N-16 NOZZLES UPPER SHELF ENERGY EVALUATION

Technical Report No. 96124-TR-01
Revision 0

prepared for:

Carolina Power & Light Company
Brunswick Unit 1

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1.0 EXECUTIVE SUMMARY

10 CFR 50 Appendix G [1] requires that the upper-shelf Charpy V Notch Energy (CVN) of the reactor vessel beltline region be greater than 75 ft-lb initially, and remain above 50 ft-lb throughout the operating license of the plant. If this minimum requirement is not maintained, the plant operator is required to demonstrate that lower values of upper shelf energy will provide margins of safety against fracture equivalent to those required by the ASME Code Section XI, Appendix G [2].

N-16A and N-16B are 2" instrument nozzles located in the beltline region of the Brunswick Unit 1 and 2 reactor vessels. All four nozzle forgings are from the same heat of material, but Unit 1 nozzle forgings have significantly lower reported Charpy energy at 40°F than the Unit 2 nozzle forgings. This raised a concern whether the Unit 1 N16 nozzles would meet the 10CFR50 Appendix G requirements. Since the initial CVN testing was performed for only one temperature (40°F), another concern was if the material had very low initial upper-shelf energy (USE). As a result, Carolina Power & Light (CP&L)* has decided to perform an equivalent margin analysis as required by 10CFR50 Appendix G. This report presents the results of the work performed by Altran Corporation under a CP&L Contract No. XTA 5000209, Amendment No. 3.

It is shown that the subject Brunswick Units 1 and 2 N-16 nozzles should have had an initial upper-shelf energy of at least 70 ft-lb, based on an extensive database search. In addition, a conservative projection of the end-of-life fluence shows that the initial upper-shelf energy is not anticipated to drop more than 18% for either Brunswick vessel. Therefore, the end-of-life upper-shelf energy of the nozzles for both vessels is anticipated to remain higher than the minimum requirement of 50 ft-lb.

For added conservatism, an equivalent margin analysis was performed per the guidelines provided in Reg. Guide 1.161. This evaluation demonstrates that the N-16 nozzles would meet the ASME Section XI Appendix K and Reg. Guide 1.161 J-R fracture toughness requirements with an end-of-life upper-shelf energy as low as 29 ft-lbs. It was shown in Section 3.0 that a 29 ft-lb end-of-life upper-shelf energy is equivalent to an initial upper-shelf energy of 35 ft-lbs. Based on the material database search conducted as a part of this project, it was demonstrated that the subject nozzle material should have an initial upper-shelf energy of at least 70 ft-lbs.

The equivalent margin analysis performed in this report is based on a fluence value of 1.6E18 n/cm^2 [E > 1MeV]. This fluence value is significantly conservative when compared against the maximum N-16 nozzle fluence of 1.34 E18 n/cm^2 [E > 1MeV] for 52 effective full power years of operation for the Brunswick vessels (1.34E18 projection includes 15% margin, which will bound any fluence increase resulting from a power uprate of the Brunswick Units to 105%).

The results of this report are applicable for N-16 nozzles on both of the Brunswick units.

2.0 OVERALL WORK SCOPE

The scope of the analysis presented in this report is to evaluate the N-16A and N-16B reactor vessel nozzles at Brunswick Units 1 and 2 for compliance with the requirements of 10CFR50, Appendix G. Compliance will be demonstrated in two ways. First, by showing that the end-of-life upper shelf energy will not drop below the minimum requirement of 50 ft-lbs. Second, by performing an equivalent margin analysis which demonstrates that an upper-shelf energy of less than 50 ft-lbs would still provide margins of safety against fracture equivalent to those required by Appendix G of the ASME Code Section XI.

Numerous documents published by ASME, EPRI, and Nuclear Regulatory Commission (NRC) present methodology of meeting the intent of 10CFR50, Appendix G requirement of an equivalent margin analysis. A material property required to perform these analyses is the J-Resistance (J_R) fracture toughness curve. J_R curves are a function of the material chemistry, heat treatment condition, irradiation condition, and material temperature. In some cases, J_R data can be obtained through testing of the irradiated and/or surveillance materials.

However, in many cases J_R curves of the material in question are not always available for the specific weld or heat in service or at the irradiation conditions which match the case to be analyzed. Therefore, it is necessary to reliably estimate J_R curves from available data such as material chemistry, radiation exposure, tensile properties, and Charpy impact data.

A recent edition of ASME Section XI, Appendix K [2] provides acceptance criteria and evaluation procedures for determining acceptability of reactor vessels with low upper shelf Charpy V Notch (CVN) impact energy levels. It should be noted that the Appendix K of ASME Section XI is not a mandatory appendix. As such, there are other documents in the literature which also propose acceptance criteria and analysis methodologies for low CVN materials.

The overall work scope was divided into specific tasks which are presented in this report as follows:

1. Section 3.0 presents the mechanical and fracture toughness properties of all N-16 nozzles from Brunswick Units 1 and 2. Database search results are presented to conservatively estimate the pre-irradiated Charpy V notch upper-shelf energy (USE) and compare it with 10CFR50, Appendix G requirements.

2. ASME Section XI, Appendix K acceptance criteria are briefly reviewed in Section 4.0.

3. A J_R fracture toughness model of the N-16 nozzle materials, based on the literature search, is presented in Section 5.0.

4. The equivalent safety margin analysis method implemented in this report is described in Section 6.0.

5. Section 7.0 presents the summary of the evaluation results.

3.0 N-16 NOZZLES MATERIAL UPPER-SHELF ENERGY EVALUATION

ASME Code Section III impact property requirements were changed significantly starting Summer 1972 addenda of the 1971 Edition. Prior to 1972, limited Charpy impact testing was required and there were no requirements for establishing reference nil-ductility temperature (RT_{NDT}) or upper shelf energy levels. However, 10CFR50 Appendix G Paragraph III invokes impact property requirements by stating that " For a reactor vessel that was constructed to an ASME Code earlier than the Summary 1972 Addenda of the 1971 Edition (under § 50.55a of this part), the fracture toughness data and data analyses must be supplemented in a manner approved by the Director, office of Nuclear Reactor Regulation, to demonstrate equivalence with the fracture toughness requirements of this appendix.... Reactor vessel beltline materials must have Charpy upper-shaft energy of no less than 75 ft-lb (102 Joules) initially and must maintain upper-shelf energy throughout the life of the vessel of no less than 50 ft-lb (68 Joules), unless it is demonstrated in a manner approved by the Director, Office of Nuclear Reactor Regulation, that lower values of upper-shelf energy will provide margins of safety against fracture equivalent those required by Appendix G of the ASME Code."

This report addresses the 10CFR50 Appendix G requirement of equivalent margin analysis with respect to Charpy upper shelf energy. The 10CFR50 requirements related to RT_{NDT} have been addressed earlier by CP&L in the reports presented in References 3, 4, 5, 6, 7, and 15.

3.1 N-16 Nozzle Material Test Data

Nozzles N-16A and N-16B for Brunswick Units 1 and 2 are A-508, Class 2, CBI Specification MS-2 and were supplied by Lenape Forge Division. The nozzles were specified to ASME Section III 1965 Edition and Addenda through Summer 1967 and General Electric APED Specification [8]. The nozzles are 2" instrument nozzles and are located in upper region of the reactor vessel belt line region as shown in Figure 3-1 [10]. The geometry of the nozzles is shown in Figure 3-2 [9].

All four nozzles were made from the same heat of material Q2Q1VW, but they were fabricated from two separate ring forgings. This is evident from their similarities in chemistry. See Tables 3-1 and 3-2.

The material test data of N-16 nozzles for both units will be presented and discussed, since all four nozzle materials are from the same heat.

The test data were taken from References 10 and 11. For completeness of this report, they are included in Appendix A. Tables 3-1 and 3-2 provide the summary of Unit 1 and Unit 2 N-16 nozzles test data. As such, this report may be used for all N-16 nozzles on both units.

The forging material for all four nozzles comes from the same heat Q2Q1VW. The nozzles were specified to be procured per ASME Section III Code through Summer 1967 addenda and with the requirements of Paragraph 1.9.6, 1.9.27, 1.9.29, and 1.9.30 of GE

Spec. No. 21A1100AR, Rev. No. 12 [8]. Upon reviewing the ASME Code and GE specification, it appears that at least two tensile, three Charpy, and two drop weight specimens were required from two locations 180° from each other. The specimens' location was to be at 1/4t from the surface, but specific orientations of the test specimens were not mentioned in the material test reports presented in Appendix A. [Paragraph N-313.2(d)(4) of the 1965 Edition of ASME Section III Code indicates that Charpy specimens would be oriented "... so that their long axes will be substantially parallel to the direction of major working ..." (i.e., strong direction).]

A specified NDT requirement of 40°F or less and 30 ft-lb CVN at 40°F was required for these nozzle forgings. Based on the searched literature (Appendix B Volume 2 of References 12 and 13), the current requirement for the test specimen to be oriented in the weaker direction came after the AEC proposal in 1969 and the ASME 1972 Summer addenda of Section III.

For the purpose of this report, it is not important to know the specific fracture toughness requirements involved in the purchasing of the nozzles. However, the only item of importance is to note that for the purpose of this report, it will conservatively be assumed that all impact testing at the mill was performed in the stronger direction. The forging process for nozzles is complex and specifying the limiting test orientation is difficult. Testing is typically performed on prolongations to the forging blank.

The fracture toughness requirements were rapidly evolving in the early 1970's by AEC (presently NRC), WRC/PVRC, and ASME. Detailed discussion is presented in References 12 and 13. Clearly, when the subject nozzle forging materials were procured, the upper-shelf energy (USE) requirements were not required, and therefore, were not incorporated for the procurement. Therefore, the first task performed by Altran was to conservatively estimate pre-irradiated USE values based on the literature search.

3.2 Estimation of Pre-Irradiated USE Value

An estimation of pre-irradiated USE value becomes essential since the nozzle forging material is not part of the CP&L surveillance test program [11] and therefore, prediction of end-of-life (EOL) USE values based on surveillance test program would not be feasible. Moreover, as explained later, more precise models of the J integral fracture toughness (J-R) estimation are based on pre-irradiated USE values.

The following two data bases were used to estimate the pre-irradiated USE value of the N-16 nozzles:

(i) Irradiated Nuclear Pressure Vessel Steel Database, EPRI Reports NP-2428 and NP-4797 [16, 17].

(ii) Reactor vessel integrity database Version 1.1 by NRC, published in July 1995 [14]

The average Charpy values for Units 1 and 2 are 38 and 114 ft-lb respectively. Based on the significant differences in the Charpy impact values taken at 40°F, it seems that the Unit 1 specimens may have been oriented in the weaker and less ductile direction. Sulfide inclusions and other impurities in the area where the test specimen were taken may also be a major influence on the impact properties.

For the purpose of this report/activity, the Brunswick Unit 1 nozzle materials shall be considered limiting for the two vessels. Thus, the Brunswick Unit 1 nozzle properties will be conservatively used to project/estimate upper-shelf energy for the N-16 nozzles in both units.

3.3 EPRI Database

The data tabulated in Table 3-3 data are from Reference 17. It should be noted that upper-shelf CVN values and CVN values at 40°F are approximate values based on the curve-fit model approximation presented in Ref. 17.

As it was expected, it is evident that the CVN value in the transverse direction (T-L) is typically significantly lower than the CVN value in the longitudinal direction (L-T) for the same heat of material.

Comparing data in Table 3-3 for CVN values listed in Nos. 6 and 7, 8 and 9, 12 and 13, 15 and 16, 17 and 18, 19 and 20, 21 and 22, and 23 and 24 indicates that the CVN values for the transverse direction are up to 65% lower than the longitudinal CVN values for the same heat of material. Hence, it can be hypothesized that low CVN values observed for Brunswick Unit 1 are perhaps due to transverse orientation of test specimens.

All the data included in Table 3-3 are based on full CVN curves taken at multiple temperatures to fully establish upper shelf energy levels. The lowest four USE values observed are for data sets Nos. 6, 9, 17, and 19. These four sets are in the transverse direction. Their average CVN at 40°F is 31.25 ft-lb and average USE is 83.75 ft-lb. The average CVN at 40°F for Brunswick Unit 1 is 38 ft-lb, and therefore, the average pre-irradiated USE can be estimated to be at least 83.75 ft-lb or higher. Conservatively, it will be assumed that the initial USE of (the Brunswick) N-16 nozzles is the same as the lowest observed in the database which is 70 ft-lb.

3.4 NRC - Reactor Vessel Integrity Database [14]

Based upon the NRC staff review of licensee responses to Generic Letter (GL) 92-01, Rev. 1 [18], a comprehensive database, the Reactor Vessel Integrity Database (RVID), has been developed by the NRC which summarizes the materials properties of the reactor vessel beltline materials for each operating commercial nuclear power plant. The programming logic used for calculations in the RVID follows Regulatory Guide 1.99, Rev. 2 [19].

The RVID includes four tables for each plant: (1) background information table, (2) chemistry data table, (3) upper-shelf energy table, and (4) pressure-temperature limits or pressurized thermal shock table. References and notes follow each table documenting the source(s) of data to provide supplemental information.

Table 3-4 is prepared from the RVID Summary File for Upper Shelf Energy. The Table 3-5 from Ref. 14 describes the NRC method of determining the irradiated upper-shelf energy. Both databases presented in Tables 3-3 and 3-4 have many common heats of materials. It should be noted that the USE values reported in the database presented in Table 3-3 are direct measured values. Table 3-4 is a more extensive database and includes many USE data derived from various methods. Performing a detailed comparison and evaluating the methodology used to derive USE in both tables would be beyond the work scope of this project. However, the lowest pre-irradiated USE value reported in both of the tables is 70 ft-lbs.

3.5 Prediction of End-of-Life Upper-Shelf Energy

As discussed earlier, 10CFR50, Appendix G, requires that "reactor vessel beltline materials must have Charpy upper-shelf energy of no less than 75 ft-lb initially and must maintain upper-shelf energy throughout the life of the vessel of no less than 50 ft-lb unless an equivalent safety margin analysis is performed". The analysis requirements are discussed in detail in Section 4. The office of the Nuclear Regulatory Research of the NRC has published Regulatory Guides 1.99 and 1.161 [19, 20] to assist utilities in order to comply with this requirement.

N-16A/B nozzle forgings are relatively small components, and the Brunswick reactor vessel surveillance test programs do not contain specimens for the N-16 nozzle materials. Therefore, Regulatory Guide 1.99, Rev. 2, will be used to predict the end-of-life upper-shelf energy of the N-16 nozzles. Reference 21 provided neutron exposure projections at the inner radius of the reactor pressure vessel. The peak vessel 32 effective full power years (EFPY) maximum neutron exposure ($E > 1.0$ MeV) is 1.39e + 18, which is also maximum at 45° azimuthal location in the upper shell.[1] (See **Note** on Page 3-4A.)

The copper content from Ref. 11 is 0.16%. Based on the given fluence and copper content, the predicted decrease in USE is approximately 16% [Reg. Guide 1.99, Rev. 2].

The postulated flaw that will be addressed in Section 4 has a depth of 1/4 t. The fluence at this location will be lower than that at the vessel inside surface.

Three separate conservative assumptions will be made:

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[1] Based on the comments on the draft copy of this report by CP&L, the N-16 nozzles actually lag this peak vessel fluence by a factor of approximately 2.5.

(1) The end-of-life fluence used in this report for the N-16 nozzles is 15% more than the predicted maximum vessel beltline value of 1.39e + 18. (Nozzles actually lag the peak vessel fluence by a factor of approximately 2.5.)

(2) The fluence at the crack tip (at 1/4 t) is the same as that for the inside surface.

(3) The decrease in USE for 1.6e + 18 fluence level is approximately 18%.

Now it is conservatively assumed that the N-16 nozzles have the lowest pre-irradiated USE of 70 ft-lb observed for A-508 Class 2 material tabulated in Tables 3-3 and 3-4.

After a reduction of 18% in USE, the end-of-life predicted USE would be 57.4 ft-lb. Therefore, the 10CFR50, Appendix G, 50 ft-lb screening criteria will be met. As such, no equivalent margin analysis needs to be performed. However, the analysis is performed in this report for further proof of sufficient margin of safety against fracture.

Note:

At the time of preparing the calculations supporting this report, fluence projection data from Ref. 21 was used in which the 32 EFPY maximum fluence projection was 1.39E18 for the vessel peak location (N-16 nozzles fluence lags vessel peak location by a factor of approximately 2.5). However, the latest available fluence data for the N-16 nozzles is presented in the following table from Ref. 28, based upon recently acquired Brunswick Unit 2 surveillance results.

	Fluence 32 efpy (EOL)		Fluence 52 efpy (EOL+20)	
		x 1.15		x 1.15
Unit 1	5.42E17	6.23E17	8.69E17	9.99E17
Unit 2	6.08E17	6.99E17	9.88E17	1.34E18

Based on the above information, the 32 EFPY (EOL) maximum N-16 fluence projection for Unit 2 is 6.99E17 and for 52 EFPY (EOL + 20 years) is 1.34E18, including 15% margin. The fluence value used in the analysis presented in Sections 5.0 and 6.0 is 1.6E18 (1.39E18 + 15%), which is very conservative when compared to the actual 32 EFPY and 52 EFPY fluence projections for the N-16 nozzles.

Table 3-1 - Brunswick Unit No. 1
N-16 Nozzle Test Data Summary [10, 11]

Product Identification Numbers

Nozzle	Piece No.	Heat No.	Forging No.
N-16A	302	Q2Q1VW	247P-4A
N-16B	302	Q2Q1VW	247P-4B

Chemistry

C	Mn	P	S	Cu	Si	Ni	Mo	
0.21	0.75	0.01	0.015	0.16*	0.23	0.80	0.69	Ladle
0.219	0.63	0.006	0.025	N/R	0.24	0.84	0.72	Check

* From Product Analysis

Tensile Properties

Slab No.	Yield Strength	Ultimate Strength	Elongation
0°	78.0 ksi	97.25 ksi	21.0%
180°	73.0 ksi	94.5 ksi	20.0%

Fracture Toughness Properties

Plates	Drop Weight NDTT	Charpy Test Valves	Temperature Test
0°	+40°F	38, 39, 41 ft-lb	40°F
180°	+40°F	31, 35, 44 ft-lb	40°F

Table 3-2 - Brunswick Unit No. 2
N-16 Nozzle Test Data Summary [10, 11]

Product Identification Numbers

Nozzle	Piece No.	Heat No.	Forging No.
N-16A	302	Q2Q1VW	247P-3A
N-16B	302	Q2Q1VW	247P-3B

Chemistry

C	Mn	P	S	Cu	Si	Ni	Mo	
0.21	0.75	~0.01	0.015	0.16*	0.23	0.80	0.69	Ladle
0.16	0.71	0.006	0.013	N/R	0.24	0.81	0.60	Check

* From Product Analysis

Tensile Properties

Slab No.	Yield Strength	Ultimate Strength	Elongation
0°	69.00 ksi	88.65 ksi	22.5%
180°	69.75 ksi	88.50 ksi	24.5%

Fracture Toughness Properties

Plates	Drop Weight NDTT	Charpy Test Valves	Temperature Test
0°	+40°F	116, 110,112 ft-lb	40°F
180°	+40°F	133, 74, 141 ft-lb	40°F

Table 3-3 - A508-Class 2 Material Pre-Irradiated CVN Data [17]

No.	Plant	Heat No.	Charpy Test Direction	CVN @ 40°F (ft-lb)	CVN @ USE (ft-lb)	Page No. From Ref. 17
1	Turkey Point 4	122S180-VA1	L-T	85	130	53-12
2	Turkey Point 4	123P481-VA1	L-T	55	143	53-9
3	Turkey Point 3	123P461-VA1	L-T	115	150	52-8
4	Turkey Point 3	123S266-VA1	L-T	110	165	52-9
5	Watts Bar 1	527536	L-T	65	135	54-5
6	Sequoyah 1	980919/28158	T-L	35	70	44 -8
7	Sequoyah 1	980919/28158	L-T	80	120	44-7
8	Sequoyah 2	288757/98105	L-T	90	140	45-6
9	Sequoyah 2	288757/98105	T-L	40	100	45-7
10	Point Beach 2	122W195-VA1	L-T	90	165	34-11
11	Point Beach 2	123V500-VA1	L-T	110	180	34-10
12	Oconee 3	522314K	T-L	50	110	30-14
13	Oconee 3	522314K	L-T	85	155	30-13
14	Oconee 3	522194	T-L	75	140	30-10
15	Oconee 2	3P2359	L-T	95	145	29-8
16	Oconee 2	3P2359	T-L	80	130	29-9
17	North Anna 2	990496/29242	T-L	25	75	27-7
18	North Anna 2	990496/29242	L-T	70	125	27-6
19	North Anna 1	990400/29233	T-L	25	90	26-7
20	North Anna 1	990400/29233	L-T	70	130	26-6
21	Kewaunee	123X167-VA1	T-L	125	165	21-15
22	Kewaunee	123X167-VA1	L-T	120	160	21-14
23	Kewaunee	122X208-VA1	T-L	65	145	21-11
24	Kewaunee	122X208-VA1	L-T	70	165	21-10
25	R.E. Ginna 1	125S255-VA1	L-T	80	170	17-12
26	R.E. Ginna 1	125P666-VA1	L-T	100	185	17-9

Table 3-4 - Summary A-508 Class 2 Material Upper Shelf Energy From NRC Database RVID [14]

No.	Plant	Heat No.	Unirradiated USE (ft-lb)	Method
1	Arkansas 1	AYN 131	109	Generic
2	Braidwood 1	5P-7016	162	Direct
3	Byron 1	123J218	138	Direct
4	Byron 1	5P-5933	138	Direct
5	Byron 1	5P-5951	150	Direct
6	Byron 2	49D329-1-1	149	Direct
7	Byron 2	49D330-1-1	127	Direct
8	Byron 2	4P-6107	155	Direct
9	Catawba 1	411343	134	Direct
10	Catawba 1	527708	134	Direct
11	Crystal River 3	AZJ94	109	Generic
12	Davis Besse	123X244	140	Direct
13	Davis-Besse	123317	132	Direct
14	Davis-Besse	5P4086	122	Direct
15	R.E. Ginna	125P666VA1	114	65%
16	R.E. Ginna	125S255VA1	91	65%
17	Kewaunee	122X208VA1	92	65%
18	Kewaunee	123X167VA1	97	65%
19	McGuire 2	411337-11	97	65%
20	McGuire 2	526840	100	Direct
21	North Anna 1	990286	75	Generic
22	North Anna 1	990311	92	Direct
23	North Anna 2	990496	74	Direct
24	North Anna 2	990533	80	Direct
25	North Anna	990598	74	Direct
26	Oconee 1	AHR54	109	Generic

Table 3-4 (Cont.)

No.	Plant	Heat No.	Unirradiated USE (ft-lb)	Method
27	Oconee 2	AAW-163	133	Direct
28	Oconee 2	AMX-77	109	Generic
29	Oconee 2	AWG-164	138	Direct
30	Oconee 3	AG-4680	109	Generic
31	Oconee 3	ANK-191	144	Direct
32	Oconee 3	AWS-192	112	Direct
33	Point Beach 1	122P237VA1	78	65%
34	Point Beach 2	122W195VA1	94	65%
35	Point Beach 2	123V352VA1	78	65%
36	Point Beach 2	123V500VA1	117	65%
37	Sequoyah 1	980807	74	65%
38	Sequoyah 1	980919	72	Direct
39	Sequoyah 2	990469	100	65%
40	Sequoyah 2	288757	88	Direct
41	Surry 1	122V109VA1	83	65%
42	Surry 2	123V303VA1	104	65%
43	TMI 1	ARY 059	109	Generic
44	Turkey Point 4	122S180VA1	86	65%
45	Turkey Point 4	123P481VA1	88	65%
46	Turkey Point 4	124S309	103	65%
47	Watts Bar 1	528522	111	65%
48	Zion 1	ANA102	87	65%
49	Zion 2	ZV3855	109	Generic

Direct--For plates, this indicates that the unirradiated USE was from a transverse specimen. For welds, this indicates that the unirradiated USE was from test data.

65%--This indicates that the unirradiated USE was 65% of the USE from a longitudinal specimen.

Generic--This indicates that the unirradiated USE was reported by the licensee from other plants with similar materials to the beltline material.

NRC Generi-NRC Generic indicates that the unirradiated USE was derived by the staff from other plants with similar materials to the beltline material.

10, 30, 40, or 50 o F--This indicates that the unirradiated USE was derived from Charpy tests conducted at 10, 30, 40 or 50 o F.

Surv Weld--This indicates that the unirradiated USE was from the surveillance weld having the same weld wire heat number.

Sister Plant--This indicates that the unirradiated USE was derived by using the reported value from other plant(s) with the same weld wire heat number.

EMA--This indicates that an unirradiated USE is unnecessary because the licensee has satisfied the upper-shelf energy requirements of Appendix G, 10 CFR Part 50, through an equivalent margins analysis.

Table 3-5

NRC Method of Determining USE [14]

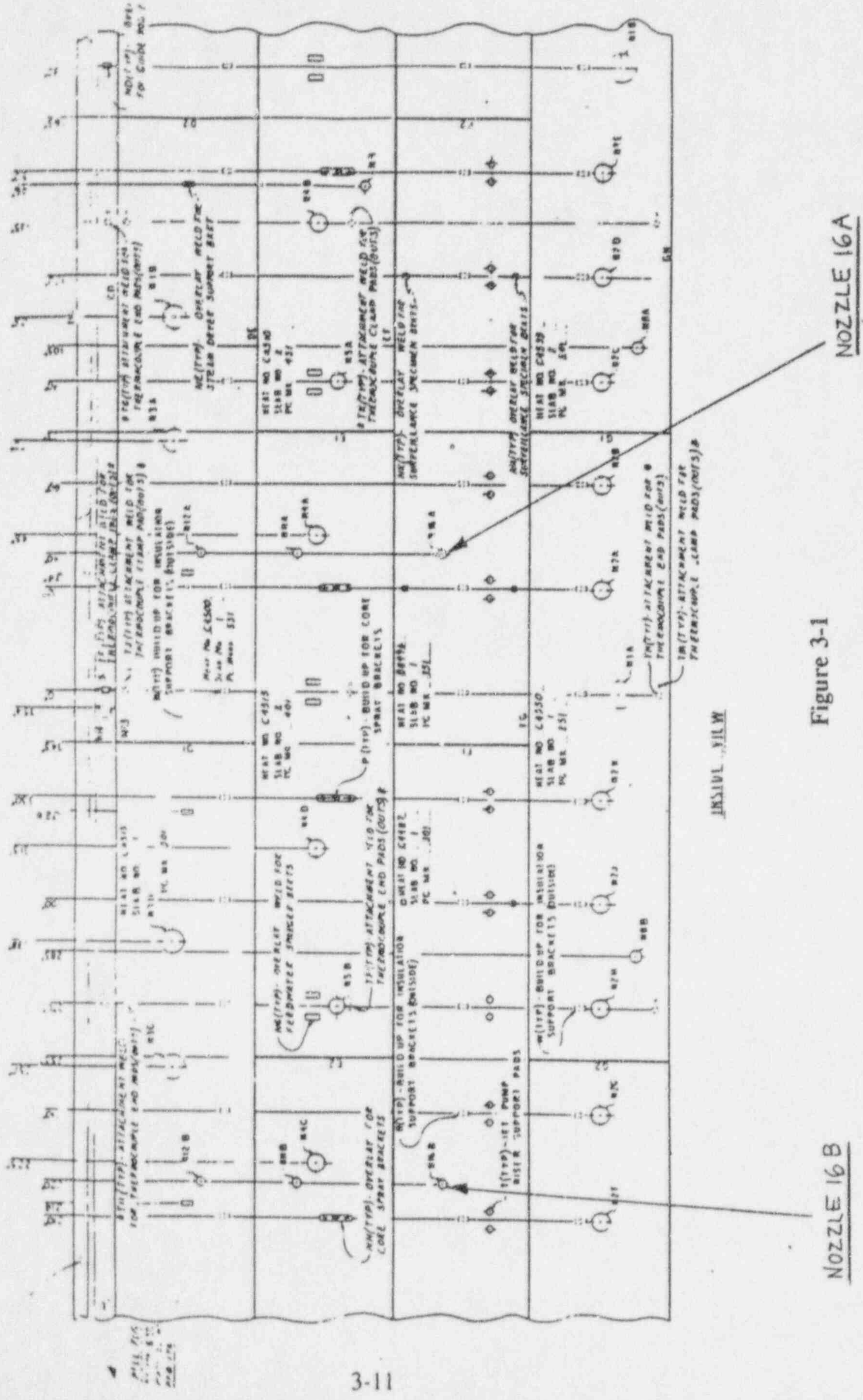

Figure 3-1

Location of N-16 Nozzles

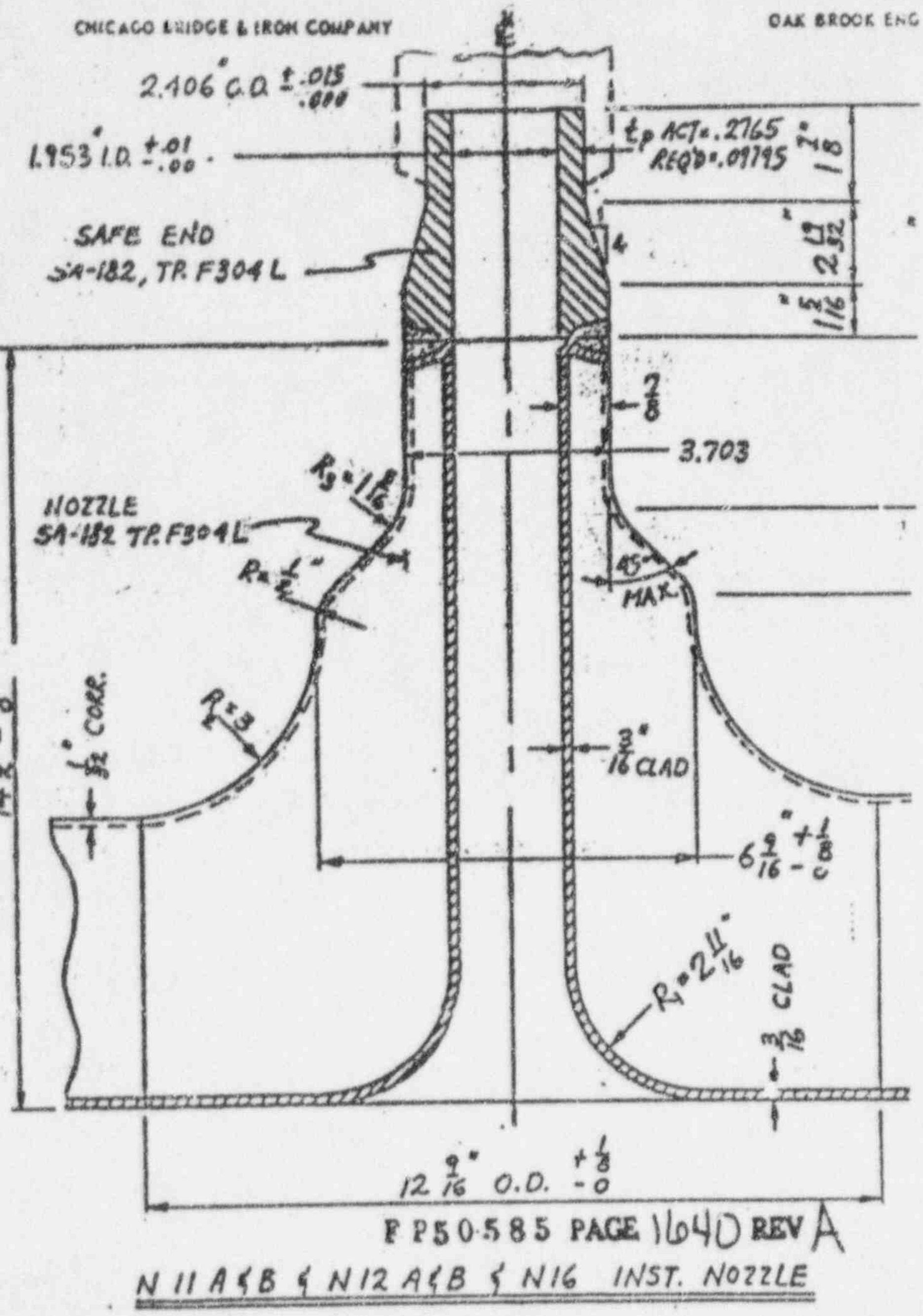

Figure 3-2

N-16 Nozzle Geometry [9]

4.0 ACCEPTANCE CRITERIA

There are numerous reports which present equivalent safety margin analysis methodology to meet 10CFR50, Appendix G requirements, however, the basic criteria are similar to those presented in ASME Section III, Appendix K. The major documents reviewed for determining the methodology for this project are in References 12, 20, 22, 23, and 24.

The acceptance criteria used in this report are those prescribed in ASME Section XI, Appendix K [2].

Criterion 1

$J = J_R$

Where J is the J-integral due to applied loads for the postulated flaw in the vessel and J_R is the J-integral resistance to ductile tearing for the material.

Criterion 2

$$\frac{\partial J}{\partial A} < \frac{dJ_R}{da}$$

This criterion assu[illegible] a stable flaw extension requiring an increasing load as long as $\partial J/\partial a$ remains less than dJ_R/da.

These criterion for Level A, B, C, and D service conditions are similar except Level C and Level D service loadings permit small initial flaw. Also no added safety factors on pressure loadings are required. These differences will be discussed in Section 7.0.

The evaluation of Level A and B loadings in Appendix K required J-integral evaluation at a pressure 1.15 times the accumulation pressure. Regulatory Guide 1.161 stipulates that a pressure 1.1 times the design pressure may be used for the maximum accumulation pressure for Level A and B loadings.

All referenced methodology documents [12, 20, 22, 23, 24] present evaluation of low CVN beltline material for the straight cylindrical geometry. The software and the equations presented in these documents would not be applicable for the nozzle geometry. Also, ASME Section III, Appendix K does not present any guidelines for the selection of J_R material properties or the details on the transients selection. This N-16 nozzles evaluation report heavily draws from the Reg. Guide 1.161 [20], NUREG/CR-6023 [22], and NUREG/CR-5729 [24] for transient selection, material properties selection, and the overall methodology.

5.0 J_R FRACTURE TOUGHNESS MATERIAL PROPERTIES

Appendix K of Section XI does not provide any guidelines for determining the J-integral fracture resistance of the beltline region material for which no archive or surveillance material test data exist. In some cases, archive material of the material in question may exist. However, by conservatively bounding J_R properties in the analysis, if it can be shown that the Appendix K requirements can be met, then the material specific testing would not be necessary.

NUREG/CR-5759 [24] is an industry accepted source of pressure vessel and piping J_R data. Multi-variable models presented in this document predict J_R curves from available data, such as material chemistry, radiation exposure, temperature, and Charpy V-notch energy. Separate models are fitted for different material groups, including reactor pressure vessel welds, Linde 80 welds, base metals, piping welds, piping base metals, and a combined materials group. These different types of models were considered each involving different variables: a Charpy model, a pre-irradiation model, and a copper-fluence model. In general, the best results were obtained with the pre-irradiation Charpy model, using pre-irradiation Charpy impact energy, temperature, and the fluence. Extensive details of each type of model for each type of material category are provided in NUREG/CR-5729.

After a detailed review of the guidelines provided in Reg. Guide 1.161 and a review of all of J_R models in NUREG/CR-5729, a pre-irradiation Charpy model was selected for the subject nozzle forgings. The selected model is from the RPV base metals database that is made up of J_R curves and selected material and specimen data from 144 irradiated and un-irradiated test specimens of A508 and A533 base metals. The model is presented in Table 5-1.

For this evaluation purpose, a very conservative pre-irradiated CVN_P[2] was assumed (35, 40, 45, and 55 ft-lb). Also, the crack tip temperature was conservatively assumed to be 550°F. The end of life fluence value was conservatively assumed to be 15% higher than the predicted peak vessel location value 1.39e + 18 = 1.6e + 18 n/cm^2 [21]. The resultant values of J_R for different crack extensions (0.02, 0.05, 0.1, 0.15, 0.2, 0.25, 0.3, 0.35, and 0.4 inch) and different pre-irradiated CVN_P are presented in Appendix B. The EOL J_R curves for 0.1 inch crack extension required for Criterion 1 are shown in Figure 7-1.

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[2] CVN_P is the pre-irradiated upper shelf energy (USE) of the material.

Table 5-1

RPV Base Metal Pre-Irradiated CVN_p Model [24]

$$J = C1\ (\Delta a)^{C2} \exp\ [C3(\Delta a)^{C4}]$$

Where:
$lnC1 = a_1 + a_2\ ln\ CVN_p + a_3\ T + a_5\ \varnothing t$
$C2 = d_1 + d_2\ lnC1$
$C3 = d_4 + d_5\ lnC1$
$C4 = -0.408$

Where:
J = J-integral of material (kip-in/in^2) (end of life irradiated)
Δa = Crack extension (in)
CVN_p = Pre-irradiated Charpy impact energy (ft-lb)
T = Crack tip temperature (°F)
$\varnothing t$ = Fluence (10^{18}n/cm^2) (E > 1MeV)

Fitting Constants

a_1 = -2.53	d_1 = 0.077
a_2 = 1.15	d_2 = 0.116
a_3 = -0.0027	d_4 = -0.0812
a_5 = -0.0104	d_5 = -0.0092

And, $J_R = MF \bullet J$

Where margin factor MF = 0.749 for Service Levels A and B [20]
MF = 1.0 for Service Levels C and D [20]

6.0 ANALYSIS METHODS

The analysis methods used in this evaluation are similar to those proposed in Reg. Guide 1.161, NUREG/CR-6023, and ASME Section III, Appendix K. The major difference is that all these documents present methods for cylindrical geometry, whereas the subject evaluation is for a nozzle geometry. Necessary changes were made in the applied J-integral evaluation. The basic approach is similar to those proposed in these documents.

6.1 Levels A and B Conditions

The earlier efforts organized by the BWR Owner's Group through GE Nuclear Energy performed similar evaluation for BWR cylindrical vessel shell materials which is presented in Ref. [25]. This effort concluded that the application of maximum accumulation pressure in conjunction with 100°F/hour cooldown rate will bound all Level A and B conditions. Reference 25 addresses the loss of feedwater pump transient and concludes that even though this is a significant thermal transient, the accompanying pressure is low. Therefore, the maximum accumulation pressure as 1.1 times the design pressure and 100°F/hr. cooldown, will bound conditions for Levels A and B loadings.

6.2 Analysis Input Data

All the work performed earlier on these nozzles was carefully reviewed, and the following data were selected for this analysis. References are listed next to the data.

- Design Pressure = 1250 psi [9, 21/S11]
- Design Temperature = 575°F [9, 2/S11]
- Accumulation Pressure = 1.1(1250) = 1375 psi
- At ¼t depth, the K_{It} due to the thermal transient is approximately 5.4 ksi$\sqrt{in}$. The steady state dt between the ¼t depth and the inside surface is 9.53°F. [Page 2/8 of Ref. 3]
- From Page 7/19 of Ref. 4, the stress intensity factor solution for a corner crack in a nozzle is shown in Table 6-1.
- σ_y at ¼t due to 1000 psi pressure is 22.83 ksi (A6/A10, Ref. 4). (Stress at the crack tip.)

6.3 Applied J-Integral for Level A and B Conditions

The basic method is similar to those discussed in Reg. Guide 1.161 and NUREG/CR-6023 which is briefly summarized in the following steps.

Step 1 - Pressure Stress Intensity Factor

For a nozzle corner crack with depth 'a' equal to (0.25t + 0.1 inch), calculate the stress intensity factor from an internal pressure Pa equal to maximum accumulation pressure with a safety factor, SF, on pressure equal to 1.15.

The pressure stress intensity factors were derived using two different methods; using the method presented in Table 6-1, and second method using the approach presented in WRC-175 [26]. The results are presented in Tables 6-2 and 6-3. Results from both methods are very similar. In order to be consistent with the earlier work on this nozzle, Table 6-1 methods will be used in this report for analyzing K_{IP} due to pressure.

Step 2 - Thermal Stress Intensity Factor

For a flaw with depth 'a' equal to (0.25t + 0.1 in), the steady state (time independent) stress intensity factor from radial thermal gradient is obtained by using the following equation from Reg. Guide 1.161.

$$K_{It} = ((CR)/1000)t^{2.5}\,F_3$$

$$F_3 = 0.69 + 3.127\,(a/t) - 7.435\,(a/t)^2 + 3.532\,(a/t)^3 \quad \text{[Eq. 8, Ref. 20]}$$

This equation for K_{It} is valid for $0.2 \leq a/t \leq 0.5$ and $0 \leq CR \leq 100$°F/hour.

It should be noted that the above equation is for thermal stresses in a cylindrical shell. The earlier efforts presented in Ref. 3 determined K_{It} to be approximately 5.4 ksi$\sqrt{in}$. at the ¼t depth in the nozzle corner flaw. The Reg. Guide 1.161 equation, presented above, results in approximately 8.4 ksi$\sqrt{in}$. For conservatism, Reg. Guide 1.161 formula for K_{It} will be used in this report.

Step 3 - Calculation of Effective Flaw Depth

Calculate the effective flaw depth for small scale yielding using the following equation:

$$a_e = a + \left(\frac{1}{6\pi}\right)\left[\frac{(K_{IP} + K_{It})}{\sigma_y}\right]^2$$

Where σ_y is equal to the material yield stress.

Step 4 - Revised Stress Intensity Factors

Based on the revised flaw depth a_e, reanalyze K_{IP} and K_{It} and define them as K'_{IP} and K'_{It}.

Step 5 - Calculate Applied J-Integral

The applied J-integral from the applied loads for small scale yielding is given by the following equation:

$$J_{applied} = 1000(K'_{IP} + K'_{It})^2/E'$$

Where $E' = E/(1-\upsilon^2)$ is the modified modulus of elasticity.

Step 6 - Comparison of $J_{applied}$ and Material J-R Fracture Toughness (Criterion 1)

Appendix K of ASME Section XI requires that:

$$J_{applied} < J_{0.1}$$

Where $J_{0.1}$ = the J-integral fracture toughness at a ductile flaw extension of 0.1 inch.

As discussed in Section 5, Appendix C presents J-integral fracture toughness of the nozzle material for different initial upper shelf energy CVN_P values and different crack extension lengths.

$J_{applied}$ value is obtained from Step 5.

6.4 Evaluation of Flaw Stability (Criterion 2) .

For these evaluations, the postulated flaw must be stable under ductile crack growth which is presented by the following equation.

$$\frac{\partial J_{applied}}{\partial a} < \frac{\partial J_{material}}{\partial a}$$

With load held constant and at $J_{applied} = J_{material}$.

The applied J-integral is calculated for a series of flaw depths corresponding to increasing amounts of ductile flaw growth. The applied pressure, P, is set equal to the maximum accumulated pressure for Service Level A and B conditions, P_a, with a safety factor, SF, equal to 1.25. The applied J-integral for Service Level A and B conditions may be calculated using steps shown in 6.3. Each pair of the applied J-integral and flaw depth

is plotted on a crack driving force diagram to produce the applied J-integral curve as illustrated in Figure 6-1. The material's J-R curve also is plotted on the crack driving force diagram. Flaw stability is confirmed if the slope of the applied J-integral curve is less than the slope of the material's J-R curve at the equilibrium point on the J-R curve where the two curves intersect [22].

Appendix K of ASME Section XI presents two other alternate criteria for a postulated initial flaw depth of one-quarter of the wall thickness which is not used in this evaluation.

6.5 Level C and D Conditions

Appendix K of ASME Section XI provides the following guidelines for Level C loadings.

- The postulated flaw depth may be up to 1/10 of the base metal wall thickness, plus the cladding thickness, with total depth not exceeding 1.0 inch, and surface length six times the depth.

- Use a factor of safety of 1.0 on loading for both criteria.

Based on a telecon [27] with cognizant CP&L staff, there are no applicable Level D conditions (pressure-temperature transients) for the subject nozzle.

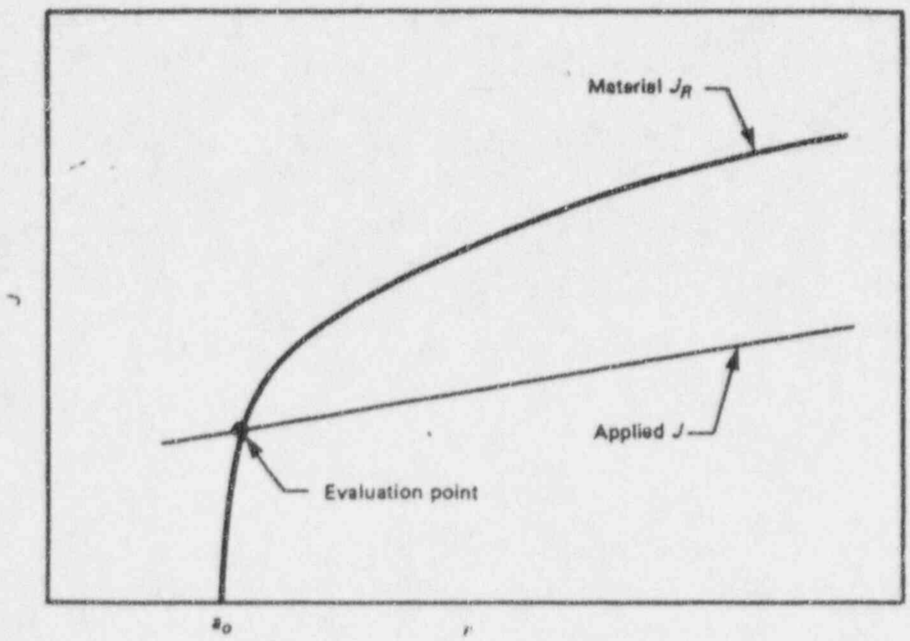

Figure 6-1 [2]

Example Comparison of the Slope of the Applied J-Integral and J-R Curve

Table 6-1

Stress Intensity Factor solution for a Corner Crack in a Nozzle [4, 48/A-10]

Stress Polynomial Coefficient

$A_0 := 54512$

$A_1 := -284300$

$A_2 := 804120$

$A_3 := -775260$

shell Thickness $t := 5.5625 \cdot in$

Pressure $P := 1000 \cdot psi$

Flaw depth $a := 0.25 \cdot t$

$a = 1.391 \cdot in$

$$K_I := \frac{P}{1000} \cdot \sqrt{\pi \cdot a} \cdot \left[0.706 \cdot A_0 + 0.537 \cdot \left(2 \cdot \frac{\frac{a}{t}}{\pi} \right) \cdot A_1 + 0.448 \cdot \left[\frac{\left(\frac{a}{t}\right)^2}{2 \cdot \pi} \cdot 3 \right] \cdot A_2 + 0.393 \cdot \left[4 \cdot \frac{\left(\frac{a}{t}\right)^3}{3 \cdot \pi} \right] \cdot A_3 \right]$$

The stress intensity factor due to 1000 psi for a nozzle corner flaw with a depth a = 1/4*t

$K_I = 47.901 \cdot ksi \cdot \sqrt{in}$

Note: This Table illustrates only the derivation of the stress intensity factor due to pressure. No results are used from this Table.

NOTE: Note that the evaluation in this report uses 5.5 in. as the nominal vessel thickness, whereas, the nominal thickness is 5.625 inches. In the above K1 evaluation, the K1 value for the 5.5 in. thickness will be 47.631 ksi*in$^{1/2}$. The resultant error is less than 1%. Considering the numerous conservatism incorporated in this evaluation, the error introduced due to the assumption of 5.5 in. as the nominal vessel thickness is negligible.

Table 6-2
Stress Intensity Factor Due to Pressure
(Results)

(GE Approach)

Sheli Thickness	t = 5.5 in
Clad Thckness	=3/16 in
Vessel Thickness for Analysis	t'=5.6875 in
Design Pressure	p=1250 psi
Accumulation Pressure	Pa = 1.1(p) = 1375 psi
Crack Extension	da = 0.1 in
Flaw depth	=%(t) + 0.1 in

Vessel Thckness (inch) t	Flaw Depth % of t	Flaw Depth (inch) a	a/t	Pressure (psi)	Stress Intensity Factor Kip psi*in^1/2
5.6875	10	0.669	0.12	1375	58250
5.6875	15	0.953	0.17	1375	62865
5.6875	20	1.238	0.22	1375	65476
5.6875	25	1.522	0.27	1375	67100
5.6875	30	1.806	0.32	1375	68216
5.6875	35	2.091	0.37	1375	68993
5.6875	40	2.375	0.42	1375	69402

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Table 6-3
Stress Intensity Factor Due to Pressure - WRC 175 Approach

			(WRC-175 Approach)				
Shell Thickness			t = 5.5 in				
Clad Thickness			=3/16 in				
Vessel Thickness for Analysis			t'=5.6875 in				
Design Pressure			p=1250 psi				
Accumulation Pressure			Pa = 1.1(p) = 1375 psi				
Crack Extension			da = 0.1 in				
Flaw depth			=%(t) + 0.1 in				
Vessel Radius			110.5				
Hoop Stress			27625 ps				
Vessel Thckness (inch) t	Flaw Depth % of t	Flaw depth + Cladding (inch) a	Apprant Rad. of Nozzle rn	a/rn	Geometry Factor (WRC175) F(a/rn)	Shell Hoop Stress (psi)	Stress Intensity Factor psi*in^1/2
5.6875	10	0.669	1.943	0.344	1.4	27625	56057
5.6875	15	0.953	1.943	0.491	1.3	27625	59752
5.6875	20	1.238	1.943	0.637	1.2	27625	62638
5.6875	25	1.522	1.943	0.783	1.1	27625	66444
5.6875	30	1.806	1.943	0.930	1.0	27625	65805
5.6875	35	2.091	1.943	1.076	1.0	27625	70796
5.6875	40	2.375	1.943	1.222	1.0	27625	75458

7.0 ANALYSIS RESULTS

As discussed in Section 6.0, two acceptance criteria are evaluated, applied J-integral for a ¼t flaw with an 0.1 inch crack extension, and the flaw stability.

7.1 Level A and B Loadings

Level A and B loadings will be enveloped by the accumulation pressure of 1,375 psi and 100°F/hr. cooldown rate as discussed in 6.1.

Criterion 1 - Equilibrium Equation for Stable Flaw Extension

In Table 6-3, stress intensity factors due to internal pressure using the WRC-175 approach are presented. Assumed flaw depths are from 10% to 40% through wall thickness and as required by Reg. Guide 1.161, the cladding thickness is included in the flaw depth.

Table 6-2 presents pressure stress intensity factors based on the earlier efforts on these nozzles presented in Reference 17. By comparing table 6-2 and 6-3, it is observed that the differences between those two methods are not significant. In order to be consistent with the earlier efforts, the pressure stress intensity factor model presented in Table 6-2 will be used in this report.

As outlined in Section 6.3, Table 7-1 presents the applied J-integral for the prescribed conditions (an accumulation pressure of 1375 psi and a cooldown rate of 100°F/hour). The postulated initial flaw at the nozzle corner radius is ¼ the wall thickness of vessel shell. Applied J-integral for various crack from 0.01 inch to 0.4 inch are presented in Table 7-1.

The J-resistance material fracture toughness for different initial pre-irradiated upper-shelf energy and different crack extensions are presented in Appendix C. Assumed initial upper-shelf energy values (CVN_P) were 35, 40, 45, 50, and 55 ft-lb. J_R was evaluated for crack extensions of 0.01, 0.02, 0.05, 0.1, 0.15, 0.2, 0.25, 0.3, 0.35, and 0.4" for temperature range from 100°F to 650°F. The J_R toughness vs. temperature for an initial crack of ¼t and a crack extension of 0.1 inch is shown in Figure 7-1. The J_R fracture toughness values for different initial USE and different flaw extensions for 550°F are shown in Table 7-3, which is constructed from the data presented in Appendix C.

As presented in Table 7-1, the applied J-integral for 0.1 inch crack extension is 251 inch-lb/in^2. The J_R for an assumed initial upper-shelf energy (CVN_P) of 35 ft-lb and 0.1 inch crack extension at 550°F is 530 inch-lb/in^2. Therefore, the applied J-integral is less than $J_{R(1.1)}$, and Criterion 1 is satisfied. The assumed initial CVN_P of 35 ft-lb used in the analysis/calculation is approximately equivalent to 29 ft-lb EOL USE assuming 18% drop in initial USE as explained earlier.

Criterion 2 - Inequality for Flaw Stability Due to Ductile Tearing

The necessary analyzed data are presented in Table 7-1, Table 7-2, and Appendix C. Figure 7-2 presents J_R values for different flaw extensions and different initial upper-shelf energy (CVN_P) values. Applied J-integral for an initial postulated flaw depth of ¼t with flaw extensions from 0.01 inch to 0.4 inch is also superimposed in Figure 7-2. The only difference between Table 7-1 and 7-2 is the safety factor on pressure. Criterion 1 requires 1.15 safety factor on pressure, whereas Criterion 2 requires 1.25. Figure 7-1 clearly depicts the slope of the applied J-integral is less than the slopes of all the J-R curves at the point on the J-R curves where the two curves intersect.

It is interesting to notice that the increase in the applied J-integral for various crack extensions from an initial flaw of 1.42 inch to 1.82 inch is very small. The primary reason is the existence of significant amounts of throughwall bending due to the pressure stress at the nozzle to shell junction. As the crack extends, the pressure stress intensity factor decreases.

The above evaluation clearly demonstrates that the N-16 nozzles, in spite of a very conservative assumption of an initial upper-shelf energy as low as 35 ft-lb, will meet the equivalent margin analysis requirements of ASME Section XI Appendix K for Level A and B loadings.

7.2 Level C Loading

Based on the telephone conversation with CP&L Staff [27], there are no Level D loadings defined for pressure thermal transients. There is only one pressure-thermal loading for Level C loading. The pressure rises to 1,375 psi and the temperature rises to 600°F. This transient lasts only for a few seconds. In Level A and B loading analyses, the pressure assumed was 1,581 psi (1,250 x 1.1 x 1.15) including safety factor of 1.15, which is more than the Level C pressure of 1,375 psi. Also, during the heat-up, the inside surface stresses will be compressive and will reduce the total stress intensity factor. Therefore, the Level A and B loading presented in 7.1 will envelope Level C loading.

7.3 Conclusion

This evaluation demonstrates that the N-16 nozzles can meet the ASME Section XI Appendix K and Reg. Guide 1.161 J-R fracture toughness requirements with an end-of-life upper-shelf energy as low as 29 ft-lbs. It was shown in Section 3.0 that a 29 ft-lb end-of-life upper-shelf energy would be equivalent to an initial upper-shelf energy of 35 ft-lbs, assuming an 18% drop in USE over vessel life. Based on the material database search, it was demonstrated that the subject nozzle material should have an initial upper shelf energy of at least 70 ft-lbs.

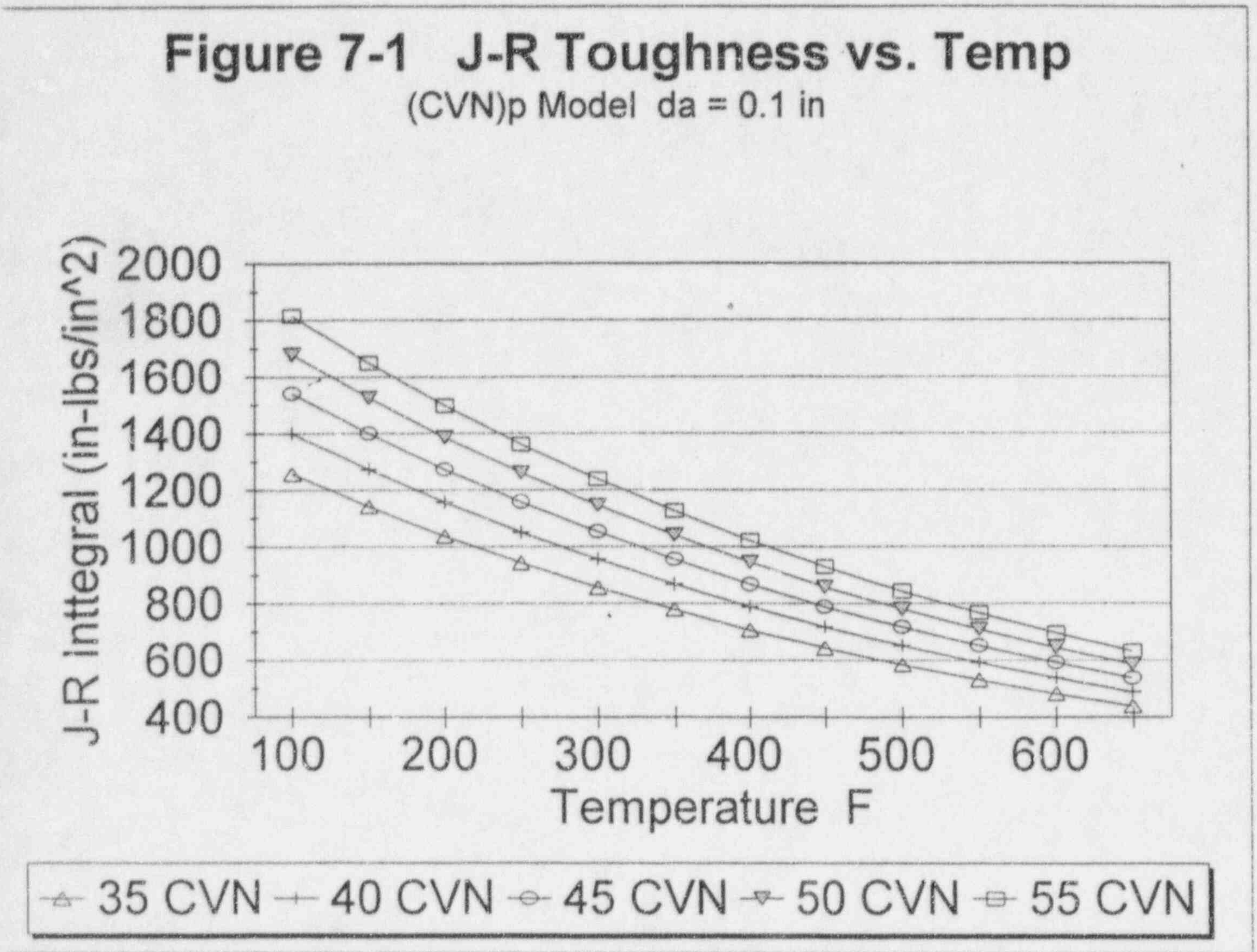
Figure 7-1 J-R Toughness vs. Temp
(CVN)p Model da = 0.1 in
J-R Inttegral (in-lbs/in^2)
2000
1800
1600
1400
1200
1000
800
600
400
100
200
300
400
500
600
Temperature F
35 CVN
40 CVN
45 CVN
50 CVN
55 CVN

Table 7-1

Criterion I - Crack Driving Force vs. Fracture Toughness Evaluation

Input: P=1375*1.15psi, CR = 100 f/hr, SF=1.15 on Kip for Criterion I Evaluation

Stress Intensity Factor Due to Pressure, Initial Flaw Depth 25% of t
(GE Approach)

Vessel Thckness (inch) t	Initial Flaw Depth 25% of t	Flaw Extension (inch) da	Final Flaw Depth (inch) a	Pressure (psi)	Flaw Ratio a/t	Stress Intensity Factor Kip psi*in^1/2
5.6875	1.4219	0.00	1.4219	1582	0.250	76631
5.6875	1.4219	0.01	1.4319	1582	0.252	76692
5.6875	1.4219	0.02	1.4419	1582	0.254	76751
5.6875	1.4219	0.05	1.4719	1582	0.259	76926
5.6875	1.4219	0.10	1.5219	1582	0.268	77202
5.6875	1.4219	0.15	1.5719	1582	0.276	77461
5.6875	1.4219	0.20	1.6219	1582	0.285	77704
5.6875	1.4219	0.25	1.6719	1582	0.294	77933
5.6875	1.4219	0.30	1.7219	1582	0.303	78149
5.6875	1.4219	0.35	1.7719	1582	0.312	78352
5.6875	1.4219	0.40	1.8219	1582	0.320	78544

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Stress Intensity Factor due to Thermal
(Reg. Guide 1.161)

Cooling Rate (CR) F/HR	Shell Thickness t in	Final Flaw Depth (inch) a	Thermal Factor F3	Stress Intensity Factor Kit psi*in^1/2
100	5.6875	1.4219	1.062	8195
100	5.6875	1.4319	1.062	8196
100	5.6875	1.4419	1.062	8196
100	5.6875	1.4719	1.063	8197
100	5.6875	1.5219	1.062	8193
100	5.6875	1.5719	1.061	8184
100	5.6875	1.6219	1.059	8170
100	5.6875	1.6719	1.056	8150
100	5.6875	1.7219	1.053	8125
100	5.6875	1.7719	1.049	8095
100	5.6875	1.8219	1.045	8060

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Table 7-1 (Cont'd)

Criterion I - Crack Driving Force vs. Fracture Toughness Evaluation

J applied Evaluation for Different Crack Extension

Revised Stress Intensity Factor Due to Pressure					Revised Thermal Stress Intensity Factor					J Applied Evaluation			
Vessel Thckness (inch) t	Revised Flaw depth a	a/t	Pressure (psi)	Stress Intensity Factor Kip' psi*in^1/2	Cooling Rate (CR) F/HR	Shell Thickness t in	Revised Flaw Depth a in	Thermal Factor F3	Stress Intensity Factor (Kit)' psi*in^1/2	Modulus of Elasticity E psi	Nu	Modulus of Elasticity E' psi	J Applied psi*in^1/2
5.6875	1.619	0.285	1582	77691	100	5.688	1.619	1.059	8171	2.70E+07	0.3	2.97E+07	248
5.6875	1.629	0.286	1582	77739	100	5.688	1.629	1.059	8167	2.70E+07	0.3	2.97E+07	249
5.6875	1.640	0.288	1582	77787	100	5.688	1.640	1.058	8163	2.70E+07	0.3	2.97E+07	249
5.6875	1.670	0.294	1582	77927	100	5.688	1.670	1.057	8151	2.70E+07	0.3	2.97E+07	250
5.6875	1.722	0.303	1582	78148	100	5.688	1.722	1.053	8125	2.70E+07	0.3	2.97E+07	251
5.6875	1.773	0.312	1582	78356	100	5.688	1.773	1.049	8095	2.70E+07	0.3	2.97E+07	252
5.6875	1.824	0.321	1582	78552	100	5.688	1.824	1.045	8059	2.70E+07	0.3	2.97E+07	253
5.6875	1.875	0.330	1582	78735	100	5.688	1.875	1.039	8018	2.70E+07	0.3	2.97E+07	254
5.6875	1.926	0.339	1582	78906	100	5.688	1.926	1.033	7973	2.70E+07	0.3	2.97E+07	254
5.6875	1.977	0.348	1582	79066	100	5.688	1.977	1.027	7923	2.70E+07	0.3	2.97E+07	255
5.6875	2.027	0.356	1582	79213	100	5.688	2.027	1.020	7868	2.70E+07	0.3	2.97E+07	256

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Table 7-2

Criterion II - Flaw Stability vs. Ductile Crack Growth

Input: P=1375*1.25psi, CR = 100 f/hr, SF=1.25 on Kip for Criterion II Evaluation

Stress Intensity Factor Due to Pressure, Initial Flaw Depth 25% of t
(GE Approach)

Vessel Thckness (inch) t	Initial Flaw Depth 25% of t	Flaw Extension (inch) da	Final Flaw Depth (inch) a	Pressure (psi)	Flaw Ratio a/t	Stress Intensity Factor Kip psi*in^1/2
5.6875	1.4219	0.00	1.4219	1719	0.250	83267
5.6875	1.4219	0.01	1.4319	1719	0.252	83333
5.6875	1.4219	0.02	1.4419	1719	0.254	83398
5.6875	1.4219	0.05	1.4719	1719	0.259	83588
5.6875	1.4219	0.10	1.5219	1719	0.268	83888
5.6875	1.4219	0.15	1.5719	1719	0.276	84169
5.6875	1.4219	0.20	1.6219	1719	0.285	84433
5.6875	1.4219	0.25	1.6719	1719	0.294	84682
5.6875	1.4219	0.30	1.7219	1719	0.303	84916
5.6875	1.4219	0.35	1.7719	1719	0.312	85138
5.6875	1.4219	0.40	1.8219	1719	0.320	85346

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Stress Intensity Factor due to Thermal
(Reg. Guide 1.161)

Cooling Rate (CR) F/HR	Shell Thickness t in	Final Flaw Depth (inch) a	Thermal Factor F3	Stress Intensity Factor Kit psi*in^1/2
100	5.6875	1.4219	1.062	8195
100	5.6875	1.4319	1.062	8196
100	5.6875	1.4419	1.062	8196
100	5.6875	1.4719	1.063	8197
100	5.6875	1.5219	1.062	8193
100	5.6875	1.5719	1.061	8184
100	5.6875	1.6219	1.059	8170
100	5.6875	1.6719	1.056	8150
100	5.6875	1.7219	1.053	8125
100	5.6875	1.7719	1.049	8095
100	5.6875	1.8219	1.045	8060

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Table 7-2 (Cont'd)

Criterion II - Flaw Stability vs. Ductile Crack Growth

J applied Evaluation for Different Crack Extension

Revised Stress Intensity Factor Due to Pressure					Revised Thermal Stress Intensity Factor					J applied Evaluation			
Vessel Thckness (inch) t	Revised Flaw depth a	a/t	Pressure (psi)	Stress Intensity Factor Kip' psi*in^1/2	Cooling Rate (CR) F/HR	Shell Thickness t in	Revised Flaw Depth a in	Thermal Factor F3	Stress Intensity Factor (Kit)' psi*in^1/2	Modulus of Elasticity E psi	Nu	Modulus of Elasticity E' psi	J Applied psi*in^1/2
5.6875	1.651	0.290	1719	84580	100	5.688	1.651	1.058	8159	2.70E+07	0.3	2.97E+07	290
5.6875	1.661	0.292	1719	84631	100	5.688	1.661	1.057	8154	2.70E+07	0.3	2.97E+07	290
5.6875	1.672	0.294	1719	84681	100	5.688	1.672	1.056	8150	2.70E+07	0.3	2.97E+07	290
5.6875	1.703	0.299	1719	84828	100	5.688	1.703	1.055	8135	2.70E+07	0.3	2.97E+07	291
5.6875	1.754	0.308	1719	85061	100	5.688	1.754	1.051	8106	2.70E+07	0.3	2.97E+07	293
5.6875	1.806	0.317	1719	85279	100	5.688	1.806	1.046	8072	2.70E+07	0.3	2.97E+07	294
5.6875	1.857	0.326	1719	85484	100	5.688	1.857	1.041	8033	2.70E+07	0.3	2.97E+07	295
5.6875	1.908	0.335	1719	85676	100	5.688	1.908	1.036	7989	2.70E+07	0.3	2.97E+07	296
5.6875	1.959	0.344	1719	85854	100	5.688	1.959	1.029	7940	2.70E+07	0.3	2.97E+07	297
5.6875	2.010	0.353	1719	86020	100	5.688	2.010	1.022	7887	2.70E+07	0.3	2.97E+07	297
5.6875	2.061	0.362	1719	86172	100	5.688	2.061	1.015	7829	2.70E+07	0.3	2.97E+07	298

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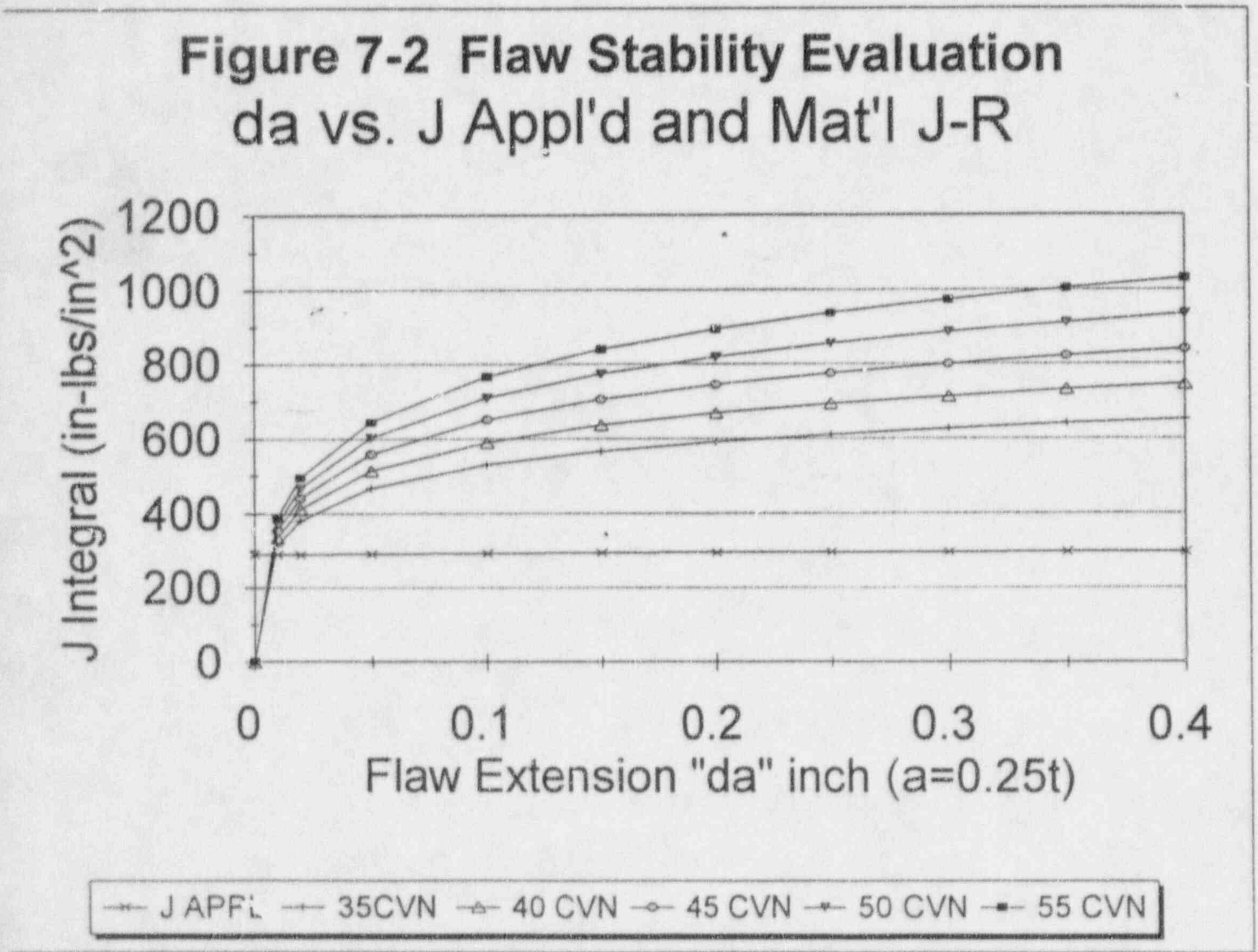
Figure 7-2 Flaw Stability Evaluation
da vs. J Appl'd and Mat'l J-R
J Integral (in-lbs/in^2)
1200
1000
800
600
400
200
0
0
0.1
0.2
0.3
0.4
Flaw Extension "da" inch (a=0.25t)
J APPL
35CVN
40 CVN
45 CVN
50 CVN
55 CVN

Table 7-3

Initial Flaw = 1/4*t , Crack Tip Temperature = 550F

Stability Evaluation - Criterion II

Initial Flaw depth (in) a	Flaw Extension (in) da	J Applied from Table 7-2	J-R for 35 CVN	J-R for 40 CVN	J-R for 45 CVN	J-R for 50 CVN	J-R for 55 CVN
1.422	0.00	290	0	0	0	0	0
1.422	0.01	290	315	335	354	372	389
1.422	0.02	290	381	412	441	468	495
1.422	0.05	291	467	514	559	603	645
1.422	0.10	293	530	591	651	710	767
1.422	0.15	294	567	637	706	774	841
1.422	0.20	295	592	669	745	820	895
1.422	0.25	296	611	694	776	857	938
1.422	0.30	297	627	714	801	887	973
1.422	0.35	297	641	732	822	913	1004
1.422	0.40	298	652	747	841	936	1031

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8.0 FRACTURE TOUGHNESS EVALUATION USING VESSEL

EPRI prepared VESSEL Software Version 6 [23] was also utilized on this project. In all previous discussions, the location of the postulated flaw was at the inner corner radius which is the highest stressed location in the nozzle. The stress at this location can be as high as three times the hoop stress in the vessel shell. The majority of the stress is a bending stress through the nozzle wall thickness, and therefore, as the crack grows deeper, the driving force also decreases.

In this section, a postulated ¼t flaw, as shown in Figure 8-1, is oriented in the axial direction because this is the more critical orientation due to the dominance of the hoop stress compared to axial stress. The VESSEL software computes the pressure at 0.1 inch crack extension, and the J-integral, pressure, and crack extension at the instability of the postulated interior flaw that is either axial or circumferential and has a depth of one-quarter of the well thickness and a length of six times the depth. The calculated pressure can be used to determine if the vessel beltline material has adequate upper shelf toughness to meet the ASME Section XI, Appendix K upper shelf criteria for Service Level A and B conditions.

The following was the input:

Vessel Outer Radius	= 115.8 in.
Vessel Thickness	= 5.5 in.
Cooldown Rate	= 100°F/hr.
Elastic Modulus @ 550°F	= 25,500,500 psi
Flow Stress @ 550°F	= 62,100 psi

The following J_R data was taken from the material evaluation discussed in Section 5.0 and material J_R data presented in Appendix C.

Crack Extension (in.)	J-Actual (in-lb/in^2)
0.02	381
0.05	467
0.10	530
0.15	567
0.20	592
0.25	611
0.30	627
0.35	641
0.40	652

The complete input and output of VESSEL are provided in Appendix D. The summary is provided in Table 8-1 and Figure 8-2.

Criterion 1

At 0.1 in. flaw extension,

J-integral (applied)	= 89 in-lb/sq. in.
J_R material	= 533 in-lb/sq. in.

Since J-Applied < J_R material, Criterion 1 is met.

Also, the pressure at which the flaw would extend by 0.1 inch is 2,228 psi which is higher than the accumulation pressure of 1,375 psi.

Criterion 2

The VESSEL analyzed pressure at instability is 2,266 psi and the limit load analysis based maximum pressure is 2,981 psi. Both of these pressures are higher than 1.25 times the accumulation pressure, and therefore, Criterion 2 is met.

It should be noted that the VESSEL software outputs are in terms of pressures which are then compared with the accumulation pressure. Whereas, in Section 7.0 the analyses were performed directly in terms of J-integral.

NOTE: It should be noted that the VESSEL program results are printed and included in this report for information only. This is not an Altran QA program. No conclusions are drawn from the results of the VESSEL program.

Table 8-1

Results from VESSEL Program

Flaw Extension da (inch)	J -Appl'd in-lb/sq. in	J - Matl in-lb/sq. in	T - Appld	T - Matl	Pressure (psi)
0.229	606	606	2.404	2.402	2266
0.200	125	592	0.494	2.730	2246
0.150	107	568	0.424	3.606	2248
0.100	89	533	0.353	6.000	2228
0.050	71	466	0.263	13.068	2140
0.040	53	444	0.212	16.099	2102
0.030	36	417	0.141	20.248	2050
0.020	18	382	0.070	26.131	1976
0.010	0	337	0.000	34.758	1868

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Table 8-1

Results from VESSEL Program

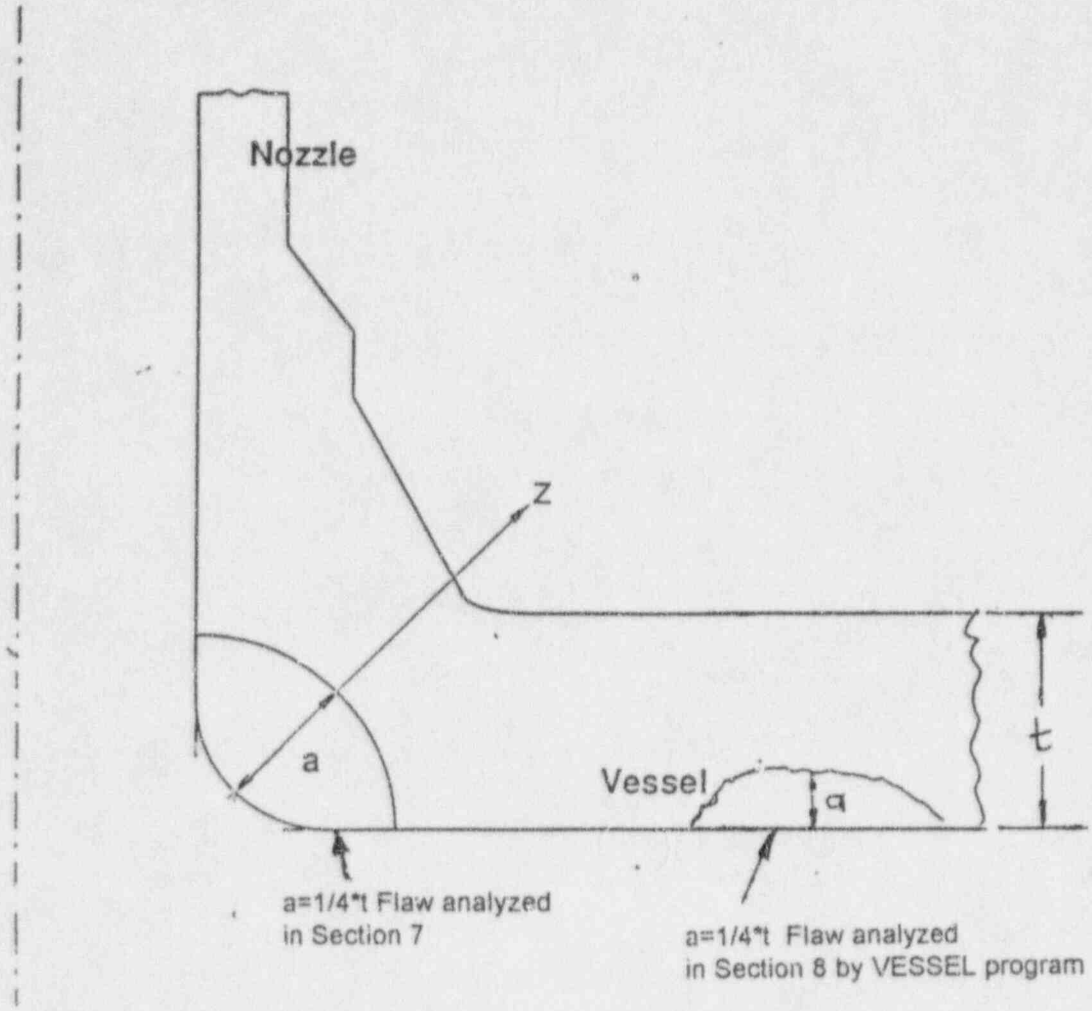

Figure 8-1

Postulated Flaw Geometry for VESSEL Input

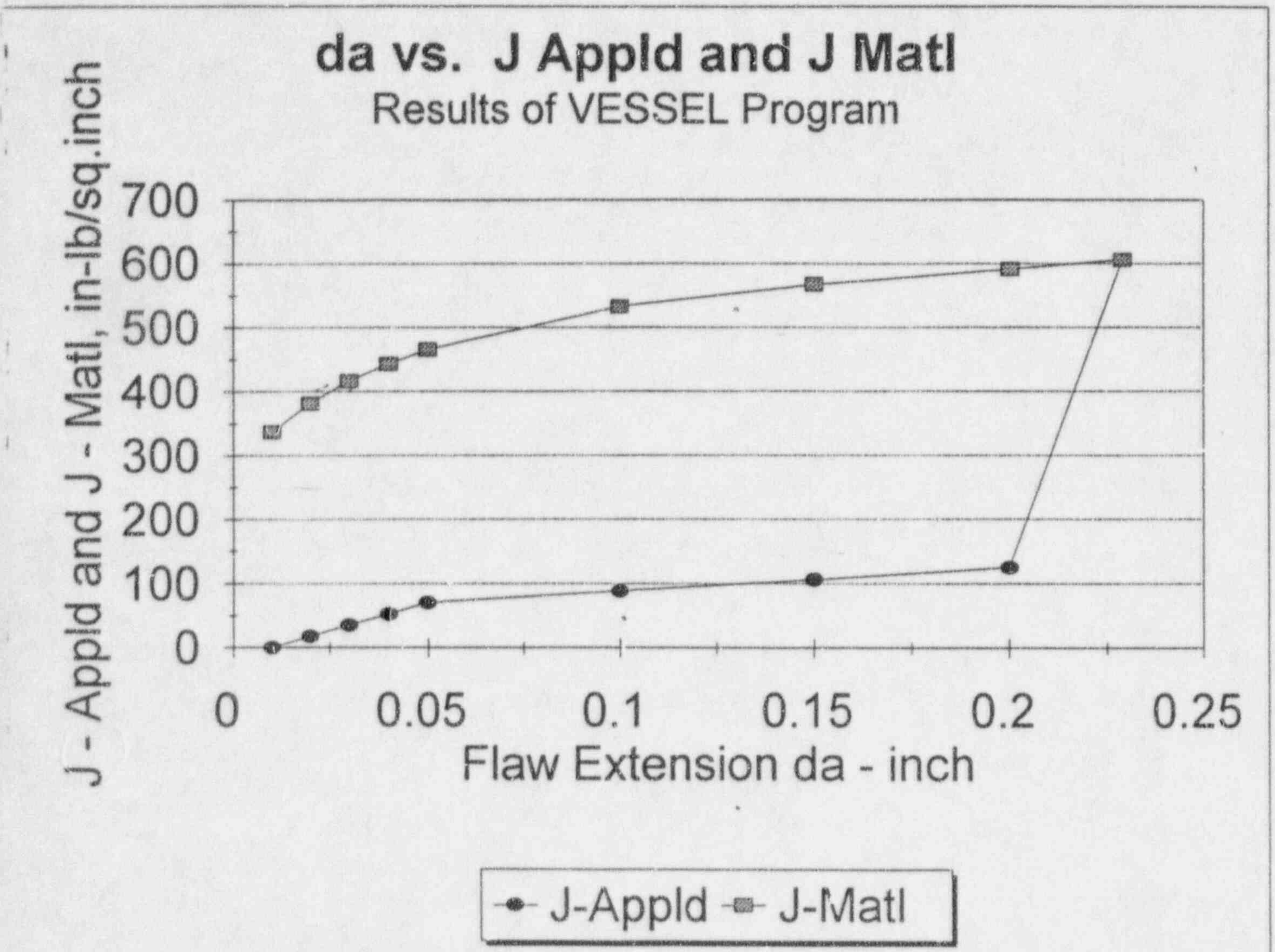

Figure 8-2

da vs. J-Applied and J-Mat'l - Results of VESSEL Program

9.0 REFERENCES

1. 10CFR, Part 50, Appendix G.

2. 1995 Edition of ASME Section XI, Appendix K.

3. SIA Report CPL-36Q-306, Evaluation of BSEP Unit 1 Curves for Heat-up and Cool-down.

4. SIA Report CPL-36Q-301, Hydro Test Curves Development.

5. SIA Report CPL-36Q-302, 2" Instrumentation Nozzle Pressure Analysis.

6. SIA Report CPL-36Q-303, ASME Code Appendix A vs. Appendix G.

7. SIA Report CPL-36Q-1-305, Cooldown Thermal Stress Analysis of the N-16 Nozzles.

8. General Electric Reactor Vessel Purchase Specification Data Sheets - Spec. No. 21A1100AR, Rev. 12.

9. Reactor Vessel Nozzles Analyses, CB&I Contract 68-2471, GE Purchase Order 204-H1332, FP 50585.

10. Information on Reactor Vessel Material Surveillance Program, Brunswick Unit 2, General Electric Report NED0-24157,.Rev. 2, June 1994.

11. Information on Reactor Vessel Material Surveillance Program, Brunswick Unit 1, General Electric Report NEDO-24161, Rev. 1, June 1992.

12. Reactor Vessel Embrittlement Management Handbook, EPRI Report TR-101975-T2, December 1993.

13. White Paper on Reactor Vessel Integrity Requirements for Level A and B Conditions, EPRI Report TR-100251, January 1993.

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20. Evaluation of Reactor Pressure Vessels with Charpy Upper-Shelf Energy Less than 50 ft-lb, Reg. Guide 1.161.

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23. VESSEL, A Computer Program Prepared by EPRI for Upper Shelf Charpy Energy Evaluation.

24. Multivariable Modelling of Pressure Vessel and Piping J_R Data, NRC Document NUREG/CR-5729, April 1991.

25. 10CFR50, Appendix G, Equivalent Margin analysis for Low Upper Shelf Energy in BWR/2 Through BWR/6 Vessels, General Electric Report NEDO-32205-A, Rev. 1, prepared for BWR Owner's Group.

26. Welding Research Council Bulletin WRC 175, PVRC Recommendations on Fracture Toughness Requirements on Ferritic Materials.

27. Telephone Conversation Summary Between Altran (P.K. Shah) and CP&L (Charlie Griffin and John Voss) dated April 15, 1996.

28. Fax Transmission from J.W. Voss, Jr. of CP&L to P.K. Shah of Altran, dated November 4, 1996.

Altran Corporation
Technical Report No. 96124-TR-01
Revision 0

Appendix A

N-16 Nozzles Material Test Data

UNIT 1 N16 NOZZLES

MK 302-N1CA&B

MATERIAL TEST REPORT

DATE July 2, 1969

S.O. No. 0170-9

Purchaser's Order No. Temp. P.O. [illegible]-2472, Contract [illegible] 2472

Purchaser Chicago Bridge and Iron Company

Distributor's Order No. 4329

Distributor C. I. Grain Co., Inc.

ITEM NO.	QTY.	PRODUCT	SPEC.	HEAT OR CODE NO.	FORGING NO.	HEAT TREATMENT	FCE CHARTS ATTACHED YES	FCE CHARTS ATTACHED NO
1	2	2" Dia. Special Welding Stubs per Dwg. 103, Rev. 2 (N12)	CBI Spec. H32, Rev. 3 of 5/3/68 (ASTM-A508-2) H32 Par. 3.13.1	Q2Q1VW	247P-4A,4B	1675± 25°F. 1 Hr/in Air Cool 1550± 25°F. 1 Hr/in Water Quench 1220± 25°F. 1 Hr/in Air Cool Tests stress relieved at: 1150± 25°F. for 50 hours	X	

CHEMICAL ANALYSIS AND MECHANICAL PROPERTIES

FORGING NO	HEAT NO.	C	MN	P	S	SI	CR	NI	MO	V		U.T.	M.P.	D.P.	REMARKS
247P-4A, 4B	Q2Q1VW	.21 .219	.75 .63	.010 .006	.015 .025	.23 .24	.37 .30	.80 .84	.69 .72	.05 .02	Ladle Check	X	X	X	2 Dropweights - no break +50°F. Ferritic Grain Size 7-8

(NDT REPORTS ATTACHED: U.T., M.P., D.P.)

(V-Notch at +40°F.) IMPACT TESTS (Keyhole @)

FORGING NO	HEAT NO.	TEST TEMP.	TENSILE PSI x 1000	YIELD PSI x 1000	ELONG. % in 2"	R.A. %	B.H.N	ENERGY (ft lbs.)	LATERAL EXP. (in")	% SHEAR
247P-4A, 4B	Q2Q1VW 0°	Room Temp	97.25	78.0	21.0	58.2		38-39-41	.031-.031-.035	36-30-30
	150°	Room Temp	94.5	73.0	20.0	56.2		31-35-44	.027-.033-.037	40-30-50

CORRECTED TEST REPORT - Please destroy copy dated January 7, 1969.
"We hereby certify the above results are correct and that all requirements of above referenced specifications and the pu[rchase] order have [been] fulfilled."

We hereby certify the above results to be as contained in the records of the Company.

A-1

(1)

Bonney Forge & [illegible]dry Inc.

MATERIAL TEST REPORT

DATE July 3, 1968

S.O. No. 4068-8

Purchaser Chicago Bridge and Iron Company

Distributor C. I. Crais Co., Inc.

Purchaser's Order No. Tag: P.O. B62504-2471U, Contract 68 2471U

Distributor's Order No. 4949

ITEM NO.	QTY.	PRODUCT	SPEC.	HEAT OR CODE NO.	FORGING NO.	HEAT TREATMENT	FCE CHARTS ATTACHED YES	NO
2	2	2" Dia. Special Welding Stubs per Dwg. M13, Rev. 2	CB&I Spec. MS 2, Rev.3 of 5/8/68 (ASTM-A508-2) MS2, Par. 3.13.1	Q2Q1VW	247P-3A,3B	1675± 25°F. 1 Hr/in Air Cool 1560± 25°F. 1 Hr/in Water Quench 1290± 25°F. 1 Hr/in Air Cool Tests stress relieved at: 1150± 25°F. for 50 hours	X	

UNIT 2 N16 N-16 [illegible]

CHEMICAL ANALYSIS AND MECHANICAL PROPERTIES

FORGING NO.	HEAT NO.	C	MN	P	S	SI	CR	NI	MO	V			NDT REPORTS ATTACHED U.T.	M.P.	D.P.	REMARKS
247P-3A, 3B	Q2Q1VW	.21 .16	.75 .71	.010 .006	.015 .013	.23 .24	.37 .36	.80 .81	.69 .60	.05 .03	Ladle Check		X	X	X	2 Dropweights - [illegible] break +50°F. Ferritic Grain S[illegible] 9

FORGING NO.	HEAT NO.	TEST TEMP.	TENSILE PSI x 1000	YIELD PSI x 1000	ELONG. % in 2"	R.A. %	B.H.N.	IMPACT TESTS (V-Notch at +40°F.) ENERGY (ft-lbs.)	LATERAL EXP. (in")	% SHEAR
247P-3A, 3B	Q2Q1VW 0°	Room Temp	88.65	69.0	22.5	66.5		116-100-112	.081-.074-.080	90-80-95
	180°	Room Temp	88.5	69.75	24.5	69.5		133-74-141	.085-.065-.087	95-60-95

CORRECTED TEST REPORT - Please destroy copy dated January 8, 1969.
"We hereby certify the above results are correct and that all requirements of above referenced specifications and the purchase order have been fulfilled."

[signature]

We hereby certify the above results to be correct as contained in the records of the Company.

A-2

Lenape Forge, Inc.
1280 West Chester Rd.
West Chester, Pa. 19382

March 14, 1989

Carolina Power & Light Co.
Box 1551
Raleigh, North Carolina 27602

Attn: Mr. Sam Grant

Gentlemen,

The following information is being provided for your information and is applicable to Lenape Forge, Inc. Heat Code Q2Q1V . A508-2 material melted by Sharon Steel Co. and received by Lenape Forge Inc. in June of 1988.

	C	Mn	P	S	Si	Cr	Ni	Mo	Cu
Ladle Analysis: (Wt %)	.21	.75	.010	.015	.23	.37	.80	.69	
Product Analysis (Wt %)	.21	.75	.010	.014	.24	.37	.82	.69	.16

Drop Wt. Test Results Reported On Material Forged From Heat Code Q2Q1V.
(Testing performed using P-3 specimens per ASTM E 208)

Material Heat Treated Condition:

Normalized at 1850 F - cooled in air
Austenitized at 1560 F - water quenched
Tempered at 1290 F - cooled in air
Stress Relieved at
1150 F 30 Hrs.

Drop weight test results: -20 F, -10 F, 0 F : Break
0 F, +10 F, +10 F: No Break

Please note, test results presented have been obtained by processing (forging and heat treating) starting stock selected from Lenape Forge Heat Code Q2Q1V. The above results are not intended to be used to certify any particular forgings in your possession. For specific forgings of concern, please refer to the applicable MTR (Material Test Report) supplied with forging shipment.

Sincerely,

R. D. Trout

R. Douglass Trout
Plant Metallurgist

Appendix B

Analyzed J-Resistance (J_R) Fracture Toughness Data of the N-16 Nozzle Material

Table B-1

N-16 Nozzle Evaluation **Carolina Power & Light**

Pre-Irradiated CVN Model

flie = CPL5 **Crack Extension da =0.01 inch**

MF	Temp F	CVN ft-lb	C1	C2	C3	C4	da (inch)	JR in-lb/in^2
0.749	100	35	3.568	0.225	-0.093	-0.409	0.01	516
0.749	150	35	3.117	0.209	-0.092	-0.409	0.01	488
0.749	200	35	2.724	0.193	-0.090	-0.409	0.01	462
0.749	250	35	2.380	0.178	-0.089	-0.409	0.01	438
0.749	300	35	2.079	0.162	-0.088	-0.409	0.01	414
0.749	350	35	1.817	0.146	-0.087	-0.409	0.01	392
0.749	400	35	1.587	0.131	-0.085	-0.409	0.01	371
0.749	450	35	1.387	0.115	-0.084	-0.409	0.01	352
0.749	500	35	1.212	0.099	-0.083	-0.409	0.01	333
0.749	550	35	1.059	0.084	-0.082	-0.409	0.01	315
0.749	600	35	0.925	0.068	-0.080	-0.408	0.01	298
0.749	650	35	0.808	0.052	-0.079	-0.409	0.01	283

MF	Temp F	CVN ft-lb	C1	C2	C3	C4	da	JR
0.749	100	40	4.160	0.242	-0.094	-0.409	0.01	549
0.749	150	40	3.635	0.227	-0.093	-0.409	0.01	520
0.749	200	40	3.176	0.211	-0.092	-0.409	0.01	492
0.749	250	40	2.775	0.195	-0.091	-0.409	0.01	466
0.749	300	40	2.424	0.180	-0.089	-0.409	0.01	441
0.749	350	40	2.118	0.164	-0.088	-0.409	0.01	418
0.749	400	40	1.851	0.148	-0.087	-0.409	0.01	395
0.749	450	40	1.617	0.133	-0.086	-0.409	0.01	374
0.749	500	40	1.413	0.117	-0.084	-0.409	0.01	354
0.749	550	40	1.234	0.101	-0.083	-0.409	0.01	335
0.749	600	40	1.079	0.086	-0.082	-0.409	0.01	318
0.749	650	40	0.942	0.070	-0.081	-0.409	0.01	301

MF	Temp F	CVN ft-lb	C1	C2	C3	C4	da	JR
0.749	100	45	4.764	0.258	-0.096	-0.409	0.01	580
0.749	150	45	4.162	0.242	-0.094	-0.409	0.01	549
0.749	200	45	3.637	0.227	-0.093	-0.409	0.01	520
0.749	250	45	3.177	0.211	-0.092	-0.409	0.01	492
0.749	300	45	2.776	0.195	-0.091	-0.409	0.01	466
0.749	350	45	2.425	0.180	-0.089	-0.409	0.01	441
0.749	400	45	2.119	0.164	-0.088	-0.409	0.01	418
0.749	450	45	1.852	0.148	-0.087	-0.409	0.01	395
0.749	500	45	1.618	0.133	-0.086	-0.409	0.01	374
0.749	550	45	1.413	0.117	-0.084	-0.409	0.01	354
0.749	600	45	1.235	0.101	-0.083	-0.409	0.01	336
0.749	650	45	1.079	0.086	-0.082	-0.409	0.01	318

MF	Temp F	CVN ft-lb	C1	C2	C3	C4	da	JR
0.749	100	50	5.377	0.272	-0.097	-0.409	0.01	609
0.749	150	50	4.698	0.256	-0.095	-0.409	0.01	577
0.749	200	50	4.105	0.241	-0.094	-0.409	0.01	546
0.749	250	50	3.587	0.225	-0.093	-0.409	0.01	517
0.749	300	50	3.134	0.209	-0.092	-0.409	0.01	489
0.749	350	50	2.738	0.194	-0.090	-0.409	0.01	463
0.749	400	50	2.392	0.178	-0.089	-0.409	0.01	439
0.749	450	50	2.090	0.163	-0.088	-0.409	0.01	415
0.749	500	50	1.826	0.147	-0.087	-0.409	0.01	393
0.749	550	50	1.[illegible]5	0.131	-0.085	-0.409	0.01	372
0.749	600	50	1.394	0.116	-0.084	-0.409	0.01	352
0.749	650	50	1.218	0.100	-0.083	-0.409	0.01	334

MF	Temp F	CVN ft-lb	C1	C2	C3	C4	da	JR
0.749	100	55	6.000	0.285	-0.098	-0.409	0.01	637
0.749	150	55	5.242	0.269	-0.096	-0.409	0.01	603
0.749	200	55	4.580	0.254	-0.095	-0.409	0.01	571
0.749	250	55	4.002	0.238	-0.094	-0.409	0.01	540
0.749	300	55	3.497	0.222	-0.093	-0.409	0.01	512
0.749	350	55	3.055	0.207	-0.091	-0.409	0.01	484
0.749	400	55	2.669	0.191	-0.090	-0.409	0.01	459
0.749	450	55	2.332	0.175	-0.089	-0.409	0.01	434
0.749	500	55	2.038	0.160	-0.088	-0.409	0.01	411
0.749	550	55	1.780	0.144	-0.087	-0.409	0.01	389
0.749	600	55	1.555	0.128	-0.085	-0.409	0.01	368
0.749	650	55	1.359	0.113	-0.084	-0.409	0.01	349

Table B-1 (cont'd)

N-16 Nozzle Evaluation — Carolina Power & Light

Pre-Irradiated CVN Model

file = CPL5 — Crack Extension da =0.02 inch

MF	Temp F	CVN ft-lb	C1	C2	C3	C4	da (inch)	JR in-lb/in^2
0.749	100	35	3.568	0.225	-0.093	-0.409	0.02	701
0.749	150	35	3.117	0.209	-0.092	-0.409	0.02	655
0.749	200	35	2.724	0.193	-0.090	-0.409	0.02	612
0.749	250	35	2.380	0.178	-0.089	-0.409	0.02	572
0.749	300	35	2.079	0.162	-0.088	-0.409	0.02	535
0.749	350	35	1.817	0.146	-0.087	-0.409	0.02	500
0.749	400	35	1.587	0.131	-0.085	-0.409	0.02	467
0.749	450	35	1.387	0.115	-0.084	-0.409	0.02	437
0.749	500	35	1.212	0.099	-0.083	-0.409	0.02	408
0.749	550	35	1.059	0.084	-0.082	-0.409	0.02	381
0.749	600	35	0.925	0.068	-0.080	-0.409	0.02	356
0.749	650	35	0.808	0.052	-0.079	-0.409	0.02	333

MF	Temp F	CVN ft-lb	C1	C2	C3	C4	da	JR
0.749	100	40	4.160	0.242	-0.094	-0.409	0.02	757
0.749	150	40	3.635	0.227	-0.093	-0.409	0.02	707
0.749	200	40	3.176	0.211	-0.092	-0.409	0.02	661
0.749	250	40	2.775	0.195	-0.091	-0.409	0.02	618
0.749	300	40	2.424	0.180	-0.089	-0.409	0.02	577
0.749	350	40	2.118	0.164	-0.088	-0.409	0.02	540
0.749	400	40	1.851	0.148	-0.087	-0.409	0.02	504
0.749	450	40	1.617	0.133	-0.086	-0.405	0.02	471
0.749	500	40	1.413	0.117	-0.084	-0.409	0.02	441
0.749	550	40	1.234	0.101	-0.083	-0.409	0.02	412
0.749	600	40	1.079	0.086	-0.082	-0.409	0.02	385
0.749	650	40	0.942	0.070	-0.081	-0.409	0.02	360

MF	Temp F	CVN ft-lb	C1	C2	C3	C4	da	JR
0.749	100	45	4.764	0.258	-0.096	-0.409	0.02	810
0.749	150	45	4.162	0.242	-0.094	-0.409	0.02	757
0.749	200	45	3.637	0.227	-0.093	-0.409	0.02	707
0.749	250	45	3.177	0.211	-0.092	-0.409	0.02	661
0.749	300	45	2.776	0.195	-0.091	-0.409	0.02	618
0.749	350	45	2.425	0.180	-0.089	-0.409	0.02	578
0.749	400	45	2.119	0.164	-0.088	-0.409	0.02	540
0.749	450	45	1.852	0.148	-0.087	-0.409	0.02	505
0.749	500	45	1.618	0.133	-0.086	-0.409	0.02	472
0.749	550	45	1.413	0.117	-0.084	-0.409	0.02	441
0.749	600	45	1.235	0.101	-0.083	-0.409	0.02	412
0.749	650	45	1.079	0.086	-0.082	-0.409	0.02	385

MF	Temp F	CVN ft-lb	C1	C2	C3	C4	da	JR
0.749	100	50	5.377	0.272	-0.097	-0.409	0.02	860
0.749	150	50	4.698	0.256	-0.005	-0.409	0.02	804
0.749	200	50	4.105	0.241	-0.094	-0.409	0.02	752
0.749	250	50	3.587	0.225	-0.093	-0.409	0.02	703
0.749	300	50	3.134	0.209	-0.092	-0.409	0.02	657
0.749	350	50	2.738	0.194	-0.090	-0.409	0.02	614
0.749	400	50	2.392	0.178	-0.089	-0.409	0.02	574
0.749	450	50	2.090	0.163	-0.088	-0.409	0.02	536
0.749	500	50	1.826	0.147	-0.087	-0.409	0.02	501
0.749	550	50	1.595	0.131	-0.085	-0.409	0.02	468
0.749	600	50	1.394	0.116	-0.084	-0.409	0.02	438
0.749	650	50	1.218	0.100	-0.083	-0.409	0.02	409

MF	Temp F	CVN ft-lb	C1	C2	C3	C4	da	JR
0.749	100	55	6.000	0.285	-0.098	-0.409	0.02	909
0.749	150	55	5.242	0.269	-0.096	-0.409	0.02	850
0.749	200	55	4.580	0.254	-0.095	-0.409	0.02	794
0.749	250	55	4.002	0.238	-0.094	-0.409	0.02	742
0.749	300	55	3.497	0.222	-0.093	-0.409	0.02	694
0.749	350	55	3.055	0.207	-0.091	-0.409	0.02	648
0.749	400	55	2.669	0.191	-0.090	-0.409	0.02	606
0.749	450	55	2.332	0.175	-0.089	-0.409	0.02	566
0.749	500	55	2.038	0.160	-0.088	-0.409	0.02	529
0.749	550	55	1.780	0.144	-0.087	-0.409	0.02	495
0.749	600	55	1.555	0.128	-0.085	-0.409	0.02	462
0.749	650	55	1.359	0.113	-0.084	-0.409	0.02	432

Table B-1 (cont'd)

N-16 Nozzle Evaluation — Carolina Power & Light

Pre-Irradiated CVN Model

file = CPL5 Crack Extension da =0.05 inch

MF	Temp F	CVN ft-lb	C1	C2	C3	C4	da (inch)	JR in-lb/in^2
0.749	100	35	3.568	0.225	-0.093	-0.409	0.05	994
0.749	150	35	3.117	0.209	-0.092	-0.409	0.05	914
0.749	200	35	2.724	0.193	-0.090	-0.409	0.05	840
0.749	250	35	2.380	0.178	-0.089	-0.409	0.05	773
0.749	300	35	2.079	0.162	-0.088	-0.409	0.05	711
0.749	350	35	1.817	0.146	-0.087	-0.409	0.05	654
0.749	400	35	1.587	0.131	-0.085	-0.409	0.05	601
0.749	450	35	1.387	0.115	-0.084	-0.409	0.05	553
0.749	500	35	1.212	0.099	-0.083	-0.409	0.05	508
0.749	550	35	1.059	0.084	-0.082	-0.409	0.05	467
0.749	600	35	0.925	0.068	-0.080	-0.409	0.05	430
0.749	650	35	0.808	0.052	-0.079	-0.409	0.05	395

MF	Temp F	CVN ft-lb	C1	C2	C3	C4	da	JR
0.749	100	40	4.160	0.242	-0.094	-0.409	0.05	1093
0.749	150	40	3.675	0.227	-0.093	-0.409	0.05	1006
0.749	200	40	3.176	0.211	-0.092	-0.409	0.05	925
0.749	250	40	2.775	0.195	-0.091	-0.409	0.05	850
0.749	300	40	2.424	0.180	-0.089	-0.409	0.05	782
0.749	350	40	2.118	0.164	-0.088	-0.409	0.05	719
0.749	400	40	1.851	0.148	-0.087	-0.409	0.05	661
0.749	450	40	1.617	0.133	-0.086	-0.409	0.05	608
0.749	500	40	1.413	0.117	-0.084	-0.409	0.05	559
0.749	550	40	1.234	0.101	-0.083	-0.409	0.05	514
0.749	600	40	1.079	0.086	-0.082	-0.409	0.05	473
0.749	650	40	0.942	0.070	-0.081	-0.409	0.05	435

MF	Temp F	CVN ft-lb	C1	C2	C3	C4	da	JR
0.749	100	45	4.764	0.258	-0.096	-0.409	0.05	1189
0.749	150	45	4.162	0.242	-0.094	-0.409	0.05	1094
0.749	200	45	3.637	0.227	-0.093	-0.409	0.05	1006
0.749	250	45	3.177	0.211	-0.092	-0.409	0.05	925
0.749	300	45	2.776	0.195	-0.091	-0.409	0.05	850
0.749	350	45	2.425	0.180	-0.089	-0.409	0.05	782
0.749	400	45	2.119	0.164	-0.088	-0.409	0.05	719
0.749	450	45	1.852	0.148	-0.087	-0.409	0.05	661
0.749	500	45	1.618	0.133	-0.086	-0.409	0.05	608
0.749	550	45	1.413	0.117	-0.084	-0.409	0.05	559
0.749	600	45	1.235	0.101	-0.083	-0.409	0.05	514
0.749	650	45	1.079	0.086	-0.082	-0.409	0.05	473

MF	Temp F	CVN ft-lb	C1	C2	C3	C4	da	JR
0.749	100	50	5.377	0.272	-0.097	-0.409	0.05	1282
0.749	150	50	4.698	0.256	-0.095	-0.409	0.05	1179
0.749	200	50	4.105	0.241	-0.094	-0.409	0.05	1084
0.749	250	50	3.587	0.225	-0.093	-0.409	0.05	997
0.749	300	50	3.134	0.209	-0.092	-0.409	0.05	917
0.749	350	50	2.738	0.194	-0.090	-0.409	0.05	843
0.749	400	50	2.392	0.178	-0.089	-0.409	0.05	775
0.749	450	50	2.090	0.163	-0.088	-0.409	0.05	713
0.749	500	50	1.826	0.147	-0.087	-0.409	0.05	656
0.749	550	50	1.595	0.131	-0.085	-0.409	0.05	603
0.749	600	50	1.394	0.116	-0.084	-0.409	0.05	554
0.749	650	50	1.218	0.100	-0.083	-0.409	0.05	510

MF	Temp F	CVN ft-lb	C1	C2	C3	C4	da	JR
0.749	100	55	6.000	0.285	-0.098	-0.409	0.05	1373
0.749	150	55	5.242	0.269	-0.096	-0.409	0.05	1262
0.749	200	55	4.580	0.254	-0.095	-0.409	0.05	1161
0.749	250	55	4.002	0.238	-0.094	-0.409	0.05	1067
0.749	300	55	3.497	0.222	-0.093	-0.409	0.05	982
0.749	350	55	3.055	0.207	-0.091	-0.409	0.05	903
0.749	400	55	2.669	0.191	-0.090	-0.409	0.05	830
0.749	450	55	2.332	0.175	-0.089	-0.409	0.05	763
0.749	500	55	2.038	0.160	-0.088	-0.409	0.05	702
0.749	550	55	1.780	0.144	-0.087	-0.409	0.05	645
0.749	600	55	1.555	0.128	-0.085	-0.409	0.05	593
0.749	650	55	1.359	0.113	-0.084	-0.409	0.05	546

Table B-1 (cont'd)

N-16 Nozzle Evaluation — Carolina Power & Light

Pre-Irradiated CVN Model

flie = CPL5 — Crack Extension da =0.1 inch

MF	Temp F	CVN ft-lb	C1	C2	C3	C4	da (inch)	JR in-lb/in^2
0.749	100	35	3.588	0.225	-0.093	-0.409	0.1	1258
0.749	150	35	3.117	0.209	-0.092	-0.409	0.1	1141
0.749	200	35	2.724	0.193	-0.090	-0.409	0.1	1037
0.749	250	35	2.380	0.178	-0.089	-0.409	0.1	942
0.749	300	35	2.079	0.162	-0.088	-0.409	0.1	856
0.749	350	35	1.817	0.146	-0.087	-0.409	0.1	778
0.749	400	35	1.587	0.131	-0.085	-0.409	0.1	707
0.749	450	35	1.387	0.115	-0.084	-0.409	0.1	642
0.749	500	35	1.212	0.099	-0.083	-0.409	0.1	584
0.749	550	35	1.059	0.084	-0.082	-0.409	0.1	530
0.749	600	35	0.925	0.068	-0.080	-0.409	0.1	482
0.749	650	35	0.808	0.052	-0.079	-0.409	0.1	438

MF	Temp F	CVN ft-lb	C1	C2	C3	C4	da	JR
0.749	100	40	4.160	0.242	-0.094	-0.409	0.1	1400
0.749	150	40	3.635	0.227	-0.093	-0.409	0.1	1272
0.749	200	40	3.176	0.211	-0.092	-0.409	0.1	1156
0.749	250	40	2.775	0.195	-0.091	-0.409	0.1	1051
0.749	300	40	2.424	0.180	-0.089	-0.409	0.1	955
0.749	350	40	2.118	0.164	-0.088	-0.409	0.1	867
0.749	400	40	1.851	0.148	-0.087	-0.409	0.1	788
0.749	450	40	1.617	0.133	-0.086	-0.409	0.1	716
0.749	500	40	1.413	0.117	-0.084	-0.409	0.1	651
0.749	550	40	1.234	0.101	-0.083	-0.409	0.1	591
0.749	600	40	1.079	0.086	-0.082	-0.409	0.1	537
0.749	650	40	0.942	0.070	-0.081	-0.409	0.1	488

MF	Temp F	CVN ft-lb	C1	C2	C3	C4	da	JR
0.749	100	45	4.764	0.258	-0.096	-0.409	0.1	1541
0.749	150	45	4.162	0.242	-0.094	-0.409	0.1	1401
0.749	200	45	3.637	0.227	-0.093	-0.409	0.1	1273
0.749	250	45	3.177	0.211	-0.092	-0.409	0.1	1157
0.749	300	45	2.776	0.195	-0.091	-0.409	0.1	1051
0.749	350	45	2.425	0.180	-0.089	-0.409	0.1	955
0.749	400	45	2.119	0.164	-0.088	-0.409	0.1	868
0.749	450	45	1.852	0.148	-0.087	-0.409	0.1	789
0.749	500	45	1.618	0.133	-0.086	-0.409	0.1	717
0.749	550	45	1.413	0.117	-0.084	-0.409	0.1	651
0.749	600	45	1.235	0.101	-0.083	-0.409	0.1	592
0.749	650	45	1.079	0.086	-0.082	-0.409	0.1	538

MF	Temp c	CVN ft-lb	C1	C2	C3	C4	da	JR
0.749	100	50	5.377	0.272	-0.097	-0.409	0.1	16[illegible]0
0.749	150	50	4.698	0.256	-0.095	-0.409	0.1	1526
0.749	200	50	4.105	0.241	-0.094	-0.409	0.1	1387
0.749	250	50	3.587	0.225	-0.093	-0.409	0.1	1260
0.749	300	50	3.134	0.209	-0.092	-0.409	0.1	1145
0.749	350	50	2.738	0.194	-0.090	-0.409	0.1	1041
0.749	400	50	2.392	0.178	-0.089	-0.409	0.1	946
0.749	450	50	2.090	0.163	-0.088	-0.409	0.1	859
0.749	500	50	1.826	0.147	-0.087	-0.409	0.1	781
0.749	550	50	1.595	0.131	-0.085	-0.409	0.1	710
0.749	600	50	1.394	0.116	-0.084	-0.409	0.1	645
0.749	650	50	1.218	0.100	-0.083	-0.409	0.1	585

MF	Temp F	CVN ft-lb	C1	C2	C3	C4	da	JR
0.749	100	55	6.000	0.285	-0.098	-0.409	0.1	1816
0.749	150	55	5.242	0.269	-0.096	-0.409	0.1	1650
0.749	200	55	4.580	0.254	-0.095	-0.409	0.1	1499
0.749	250	55	4.002	0.236	-0.094	-0.409	0.1	1362
0.749	300	55	3.497	0.222	-0.093	-0.409	0.1	1238
0.749	350	55	3.055	0.207	-0.091	-0.409	0.1	1125
0.749	400	55	2.669	0.191	-0.090	-0.409	0.1	1022
0.749	450	55	2.332	0.175	-0.089	-0.409	0.1	929
0.749	500	55	2.038	0.160	-0.088	-0.409	0.1	844
0.749	550	55	1.780	0.144	-0.087	-0.409	0.1	767
0.749	600	55	1.555	0.128	-0.085	-0.409	0.1	697
0.749	650	55	1.359	0.113	-0.084	-0.409	0.1	633

Table B-1 (cont'd)

N-16 Nozzle Evaluation **Carolina Power & Light**

Pre-Irradiated CVN Model

flie = CPL5 Crack Extension da =0.15 inch

MF	Temp F	CVN ft-lb	C1	C2	C3	C4	da (inch)	JR in-lb/in^2
0.749	100	35	3.568	0.225	-0.093	-0.409	0.15	1426
0.749	150	35	3.117	0.209	-0.092	-0.409	0.15	1287
0.749	200	35	2.724	0.193	-0.090	-0.409	0.15	1162
0.749	250	35	2.380	0.175	-0.089	-0.409	0.15	1049
0.749	300	35	2.079	0.162	-0.088	-0.409	0.15	946
0.749	350	35	1.817	0.146	-0.087	-0.409	0.15	854
0.749	400	35	1.587	0.131	-0.085	-0.409	0.15	771
0.749	450	35	1.387	0.115	-0.084	-0.409	0.15	696
0.749	500	35	1.212	0.099	-0.083	-0.409	0.15	628
0.749	550	35	1.059	0.084	-0.082	-0.409	0.15	567
0.749	600	35	0.925	0.068	-0.080	-0.409	0.15	511
0.749	650	35	0.808	0.052	-0.079	-0.409	0.15	461

MF	Temp F	CVN ft-lb	C1	C2	C3	C4	da	JR
0.749	100	40	4.160	0.242	-0.094	-0.409	0.15	1603
0.749	150	40	3.635	0.227	-0.093	-0.409	0.15	1447
0.749	200	40	3.176	0.211	-0.092	-0.409	0.15	1306
0.749	250	40	2.775	0.195	-0.091	-0.409	0.15	1178
0.749	300	40	2.424	0.180	-0.089	-0.409	0.15	1063
0.749	350	40	2.118	0.164	-0.088	-0.409	0.15	960
0.749	400	40	1.851	0.148	-0.087	-0.409	0.15	866
0.749	450	40	1.617	0.133	-0.086	-0.409	0.15	782
0.749	500	40	1.413	0.117	-0.084	-0.409	0.15	705
0.749	550	40	1.234	0.101	-0.083	-0.409	0.15	637
0.749	600	40	1.079	0.086	-0.082	-0.409	0.15	575
0.749	650	40	0.942	0.070	-0.081	-0.409	0.15	519

MF	Temp F	CVN ft-lb	C1	C2	C3	C4	da	JR
0.749	100	45	4.764	0.258	-0.096	-0.409	0.15	1777
0.749	150	45	4.162	0.242	-0.094	-0.409	0.15	1604
0.749	200	45	3.637	0.227	-0.093	-0.409	0.15	1447
0.749	250	45	3.177	0.211	-0.092	-0.409	0.15	1306
0.749	300	45	2.776	0.195	-0.091	-0.409	0.15	1179
0.749	350	45	2.425	0.180	-0.089	-0.409	0.15	1064
0.749	400	45	2.119	0.164	-0.088	-0.409	0.15	960
0.749	450	45	1.852	0.148	-0.087	-0.409	0.15	866
0.749	500	45	1.618	0.133	-0.086	-0.409	0.15	782
0.749	550	45	1.413	0.117	-0.084	-0.409	0.15	706
0.749	600	45	1.235	0.101	-0.083	-0.409	0.15	637
0.749	650	45	1.079	0.086	-0.082	-0.409	0.15	575

MF	Temp F	CVN ft-lb	C1	C2	C3	C4	da	JR
0.749	100	50	5.377	0.272	-0.097	-0.409	0.15	1948
0.749	150	50	4.698	0.256	-0.095	-0.409	0.15	1758
0.749	200	50	4.105	0.241	-0.094	-0.409	0.15	1587
0.749	250	50	3.567	0.225	-0.093	-0.409	0.15	1432
0.749	300	50	3.134	0.209	-0.092	-0.409	0.15	1292
0.749	350	50	2.738	0.194	-0.090	-0.409	0.15	1166
0.749	400	50	2.392	0.178	-0.089	-0.409	0.15	1053
0.749	450	50	2.090	0.163	-0.088	-0.409	0.15	950
0.749	500	50	1.826	0.147	-0.087	-0.409	0.15	857
0.749	550	50	1.595	0.131	-0.085	-0.409	0.15	774
0.749	600	50	1.394	0.116	-0.084	-0.409	0.15	696
0.749	650	50	1.218	0.100	-0.083	-0.409	0.15	630

MF	Temp F	CVN ft-lb	C1	C2	C3	C4	da	JR
0.749	100	55	6.000	0.285	-0.098	-0.409	0.15	2117
0.749	150	55	5.242	0.269	-0.096	-0.409	0.15	1911
0.749	200	55	4.580	0.254	-0.095	-0.409	0.15	1725
0.749	250	55	4.002	0.238	-0.094	-0.409	0.15	1556
0.749	300	55	3.497	0.222	-0.093	-0.409	0.15	1405
0.749	350	55	3.055	0.207	-0.091	-0.409	0.15	1268
0.749	400	55	2.669	0.191	-0.090	-0.409	0.15	1144
0.749	450	55	2.332	0.175	-0.089	-0.409	0.15	1033
0.749	500	55	2.038	0.160	-0.088	-0.409	0.15	932
0.749	550	55	1.780	0.144	-0.087	-0.409	0.15	841
0.749	600	55	1.555	0.128	-0.085	-0.409	0.15	759
0.749	650	55	1.359	0.113	-0.084	-0.409	0.15	685

Table B-1 (cont'd)

N-16 Nozzle Evaluation — Carolina Power & Light

Pre-irradiated CVN Model

flie = CPL5 Crack Extension da =0.20 inch

MF	Temp F	CVN ft-lb	C1	C2	C3	C4	da (inch)	JR in-lb/in^2
0.749	100	35	3.568	0.225	-0.093	-0.409	0.2	1556
0.749	150	35	3.117	0.2[illegible]9	-0.092	-0.409	0.2	1398
0.749	200	35	2.724	0.193	-0.090	-0.409	0.2	1255
0.749	250	35	2.380	0.178	-0.089	-0.409	0.2	1127
0.749	300	35	2.079	0.162	-0.088	-0.409	0.2	1013
0.749	350	35	1.817	0.146	-0.087	-0.409	0.2	910
0.749	400	35	1.587	0.131	-0.085	-0.409	0.2	817
0.749	450	35	1.387	0.115	-0.084	-0.409	0.2	734
0.749	500	35	1.212	0.099	-0.083	-0.409	0.2	659
0.749	550	35	1.059	0.084	-0.082	-0.409	0.2	592
0.749	600	35	0.925	0.068	-0.080	-0.409	0.2	532
0.749	650	35	0.808	0.052	-0.079	-0.409	0.2	477

MF	Temp F	CVN ft-lb	C1	C2	C3	C4	da	JR
0.749	100	40	4.160	0.242	-0.094	-0.409	0.2	1758
0.749	150	40	3.635	0.227	-0.093	-0.409	0.2	1579
0.749	200	40	3.176	0.211	-0.092	-0.409	0.2	1418
0.749	250	40	2.775	0.195	-0.091	-0.409	0.2	1274
0.749	300	40	2.424	0.180	-0.089	-0.409	0.2	1144
0.749	350	40	2.118	0.164	-0.088	-0.409	0.2	1028
0.749	400	40	1.851	0.148	-0.087	-0.409	0.2	923
0.749	450	40	1.617	0.133	-0.086	-0.409	0.2	829
0.749	500	40	1.413	0.117	-0.084	-0.409	0.2	745
0.749	550	40	1.234	0.101	-0.083	-0.409	0.2	669
0.749	600	40	1.079	0.086	-0.082	-0.409	0.2	601
0.749	650	40	0.942	0.070	-0.081	-0.409	0.2	540

MF	Temp F	CVN ft-lb	C1	C2	C3	C4	da	JR
0.749	100	45	4.764	0.258	-0.096	-0.409	0.2	1958
0.749	150	45	4.162	0.242	-0.094	-0.409	0.2	1759
0.749	200	45	3.637	0.227	-0.093	-0.409	0.2	1580
0.749	250	45	3.177	0.211	-0.092	-0.409	0.2	1419
0.749	300	45	2.776	0.195	-0.091	-0.409	0.2	1274
0.749	350	45	2.425	0.180	-0.089	-0.409	0.2	1145
0.749	400	45	2.119	0.164	-0.088	-0.409	0.2	1028
0.749	450	45	1.852	0.148	-0.087	-0.409	0.2	923
0.749	500	45	1.618	0.133	-0.086	-0.409	0.2	829
0.749	550	45	1.413	0.117	-0.084	-0.409	0.2	745
0.749	600	45	1.235	0.101	-0.083	-0.409	0.2	669
0.749	650	45	1.079	0.086	-0.082	-0.409	0.2	601

MF	Temp F	CVN ft-lb	C1	C2	C3	C4	da	JR
0.749	100	50	5.377	0.272	-0.097	-0.409	0.2	2156
0.749	150	50	4.698	0.256	-0.095	-0.409	0.2	1937
0.749	200	50	4.105	0.241	-0.094	-0.409	0.2	1740
0.749	250	50	3.587	0.225	-0.093	-0.409	0.2	1562
0.749	300	50	3.134	0.209	-0.092	-0.409	0.2	1403
0.749	350	50	2.738	0.194	-0.090	-0.409	0.2	1260
0.749	400	50	2.39[illegible]	0.178	-0.089	-0.409	0.2	1132
0.749	450	50	2.090	0.163	-0.088	-0.409	0.2	1017
0.749	500	50	1.826	0.147	-0.087	-0.409	0.2	913
0.749	550	50	1.595	0.131	-0.085	-0.409	0.2	820
0.749	600	50	1.394	0.116	-0.084	-0.409	0.2	737
0.749	650	50	1.218	0.100	-0.083	-0.409	0.2	662

MF	Temp F	CVN ft-lb	C1	C2	C3	C4	da	JR
0.749	100	55	6.000	0.285	-0.098	-0.409	0.2	2353
0.749	150	55	5.242	0.269	-0.096	-0.409	0.2	2113
0.749	200	55	4.580	0.254	-0.095	-0.409	0.2	1898
0.749	250	55	4.002	0.238	-0.094	-0.409	0.2	1705
0.749	300	55	3.497	0.222	-0.093	-0.409	0.2	1531
0.749	350	55	3.055	0.207	-0.091	-0.409	0.2	1375
0.749	400	55	2.669	0.191	-0.090	-0.400	0.2	1235
0.749	450	55	2.332	0.175	-0.089	-0.409	0.2	1109
0.749	5[illegible]	55	2.038	0.160	-0.088	-0.409	0.2	996
0.749	5[illegible]	55	1.780	0.144	-0.087	-0.409	0.2	895
0.749	600	55	1.555	0.128	-0.085	-0.409	0.2	804
0.749	650	55	1.359	0.113	-0.084	-0.409	0.2	722

Table B-1 (cont'd)

N-16 Nozzle Evaluation — Carolina Power & Light

Pre-Irradiated CVN Model

flie = CPL5 — Crack Extension da =0.25 inch

MF	Temp F	CVN ft-lb	C1	C2	C3	C4	da (inch)	JR in-lb/in^2
0.749	100	35	3.568	0.225	-0.093	-0.409	0.25	1662
0.749	150	35	3.117	0.209	-0.092	-0.409	0.25	1487
0.749	200	35	2.724	0.193	-0.090	-0.409	0.25	1331
0.749	250	35	2.380	0.178	-0.089	-0.409	0.25	1191
0.749	300	35	2.079	0.162	-0.088	-0.409	0.25	1066
0.749	350	35	1.817	0.146	-0.087	-0.409	0.25	954
0.749	400	35	1.587	0.131	-0.085	-0.409	0.25	853
0.749	450	35	1.387	0.115	-0.084	-0.409	0.25	764
0.749	500	35	1.212	0.099	-0.083	-0.409	0.25	683
0.749	550	35	1.059	0.084	-0.082	-0.409	0.25	611
0.749	600	35	0.925	0.068	-0.080	-0.409	0.25	547
0.749	650	35	0.808	0.052	-0.079	-0.409	0.25	490

MF	Temp F	CVN ft-lb	C1	C2	C3	C4	da	JR
0.749	100	40	4.160	0.242	-0.094	-0.409	0.25	1886
0.749	150	40	3.635	0.227	-0.093	-0.409	0.25	1687
0.749	200	40	3.176	0.211	-0.092	-0.409	0.25	1510
0.749	250	40	2.775	0.195	-0.091	-0.409	0.25	1351
0.749	300	40	2.424	0.180	-0.089	-0.409	0.25	1209
0.749	350	40	2.118	0.164	-0.088	-0.409	0.25	1082
0.749	400	40	1.851	0.148	-0.087	-0.409	0.25	968
0.749	450	40	1.617	0.133	-0.086	-0.409	0.25	866
0.749	500	40	1.413	0.117	-0.084	-0.409	0.25	775
0.749	550	40	1.234	0.101	-0.083	-0.409	0.25	694
0.749	600	40	1.079	0.086	-0.082	-0.409	0.25	621
0.749	650	40	0.942	0.070	-0.081	-0.409	0.25	556

MF	Temp F	CVN ft-lb	C1	C2	C3	C4	da	JR
0.749	100	45	4.764	0.258	-0.096	-0.409	0.25	2106
0.749	150	45	4.162	0.242	-0.094	-0.409	0.25	1886
0.749	200	45	3.637	0.227	-0.093	-0.409	0.25	1688
0.749	250	45	3.177	0.211	-0.092	-0.409	0.25	1511
0.749	300	45	2.776	0.195	-0.091	-0.409	0.25	1352
0.749	350	45	2.425	0.180	-0.089	-0.409	0.25	1210
0.749	400	45	2.119	0.164	-0.088	-0.409	0.25	1082
0.749	450	45	1.852	0.148	-0.087	-0.409	0.25	969
0.749	500	45	1.618	0.133	-0.086	-0.409	0.25	867
0.749	550	45	1.413	0.117	-0.084	-0.409	0.25	776
0.749	600	45	1.235	0.101	-0.083	-0.409	0.25	694
0.749	650	45	1.079	0.086	-0.082	-0.409	0.25	621

MF	Temp F	CVN ft-lb	C1	C2	C3	C4	da	JR
0.749	100	50	5.377	0.272	-0.097	-0.409	0.25	2329
0.749	150	50	4.698	0.256	-0.095	-0.409	0.25	2084
0.749	200	50	4.105	0.241	-0.094	-0.409	0.25	1865
0.749	250	50	3.587	0.225	-0.093	-0.409	0.25	1669
0.749	300	50	3.134	0.209	-0.092	-0.409	0.25	1493
0.749	350	50	2.738	0.194	-0.090	-0.409	0.25	1336
0.749	400	50	2.392	0.178	-0.089	-0.409	0.25	1196
0.749	450	50	2.090	0.163	-0.088	-0.409	0.25	1070
0.749	500	50	1.826	0.147	-0.087	-0.409	0.25	958
0.749	550	50	1.595	0.131	-0.085	-0.409	0.25	857
0.749	600	50	1.394	0.116	-0.084	-0.409	0.25	767
0.749	650	50	1.218	0.100	-0.083	-0.409	0.25	686

MF	Temp F	CVN ft-lb	C1	C2	C3	C4	da	JR
0.749	100	55	6.000	0.285	-0.098	-0.409	0.25	2549
0.749	150	55	5.242	0.269	-0.096	-0.409	0.25	2281
0.749	200	55	4.580	0.254	-0.095	-0.409	0.25	2041
0.749	250	55	4.002	0.238	-0.094	-0.409	0.25	1826
0.749	300	55	3.497	0.222	-0.093	-0.409	0.25	1634
0.749	350	55	3.055	0.207	-0.091	-0.409	0.25	1463
0.749	400	55	2.669	0.191	-0.090	-0.409	0.25	1309
0.749	450	55	2.332	0.175	-0.089	-0.409	0.25	1171
0.749	500	55	2.038	0.160	-0.088	-0.409	0.25	1048
0.749	550	55	1.780	0.144	-0.087	-0.409	0.25	938
0.749	600	55	1.555	0.128	-0.085	-0.409	0.25	839
0.749	650	55	1.359	0.113	-0.084	-0.409	0.25	751

Table B-1 (cont'd)

N-16 Nozzle Evaluation **C...ina Power & Light**

Pre-Irradiated CVN Model

flie = CPL5 Crack Extension da =0.3 inch

MF	Temp F	CVN ft-lb	C1	C2	C3	C4	da (inch)	JR in-lb/in^2
0.749	100	35	3.568	0.225	-0.093	-0.409	0.3	1752
0.749	150	35	3.117	0.209	-0.092	-0.409	0.3	1563
0.749	200	35	2.724	0.193	-0.090	-0.409	0.3	1394
0.749	250	35	2.380	0.178	-0.089	-0.409	0.3	1244
0.749	300	35	2.079	0.162	-0.088	-0.409	0.3	1110
0.749	350	35	1.817	0.146	-0.087	-0.409	0.3	990
0.749	400	35	1.587	0.131	-0.085	-0.409	0.3	883
0.749	450	35	1.387	0.115	-0.084	-0.409	0.3	788
0.749	500	35	1.212	0.099	-0.083	-0.409	0.3	703
0.749	550	35	1.059	0.084	-0.082	-0.409	0.3	627
0.749	600	35	0.925	0.068	-0.080	-0.409	0.3	560
0.749	650	35	0.808	0.052	-0.079	-0.409	0.3	499

MF	Temp F	CVN ft-lb	C1	C2	C3	C4	da	JR
0.749	100	40	4.160	0.242	-0.094	-0.409	0.3	1995
0.749	150	40	3.635	0.227	-0.093	-0.409	0.3	1779
0.749	200	40	3.176	0.211	-0.092	-0.409	0.3	1588
0.749	250	40	2.775	0.195	-0.091	-0.409	0.3	1416
0.749	300	40	2.424	0.180	-0.089	-0.409	0.3	1264
0.749	350	40	2.118	0.164	-0.088	-0.409	0.3	1127
0.749	400	40	1.851	0.148	-0.087	-0.409	0.3	1006
0.749	450	40	1.617	0.133	-0.086	-0.409	0.3	897
0.749	500	40	1.413	0.117	-0.084	-0.409	0.3	801
0.749	550	40	1.234	0.101	-0.083	-0.409	0.3	714
0.749	600	40	1.079	0.086	-0.082	-0.409	0.3	637
0.749	650	40	0.942	0.070	-0.081	-0.409	0.3	568

MF	Temp F	CVN ft-lb	C1	C2	C3	C4	da	JR
0.749	100	45	4.764	0.258	-0.096	-0.409	0.3	2237
0.749	150	45	4.162	0.242	-0.094	-0.409	0.3	1995
0.749	200	45	3.637	0.227	-0.093	-0.409	0.3	1780
0.749	250	45	3.177	0.211	-0.092	-0.409	0.3	1586
0.749	300	45	2.776	0.195	-0.091	-0.409	0.3	1417
0.749	350	45	2.425	0.180	-0.089	-0.409	0.3	1264
0.749	400	45	2.119	0.164	-0.088	-0.409	0.3	1128
0.749	450	45	1.852	0.148	-0.087	-0.409	0.3	1006
0.749	500	45	1.618	0.133	-0.086	-0.409	0.3	898
0.749	550	45	1.413	0.117	-0.084	-0.409	0.3	801
0.749	600	45	1.235	0.101	-0.083	-0.409	0.3	714
0.749	650	45	1.079	0.086	-0.082	-0.409	0.3	637

MF	Temp F	CVN ft-lb	C1	C2	C3	C4	da	JR
0.749	100	50	5.377	0.272	-0.097	-0.409	0.3	2478
0.749	150	50	4.698	0.258	-0.095	-0.409	0.3	2211
0.749	200	50	4.105	0.241	-0.094	-0.409	0.3	1972
0.749	250	50	3.587	0.225	-0.093	-0.409	0.3	1759
0.749	300	50	3.134	0.209	-0.092	-0.409	0.3	1570
0.749	350	50	2.738	0.194	-0.090	-0.409	0.3	1400
0.749	400	50	2.392	0.178	-0.089	-0.409	0.3	1249
0.749	450	50	2.090	0.163	-0.088	-0.409	0.3	1115
0.749	500	50	1.826	0.147	-0.087	-0.409	0.3	994
0.749	550	50	1.595	0.131	-0.085	-0.409	0.3	887
0.749	600	50	1.394	0.116	-0.084	-0.409	0.3	792
0.749	650	50	1.218	0.100	-0.083	-0.409	0.3	706

MF	Temp F	CVN ft-lb	C1	C2	C3	C4	da	JR
0.749	100	55	6.000	0.285	-0.098	-0.409	0.3	2718
0.749	150	55	5.242	0.269	-0.096	-0.409	0.3	2425
0.749	200	55	4.580	0.254	-0.095	-0.409	0.3	2164
0.749	250	55	4.002	0.238	-0.094	-0.409	0.3	1930
0.749	300	55	3.497	0.222	-0.093	-0.409	0.3	1722
0.749	350	55	3.055	0.207	-0.091	-0.409	0.3	1536
0.749	400	55	2.669	0.191	-0.090	-0.409	0.3	1371
0.749	450	55	2.332	0.175	-0.089	-0.409	0.3	1223
0.749	500	55	2.038	0.160	-0.088	-0.409	0.3	1091
0.749	550	55	1.780	0.144	-0.087	-0.409	0.3	973
0.749	600	55	1.555	0.128	-0.085	-0.409	0.3	868
0.749	650	55	1.359	0.113	-0.084	-0.409	0.3	775

Table B-1 (cont'd)

N-16 Nozzle Evaluation — Carolina Power & Light

Pre-Irradiated CVN Model

flie = CPL5 — Crack Extension da =0.35 inch

MF	Temp F	CVN ft-lb	C1	C2	C3	C4	da (inch)	JR in-lb/in^2
0.749	100	35	3.568	0.225	-0.093	-0.409	0.35	1830
0.749	150	35	3.117	0.209	-0.092	-0.409	0.35	1629
0.749	200	35	2.724	0.193	-0.090	-0.409	0.35	1450
0.749	250	35	2.380	0.178	-0.089	-0.409	0.35	1290
0.749	300	35	2.079	0.162	-0.088	-0.409	0.35	1148
0.749	350	35	1.817	0.146	-0.087	-0.409	0.35	1021
0.749	400	35	1.587	0.131	-0.085	-0.409	0.35	909
0.749	450	35	1.387	0.115	-0.084	-0.409	0.35	809
0.749	500	35	1.212	0.099	-0.083	-0.409	0.35	720
0.749	550	35	1.059	0.084	-0.082	-0.409	0.35	641
0.749	600	35	0.925	0.068	-0.080	-0.409	0.35	570
0.749	650	35	0.808	0.052	-0.079	-0.409	0.35	507

MF	Temp F	CVN ft-lb	C1	C2	C3	C4	da	JR
0.749	100	40	4.160	0.242	-0.094	-0.409	0.35	2090
0.749	150	40	3.635	0.227	-0.093	-0.409	0.35	1860
0.749	200	40	3.176	0.211	-0.092	-0.409	0.35	1655
0.749	250	40	2.775	0.195	-0.091	-0.409	0.35	1473
0.749	300	40	2.424	0.180	-0.089	-0.409	0.35	1311
0.749	350	40	2.118	0.164	-0.088	-0.409	0.35	1166
0.749	400	40	1.851	0.148	-0.087	-0.409	0.35	1038
0.749	450	40	1.617	0.133	-0.086	-0.409	0.35	924
0.749	500	40	1.413	0.117	-0.084	-0.409	0.35	822
0.749	550	40	1.234	0.101	-0.083	-0.409	0.35	732
0.749	600	40	1.079	0.086	-0.082	-0.409	0.35	651
0.749	650	40	0.942	0.070	-0.081	-0.409	0.35	579

MF	Temp F	CVN ft-lb	C1	C2	C3	C4	da	JR
0.749	100	45	4.764	0.258	-0.096	-0.409	0.35	2350
0.749	150	45	4.162	0.242	-0.094	-0.409	0.35	2091
0.749	200	45	3.637	0.227	-0.093	-0.409	0.35	1861
0.749	250	45	3.177	0.211	-0.092	-0.409	0.35	1656
0.749	300	45	2.776	0.195	-0.091	-0.409	0.35	1474
0.749	350	45	2.425	0.180	-0.089	-0.409	0.35	1311
0.749	400	45	2.119	0.164	-0.088	-0.409	0.35	1167
0.749	450	45	1.852	0.148	-0.087	-0.409	0.35	1038
0.749	500	45	1.618	0.133	-0.086	-0.409	0.35	924
0.749	550	45	1.413	0.117	-0.084	-0.409	0.35	822
0.749	600	45	1.235	0.101	-0.083	-0.409	0.35	732
0.749	650	45	1.079	0.086	-0.082	-0.409	0.35	651

MF	Temp F	CVN ft-lb	C1	C2	C3	C4	da	JR
0.749	100	50	5.377	0.272	-0.097	-0.409	0.35	2609
0.749	150	50	4.698	0.256	-0.095	-0.409	0.35	2322
0.749	200	50	4.105	0.241	-0.094	-0.409	0.35	2066
0.749	250	50	3.587	0.225	-0.093	-0.409	0.35	1839
0.749	300	50	3.134	0.209	-0.092	-0.409	0.35	1636
0.749	350	50	2.738	0.194	-0.090	-0.409	0.35	1456
0.749	400	50	2.392	0.178	-0.089	-0.409	0.35	1296
0.749	450	50	2.090	0.163	-0.088	-0.409	0.35	1153
0.749	500	50	1.826	0.147	-0.087	-0.409	0.35	1026
0.749	550	50	1.595	0.131	-0.085	-0.409	0.35	913
0.749	600	50	1.394	0.116	-0.084	-0.409	0.35	813
0.749	650	50	1.218	0.100	-0.083	-0.409	0.35	723

MF	Temp F	CVN ft-lb	C1	C2	C3	C4	da	JR
0.749	100	55	6.000	0.285	-0.098	-0.409	0.35	2868
0.749	150	55	5.242	0.269	-0.096	-0.409	0.35	2552
0.749	200	55	4.580	0.254	-0.095	-0.409	0.35	2271
0.749	250	55	4.002	0.238	-0.094	-0.409	0.35	2021
0.749	300	55	3.497	0.222	-0.093	-0.409	0.35	1799
0.749	350	55	3.055	0.207	-0.091	-0.409	0.35	1601
0.749	400	55	2.669	0.191	-0.090	-0.409	0.35	1424
0.749	450	55	2.332	0.175	-0.089	-0.409	0.35	1268
0.749	500	55	2.038	0.160	-0.088	-0.409	0.35	1128
0.749	550	55	1.780	0.144	-0.087	-0.409	0.35	1004
0.749	600	55	1.555	0.128	-0.085	-0.409	0.35	893
0.749	650	55	1.359	0.113	-0.084	-0.409	0.35	795

Table B-1 (cont'd)

N-16 Nozzle Evaluation — Carolina Power & Light

Pre-Irradiated CVN Model

flie = CPL5 Crack Extension da =0.4 inch

MF	Temp F	CVN ft-lb	C1	C2	C3	C4	da (inch)	JR in-lb/in^2
0.749	100	35	3.568	0.225	-0.093	-0.409	0.4	1900
0.749	150	35	3.117	0.209	-0.092	-0.409	0.4	1688
0.749	200	35	2.724	0.193	-0.090	-0.409	0.4	1498
0.749	250	35	2.380	0.178	-0.089	-0.409	0.4	1331
0.749	300	35	2.079	0.162	-0.088	-0.409	0.4	1181
0.749	350	35	1.817	0.146	-0.087	-0.409	0.4	1049
0.749	400	35	1.587	0.131	-0.085	-0.409	0.4	931
0.749	450	35	1.387	0.115	-0.084	-0.409	0.4	827
0.749	500	35	1.212	0.099	-0.083	-0.409	0.4	734
0.749	550	35	1.059	0.084	-0.082	-0.409	0.4	652
0.749	600	35	0.925	0.068	-0.080	-0.409	0.4	579
0.749	650	35	0.806	0.052	-0.079	-0.409	0.4	514

MF	Temp F	CVN ft-lb	C1	C2	C3	C4	da	JR
0.749	100	40	4.160	0.242	-0.094	-0.409	0.4	2176
0.749	150	40	3.635	0.227	-0.093	-0.409	0.4	1932
0.749	200	40	3.176	0.211	-0.092	-0.409	0.4	1715
0.749	250	40	2.775	0.195	-0.091	-0.409	0.4	1523
0.749	300	40	2.424	0.180	-0.089	-0.409	0.4	1352
0.749	350	40	2.118	0.164	-0.088	-0.409	0.4	1201
0.749	400	40	1.851	0.148	-0.087	-0.409	0.4	1068
0.749	450	40	1.617	0.133	-0.086	-0.409	0.4	947
0.749	500	40	1.413	0.117	-0.084	-0.409	0.4	841
0.749	550	40	1.234	0.101	-0.083	-0.409	0.4	747
0.749	600	40	1.079	0.086	-0.082	-0.409	0.4	663
0.749	650	40	0.942	0.070	-0.081	-0.409	0.4	589

MF	Temp F	CVN ft-lb	C1	C2	C3	C4	da	JR
0.749	100	45	4.764	0.258	-0.096	-0.409	0.4	2451
0.749	150	45	4.162	0.242	-0.094	-0.409	0.4	2176
0.749	200	45	3.637	0.227	-0.093	-0.409	0.4	1933
0.749	250	45	3.177	0.211	-0.092	-0.409	0.4	1716
0.749	300	45	2.776	0.195	-0.091	-0.409	0.4	1524
0.749	350	45	2.425	0.180	-0.089	-0.409	0.4	1353
0.749	400	45	2.119	0.164	-0.088	-0.409	0.4	1201
0.749	450	45	1.852	0.148	-0.087	-0.409	0.4	1067
0.749	500	45	1.618	0.133	-0.086	-0.409	0.4	947
0.749	550	45	1.413	0.117	-0.084	-0.409	0.4	841
0.749	600	45	1.235	0.101	-0.083	-0.409	0.4	747
0.749	650	45	1.079	0.086	-0.082	-0.409	0.4	663

MF	Temp F	CVN ft-lb	C1	C2	C3	C4	da	JR
0.749	100	50	5.377	0.272	-0.097	-0.409	0.4	2727
0.749	150	50	4.698	0.256	-0.095	-0.409	0.4	2421
0.749	200	50	4.105	0.241	-0.094	-0.409	0.4	2150
0.749	250	50	3.587	0.225	-0.093	-0.409	0.4	1909
0.749	300	50	3.134	0.209	-0.092	-0.409	0.4	1695
0.749	350	50	2.738	0.194	-0.090	-0.409	0.4	1505
0.749	400	50	2.392	0.178	-0.089	-0.409	0.4	1337
0.749	450	50	2.090	0.163	-0.088	-0.409	0.4	1187
0.749	500	50	1.826	0.147	-0.087	-0.409	0.4	1054
0.749	550	50	1.595	0.131	-0.085	-0.409	0.4	936
0.749	600	50	1.394	0.116	-0.084	-0.409	0.4	831
0.749	650	50	1.218	0.100	-0.083	-0.409	0.4	738

MF	Temp F	CVN ft-lb	C1	C2	C3	C4	da	JR
0.749	100	55	6.000	0.285	-0.098	-0.409	0.4	3003
0.749	150	55	5.242	0.269	-0.096	-0.409	0.4	2667
0.749	200	55	4.580	0.254	-0.095	-0.409	0.4	2368
0.749	250	55	4.002	0.238	-0.094	-0.409	0.4	2103
0.749	300	55	3.497	0.222	-0.093	-0.409	0.4	1867
0.749	350	55	3.055	0.207	-0.091	-0.409	0.4	1658
0.749	400	55	2.669	0.191	-0.090	-0.409	0.4	1472
0.749	450	55	2.332	0.175	-0.089	-0.409	0.4	1307
0.749	500	55	2.038	0.160	-0.088	-0.409	0.4	1161
0.749	550	55	1.780	0.144	-0.087	-0.409	0.4	1031
0.749	600	55	1.555	0.128	-0.085	-0.409	0.4	915
0.749	650	55	1.359	0.113	-0.084	-0.409	0.4	813

Appendix C

VESSEL Program Input and Output

NOTE: The information presented in this Appendix is for information only. As such, no conclusions are drawn from this Appendix. The computer program presented in this Appendix is not a verified program per Altran's Quality Assurance requirements.

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                           C
C                           C
C          VESSEL           C
C        VERSION 6.0        C
C       AUGUST, 1993        C
C                           C
C                           C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCC
```

```
************************************
*                                  *
*      LONGITUDINAL FLAW DATA      *
*                                  *
************************************
```

N-16 NOZZLES USE EVALUATION - BRUNSWICK UNIT 1

******ECHO OF INPUT DATA******

```
*************************************
*                                   *
*        VESSEL DIMENSIONS          *
*                                   *
*************************************
```

```
VESSEL OUTER RADIUS =        116.0  IN.
VESSEL THICKNESS =             5.5  IN.
```

```
************************************
*                                  *
*          COOLDOWN RATE           *
*                                  *
************************************
```

```
COOLDOWN RATE =              100.0 F/HR
```

```
*************************************
*                                   *
*    VESSEL MATERIAL PROPERTIES     *
*                                   *
*************************************
```

ELASTIC MODULUS = 25500500. PSI
FLOW STRESS = 62100. PSI

****
* J VS. CRACK EXTENSION *
****

DELTA A (INCHES)	J-ACTUAL (IN-LB/SQ IN)
.0200	382.00
.0500	468.00
.1000	531.00
.1500	567.00
.2000	593.00
.2500	612.00
.3000	628.00
.3500	642.00
.4000	653.00

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                      C
C                                      C
C       RESULTS OF PROGRAM VESSEL      C
C                                      C
C                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
```

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***********************************
*   J-R AND J/T MATERIAL CURVES   *
***********************************
```

```
J =      573.4 +     226.6*(DA) + (    -2.156)*( .085 + DA)**(-2)
```

T-MATL	J-MATL (IN-LB/SQ IN)	DELTA A (INCHES)

1.506	912.5	1.500
1.506	901.1	1.450
1.507	889.7	1.400
1.508	878.3	1.350
1.509	866.9	1.300
1.511	855.4	1.250
1.512	844.0	1.200
1.514	832.6	1.150
1.516	821.1	1.100
1.518	809.7	1.050
1.521	798.2	1.000
1.524	786.7	.950
1.528	775.1	.900
1.533	763.5	.850
1.540	751.9	.800
1.548	740.3	.750
1.558	728.5	.700
1.570	716.7	.650
1.587	704.8	.600
1.610	692.7	.550
1.641	680.4	.500
1.685	667.8	.450
1.749	654.9	.400
1.845	641.3	.350
1.998	626.8	.300
2.257	610.8	.250
2.730	592.1	.200
3.696	568.3	.150
6.002	533.0	.100
13.088	466.4	.050
16.099	444.4	.040
20.248	417.1	.030
26.131	382.3	.020
34.758	336.7	.010

```
************************************
*        J/T APPLIED CURVE         *
************************************
```

T-APPL	J-APPL (IN-LB/SQ IN)
2.402	605.6
2.331	587.7
2.260	569.9
2.190	552.1
2.119	534.3
2.048	516.5
1.978	498.7
1.907	480.9
1.836	463.1
1.766	445.3
1.695	427.4
1.625	409.6
1.554	391.8
1.483	374.0
1.413	356.2
1.342	338.4
1.271	320.6
1.201	302.8
1.130	285.0
1.059	267.2
.989	249.3
.918	231.5
.848	213.7
.777	195.9
.706	17[illegible]
.636	160.[illegible]
.565	142.5
.494	124.7
.424	106.9

.353	89.1
.283	71.2
.212	53.4
.141	35.6
.071	17.8
.000	.0

```
**************************************
*    DETERMINATION OF INSTABILITY    *
*              PRESSURE              *
**************************************
```

A EFF (INCH)	PL (PSI)	P-I (PSI)	PI/PL	J-I (IN-LB/SQ IN)
1.837	2981.	2266.	.76	606.

```
**************************************
*    DETERMINATION OF PRESSURE vs.   *
```

*   CRACK EXTENSION   *
****

da (INCH)	PRESSURE (PSI)
.229	2266.
.200	2246.
.150	2248.
.100	2228.
.050	2140.
.040	2102.
.030	2050.
.020	1976.
.010	1868.

PRESSURE, (PSI),	J-MATL, (IN-LB/SQ IN),	T-MATL,	da, (INCH),	J-APPL, (IN-LB/SQ IN),	T-APPL,
2266.	606.	2.402	.229	606.	2.402
2246.	592.	2.730	.200	125.	.494
2248.	568.	3.696	.150	107.	.424
2228.	533.	6.002	.100	89.	.353
2140.	466.	13.088	.050	71.	.283
2102.	444.	16.099	.040	53.	.212
2050.	417.	20.248	.030	36.	.141
1976.	382.	26.131	.020	18.	.071
1868.	337.	34.758	.010	0.	.000

PRESSURE, (PSI),	J-MATL, (IN-LB/SQ IN),	T-MATL,	da, (INCH),	J-APPL, (IN-LB/SQ IN),	T-APPL,
2266.	606.	2.402	.229	606.	2.402
2246.	592.	2.730	.200	125.	.494
2248.	568.	3.696	.150	107.	.424
2228.	533.	6.002	.100	89.	.353
2140.	466.	13.088	.050	71.	.283
2102.	444.	16.099	.040	53.	.212
2050.	417.	20.248	.030	36.	.141
1976.	382.	26.131	.020	18.	.071
1868.	337.	34.758	.010	0.	.000

ENCLOSURE 3

BRUNSWICK STEAM ELECTRIC PLANT, UNIT NOS. 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

LIST OF REGULATORY COMMITMENTS

The following table identifies those actions committed to by Carolina Power & Light Company in this document. Any other actions discussed in the submittal represent intended or planned actions by Carolina Power & Light Company. They are described to the NRC for the NRC's information and are not regulatory commitments. Please notify the Manager-Regulatory Affairs at the Brunswick Nuclear Plant of any questions regarding this document or any associated regulatory commitments.

Commitment	Committed date or outage
None	