650 gpm should be maintained. Operating Procedures described in DCD Section 13.5.2 address required administrative controls during mid-loop operations when RCS loops are not filled.

Pre-operational CS/RHR pump testing will be conducted at the RCS Low water level to confirm acceptable long term operation at the lowest assumed RCS level of pump operation.

As part of the pre-operational CS/RHR pump testing at RCS Low water level, the RHRS is surveyed for accumulated gas following CS/RHR pump shutdown. Acceptance criteria are established at susceptible locations in the RHRS during Low RCS water level to verify operability as part of the technical specifications. If accumulated gas is discovered that DCD_05.04.07-16 S02 exceeds the acceptance criteria for the susceptible location (or the volume of accumulated gas at one or more susceptible locations exceeds an acceptance criterion at the suction or discharge of the CS/RHR pump), then the surveillance is not met. If it is determined by subsequent evaluation that the RHRS is not rendered inoperable by the accumulated gas (i.e. the system is sufficiently filled with water), the surveillance may be declared met. Accumulated gas should be eliminated or brought within the acceptance criteria limits. DCD_05.04.07-16 S02

The features of mid-loop operation in US-APWR are shown as follows;

A. High RCS water Level

Maintaining a high RCS water level for the duration of SG primary side water drainage and vacuum venting operation decreases the possibility of air intake to the RHRS. Since the SG installation level for the US-APWR is higher than the top of the MCP, a high RCS water level can be maintained during the installation/removal of SG nozzle dams.

B. Water level instrument

Redundant narrow range water level instrument and a mid-range water level instrument, which are shown in Figure 5.1-2 (Sheet 3 of 3), are provided to measure mid-loop water level. Installation of a redundant water narrow level instrument enhances reliability of the mid-loop operation.

A temporary mid-loop water level sensor that measures the RCS water level with reference to pressure at the reactor vessel head vent line and cross over leg is installed in addition to these permanent water level sensors to cope with surge line flooding events.

C. Interlock for abnormal water level decrease

When the water level of RCS drops below the RCS Low water level (0.47 feet higher than loop center), low pressure letdown lines are isolated automatically. This interlock is useful to prevent loss of reactor coolant inventory

D. Water supply from spent fuel pit

When the water level of RCS abnormally drops and all RHR pumps cannot be operated because of air intake, operator can supply water from the spent fuel pit (SFP) to the reactor vessel when the RCS is at atmospheric pressure. Since the RHRS is connected to the SFP, SFP water can be injected by gravity.

In addition to the above features to reduce the risk of loss of Decay Heat Removal, the following operational considerations are incorporated into the US-APWR operating procedures:

- ~~As noted in GL 88-17 (Ref. 5.4-24), there is a possibility of rapid loss of RCS inventory by ejection of water through the cold leg SG manways in the event of a loss of RHR and subsequent RCS pressurization. To minimize this potential, an RCS vent path is required in accordance with GL 88-17. Whenever a cold leg~~ DCD_19-578 S01

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. ~~.~~Following CS/RHR pump shutdown after RCS Low water level testing, RHRS operability is verified by surveying the RHRS for accumulated gas. DCD_05.04.07-16 S01 DCD_05.04.07-16 S02

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 volume of accumulated gas in the RHRS following CS/RHR pump shutdown after the RHRS operation during RCS mid-loop Low water level does not exceed established acceptance criteria for RHRS operability. DCD_05.04.07-16 S02

7. 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.

8. Indications and alarms operate as described in Subsection 5.4.7.2.5.

9. The SFP water can be injected to the RCS by gravity during mid-loop operation.

14.2.12.1.23 Main Steam Isolation Valve (MSIV), Main Feedwater Isolation Valve (MFIV) and Main Steam Check Valve Preoperational Test

A. Objectives

1. To demonstrate acceptable closing times of the MSIVs and the MSIV bypass valves.

2. To demonstrate acceptable closing times for the MFIVs.

3. To demonstrate failure position of MSIVs and MFIVs upon loss of valve motive force.

4. To demonstrate that the main steam check valve prevents blowdown by steam backflow for intact steam generator in the event of breaking the upstream of main steam check valve.

B. Prerequisites

1. Required construction testing is completed.

2. Component testing and instrument calibration is completed.

3. Test instrumentation is available and calibrated.

4. Required support system are available.

C. Test Method

1. The MSIV system's manual and automatic operation and MSIV and MSIV bypass valve closure times are demonstrated.

2. The MFIV system's manual and automatic operation and MFIV valve closure times are demonstrated.

3. Verify alarms and status indications are functional.

D. Acceptance Criteria