ENCLOSURE 2

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0000-0071-8269-R3-NP, Revision 3

GEH Marathon Control Rod Lifetime Surveillance Update

Non-Proprietary Information – Class I (Public)

IMPORTANT NOTICE

This is a non-proprietary version of 0000-0071-8269-R3-P, Revision 3, which has the proprietary information removed. Portions of the document that have been removed are indicated by white space with an open and closed bracket as shown here [[ ]].

GE Hitachi Nuclear Energy

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IMPORTANT NOTICE REGARDING CONTENTS OF THIS REPORT

Please Read Carefully

TABLE OF CONTENTS

1. INTRODUCTION

Since the beginning of the Marathon control rod product line, GE-Hitachi Nuclear Energy Americas, LLC (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 (Reference 1). A summary of the status of this surveillance program (Reference 2) was last forwarded to the Nuclear Regulatory Commission (NRC) via MFN 10-153 and was also provided to the Boiling Water Reactor (BWR) fleet. This report updates Reference 2, including:

- New inspection results
- A listing of planned inspections
- A summary of the recently completed failure analysis of Marathon control rods and associated lifetime reduction for all D and S lattice Marathon control rods (Reference 3).
- A discussion of the Marathon Ultra control rod design.

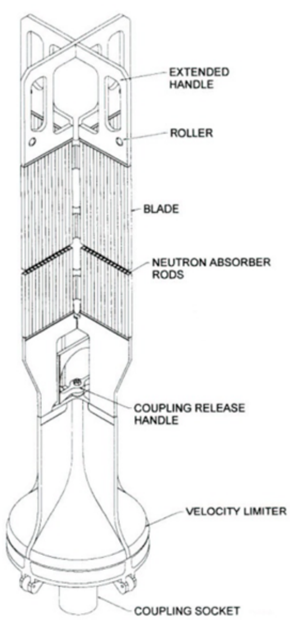
GEH will continue to provide updates of the Marathon control rod surveillance program on an annual basis, at minimum.

2. MARATHON CONTROL ROD DESCRIPTION

As described in Reference 1, the Marathon control rod consists of ‘square’ absorber tubes, edge welded together to form the control rod wings. The ‘lobes’ of the square absorber tubes provide both a welding surface area and act as a wear surface. The four wings are welded to central tie rod segments to form a cruciform shape. A cross-sectional view of the control rod absorber section is shown in Figure 1.

The square absorber tubes are filled with capsules containing compacted boron carbide powder, empty capsule plenums, or hafnium rods. [[

]] All absorber contents are sealed within the absorber tubes by welded end plugs. A handle and velocity limiter are attached at the top and bottom respectively to complete the assembly (Figure 1).



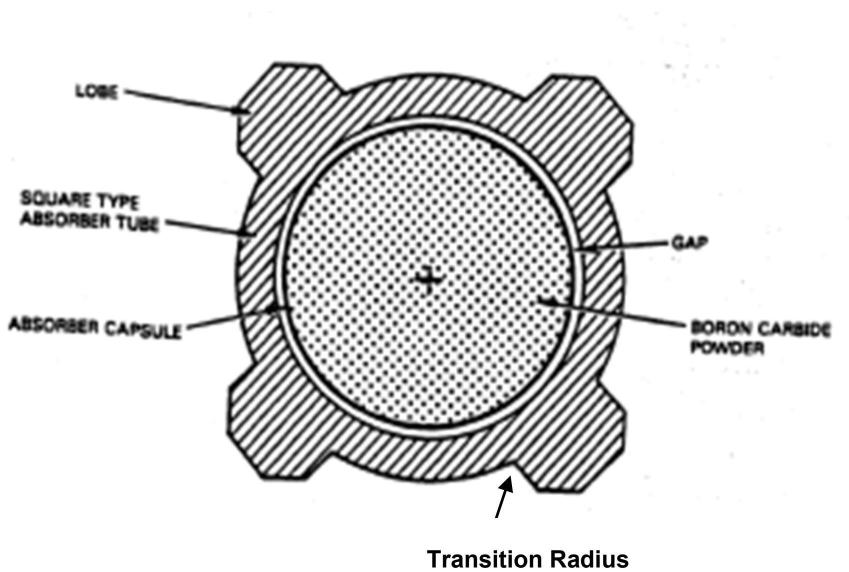


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Figure 1: Marathon Control Rod Diagram

3. 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 2 of this report (Reference 2), four additional inspections of high depletion, S lattice Marathon control rods have been performed at Plant O. These inspections revealed cracks that are much more numerous, and occur at much lower local Boron-10 depletion than those previously observed. These added inspections are noted in bold in Table 1.

Tables 1 and 2 show the serial number of each control rod inspected, as well as the year the control rod was delivered to the plant, and the month and year of the inspection. It is noted that in some cases, the same control rod has been inspected during multiple outages as it has been irradiated. In terms of plant coolant chemistry, the date that Hydrogen Water Chemistry (HWC) was implemented is shown for each plant.

The depletion of each control rod is represented using four measures:

- The approximate thermal fluence of the peak ¼ segment, in units of snvt.
- The percent Boron-10 depletion of the peak ¼ segment, expressed as a percent.
- The peak local Boron-10 depletion, at the highest depletion node and tube location, also expressed as a percent.
- For control rod inspections with crack indications, the range of local Boron-10 depletion at which cracks are observed.

Tables 1 and 2 identify whether or not the visual inspections identified crack indications on the control rods. [[

]] Note that D and S lattice Marathon control rods use identical square absorber tube and boron carbide capsule dimensions.

Tables 1 and 2 also identify those control rods that are part of the 'etch-affected' population described by Reference 4. For a certain population of control rods manufactured between 1997 and 2002, an incomplete cleaning operation prior to an annealing process at the absorber tubing vendor left localized locations on the tubes that are potentially sensitized to Irradiation Assisted Stress Corrosion Cracking (IASCC). In response, GEH reduced the lifetime of these control rods, and embarked on a campaign of visual inspections to determine the actual effect. As noted in Table 1, two of the newly inspected Plant O control rods were part of the etch-affected population, and two were not. The effort to acquire additional inspection data for highly irradiated etch-affected control rods is on-going.

The last column of Tables 1 and 2 also identify the vendor for the outer absorber tubing. As shown, GEH has used two tube vendors since the outset of the Marathon product line. 'Vendor 1' was used until 1994, with 'Vendor 2' used since 1994 to the present date.

Table 1: D/S Lattice* Marathon Inspection Results

Plant	Serial Number	Ship Year	Inspection Date	HWC Start Date	Thermal Fluence (snvt)	¼-Segment B-10 Depletion (%)	Peak Local B-10 Depletion (%)	Crack Indications ?	Local B-10 Depletion at Crack Location (%)	Etch-Affected?	Tube Vendor
Plant A (US BWR/4)	[[										
											]]

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

Plant	Serial Number	Ship Year	Inspection Date	HWC Start Date	Thermal Fluence (snvt)	¼-Segment B-10 Depletion (%)	Peak Local B-10 Depletion (%)	Crack Indications ?	Local B-10 Depletion at Crack Location (%)	Etch-Affected?	Tube Vendor
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 O (International BWR/6)											
Plant P (International BWR)											
											]]

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

Table 2: C Lattice* Marathon Inspection Results

C Lattice Visual Inspection Data Plant	Serial Number	Ship Year	Inspection Date	HWC Start Date	Thermal Fluence (snvt)	¼-Segment B-10 Depletion (%)	Peak Local B-10 Depletion (%)	Crack Indications ?	Etch-Affected?	Tube Vendor
Plant B (International BWR)	[[									
Plant C (International BWR)										
Plant F (US BWR/4)										
Plant G (International BWR)										
										]]

Note: * "C" square tubes are used for GEH C lattice (BWR/4,5) applications.

Figures 2 and 3 show the results of visual inspections plotted against the year that the control rods were manufactured and shipped to the plant. The vertical axis is peak local depletion, which is the Boron-10 depletion at a particular axial node, and in a particular absorber tube. The local Boron-10 depletion is chosen as the figure of merit [[

]] For inspections with no observed crack indications, a single point is identified showing the peak local Boron-10 depletion for the entire control rod. For inspections with observed crack indications, the range of local Boron-10 depletions at which cracks are observed is shown by a vertical bar.

In Figures 2 and 3, the plants have been identified for the higher depletion inspections. For comparison purposes, horizontal lines have been marked on the figures identifying the peak local depletion at which a Marathon control rod for a GEH BWR has reached 80% and 90% of the original nuclear lifetime limit. These lines are identified as "80% EOL" and "90% EOL", respectively. Control rod lifetime limits for control rods in GEH BWRs can be found in Reference 5.

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Figure 2: D/S Lattice Visual Inspection Results by Year Shipped

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Figure 3: C Lattice Visual Inspection Results by Year Shipped

From the inspection statistics, several conclusions may be drawn.

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- The cracks on the recent Plant O inspections are significantly worse than those observed during other inspections, both in terms of the frequency of cracks, and in terms of the low local Boron-10 depletion at which the cracks occur.

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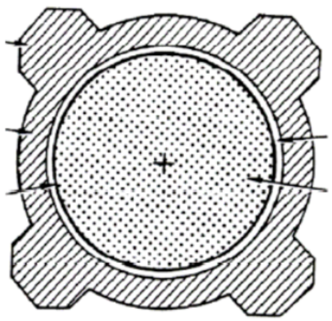
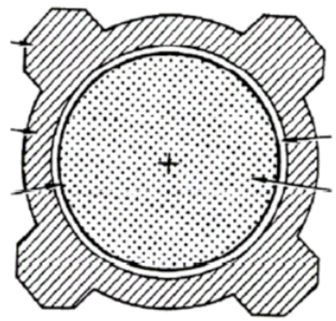
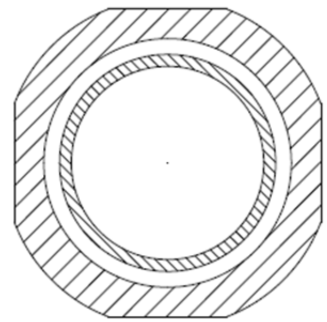
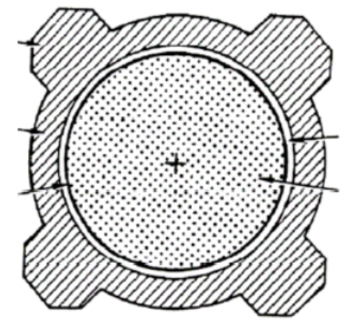
Parameter	**Marathon D/S**	**Marathon C**	**Marathon Ultra** (Marathon Ultra MD, Marathon Ultra HD, ABWR, ESBWR)	**New Designs** (ESBWR)
Absorber Tube				
Local Boron-10 Depletion at Capsule Contact	[[			
Swelling Induced Strain at 100% Local Depletion			]]	

Figure 4: Marathon Swelling Strain Design Evolution

4. FAILURE EVALUATIONS

From paragraph C on page xxiv of the Marathon control rod SER (Reference 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 performed failure investigations to determine the root cause of the cracks for each of the previous Marathon crack occurrences. Previous investigations include the post-irradiation examination (PIE) of one cracked Marathon control rod from Plant A (Reference 6). [[

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5. MARATHON LIFETIME REDUCTION

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

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

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The resulting nuclear ¼ segment limits for GEH design BWRs are shown in Table 3, taken from Table 3-3 and Table B-3 of Reference 5. For additional discussion of the new lifetime limits, see Reference 5. For Marathon control rods in non-GEH design BWRs, individual guidance has been provided separately.

Table 3: Updated Marathon Lifetime Recommendations

(GEH BWRs)

Control Rod Type	¼ Segment Equivalent Boron-10 Depletion, Nuclear Lifetime Limit (%)	Approximate Equivalent Thermal Fluence (snvt)
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6. PLANNED INSPECTIONS

In accordance with the Marathon SER (Reference 1), GEH is continuing to pursue visual inspections of high depletion Marathon control rods in order to confirm the new lifetime limits contained in Reference 5. Table 4 shows a listing of planned inspections.

Table 4: Planned Marathon Control Rod Inspections

Plant	Square Tube Type*	Control Rod Type	Planned Inspection Date	Number of Control Rod Blades (CRBs) to be Inspected	Approximate Fluence (snvts)	¼-Segment B-10 Depletion (%)	Peak Local Depletion (%)
Plant N** (International BWR)	D/S	Marathon Ultra MD[1]	Summer 2011	[[			
Plant M** (US BWR/4)	D/S	Marathon Ultra MD[1]	Fall 2011				
Plant M** (US BWR/4)	D/S	Marathon	Fall 2011				
Plant A (US BWR/4)	D/S	Marathon	Summer 2011				]]

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

** Plants M and N will inspect Marathon Ultra MD[1] control rods in 2011 as the lead assemblies for this type.

[1] Marathon Ultra MD (MD = Medium Duty) was licensed as Marathon-5S via Reference 7.

7. MARATHON SQUARE ABSORBER TUBE DESIGN MODIFICATION

Figure 5 shows a design modification that has been made to the geometry of the Marathon 'square' absorber tube. [[

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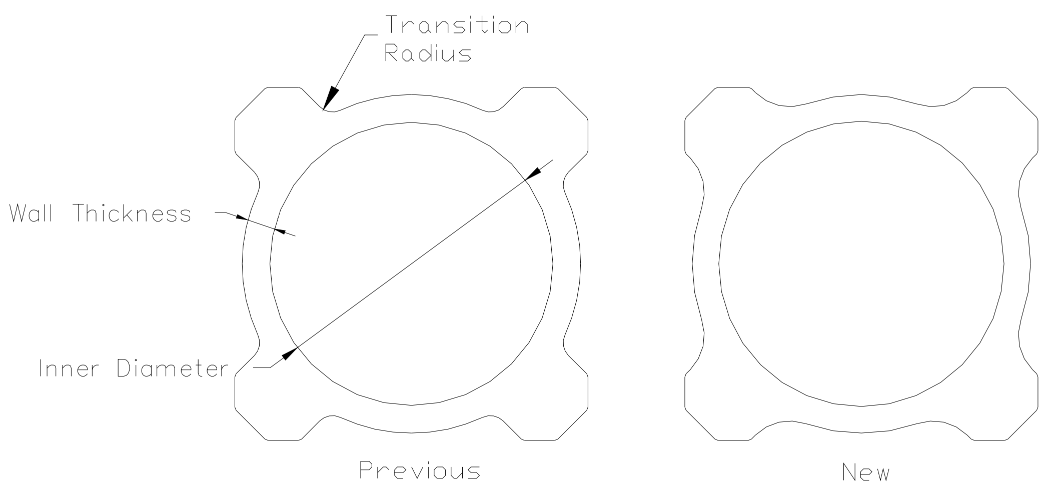

Figure 5: D/S Lattice Square Absorber Tube Geometry Modification

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.

8. MARATHON ULTRA DESIGNS

GEH has submitted several new Marathon control rod designs for NRC approval. NRC approved Marathon-5S, now known as Marathon Ultra MD, as shown in Reference 7. NRC also recently approved an ESBWR Marathon design (References 8 and 9). In addition, GEH has submitted the Marathon Ultra HD design (Reference 10) for NRC review.

The Marathon Ultra and ESBWR designs [[

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Table 5 shows a comparison between the original Marathon control rod, approved by NEDE-31758P-A (Reference 1) the ESBWR design (References 8 and 9), and the Marathon Ultra designs (References 7 and 10).

Table 5: 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 (Reference 1)	[[
Marathon – C Lattice	NEDE-31758P-A (Reference 1)	
ESBWR Marathon	NEDE-33243P Revision 2 (Reference 8) NEDE-33244P Revision 1 (Reference 9)	
Marathon Ultra MD[2] – D/S Lattice	NEDE-33284P-A Revision 2 (Reference 7)	
Marathon Ultra MD[2] – C Lattice	NEDE-33284P-A Revision 2 (Reference 7)	
Marathon Ultra HD[3] – D/S Lattice	NEDE-33284P Supplement 1 (Reference 10)	
Marathon Ultra HD[3] – C Lattice	NEDE-33284P Supplement 1 (Reference 10)	]]

Note: * 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 [[ ]].

2 Marathon Ultra MD was licensed as Marathon-5S via Reference 7.

3 Marathon Ultra HD (HD = High Duty) was submitted for licensing approval as Marathon-Ultra via Reference 10.

All Marathon Ultra and ESBWR 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 9, Section 3.6 of Reference 7, and Section 3.6 of Reference 10, [[

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The evolution of the Marathon designs is also demonstrated in Figure 4. [[

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9. RESISTANCE TO IASCC

IASCC is a dominant failure mechanism in stainless steels exposed to neutron fluence. Based on the PIE, the Marathon failure analyses and the material failures of previous control rod designs, IASCC is the most likely failure mechanism 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 6 and described below.

9.1 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.

9.2 Susceptible Material

Square or simplified absorber tubes used in Marathon and Marathon Ultra control rod designs use 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.

9.3 Corrosive Environment

The Marathon and Marathon Ultra absorber sections 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.

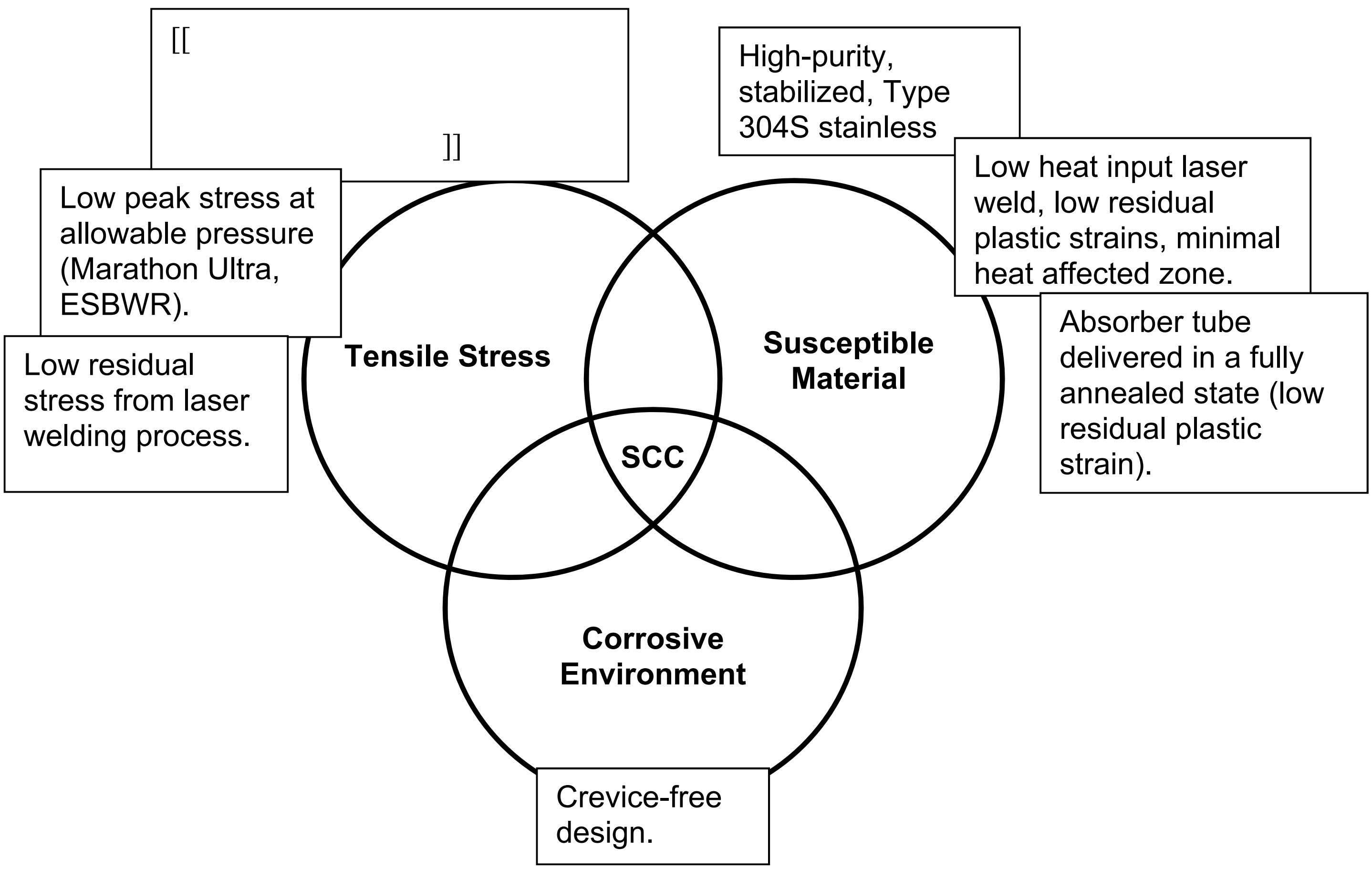

Figure 6: Marathon IASCC Resistance

10. REFERENCES

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3. Safety Communication SC 11-01, "Part 21 Reportable Condition Notification: Design Life of D and S Lattice Marathon Control Blades," February 15, 2011.
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