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NORTH ANNA 3 CONTROL ROD SEISMIC ANALYSIS

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NORTH ANNA 3 CONTROL ROD SEISMIC ANALYSIS

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1. INTRODUCTION

The structural integrity of the ESBWR Marathon control rod is evaluated under standard plant conditions in References 1 and 3. Question 04.02-1 of Request for Additional Information 130, Reference 2, requests an evaluation using site-specific, North Anna Unit 3 (NA3), Safe Shutdown Earthquake (SSE) seismic conditions.

The basis of the mechanical analysis for the standard plant ESBWR Marathon control rod under SSE conditions is a maximum horizontal fuel channel oscillation amplitude of [[ ]]. A NA3, site-specific seismic evaluation, using approved methodologies described in DCD and FSAR Section 3.7.2, calculates a maximum horizontal fuel channel oscillation amplitude of [[ ]]. This value from Table 4.4-1 of Reference 4 is less than 10% higher than the value used in Reference 1.

References 1 and 3 are reviewed in their entirety for the purpose of identifying any evaluations that are potentially affected by the slightly larger seismic fuel channel oscillations, which could affect control rod scram times and maximum stresses and strains experienced during control rod insertion. Three evaluations are identified: (1) control rod wing outer edge bending, (2) absorber tube to tie rod weld, and (3) seismic scram testing. This report re-evaluates these affected analyses using the NA3 site-specific maximum horizontal fuel channel oscillation amplitude based on plant-specific seismic loads and the allowable limits (identified below), which are obtained from Reference 1. All other evaluations in References 1 and 3 remain bounding for the NA3 application.

Fuel channel deflections due to LOCA and SRV events for the ESBWR are developed through detailed design. For the purpose of demonstrating margin in the NA3 evaluations, which are described below, it is conservatively assumed that fuel channel deflections for each of the LOCA and SRV events are equal to that of the NA3 SSE event, which is fuel channel deflections of [[ ]]. This is conservative, as the BWR operating fleet experience indicates that the SSE acceleration is the primary contribution to the combined acceleration, and ESBWR LOCA and SRV accelerations are expected to be less than the operating fleet.

A summary of two NA3 load cases is shown in Table 1. For these evaluations, all fuel channel deflections are the maximum single directional displacement. All final values for fuel channel deflections will be determined at the ITAAC stage, as described in Section 3.

Fuel Channel Deflection Due To:	**Seismic + Fuel Channel Bow 550 °F**	**Seismic + Fuel Channel Bow + LOCA + SRV 550 °F**
Seismic (SSE)	[[	
Fuel Channel Bow		
LOCA		
SRV		
Total		]]

Table 1: Fuel Channel Deflection Summary

[1] Only for the purpose of demonstrating the amount of margin in the control rod seismic evaluations, it is conservatively assumed that fuel channel deflections due to LOCA and SRV are each equal to that of an SSE event.

[2] For the purpose of demonstrating the amount of margin in the control rod seismic evaluations, fuel channel deflections due to SSE, channel bow, LOCA and SRV are conservatively summed to a total number. For future evaluations, these various fuel channel deflections may be combined using the Square Root Sum of Squares (SRSS) method.

2. EVALUATION

2.1 Wing Outer Edge Bending

Section 3.4.1 of Reference 1 evaluates the maximum strain of the outer edge of the control rod wing due to a combined loading of (1) fuel channel displacement due to an SSE seismic event, (2) fuel channel displacement due to worst-case channel bulge and bow, (3) maximum absorber tube internal pressure, and (4) a failed buffer scram. Using the standard design methodology, the NA3 site-specific SSE loading is shown in Table 2. Also, an additional case is shown in Table 2, with assumed LOCA and SRV fuel channel deflections, as discussed in Section 1.

As shown in Table 2, the maximum strain at the outer edge of the control rod wing for the NA3 SSE is well within the material allowable strain limit, which is one-half of the ultimate tensile strain for irradiated stainless steel. When adding the conservative LOCA and SRV channel deflections, the resulting total strain increases somewhat. However, the resulting strain remains significantly below one half of the ultimate tensile strain for irradiated stainless steel. Therefore, the ESBWR control rod structure is acceptable under NA3 combined seismic loading, including conservatively assumed LOCA and SRV loads.

Description	Seismic + Fuel Channel Bow + Internal Pressure + Scram 550 °F	Seismic + Fuel Channel Bow + Internal Pressure + Scram + LOCA + SRV 550 °F
Outer Edge Bending Strain, Seismic (%)	[[	
Outer Edge Bending Strain, Seismic + Channel Bow (%)		
Outer Edge Bending Strain, Seismic + Channel Bow + LOCA + SRV (%)		
Max Internal Pressure Axial Stress (ksi)		
Max Failed Buffer Scram Stress (ksi)		
Total Outer Edge Strain, Seismic + Failed Buffer Scram + Absorber Tube Internal Pressure (%)		
Total Outer Edge Strain, Seismic + Channel Bow + Failed Buffer Scram + Absorber Tube Internal Pressure (%)		
Total Outer Edge Strain, Seismic + Channel Bow + Failed Buffer Scram + Absorber Tube Internal Pressure + LOCA + SRV		
Allowable Strain (%) ½ Ultimate, Irradiated (from Table 3-6 of Reference 1)		
Design Ratio		]]

Table 2: Outer Edge Bending Strain due to Seismic and Channel Bow Bending, Internal Absorber Tube Pressure and Failed Buffer Scram

2.2 Absorber Tube to Tie Rod Weld

Section 3.4.2 of Reference 1 calculates the maximum stress at the absorber tube to tie rod weld, under a combined loading of (1) fuel channel deflection due to an SSE seismic event, (2) fuel channel deflection due to worst-case channel bulge and bow, and (3) maximum absorber tube internal pressure. Using the standard design methodology, the NA3 site-specific SSE loading is shown in Table 3. Also, an additional case is shown, with assumed LOCA and SRV fuel channel deflections, as discussed in Section 1.

Description	Seismic + Fuel Channel Bow + Internal Pressure 550 °F	Seismic + Fuel Channel Bow + Internal Pressure + LOCA + SRV 550 °F
Seismic + Internal Pressure, Max S_{INT} (ksi)	[[	
Seismic + Channel Bow + Internal Pressure, Max S_{INT} (ksi)		
Seismic + Channel Bow + Internal Pressure + LOCA + SRV, Max S_{INT} (ksi)		
True Ultimate Tensile Stress (ksi) (from Table 3-7 of Reference 1)		
Design Ratio		]]

Table 3: Absorber Tube to Tie Rod Weld Stress

As shown in Table 3, the maximum stress at the absorber tube to tie rod weld, for the NA3 SSE only case is well below the material allowable stress (true ultimate tensile stress). For the case adding LOCA and SRV fuel channel deflections, the maximum stress increases. However, the maximum stress remains well below the material allowable stress, which is the true ultimate tensile stress, as in Reference 1. Therefore, the ESBWR control rod structure is acceptable under NA3 combined seismic loading, including conservatively assumed LOCA and SRV loads.

2.3 Seismic Scram Testing

Seismic scram testing of an ABWR Marathon control rod and its applicability to ESBWR is discussed in Section 4.2 of NEDE-33244P-A (Reference 1) and FSAR Section 4.2.4.2. As noted in both documents, the testing confirmed that scram time requirements were met through 40 mm of fuel channel oscillation with no control rod damage. The 40 mm fuel channel oscillation easily bounds the NA3 SSE value of [[ ]]. If fuel channel oscillation amplitude for LOCA and SRV events are each conservatively assumed to be [[ ]] as discussed in Section 1, and if SSE, LOCA, and SRV fuel channel oscillation amplitudes are conservatively summed, the resulting oscillation amplitude of [[ ]] is still well bounded by the tested value of 40 mm. Note that this conservatively adds the maximum single-direction deflections, which assumes they are all in the same direction at the same time. This conservative assessment of combined fuel channel oscillation deflections demonstrates that there is margin to the approved limit. This provides adequate assurance that the control rod design is acceptable for use at NA3.

3. COMPLETION OF ITAAC

ITAAC 1 in Part 10, Table 2.4.19-1, specifies that the control rods to be loaded into the initial core will be evaluated for stress, strain, and fatigue, considering loads due to seismic, LOCA and SRV events. The acceptance criteria are that the control rod stresses and strains do not exceed the ultimate stress or strain limit of the material, structure, or welded connection, and that the cumulative fatigue does not exceed a fatigue usage factor of 1.0. The deflection calculated for the final as-built seismic, LOCA and SRV loads, combined with the site-specific seismic loads must be within the acceptance limit of 40 mm.

The approach for performing the evaluations is as described in this report, using final as-built information. The acceptance criteria and limits that ensure these acceptance criteria are met are as described in this report and are based on DCD Appendix 4C, Reference 5, and FSAR 4.2.4.2. Approved methods will be used in performing the evaluations for completing the ITAAC.

4. CONCLUSIONS

A site-specific seismic analysis concludes that the horizontal deflection of the fuel channels is within the acceptance limits. Using approved standard design methodologies, the affected evaluations are re-evaluated using the NA3 site-specific larger fuel channel deflection values.

The higher fuel channel deflection causes a slight increase in the strain at the outer edge of the control rod wing due to the combined loading of SSE seismic event, channel bow induced bending, maximum tube internal pressure, and failed buffer scram. The resulting strain remains well within the material allowable strain.

The higher fuel channel deflection causes a slight increase in the stress at the absorber tube to tie rod weld due to the combined loading of an SSE seismic event, channel bow induced bending, and maximum tube internal pressure. The resulting stress remains within the material allowable stress.

The ABWR seismic scram testing remains bounding over the NA3 seismic loading case.

To demonstrate the margin present in the NA3 evaluations described in this report, conservative values for fuel channel deflection due to LOCA and SRV loads are added to each evaluation. The evaluations demonstrate adequate margin remains when including the conservatively assumed LOCA and SRV loads, along with the NA3 SSE loading. Therefore, the control rod structure is adequate for use at NA3 and will be further confirmed through ITAAC for final as-built values.

5. REFERENCES

1) NEDE-33244P-A Rev. 2, "ESBWR Marathon Control Rod Mechanical Design Report", September 2010.

2) North Anna 3, Docket Number 52-017, Request for Additional Information 130, July 2014.

3) 26A6642AP Rev. 10, ESBWR Design Control Document, Tier 2, Chapter 4.2.

4) SER-DMN-019 Rev. 1, "RB/FB Seismic Analyses Bounding Results and In-Structure Response Criteria", March 2016.

5) 26A6642AP Rev. 10, ESBWR Design Control Document, Tier 2, Appendix 4C.