UNITED STATES
NUCLEAR REGULATORY COMMISSION
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SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

EQUIVALENT MARGINS ANALYSIS FOR THE NO. N-16A/B INSTRUMENT NOZZLES

CAROLINA POWER AND LIGHT COMPANY

BRUNSWICK STEAM ELECTRIC PLANT UNITS 1 AND 2

DOCKET NOS.: 50-324 AND 50-325

1.0 BACKGROUND

On April 14, 1997 (Ref. 1), Carolina Power and Light Company (CP&L) submitted an equivalent margins analysis (EMA) for the No. N-16A/B instrument nozzles that are welded to the beltline regions of the reactor pressure vessels (RPVs) at the Brunswick Steam Electric Plant (BSEP) Units 1 and 2. CP&L submitted the EMA for the nozzles at the staff's request in order to demonstrate that the instrument nozzles would meet the fracture toughness requirements stated in Appendix G to Part 50 of *Title 10 to the Code of Federal Regulations* (10 CFR Part 50, Appendix G, Ref. 2). 10 CFR Part 50, Appendix G, in part, requires that ferritic components in the reactor coolant pressure boundary (RCPB) must comply with the fracture toughness requirements specified in Appendix G to Section XI of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (henceforth Appendix G of the Code, Ref. 3). These requirements can be satisfied by meeting the criteria specified in Appendix K to Section XI of the ASME Code (henceforth, Appendix K to the Code, Ref. 4), or the criteria and methodology specified in Regulatory Guide (RG) 1.161 (Ref. 5). The staff has completed its evaluation of the CP&L submittal of April 14, 1997. A summary of CP&L's upper shelf energy analysis for the No. N-16A/B instrument nozzles is presented in Section 2.0. The staff's independent safety evaluation of the nozzles is provided in Section 3.0.

2.0 CP&L'S FRACTURE TOUGHNESS EVALUATION OF THE BSEP NO. N-16A/B INSTRUMENT NOZZLES

10 CFR Part 50, Appendix G, requires that "[r]eactor vessel beltline materials must have Charpy upper-shelf energy[1], 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 can be demonstrated in a manner approved by the Director of the Office of Nuclear Reactor Regulation, that lower values of Charpy upper-shelf energy will provide margins of safety against fracture equivalent to those required by Appendix G of the . . Code." The No. N-16A/B instrument nozzles at the BSEP Unit 1 and Unit 2 plants are 2-inch diameter

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1 Charpy upper-shelf energy is defined in ASTM E 185-79 and -82 (Ref. 6), which are incorporated by reference in Appendix H to 10 CFR Part 50 (Ref. 7).

Enclosure 2

nozzles that are welded to the BSEP RPVs near the top of the BSEP lower-intermediate shells. The neutron fluences for these components in the beltline regions of the BSEP RPVs are all projected to exceed 1.0 x 10^{17} n/cm^2 at the end-of-license (EOL) for the plants. These nozzles therefore have to be included among the beltline components that are assessed for fracture toughness over the life of the plants.

2.1 Estimation of the Unirradiated Upper Shelf Energy (UUSE)

CP&L indicated that the No. N-16A/B instrument nozzles are fabricated from A 508 Class 2 forging material (the material heat is Q2Q1VW). Since the nozzle materials are not represented in the materials surveillance programs for the BSEP RPVs, CP&L did not have a sufficient amount of Charpy-V notch testing data to be capable of determining the unirradiated upper-shelf energy (UUSE) values for the instrument nozzle forgings. Instead, CP&L estimated the UUSE values for the nozzle forgings by performing a database search of the UUSE values listed for A 508, Class 2 material heats used in RPVs of domestic nuclear plants. The UUSE values obtained from Charpy impact tests of L-T oriented Charpy-V specimens of A 508 Class 2 materials ranged from 70 ft-lbs to 185 ft-lbs. This range of data bounds the UUSE values listed in the NRC's Reactor Vessel Integrity Database (RVID) for A 508 Class 2 materials. CP&L has conservatively estimated the UUSE of the No. N-16A/B nozzle forgings by setting it to the lower-bound UUSE value obtained from their database search (e.g., 70 ft-lbs).

10 CFR Part 50, Appendix G, requires that ferritic materials used in the beltline regions of domestic RPVs must meet a minimum Charpy-V UUSE requirement of 75 ft-lb. However, a significant number of Charpy-V notch tests over a full range of testing temperatures are needed to be able to predict the USE value of a ferritic material. NRC Branch Technical Position MTEB 5-2 (Ref. 8) indicates that an UUSE value of 70 ft-lb may be considered for a beltline material when the end-of-license (EOL) neutron fluence (E > 1.0 MeV) for the material is projected to be < 1.0 x 10^{19} n/cm^2. NRC Branch Technical Position MTEB 5-2 also indicates that conservative estimates of the UUSE value of the material should be made using Charpy-V notch impact tests of the first surveillance capsule removed from the vessel if a full range of Charpy-V notch impact tests was not performed on the unirradiated material; however, this implies that the applicable beltline material is represented in the licensee's RPV material surveillance program (e.g., 10 CFR Part 50, Appendix H program). Estimates of the UUSE value for Material Heat No. Q2Q1VW cannot be estimated in this manner because the material is not represented in the CP&L materials surveillance program.

2.2 CP&L's Estimation of Peak EOL Neutron Fluence Used in the USE Evaluation

Recognizing that the estimated UUSE value cannot be relied upon because of the lack of surveillance capsule data, CP&L calculated an USE value by estimating the peak EOL neutron fluence. In Altran Technical Report 96124-TR-01, Revision 0 (Ref. 9), the Altran Corporation estimated that the worst case EOL (32 effective full power year [EFPY]) neutron fluence for the BSEP vessels at the inner surface of the vessels was 1.39 x 10^{18} n/cm^2. [2] For the USE analysis of the nozzles, Altran applied a projected EOL fluence of 1.6 x 10^{18} n/cm^2. This

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2 Altran Corporation Technical Report No. 96124-TR-01, Revision 0, was issued by the Altran Corporation on behalf of CP&L. This reported was enclosed by CP&L with CP&L's submittal of April 14, 1997.

neutron fluence value bounds the worst case projected EOL neutron fluence value for the nozzles calculated by the staff (1.4×10^{18} n/cm^2, Ref. 10). Therefore, the staff concludes that an estimated neutron fluence of 1.6×10^{18} n/cm^2 is a conservative value to use in the USE assessment of the BSEP No. N-16A/B instrument nozzles.

2.3 CP&L's EOL USE Evaluation and EMA of the BSEP No. N-16A/B Instrument Nozzles

In its USE evaluation of the BSEP No. N-16A/B instrument nozzles, the Altran Corporation stated that the percentage drop in 1/4T USE value for the nozzles, as determined in accordance with Figure 2 and Position 1.2 of NRC Regulatory Guide 1.99, Revision 2 (Ref. 11), would be no more than 18%. Based on an estimated UUSE of 70 ft-lb and a projected 18% drop in USE, CP&L's projected EOL USE energy value for the nozzles is 57.4 ft-lb. This value satisfies the EOL USE criteria stated in 10 CFR Part 50, Appendix G. Although the estimated UUSE and EOL USE values satisfied the criteria stated in 10 CFR Part 50, Appendix G, CP&L still performed an EMA because it lacked Charpy-V data for the unirradiated nozzle materials. The purpose of the EMA is to demonstrate that the nozzles would continue to satisfy the safety margins required by Appendix G to the Code, and by 10 CFR Part 50, Appendix G, even if the UUSE and EOL USE for the nozzles were less than 70 ft-lb and 50 ft-lb, respectively, values required by the rule.

2.4 CP&L's EMA for the No. N-16A/B Instrument Nozzle Forgings

CP&L's EMA was performed in accordance with the methods and guidance of RG 1.161. RG 1.161 provides an acceptable method for demonstrating equivalence to the margins of safety specified in Appendix G of the Code. The analysis methods in RG 1.161 are based on methods developed for Appendix K of the Code.[3] However, the RG also provides additional guidance on the selection of transients and the material properties that are to be considered in the margins analyses.

CP&L's EMA was consistent with the criteria of RG 1.161. CP&L's EMA indicated that the No. N-16A/B instrument nozzles would have sufficient remaining margin against ductile tearing down to approximately 29 ft-lbs. CP&L concluded, therefore, that even if the UUSE for the nozzles were lower than 70 ft-lb, the nozzle would in all probability have sufficient remaining margin in them to protect the nozzle materials against ductile failure.

3.0 STAFF'S USE EVALUATION OF THE NO. N-16A/B INSTRUMENT NOZZLES

The staff performed an independent USE analysis EMA for the BSEP No. N-16A/B instrument nozzles as a comparison to those performed by CP&L. The copper content for the No. N-16A/B instrument nozzles (Heat No. Q2Q1VW) is 0.16 Wt.-%. According to Figure 2 of RG 1.99, Revision 2, the %-drop in USE for a base metal containing 0.16% copper and irradiated to a fluence of 1.6×10^{18} n/cm^2 is approximately 16.5%. The 18% drop proposed by CP&L bounds this value and, therefore, should represent a conservative estimation of the drop in the 1/4T USE value for the instrument nozzles.

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3 The evaluation criteria for RG 1.161 are presented in Appendix A to this safety evaluation.

The staff also performed an EMA of the nozzles using a modified RG 1.161 elastic-plastic fracture mechanics (J-integral) analysis, and compared the results of its analysis to the results of CP&L's EMA of the nozzles. The general methods of RG 1.161 are applicable only to the assessment of postulated axial and circumferential flaws in RPVs. RG 1.161 is silent on how to perform EMAs for postulated corner flaws in nozzles which are welded to the RPV. However, Appendix G of the Code indicates that Welding Research Council Bulletin No. 175 (WRC 175, Ref. 12) provides acceptable methods for evaluating postulated flaws in nozzles which are welded to RPVs. Appendix 5 of WRC 175 provides a method for adapting fracture toughness evaluations of postulated corner flaws in nozzles to the pressure vessel case. Since it is invoked by Appendix G to the Code, the staff has used the methods of Appendix 5 in WRC 175 as a basis for evaluating the fracture toughness properties of RPV beltline nozzles.
The staff's stress intensity factors due to internal pressure were calculated using the methods found in Appendix 5 of WRC 175, as modified using the safety factor and geometric factor from equation (6) of RG 1.161.[4] Otherwise, the $J_{applied}$ values for normal operating and transient loading (A and B loading) conditions were calculated using the analysis methods in Section 2.1 of RG 1.161. The materials J-integral fracture resistance (J-R) values were calculated applying equation (17) and the methods in Section 3.3.1 of RG 1.161 to the nozzle evaluation case.[5] $J_{applied}$ and J-R values were calculated for postulated flaw extensions of 0.01, 0.02, 0.05. 0.10, 0.15, 0.20, 0.25, 0.30, 0.35, and 0.40 inches. A separate J-R integral curve was generated for Charpy-V notch impact energy inputs of 30 ft-lb, 35 ft-lb, 40 ft-lb, 45 ft-lb, 50 ft-lb, and 55 ft-lb. In the staff's assessment, the staff calculated $J_{applied}$ values for both evaluation Criteria 1 and 2 (refer to the EMA evaluation criteria in Appendix A to this SER) using a safety factor (SF) of 1.25 and compared them to the corresponding values compiled by CP&L; with regard to the assessment of EMA Criterion 1, these values bound all $J_{applied}$ values calculated using a SF of 1.15 and represent an added conservatism in the analysis. Emergency and faulted loading conditions (C and D loading conditions) were confirmed by the staff to be bounded by loading conditions for normal operating and transient loading conditions (A and B loading conditions). Therefore, no J-integral evaluations were performed for C or D type loading conditions on the No. N-16A/B instrument nozzles, as these analyses would have been bounded by the J-integral analyses for the A and B type loading conditions. The staff determined that for all Charpy-V notch impact energy inputs analyzed, the N-16A/B instrument nozzles materials satisfy the criteria of RG 1.161 analysis methods. The staff's EMA indicates that the BSEP No. N-16A/B

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4 In this analysis, since Regulatory Guide (RG) 1.161 is silent on how to calculate the stress intensity factor due to pressure (K_{1p} values) for a postulated corner flaw in a nozzle, the staff used the methods of Appendix 5 of WRC 175 to determine the K_{1p} values for the nozzles, and substituted these values into the stress intensity portions of equation (6) in the RG. Adjustment to the K_{1p} values were then made using the appropriate geometric factors and safety factors in the equation (6). The staff concluded that this modified method could be used because Appendix 5 of WRC 175 assesses welded RPV nozzles as if they are holes in a ferritic plate.

5 Section 3.3.1 was applicable to use because it provides guidelines for estimating the J-R values of high-toughness (Sulfur content < 0.018 Wt.-%) base materials. The N-16A/B instruments nozzles were determined to fall within the analysis scope of Section 3.3.1 because the nozzle materials have an average sulfur content 0.017 ± 0.005 Wt.-%, as determined from the two copies of the Certified Material Test Reports provided by the Chicago Bridge and Iron Company, and because the nozzles were fabricated from A 502 Class 2 forging materials which normally have increased fracture toughness properties when contrasted to those of rolled, ferritic plate materials.

instrument nozzles have acceptable inherent margins against ductile tearing to at least 30 ft-lb. The results of analyses performed by the staff were in good agreement and consistent with the results of the EMA analyses performed by CP&L.

4.0 CONCLUSIONS REGARDING CP&L'S USE ANALYSIS FOR THE NO. N-16A/B INSTRUMENT NOZZLES

The staff has determined that CP&L's USE evaluation of the No. N-16A/B instrument nozzles represents a sufficiently conservative assessment of the fracture toughness properties of the nozzles. CP&L's assessment indicates that USE of the nozzles will not fall below the 50 ft-lb value required by the rule at the EOL for the plants. However, since the UUSE for the nozzles has been estimated in the case, CP&L has shown the instrument nozzles should have sufficient protection against ductile tearing down to a value of 29 ft-lbs. By the staff's calculations, the nozzles should have sufficient margin down to at least a value of 30 ft-lb. These values are not statistically different. The EMAs for the nozzles therefore indicate that even the EOL USE were lower than the 50 ft-lbs required by the rule, the nozzles have sufficient margin against fracture at USE values lower than those required by the rule, and that the nozzles therefore satisfy the EMA criteria stated in 10 CFR Part 50, Appendix G. Therefore, the staff concludes that CP&L's method for establishing the UUSE and EOL USE values (70 ft-lb and 57.4 ft-lb, respectively) for the nozzle forgings, when coupled with the results of CP&L's EMA for the nozzle forgings, is sufficiently conservative in this case, and therefore, is acceptable.

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5.0 REFERENCES

1. April 14, 1997 - Letter from W.R. Campbell, Vice President - Brunswick Nuclear Plant, to the U.S. Nuclear Regulatory Commission Document Control Desk, "Brunswick Steam Electric Plant, Units 1 and 2, Docket Nos. 50-325 and 50-324, License Nos. DPR-71 and DPR-62, Supplemental Information for Generic Letter 92-01, Reactor Vessel Structural Integrity."

2. Appendix G, "Fracture Toughness Requirements," to Part 50 of Title 10, *Code of Federal Regulations*.

3. Appendix G, "Fracture Toughness Criteria for Protection Against Failure," to Section XI of the American Society of Mechanical Engineers Boiler and Pressure Vessel Code.

4. Appendix K, "Assessment of Reactor Vessels with Low Upper Shelf Charpy Impact Energy Levels," to Section XI of the American Society of Mechanical Engineers Boiler and Pressure Vessel Code.

5. June 1995 - Regulatory Guide 1.161, "Evaluation of Reactor Pressure Vessels with Charpy Upper-Shelf Energy Less Than 50 Ft-Lb."

6. 1979 and 1982 Editions of American Society for Testing and Materials Designation E-185, "Standard Practice for Conducting Surveillance Tests for Light-Water Cooled Nuclear Power Reactor Vessel, E 706."

7. Appendix H to Part 50 of *Title 10 to the Code of Federal Regulations*, Reactor Vessel Material Surveillance Program Requirements."

8. July 1981 - Branch Technical Position - MTEB 5-2,"Fracture Toughness Requirements," to NUREG-0800, U.S.N.R.C. Standard Review Plan, Section 5.3.2, "Pressure-Temperature Limits."

9. December 1996 - Altran Corporation Technical Report No.96124-TR-01, Revision 0, "N-16 Nozzles Upper Shelf Energy Evaluation."

10. November 1996 - WCAP-14774, "Analysis of the 300 Deg Capsule from the Carolina Power and Light Company Brunswick Unit 2 Reactor Vessel Radiation Surveillance Program."

11. May 1988 - Regulatory Guide 1.99, Revision 2, "Radiation Embrittlement of Reactor Vessel Materials."

12. August 1972 - Welding Research Council Bulletin No. 175, "PVRC Recommendations on Toughness Requirements for Ferritic Materials."