Enclosure G
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"Framatome Inc. Document 86-9344713-000
"Davis-Besse Reactor Vessel Embrittlement Fluence Reconciliation Through 60 Years"

(10 Pages Follow)

framatome CALCULATION SUMMARY SHEET (CSS)

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Title Davis-Besse Reactor Vessel Embrittlement Fluence Reconciliation Through 60 Years Summary Report

PURPOSE AND SUMMARY OF RESULTS:

Purpose:

The purpose of this document is to compare the 52 effective full power year (EFPY) fluence (E > 1.0 MeV) values used in the regulatory fracture toughness calculations for the Davis-Besse (DB1) reactor vessel ferritic materials resulting from exposure to neutron irradiation and the thermal environment (i.e., current licensing basis (CLB)) to the updated reactor vessel fluence (E > 1.0 MeV) values. This comparison is performed for the existing adjusted reference temperature (ART) calculation supporting the updated pressure-temperature (P-T) limit curves, for the underclad cracking (UCC) assessment, equivalent margins analysis (EMA) for the Linde 80 welds, Charpy upper-shelf energy (CvUSE) drop, pressurized thermal shock reference temperature (RT_{PTS}) values, and for reactor vessel surveillance program (RVSP) compliance.

Summary of Results:

Based on the fluence comparisons, the ART calculation supporting the current P-T limit curves, UCC assessment, and EMA for the DB1 Linde 80 welds are affected by the updated 52 EFPY fluence values. Based on the updated fluence values:

1. The current applicability for the DB1 P-T limit curves is reduced to 43.5 EFPY.
2. The current applicability for the DB1 UCC assessment is reduced to 49.2 EFPY.
3. The current applicability for the DB1 EMA for the DB1 Linde 80 welds is reduced to 43.8 EFPY.

Based on the updated fluences, the “fifth” surveillance capsule, TE1-C, continues to meet the ASTM E185-82 criterion, which states that the fifth capsule may be removed when the capsule neutron fluence is between one and two times the limiting fluence calculated for the vessel at end-of-life.

Based on the updated fluences, the predicted 52 EFPY CvUSE values for all applicable DB1 reactor vessel base metals are above 50 ft-lbs. Therefore, all the DB1 reactor vessel base metals continue to meet the CvUSE requirements within 10 CFR 50, Appendix G. The predicted 52 EFPY CvUSE values for all applicable welds in the DB1 reactor vessel fall below the 50 ft-lb requirement of 10 CFR 50 Appendix G. An EMA is still necessary for the DB1 reactor vessel Linde 80 welds in accordance with the requirements of 10 CFR 50, Appendix G. As indicated above, the current applicability for the DB1 EMA is reduced to 43.8 EFPY.

Based on the updated fluences, the predicted 52 EFPY RT_{PTS} values (in accordance with 10 CFR 50.61) for the applicable DB1 reactor vessel materials remain below the screening criteria specified therein.

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Revision No.	Pages/Sections/Paragraphs Changed	Brief Description / Change Authorization
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Table of Contents

Page

1.0 ANALYTICAL METHODOLOGY

Nuclear Regulatory Commission (NRC) Code of Regulations, Title 10 (10 CFR), Part 50.60 [1] provides fracture toughness requirements and acceptance criteria applicable to the Davis-Besse Nuclear Station Unit 1 (DB1) nuclear power reactor vessel.

Part 50.60 to 10 CFR requires that all light water nuclear power reactors meet the requirements of 10 CFR 50, Appendix G [2] and 10 CFR 50, Appendix H [3]. Appendix G specifies fracture toughness requirements for the reactor vessel in terms of pressure temperature (P-T) limits based on adjusted reference temperature (ART) of the reactor vessel materials. Appendix H to 10 CFR 50 requires that all light water nuclear power reactors that have ferritic materials exposed to neutron fluences (E > 1.0 MeV) greater than 1.0E+17 neutrons per centimeter squared (n/cm^2) have a reactor vessel surveillance program (RVSP) to monitor changes in the fracture toughness properties of the ferritic materials.

In August 2010, FirstEnergy Nuclear Operating Company submitted their License Renewal Application (LRA) for DB1 Nuclear Power Station for review and approval [4]. The LRA included 60-year (52 effective full power years (EFPY)) calculations assessing the regulatory fracture toughness requirements for the DB1 reactor vessel ferritic materials resulting from exposure to neutron irradiation and the thermal environment. The NRC reviewed and approved the DB1 LRA as documented in NUREG-2193 [5].

The purpose of this document is to compare the 52 EFPY fluence (E > 1.0 MeV) values used in the regulatory fracture toughness calculations for the DB1 reactor vessel ferritic materials resulting from exposure to neutron irradiation and the thermal environment (i.e., current licensing basis (CLB)) to the updated fluence (E > 1.0 MeV) values. This comparison is performed for the existing ART calculation supporting the updated P-T limit curves, for the underclad cracking (UCC) assessment, equivalent margins analysis (EMA), and for RVSP compliance. Additionally, reconciliations based on the updated fluence values for Charpy upper-shelf energy (CvUSE) drop and pressurized thermal shock reference temperature (RT_{PTS}) predicted values are performed.

2.0 ASSUMPTIONS

2.1 Unverified Assumptions

No assumptions requiring verification are used in this document.

2.2 Justified Assumptions

The EFPY for the fracture toughness calculations applicability was calculated by linear interpolation using the updated projected 32, 52 and 65 EFPY fluence (E > 1.0 MeV) values for each reactor vessel material. This is justified in that the extrapolated flux after the last cycle analyzed in the updated fluence analysis is constant respective of the increasing time to 32, 52, and 65 EFPY.

3.0 DESIGN INPUTS

The DB1 CLB documents for reactor vessel ART/ P-T limit curves, UCC assessment, EMA RVSP, CvUSE, and RT_{PTS} each contain their respective design inputs supporting the calculations.

4.0 CALCULATIONS

Sub-sections 4.1 through 4.4 assess the validity of the existing DB1 reactor vessel embrittlement analyses by summarizing the comparison of those fluence (E > 1.0 MeV) values used in the CLB analyses to the updated fluence (E > 1.0 MeV) values. Sub-sections 4.5 and 4.6 determine if DB1 reactor vessel embrittlement analyses, based on updated fluences, continue to meet the applicable 10 CFR 50 requirements.

4.1 Adjusted Reference Temperature (ART)

In accordance with 10 CFR 50 Appendix G, P-T limits are to be based on RT_{NDT} values that are adjusted for the effect of neutron irradiation. The limiting ART values are based on evaluations performed using 52 EFPY wetted surface fluences (E > 1.0 MeV). In order to maintain the validity of the P-T limit curve evaluation, the 52 EFPY fluence values (E > 1.0 MeV) must be maintained equal or below the fluence values used to calculate the limiting ART values.

The fluence values used in the CLB for the DB1 P-T limits were compared with the updated 52 EFPY fluences. To maintain the validity of the existing limiting ART values and P-T analyses (i.e., CLB), the DB1 reactor vessel materials with updated 52 EFPY fluence values not bounded by the CLB fluence values were assessed based on the updated fluence values such that the ART values used in the CLB are not exceeded. This assessment consisted of the following:

- The projected EFPY was reduced based on the interpolation of the updated 52 EFPY fluence value such that the fluence values used in the CLB for the ART values were not exceeded; the limiting EFPY value is reported in Section 5.0.

4.2 Underclad Cracking (UCC)

Intergranular separations in low alloy steel heat-affected zones under austenitic stainless steel weld claddings were detected in SA-508, Class 2 reactor vessel forgings manufactured to a coarse grain practice, and clad by high-heat-input submerged arc processes. In response to this cracking issue, Topical Report BAW-10013 [6] was prepared for the B&W-design plants documenting that the intergranular separations found in B&W reactor vessels would not lead to vessel failure. This conclusion was accepted by the Atomic Energy Commission (AEC) [7]. To cover the period of extended operation (60-year operation), a follow-on fracture mechanics analysis was performed for DB1, assessing the UCC issue.

Four (4) regions of the reactor vessel were evaluated for UCC: (1) reactor vessel flange, (2) nozzle belt, (3) the upper and lower shell, and (4) the Dutchman. Note the reactor vessel closure head is not included in the present flaw evaluations since a one-piece forged SA-508 Class 3 replacement head, which is not susceptible to UCC, was installed in 2014, prior to the period of extended operation. This analysis concluded that the potential for UCC in the DB1 reactor vessel are within the acceptable margins of the ASME Code [8] for fracture toughness of the susceptible SA-508 Class 2 forging material for the period of extended operation (52 EFPY).

The fluence values used in the CLB for the DB1 UCC analysis were compared with the updated 52 EFPY fluences. To maintain the validity of the existing limiting UCC analysis (i.e., CLB), the DB1 reactor materials with updated 52 EFPY fluences not bounded by the CLB fluence values were assessed based on the updated fluence values such that the fluence values used in the UCC analysis CLB are not exceeded. This assessment consisted of the following:

- The projected EFPY was reduced based on the interpolation of the updated 52 EFPY fluence value such that the fluence values used in the CLB for the UCC analysis were not exceeded; the limiting EFPY value is reported in Section 5.0.

4.3 Linde 80 Weld Metal Equivalent Margins Analysis (EMA)

Reactor vessel beltline materials exhibiting CvUSE levels below 50 ft-lbs are required by 10 CFR Part 50, Appendix G [2], to be analyzed to show margins of safety against fracture equivalent to those required by Appendix G of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code. Welds in the beltline region of the DB1 reactor vessel have already been analyzed for 52 EFPY of operation to demonstrate that these low upper-shelf energy materials would continue to satisfy federal requirements for license renewal. In addition, the reactor vessel inlet and outlet nozzle-to-shell welds and transition welds at or near transitions in vessel thickness have been evaluated for low upper-shelf energy levels by analytical techniques to satisfy the requirements of Appendix K to Section XI of the ASME Boiler and Pressure Vessel Code.

The fluence values used in the CLB for the DB1 EMA calculations were compared with the updated 52 EFPY fluences. To maintain the validity of the existing EMA for the DB1 reactor vessel materials with updated 52 EFPY fluences not bounded by the CLB fluence values were assessed based on the updated fluence value such that the fluence values used in the CLB EMA are not exceeded. This assessment consisted of the following:

- The projected EFPY was reduced based on the interpolation of the updated 52 EFPY fluence value such that the fluence values used in the CLB for the EMA were not exceeded; the limiting EFPY value is reported in Section 5.0.

4.4 Reactor Vessel Surveillance Program (RVSP)

DB1 participates in the Pressurized Water Reactor Owners Group (PWROG) Master Integrated Reactor Vessel Surveillance Program (MIRVP) [9] [10]. The NRC has concluded that the MIRVP met the criteria provided by Appendix H to 10 CFR Part 50 and that the current surveillance capsule withdrawal schedule in Reference [10] for DB1 satisfies the ASTM Standard E185-82 [11].

In accordance with the current capsule withdraw schedule, a "fifth" surveillance capsule supports the extended operation (i.e., 60-year operation) for DB1 [10]. Comparison of the "fifth" surveillance capsule (TE1-C) fluence to the updated 52 EFPY peak fast neutron fluence for the DB1 reactor vessel shows that capsule TE1-C continues to meet the ASTM E185-82 criterion, which states that the fifth capsule may be removed when the capsule neutron fluence is between one and two times the limiting fluence calculated for the vessel at end-of-life.

4.5 Reactor Vessel Charpy Upper Shelf Energy (CvUSE)

Requirements of 10 CFR 50, Appendix G [2] require that reactor vessel materials must maintain Charpy upper-shelf energy (CvUSE) of no less than 50 ft-lbs. If the CvUSE decreases below 50 ft-lbs, it must be demonstrated, in a manner approved by the Office of Nuclear Reactor Regulation, that the lower values will provide adequate margins of safety.

Calculation methods from Regulatory Guide 1.99, Revision 2 [12] were used to determine the 52 EFPY CvUSE decrease predictions at the ¼T wall location for DB1 reactor vessel materials. Reactor vessel materials of concern are defined within NRC Regulatory Issue Summary 2014-11 [13] as materials with a projected neutron fluence of greater than 1.0E+17 n/cm^2 (E > 1.0 MeV) at the end of license (52 EFPY). The updated fluence values are used as inputs to these calculation methods to predict the 52 EFPY CvUSE values for applicable DB1 base metals and weld metals.

The predicted 52 EFPY CvUSE values for all applicable DB1 reactor vessel base metals are above 50 ft-lbs. Therefore, all the DB1 reactor vessel base metals continue to meet the CvUSE requirements within 10 CFR 50, Appendix G. The predicted 52 EFPY CvUSE values for all applicable weld metals in the DB1 reactor vessel fall below the 50 ft-lb requirement of 10 CFR 50, Appendix G. An equivalent margins analysis (EMA) is still necessary for the DB1 reactor vessel weld metals in accordance with the requirements of 10 CFR 50, Appendix G. The EMA evaluation is discussed in Section 4.3 of this document and the limiting EFPY value is reported in Section 5.0.

4.6 Pressurized Thermal Shock Reference Temperature (RT_{PTS})

Requirements of 10 CFR 50.61 [14] provide protection against pressurized thermal shock events for pressurized water reactors. Licensees are required to perform an assessment of the projected values of pressurized thermal shock reference temperature (RT_{PTS}) whenever a significant change occurs in projected values of RT_{PTS}, or upon request for a change in the expiration date for the operation of the facility.

10 CFR 50.61 provides two methods for determining RT_{PTS}: (Method 1) for material that does not have surveillance data available and (Method 2) for material that does have surveillance data. Availability of surveillance data is not the only measure of whether (Method 2) may be used; the data must also meet tests of sufficiency and credibility before it can be utilized. The updated fluence values are used as inputs to these calculation methods to predict the 52 EFPY RT_{PTS} values for applicable DB1 base metals and weld metals.

10 CFR 50.61 establishes screening criteria for RT_{PTS}: 270°F for plates, forgings, and axial welds and 300°F for circumferential welds. The DB1 reactor vessel projected RT_{PTS} values are below the established 10 CFR 50.61 screening criteria at 52 EFPY (60 calendar years).

5.0 RESULTS

The embrittlement evaluations originally performed to address reactor vessel integrity for extended operation (60-year operation) for the DB1 reactor vessel materials have been re-evaluated to assess their validity based on updated fluence analysis. Based on the updated fluences (E > 1.0 MeV), validated limiting EFPYs to preserve the applicability of the ART, P-T limits, UCC, and Linde 80 weld metal EMA evaluations are shown below.

Based on the updated fluences, the "fifth" surveillance capsule, TE1-C, continues to meet the ASTM E185-82 criterion, which states that the fifth capsule may be removed when the capsule neutron fluence is between one and two times the limiting fluence calculated for the vessel at end-of-life.

Based on the updated fluences, the predicted 52 EFPY CvUSE values for all applicable DB1 reactor vessel base metals are above 50 ft-lbs. Therefore, all the DB1 reactor vessel base metals continue to meet the CvUSE requirements within 10 CFR 50, Appendix G. The predicted 52 EFPY CvUSE values for all applicable welds in the DB1 reactor vessel fall below the 50 ft-lb requirement of 10 CFR 50 Appendix G. An EMA is still necessary for the DB1 reactor vessel Linde 80 welds in accordance with the requirements of 10 CFR 50, Appendix G. Based on the updated fluences (E > 1.0 MeV), validated limiting EFPYs to preserve the applicability of the EMA evaluations are shown below. Based on the updated fluences, the predicted 52 EFPY RT_{PTS} values (in accordance with 10 CFR 50.61) for the applicable DB1 reactor vessel materials remain below the screening criteria specified therein.

Based on the comparisons of the CLB basis fluences used in the reactor vessel integrity evaluations and the updated fluences, the ART calculation supporting the current P-T limit curves, UCC assessment, and EMA for the DB1 Linde 80 welds are affected by the updated 52 EFPY fluence values. Specifically:

1. The current applicability for the DB1 ART calculation and P-T limit curves is reduced to 43.5 EFPY.
2. The current applicability for the DB1 UCC assessment is reduced to 49.2 EFPY.
3. The current applicability for the DB1 Linde 80 weld metal EMA is reduced to 43.8 EFPY.

6.0 REFERENCES

1. Code of Federal Regulations, Title 10, “Domestic Licensing of Production and Utilization Facilities,” Part 50.60, “Acceptance Criteria for Fracture Prevention Measures for Lightwater Nuclear Power Reactors for Normal Operation,” Latest Amendment: July 29, 1996.

2. U.S. Nuclear Regulatory Commission, Code of Federal Regulations, Title 10, Part 50 (10 CFR 50), Appendix G, “Fracture Toughness Requirements,” Federal Register, Volume 60, No. 243, December 19, 1995. [60 FR 65474, Dec. 19, 1995; 73 FR 5723, Jan. 31, 2008; 78 FR 34248, Jun. 7, 2013; 78 FR 75450, Dec. 12, 2013].

3. U.S. Nuclear Regulatory Commission, Code of Federal Regulations, Title 10, Part 50 (10 CFR 50), Appendix H, “Reactor Vessel Material Surveillance Program Requirements,” Federal Register, Volume 60, No. 243, December 19, 1995. [60 FR 65476, Dec. 19, 1995; 68 FR 75390, Dec. 31, 2003; 73 FR 5723, Jan. 31, 2008].

4. Letter from Barry S. Allen, Vice President-Nuclear, FirstEnergy Nuclear Operating Company to Document Control Desk, U.S. Nuclear Regulatory Commission, Subject: Davis-Besse Nuclear Power Station, Unit No. 1, Docket No. 50-346, License Number NPF-3, License Renewal Application and Ohio Coastal Management Program Consistency Certification, dated August 27, 2010.

5. U.S. Nuclear Regulatory Commission, NUREG-2193, “Safety Evaluation Report Related to the License Renewal of Davis-Besse Nuclear Power Station,” Date Published: April 2016. (NRC Accession Nos. ML16104A207, ML16104A301, and ML16104A350)

6. Framatome Inc. Document BAW-10013, “Study of Intergranular Separations in Low-Alloy Steel Heat-Affected Zones Under Austenitic Stainless Steel Weld Cladding,” December 1971 with revised pages dated February 15, 1972.

7. Framatome Inc. Document 43-10013-01 (BAW-10013A, Revision 1), “Study of Intergranular Separations in Low-Alloy Steel Heat-Affected Zones Under Austenitic Stainless Steel Weld Cladding,” October 1972.

8. ASME Boiler and Pressure Vessel Code, Section XI, Rules for Inservice Inspection of Nuclear Power Plant Components, 1995 Edition with Addenda through 1996, American Society of Mechanical Engineers, New York, NY.

9. Framatome Inc. Document 43-1543-04 (BAW-1543NP, Revision 4), “Master Integrated Reactor Vessel Surveillance Program,” February 1993.

10. Framatome Inc. Document 43-1543-04_Supplement_7-A-000 (BAW-1543, Revision 4, Supplement 7-A), “Supplement to the Master Integrated Reactor Vessel Surveillance Program,” March 2018.

11. ASTM Standard E185-82, “Standard Practice for Conducting Surveillance Tests for Light-Water Cooled Nuclear Power Reactor Vessels,” American Society for Testing and Materials, Philadelphia, Pennsylvania.

12. U. S. Nuclear Regulatory Commission, “Radiation Embrittlement of Reactor Vessel Materials,” Regulatory Guide 1.99, Revision 2, May 1988.

13. U.S. NRC Regulatory Issue Summary (RIS) 2014–11, “Information on Licensing Applications for Fracture Toughness Requirements for Ferritic Reactor Coolant Pressure Boundary Components,” October 14, 2014 (NRC Accession No. ML14149A165).

14. U.S. NRC Code of Federal Regulations, Title 10, Part 50.61, "Fracture Toughness Requirements for Protection Against Pressurized Thermal Shock Events," January 4, 2010 [60 FR 65468, Dec. 19, 1995, as amended at 61 FR 39300, July 29, 1996; 72 FR 49500, Aug. 28, 2007; 73 FR 5722, Jan. 31, 2008; 75 FR 23, Jan. 4, 2010].