February 20, 2001

Mr. Steve Byrne
Vice President, Nuclear Operations
South Carolina Electric & Gas Company
Virgil C. Summer Nuclear Station
Post Office Box 88
Jenkinsville, South Carolina 29065

SUBJECT: SAFETY EVALUATION REPORT - WCAP-15615, “INTEGRITY EVALUATION FOR FUTURE OPERATION: VIRGIL C. SUMMER NUCLEAR PLANT REACTOR VESSEL NOZZLE TO PIPE WELD REGIONS” (TAC NO. MB0251)

Dear Mr. Byrne:

NRC letter dated November 3, 2000, requested South Carolina Electric & Gas Company (SCE&G, the licensee) to assess and characterize detected flaws in the V. C. Summer Nuclear Plant reactor vessel hot leg nozzle-to-pipe welds, and provide information regarding resolution of the issues. By a letter dated December 26, 2000, SCE&G submitted WCAP-15615, Revision 1 (proprietary), and WCAP-15617, Revision 0 (non-proprietary), entitled, "Integrity Evaluation for Future Operation: Virgil C. Summer Nuclear Plant Reactor Vessel Nozzle to Pipe Weld Regions," for staff review. This evaluation was prepared to address the integrity of the reactor hot leg nozzle-to-pipe welds after discovery of a small leak in the A loop hot leg weld and identification of indications in all such hot leg welds. The staff also reviewed supplementary information contained in SCE&G’s January 9, 2001, response to the staff request for additional information (RAI) and in SCE&G’s presentation at the public meeting held at the plant site on January 18, 2001.

The proprietary WCAP-15615 contains the results of the Westinghouse examination and analysis of the reactor pressure vessel (RPV) nozzle-to-pipe welds for the hot and cold legs of all three loops (A, B, and C) using ultrasonic testing (UT) and eddy current testing (ET). In a letter dated January 16, 2001, the licensee stated that the A loop hot leg weld was removed in its entirety and sent off for non-destructive and destructive metallurgical testing. This repair technique of replacing the affected weld with an ASME Code-acceptable weld eliminates staff concerns with the A loop hot leg nozzle-to-pipe weld. The proprietary WCAP-15615 also contains a flaw evaluation to support the licensee’s conclusion that the unit, with ET indications on loops B and C hot leg nozzle welds, could be operated for at least two fuel cycles. The non-proprietary WCAP-15617 contains basically the same information as in WCAP-15615, but with certain portions deleted to address 10 CFR 2.790 withholding concerns.

The NRC staff reviewed SCE&G’s flaw evaluation regarding the detected indications in the RPV loops B and C hot leg nozzle-to-pipe welds. Based on this evaluation, the staff has concluded that the licensee’s determination that V. C. Summer can operate for two fuel cycles with the existing flaw indications, without confirmatory inspections, is not fully justified. The staff reached this conclusion based on the consideration that it is more appropriate to use a bounding crack growth rate instead of a best-estimate value because of the limited amount of data available regarding the crack growth rate for the material under consideration. The staff did conclude, however that the unit could be operated with ET indications in its loops B and C hot leg nozzle welds for one fuel cycle since the staff's evaluation finds that the subject nozzle welds satisfy the intent of Section XI requirements for flawed components.

In a letter dated January 9, 2001, SCE&G committed to perform the best and most meaningful nondestructive examination inspection available to ensure the integrity of the two susceptible hot leg welds at V. C. Summer. In that letter, at a minimum, the licensee has committed to undertake the best available ultrasonic inspection methods on the B and C hot leg nozzle-to-pipe welds at the completion of one cycle of V.C. Summer's operation, which will be Refueling Outage 13.

The Safety Evaluation is enclosed. This completes our effort on TAC No. MB0251.

Sincerely,

/RA/

Karen R. Cotton, Project Manager, Section 1
Project Directorate II
Division of Project Licensing Management
Office of Nuclear Reactor Regulation

Docket No. 50-395

Enclosure: As stated

cc w/encl: See next page

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SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

WCAP - 15615, INTEGRITY EVALUATION FOR FUTURE OPERATION

VIRGIL C. SUMMER NUCLEAR PLANT

REACTOR VESSEL NOZZLE TO PIPE WELD REGIONS

SOUTH CAROLINA ELECTRIC & GAS COMPANY

DOCKET NO.: 50-395

1.0 INTRODUCTION

By letter dated December 26, 2000, South Carolina Electric & Gas Company (SCE&G, the licensee) submitted WCAP-15615, Revision 1 (proprietary), and WCAP-15617, Revision 0 (non-proprietary), entitled, "Integrity Evaluation for Future Operation: Virgil C. Summer Nuclear Plant Reactor Vessel Nozzle to Pipe Weld Regions," for staff review. The staff also reviewed supplementary information contained in SCE&G's January 9, 2001, response to the staff request for additional information (RAI) resulting from the preliminary staff review of the subject WCAPs and in SCE&G's presentation at the public meeting held at the plant site on January 18, 2001. The proprietary WCAP-15615 contains the results of the Westinghouse examination of the reactor pressure vessel (RPV) nozzle to pipe welds for all three loops (loops A, B, and C) using ultrasonic testing (UT) and eddy current testing (ET). The proprietary WCAP-15615 also contains a flaw evaluation to support the licensee's conclusion that the unit, with ET indications on Loops B and C hot leg nozzle welds, could be operated for at least two fuel cycles. The non-proprietary WCAP-15617 contains basically the same information as in WCAP-15615, but with certain portions deleted to address 10 CFR 2.790 withholding concerns.

The staff has performed an independent evaluation using a bounding primary water stress corrosion cracking (PWSCC) growth rate, the initial ET indication length and depth, and the flow stress for Alloy 182, acceptable to the staff as described below. The staff also considered in this review the input provided by Argonne and Pacific Northwest National Laboratories (ANL and PNNL, respectively).

2.0 EVALUATION

2.1 Licensee's Flaw Evaluation

2.1.1 Fatigue Crack Growth

The licensee attributed the through-wall cracking in Loop A hot leg nozzle-to-pipe weld to interdendritic PWSCC. The licensee performed a parametric study to assess the impact due to fatigue crack growth using design transients. The analysis covered both the circumferential crack with an aspect ratio of 6 and the axial crack with an aspect ratio of 2, assuming initial flaw depths ranging from 0.2 inch to 0.8 inch with an increment of 0.2 inch (aspect ratio being the ratio of flaw length and depth). The results indicated that the fatigue crack growth for the longest assumed initial flaw depth of 0.8 inch is 0.053 inch for the circumferential crack and 0.0001 inch for the axial crack in a period of 10 years. Because these crack growths are small, the licensee concluded that PWSCC is the limiting mechanism for crack growth.

2.1.2 PWSCC Crack Growth

2.1.2.1 Initial Crack Length and Depth

The initial crack length and depth used by the licensee in its flaw evaluation for the axial indication were 0.234 inch and 0.117 inch, respectively. Using ET, the licensee detected two axial indications of length 0.25 inch in the RPV nozzle-to-pipe weld of Loop B hot leg. The licensee then projected the aspect ratio and the depth of these indications based on the ET results and the destructive inspection results later performed for a cut-out section containing the RPV nozzle-to-pipe weld of Loop A hot leg. Three axial flaws having similar length characteristics (i.e., 0.2, 0.275, and 0.350 inch) from destructive testing were selected, and their aspect ratios (2.2, 2.1, and 2.7, respectively) were used to justify the selection of an aspect ratio of 2 for the axial indication. The depth was the average of the depths (0.09, 0.129, and 0.132 inch, respectively) for the same axial flaws mentioned above.

In the flaw evaluation of the circumferential flaw, the licensee considered crack shapes of three aspect ratios 2, 3, and 6. The initial crack length for all three crack configurations was kept at a constant value of 0.55 inch, which was determined based on the two ET indications from Loop B hot leg (0.6 inch) and Loop C hot leg (0.5 inch). The use of the aspect ratio of two was based on the ET inspection results for axial flaws. The other aspect ratios were added for the parametric evaluation.

2.1.2.2 PWSCC Crack Growth

The licensee used the empirical formula for Alloy 182 weld from the EPRI proprietary report 1000037, “Crack Growth of Alloy 182 Weld Metal in PWR Environments (PWRMRP-21),” dated June 2000, to predict the PWSCC crack growth rate (CGR) for indications found in the Loops B and C RPV nozzle-to-pipe welds. This empirical CGR is a function of the stress intensity factor (K), and is based on 17 specimens from three different welds. With the initial crack configuration defined above and the empirical formula applied, the licensee calculated, in turn, (1) the applied K for the detected axial cracks using pressure and residual stresses, (2) the crack growth associated with this flaw for a period of 1 hour, and (3) a new crack depth by adding this growth to the initial crack depth. This process was repeated for every hour of crack growth until the allowable crack depth, from an ASME Code, Section XI analysis, was reached. Similarly, the above process was applied to the circumferential flaws using pressure, thermal, deadweight, and residual stresses to calculate the applied K for this case. The rest of the process remained the same for the circumferential flaws. The residual stresses were from the basis document for the piping flaw evaluation process of Section XI.

2.1.2.3 ASME Code, Section XI, Allowable Flaw Depth

The licensee performed an ASME Code, Section XI, Appendix C analysis to determine the allowable flaw depths for both the axial and circumferential indications. The loading includes pressure, deadweight, thermal, and operating basis earthquake (OBE), for the normal and upset conditions, and pressure, deadweight, thermal, and safe shutdown earthquake (SSE), for the emergency and faulted conditions. The safety factor is 2.77 for the former and 1.41 for the latter. Since the Code does not specify the stress intensity, S_m, for Alloy 182, the licensee used the Code-specified S_m of 23.3 ksi at 600°F for the base material, Alloy 600, in this application. The results indicated that the allowable crack depth is 75 percent of the pipe wall thickness, the maximum depth permitted by the Code, for both axial and circumferential flaws. It should be noted that this flaw evaluation was not required under the rules of Section XI of the ASME Code since the assumed depth of the ET indications were less than 10 percent through-wall.

2.1.2.4 Operating Time Determination

With the initial indication length and depth determined, the licensee proceeded to calculate the growth from this initial indication according to the procedure described in Section 2.1.2.2 on an hourly basis until the allowable depth, i.e., 75 percent of the wall thickness, is reached. This accumulated crack growth time at the allowable depth is the operating time for the unit to continue to operate with ET indications on RPV nozzle to pipe welds of Loops B and C hot legs. The licensee's results indicated that the operating time is 3.2 years for the axial flaw and 14 years, 8.4 years, and 3.4 years for the circumferential flaws with aspect ratios of 2, 3, and 6, respectively. Hence, the licensee concluded that the unit, with ET indications in Loops B and C hot leg nozzle welds, could be operated for at least two fuel cycles.

2.2 <u>Staff's Evaluation</u>

2.2.1 Fatigue Crack Growth

The licensee's fatigue crack growth analysis is in accordance with Section XI of the Code. The Section XI crack growth rate depends on the range of K (ΔK) induced by certain specified transients. The ΔK value, in turn, depends on the crack geometry (or aspect ratio) of the flaw. The licensee used an aspect ratio of 2 for the axial flaw and 6 for the circumferential flaw. These aspect ratios will be discussed in Section 2.2.2.1 below. As to the initial crack length and depth, the staff noted that, even for the deepest assumed flaw of 0.8 inch, the fatigue crack growth in 10 years would be 0.0528 inch for the circumferential flaw and 0.0001 inch for the axial flaw. The fatigue crack growth in a fuel cycle (1.5 years) would be correspondingly less. Therefore, the staff agrees with the licensee that PWSCC is the limiting mechanism of crack growth.

2.2.2 PWSCC Crack Growth

2.2.2.1 Initial Crack Length and Depth

UT is the only testing recognized by the Code for depth sizing of detected flaws in welds; therefore, the Code requires that the flaw evaluation be based on the crack dimensions as sized by UT for any detected indications. In the UT examination of the Loop A hot leg nozzle weld, a number of flaw indications were not detected by UT. Based on the destructive examination of the A hot leg weld, the deepest flaw indication missed by the UT examination was an axial flaw of 0.75 inch long and 0.615 inch deep. However, this flaw indication was detected by ET, which gave its length as 0.5 inch. A total of six ET indications were destructively confirmed and their flaw sizes were measured in the Westinghouse hot cell facility. The length uncertainties associated with the ET measurements based on this examination are shown in Table 1. The ET length uncertainties are calculated based on deviation from the destructively measured length. The staff notes that ET undersized the flaw length by as much as 60 percent for longer or deeper flaws (flaws #1, #2, and #3). However, for short or shallow flaws (flaws #4, #5, and #6), ET oversized the flaw length by as much as 66 percent. The ET indications reported in Loops B and C hot leg nozzle welds are relatively short with the longest indication in the axial orientation being only 0.25 inch. Therefore, the staff has determined that it is appropriate not to add additional uncertainties to the ET measured lengths in performing the subject flaw evaluation. As for the flaw aspect ratios shown in Table 1, the average aspect ratio of the four axial flaws is 2.05. The aspect ratios of flaws #1 and #2 are not displayed in Table 1 because the growth of these flaws is limited in the length and depth direction, respectively. Therefore, the aspect ratios of these flaws are not appropriate for generic application. It should be noted that for evaluation of indications in Loops B and C hot leg nozzle welds, the staff's initial length of 0.25 inch and depth of 0.125 inch, which were determined from the aspect ratio of 2 and the ET indications on the same welds, are more appropriate than the licensee's initial length of 0.234 inch and depth of 0.117 inch, which were determined from the aspect ratio of 2 and the ET indications in a different weld (Loop A hot leg nozzle weld.) Based on the above considerations, the staff has determined that it is reasonably conservative to use the as-reported ET indication length and an aspect ratio of 2.0 in the flaw growth calculation for Loop B and C hot leg nozzle welds. Hence, the flaw sizing meets the intent of Section XI requirements, and is consistent with the comments provided by PNNL.

2.2.2.2 PWSCC Crack Growth Rate

As stated previously, the licensee used an empirical K dependent formula, based on 17 specimens from three different welds, to predict the PWSCC CGR for flaw indications found in Loops B and C RPV hot leg nozzle to pipe welds. The licensee's formula takes the following form:

$$\text{CGR} = 1.4 \times 10^{-11} (K - 9)^{1.16} \text{ m/sec.}$$

The staff notes that the proposed CGR does not bound all data. Therefore, due to the lack of sufficient data, especially for Alloy 182 weld material for which only limited data are available, to be prudent the staff increased the rate by 50 percent to bound all data, and the revised (staff's) CGR becomes:

$$\text{CGR} = 2.1 \times 10^{-11} (K - 9)^{1.16} \text{ m/sec.}$$

This revised formula, which is consistent with the comments from ANL, was used throughout the staff's evaluation of the Summer cracking. The staff used this conservative CGR to account for uncertainties associated with the referenced CGR data and the residual stress distribution.

For the only variable in the above CGR formula, K, the licensee employed the Appendix A approach, which is based on the three-dimensional (3-D) finite element results of Raju-Newman. Although Appendix A was intended for an RPV integrity evaluation, its applicability to the piping is justified because the radius-to-thickness (R/t) ratio for the piping is 6.73, not far off from that for a RPV. Further, modeling the 3-D crack geometry affects K values much more than would be caused by using the precise R/t value.

2.2.2.3 Section XI Allowable Flaw Depth

The licensee performed a Section XI, Appendix C analysis and concluded that the allowable crack depth is 75 percent of the pipe wall thickness for both axial and circumferential indications. The 75 percent depth limit specified in the Code is based on consideration of UT limitations, not on structural concerns. The staff performed a parametric study to find the allowable flaw length and depth beyond the Code limit, which are limited by structural integrity concerns. To achieve this, the staff used the limit load approach of Appendix C and the loadings given in Table 2-1 of the WCAP to derive the piping membrane stress (P_m), the piping bending stress (P_b), and the piping expansion stress (P_e), to calculate the allowable flaw length and depth for the circumferential flaw. Formulas for axial flaws are also available in Appendix C; however, unlike the formulas for the circumferential flaws which were analytically derived, they are empirically derived from test results on both austenitic and ferritic piping. The staff used an S_m of 20.6 ksi, instead of the licensee's value of 23.3 ksi, in this analysis. Since S_m is not specified in the Code for Alloy 182, the staff derived it from the yield stress and the ultimate tensile stress for Alloy 182 at 619°F. The staff considered that deriving the flow stress from the yield and ultimate tensile stresses of Alloy 182 is more appropriate than using the Code-specified S_m for Alloy 600. The staff summarized the calculated allowable flaw length and depth for both the axial and circumferential indications in Table 2.

It should be noted that for axial and circumferential cracks growing radially and not yet reaching the outer wall, the allowable flaw lengths become smaller when the cracks grow closer to the outer wall. However, when the axial crack grows through-wall, the allowable crack becomes approximately ten-fold longer. This phenomenon does not occur with the circumferential flaw, since for a circumferential flaw, ductile collapse occurs when the entire cross-section of the piping containing the circumferential crack reaches the flow stress, with no sudden change in its load-bearing cross section when the circumferential flaw becomes through-wall. For an axial flaw, when the crack is not through-wall, ductile collapse occurs when the remaining ligament and a small amount of material in front of the axial crack reaches the flow stress; and, when the crack is through-wall, ductile collapse occurs when a significant amount of material in front of the axial crack reaches the flow stress. This significant amount of material in front of the axial crack cannot be defined by theory, and, consequently, the Appendix C formulas for the allowable axial crack depth are based on test data.

The staff's results confirmed the licensee's allowable flaw depth of 75 percent of the piping wall for the axial flaw and the circumferential flaws with aspect ratios of 2 and 3. The staff's result indicated, however, that the aspect ratio of the allowable circumferential flaw reaching 75 percent of the piping wall is 5.15, as opposed to the licensee's value of 6. This indicates a shorter flaw length per staff analysis vice the licensee's analysis. However, this difference is not significant. This discrepancy is caused by the staff's use of the S_m of 20.6 ksi in the calculation.

2.2.2.4 Operating Time Determination

The staff also performed a study to determine the operating time for Summer. The licensee's results indicated that the axial indication is limiting even when it was compared to a circumferential flaw with an aspect ratio of 6. It should be noted that this aspect ratio was selected by the licensee for the parametric evaluation showing how far the analyses can go, in terms of crack configurations, to support the operation time that they requested. Since the current data on circumferential flaws were insufficient to determine the aspect ratio, using the ratio of 2 for the axial flaws with additional conservatism is appropriate. Since the licensee's results indicated that the unit could be operated for 8.4 years for a circumferential flaw of aspect ratio 3, which exceed the 3.2 years for the axial flaw, the staff determined that the staff's evaluation on axial flaws is sufficient and bounding.

Also, unlike the licensee's approach, the staff started from the allowable flaw depth (with an aspect ratio of 2) and worked backward to determine the initial flaw depth, from which the crack will grow to the allowable flaw depth in a fuel cycle. The staff relied on hand calculations to carry out the simulations, only nine steps within the growth period have been conducted, as opposed to the licensee's one-hour-per-step approach. Table 3 documented the staff's effort in calculating the crack growth in one fuel cycle. The staff determined the K values in Table 3 using the Appendix A approach. According to the results obtained from using nine growth steps, the calculated allowable initial flaw depth is 0.148 inch, bounding the initial flaw depth of 0.125 inch, which demonstrates that the unit could be operated for 1.5 years.

3.0 CONCLUSION

The NRC staff has reviewed the licensee's flaw evaluation on the detected indications on the Loops B and C RPV hot leg nozzle-to-pipe welds. Based on the evaluation, the staff has determined that the licensee's request for two fuel cycles of operation is not justified. The staff concluded that the unit could be operated with ET indications in its Loops B and C RPV hot leg nozzle welds for one fuel cycle, since the allowable initial flaw depth of 0.148 inch bounds the initial flaw depth of 0.125 inch. Hence, the staff's independent evaluation satisfied the intent of Section XI requirements for flawed components.

Principle Contributor: S. Sheng, EMCB/DE

Date: February 20, 2001

TABLE 1

FLAW LENGTH COMPARISON: ET AND HOT CELL MEASUREMENTS
(Loop A hot leg nozzle weld)

Flaw No.	Direction	ET Length (inch)	Actual Crack Shape		ET Length Uncertainties		Aspect Ratio (Length/ Depth)
			Length (inch)	Depth (inch)	Δ (1) (inch)	Δ (2) (percent)	
1	Axial	1.75	2.5	2.5	-0.75	-42	-
2	Circ.	1.00	1.6	0.2	-0.60	-60	-
3	Axial	0.5	0.75	0.615	-0.25	-50	1.21
4	Axial	0.5	0.35	0.132	0.15	30	2.65
5	Axial	0.4	0.275	0.129	0.125	31	2.13
6	Axial	0.6	0.20	0.090	0.40	66	2.22

Notes:

(1) Δ (inch) = (ET Length) - (Actual Crack Length)
(2) Δ (percent) = (ET Length - Actual Crack Length)/(ET Length)

TABLE 2

ALLOWABLE FLAW LENGTH BASED ON SECTION XI METHODOLOGY

crack depth/ wall thickness (a/t)	Allowable flaw length based on Section XI methodology			
	Axial flaw		Circumferential flaw	
	Length (inches)	Aspect ratio	Length (inches)	Aspect ratio
0.75	4.35	2.47	9.06	5.15
0.875	2.74	1.34	7.76	3.78
1.0	35	Through-wall	6.78	Through-wall

TABLE 3

ALLOWABLE INITIAL FLAW DEPTH WHICH CAN SUSTAIN ONE FUEL CYCLE (AXIAL FLAWS)

	Allowable final flaw configurations for axial flaws (l = 4.35 inches; a/t = 0.75; a/l = 1/2.0) 9 growth steps		
a/t for the growing crack front	K(ksi. √in)	CGR (in/hr) $x10^{-4}$	Time (yrs)
0.083	16.45	0.385	0.279
0.125	20.23	0.595	0.187
0.167	23.47	0.785	0.142
0.208	26.30	0.956	0.117
0.256	29.31	1.142	0.195
0.375	36.14	1.581	0.212
0.500	42.53	2.008	0.167
0.625	48.20	2.397	0.140
0.750	52.83	2.721	0.061
		∑=	1.5
Allowable Initial a/t	0.063 (or 0.148 inch)		

cc:

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