ENCLOSURE 2

MFN 10-153

0000-0071-8269-R2-NP, Revision 2

GEH Marathon Control Rod Lifetime Surveillance Update

Non-Proprietary Version

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GE Hitachi Nuclear Energy

0000-0071-8269-R2-NP
Revision 2
Class I
eDRFSection 0000-0117-8735 R0
May 2010

Non-Proprietary Information

GEH Marathon Control Rod

Lifetime Surveillance Update

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1. INTRODUCTION

Since the beginning of the Marathon control rod product line, GEH has actively maintained a surveillance program consisting of visual inspections of Marathon control rods. This is in accordance with the approved Safety Evaluation Report (SER) for the Marathon control rod (Ref. 1). A summary of the status of this surveillance program (Ref. 5) was last forwarded to NRC via MFN 09-266, and was also provided to the BWR fleet. This report updates Reference 5, including:

- New inspection results
- A listing of planned inspections
- A summary of the recently updated root cause analysis, part of which is a Marathon Post-Irradiation Examination (PIE)
- A discussion of a design change to the original D/S lattice Marathon absorber tube design.
- A discussion of new control rod designs.

GEH will continue to provide updates of the Marathon control rod surveillance program on an annual basis, at minimum.

2. INSPECTION DATA

Tables 1 and 2 contain a summary of [[ ]] visual inspections of Marathon control rods that GEH has performed or reviewed to date. Since revision 1 of this report (Ref. 5), four additional inspections of high depletion, D/S lattice Marathon control rods have been performed. The inspection of one of these four control rods revealed two minor crack indications. These added inspections are noted in bold in Table 1.

Control rods that have reached end of life, or near end of life are identified in Tables 1 and 2. For the purposes of this report, control rods are considered to be at 'end of life' if the peak local depletion exceeds 90% of the peak local depletion for a Marathon control rod at its lifetime limit in a GEH BWR (Reference 7). Similarly, control rods are considered to be 'near end of life' if the peak local depletion exceeds 80% of the peak local depletion for a Marathon control rod at its lifetime limit in a GEH BWR.

Table 1: D/S Lattice* Marathon Inspection Results

Plant	Serial Number	Ship Year	Inspection Date	Thermal Fluence (snvt)	¼-Segment B-10 Depletion (%)	Peak Local B-10 Depletion (%)	Crack Indications ?
Plant A (US BWR/4)	[[						
							]]

Table 1: D/S Lattice* Marathon Inspection Results (Continued)

Plant	Serial Number	Ship Year	Inspection Date	Thermal Fluence (snvt)	¼-Segment B-10 Depletion (%)	Peak Local B-10 Depletion (%)	Crack Indications ?
Plant D (International BWR)	[[						
Plant E (US BWR/2)							
Plant J (International BWR)							
Plant K (International BWR)							
Plant L (US BWR/6)							
Plant M (US BWR/4)							
Plant P (International BWR)							
							]]

* "D/S" square tubes are used for GEH D lattice (BWR/2-4) and S lattice (BWR/6) applications.

*** Part of etch-indication population. See Safety Communication SC07-02 (Reference 6).

Table 2: C Lattice* Marathon Inspection Results

Plant	Serial Number	Ship Year	Inspection Date	Thermal Fluence (snvt)	¼-Segment B-10 Depletion (%)	Peak Local B-10 Depletion (%)	Crack Indications ?
Plant B (International BWR)	[[						
Plant C (International BWR)							
Plant F (US BWR/4)							
Plant G (International BWR)							
							]]

* "C" square tubes are used for GEH C lattice (BWR/4,5) applications.
*** Part of etch-indication population. See Safety Communication SC07-02 (Reference 6).

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From paragraph C on page xxiv of the Marathon control rod SER (Ref. 1), GEH is responsible for the following action if a material integrity problem should arise:

"(1) arrangements will be made to inspect additional Marathon control rods to the extent necessary to identify the root cause"

Accordingly, GEH has completed, or is taking, the following actions.

- GEH has recently completed and updated root cause analysis for the observed crack indications. The results of this analysis are summarized in Section 4.
- GEH is pursuing additional inspections of high depletion Marathon control rods. A listing of planned control rod inspections is contained in Section 3.

In paragraph C on page xxiv of the Marathon control rod SER (Ref. 1), GEH is also responsible for the following action if a material integrity problem should arise:

"(2) if appropriate, GEH shall recommend a revised lifetime limit to the NRC based on the inspections and other applicable information available."

The available inspection data does not suggest a generic design or material issue with the Marathon control rod, which would require a reduced lifetime recommendation. Therefore, GEH has not recommended a revised lifetime for Marathon control rods. As noted, GEH is actively pursuing additional visual inspections of high-depletion Marathon control rods, as discussed in Section 3.

3. PLANNED INSPECTIONS

In accordance with the Marathon SER (Ref. 1), GEH is continuing to pursue visual inspections of high depletion Marathon control rods. Table 3 shows a listing of planned inspections.

Table 3: Planned Marathon Control Rod Inspections

Plant	Square Tube Type*	Control Rod Type	Planned Inspection Date	Number of CRBs to be Inspected	Approx. Fluence (snvts)	Peak Local Depletion (%)
Plant F (US BWR/4)	C	Marathon***	Fall 2010	[[		
Plant O (International BWR/6)	D/S	Marathon	Summer 2010			
Plant N (International BWR)	D/S	Marathon-5S[1]	Summer 2011			
Plant M (US BWR/4)	D/S	Marathon-5S[1]	Fall 2011			]]

* "D/S" square tubes are used for GE D lattice (BWR/2-4) and S lattice (BWR/6) applications. "C" square tubes are used for GE C lattice (BWR/4,5) applications.

*** Part of etch-indication population. See Safety Communication SC07-02 (Reference 6).

Notes for Table 3:

- Plant F has discharged 2 Marathon control rods. GEH is awaiting an opportunity to perform inspections.
- Plant O is discharging four end-of-life Marathon control rods in August 2010. GEH and the plant have plans in place to perform visual inspections.
- Plants M and N will inspect Marathon-5S[1] control rods in 2011 as the lead assemblies for this type.

[1] Marathon-5S is known commercially as Marathon Ultra MD (MD = Medium Duty)

4. ROOT CAUSE ANALYSIS

GEH recently updated the root cause analysis for the observed Marathon crack indications, based on a review of the inspection database, manufacturing records, and the completion of a Post-Irradiation Examination (PIE) of an irradiated Marathon control rod (serial number 006 from Plant A).

Since the inception of the Marathon control rod surveillance program, a total of [[ ]] visual inspections have been performed at twelve different plants. [[

]]

The database of marathon control rod visual inspection results is thoroughly reviewed, comparing the appearance of crack indications to control rod depletion level or lifetime, year of manufacture, plant, fuel lattice type, plant coolant chemistry, and absorber tube vendor. This review makes three significant observations:

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- Crack indications in early manufacture control rods are much more severe than those observed in later manufacture control rods.
- Those plants with better reactor coolant chemistry, as generically measured by the implementation of Hydrogen Water Chemistry, appear to have lower incidences of cracking.

GEH investigated each of the crack indications including reviews of manufacturing records, plant coolant chemistry, and the Marathon design methodology itself. GEH performed a Post-Irradiation Examination (PIE) of one of the control rods with crack indications. The PIE included neutron radiography to assess the condition of the neutron absorber. It also performed metallurgical evaluations of the irradiated stainless steel structure, and gathered data on the swelling phenomenon and helium release of irradiated boron carbide absorber. To supplement the investigation, metallurgical testing was performed on mock-ups of early absorber tube and control rod manufacturing processes.

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The manufacturing and design improvements identified above result in control rods with significantly improved reliability and resistance to IASCC.

5. MARATHON SQUARE ABSORBER TUBE DESIGN MODIFICATION

Figure 1 shows a design modification that has been made to the geometry of the Marathon 'square' absorber tube. [[

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Figure 1: D/S Lattice Square Absorber Tube Geometry Modification

Figure 2 demonstrates the reduction in absorber tube strain due to the geometry modification. The figure shows the resulting peak tangential strain on the outer surface of the tube, versus the local boron-10 depletion. As shown, the peak strain is significantly reduced for the modified geometry, [[
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[[

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Figure 2: Peak Tangential Strain Versus Local B-10 Depletion

Finite element analysis is used to demonstrate that the new geometry meets all design requirements for maximum outer diameter strain due to capsule swelling, internal pressure, and maximum stress from loads imposed by channel bow. The new geometry is demonstrated to meet stuck rod requirements, and all control rod welds affected by the new absorber tube geometry are demonstrated to withstand loads from scram, seismic events and channel bow.

The new D/S lattice square tube geometry began implementation in 2006. All 2008 and future deliveries will use the new square absorber tube geometry. No changes have been made to the C lattice square tube design.

6. NEW DESIGNS

GEH has submitted several new Marathon control rod designs for NRC approval. NRC recently approved the Marathon-5S, know commercially as the Marathon Ultra MD, as shown in Reference 4. In addition, GEH has submitted an ESBWR Marathon design (Ref. 2,3), as well as the Marathon-Ultra design (Ref. 9, Marathon Ultra HD) for NRC review.

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Table 4: Marathon Capsule to Absorber Tube Gap Comparison

Marathon Design	Licensing Topical Report(s)	Local Depletion at Capsule Contact with Absorber Tube Inside Diameter (Nominal)
Marathon – D/S Lattice	NEDE-31758P-A (Ref. 1)	[[
Marathon – C Lattice	NEDE-31758P-A (Ref. 1)	
ESBWR Marathon	NEDE-33243P Rev. 2 (Ref. 2) NEDE-33244P Rev. 1 (Ref. 3)	
Marathon-5S[2] – D/S Lattice	NEDE-33284P-A Rev. 2 (Ref. 4)	
Marathon-5S[2] – C Lattice	NEDE-33284P-A Rev. 2 (Ref. 4)	
Marathon-Ultra[3] – D/S Lattice	NEDE-33284P Supp 1 (Ref. 9)	
Marathon-Ultra[3] – C Lattice	NEDE-33284P Supp 1 (Ref. 9)	]]

*Nominal depletion at contact based on original square absorber tube geometry. Nominal depletion at contact for the modified D/S lattice square tube geometry is [[ ]].

All new design control rods use a capsule cross-sectional geometry that provides a larger gap between the inner capsule and the outer absorber tube. As discussed in Section 3.6 of Reference 3, Section 3.6 of Reference 4, and Section 3.6 of Reference 9, all new control rods are designed such that [[

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[2] Marathon-5S is known commercially as Marathon Ultra MD (MD = Medium Duty)

[3] Marathon-Ultra is known commercially as Marathon Ultra HD (HD = High Duty)

The evolution of the Marathon designs is also demonstrated in Figure 3. This figure compares the peak absorber tube swelling strain for the original D lattice Marathon design, to the original C lattice Marathon design, and new designs. As discussed in Section 2, [[

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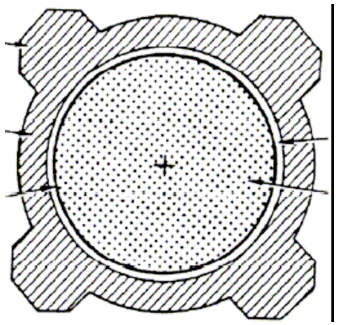
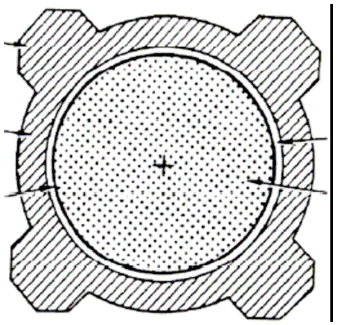
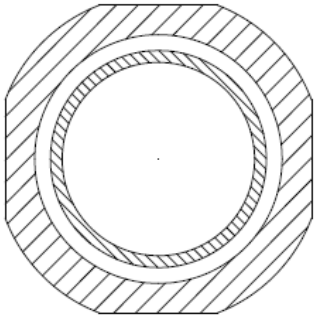
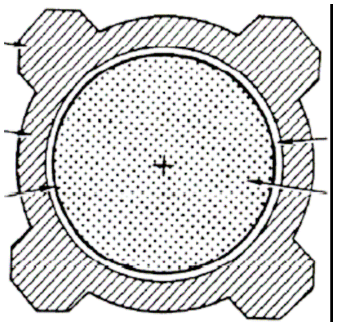
Parameter	Marathon D/S	Marathon C	New Designs **(Marathon Ultra MD, Marathon Ultra HD, ABWR, ESBWR)**	New Designs **(ESBWR)**
Absorber Tube				
Local Boron-10 Depletion at Capsule Contact	[[			
Swelling Induced Strain at 100% Local Depletion				]]

Figure 3: Marathon Swelling Strain Design Evolution

7. RESISTANCE TO IASCC

Irradiation Assisted Stress Corrosion Cracking (IASCC) is a dominant failure mechanism in stainless steels exposed to neutron fluence. Based on the Post-Irradiation Examination, the root cause analysis and the material failures of previous control rod designs, IASCC is the most likely failure mechanisms for Marathon control rod designs. The requirements for IASCC are three-fold:

- Residual or Applied Tensile Stress
- Susceptible Material
- Corrosive Environment

By removing one of these three elements, the threat of IASCC is mitigated. The design strategy for Marathon control rods is to address all three elements, rather than focusing on only one. The method by which the Marathon design addresses each element is summarized in Figure 4, and described below.

7.1 Tensile Stress

The Marathon design accommodates two phenomenon associated with the irradiation of boron carbide: (1) the release of helium gas, and (2) diametral swelling of the boron carbide powder. For all Marathon designs, a diametral gap is provided between the inner capsule and the outer absorber tube to (1) provide a volume to accumulate generated helium gas, and (2) provide for the diametral expansion of the boron carbide capsules. For the original Marathon design, [[

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The other potential source of a sustained tensile stress is residual stress from manufacturing processes. The measured residual stress in current manufacture absorber tubes is very low, as is any added residual stress from the laser welding process. In particular, it is noted that test results show that the residual stress on the surface of the tube is in compression, which is advantageous in preventing the onset of IASCC.

7.2 Susceptible Material

Square or simplified absorber tubes used in Marathon control rod designs use the high-purity, IASCC-resistant type 304S stainless steel. Further, the absorber tubes are delivered in the fully annealed state, resulting in very small residual plastic strain in the tubes. The absorber tubes are welded using a low heat input laser weld process, resulting in low residual plastic strain, and a very small heat affected zone. All weld processes, including the laser weld process, are qualified to ensure that the material is not sensitized to IASCC due to the heat input coupled with bulk surface contamination. Finally, all stainless steel materials

are handled to restrict contact with halogen containing compounds, and are cleaned to ensure that the surface is free of harmful contaminants.

7.3 Corrosive Environment

The Marathon absorber section and handle are crevice-free designs. Whether the original square absorber tube, or the simplified absorber tube is employed, the full-length tube-to-tube welds fully seal the tube interface region. In addition, the absorber sections are sealed at the top and bottom, with no crevices present. Roller-less handles, either plain handles or handles with raised spacer pads, ensure that the handle has no creviced regions.

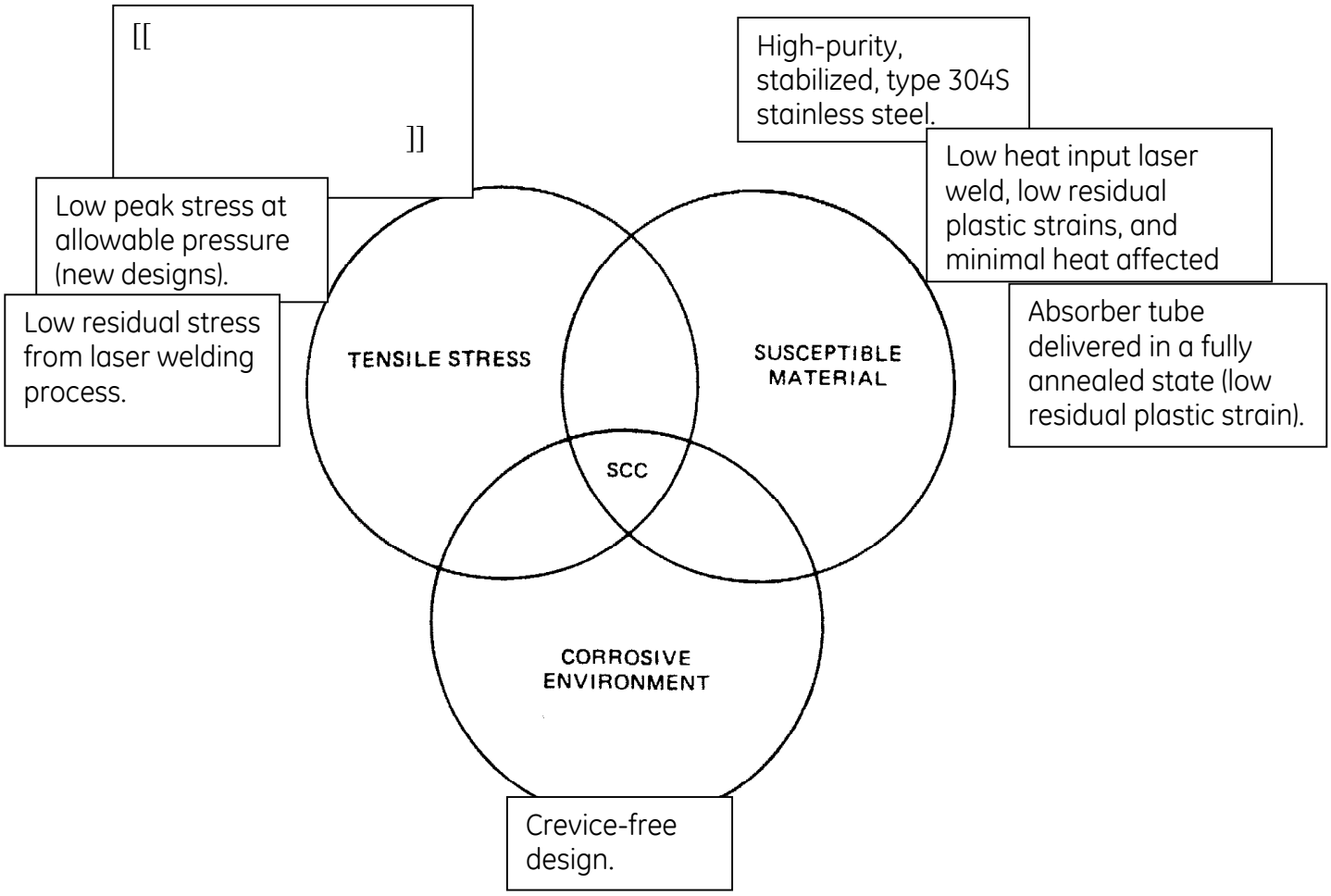

Figure 4: Marathon IASCC Resistance

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1. NEDE-31758P-A, "GE Marathon Control Rod Assembly," October 1991.
2. NEDE-33243P Rev. 2, "Licensing Topical Report: ESBWR Marathon Control Rod – Nuclear Design Report," July 2008.
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4. NEDE-33284P-A, Rev. 2 "Licensing Topical Report: Marathon-5S Control Rod Assembly," October 2009.
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6. Safety Communication SC07-02, "Update: Etch Indications on Marathon Control Rod Blade Absorber Tubes," January 2007.
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