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April 10, 2013

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

Attention: Mr. Jeffrey A. Ciocco

Docket No. 52-021
MHI Ref: UAP-HF-13086

Subject: **MHI's Response to US-APWR DCD RAI No. 1014-7047 (SRP 06.03)**

Reference: 1) "Request for Additional Information No. 1014-7047, SRP Section 06.03 – Emergency Core Cooling System - Application Section: 6.3", dated March 13, 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. 1014-7047."

Enclosed is the response to the questions contained within Reference 1.

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.

Enclosure:

1. Response to Request for Additional Information No. 1014-7047

D081
NRO

CC: J. A. Ciocco
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Enclosure 1

UAP-HF-13086
Docket No. 52-021

Response to Request for Additional Information No. 1014-7047

April 2013

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

04/10/2013

US-APWR Design Certification

Mitsubishi Heavy Industries

Docket No. 52-021

RAI NO.:	**NO. 1014-7047**
SRP SECTION:	**06.03 – Emergency Core Cooling System**
APPLICATION SECTION:	**6.3**
DATE OF RAI ISSUE:	**03/13/2013**

QUESTION NO.06.03-113:

Recirculation cavitation is a phenomenon that may occur in centrifugal pumps when operated at low flow rates significantly below their best efficiency flow. Under these conditions, fluid flow is reversed at the suction and/or discharge nozzles resulting in high velocity vortices between the two flow directions, resulting in cavitation. Recirculation cavitation is known to occur in "high suction energy pumps" and can cause significant vibration and damage pump nozzles, impellers, wear rings, seals, shafts, and bearings within a short time period. Recirculation cavitation is a distinctly different phenomenon from suction cavitation, which is caused by insufficient available NPSH (NPSHa).

By RAI 597-4590, Question 6.3-85, the NRC staff requested the applicant to provide a description of the pump design and testing that will demonstrate the design basis capability of the SI and RHR/CS pumps under cavitation recirculation conditions. In response to RAI 597-4590, Question 6.3-85, dated July 8, 2010, the applicant, in part, stated the following:

<u>Regarding SI Pump</u>:
MHI will request time-proven pumps to vendors, which withstand significantly low-flow conditions that may encounter recirculation cavitation. MHI will request evaluations for integrity to pumps that do not have enough past records.

<u>Regarding the RHR/CS Pump</u>:

(1) All RHR/CS pumps are high suction energy pumps.

(2) The required Containment Spray/Residual Heat Removal (CS/RHR) Pump operating flow rates depend on operating pump number. CS/RHR pumps deliver borated water from Refueling Water Storage Pit (RWSP) to spray ring header. CS/RHR pumps and associated piping are independent but the spray ring header is common. So, the number of operating pumps is larger, the flow rate per one pump is smaller. Therefore, the pump operating flow rates have a range from 2800 gpm, which is in all (four) pumps operating condition, to 3400 gpm, which is in two pumps operating conditions.

(3) At the minimum flow condition which differ the most from the best efficiency condition, NPSHa increases due to the decrease of pressure loss. NPSH margin (NPSHa / NPSHr) is more than 4 or 5 and the recirculation cavitation is not predicted to occur.

Staff's comments in regard to the applicant's response to RAI 597-4590, Question 6.3-85 are as follows:

Regarding the SI pumps, the applicant provided additional information in responses to RAI 867-6174 Question 3.11-103 dated January 6, 2012 and RAI 881-6203 Question 3.11-104 dated March 30, 2013 to describe the SI pump design and testing that will demonstrate the design basis capability under cavitation recirculation conditions.

Regarding the RHR/CS pumps, the applicant stated following: "At the minimum flow condition which differs the most from the best efficiency condition, NPSHa increases due to the decrease of pressure loss. NPSH margin (NPSHa/NPSHr) is more than 4 or 5 and the recirculation cavitation is not predicted to occur." However, the staff considers recirculation cavitation a phenomenon that may occur in centrifugal pumps when operated at low flow rates significantly below their best efficiency flow, independent of NPSH margin. Therefore, staff does not consider the applicant's response to provide justification that the RHR/CS pumps are not susceptible to cavitation recirculation or to describe the pump design and testing that will demonstrate the design basis capability of the RHR/CS pump under cavitation recirculation conditions. Staff requests the applicant to provide justification that the RHR/CS pumps are not susceptible to cavitation recirculation or to describe the pump design and testing that will demonstrate the design basis capability of the RHR/CS pump under cavitation recirculation conditions.

ANSWER:

As discussed in the response to RAI 801-5897 (UAP-HF-12062), safety-related pumps will be qualified in accordance with ASME QME-1-2007. ASME QME-1-2007 requires the designer to specify the design-basis minimum flow rate, and the vendor to qualify the pump through type tests or a combination of type tests and analyses. This type-testing and analyses will be summarized in Qualification reports for both the SI and CS/RHR pumps, which will be verified as part of ITAAC added in the response to RAI 901-6257 (UAP-HF-12089), dated April 10, 2012.

Pre-operational tests include testing of the as-built minimum flow line (DCD Tier 2, Subsection 14.2.12.1.22). The tests will be performed with the pump discharge isolated from the RCS cold leg and the containment spray header and pump suction aligned to the RWSP. A new ITA 8.a.iii will be added to DCD Tier 1 Table 2.4.5-5 to reference this CS/RHR system alignment for establishing minimum flow. The AC for this ITA will require that the minimum flow rate through the as-built CS/RHR minimum flow line is greater than the required pump minimum flow rate determined by type tests or a combination of type tests and analyses during equipment qualification.

Impact on DCD

A new ITA and AC will be added in Tier 1 Table 2.4.5-5 as ITA/AC 8.a.iii, as shown in the attached mark-up.

Impact on R-COLA

There is no impact on the R-COLA.

Impact on S-COLA

There is no impact on the S-COLA.

Impact on PRA

There is no impact on the PRA.

Impact on Technical/Topical Report

There is no impact on Technical/Topical Reports.

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

04/10/2013

US-APWR Design Certification

Mitsubishi Heavy Industries

Docket No. 52-021

RAI NO.:	**NO. 1014-7047**
SRP SECTION:	**06.03 – Emergency Core Cooling System**
APPLICATION SECTION:	**6.3**
DATE OF RAI ISSUE:	**03/13/2013**

QUESTION NO. 06.03-114:

Recirculation cavitation is a phenomenon that may occur in centrifugal pumps when operated at low flow rates significantly below their best efficiency flow. Under these conditions, fluid flow is reversed at the suction and/or discharge nozzles resulting in high velocity vortices between the two flow directions, resulting in cavitation. Recirculation cavitation is known to occur in "high suction energy pumps" and can cause significant vibration and damage pump nozzles, impellers, wear rings, seals, shafts, and bearings within a short time period. Recirculation cavitation is a distinctly different phenomenon from suction cavitation, which is caused by insufficient available NPSH (NPSHa).

By RAI 881-6203, Question 6.3-104 staff requested the applicant to provide ITAAC verification that the SI pumps will preclude recirculation cavitation when operated during low flow conditions. In response to RAI 881-6203, Question 6.3-104 dated March 30, 2012, the applicant described the methodology and testing to verify recirculation cavitation will not occur in the SI pumps. The applicant also stated that existing ITAAC provide verification and that no additional ITAAC are needed to verify that as-built SI pumps will operate without damaging cavitation when safety injection pumps are operated during low flow design conditions for the required mission time. The applicant's response to RAI 881-6203, Question 6.3-104 is stated below:

SI pumps are specified and purchased to provide safety injection flow to the reactor vessel at design-basis flow rates. Each pump design has a pump curve and pump minimum flow is established by the pump manufacturer for that pump design. The pump is qualified by design and by testing, including testing in accordance with ASME QME-1-2007, to operate continuously at its design minimum flow rate for the required mission time without damaging cavitation, which only occurs when the pump is operated beyond its design limits.

Subsequently, the as-built minimum flow rate through the minimum-flow line is established at a rate that is above the manufacturer's design minimum flow rate but is consistent with the pump's design capacity to provide safety injection flow to the reactor vessel during a limiting design basis event. For the standard design, minimum-flow line flow is set at 265 gpm, which expected to be bounding but may vary with purchased pump design for an as-built plant. Thus, the minimum-flow line flow rate of 265 gpm is not suitable for inclusion in Tier 1 in accordance with SRP 14.3 criteria.

DCD Tier 1 Table 2.4.4-5, ITAAC 7.b verifies as-built SI pump performance, including as-built SI pump minimum flow rate through the minimum-flow line.

Each US-APWR SI pump has a dedicated minimum-flow line. SI pump minimum-flow lines are always open. As-built minimum flow must be established in order to measure pump differential head "at the minimum flow" and as-built minimum flow is measured at SI pump injection flow shutoff (zero flow to the reactor vessel). Consequently, the tested SI pump must, as stated in AC [Acceptance Criteria] 7.b.ii, be operating "at the minimum flow," which is the minimum-flow line flow rate. This flow rate is established as a test condition prior to taking differential header measurements. Thus, SI pump minimum flow rate, or "the minimum flow," is verified as a direct result since it is a test condition specified by the ITAAC 7.b Acceptance Criterion 7.b.ii. Closure of this ITAAC requires each SI pump to establish design minimum flow through its minimum flow line. Once test results are collected, an analysis is performed to convert test results "at atmospheric pressure" to accident conditions to verify that the SI pumps are also capable of achieving these same results under design conditions. Existing ITAAC verify that as-built SI pumps will operate without damaging cavitation when safety injection pumps are operated during low flow design conditions for the required mission time. No additional ITAAC are needed for this purpose.

Staff's comments in regard the applicant's response to RAI 881-6203, Question 6.3-104. The applicant's response describes that the SI pump is qualified by design and by testing, including testing in accordance with ASME QME-1-2007, to operate continuously at its design minimum flow rate for the required mission time without damaging cavitation. To verify that recirculation cavitation will not occur under as-built low flow conditions, the applicant stated that pre-operational [as-built] testing will be performed to verify that the as-built minimum flow condition for the SI pump is greater than the manufacturer's design minimum flow rate. However, the staff does not consider ITAAC #7b in Tier 1 Table 2.4.4-5 to clearly describe the test and acceptance criteria needed to verify that cavitation recirculation will not occur in the SI pump during low flow conditions. The ITAAC needs to clearly describe that cavitation recirculation will not occur in the SI pump during low flow conditions by verification that the as-built minimum flow rate through the minimum-flow lines for the SI pump is determined to be greater than the SI pump manufacturer's design minimum flow rate.

Therefore, staff requests the applicant to revise ITAAC #7b in Tier 1 Table 2.4.4-5 to clearly describe that cavitation recirculation will not occur in the SI pump during low flow conditions by verification that the as-built minimum flow rate through the minimum-flow lines for the SI pump is determined to be greater than the SI pump manufacturer's design minimum flow rate.

ANSWER:

As discussed in the response to RAI 801-5897 (UAP-HF-12062), safety-related pumps will be qualified in accordance with ASME QME-1-2007. ASME QME-1-2007 requires the designer to specify the design-basis minimum flow rate, and the vendor to qualify the pump through type tests or a combination of type tests and analyses. This type-testing and analyses will be summarized in a Qualification reports for both the SI and CS/RHR pumps, which will be verified as part of ITAAC added in the response to RAI 901-6257 (UAP-HF-12096), dated April 10, 2012.

As discussed in the response to RAI 941-6465 (UAP-HF-12237), Tier 1 Table 2.4.4-5, ITAAC 7.b.ii includes testing of the as-built SI minimum flow line. The Acceptance Criteria in Tier 1 Table 2.4.4-5, ITAAC 7.b.ii will be revised to include confirmation that the minimum flow rate through the as-built SI minimum flow line is greater the required pump minimum flow rate determined by type tests or a combination of type tests and analyses during equipment qualification.

Impact on DCD

The AC for Tier 1, Table 2.4.4-5, 7.b.ii will be revised as shown in the attached mark-up.

Impact on R-COLA

There is no impact on the R-COLA.

Impact on S-COLA

There is no impact on the S-COLA.

Impact on PRA

There is no impact on the PRA.

Impact on Technical/Topical Report

There is no impact on Technical/Topical Reports.

Table 2.4.4-5 Emergency Core Cooling System Inspections, Tests, Analyses, and Acceptance Criteria (Sheet 7 of 12)

Design Commitment	Inspections, Tests, Analyses	Acceptance Criteria	
	7.b.ii The as-built safety injection pump injection test will be performed. Analysis will be performed to convert the test results ~~from the test conditions to the design condition~~into a pump differential head.	7.b.ii A report exists and concludes that each as-built safety injection pump has a pump differential head of no less than 3937 ft and no more than 4527 ft at the minimum flow, ~~and~~ injects no less than 1259 gpm and no more than 1462 gpm of RWSP water into the reactor vessel at atmospheric pressure, and that the minimum flow rate through the as-built SIS minimum flow line is greater than the required pump minimum flow rate.	DCD_14.03.04-51 DCD_06.03-114
	7.b.iii.a Inspections and analyses of each as-built accumulator will be conducted.	7.b.iii.a ~~The~~A report exists and concludes that the volume of each as-built accumulator is at least 3,180 ft^3.	DCD_14.03.04-52 MIC-03-T1-0 0009
	7.b.iii.b Inspections and analyses of the as-built RWSP will be conducted.	7.b.iii.b ~~The~~A report exists and concludes that the volume of the as-built RWSP is at least ~~81,230~~84,750 ft^3.	DCD_14.03.04-53 MIC-03-T1-0 0006 MIC-03-T1-0 0009
	7.b.iv Inspection and analysis of the as-built ECC/CS suction strainers will be conducted.	7.b.iv A report exists and concludes that each of the four as-built ECC/CS suction strainers have the following features: • stainless steel materials of construction for corrosion resistance; • a minimum strainer surface area ~~of 3510 square feet~~of 2,754 ft^2; • perforated plate with maximum hole diameter of 0.066 inches; • remains submerged under design basis accident conditions; • achieves head loss consistent with design basis NPSH evaluations.	MIC-03-T1-0 0003 MIC-03-T1-0 0006 (surface area) MIC-03-T1-0 0009 (head loss)

Table 2.4.5-5 Residual Heat Removal System Inspections, Tests, Analyses, and Acceptance Criteria (Sheet 6 of 11)

Design Commitment	Inspections, Tests, Analyses	Acceptance Criteria
7.a The RHRS is provided with isolation valves in each pump suction piping that are prevented from being opened to the RCS above the pressure setpoint.	7.a Tests will be performed using a simulated test signal.	7.a The interlocks prevent the as-built RHRS isolation valves in each pump suction piping identified in Table 2.4.5-2 from being opened to the RCS above the pressure setpoint.
7.b Deleted.	7.b Deleted.	7.b Deleted.
8.a The RHRS cools the reactor by removing decay heat, and other residual heat from the reactor core and the RCS during the normal plant shutdown and cool down conditions.	8.a.i An analysis is performed that determines the heat removal capability of the CS/RHR heat exchangers.	8.a.i A report exists and concludes that the product of the overall heat transfer coefficient and the effective heat transfer area, UA, of each CS/RHR heat exchanger is greater than or equal to 1.852×10^6 Btu/hr-°F.
	8.a.ii Tests will be performed to confirm that the as-built RHRS can provide flow through the CS/RHR heat exchangers when the pump suction is aligned to the RCS hot leg and the discharge is aligned to RCS cold leg, with the RCS at atmospheric pressure.	8.a.ii Each as-built CS/RHR pump is sized to deliver 3,000 gpm at a discharge head of 410 ft, and provides at least 2645 gpm to the RCS when the RCS is at atmospheric pressure.
	8.a.iii Tests will be performed to confirm that the as-built RHRS minimum flow line flow rate exceeds the required pump minimum flow rate when the pump discharge is isolated from the RCS cold leg and the containment spray header and the pump suction is aligned to the RWSP.	8.a.iii A report exists and concludes that the minimum flow rate through the as-built RHRS minimum flow line is greater than the required pump minimum flow rate.
8.b Deleted.	8.b Deleted.	8.b Deleted.
8.c Deleted.	8.c Deleted.	8.c Deleted.
8.d The RHRS provides cooling for the in-containment RWSP during normal plant operations.	8.d A test will be performed to confirm that the as-built RHRS can provide flow through the CS/RHR heat exchangers when the pump suction is aligned to the RWSP and the discharge is aligned to the RWSP.	8.d Each as-built CS/RHR pump delivers at least 2645 gpm when aligned to the RWSP.

DCD_06.03-113