UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

REQUEST TO APPLY

LEAK-BEFORE-BREAK TO ELIMINATE AUGMENTED INSPECTION PROGRAM ON

RCS BYPASS LINES

NORTH ANNA POWER STATION, UNITS 1 AND 2

VIRGINIA ELECTRIC AND POWER COMPANY

DOCKET NOS. 50-338 AND 50-339

1.0 INTRODUCTION AND BACKGROUND

By letter dated June 23, 1998, and supplemented by letter dated July 9, 1999, Virginia Electric and Power Company (the licensee) requested that the NRC review and approve their leak-before-break (LBB) methodology that was used to support the elimination of the augmented inspection program on the reactor coolant system (RCS) bypass lines from the licensing basis (UFSAR 3.6.2.3.) of North Anna, Units 1 and 2. The licensee's submittal was based on an application of Title 10 of the Code of Federal Regulations Part 50 (10 CFR 50), Appendix A, General Design Criteria (GDC) 4, which states:

> However, dynamic effects associated with postulated pipe ruptures in nuclear power units may be excluded from the design basis when analyses reviewed and approved by the Commission demonstrate that the probability of fluid system piping rupture is extremely low under conditions consistent with the design basis for the piping.

Previous pipe-rupture studies by the licensee indicated that a substantial support structure would have to be constructed along the North Anna, Units 1 and 2, bypass lines to protect components from pipe whip and jet impingement. However, construction of additional supports along the bypass lines was judged not feasible considering the existing structures surrounding the lines. As a result, the licensee implemented an augmented inservice inspection (ISI) program to inspect postulated weld locations approximately every outage in lieu of installing additional supports. This alternative was approved by the NRC. Hence, unlike other LBB submittals, which requested removal of whip restraints, the current submittal requests that the licensee be permitted to terminate the augmented ISI program for the subject bypass lines.

2.0 REGULATORY REQUIREMENTS AND STAFF POSITIONS

Nuclear power plant licensees have, in general, been required to consider the dynamic effects which could result from the rupture of sections of high energy piping (fluid systems that during normal plant operations are at a maximum operating temperature in excess of 200°F and/or a maximum operating pressure in excess of 275 psig). This requirement has been formally included in 10 CFR 50, Appendix A, GDC 4 which states, "Structures, systems, and components important to safety...shall be appropriately protected against dynamic effects, including the effects of missiles, pipe whipping, and discharging fluids, that may result from equipment failures and from events and conditions outside the nuclear power unit." For facilities such as North Anna, Units 1 and 2, which were licensed prior to the advent of the GDC, these requirements were included as part of plant-specific licensing reviews.

The philosophy of LBB behavior for high energy piping systems was developed by the NRC in the early 1980s, used in certain evaluations stemming from Unresolved Safety issue A-2, "Asymmetric Blowdown Loads on PWR Primary Systems," and was subsequently expanded for application toward resolving issues regarding defined dynamic effects from high energy piping system ruptures. The methodology developed by the NRC for performing LBB analyses was detailed in NUREG-1061, Volume 3 [1] and summarized in Draft Standard Review Plan (DSRP) Section 3.6.3, "Leak-Before-Break Evaluation Procedures," which was published for public comment in August 1987.

3.0 LICENSEE'S DETERMINATION

3.1 Piping Material Properties

The material for the pipe base metal was the American Society for Testing and Materials Specification (ASTM) A-376, Type 316 wrought stainless steel (SS). The material for the fittings was either ASTM A-182, F316 SS, or A-403, WP316 SS. The welds were fabricated by the shielded metal arc welding (SMAW) process and were identified as Type 308 SS and Type 304 SS.

Most of the material properties used in the licensee's LBB evaluations are properties at 550°F. The material properties used by the licensee are listed in Table 1. The J-integral/Tearing Modulus (J/T) curve has a J_{IC} value of 990 in-lb/in-in. The references and the justifications for using these material properties were not given in the submittal.

3.2 General Aspects of the Licensee's LBB Analysis

The analyses provided by the licensee were intended to address three principal areas established for LBB analysis acceptability in NUREG-1061, Vol. 3 and/or DSRP Section 3.6.3. The licensee first established the through-wall leakage flaw sizes corresponding to 10 gallons per minute (gpm) under normal operation (NOP) loads for limiting locations. They then used J/T analysis to ensure that a crack corresponding to twice this amount of leakage (20 gpm) is stable under NOP plus safe-shutdown earthquake (SSE) loading conditions. Lastly, the licensee evaluated the stability of the leakage flaw under the loading of NOP + $\sqrt{2}$ (SSE).

Since all cracks that we discuss in this safety evaluation (SE) are through-wall, the term "through-wall" will be dropped in later referencing of cracks.

3.3 Evaluation of RCS bypass lines

The licensee used its plant-specific version of the computer program LBB.NRC (referred to as plant-specific LBB.NRC) to calculate the leakage flaw size corresponding to a leakage rate of 10 gpm at three highly stressed limiting locations. In this analysis, the applied stresses under NOP loading were used. The NOP loading includes internal pressure, deadweight, and thermal expansion loads. The plant-specific LBB.NRC calculates the leakage rate by multiplying the crack opening area from an elastic-plastic fracture mechanics (EPFM) analysis times a "leak rate constant" of 350 gpm/in.-in. The licensee did not use the leak rate constant of 250 gpm/in.-in. as appeared in the original LBB.NRC [2]. The calculated leakage flaw sizes for 10 gpm are 4.36, 4.52, and 7.83 inches for the three limiting locations of the RCS bypass lines. Using 10 gpm to calculate the leakage flaw size, the licensee automatically assumed that the margin on leakage is 10 (consistent with the requirements of NUREG-1061, Vol. 3). The methodology of the plant-specific LBB.NRC is discussed in Section 4.3 of this SE.

For the critical (allowable) flaw size at the limiting locations, the licensee did not follow the direct approach of calculating the critical flaw size under the faulted loading, nor did the licensee divide the critical flaw size by the leakage flaw size to see whether a ratio of two is maintained. Instead, the licensee conducted a J/T EPFM analysis (available in the plant-specific LBB.NRC) for flaws approximately two times the length of the leakage flaw sizes under the faulted loading. The faulted loading is the sum of the SSE load and the NOP loading. The licensee demonstrated that the flaws being analyzed are stable because the applied J does not intersect the J/T material curve. Hence, a margin of at least two is demonstrated.

NUREG-1061, Vol. 3 also requires that the leakage flaw size be stable under loads equivalent to $\sqrt{2}$ times the sum of NOP and SSE loads. The licensee deviated from the guideline by using instead a load equivalent to NOP plus $\sqrt{2}$ times the SSE loads in a similar J/T analysis. The results indicate that the leakage flaw sizes would be stable under such loading conditions.

Separately, additional information was submitted on July 9, 1999, regarding the plant's leakage detection capability. The licensee reviewed its leakage detection system and concluded that North Anna, Units 1 and 2, have the capability of detecting 0.5 gpm of leakage.

4.0 <u>STAFF EVALUATION AND DISCUSSION</u>

The LBB methodology is proactive and DSRP 3.6.3, published in 1987, has not been finalized. Consequently, it is not surprising that the licensee's LBB methodology is different from the methodology that the staff has used to independently evaluate LBB applications in recent years. The staff's independent evaluation was necessary because the licensee's approach, which did not calculate the critical flaw sizes, makes a direct response to the concerns raised in Section 3.3 impossible. The differences between the licensee's and the staff's approaches are highlighted in Table 1. The staff's evaluation is presented below.

4.1 Piping Material Properties

NUREG-1061, Vol. 3, specifies particular aspects which should be considered when developing materials property data for LBB analyses. First, data from the testing of the plant-specific piping materials is preferred. However, in the absence of such data, generic data from the testing of samples having the same material specification may be used. Specifically, it was noted in Appendix A of the NUREG that "[m]aterial resistance to ductile crack extension should be based on a reasonable lower-bound estimate of the material's J-resistance curve," while Section 5.2 of the NUREG stated that the materials data should include "appropriate toughness and tensile data, long-term effects such as thermal aging and other limitations."

As was stated previously, the references and the justifications for using the material properties listed in Table 1 were not given in the submittal. However, the staff verified that the licensee's J_{IC} and the J/T toughness curve are consistent with those used in developing IWB-3600 and Appendix C of Section XI of the ASME Code and those in the EPRI Ductile Fracture Handbook. The staff examined the remaining material properties for the RCS bypass lines and concluded that the welds are limiting because of their susceptibility to thermal aging. The staff made a comparison in Table 1 of the weld material properties reported by the licensee with those associated with a typical aged SS weld that the staff used in evaluating LBB applications in recent years. The table indicates that, except for the fracture toughness, the two sets of material properties in Table 1 are comparable. Hence, the staff concurred with the use of the Ramberg-Osgood representation proposed by the licensee for the stress-strain properties for the welds.

The staff finds that the licensee's J/T toughness curve of the SS welds is not acceptable. The J/T curve which had been used to develop the flaw evaluation criteria in ASME Section XI did not account for the effects of thermal aging. It is the staff's position that an LBB analysis is significantly different from a flaw evaluation and that the thermal aging of SS weld materials must be explicitly addressed. A study from Argonne National Laboratory [3] was the staff's reference for this information. The mean minus one standard deviation lower bound J-R curve used by the staff was actually developed by Wilkowski and Ghadiali at Battelle Columbus Laboratory as a fit to unaged SS weld data, but the conclusions of Reference 3 noted that there was little observed change in the fracture toughness behavior with thermal aging for those welds that began with inferior fracture toughness properties. The J-R curve used by the staff was more conservative than the corresponding J-R curve based on the J-T curve used by the licensee.

4.2 General Aspects of the Staff's LBB Analysis

The staff's analysis was performed in accordance with the guidance provided in NUREG-1061, Vol. 3. Based on the information submitted by the licensee, the staff calculated the leakage flaw sizes at the limiting locations corresponding to 10 gpm of leakage under NOP conditions using the PICEP analytic code. Unlike the licensee's approach of using the empirically determined leak rate constant, PICEP calculates the leakage flow rate based on Henry's homogeneous nonequilibrium two-phase critical flow model. The factor of 10, which is applied to the detection capability of the leakage detection systems, accounts for thermohydraulic uncertainties in calculating the leakage through small cracks. It should be emphasized, however, that using 1-gpm detection capability is for the purpose of comparing the staff's final results with those of the licensee's. The staff's evaluation is based on North Anna's leakage detection capability of 0.5 gpm.

The staff determined the critical flaw sizes at these locations for the piping using the codes compiled in the NRC's Pipe Fracture Encyclopedia [4]. Specifically, the staff used the LBB.ENG2 code developed by Brust and Gilles [5] to calculate the critical flaw in the thermallyaged weld SS material. The critical flaw size is determined when the applied J exceeds the material J_{IC} and the rate of increase of the applied J with crack extension (dJ/da) exceeds the rate of increase of the piping material's J-R curve with crack extension (d(J-R)/da). The ratio of the critical flaw size to the leakage flaw size is then examined. For the most limiting location where the ratio is below 2, the staff used the LBB.ENG3 code developed by Battelle [5] for additional analysis. The LBB.ENG3 methodology is different from the other codes in Reference 4 and from the licensee's analysis in that LBB.ENG3 explicitly accounts for the differences in the stress-strain properties of the weld and the adjoining base material.

The stability of the leakage flaw under loadings of √2 times the sum of SSE and NOP loads was subsequently evaluated to check the final acceptance criteria of NUREG-1061, Vol. 3.

4.3 Evaluation of the RCS Bypass Lines

Based on the licensee's results and the loadings supplied by the licensee, the staff concluded that only two (nodes N10 and N70) of the three limiting locations need to be examined. The results for the third location (node N45) would be bounded by the results of these two. The critical flaw sizes for nodes N10 and N70 were found to be 10.17 and 4.8 inches under SSE+NOP loading conditions while the 5-gpm leakage flaw sizes were found to be 5.70 and 2.75 inches. Based on the above, the staff obtained margin ratios of 1.78 and 1.75 for nodes N10 and N70. It should be noted that the results for the two nodes were obtained by using LBB.ENG3 which accounts for both base and weld material properties. The results for the critical flaw sizes and the leakage flaw sizes for 10 gpm are tabulated in Table 2, along with the licensee's results, for comparison.

In the refined analysis for Node N10 using LBB.ENG3, it was assumed that the weld was flanked by the wrought 316 SS piping material. Three different wrought 316 SS stress-strain property representations are available: two of which assumed "typical" yield strength (YS) and ultimate tensile strength (UTS) properties for the material (YS = 25 ksi, UTS = 75 ksi) and differed only in their Ramberg-Osgood parameters (α = 6.9, n = 4.8 or α = 5.8, n=3.6), and the third one was from Table 3.2-1 of the licensee's submittal (YS = 18.7 ksi, UTS = 71.8 ksi, α = 12.1, and n = 3.1). The licensee's stress-strain properties are consistent with the ASME Code minimum strength values at the system's operating temperature. In the review of an LBB submittal for Millstone Unit 2 in 1998, the staff performed an evaluation of the impact on the critical flaw sizes for multiple sets of stress-strain properties for wrought 316 SS material. The staff concluded in that SE that the critical flaw size based on the Code minimum would be non-conservative. Consequently, the current results by the staff are the average of the two non-Code minimum calculations. In addition, the staff confirmed that the leakage flaws were stable under √2 (SSE+NOP) loads.

In this LBB application, the staff accepts the margins about 1.75 on the critical-to-leakage flaw size for the RCS bypass lines with a margin of 10 on North Anna's leakage detection capability of 0.5 gpm. The staff has accepted comparable margins in previous LBB applications by other licensees. The margin of 1.75 on the critical-to-leakage flaw size is justified because the use of the tensile properties of two materials (piping base metal and weld) in the J-R approach and the use of Battelle's lower bound J-R curve is much more conservative than the approach of DSRP 3.6.3 using the tensile properties of one material (piping base metal or weld) in the limit load analysis and the use of the licensee's lower bound J-R curve. This finding is supported by the results from the staff's additional LBB analyses using the PICEP Code, which indicated that the margins on the critical-to-leakage flaw sizes for the RCS bypass lines are larger than 2. The PICEP Code was also used by the staff before 1997 for the evaluation of critical flaw sizes in LBB applications.

In addition to the explicit conservatism exhibited by the specified margins, there is implicit conservatism in the LBB analyses: (1) the use of the lower bound tensile and J-R curve properties, (2) the wide range of loading specified to be used in the analyses, and (3) the use of the most critical location (axially and circumferentially) for the crack under loading. Hence, the staff has concluded that North Anna, Units 1 and 2, RCS bypass piping will exhibit LBB behavior.

5.0 CONCLUSION

Based on the information and analysis supplied by the licensee, the staff was able to independently assess the LBB status of North Anna, Units 1 and 2, RCS bypass piping. The staff has concluded that it has been demonstrated that the bypass piping will exhibit LBB behavior. Hence, the licensee should be permitted to credit this conclusion for eliminating the dynamic effects associated with the postulated rupture of the bypass piping from the licensing basis for North Anna, Units 1 and 2, consistent with the provisions of 10 CFR 50, Appendix A, General Design Criteria 4. Consequently, the licensee may remove the augmented ISI program on the RCS bypass lines from the licensing basis of North Anna, Units 1 and 2.

6.0 REFERENCES

(1) NUREG-1061, Volume 3, “Report of the U.S. Nuclear Regulatory Commission Piping Review Committee, Evaluation of Potential for Pipe Breaks,” November 1984.

(2) NUREG/CR-4572, BMI-2134, “NRC Leak-Before-Break (LBB.NRC) Analysis Method for Circumferentially Through-Wall Cracked Pipes Under Axial Plus Bending Loads,” May 1986.

(3) NUREG/CR-6428, ANL-95/47, “Effects of Thermal Aging on Fracture Toughness and Charpy-Impact Strength of Stainless Steel Pipe Welds,” May 1996.

(4) Pipe Fracture Encyclopedia, produced on CD-ROM by Battelle-Columbus Laboratory for the U.S. Nuclear Regulatory Commission, 1997.

(5) NUREG/CR-6235, BMI-2179, “Assessment of Short Through-Wall Circumferential Cracks in Pipes,” April 1995.

Principal Contributor: S. Sheng

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Table 1 Comparison of the current NRC review standard for LBB applications with those in the licensee's submittal

PARAMETER	NRC	LICENSEE
1.0 Leakage Flaw Size Calculation		
Load	Normal	Normal
Methodology	Thermal-fluid: Henry's model (PICEP) EPFM: J-Estimation (PICEP)	Thermal-fluid: using Leak Rate Constant (LBB.NRC) EPFM: J-Estimation (LBB NRC)
Leak Rate Constant (LRC)	250 (when original LBB.NRC is used)	350
Material properties for Aged SS Welds: E	25000	25500
Yield Stress	49.4	48.1
Tensile stress	61.4	63.05
Alpha	9	9
n	9.8	9.8
Ref. stress	49.4	*48.1*
Ref. strain	0.00198 (Ref. stress/E)	*0.00189 (Ref. stress/E)*
Flow stress	*55.4*	55.5
Fracture toughness	Wilkowski's J-R curve	ASME J-T curve
Note: The values in "Italic" are derived by the staff		
2.0 Crack Stability of Leakage Flaw Size		
Load	1.4(Normal + SSE[1])	Normal + 1.414(DBET[2])
Methodology	EPFM: J-R (LBB.ENG2 for weld or base material; LBB.ENG3 for weld and base material)	EPFM: J-T (Licensee's methodology using results from LBB.NRC)
Material properties	Same as Case 1.0	Same as Case 1.0
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3.0 Critical Flaw Size Calculation		
Load	Normal + SSE	Normal + DBET
Methodology	<u>EPFM:</u> J-R (LBB.ENG2 for weld or base material; LBB.ENG3 for weld and base material)	<u>EPFM:</u> J-T (Licensee's methodology using results from LBB.NRC)
J-R Curve	Wilkowski	ASME

(1) In Draft SRP 3.6.3, two types of seismic loads have been specified: SSE(inertia) and seismic anchor motion (SAM). In a typical LBB submittal prepared by Westinghouse for a licensee, two types of seismic loads have been specified: SSEINER (SSE inertia) and SSEAM (SSE anchor motion). The staff believes that different "terminology" has been used in the two places for the same load.

(2) The licensee confirmed on 11/16/98 that DBET in the submittal is the same as SSE.

Table 2 The staff results using the current NRC review standard for LBB applications

Margin Calculation:					
	Staff			**Licensee**	
Location	**Critical Flaw size (2a)**	**Leakage Flaw Size (2a)**	**Margin Ratio**	**Margin Ratio**	
				(LRC = 350)	(LRC = 250)
Node 10	9.81 inches (LBB.ENG2)	6.65 inches	1.48	1.89	1.35
	10.17 inches (LBB.ENG3)	6.65 inches	1.53	1.89	1.35
	Note: P=2500 psi F(Pressure)= 91250 F(Total)= 104581 M=221227 **<u>NRCPIPE input:</u>** LBB.ENG2: 1.Equiv. P=2865 psi(2500x104581/91250) 2.Varying crack size so that M(max) =221227 LBB.ENG3: 1.Equiv. M=480959 (set p=0 in a run using LBB.ENG2) 2.Varying crack size so that M(max) =480959	Note: F(Pressure)= 91250 F(Total)= 101705 **<u>PICEP input:</u>** P=2500 psi M= 35087 F(w/o P)=10455 (101705-91250)	Note: N/A	Note:[1] 98.5/52=1.89	Note:[2] 1.89x(1/1.4)
Node 45	Not performed because the results are bounded by those associated with Node 10 and Node 70			2.52	1.80
				Note:[1] 75.5/30=2.52	Note:[2] 2.52x(1/1.4)

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Node 70	4.4 inches (LBB.ENG2)	3.5 inches	1.26	2.59	1.85
	4.8 inches (LBB.ENG3)	3.5 inches	1.37	1.89	1.35
	Note: F(Total)= 104569 M=863339 **NRCPIPE input:** LBB.ENG2: 1.Equiv. P=2865 psi(2500x104569/91250) 2.Varying crack size so that M(max.) =863339 LBB.ENG3: 1.Equiv. M=995978 (set p=0 in a run using LBB.ENG2) 2.Varying crack size so that M(max) =995978	Note: F(Pressure)= 91250 F(Total)= 103027 **PICEP input:** P=2500 psi M=808575 F(w/o P)=11777 (103027-91250)	Note: N/A	Note:(1) 75/29=2.59	Note:(2) 2.59x(1/1.4)

(1) 98.5, 52, 75.5, 30, 75, and 29 deg are from the licensee's computer printout.

(2) The leakage rate is proportional to LRC. If the LRC of 250 were used, the leakage would be 10 gpm/1.4. To reach 10 gpm, the leakage flaw size has to be increased by a factor of 1.4.