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April 3, 2012

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-12078

Subject: **MHI's Amended Responses to US-APWR DCD RAI No.574-4633 Revision 2 (SPP 10.02.03)**

Reference: 1) "Request for Additional Information No. 574-4633 Revision 2, SRP Section: 10.02.03 – Turbine Rotor Integrity, Application section Tier 2 FSAR Section 10.2.3," dated April 20, 2010.
2) "US-APWR DC SER-Chapter 10 (MIL111990458)," dated August 9, 2011

With this letter, Mitsubishi Heavy Industries, Ltd. ("MHI") transmits to the U.S. Nuclear Regulatory Commission ("NRC") a document entitled "MHI's Amended Responses to Request for Additional Information No. 574-4633 Revision 2"

Enclosed are the MHI's amended responses to 4 RAIs 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 the submittals. His contact information is below.

Sincerely,

Y. Ogata

Yoshiki Ogata,
Director- APWR Promoting Department
Mitsubishi Heavy Industries, LTD.

D081
NRO

Enclosure:

1. Affidavit of Yoshiki Ogata

2. MHI's Amended Responses to Request for Additional Information No. 574-4633 Revision 2 (proprietary version)

3. MHI's Amended Responses to Request for Additional Information No. 574-4633 Revision 2 (non-proprietary version)

CC: J. A. Ciocco
J. Tapia

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Enclosure 1

Docket No. 52-021
MHI Ref: UAP-HF-12078

MITSUBISHI HEAVY INDUSTRIES, LTD.

AFFIDAVIT

I, Yoshiki Ogata, state as follows:

1. I am Director, APWR Promoting Department, of Mitsubishi Heavy Industries, LTD ("MHI"), and have been delegated the function of reviewing MHI's 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 "MHI's Amended Responses to Request for Additional Information No. 574-4633 Revision 2" dated April 2012, 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 by MHI for performing the turbine rotors design of the US-APWR.

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 development of turbine rotor materials.

B. Loss of competitive advantage of the US-APWR created by benefits of information of turbine rotor materials specification.

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 3rd day of April, 2012.

Y. Ogata

Yoshiki Ogata,
Director- APWR Promoting Department
Mitsubishi Heavy Industries, LTD.

Enclosure 3

UAP-HF-12078
Docket Number 52-021

MHI's Amended Responses to Request for Additional Information No. 574-4633 Revision 2

April 2012
(Non-Proprietary)

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

03/30/2012

US-APWR Design Certification
Mitsubishi Heavy Industries
Docket No. 52-021

RAI NO.:	**NO. 574-4633**
SRP SECTION:	**10.02.03 – Turbine Rotor Integrity**
APPLICATION SECTION:	**Application Section: Tier 2 FSAR Section 10.2.3**
DATE OF RAI ISSUE:	**4/20/2010**

QUESTION NO.: 10.02.03-8, RAI 10.2.3-8

Revision 2 to the US-APWR FSAR revised Section 10.2.3.1 to delete the reference to grade C (Classes 5, 6 and 7). Therefore the FSAR no longer specifies the type of material (Grade or Classification) from ASTM A470. Since there are different Grades and Classifications in ASTM A470 that have different chemical compositions and mechanical properties, the NRC staff cannot assess the acceptability of the material concerning the turbine rotor integrity as described in SRP 10.2.3, and whether the turbine rotor material is bounded by the turbine missile analysis. Therefore, the specific Grade and Classification of ASTM A470 material or reference to the specific material ordering requirements should be included in the US-APWR FSAR that is bounded by the turbine missile analysis.

ANSWER:

MHI deleted the reference to grade C (Classes 5, 6 and 7) in Revision 2 of US-APWR FSAR Section 10.2.3.1 in accordance with NRC requirement of letter dated May 20 2009, a response to RAI No. 324-1997, Question 03.05.01.03-1.

Additional NRC Comment (Open Item 10.2.3-1):

The response is incomplete, since ASTM A470 with no specific grade/class no longer specifies the type of material. Discuss;

1) What type of material shall be applied to the US-APWR LP rotor?
2) How do the material properties relate to those used in the turbine missile analysis?
3) Specific LP rotor material name and the details of chemical composition and mechanical properties of the rotor shall be placed in this RAI response. In addition, specific LP rotor material name shall also be placed in the turbine missile analysis reports (MUAP-07028) so that the acceptance criteria of as-built rotor are bounded by the mechanical properties used in the turbine missile analysis (MUAP-07028).

MHI Response to Additional NRC Comment

I. MHI material type and the relation to the material properties used in the turbine missile analysis

1) Type of material to be applied to the US-APWR LP rotor:

US-APWR LP rotor material is an MHI proprietary material, but is similar to ASTM A470 Grade C, Class 6. There are some minor differences in chemical composition and mechanical properties as shown in Table 8-1 and Table 8-2, which are same as the tables attached in the MHI response to RAI No. 199-2073, Question 10.02.03-1.

Table 8-1 Comparison of the chemical composition ranges

	Purchase Specification of LP Rotor Forging ([ ])			ASTM A470 Grade C/Class 6
	Heat Analysis	Allowable Deviation for Product Analysis		
		For Minimum	For Maximum	
C *	[ ]	[ ]	[ ]	0.28%
Mn	[ ]	[ ]	[ ]	0.20 - 0.60%
P	[ ] Desired Value : Less than [ ]	[ ]	[ ]	0.012%
S	[ ] Desired Value : Less than [ ]	[ ]	[ ]	0.015%
Si	[ ]	[ ]	[ ]	(B,C)
Ni	[ ]	[ ]	[ ]	3.25 - 4.00%
Cr	[ ]	[ ]	[ ]	1.25 - 2.00%
Mo	[ ]	[ ]	[ ]	0.25 - 0.60%
V	[ ]	[ ]	[ ]	0.05 - 0.15%
Sb **	[ ]	[ ]	[ ]	(E)
Al **	[ ]	[ ]	[ ]	0.015%
Cu **	[ ]	[ ]	[ ]	Not Specified
Sn **	[ ]	[ ]	[ ]	Not Specified
As **	[ ]	[ ]	[ ]	Not Specified

* It is desirable that carbon content shall be held to as low a level as possible.
** These are the desired values.

(B) 0.10% max, unless an alternative value, not in excess of 0.30%, is specified in the purchase order.
(C) 0.15 to 0.30% silicon is permitted for material that is subsequently VAR Processed.
(E) To be reported for information only on all Grades.

Table 8-2 Comparison of the mechanical properties

Test	Item	Purchase Specification of LP Rotor Forging ([ ])	ASTM A470 Grade C/Class 6
Tensile Test	Tensile Strength	[ ]	725 - 860 MPa
	Yield Strength (0.2% offset)	[ ]	Min.620 MPa
	Elongation	[ ]	Min.17%
	Reduction of Area	[ ]	Min.50%
Charpy Test	Absorbed Energy at 21-27 deg C	[ ]	Min.61J
	50% FATT	[ ]	Max.-7 deg C
	Upper Shelf Energy Level	[ ]	-

2) Relation between material properties of the purchase specification and those used in the turbine missile analysis:

Specified minimum yield strength in MHI purchase specification of the LP rotor material [ ] is explicitly used in the turbine missile analysis (MUAP-07028 (R1)) and actual yield strength of the as-built rotors will be confirmed. 50 percent fracture appearance transition temperature (FATT) of [ ] and Upper Shelf Energy Level of [ ], which are also discussed in the turbine missile analysis (MUAP-07028 (R1)) will be confirmed on the as-built rotors as well as yield strength to confirm that K_{IC} applied to the above turbine missile analysis is adequate.

II. Placing specific LP rotor material name

MHI agrees to place the LP rotor material name [ ] in this RAI response (Table 8-1 and Table 8-2) and turbine missile analysis (MUAP-07028). The turbine missile analysis report (MUAP-07028) Section 2 DESIGN FEATURES will be revised as follows:

2.0 DESIGN FEATURES

A typical integral rotor is shown in Figure 2-1. A major advantage of this design is the elimination of the disc bores and keyways. Rotors with shrunk-on discs have peak stresses around the locations where the discs are shrunk-on and keyed to the shaft. The elimination of these structures has shifted the location of peak stress from the keyways to blade fastening regions at the rim of the rotor, whose local stress is much lower than that of the shrunk-on discs. Since cracks are likely to occur in high stressed regions, reduction of the peak stress throughout the rotor significantly contributes to the reduction of the rotor burst probability.

In addition to lower local stress throughout the rotor, the integral structure also has the benefit of reduced average tangential stress of the discs and this fact allows us to apply lower yield strength material with traditional safety margins remaining as they are. The integral rotor forgings of the 3.5% Ni-Cr-Mo-V alloy steel [ ] are heat-treated to obtain minimum yield strengths of [ ], maximum FATT of [ ], and minimum upper shelf energy of [ ] depending upon the requirements of the particular application. Many years of experience and testing the rotor material have demonstrated better ductility, toughness and resistance to stress corrosion cracking at a lower yield strength. These benefits can be important factors to reduce the possibility of turbine missile generation.

Impact on DCD

Refer to "Impact on DCD" in the response to RAI 574-4633, Question 10.02.03-10, RAI10.2.3-10.

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**

Refer to above II. (Placing specific LP rotor material name) of MHI Response to Additional NRC Comment for Additional NRC Comment (Open Item 10.2.3-1).

03/30/2012

US-APWR Design Certification

Mitsubishi Heavy Industries

Docket No. 52-021

RAI NO.:	**NO. 574-4633**
SRP SECTION:	**10.02.03 – Turbine Rotor Integrity**
APPLICATION SECTION:	**Application Section: Tier 2 FSAR Section 10.2.3**
DATE OF RAI ISSUE:	**4/20/2010**

QUESTION NO.: 10.02.03-9, RAI 10.2.3-9

In a letter dated March 10, 2009, the response to RAI No. 199-2073, Question 10.02.03-2 provided acceptance criteria for the 50% FATT and Charpy V-notch energy which do not meet the acceptance criteria of -18°C (0°F) and 8.3 kg-m (60 ft-lbs), respectively, as provided in SRP Sections 10.2.3 (paragraphs II.1b and II.1c). Therefore, provide a discussion on why the material properties for the 50% FATT and Charpy V-notch energy provided in the response to RAI No. 199-2073, Question 10.02.03-2 ensures that the turbine rotor has adequate fracture toughness during startup and normal operating temperatures.

ANSWER:

It is confirmed in the rotor design that the rotor has adequate fracture toughness.

The fracture analysis done in the design includes determining the stresses in the rotor resulting from rotation, steady-state thermal loads and transient thermal loads from startup and stop. Fracture toughness K_{IC} used in the fracture analysis is introduced by specified mechanical properties of the rotor material, 50%FATT and Upper Shelf Absorbed Energy, with Begley-Logsdon method.

Figure 9-1 Begley-Logsdon method

Additional NRC Comment (Open Item 10.2.3-2):

The acceptance criteria provided in the response to RAI 199-2073, Question 10.2.3-2, for the 50 percent FATT and Charpy V-notch energy do not meet the acceptance criteria of -18 °C (0 °F) and 8.3 kg-m (60 ft lbs or 81 J), respectively, which are provided in SRP Sections 10.2.3 (Paragraphs II.1b and II.1c).

Therefore, the applicant is requested to provide a discussion on why the material properties for the 50 percent FATT and Charpy V-notch energy of [ ] and [ ] respectively provided in the response to RAI 199-2073, Question 10.2.3-2, is sufficient to ensure that the turbine rotor has adequate fracture toughness during startup and normal operating temperatures.

SRP section 10.2.3 paragraph II.1b and c require the Charpy V-Notch energy and FATT curves to be well defined to use the Begley-Logsdon method. The applicant is requested to provide NRC with the confirmation that The Charpy V-Notch energy and FATT curves are well defined for the material which is to be used for the US-APWR LP turbine rotors.

MHI Response to Additional NRC Comment

I. Minimum requirement for the 50 percent FATT and Charpy V-notch energy

It is true that criteria for the 50 percent FATT and Charpy V-notch (C_v) energy in MHI purchase specification is equivalent to those specified in ASTM A470 Grade C, Class 6, which is not as conservative as SRP Criteria as shown in the following table.

Table 9A-1 Comparison of mechanical property requirements

	Unit	MHI purchase specification	ASTM A470 Grade C Class 6	SRP 10.2.3
50 percent FATT	Max. °C	[ ]	-7	-18
C_v energy	Min. J at RT	[ ]	61	81

RT: Room Temperature

But the following reasons show that above requirements of MHI purchase specification ([ ]) are conservative enough to obtain the fracture toughness (K_{IC}) to secure the probability of the turbine missile ejection less than 1×10^{-5} per year, which is the criteria for unfavorably oriented turbine.

(1) K_{IC} applied to the turbine missile analysis (MUAP-07028 (R1)) was obtained based on the most conservative C_v energy and 50 percent FATT specified in the rotor purchase specification through Begley-Logsdon Method. Therefore, the K_{IC} applied to the turbine missile analysis and the rotor purchase specification are being kept consistent with each other.

(2) K_{IC} of [ ] which is actually used in the turbine missile analysis includes [ ] safety margin against the above calculated K_{IC} of [ ] (refer to Figure 9A-1).

(3) Actual obtainable K_{IC} at the center bore core region of the actual full integral LP rotors is greater than 200 ksi·in$^{1/2}$ (220 MPa·m$^{1/2}$), while much lower K_{IC} of [ ] was applied to the turbine missile analysis (refer to Figure 9A-1).

Figure 9A-1 Relation between K_{IC} used in missile analysis and actual obtainable K_{IC} based on MHI Purchase Specification

Notes on the above figures;

(1) Actual Fracture toughness (K_{IC}) at the center bore core of the full integral rotors are significantly higher than that used in the turbine missile analysis [ ].

(2) This fact ensures that the turbine missile ejection probability can be kept low enough compared to the criteria in the SRP, even if MHI purchase specification does not comply with the requirement of SRP 10.2.3 in regard to 50 percent FATT and C_v energy.

II. Application of the Begley-Logsdon method to the LP rotor material [ ]

(1) Sample of measured "Percent of brittle fracture" and "Absorbed energy" of the material [ ], which is to be applied to US-APWR LP rotors, are given in Figure 9A-2.

(2) Those parameters and their approximate curves clearly show prominent temperature-dependent characteristics.

(3) FATT and Upper-shelf energy can be well (clearly) defined by the approximate curves. The material of [ ] surely satisfies the conditions stipulated in the SRP section 10.2.3 paragraph II.1b for the application of Begley-Logsdon method to estimate actual Kic of manufactured LP rotors.

(4) Measuring method of those parameters;

- ✓ Confirm temperature-dependent properties by measuring the brittle fracture appearance rate and the absorbed energy at different temperatures more than eight points, and draw approximate curves.

- ✓ 50%FATT is determined by this approximate curves and absorbed energy is determined by approximate curve at both room temperature (approx. 25℃) and temperature at the value of 0% of brittle fracture

Figure 9A-2 Example of measured "Percent of brittle fracture" and "Absorbed energy" of the LP rotor material [ ]

Notes on the above figure;

(1) Percent brittle fracture; Brittle fracture appearance/Area of fracture surface

(2) Absorbed energy; The energy to fracture a test specimen in a Charpy test

Impact on DCD

There is no impact on the DCD.

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 a Technical/Topical Report.

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

03/30/2012

US-APWR Design Certification

Mitsubishi Heavy Industries

Docket No. 52-021

RAI NO.:	**NO. 574-4633**
SRP SECTION:	**10.02.03 – Turbine Rotor Integrity**
APPLICATION SECTION:	**Application Section: Tier 2 FSAR Section 10.2.3**
DATE OF RAI ISSUE:	**4/20/2010**

QUESTION NO.: 10.02.03-10, RAI 10.2.3-10

In a letter dated March 10, 2009, MHI provided a response to RAI No. 199-2073, Question 10.02.03-2, stated that the tensile and charpy testing will be performed on five specimens from the outer periphery of the turbine rotor. For a bored rotor, additional tensile and Charpy testing will be performed from three specimens on the interior bore periphery of the turbine rotor. However, the staff notes that Revision 2 of the US-APWR FSAR did not include the number of specimens to be tested as provided in the response to RAI No. 199-2073, Question 10.2.3-2. In addition, the staff notes that neither MHI's response to RAI No. 199-2073, Question 10.02.03-2 provided in a letter dated March 10, 2009, nor Section 10.2.3.2 of the US-APWR FSAR, Revision 2, Tier 2 provides the method of calculating the fracture toughness value for the turbine rotor material.

SRP Section 10.2.3 (paragraph II.2) lists four acceptable methods for obtaining the fracture toughness properties. Therefore, the staff requests that the USAPWR FSAR be revised to:

a. Include the number of test specimens as stated in its response to RAI No. 199-2073, Question 10.02.03-2
b. Include the test method and fracture toughness acceptance criteria that will be used for the turbine rotor design.

ANSWER:

a. The numbers of test specimens will be added to FSAR section 10.2.3.
   The location of test coupons is shown as Figure 10-1.
b. The Charpy test criteria will be added to FSAR section 10.2.3.
   The Acceptance criteria for the Charpy test are shown as Table 10-1.

[ ]

Note: Test specimens for Tensile test (TT) and Charpy test (VT) are to be taken from X-1 through X-5. The number of the test specimens taken from each sampling location is shown below.

Sampling location	Number of specimens for Tensile test (TT)	Number of specimens for Charpy test (VT)
X-1	4	Min. 8 (Note 1)
X-2	4	Min. 8 (Note 1)
X-3	4	Min. 8 (Note 1)
X-4	4	Min. 8 (Note 1)
X-5	4	Min. 8 (Note 1)
Total	20 per LP rotor	Min. 40 per LP rotor

Note 1: Min. 3 specimens for the Charpy tests at Room Temperature
Min. 5 specimens for the Charpy tests at other temperature for the determination of a transition temperature.

Figure 10-1 Location of sampling for Tensile and Charpy tests

Table 10-1 Acceptance criteria of the Charpy test

Test	Item	Purchase Specification of LP Rotor Forging
Charpy Test	Absorbed Energy at 21-27 deg C	[ ]
	50% FATT	[ ]
	Upper Shelf Energy Level	[ ]

Additional NRC Comment (Open Item 10.2.3-3):

Regarding the locations of the test specimens and the material properties of the internal regions for a non-bored rotor, the applicant stated in its response to RAI 199-2073, Question 10.2.3-2, that the tensile and Charpy testing will be performed on five coupons from the outer periphery of the turbine rotor. For a bored rotor, additional tensile and Charpy testing will be performed from three coupons on the interior bore periphery of the turbine rotor. The staff finds the number of specimens acceptable since it meets the guidance provided in SRP 10.2.3.

However, the staff identifies that Revision 2 of the DCD should include the number of coupons and specimens to be tested as provided in the response to RAI 199-2073, Question 10.2.3-2.

MHI Response to Additional NRC Comment

The following sentence will be added in Revision 3 of the DCD:

Five coupons will be taken from one LP rotor. Four tensile test specimens and minimum eight Charpy V-notch (C_v) test specimens, which includes minimum three C_v test specimens at room temperature are cut out from each coupon.

Impact on DCD

The 1st paragraph of the US-APWR, Tier 2, Section 10.2.3.1 and the 1st paragraph of the US-APWR, Tier 2, Section 10.2.3.2 will be revised as follows. (See attachment-1.)

10.2.3.1 Materials Selection

Fully integral turbine rotors are made from ladle refined, vacuum deoxidized Ni-Cr-Mo-V alloy steel by processes that maximize the cleanliness and toughness of the steel. The lowest practical concentrations of residual elements are obtained through the melting process. The LP turbine rotor material is similar to ASTM A470, Grade C, Class 6 (Reference 10.2-5) as specified in the turbine missile analysis (Reference 10.2-9). This material has the lowest fracture appearance transit temperatures (FATT) and the highest Charpy V-notch (C_v) energies obtainable on a consistent basis from water-quenched Ni-Cr-Mo-V material at the sizes and strength levels used. Mechanical properties such as tensile strength, yield strength, elongation, reduction of area, absorbed energy at Charpy test at room temperature and 50 percent FATT are equal to or more conservative than those of ASTM A470, Grade C, Class 6. Charpy tests and tensile tests are conducted in accordance with ASTM, A370 (Reference 10.2-6). Five coupons will be taken from one LP rotor. Four tensile test specimens and minimum eight Charpy V-notch (C_v) test specimens, which includes minimum three C_v test specimens at room temperature are cut out from each coupon and tested in accordance with the requirement of ASTM A370 (Reference 10.2-6).

10.2.3.2 Fracture Toughness

Suitable material toughness is obtained through the use of materials described in Subsection 10.2.3.1 to produce a balance of material strength and toughness to provide safety while simultaneously providing high reliability, availability, and efficiency during operation. The restrictions on phosphorous (P), sulphur (S), aluminum (Al), antimony (Sb), tin (Sn), Arsenic (As) and copper (Cu) in the specification for the rotor steel provide the appropriate balance of material strength and toughness. The absorbed energy and 50 percent FATT requirements are equal to or more rigorous than those given in ASTM A470, Grade C, Class 6.

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/T**opical Report**

There is no impact on a Technical/Topical Report.

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

03/30/2012

US-APWR Design Certification

Mitsubishi Heavy Industries

Docket No. 52-021

RAI NO.:	**NO. 574-4633**
SRP SECTION:	**10.02.03 – Turbine Rotor Integrity**
APPLICATION SECTION:	**Application Section: Tier 2 FSAR Section 10.2.3**
DATE OF RAI ISSUE:	**4/20/2010**

QUESTION NO.: 10.02.03-11, RAI 10.2.3-11

In a letter dated March 10, 2009, MHI provided responses to RAI No. 199-2073, Questions 10.02.03-2 and 10.02.03-5 concerning the integrity of a non-bored (solid) turbine rotor.

MHI response to RAI No. 199-2073, Questions 10.02.03-2 provided some material test result comparisons between the rotor outer periphery and the rotor center core so that the mechanical properties at the rotor center core can be evaluated using the material at the outer periphery of the turbine rotor. Based on this comparison, chemical composition and mechanical testing of the core for non-bored rotors would not be performed. The NRC staff notes that the comparative material test results provided shows that the material at the center core of the turbine rotor has material properties that are less conservative (lower reduction of area, lower impact energy and higher 50 percent FATT temperature) than at the outer periphery, which is due to the different solidification rates of this large component. Therefore, the material properties cannot be accurately and consistently determined using only test specimens from the outer periphery of the turbine rotor.

In its response to RAI No. 199-2073, Question 10.02.03-05, MHI stated that ultrasonic inspection of the turbine rotor will be performed prior to gashing (final outside periphery machining) so that 100% ultrasonic inspection can be performed on the turbine rotor due to its drum shape.

However, it also states that as ultrasonic testing technology advances, potential defects at the center core region will be detected. Therefore, this implies that currently, ultrasonic inspection is not capable of ensuring the integrity of non-bored turbine rotors at the center region.

Therefore, the integrity of non-bored turbine rotors cannot be verified, since the non-destructive examinations (pre-service and in-service volumetric inspections) are not capable of detecting defects at the center core region, and destructive testing cannot be performed on non-bored rotors to confirm the material properties. Therefore, the non-bored rotor design should be deleted from the US-APWR FSAR, or provide the following:

- Specific destructive testing that can confirm the material properties at the core region, and/or more extensive test results.
- Specific non-destructive testing that can detect defects at the center core region, or provide specific in-service non-destructive examinations, including inspection types, inspection interval, acceptance criteria, etc. taking into consideration that material properties and the presence of internal defects of the as-built turbine rotor cannot be confirmed.

- Appropriate operating experience which justifies the integrity of the turbine rotor can be maintained.

ANSWER:

Through the progress of steel making technology, the content of S (Sulfur) and P (Phosphorous) that have adverse effects on inclusion and segmentation have been significantly reduced. Figure 11-1 shows the history of reduction in the content of S and P. Figure 11-2 also shows the material test record sample for rotors manufactured over the last 20 years. The test result shows that the mechanical properties at the center core of the rotor are stable enough to satisfy the specification requirements.

Please note that there are similar figures to Figure 11-2 in the answer to Q10.02.03-1 and Q10.02.03-5 in RAI 199-2073 as "Figure 2-2" and "Figure 5-1". But those Figures in the response to the RAI 199-2073 need to be replaced by the updated Figure 11-2 in this response to RAI 574-4633, Question No. 10.02.03-11, because illegible figures in the response to the RAI 199-2073 show the mechanical properties of the LP rotors for fossil usage and is not suitable for the evaluation of the LP rotors for nuclear usage due to the following reasons;

- All the rotors listed in Figure 2-2 and Figure 5-1 in RAI 199-2073 rotates at full speed (3,000 or 3,600rpm) and the size of the rotors are much smaller than those usually used in nuclear power plants, which rotates at half speed (1,500 or 1,800rpm).
- There are also significant differences in mechanical properties such as yield strength and tensile strength between the rotors for fossil and nuclear usage. Those differences could have serious impacts on the mechanical properties and homogeneity of the rotors, especially at around the axial center of the rotors.

Figure 11-1 Reduction history of the content of S and P

Figure 11-2 Example of the LP rotor material test result from last 20 year record (all the rotors from A through G are for nuclear usage)

Through past improvement in ultrasonic testing technology, it is possible to detect small defects at the center of the rotor from the rotor periphery. As indicated in Figure 11-3, it is verified that ultrasonic inspection from the rotor periphery can reliably detect flaws [ ] in length.

Figure 11-3 Minimum detectable flaw size at the center of the rotor by the ultrasonic inspection

Table 11-1 shows examples of bore inspection record after long term operation. From this record, it is confirmed that integrity of the turbine rotor has been maintained for more than [ ].

All the units included in the Table 11-1 are the ones for fossil usage and do not include the units for nuclear usage. But please note that the low pressure turbines for unit A, C and D are of half speed (1,800rpm) design like nuclear machines, and the rotor size and the material properties are same as that for the nuclear units. In addition, operating conditions such as inlet temperature and the number of starts/stops of fossil LP turbines is much severer than nuclear steam turbines in terms of imposed stresses on the rotors. It can be concluded that operating experience at fossil unit A, C and D bounds the experience at nuclear units.

Table 11-1 Examples of bore inspection after operation (with-bored rotor)

Additional NRC Comment (Open Item 10.2.3-4):

Based on the above, the turbine rotor can be either a bored or non-bored rotor design. The applicant also stated that the homogeneity and quality of the material at the center core of a non-bored rotor is ensured through the steel making process. In addition, in its response to RAI 199-2073, Question 10.2.3-2, the applicant provided some material test result comparisons between the rotor outer periphery and the rotor center core so that the mechanical properties at the rotor center core can be evaluated using the material at the outer periphery of the turbine rotor. Therefore the applicant will not perform chemical composition and mechanical testing of the core for non-bored rotors.

The NRC staff notes that the comparative material test results provided show that the material at the center core of the turbine rotor has material properties (lower reduction of area, lower impact energy and higher 50 percent FATT temperature) that are less conservative than at the outer periphery, which is due to the different solidification rates of this large component. Therefore, the material properties cannot be accurately and consistently determined using only test specimens from the outer periphery of the turbine rotor. Since the material properties do vary from the outer periphery to the internal center core, and the internal core of each non-bored as-built turbine rotor cannot be verified, the applicant should delete the non-bored turbine rotor from its design, or provide specific destructive testing and nondestructive testing taking into consideration that the internal material properties and the presence of internal defects of the as-built rotor cannot be confirmed. In addition, appropriate operating experience should be provided which justifies that the integrity of the rotor can be maintained.

MHI Response to Additional NRC Comment

I. Internal material of the non-bored LP rotors

1. Reasons for use of non-bored rotor

   MHI explained in the response to RAI No. 199-2073, Questions 10.02.03-2 and 10.02.03-5 that non-bored rotors are to be applied to the US-APWR steam turbine due to the following reasons:

(1) Inherent low tangential stress due to centrifugal forces at around the center of the rotor,

(2) Advancement of steel making process which realizes homogeneity along radial line of large size of LP rotors and mechanical properties at the center of the rotors can be reliably and stably kept within the limitation specified in MHI purchase specification.

2. Mechanical properties at the center of LP rotors;

   Measured mechanical properties at the center bore core of the full integral rotor with drum diameter of [ ] are shown in Figure 11A-1. The figure shows that all the mean values of the mechanical properties ± 3σ (99.7% reliability) are secured to satisfy the minimum required values of the purchase specification. As the LP rotor size of the US-APWR is almost same as that of the rotors listed in Figure 11A-1 (this implies that the drum diameter of the US-APWR LP rotors is expected to be the same as the maximum diameter of the above range), it is concluded that the mechanical properties including "Absorbed Energy" and "50 percent FATT" are stably and reliably stay in the reliability higher than 99.7 percent within the allowable ranges which is specified in the MHI purchase specification.

3. Turbine missile probability

   Due to the following three reasons, it was concluded that non-bored LP rotors keep the turbine missile probability less than the criteria specified in the SRP without destructive testing at the center bore core:

   (1) Inherent low tangential stress around the center of the rotor,

   (2) Mechanical properties at the rotor center stay in the reliability higher than 99.7 percent within allowable range,

   (3) Fracture toughness (K_{IC}) applied to the report "Probability of Missile Generation from Low Pressure Turbines, MUAP-07028 (R1)" is [ ]. This K_{IC} of [ ] is calculated based on the minimum requirement of the absorbed energy and 50 percent FATT which can be achieved in the reliability higher than 99.7 percent. Furthermore, additional safety margin of [ ] in the fracture toughness (K_{IC}) was applied to the LP turbine missile analysis (refer to **Figure 9A-1** in the MHI's amended response to the Question 10.02.03-9).

II. Inspection of the internal defects of non-bored LP rotors

As is explained in the DCD Section 10.2.3.3 "Preservice Inspection", each LP rotor forging is subject to a 100 percent volumetric examination (UT inspection). 100% UT inspection after periphery machining of the as-build rotors will be carried out to define the initial internal defect size and location, including the ones around the center of the rotors. This UT inspection can detect the defects as small as [ ] at the center of the rotors, while we assumed initial crack size is [ ] in the turbine missile analysis conservatively to compensate for the possible inclined cracks. Therefore, the UT inspection from the rotor outer periphery as part of the preservice inspection is enough to keep the turbine missile probability due to the low cycle fatigue less than the criteria specified in the SRP.

LP rotor outer surface is exposed to wet steam and material degradation could be occurred due to corrosive environment, while center of the rotor is isolated from the steam and there is no possibility of material degradation due to such environmental effects. In light of this fact, we concluded that initial 100 percent UT inspection of the rotor and the turbine missile probability analysis using the initial crack size and location of the as built-rotor is enough to secure the turbine missile probability less than the criteria for the plant life time. This means that it is not necessarily mandatory to do the UT inspection around the center of the rotors during periodical inspection.

Figure 11A-1 Test results of mechanical properties at the center bore core of full integral LP rotors for nuclear usage

(Refer to the Notes on the next page)

Notes for Figure 11A-1 (Figure of the previous pages):

Note 1: All the data in Figure 11A-1 is the one for center bore core of full integral rotors with drum diameter between [ ] inches, while drum diameter of the US-APWR LP rotors is expected to be almost same as the maximum of the above range.

Note 2: Steel forging manufacturer of all the rotors listed in this figure is the one who are going to supply the LP rotor forgings for US-APWR.

Note 3: The positions of the test coupons from B1 through B3 are shown below:

Note 4: Blue dotted lines show the range of ±3σ (99.7 percent reliability).
All the mechanical properties including "Absorbed energy" and "50 percent FATT" are confirmed to be in the reliability higher than 99.7 percent.

Note 5: Minimum yield strength requirement of the LP rotors of Unit C and D changed from [ ] to [ ] to keep the Stress Corrosion Cracking (SCC) sensitivity as low as possible depending on the safety margin of the rotors against centrifugal forces. Tensile strength of the same rotors also reduced along with the reduction of yield strength.

Impact on DCD

The 2nd paragraph from the last of the US-APWR, Tier 2, Section 10.2.3.4 will be revised as follows. (See attachment-1.)

The non-bored design of the high-pressure and low-pressure turbine rotor provides the necessary design margin by virtue of its inherently lower centerline stress. Metallurgical processes permit fabrication of the rotors without a center borehole. The use of solid rotor forgings was verified by an evaluation of the material removed from center-bored rotors for nuclear power plants. This evaluation demonstrated that the material at the center of the rotors satisfied the rotor material specification requirements. Forgings for no-bore rotors are provided by suppliers who have been qualified based on bore material performance.

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 a Technical/Topical Report.

10.2.3.1 Materials Selection

Fully integral turbine rotors are made from ladle refined, vacuum deoxidized Ni-Cr-Mo-V alloy steel by processes that maximize the cleanliness and toughness of the steel. The lowest practical concentrations of residual elements are obtained through the melting process. ~~The turbine rotor material complies with the chemical property limits of ASTM A470 (Reference 10.2-5). The specification for the rotor steel has lower limitations than indicated in the ASTM standard (Reference 10.2-5) for phosphorous, sulphur, aluminum and antimony.~~The LP turbine rotor material is similar to ASTM A470, Grade C, Class 6 (Reference 10.2-5) as specified in the turbine missile analysis (Reference 10.2-9). This material has the lowest fracture appearance transit temperatures (FATT) and the highest Charpy V-notch energies obtainable on a consistent basis from water-quenched Ni-Cr-Mo-V material at the sizes and strength levels used. Mechanical properties such as tensile strength, yield strength, elongation, reduction of area, absorbed energy at Charpy test at room temperature and 50 percent FATT are equal to or more conservative than those of ASTM A470, Grade C, Class 6. Charpy tests and tensile tests are conducted in accordance with ASTM, A370 (Reference 10.2-6). ~~A minimum of three Charpy test specimens are tested using the impact test criteria that satisfy ASTM A470 Grade C (Class 6).~~Five coupons will be taken from one LP rotor. Four tensile test specimens and minimum eight Charpy V-notch (C_V) test specimens, which includes minimum three C_V test specimens at room temperature are cut out from each coupon and tested in accordance with the requirement of ASTM A370 (Reference 10.2-6). DCD_10.2.3-10 S01 DCD_10.2.3-10 S01

The production of steel for the turbine rotors starts with the use of high-quality, low residual element scrap. An oxidizing electric furnace is used to melt and dephosphorize the steel. Ladle furnace refining is then used to remove oxygen, sulphur, and hydrogen from the rotor steel. The steel is then further degassed using a process whereby steel is poured into a mold under vacuum to produce an ingot with the desired material properties. This process minimizes the degree of chemical segregation since silicon is not used to deoxidize the steel.

10.2.3.2 Fracture Toughness

Suitable material toughness is obtained through the use of materials described in Subsection 10.2.3.1 to produce a balance of material strength and toughness to provide safety while simultaneously providing high reliability, availability, and efficiency during operation. The restrictions on phosphorous (P), sulphur (S), aluminum (Al), antimony (Sb), tin (Sn), arsenic (As) ~~argon,~~ and copper (Cu) in the specification for the rotor steel provides~~s for~~ the appropriate balance of material strength and toughness. The ~~impact~~absorbed energy and 50 percent FATT~~transition temperature~~ requirements are equal to or more rigorous than those given in ASTM A470, Grade C, Class 6~~ or 7 and their equivalents~~. DCD_10.2.3-10 S01

Stress calculations include components due to centrifugal loads and thermal gradients where applicable. Fracture toughness will be at least 200ksi·in$^{1/2}$ (220MPa·m$^{1/2}$). For the purpose of conservative evaluation, fracture analysis is to be done using ~~a~~ fracture toughness with margin against minimum expected values on the rotors. The material fracture toughness needed to maintain this conservative margin is verified by mechanical property tests on material taken from the rotor. DCD_10.02-3

The non-bored design of the high-pressure and low-pressure turbine rotor provides the necessary design margin by virtue of its inherently lower centerline stress. Metallurgical processes permit fabrication of the rotors without a center borehole. The use of solid rotor forgings was verified by an evaluation of the material removed from center-bored rotors for ~~fossil~~nuclear power plants. This evaluation demonstrated that the material at the center of the rotors satisfied the rotor material specification requirements. Forgings for no-bore rotors are provided by suppliers who have been qualified based on bore material performance. DCD_10.2.3-11 S01

All the low-pressure turbine rotating blades are attached to the rotor using christmas tree, side entry type root.

10.2.3.5 Inservice Inspection

The inservice inspection program for the LP turbine provides assurance that rotor flaws that might lead to brittle failure of a rotor at speeds up to design speed will be detected. This inspection includes disassembly of the turbine at equal or less than 10-year intervals during plant shutdowns coincident with the inservice inspection schedule required by IWA-2430 of the 2007 Edition with 2008 Addenda of Section XI, Division 1 ASME Boiler & Pressure Vessel Code. Inspection of parts that are normally inaccessible when the turbine is assembled for operation (couplings, coupling bolts, turbine rotors, and low pressure turbine blades) is conducted.

The maintenance and inspection program plan for the turbine assembly and valves is based on turbine missile probability calculations, operating experience of similar equipment and inspection results. The turbine missile generation probability due to rotor material failure below design overspeed was submitted in Reference 10.2-9. The analysis of missile generation probability due to failure of the overspeed protection system is used to determine turbine valve test frequency and is described in Reference 10.2-10. The maintenance and inspection program includes the activities outlined below:

- This inspection consists of visual, surface, and volumetric examinations as indicated below:
  - Each rotor, stationary and the rotating blade path component is inspected visually and by magnetic particle testing on its accessible surfaces. Ultrasonic inspection of the side entry blade grooves is conducted. These inspections are conducted at intervals equal or less than 10 years for both high-pressure and low-pressure turbines.
  - A 100 percent surface examination of couplings and coupling bolts is performed.
  - The fluorescent penetrant examination is conducted on nonmagnetic components.
- At least one main steam stop valve, one main steam control valve, one reheat stop valve, and one intercept valve are dismantled approximately every 4 years during scheduled refueling or maintenance shutdowns. A visual and surface examination of the valve internals is conducted. If unacceptable flaws or excessive corrosion are