4.0 REACTOR

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4.1 Introduction

This chapter of the U.S. Nuclear Regulatory Commission's (NRC's) safety evaluation report (SER) provides the staff evaluation of the North Anna 3 Combined License (COL) Final Safety Analysis Report (FSAR) Chapter 4 which describes the reactor mechanical components of the North Anna 3 Economic Simplified Boiling-Water-Reactor (ESBWR), which includes the reactor internals, control blades and control rod drive, core support structural materials, fuel system design (fuel rods and assemblies), nuclear design, and thermal-hydraulic design. Furthermore, it provides an evaluation of the capability of the reactor to perform its safety functions throughout its design lifetime under all normal operational modes, including transient, steady-state, and accident conditions. This chapter also includes information to support the accident analysis in Chapter 15 of this SER.

4.2 Summary of Application

Chapter 4 of the North Anna 3 COL application (COLA), FSAR, Revision 8, incorporates by reference Chapter 4 of Revision 10 of the Design Control Document (DCD) for the ESBWR, referenced in Appendix E to Title 10 of the *Code of Federal Regulations* (10 CFR) Part 52, "Licenses, Certifications, and Approvals for Nuclear Power Plants." In addition, in FSAR Chapter 4, the applicant provides the following:

Tier 2 Departures Requiring Prior NRC Approval

- NAPS DEP 3.7-1 — Ground Response Spectra for Seismic Structural Loads and Floor Response Spectra

This departure increases the fuel assembly and control blade seismic loads beyond the certified design fuel assembly and control blade loads by including the site-specific seismic response as part of the safe shutdown earthquake (SSE) for North Anna 3.

COL items

- STD COL 4.3-1-A — Variances from Certified Design

The applicant shall address changes to the reference design of the fuel, control rod or core design.

- STD COL 4A-1-A — Variances from Certified Design

The applicant shall address changes to the reference design of the fuel, control rod or core design.

For all combined license (COL) items, the applicant states that there are no changes to the fuel, control rod, or core design from the referenced certified design.

4.3 Regulatory Basis

The regulatory basis of the information incorporated by reference is described in NUREG–1966, "Final Safety Evaluation Report Related to the Certification of the Economic Simplified Boiling-

Water Reactor." In addition, the relevant requirements of the Commission regulations for the reactor, and the associated acceptance criteria, are in Chapter 4 of NUREG–0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants (LWR Edition)," Revision 3, March 2007.

In accordance with Section VIII, "Processes for Changes and Departures," of Appendix E to Part 52, the applicant identifies Tier 1 and Tier 2 departures. Tier 1 departures require prior NRC approval and are subject to the requirements specified in 10 CFR Part 52, Appendix E, Section VIII.A.4. Tier 2 departures affecting technical specifications require prior NRC approval and are subject to the requirements of 10 CFR Part 52, Appendix E, Section VIII.C.4. Tier 2 departures not requiring prior NRC approval are subject to the requirements of 10 CFR Part 52, Appendix E, Section VIII.B.5, which are similar to the requirements of 10 CFR 50.59, "Changes, tests, and experiments."

The staff review of North Anna 3 Departure NAPS DEP 3.7-1 and whether it is acceptable is based on compliance with 10 CFR Part 50, "Domestic Licensing of Production and Utilization Facilities," Appendix A, "General Design Criteria for Nuclear Power Plants," General Design Criteria (GDC) 2, "Design Bases for Protection Against Natural Phenomena," as it relates to the structural protection for fuel assemblies and control blades during accidents involving earthquakes. GDC 2 requires the design bases of structures, systems, and components, which include fuel assemblies and control blades, to reflect appropriate consideration of natural phenomena, which includes consideration of combined loading due to natural phenomena and limiting hydrodynamic loads.

4.4 Technical Evaluation

As documented in NUREG–1966, the staff reviewed and approved Chapter 4 of the ESBWR DCD. The staff reviewed Chapter 4 of the North Anna 3 COL FSAR and checked the referenced ESBWR DCD to ensure that the combination of the information in the COL FSAR and the information in the ESBWR DCD represents the complete scope of information relating to this review topic.[1] The staff's review confirmed that the information in the application and the information incorporated by reference address the required information relating to this chapter.

Chapter 4 of the North Anna 3 COL FSAR contains the following sections:

4.1 Summary Description
4.2 Fuel System Design
4.3 Nuclear Design
4.4 Thermal and Hydraulic Design
4.5 Reactor Materials
4.6 Functional Design of Reactivity Control System

Appendix 4A Typical Control Rod Patterns and Associated Power Distribution for ESBWR
Appendix 4B Fuel Licensing Acceptance Criteria
Appendix 4C Control Rod Licensing Acceptance Criteria
Appendix 4D Stability Evaluation

[1] See "*Finality of Referenced NRC Approvals*" in SER Section 1.2.2 for a discussion on the staff's review related to verification of the scope of information to be included in a COL application that references a design certification.

The staff reviewed the following information in the COL FSAR:

Tier 2 Departures Requiring Prior NRC Approval

- NAPS DEP 3.7-1 — Ground Response Spectra for Seismic Structural Loads and Floor Response Spectra

The staff reviewed NAPS DEP 3.7-1 as it relates to the site-specific seismic ground motion exceedances of the ESBWR Certified Seismic Design Response Spectra (CSDRS) and documented its safety finding in Chapter 3 of this report. In the COLA, Part 7: Departures Report, regarding NAPS DEP 3.7-1, the applicant stated a change to FSAR Chapter 4.2 was made as a result of site-specific seismic exceedances. The staff reviewed the changes to Chapter 4.2 to ensure the site-specific fuel assemblies and control blades were still in compliance with the Commission's regulations. The staff notes that the ESBWR standard plant seismic analysis, which utilizes the CSDRS, forms the basis of the GE14E fuel assembly and ESBWR Marathon control blade mechanical designs. DCD Tier 2* Reference 4.2-4 (in ESBWR DCD Section 4.2.7) describes the structural capability of the GE14E assembly and assembly components to withstand seismic/dynamic loading. DCD Tier 2* Reference 4.2-8 describes the structural capability of the ESBWR Marathon control rod blade.

As a result of the site-specific seismic exceedances of the CSDRS, the staff was unable to determine from the information provided in the FSAR whether the fuel and control blades to be loaded in the North Anna 3 reactor would be able to withstand loads resulting from natural phenomena, as required by GDC 2. Therefore, on July 24, 2014, the staff asked the applicant in RAI 04.02-1, to provide site-specific supplemental information in Chapter 4.2 of the FSAR that demonstrates that the North Anna 3 fuel assembly and control blade mechanical loads remain bounded by the component design analyses and testing performed for the ESBWR Design Certification (Agencywide Documents Access and Management System (ADAMS) Accession No. ML14283A563). On May 19, 2016, the applicant provided a response to RAI 04.02-1 (ADAMS Accession No. ML16146A277). The staff's review of the response and supplemental information is described below.

Fuel Assembly

As part of its response to RAI 04.02-1, the applicant provided to the staff a site-specific Technical Report WG3-002N9544, "North Anna Unit 3 Site-Specific GE14E Fuel Assembly Mechanical Design Report," Revision 2 (ADAMS Accession No. ML16146A278), which documents the analysis performed to show that the North Anna 3 fuel assembly mechanical loads remain bounded by the fuel assembly capacity limits.

In general, the staff notes that the applicant's methodology for evaluating the site-specific fuel assembly mechanical loads follows the methodology described in the ESBWR DCD, Chapter 4; that is, the applicant provided an evaluation of combined loads (*i.e.*, loss of coolant accident (LOCA), SSE, and safety relief valve (SRV) actuation load) on the fuel assembly to demonstrate that the site-specific loads remain bounded by the capacity limits of the GE14E fuel assembly, as described in DCD Tier 2* (ESBWR DCD, Revision 10, Reference 4.2-4, NEDC-33240P-A, "GE14E Fuel Assembly Mechanical Design Report," Revision 1) and approved for application to the ESBWR design in 10 CFR Part 52, Appendix E. The applicant also stated in the response to RAI 04.02-1 that the inspections, tests, analyses, and acceptance criteria (ITAAC) associated with the fuel assembly (DCD Tier 1, ITAAC Item 15, Table 2.1.1-3, "ITAAC for the Reactor Pressure Vessel and Internals") ensures that a full analysis, as described in WG3-002N9544

and NEDC-33240P-A, will be completed prior to fuel load using the as-built characteristics of the fuel assembly and reactor pressure vessel to confirm that the as-built North Anna 3 combined loads on the fuel assembly remain bounded by the fuel assembly capacity limits. Furthermore, the ITAAC Item 15 in Table 2.1.1-3 requires a fuel lift analysis in accordance with NEDC-21175-3-P-A, "BWR [Boiling Water Reactor] Fuel Assembly Evaluation of Combined Safe Shutdown (SSE) and Loss-of-Coolant Accident (LOCA) Loadings (Amendment No. 3)," to ensure fuel bundle lift-out from the fuel support piece does not exceed the acceptance limit given in WG3-002N9544. While the applicant has not performed the fuel lift analysis as part of its current evaluation presented in WG3-002N9544, the staff confirmed that the methodology described in WG3-002N9544 is in accordance with the ESBWR DCD and assures as-built fuel assembly compliance with GDC 2.

During the review of the site-specific fuel assembly analysis, the staff noted that the site-specific exceedances of the seismic response spectra parameters would result in a reduction in margin to the GE14E fuel capacity limits. Therefore, the staff considered several areas to examine more closely, which included the overall methodology for addressing the site-specific seismic exceedances at the fuel assembly level, the site-specific seismic calculation for determining the seismic accelerations of the fuel, the combination of loads for assessing fuel assembly structural adequacy, and the irradiation effects on the fuel assembly seismic response analyses. Between March 2016 and May 2016, the staff conducted a regulatory audit to confirm the information presented in the applicant's response to RAI 04.02-1 and the supplemental information provided in WG3-002N9544 in the areas listed above (ADAMS Accession No. ML16077A343). The regulatory audit included a 3-day onsite meeting (March 23 – March 25, 2016) with the applicant to review supporting calculations. The audit also included the staff's use of the applicant's Electronic Reading Room to review additional calculations and supporting information related to Chapter 4 of the FSAR. The staff issued an audit report to document the results of the audit (ADAMS Accession No. ML16188A142). A summary of the staff's audit activities related to the site-specific fuel analyses is set forth below.

During the on-site audit and during subsequent public meetings,[2] the applicant clarified the specific steps of the methodology followed to address the fuel assembly response due to the site-specific seismic exceedances. Subsequently, the applicant submitted to the NRC, by letter dated May 19, 2016, a revised RAI 04.02-1 response and associated technical reports (ADAMS Accession No. ML16146A277). The revised response included FSAR Chapter 4 markups. The staff confirmed how the applicant obtained the site-specific accelerations at the fuel and confirmed that the methodology used in WG3-002N9544 for determining combined loads follows the methodology described in the ESBWR DCD. Additionally, the staff confirmed that the method for determining the site-specific accelerations, which is described in the FSAR Section 4.2 markups (ADAMS Accession No. ML16146A277), is identical to that used to complete ITAAC Item 15 of Table 2.1.1-3 in the ESBWR DCD. The staff further confirmed that all changes to the FSAR as provided in the revised response to RAI 04.02-1 (ADAMS Accession No. ML16146A277) were incorporated in Revision 9 of Part 2 (FSAR) of the North Anna 3 COLA. Furthermore, the applicant updated Revision 9 of Part 2 of the North Anna 3 COLA to correct Section 4.2.7 regarding the Tier 2* marking of Reference 4.2-201. Therefore

[2] Summaries of these meetings are posted in ADAMS at Accession Nos. ML16050A485, ML16071A370, ML16078A401, ML16103A343, ML16078A429, ML16097A606, ML16095A194, ML16110A022, ML16110A023, ML16111B309, ML16137A064, ML16147A433, and ML16148A091. Portions of the public meetings were closed to discuss proprietary information.

the Confirmatory Item 4.2-1 from the staff advanced SER for North Anna 3 is resolved and closed.

Also during the audit, the staff examined the calculations the applicant had completed to develop the site-specific seismic loading at the fuel assembly. The staff noted that the applicant analyzed the time-history motion of the fuel assemblies for determining the maximum resultant horizontal fuel acceleration. The staff confirmed that the calculations represent the most limiting seismic motions (as reviewed in Chapter 3 of this SER) and that the applicant's method for determining the maximum seismic acceleration in the horizontal and vertical directions, which is described in the FSAR Section 4.2 markups (ADAMS Accession No. ML16146A277), is consistent with NRC Regulatory Guide 1.92, "Combining Modal Responses and Spatial Components in Seismic Response Analysis," Revision 2. The staff also confirmed that the applicant's methodology for calculating the seismic accelerations of the fuel assemblies is identical to the methodology described in the DCD. The staff further confirmed that all changes to the FSAR as provided in the revised response to RAI 04.02-1 (ADAMS Accession No. ML16146A277) were incorporated in Revision 9 of Part 2 (FSAR) of the North Anna 3 COLA. Furthermore, the applicant updated Revision 9 of Part 2 of the North Anna 3 COLA to correct Section 4.2.7 regarding the Tier 2* marking of Reference 4.2-201. Therefore the Confirmatory Item 4.2-1 from the staff advanced SER for North Anna 3 is resolved and closed.

Due to the decrease in margin to the GE14E fuel assembly capacity limits, the staff also audited the applicant's calculation for combining loads (i.e., seismic + accident loads) to confirm that accident loads (i.e., LOCA and SRV) in addition to the increased site-specific seismic loads do not cause the fuel assembly capacity limits to be exceeded. The applicant provided a calculation, as mentioned in the response to RAI 04.02-1 that considered bounding LOCA and SRV loadings in combination with the site-specific seismic loads. The staff confirmed that the calculation of combining loads is conservative for the North Anna 3 reactor and that the site-specific loads at the fuel assembly, as presented in the response to RAI 04.02-1 (ADAMS Accession No. ML16146A277), are less than the fuel assembly's capacity limits. The staff further confirmed that all changes to the FSAR as provided in the revised response to RAI 04.02-1 (ADAMS Accession No. ML16146A277) were incorporated in Revision 9 of Part 2 (FSAR) of the North Anna 3 COLA. Furthermore, the applicant updated Revision 9 of Part 2 of the North Anna 3 COLA to correct Section 4.2.7 regarding the Tier 2* marking of Reference 4.2-201. Therefore the Confirmatory Item 4.2-1 from the staff advanced SER for North Anna 3 is resolved and closed.

During the staff's review of the application, the staff determined that the applicant's primary structure model (FSAR Chapter 3) is the same as the DCD model, and both the applicant's and DCD's models use mass and stiffness as inputs for the fuel. The staff further noted that, identical to the DCD model, the applicant's primary structure model does not account for fuel assembly spacer grids and other fuel assembly components. The staff determined that due to the increased site-specific seismic loadings and decreased margin to the site-specific fuel assembly acceptance limits, the effect of spacer grid spring relaxation due to irradiation, as discussed in NRC Information Notice (IN) 2012-09, "Irradiation Effects on Fuel Assembly Spacer Grid Crush Strength," could cause an additional increase in site-specific seismic loads; however, the staff also noted that boiling water reactor fuel is channeled and that, in general, the fuel channel dominates the fuel bundle's structural response to loads. During the audit, the staff examined a condition report that documented the applicant's assessment of IN 2012-09. The staff confirmed that the applicant's site-specific primary structure model is adequate for determining fuel assembly seismic loads in light of IN 2012-09 because the stiffness of the fuel assembly channel box dominates the fuel assembly mechanical response.

To summarize the staff's review regarding the site-specific fuel assembly, the staff gathered information in the regulatory audit that confirmed the information provided in the docketed RAI response, which is incorporated into Revision 9 of Part 2 of the North Anna 3 COLA. Based on the applicant's response to RAI 04.02-1 and Technical Report WG3-002N9544, Revision 2, as confirmed by the staff's regulatory audit, the staff finds that the GE14E fuel to be loaded into the North Anna 3 reactor meets GDC 2.

Control Blade

As part of its response to RAI 04.02-1 (ADAMS Accession No. ML16146A277), the applicant provided to the staff a site-specific Technical Report 002N8005, "North Anna 3 Control Rod Seismic Analysis," Revision 2 (ADAMS Accession No. ML16146A279), which documents the analysis performed to show that the North Anna 3 control blade mechanical loads and scram insertion times are bounded by the control blade capacity limits and scram insertion time limits in the ESBWR DCD, Chapter 4.2.4.

In general, the staff noted that the applicant's methodology for evaluating the site-specific control blade mechanical loads follows the methodology described in the ESBWR DCD, Chapter 4; that is, the applicant provided an analysis of combined loads (i.e., LOCA, SSE, and SRV actuation load) on the control blades to demonstrate that the site-specific loads remain bounded by the capacity limits of the ESBWR Marathon control blade, as described in DCD Tier 2* Reference 4.2-8 (NEDE-33244P-A, "ESBWR Marathon Control Rod Mechanical Design Report," Revision 2.). The staff noted increases in the site-specific control blade loads from the analysis presented in the DCD; however, margin to the control blade capacity limits still exists. The applicant also evaluated the site-specific seismic motion on the effect of control blade insertion times. The staff noted ample margin in the site-specific calculation of fuel assembly displacement to the acceptance limits defined in the ESBWR DCD, Chapter 4 and NEDE-33244P-A for the Marathon control blade.

As part of the North Anna 3 COLA, the applicant added a site-specific ITAAC for the control blades (COLA Part 10, ITAAC Item 1, Table 2.4.19-1). In accordance with the methodology described in the DCD, the applicant stated in the response to RAI 04.02-1 (ADAMS Accession No. ML16146A277), that the site-specific ITAAC associated with the control blades ensures that a full analysis, as described in Technical Report 002N8005 and NEDE-33244P-A, will be completed prior to fuel load using the as-built characteristics of the control blades and other reactor components to confirm that the North Anna 3 combined loads on the control blade remain bounded by the control blade capacity limits and the scram insertion time limits for the Marathon control blade. The staff determined this site-specific ITAAC to be acceptable and confirmed that the methodology described assures as-built control blade compliance with GDC 2.

During the same regulatory audit, the staff reviewed the calculation that determined the site-specific fuel channel oscillation and confirmed that the results presented in Technical Report 002N8005 accurately represent the site-specific seismic analysis. The staff issued an audit report to document the audit results (ADAMS Accession No. ML16188A142).

Based on the applicant's response to RAI 04.02-1 and Technical Report 002N8005, Revision 2, as confirmed by the staff's regulatory audit, the staff finds that the Marathon control blades to be used in the North Anna 3 reactor meet GDC 2.

In conclusion, despite the seismic exceedances from the ESBWR DCD in ground motion at the North Anna 3 site, the applicant has adequately demonstrated that these exceedances do not cause the GE14E fuel assemblies nor the Marathon control blades to be used in the North Anna 3 reactor to experience accident and seismic loads in excess of the design's acceptance limits. Accordingly, the staff finds that the GE14E fuel assemblies and Marathon control blades to be used in the North Anna 3 reactor are in compliance with the Commission's regulations.

COL Information Items

- STD COL 4.3-1-A Variances from Certified Design
- STD COL 4A-1-A Variances from Certified Design

For COL Items STD COL 4.3-1-A and STD COL 4A-1-A, the applicant states that there are no changes to the fuel, control rod or core design from the referenced certified design. The staff reviewed the information in the COL FSAR and concludes that the application does not depart from the standard design in regards to fuel, control rod, or core design, and no further evaluation of these matters is necessary.

4.5 Post Combined License Activities

The applicant added a site-specific ITAAC in Part 10 of the COLA Table 2.4.19-1, Item 1, to ensure that a full analysis, as described in Technical Report 002N8005 and NEDE-33244P-A, will be completed prior to fuel load using the as-built characteristics of the control blades and other reactor components to confirm that the site-specific combined loads on the control blade remain bounded by the control blade capacity limits and the scram insertion time limits for the Marathon control blade.

4.6 Conclusion

The staff reviewed the application and checked the referenced DCD. The staff's review confirmed that the applicant has addressed the required information, and no outstanding information remains to be addressed in the COL FSAR related to this chapter. The results of the staff's technical evaluation of the DCD information are incorporated by reference in NUREG–1966. The staff's review confirmed that the applicant has adequately addressed COL Items STD COL 4.3-1-A and STD COL 4A-1-A.

The staff's review also confirmed that the applicant has adequately addressed NAPS DEP 3.7-1 relating to the North Anna 3 fuel assemblies and control blades. The staff reviewed the applicant's analysis of the fuel assemblies and control blades relating to NAPS DEP 3.7-1 and, for the reasons set forth above, finds that analysis acceptable. The staff further confirmed that all changes to the FSAR as provided in the revised response to RAI 04.02-1 (ADAMS Accession No. ML16146A277) were incorporated in Revision 9 of Part 2 (FSAR) of the North Anna 3 COLA. Furthermore, the applicant updated Revision 9 of Part 2 of the North Anna 3 COLA to correct Section 4.2.7 regarding the Tier 2* marking of Reference 4.2-201. Therefore the Confirmatory Item 4.2-1 from the staff advanced SER for North Anna 3 is resolved and closed.

References

1. 10 CFR 50.59, "Changes, tests and experiments."

2. 10 CFR Part 50, "Domestic Licensing of Production and Utilization Facilities."

3. 10 CFR Part 50, Appendix A, "General Design Criteria for Nuclear Power Plants."

4. 10 CFR Part 50, Appendix A, GDC 2, "Design bases for protection against natural phenomena."

5. 10 CFR Part 52, "Licenses, Certifications, and Approvals for Nuclear Power Plants."

6. 10 CFR Part 52, Appendix E, "Design Certification Rule for the ESBWR Design."

7. GEH ESBWR Design Control Document (DCD), Revision 10, April 2014 (ADAMS Accession No. ML14104A929).

8. GEH Technical Report 002N8005, "North Anna 3 Control Rod Seismic Analysis," Revision 2 (ADAMS Accession No. ML16146A279)

9. GEH Technical Report WG3-002N9544, "North Anna Unit 3 Site-Specific GE14E Fuel Assembly Mechanical Design Report," Revision 2 (ADAMS Accession No. ML16146A278).

10. NEDC 21175 3-P-A, "BWR [Boiling Water Reactor] Fuel Assembly Evaluation of Combined Safe Shutdown (SSE) and Loss-of-Coolant Accident (LOCA) Loadings (Amendment No. 3)."

11. NEDC 33240P-A, "GE14E Fuel Assembly Mechanical Design Report," Revision 1.

12. NEDE-33244P-A, "ESBWR Marathon Control Rod Mechanical Design Report," Revision 2.

13. NRC IN 2012-09, "Irradiation Effects on Fuel Assembly Spacer Grid Crush Strength,"

14. NRC RG 1.92, Revision 2, "Combining Modal Responses and Spatial Components in Seismic Response Analysis," September 2012 (ADAMS Accession No. ML12220A043).

15. NRC Staff NUREG–0800, "Standard Review Plan [SRP] for the Review of Safety Analysis Reports for Nuclear Power Plants (LWR Edition)," March 2007 (ADAMS Accession No. ML070660036).

16. NRC Staff NUREG-1966, "Final Safety Evaluation Report Related to the Certification of the Economic Simplified Boiling-Water Reactor Standard Design," and its Supplement 1, April 2014 (ADAMS Accession Nos. ML14099A519, ML14099A522, ML14099A532, ML14100A187, ML14100A190, ML14100A194, ML14265A084).