MITSUBISHI HEAVY INDUSTRIES, LTD.
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TOKYO, JAPAN

March 21, 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-14030

Subject: MHI's Responses to US-APWR DCD RAI No. 1013-7031 (SRP 03.09.02)

Reference: 1) "Request for Additional Information No. 1013-7031, SRP Section: 03.09.02 - DYNAMIC TESTING AND ANALYSIS OF SYSTEMS STRUCTURES AND COMPONENTS - APPLICATION SECTION 3.2.2" dated March 11, 2013.

With this letter, Mitsubishi Heavy Industries, Ltd. ("MHI") transmits to the U.S. Nuclear Regulatory Commission ("NRC") a document entitled "Responses to Request for Additional Information No. 1013-7031 (SRP Section 03.09.02)."

Enclosed are the responses to the questions contained within Reference 1.

As indicated in the enclosed materials, this document contains information that MHI considers proprietary, and therefore should be withheld from public disclosure pursuant to 10 C.F.R. § 2.390 (a)(4) as trade secrets and commercial or financial information which is privileged or confidential. A non-proprietary version of the document is also being submitted with the information identified as proprietary redacted and replaced by the designation "[ ]."

This letter includes a copy of the proprietary version (Enclosure 2), a copy of the non-proprietary version (Enclosure 3), and the Affidavit of Yoshiki Ogata (Enclosure 1) which identifies the reasons MHI respectfully requests that all materials designated as "Proprietary" in Enclosure 2 be withheld from public disclosure pursuant to 10 C.F.R. § 2.390 (a)(4).

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.
Enclosures:

D081
NRO

1. Affidavit of Yoshiki Ogata

2. Responses to Request for Additional Information No. 1013-7031 (SRP Section 03.09.02) (Proprietary version)

3. Responses to Request for Additional Information No. 1013-7031 (SRP Section 03.09.02) (Non-proprietary version)

CC: P. Buckberg
J. Tapia

Contact Information
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Enclosure 1

Docket No. 52-021
MHI Ref: UAP-HF-14030

MITSUBISHI HEAVY INDUSTRIES, LTD.

AFFIDAVIT

I, Yoshiki Ogata, state as follows:

1. I am Executive Vice President of Mitsubishi Nuclear Energy Systems, Inc., and have been delegated the function of reviewing Mitsubishi Heavy Industries, Ltd.'s ("MHI") US-APWR documentation to determine whether it contains information that should be withheld from public disclosure pursuant to 10 C.F.R. § 2.390 (a)(4) as trade secrets and commercial or financial information which is privileged or confidential.

2. In accordance with my responsibilities, I have reviewed the enclosed document entitled Responses to Request for Additional Information No. 1013-7031 (SRP Section 03.09.02) dated March 2014, and have determined that portions of the document contain proprietary information that should be withheld from public disclosure. Those pages containing proprietary information are identified with the label "Proprietary" on the top of the page and the proprietary information has been bracketed with an open and closed bracket as shown here "[ ]." The first page of the document indicates that all information identified as "Proprietary" should be withheld from public disclosure pursuant to 10 C.F.R. § 2.390 (a)(4).

3. The information identified as proprietary in the enclosed document has in the past been, and will continue to be, held in confidence by MHI and its disclosure outside the company is limited to regulatory bodies, customers and potential customers, and their agents, suppliers, and licensees, and others with a legitimate need for the information, and is always subject to suitable measures to protect it from unauthorized use or disclosure.

4. The basis for holding the referenced information confidential is that it describes the unique design information and methodology developed by MHI and includes specific US utilities information. This information was developed at significant cost to MHI, since it required the performance of Research and Development and detailed design for its software and hardware extending over several years.

5. The referenced information is being furnished to the Nuclear Regulatory Commission ("NRC") in confidence and solely for the purpose of information to the NRC staff.

6. The referenced information is not available in public sources and could not be gathered readily from other publicly available information. Other than through the provisions in paragraph 3 above, MHI knows of no way the information could be lawfully acquired by organizations or individuals outside of MHI.

7. Public disclosure of the referenced information would assist competitors of MHI in their design of new nuclear power plants without incurring the costs or risks associated with the design of the subject systems. Therefore, disclosure of the information contained in

the referenced document would have the following negative impacts on the competitive position of MHI in the U.S. nuclear plant market:

A. Loss of competitive advantage due to the costs associated with the development of the unique design parameters. Providing public access to such information permits competitors to duplicate the information without incurring the associated cost.

I declare under penalty of perjury that the foregoing affidavit and the matters stated therein are true and correct to the best of my knowledge, information and belief.

Executed on this 21st day of March, 2014.

Y. Ogata

Yoshiki Ogata,
Executive Vice President
Mitsubishi Nuclear Energy Systems, Inc.

Enclosure 3

UAP-HF-14030
Docket Number 52-021

Responses to Request for Additional Information No. 1013-7031,
(SRP Section 03.09.02)

March 2014
(Non-Proprietary)

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

3/21/2014

US-APWR Design Certification

Mitsubishi Heavy Industries

Docket No. 52-021

RAI NO.:	**NO. 1031-7031**
SRP Section:	**03.09.02 - DYNAMIC TESTING AND ANALYSIS OF SYSTEMS STRUCTURES AND COMPONENTS**
APPLICATION SECTION:	**3.9.2**
DATE OF RAI ISSUE:	**03/11/2013**

QUESTION NO.03.09.02-103:

In the response to RAI No. 930-6494, 05.04.02.01-13 dated December 12, 2012, the applicant attributes the tube-to-tube wear and tube-to-support [anti vibration bar (AVB) and tube support plate (TSP)] to the high steam quality and small contact force with AVBs. For the steam generators of the US-APWR, the applicant states that the steam quality will be lower and the contact force will be more effective than that of the San Onofre (SONGS) replacement steam generators (RSG), without discussing the effect of these parameters on the critical velocity of the fluid elastic instability.

The applicant is requested to:

(a) Provide a comparison of technical data of both steam generators (SONGS & US-APWR) to illustrate that the critical velocity has been exceeded in the SONGS case but will not be exceeded in the US-APWR case,
(b) Explain any design differences between the SG of the US-APWR and the Fort Calhoun RSGs and clarify the effect of these differences (if any) on the flow-induced vibration response of the tube bundle.
(c) Explain how the contact force of the AVBs will be checked to ensure it is sufficiently high to prevent in-plane tube instability.
(d) Explain why the wear at the tube support plates is considered to be caused by turbulence excitation and not by in-plane tube instability.
The staff requests the applicant to include the information in the DCD, MUAP-07027, or a new report.

ANSWER:

(a) Until the January 30, 2012 steam generator tube leak at SONGS Unit 3, it had been the accepted industry practice to regard the risk of in-plane fluid elastic instability (FEI) of the steam generator tubes as not needing separate consideration in steam generator design because the tube bundles are more susceptible to FEI in the out-of-

plane direction than in the in-plane direction. It was expected that protection against out-of-plane FEI would prevent in-plane FEI as well.

As evaluated in Reference 1, tube-to-tube wear occurred in the SONGS RSG as a consequence of the effective velocity exceeding the in-plane FEI critical velocity (i.e., the in-plane FEI stability ratio exceeded 1.0).

It is not currently possible to calculate the critical velocity at which this phenomenon would occur in the US-APWR SG because the critical velocity for in-plane FEI will depend on the detailed design of the anti-vibration bar (AVB) structure, which is determined at a later stage of design. The critical velocity depends on tube vibratory frequency, and the tube vibratory frequency depends on the tube's supporting conditions, which in the case of flat bar type AVBs in U bend type steam generators are determined by contact forces. In turn, these contact forces are determined by the design of the AVB structures.

Because in-plane FEI is caused by combination of weak contact forces at the tube supports and high thermal/hydraulic conditions, MHI analyzed thermal/hydraulic conditions in the secondary side of the US-APWR SGs, as described in response to RAI 930-6494 (Q.05.04.02.01-13). The results showed that the maximum steam quality in the secondary side of US-APWR steam generators is significantly lower than that in the SONGS RSGs due to fundamental design differences between those two types of SGs. For the US-APWR SGs, the lower steam quality provides higher damping and a lower stability ratio. Therefore, the thermal-hydraulic environment in the US-APWR SGs is significantly less conductive to in-plane FEI than that in the SONGS RSGs, so that the tube-to-tube wear observed at SONGS will not occur in the US-APWR SGs.

After the detailed AVB structure is designed, the in-plane FEI stability ratio for the US-APWR SG tube bundles will be evaluated using the methodology and criteria presented in the response to Q.03.09.02-104. As described in that response, the US-APWR acceptance criterion will require that the in-plane FEI stability ratio shall be less than 0.75.

(b) Design differences between the SGs for the US-APWR and the Fort Calhoun RSGs are summarized in Table b-1. As shown in Table b-1, the steam quality in the secondary side of Fort Calhoun RSGs is greater than that in the US-APWR SG. For that reason, the US-APWR SGs are expected to be less susceptible to FEI than those at Fort Calhoun. As stated in the response to RAI 930-6494 (Q.05.04.02.01-13), no tube-to-tube wear has been observed in the Fort Calhoun RSGs.

In addition, Table b-1 summarizes the design differences between the US-APWR SGs and [ ]. [ ], for which no tube-to-tube wear has been reported, have a higher heat flux and a larger tube bundle with thinner tubes than the US-APWR SGs. Due to the higher heat flux, the maximum steam quality of [ ] would be higher than that of the US-APWR SGs, and due to the larger tube bundle and thinner tubes the minimum tube vibration frequency of [ ] would be lower than that of the US-APWR SGs.

Therefore, the US-APWR SG design is bounded by that of [ ] from the view point of in-plane FEI.

The detailed mechanical vibration characteristics of the US-APWR steam generator tube bundles are not available at this time since the detailed design of the US-APWR SG will be completed in the detailed design phase.
MHI will provide an AVB design that has a support condition such that the in-plane FEI stability ratio for the US-APWR SGs will meet the acceptance criterion of less than 0.75 as provided in the response to Q.03.09.02-104.

Table b-1 Design features of the US-APWR SG versus those of other steam generators

(c) The contact force of the AVBs in the in-plane direction serves to reduce or preclude in-plane tube instability, as described in the response to Q.03.09.02-104. The US-APWR SG AVBs will be designed to provide the required contact force, which will be calculated by contact force analysis at the detailed design stage to ensure the prevention of in-plane FEI under the expected thermal hydraulic conditions for the US-APWR SGs. In addition, non-destructive examination will be performed to verify the as-built AVB supporting condition after the fabrication. Reconciliation ITAAC will confirm that the as-built SGs meet the design requirements, including meeting the

acceptance criteria of less than 0.75 stability ratio as provided in the response to Q.03.09.02-103 (b).

As stated in the response to RAI 930-6494 (Q.05.04.02.01-13), providing a contact force of the AVBs in the in-plane direction so as to preclude in-plane tube instability implements one of two lessons learned from SONGS experience, "a need to assure effective AVB contact force to prevent in-plane fluid elastic instability and random vibration and subsequent wear under high localized thermal-hydraulic conditions".

The other lesson learned from SONGS is "a need to evaluate and analyze as necessary flow induced vibration of retainer bars". At the detailed design stage of the US-APWR, MHI will design the retainer bars to have high natural frequency to avoid the random vibration of the retainer bars which caused the tube-to-retainer bar wear in the SONGS RSGs.

(d) As described in Attachment-4 Appendix-2 of Reference-1, MHI concludes the tube wear at the tube support plates observed at SONGS is not due to FEI, but is caused by turbulence excitation.

Industry experience shows that SG tube-to-TSP wear is a slow process that can be controlled by regular inspections and tube plugging. The SONGS Unit-2 RSGs operated for a full fuel cycle (~22 months) without plugging any tubes for tube-to-TSP wear. The SONGS Unit-3 RSGs operated for a shorter period (~11 months) and (excluding tubes with U-bend instability) had significantly fewer tube-to-TSP indications. Therefore, if tube-to-TSP wear occurs in the US-APWR SGs it too is expected to be controllable by regular inspections and tube plugging.

Because the SONGS TSP diameter is larger than the US-APWR TSP, the variation in flatness of the SONGS TSPs is greater than that expected for the US-APWR. TSP flatness can affect the angular orientation of the TSP tube-holes relative to the tubes causing the tube to bear on the corner or edge of the tube-hole. Wear at a corner has a larger depth-to-volume ratio and therefore produces a larger ECT signal in a shorter time. This geometric condition may produce ECT indications early in the operation of a new SG, but as the corner is worn, the wear rate slows and the wear depth plateaus. Since the US-APWR TSP diameter is not as large as that of SONGS it is easier to control TSP flatness and is expected to have less potential for tube-to-TSP wear.

References:

[1] Docket No.50-361, Confirmatory Action Letter – Actions to Address Steam Generator Tube Degradation San Onofre Nuclear Generating Station, Unit 2

Impact on DCD

US-APWR DCD Tier 2 Subsection 5.4.2 will be revised as shown on the attached markup.

Impact on R-COLA

There is no impact on the R-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

3/21/2014

US-APWR Design Certification

Mitsubishi Heavy Industries

Docket No. 52-021

RAI NO.:	**NO. 1031-7031**
SRP Section:	**03.09.02 - DYNAMIC TESTING AND ANALYSIS OF SYSTEMS STRUCTURES AND COMPONENTS**
APPLICATION SECTION:	**3.9.2**
DATE OF RAI ISSUE:	**03/11/2013**

QUESTION NO.03.09.02-104:

The staff requests the applicant to provide the preliminary design of the steam generator tube bundle and the design criteria for the steam generator tubes and retainer bars against flow induced excitations, including random turbulence, fluid elastic instability (out-of-plane and in-plane), and vortex shedding. The staff requests the applicant to include the information in the DCD, MUAP-07027, or a new report.

ANSWER:

The preliminary design of of the US-APWR steam generator tube bundle is shown in Table 1.

Table 1 Preliminary design of steam generator tube bundle

Item	Unit	US-APWR SG
Tube outer diameter	Inch	0.75
Tube pitch	Inch	1.00
Max. tube bending radius	Inch	63
Tube number	-	6,747
Heat transfer area	ft^2	91,500

As stated in the responses to the RAI 930-6494 Q.05.04.02.01-13, dated December 2012, FEI in the in-plane direction will not occur in the US-APWR SGs because the steam quality of the US-APWR SG secondary side is significantly lower than the steam quality of the SONGS RSGs in the region where the in-plane FEI occurred. As mentioned in the response to Q.03.09.02-103, acceptance criteria for the design of the anti-vibration bar (AVB) structure for the US-APWR (which is to provide the contact forces to prevent FEI under the expected thermal hydraulic conditions for the US-APWR SGs) are provided below. Also, the acceptance criterion for the design of the retainer bar is to avoid the random vibration of the retainer bar which caused the tube-to-retainer bar

wear in the SONGS RSGs. MHI will design the retainer bars to have high natural frequency and will analyze the vibration in the detailed design stage.

Design methodology

The following Connor's equation used for the out-of-plane FEI stability ratio calculation, suggested by ASME Section III Appendix N-1330, would be also applicable for the in-plane FEI stability ratio calculation.

The stability ratio (SR) is the ratio between the critical velocity (U_c) and effective velocity (U_e);

$$SR = \frac{U_e}{Uc}$$

The critical velocity and the effective velocity are obtained by the following equations.

$$\frac{U_c}{fD_o} = K\left[\frac{m_o\delta}{\rho_o D_o^2}\right]^{0.5}$$

$$U_e = \left[\frac{\int_0^L \frac{\rho(x)}{\rho_o} U(x)^2 \phi(x)^2 dx}{\int_0^L \frac{m(x)}{m_o} \phi(x)^2 dx}\right]^{0.5}$$

Where,

- f : Tube natural frequency (depends on the AVB structure design)
- D_o : Tube outside diameter
- K : Connor's constant
- m_0 : Average tube mass per unit length
- δ : Tube logarithmic decrement(= $2\pi\zeta$)
- ζ : Damping ratio
- ρ_o : Average fluid density of the steam-water mixture outside the tube in the tube axis direction
- $\varphi(x)$: Vibration mode
- $\rho(x)$: Fluid density distribution of the steam-water mixture outside the tube in tube axis direction
- $m(x)$: Tube mass distribution per unit length in tube axis direction
- $U(x)$: Cross flow velocity of steam-water mixture along the tube span
- x : Coordinate component along tube axis
- L : Tube length

The Connor's constant, damping ratio and tube natural frequency in the in-plane direction are different from the out-of-plane direction as follows.

- Connor's constant

For out-of-plane FEI evaluation, ASME Section III Appendix N-1330 recommends to use 2.4 as the Connor's constant. However, this recommended value was the minimum value of various test results, used for the out-of-plane FEI evaluation. It is too conservative for use in the in-plane FEI evaluation because the out-of-plane FEI is more likely occur than in-plane FEI as reported in Reference 1 and 2. Therefore, MHI determines the Connor's constant for in-plane FEI based on experimental data.

- Damping ratio

For U-bend tubes in two phase flow, there are three sources of damping: mechanical damping, two-phase damping and viscous damping. MHI determines the mechanical damping and the two phase damping based on experimental data. The mechanical damping includes the material damping, the friction damping and the squeeze film damping. The viscous damping is not taken into account because the viscous effects are negligibly small in two-phase flow (homogeneous void fraction is 40% or greater) as described in Reference 3.

$$\zeta=\zeta_m+\zeta_{TP}+\zeta_V$$

Where,

ζ : Total damping ratio

ζ_m : Mechanical damping ratio

ζ_{TP} : Two-phase damping ratio

ζ_V : Viscous damping ratio

- Tube natural frequency

As mentioned in the second paragraph of response to Q.03.09.02-103 (a), the natural frequency of the US-APWR SG U-tubes depends on the detailed design of the anti-vibration bar (AVB) structure, which will be determined at a later detailed design stage. It is not possible to determine the tube natural frequency at this time.

At the detailed design stage, MHI will analyze the tube contact forces based on the AVB structure design by using the full tube bundle FEM model. MHI will also determine the pinning force needed to restrain in-plane movement against the US-APWR fluid forces exciting the tube, thereby preventing in-plane FEI. Then, the contact force will be compared with the pinning force; if the contact force is greater than the pinning force at an AVB intersection, this AVB support point will be considered to be an active (pinned) support in the in-plane direction. Based on the active (pinned) support conditions determined by the comparisons between the contact forces and the pinning forces, the tube vibration mode and natural frequency will be calculated. As described in the response to Q.03.09.02-103 (c), non-destructive examination will be performed to verify the as-built AVB supporting conditions after the fabrication.

<u>Acceptance Criteria</u>

Fluid elastic instability (FEI) will not occur where the stability ratio is less than 1.0. For the US-APWR SGs, the in-plane FEI stability ratios and the out-of-plane stability ratios shall be required to be less than 0.75, which is consistent with contemporary industrial practice.

References:

[1] K. Hirota et al, Investigation on in-flow fluidelastic instability of an array of tubes, 2013, ASME 2013 PVP Conf., PVP2013-97163

[2] T.Nakamura, et al, 2012, Flow-Induced Vibration,Meskell & Bennett (eds) ISBN 978-0-9548583-4-6, "Study on In-flow Fluid-elastic Instability of Circular Cylinder Arrays"

[3] M.J. Pettigrew.,et.al.,2003,"Vibration analysis of shell-and-tube heat exchangers" Journal of Fluids and Structures 18 (2003) 469-483

Impact on DCD

US-APWR DCD Tier 2 Subsection 5.4.2 will be revised as shown in the attached markup.

Impact on R-COLA

There is no impact on the R-COLA.

Impact on PRA

There is no impact on the PRA.

Impact on Technical/Topical Report

There is no impact on Technical/Topical Reports.

The tube support plate material is corrosion resistant type 405 stainless steel. The oxide volume growth behavior of this material inhibits the tube denting mechanism common to drilled carbon steel support plates of earlier SG models.

5.4.2.1.2.6 Flow Induced Vibration of Tube Bundle

The following potential secondary side flow induced tube vibration mechanisms are evaluated for the SG tube bundle during normal operation and the adequacy of the tube support spans is confirmed.

1. Vortex shedding: It is generally accepted that vortex shedding does not occur in two-phase flow and is only a concern in single-phase (all water) regions. In the SG tube bundle there are two regions where flow crosses the tubes. One is in the U-bend and the other is at the wrapper opening just above the tubesheet. In the U-bend, the fluid is a two-phase mixture of water and steam. At the wrapper opening the fluid is subcooled water (single-phase fluid). Vortex shedding tests of tube arrays with this geometry indicate that vortex shedding does not occur. However, analysis is performed conservatively assuming a vortex shedding mechanism is active using the procedure defined in the ASME Code Section III non-mandatory Appendix N (N-1320). The vortex shedding tube response is negligible.

2. Fluidelastic excitation: ~~Tube spans between supports (tube support plates and anti-vibration bars) are selected as to avoid fluidelastic instability such~~The anti-vibration bars are designed to provide adequate contact force to prevent in-plane and out-of-plane fluid-elastic instability and to assure that the calculated stability ratios do not exceed 0.75. Non-destructive examination will be performed to verify the as-built anti-vibration bar supporting condition after fabrication. The tubes are conservatively analyzed in accordance with the procedures ~~and~~ suggested ~~inputs given in~~ by the ASME Code Section III non-mandatory Appendix N (N-1330) and inputs based on experimental data. DCD_03.09.02-103 DCD_03.09.02-104

3. Turbulence: The tube support spacing is selected to minimize the influence of flow turbulence. Evaluation of turbulence induced tube vibration indicates that the tube response is low enough to avoid unacceptable fatigue or fretting wear (Ref. 5.4-20). The attachments of the anti-vibration bar assembly, such as the retainer bars, are also designed to have high natural frequency to avoid the influence of flow turbulence which may cause tube wear. DCD_03.09.02-103 DCD_03.09.02-104

5.4.2.1.2.7 Cavitation of Tubes

There has been no experience of cavitation in SG tubes made by MHI. The primary side flow velocity inside of tubes is relatively low compared with that of coolant pipes, and the flow area configuration is relatively smooth from tube inlet to tube outlet. Therefore the pressure drop is small enough not to produce cavitation. The operating pressure inside of the SG tubes (2,235 psig) is high enough compared with the saturation pressure (1,700 psig) of maximum hot leg temperature (617°F). The secondary side flow path around the tubes is also relatively smooth and the flow is natural circulation. Therefore, the pressure