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Low Upper-Shelf Toughness Fracture Mechanics Analysis of Reactor Vessels of B&W Owners Reactor Vessel Working Group for Levels A & B Service Loads

BAW-2192
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Nature of Changes

Item	Section(s) or Page(s)	Description and Justification
1	All	Initial Issue

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Nomenclature

Acronym	Definition
B&W	Babcock and Wilcox
B&WOG	Babcock and Wilcox Owners Group
CvUSE	Charpy Upper Shelf Energy
EFPY	Effective Full Power Years
EMA	Equivalent Margins Analysis
INF	Inlet Nozzle Forging
Jd	J deformation
J-R	J-integral Resistance
MUR	Measurement Uncertainty Recapture
NA	North Anna
RV	Reactor Vessel
RVWG	Reactor Vessel Working Group
SLR	Subsequent License Renewal
SPS	Surry Power Station
SRP	Standard Review Plan
Sy	Yield Strength
TSs	Technical Specifications
USE	Upper Shelf Energy

ABSTRACT

The purpose of BAW-2192, Revision 0, Supplement 2P, Revision 0 is to compare newly acquired Rotterdam Weld J-integral resistance data to B&WOG J-integral resistance Model 6B reported in BAW-2192, Revision 0, Supplement 1P-A, Revision 0, Appendix A to provide additional justification that the J-R Model 6B may be applied to Rotterdam welds used to fabricate North Anna and Surry reactor vessels. The comparison of the newly acquired Rotterdam weld J-R test data from North Anna and Surry capsules to Model 6B is reported in this supplement. The comparison of the new J-R data to Model 6B at standard conditions [

] includes the new B&WOG Linde 80 data reported in Table A-2 of Supplement 1 and the new Rotterdam data reported in Table 3-1 of this supplement. A comparison of the newly acquired Rotterdam weld J-R test data to Model 6B is reported in Figure 3-1 of this supplement. The new Rotterdam data from North Anna and Surry is all above the Model 6B mean. Therefore, Model 6B is considered a conservative J-integral resistance model for North Anna and Surry reactor vessel Rotterdam weld materials. There is no need to regenerate the B&WOG J-integral resistance Model 6B to include Rotterdam weld data.

1.0 INTRODUCTION

The purpose of BAW-2192, Revision 0, Supplement 2P, Revision 0 is to compare newly acquired Rotterdam Weld J-integral resistance data to B&WOG J-integral resistance Model 6B reported in BAW-2192, Revision 0, Supplement 1P-A, Revision 0, Appendix A [1] to provide additional justification that the J-R Model 6B may be applied to Rotterdam welds used to fabricate North Anna and Surry reactor vessels. The comparison of the newly acquired Rotterdam weld J-R test data to Model 6B is reported in Section 3.0 of this supplement. This report is applicable to Rotterdam welds used to fabricate North Anna Units 1 and 2 and Surry Units 1 and 2 reactor vessels.

Eighty year (72 EFPY) upper shelf energy projections by Dominion for North Anna Units 1 and 2 indicate that the following item will have upper shelf energy values less than 50 ft-lbs at 72 EFPY and will require equivalent margins analyses using a J-integral resistance model that is qualified for base metal (e.g., NUREG/CR-5729 [2]): North Anna Unit 2 Intermediate Shell Forging 04. In addition, 72 EFPY upper shelf energy values for selected RV welds for North Anna Unit 1 are greater than 50 ft-lbs but less than 55 ft-lbs. As such, Dominion has elected to perform equivalent margins analyses for selected North Anna RV welds using B&WOG Model 6B to demonstrate acceptability to the requirements of 10 CFR 50, Appendix G. The equivalent margins analyses for North Anna Unit 1 and 2 are not within the scope of this report. This report focuses on demonstrating the applicability of B&WOG Model 6B to Rotterdam weld material used to fabricate North Anna and Surry reactor vessels.

1.1 *Upper Shelf Energy—Analysis of Record for North Anna 1 and 2*

The current licensing basis with respect to 60-year upper shelf energy for North Anna Units 1 and 2 is summarized in Section 3.7.2.2 of the NRC safety evaluation [3] of the North Anna license amendment request for measurement uncertainty recapture (MUR) power uprate [4]. The NRC findings are reported below for information only.

"The NRC staff has evaluated the information provided by the licensee in the submittal, as well as information contained in NUREG-1766 (ADAMS Accession No. ML023090559), "Safety Evaluation Report Related to the License Renewal of North Anna Power Station, Units 1 and 2, and Surry Power Station, Units 1 and 2" and by letter dated December 13, 2005 (ADAMS Accession No. ML0534803582), in which the licensee submitted updated information for the reactor vessel integrity database, to reflect the license renewal period."

"Staff confirmed that the limiting 1/4T adjusted reference temperature (ART) value of 218.5°F for the North Anna Unit 2 lower shell forging heat number 990533/297355 is the bounding material for the extended period of operation for both units. Since the neutron fluence values for the USE under the MUR PU condition are bounded by the approved neutron fluence values for license renewal, the staff concludes that the USE would be bounded by the current analysis and that North Anna Units 1 and 2 RPV materials would continue to meet the USE criteria requirements of 10 CFR Part 50, Appendix G under the MUR PU condition. Therefore, the NRC staff finds the proposed MUR PU acceptable with respect to the P-T limits and USE."

In accordance with the update to RVID to support the 60-year license renewal application submittal and MUR submittal by Dominion for North Anna Units 1 and 2 [5], upper shelf energy values are reported at 50.3 Effective Full Power Years (EFPY) for North Anna Unit 1, and 52.3 EFPY for North Anna Unit 2. Initial and End-of-Life upper shelf energy values are reported for the following Rotterdam RV items for both units:

- Nozzle Shell Forging
- Intermediate Shell Forging
- Lower Shell Forging
- Circumferential weld that connects the nozzle shell forging to the intermediate shell forging

- Circumferential weld that connects the intermediate shell forging to the lower shell forging.

Eighty-year (72 EFPY) upper shelf energy projections by Dominion for North Anna Units 1 and 2 indicate that the following item will have upper shelf energy less than 50 ft-lbs at 72 EFPY and will require an equivalent margins analysis using a J-integral resistance model that is qualified for base metal (e.g., NUREG/CR-5729 [2]): North Anna Unit 2 Intermediate Shell Forging 04.

In addition, 72 EFPY upper shelf energy values for selected RV welds for North Anna Unit 1 are equal to or greater than 50 ft-lbs but less than 55 ft-lbs. As such, Dominion has elected to perform equivalent margins analyses for selected North Anna Unit 1 RV welds using B&WOG Model 6B, to demonstrate acceptability to the requirements of 10 CFR 50, Appendix G. Those 72 EFPY equivalent margins analyses are not within the scope of this report.

2.0 MATERIAL PROPERTIES

The copper content of the North Anna RV Units 1 and 2 Rotterdam weld material ranges from 0.07% to 0.35%. The maximum fluence (1/4 t location) at 72 EFPY for the North Anna RV Unit 1 and 2 Rotterdam welds is 4.53 E19 n/cm^2. The North Anna Rotterdam weld copper and maximum 1/4t fluence value at 72 EFPY are within the range of explanatory variables for B&WOG Model 6B reported in Section A.5 of Reference [1]. [

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A similar assessment for Surry Units 1 and 2 Rotterdam welds relative to B&WOG Model 6B is reported in Section A.5 of Reference [1].

3.0 B&WOG J-INTEGRAL RESISTANCE MODEL 6B AND COMPARISON TO ROTTERDAM TEST DATA

3.1 *Regulatory Requirements for J-Integral Resistance Model*

In accordance with 10 CFR 50, Appendix G, IV, A,1 Reactor Vessel Upper Shelf Energy Requirements are as follows:

a) Reactor vessel beltline materials must have Charpy upper-shelf energy in the transverse direction for base material and along the weld for weld material according to the ASME Code, of no less than 75 ft-lb (102 J) initially and must maintain Charpy upper-shelf energy throughout the life of the vessel of no less than 50 ft-lb (68 J), unless it is demonstrated in a manner approved by the Director, Office of Nuclear Reactor Regulation or Director, Office of New Reactors, as appropriate, that lower values of Charpy upper-shelf energy will provide margins of safety against fracture equivalent to those required by Appendix G of Section XI of the ASME Code. This analysis must use the latest edition and addenda of the ASME Code incorporated by reference into 10 CFR 50.55a (b)(2) at the time the analysis is submitted.

b) Additional evidence of the fracture toughness of the beltline materials after exposure to neutron irradiation may be obtained from results of supplemental fracture toughness tests for use in the analysis specified in section IV.A.1.a.

c) The analysis for satisfying the requirements of section IV.A.1 of this appendix must be submitted, as specified in § 50.4, for review and approval on an individual case basis at least three years prior to the date when the predicted Charpy upper-shelf energy will no longer satisfy the requirements of Section IV.A.1 of this appendix, or on a schedule approved by the Director, Office of Nuclear Reactor Regulation or Director, Office of New Reactors, as appropriate.

3.2 *ASME Section XI K-3300, Selection of J-Integral Resistance Curve*

When evaluating the vessel for Level A, B, and C Service Loadings, the J-integral resistance versus crack-extension curve (J-R curve) shall be a conservative representation of the toughness of the controlling beltline material at upper shelf temperatures in the operating range. When evaluating the vessel for Level D Service Loadings, the J-R curve shall be a best estimate representation of the toughness of the controlling beltline material at upper shelf temperatures in the operating range. One of the following options shall be used to determine the J-R curve:

a) A J-R curve shall be generated for the material by following accepted test procedures. The J-R curve shall be based on the proper combination of crack orientation, temperature, and fluence level. Crack extension shall be ductile tearing with no cleavage.

b) A J-R curve shall be generated from a J-integral database obtained from the same class of material with the same orientation using correlations for effects of temperature, chemical composition, and fluence level. Crack extension shall be ductile tearing with no cleavage.

c) When (a) or (b) cannot be used, an indirect method of estimating the J-R curve shall be used provided the method is justified for the material.

3.2.1 Model 6B and Compliance with ASME Section XI, K-3300

As described in BAW-2192, Revision 0, Supplement 1P-A, Revision 0 [1], Model 6-B was generated for the Linde 80 material by following accepted test procedures. The J-R curve was based on the proper combination of crack orientation, temperature, and fluence level. Crack extensions were ductile tearing with no cleavage. Testing of new North Anna and Surry Rotterdam welds data was performed in accordance with ASTM E1820, which is in compliance with ASME Section XI, Appendix K, K-3300, (a) [6]. The results at crack extension of 0.1 inches and standard conditions are shown in Figure 3-1. The B&WOG Model 6-B lower bound curve (Figure 3-1) may be used for the evaluation of Level A, B, and C service loadings as a conservative representation of the toughness for the North Anna Unit 1 and 2 Rotterdam welds. The B&WOG Model 6-B J-R mean curve may be used for Level D service loadings as a best estimate representation of the toughness for North Anna Unit 1 and 2 Rotterdam welds.

Note that for the equivalent margins analyses for Surry Units 1 and 2 [1, 7], Levels C and D were combined and the B&WOG lower bound curve was conservatively used for the EMA. For North Anna Units 1 and 2, the EMA will not combine Level C and D service loadings, as there are no Level C service loadings for the North Anna reactor vessel ([8], Table 5.2-4). Therefore, the Level D analysis will utilize a best estimate (i.e., Model 6B J-R mean) curve based on Figure 3-1, consistent with the methodology of ASME Section XI, Appendix K, K-3300. The Level A and B analysis will utilize a lower bound curve based on Figure 3-1, consistent with the methodology of ASME Section XI, Appendix K-3300.

3.2.1.1 COMPARISON OF NORMALIZED ROTTERDAM TEST DATA TO B&WOG J-R MODEL 6B

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Table 3-1
New B&WOG Specimen Data for Rotterdam Model Assessment

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Figure 3-1 Jd (0.1) vs. Fluence B&WOG J-R Model 6B and New Test Data (Normalized to Standard Conditions)

4.0 SUMMARY AND CONCLUSIONS

The comparison of new J-R data to Model 6B at standard conditions includes the new B&WOG Linde 80 data reported in Table A-2 of Supplement 1 and the new Rotterdam data reported in Table 3-1 of this supplement. As reported in Figure 3-1, the majority of data is above the Jd(0.1) model mean and all data is above the lower bound Jd(0.1). The new Rotterdam data [ ] is above the Model 6B mean curve. Therefore, Model 6B is considered a conservative J-integral resistance model for North Anna and Surry reactor vessel Rotterdam weld material. There is no need to regenerate the B&WOG J-integral resistance Model 6B to include Rotterdam data.

5.0 REFERENCES

1. BAW-2192, Revision 0, Supplement 1P-A, Revision 0 (43-2192-00-Supplement 1P-A-00-000), Low Upper-Shelf Toughness Fracture Mechanics Analysis of Reactor Vessels of B&W Owners Reactor Vessel Working Group for Levels A & B Service Loads.
2. NUREG/CR-5729, Multivariable Modeling of Pressure Vessel and Piping J-R Data.
3. North Anna Power Station, Unit Nos. 1 and 2, Issuance of Amendments Regarding Measurement Uncertainty Recapture Power Uprate (TAC Nos. ME0965 and ME0966, ADAMS ML092250616).
4. Virginia Electric and Power Company (Dominion) North Anna Power Station Units 1 and 2 License Amendment Request Measurement Uncertainty Recapture Power Uprate (ADAMS ML090900055).
5. Virginia Electric and Power Company (Dominion) North Anna Power Station Units 1 and 2 Update to Reactor Vessel Integrity Database to Reflect License Renewal Period (ADAMS ML053480358).
6. ASME Code Section XI, Rules for Inservice Inspection of Nuclear Plant Components, 2013 Edition.
7. BAW-2178, Revision 0, Supplement 1P-A, Revision 0 (43-2178-00-Supplement 1P-A-00-000), Low Upper-Shelf Toughness Fracture Mechanics Analysis of Reactor Vessels of B&W Owners Reactor Vessel Working Group for Levels C & D Service Loads.
8. North Anna Power Station Updated Finals Safety Analysis Report, Revision 55.