GE-Hitachi Nuclear Energy Americas LLC

James C. Kinsey
Project Manager, ESBWR Licensing

PO Box 780 M/C A-55
Wilmington, NC 28402-0780
USA

T 910 675 5057
F 910 362 5057
jim.kinsey@ge.com

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Subject: **Response to Portion of NRC Request for Additional Information Letter No. 98 – Steam and Power Conversion Systems– RAI Numbers 10.2-23, 10.2-24, and 10.2-25**

Enclosure 1 contains GEH's response to the subject NRC RAIs transmitted via the Reference 1 letter

If you have any questions or require additional information regarding the information provided here, please contact me.

Sincerely,

Kathy Sedney for

James C. Kinsey
Project Manager, ESBWR Licensing

D068
NRO

Reference:

1. MFN 07-317, Letter from U.S. Nuclear Regulatory Commission to Robert E. Brown, *Request for Additional Information Letter No. 98 Related to the ESBWR Design Certification Application*, May 29, 2007.

Enclosure:

1. MFN 07-404 – Response to Portion of NRC Request for Additional Information Letter No. 98 – RAI Numbers 10.2-23, 10.2-24, and 10.2-25
2. DCD Markups

cc:	AE Cubbage	USNRC (with enclosure)
	RE Brown	GE/Wilmington (with enclosure)
	LE Fennern	GE/San Jose (with enclosure)
	GB Stramback	GE/San Jose (with enclosure)
	eDRF:	0000-0071-5054 R1

Enclosure 1

MFN 07-404

Response to Portion of NRC Request for Additional Information Letter No. 98 Related to ESBWR Design Certification

Steam and Power Conversion System

RAI Numbers 10.2-23, 10.2-24, 10.2-25

NRC RAI 10.2-23:

DCD Tier 2, Rev. 3, Section 10.2.3.1 (page 10.2-10, third paragraph) states that the fracture appearance transition temperature will be no higher than +30 degrees F; and that the C_v energy at the minimum operating temperature will be at least 45 ft-lbs for a large integral rotor. Justify these two design limits because they are not consistent with SRP 10.2.3 II.1.

GEH Response:

Material testing has shown that fracture appearance transition temperature (FATT) increases (and C_v energy decreases) from the outer surface to the deep-seated region of the forging as a result of variation (slowing from outside to center) in the cooling rate during the quenching process. The cooling rate variation causes the FATT (and C_v energy) to change rapidly near the surface of the forging and then gradually at deeper locations. As a result, material acceptance requirements for FATT and C_v greatly depend on the location in the forging where test samples are obtained.

The original values for fracture appearance transition temperature (FATT) and C_v energy (0 degrees F and 60 ft-lbs., respectively) specified in SRP 10.2.3 II.1 are based on material acceptance data taken from specimens at the surface of a shrunk-on wheel (disc) forgings. In cases where the shrunk-on disc design is utilized, surface specimens are used because deep-seated specimens (specimens taken from near the center of the forging) cannot be obtained during acceptance testing without destroying the wheel forging. FATT test results based on surface measurements are lower (and the C_v energy is higher) than those based on deep-seated properties.

The values for FATT and C_v energy in the ESBWR DCD Tier 2, Rev. 3, section 10.2.3.1 for an integral (single piece) rotor forging are based on material acceptance data from specimens from a representative radial trepan (closer to the center of the forging), beyond the region where FATT changes rapidly with position. This is the location where measurements are made on every integral rotor forging. As such, the criteria established in the DCD for integral forgings are deep-seated values for FATT and C_v energy, as opposed to surface values. A large data set of centerline FATT values and FATT location variation is available from previous integral rotor testing. Evaluation of this data set shows that the FATT and C_v limits set forth in the DCD accurately reflect the material capability for single piece rotor forgings, and provide suitable means to evaluate the bore FATT. Based upon the known stress-related fracture mechanics associated with integral rotors, crack propagation typically originating from the center of the forging, it is more appropriate to evaluate the material characteristics based on these deep-seated values to verify structural integrity. The fact that the bore stresses for integral rotors are lower than those of the shrunk-on wheel design provides an additional margin of safety.

In conjunction with the FATT and C_v acceptance criteria previously discussed, the fracture toughness criteria identified in SRP 10.2.3 II.2 (and DCD Section 10.2.3.2) are satisfied for both the wheel and integral rotor designs, ensuring that sufficient margin exists between the operating stress intensity and the critical stress intensity factor.

DCD Impact:

No DCD changes will be made in response to this RAI.

NRC RAI 10.2-24:

DCD Tier 2, Rev. 3, Section 10.2.3.2 is not consistent with SRP 10.2.3 II.2 because it is not clear how fracture toughness properties of the turbine rotor are obtained. SRP 10.2.3 II.2 specifies four methods (a, b, c, and d) for obtaining fracture toughness properties for the turbine rotor. Discuss the method that will be used in accordance with SRP 10.2.3 II.2.

GEH Response:

Each integral (single piece) rotor forging has the following material acceptance tests conducted:

1. tensile test
2. room temperature Charpy V-notch test
3. fracture appearance transition temperature (FATT) determination

These tests are conducted in the body of the rotor at a representative radial trepan. When a rotor is bored, these tests are also conducted in the center core material. Previous testing of this nature performed on integral rotors fabricated from the same material has established a database with reliable material characteristic correlations suitable for application on new, unbored rotor forgings.

The fracture toughness (K_{Ic}) value is determined using a value of deep-seated FATT based on the measured FATT values from trepan specimens, and a correlation factor obtained from historical integral rotor test data as described above. This is the same methodology that was utilized for analysis of the shrunk-on wheel rotors in the past. This method of verification most closely resembles method (c) in SRP 10.2.3 II.2, with the exception that the correlation factors used are derived from the manufacturers test data and extensive background on integral forged rotors (in place of the Begley-Logsdon paper, which was published in 1971). The test data and calculated toughness curve are to be part of the missile analysis report for the turbine.

DCD Impact:

DCD Section 10.2.3.2 is to be revised as detailed in the proposed markup to clarify rotor fracture toughness test requirements.

NRC RAI 10.2-25:

DCD Tier 2, Rev. 3, Section 10.2.3.5 (page 10.2-11) describes the specific codes or standards to which the pre-service examinations (ultrasonic and surface) of forgings will be adhered as recommended in SRP 10.2.3 II.3. Discuss whether pre-service visual examinations of forgings will be conducted.

GEH Response:

In accordance with standard industry practices, pre-service surface and visual examinations of the finish-machined rotor forgings is conducted during the pre-service inspection phase of fabrication. DCD Section 10.2.3.5, Revision 4 is to incorporate this change.

DCD Impact:

DCD Tier 2, Section 10.2.3.5 is to be revised as noted in the attached markup.

Enclosure 2

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DCD Markups

Undesirable elements, such as sulfur and phosphorus, are controlled to the lowest practical concentrations consistent with good scrap selection and melting practice, and consistent with obtaining adequate initial and long-life fracture toughness for the environment in which the parts operate. The turbine materials have the lowest Fracture Appearance Transition Temperatures (FATT) and highest Charpy V-notch (Cv) energies obtainable, on a consistent basis from material at the sizes and strength levels used.

Low pressure turbine wheel (disc) forgings are made from vacuum treated Ni-Cr-Mo-V alloy steel forgings. The fracture appearance transition temperature (50% FATT), as obtained from Charpy tests performed in accordance with ASTM A-370, will be no higher than 0°F for low pressure turbine wheel (disc) forgings. The Cv energy at the minimum operating temperature will be at least 60 ft-lbs for a low pressure turbine wheel (disc) forging. A minimum of three Cv specimens will be tested in accordance with specification ASTM A-370 to determine this energy level. The determination of FATT is used in lieu of nil-ductility transition temperature methods.

Large integral rotors are also made from vacuum treated Ni-Cr-Mo-V alloy steel forgings. Their larger size limits the achievable properties. The fracture appearance transition temperature (50% FATT), as obtained from Charpy tests performed in accordance with ASTM A-370, will be no higher than +30°F for large integral forgings. The Cv energy at the minimum operating temperature will be at least 45 ft-lbs for a large integral rotor forging. A minimum of three Cv specimens will be tested in accordance with specification ASTM A-370 to determine this energy level.

Current turbine designs utilize rotors produced from large integral forgings. Future turbine designs may include fabricated rotors produced from multiple wrought components. Acceptable material properties will be consistent with component size and fabrication method.

10.2.3.2 Fracture Toughness

Suitable material toughness is obtained through the use of selected materials as described in Subsection 10.2.3.1, to produce a balance of material strength and toughness to ensure safety while simultaneously providing high reliability, availability and efficiency during operation.

Stress calculations include consideration of centrifugal loads, interference fit and thermal gradients where applicable. The ratio of material fracture toughness, K_{Ic} (as derived from material tests on each major part or rotor), to the maximum tangential stress intensity at speeds from normal to design overspeed, is at least two at minimum operating temperature. The fracture toughness (K_{Ic}) value is determined using a value of deep-seated FATT based on the measured FATT values from trepan specimens, and a correlation factor obtained from historical integral rotor test data. ~~Adequate material fracture toughness needed to maintain this ratio is assured by a large historical database of tests.~~ When required, sufficient warm-up time or other procedures will be specified in the turbine operating instructions to ensure that the above ratio of fracture toughness to stress intensity is maintained during all phases of anticipated turbine operation.

10.2.3.3 High Temperature Properties

The operating temperature range of both the High Pressure and Low Pressure rotors is below the stress rupture temperature range of the materials used. Therefore, creep-rupture is not considered to be a significant failure mechanism for these components.

10.2.3.4 Turbine Design

The turbine assembly is designed to maintain structural integrity during normal operating conditions including anticipated operational occurrences and accidents resulting in a turbine trip. The design of the turbine assembly meets the following criteria.

- Turbine shaft bearings are designed to retain their structural integrity under normal operating loads, anticipated operational occurrences, and accidents resulting in turbine trips.
- The natural lateral critical frequencies of the turbine shaft assemblies existing between zero speed and 20% overspeed are controlled in the design and operation so as to cause no distress to the unit during operation. A torsional vibration analysis shall show that the Turbine Generator rotor resonance is outside of the normal operating frequency and its harmonics.
- The turbine rotor average tangential stress (excluding stresses in the blade/wheel region) at design overspeed resulting from centrifugal forces, interference fit (as applicable), and thermal gradients does not exceed 0.75 of the minimum specified yield strength of the material.
- The overspeed trip set point of the turbine is approximately 110%. This overspeed trip set point is at least 1% above the highest anticipated speed resulting from loss of load, which is normally in the range of 106-109%. The turbine assembly is designed and tested to withstand the stresses corresponding to an emergency overspeed level of 120%, which is approximately 10% above the highest anticipated speed resulting from loss of load. On a unit-specific basis, a report will provide the overspeed basis (including setpoints) applicable to the site and discuss how the turbine assembly is designed to withstand the normal conditions, anticipated operational occurrences, and accidents resulting in a turbine trip.
- An integral turbine rotor design is inherently less likely to have a failure resulting in a turbine missile than previous designs with shrunk-on discs and keyways. There are no wheel keyways that can be potential locations for stress concentrations and corrosive contaminate accumulation in the steam environment. Turbine rotors are designed to facilitate in-service inspection of critical regions. On a unit-specific basis, a report will provide a general description of the design features of the turbine, rotor, shaft, couplings and buckets/blades, including number of stages, bucket (blade) design, how the buckets are attached to the rotor, whether the turbine rotor is forged, and pertinent fabrication methods, (e.g., provide drawings).

10.2.3.5 Pre-Service Inspection

The pre-service inspection procedures and acceptance criteria are as follows.

- Forgings are rough-machined with minimum stock allowance prior to heat treatment.
- Forgings undergo 100% volumetric (ultrasonic) examination ~~in all critical regions~~ subject to established inspection methods and acceptance criteria that are equivalent or more restrictive than those specified for Class 1 components in ASME Code Sections III and V. Subsurface sonic indications are not accepted if found to compromise the integrity of

the unit during its service life. Rotor forgings may be bored to remove defects, obtain material for testing and to conduct bore sonic inspection.

- Finished machined rotors are also subject to surface and visual examination. Specific portions, including any bores, keyways, or drilled holes, are subject to magnetic particle test. Surface indications are evaluated and removed if found to compromise the integrity of the unit during its service life. All flaw indications in keyways and drilled holes are removed.
- Each fully bladed turbine rotor assembly is factory spin-tested at 20% overspeed.

Additional pre-service inspections include air leakage tests performed to determine that the hydrogen cooling system is leak-tight before hydrogen is introduced into the generator casing. The hydrogen purity is tested in the generator after hydrogen has been introduced. The generator windings and required motors are megger-tested. Vibration tests are performed on required motor-driven equipment. Hydrostatic tests are performed on required coolers. Required piping is pressure-tested for leaks.

10.2.3.6 In-Service Inspection of Turbine Rotors

The in-service inspection program for the turbine assembly includes the complete inspection of all normally inaccessible parts such as couplings, coupling bolts, turbine shafts, turbine blades and turbine rotors. During plant shutdown (coinciding with the in-service inspection schedule for ASME Section III components, as required by the ASME Boiler and Pressure Vessel Code Section XI) turbine inspection is performed in sections during the refueling outages so that a total inspection has been completed at least once within the time period recommended by the manufacturer.

The recommended maintenance and inspection program plan for the turbine assembly, valves and controls ensures that the annual Turbine Generator missile probabilities are maintained at or below the acceptable level. (See Subsection 10.2.1.)

This inspection consists of visual, surface and volumetric examinations as indicated below.

- Visual, magnetic particle and ultrasonic examination of all accessible surfaces of rotors
- Visual, magnetic particle or liquid penetrant examination of all turbine blades
- Visual, magnetic particle examination of couplings and coupling bolts

10.2.3.7 In-Service Inspection of Turbine Valves

All main stop valves, control valves, extraction non-return valves, intermediate stop, and intercept valves are tested under load. Test controls installed in the MCR permit full stroking of the stop valves, control valves, and intermediate stop and intercept valves. Valve position indication is provided in the MCR. Some load reduction may be necessary before testing main stop and control valves, intermediate stop and intercept valves. Extraction non-return valves are tested by equalizing pressure across the cylinder.

Main stop valves, control valves, extraction non-return valves, and intermediate stop and intercept valves are tested in accordance with the Boiling Water Reactor Owners Group (BWROG) turbine surveillance test program, by closing each valve and observing by the MCR