UNITED STATES
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SAFETY EVALUATION REGARDING THE SUPPLEMENTAL RESPONSE TO GENERIC LETTER 94-03, "INTERGRANULAR STRESS CORROSION CRACKING OF CORE SHROUDS IN BOILING WATER REACTORS"

PENNSYLVANIA POWER & LIGHT COMPANY

SUSQUEHANNA STEAM ELECTRIC STATION, UNIT 1

DOCKET NO. 50-387

1.0 INTRODUCTION

The core shroud in a Boiling Water Reactor (BWR) is a stainless steel cylindrical component within the reactor pressure vessel (RPV) that surrounds the reactor core. The core shroud serves as a partition between feedwater in the reactor vessel's downcomer annulus region and the cooling water flowing up through the reactor core. In addition, the core shroud provides a refloodable volume for safe shutdown cooling and laterally supports the fuel assemblies to maintain control rod insertion geometry during operational transients and accidents.

In 1990, crack indications were observed at core shroud welds located in the beltline region of an overseas BWR. This reactor had completed approximately 190 months of power operation before discovery of the cracks. As a result of this discovery, General Electric Company (GE), the reactor vendor, issued Rapid Information Communication Services Information Letter (RICSIL) 054, "Core Support Shroud Crack Indications," on October 3, 1990, to all owners of GE BWRs. The RICSIL summarized the cracking found in the overseas reactor and recommended that at the next refueling outage plants with high-carbon-type 304 stainless steel shrouds perform a visual examination of the accessible areas of the seam welds and associated heat-affected zone (HAZ) on the inside and outside surfaces of the shroud.

Subsequently, a number of domestic BWR licensees performed visual examinations of their core shrouds in accordance with the recommendations in GE RICSIL 054 or in GE Services Information Letter (SIL) 572, which was issued in late 1993 to incorporate domestic inspection experience. Of the inspections performed to date, significant cracking was reported at several plants. The combined industry experience from these plants indicates that both axial and circumferential cracking can occur in the core shrouds of GE designed BWRs.

On July 25, 1994, the NRC issued Generic Letter 94-03, "Intergranular Stress Corrosion Cracking of Core Shrouds in Boiling Water Reactors" (Reference 1). The NRC staff requested in GL 94-03 that licensees take the following actions with respect to their core shrouds: 1) inspect their core shrouds in their BWR plants no later than the next refueling outage; 2) perform materials related and plant-specific consequence safety analyses with respect to their core shrouds; 3) develop core shroud inspection plans which address inspection of all core shroud welds and which take into account the latest available inspection technology; 4) develop plans for evaluation and/or repair of their core shrouds; and 5) work closely with the BWR Owners Group with respect to addressing intergranular stress corrosion cracking of BWR internals.

GL 94-03 requested that licensees submit, under oath or affirmation, the following information within 30 days of the date of issuance: 1) a schedule for inspection of their core shrouds; 2) a safety analysis, including a plant-specific safety analysis as appropriate, which supports continued operation of the facility until inspections are conducted; 3) a drawing(s) of the core shroud configurations; and 4) a history of shroud inspections completed to date. The GL also requested that licensees submit, under oath or affirmation, no later than 3 months prior to performing their core shroud inspections, their scope for inspection of their core shrouds and their plans for evaluating and/or repairing their core shrouds based on their inspection results. The GL further requested licensees to submit, under oath or affirmation their core shroud inspection results within 30 days of completing their shroud examinations.

The Pennsylvania Power and Light Company (PP&L, the licensee) responded to GL 94-03 on August 24, 1994 (Reference 2). PP&L's response of August 24, 1994 provided their schedule for implementing the Susquehanna Steam Electric Station, Unit 1 and 2, (Unit 1 will henceforth be abbreviated SSES-1; Unit 2 as SSES-2) core shroud examinations, their plant-specific safety analyses, their core shroud examination histories, and diagrams of the SSES-1 and SSES-2 core shroud configurations. The staff issued their Safety Evaluation (SE) regarding the acceptability of the PP&L response to GL 94-03 on March 23, 1995 (Reference 3). On December 19, 1994, PP&L supplemented their response to GL 94-03 (Reference 4) with information regarding the SSES-1 core shroud inspection scope. The staff acknowledged and accepted the SSES-1 shroud inspection scope on April 10, 1995 (Reference 5). On April 21, 1995, PP&L submitted its interim response to GL 94-03 with information regarding the results of the SSES-1 core shroud examinations and flaw evaluations performed during SSES-1 Refueling and Inspection Outage No. 8 (8RIO) (Reference 6). The licensee's submittals included the results and flaw evaluations regarding the licensee's core shroud examinations which were performed during 8RIO. Section 2.0 of this safety evaluation provides the staff's assessment of the licensee's submittal of April 21, 1995.

2.0 EVALUATION

2.1 Fabrication of the SSES-1 Core Shroud and Operational History of the SSES-1 Unit

The description of the SSES-1 core shroud may be found in the licensee's August 24, 1994, response to GL 94-03 (Reference 1). The staff has previously reviewed the licensee's response to GL 94-03 and has determined that the licensee's response to GL 94-03 was acceptable (Reference 2). The licensee submitted information related to the SSES-1 core shroud materials and fabrication methods in their response to GL 94-03. A brief summary of the materials and fabrication information is summarized by the items listed on the following page:

- Material specification - American Society for Testing and Materials (ASTM) A-240 Type 304L stainless steel plate. The carbon content of these plates ranged from 0.014% to 0.026%.

- Weld filler metals were either Type 308 or 308L stainless steels.

- The SSES-1 core shroud was fabricated from rolled plates which were cut to shape and welded together.

In their response to GL 94-03, PP&L also provided information regarding the operational history of SSES-1. The following information briefly summarizes the operational factors relative to intergranular stress corrosion cracking (IGSCC) of the SSES-1 core shroud.

- SSES-1 operated at relatively low ionic content levels in the reactor coolant during the initial years of operation. The initial five year average reactor coolant conductivity for the SSES-1 coolant was 0.205 μS/cm, which is lower than the entire population of U.S. BWRs (where the conductivities range from ~0.123 μS/cm to 0.717 μS/cm, and average ~ 0.340 μS/cm)

- SSES-1 has accumulated a total of 8.23 on-line years of operation. Thus, the SSES-1 core has operated for significantly less operating time than the majority of U.S. BWRs (range is 3.7 years - 17.8 years).

The staff concluded in its SE of March 23, 1995 (Reference 3) that, since the SSES-1 core shroud was fabricated using low carbon content Type 304L stainless steel, the SSES-1 core shroud should have a lower probability of having IGSCC indications than would core shrouds fabricated from high carbon, Type 304 stainless steel plates. The staff also concluded that the short duration of power operation (i.e. less total time at power operation) would also lower the probability of IGSCC. Taking these factors into account and qualitatively comparing these factors to those of other BWRs with shroud inspection data, the staff therefore determined that the SSES-1 core shroud was moderately susceptible to IGSCC. The staff's assessment was consistent with the assessment of the Boiling Water Reactor Vessel and Internals Project (BWRVIP).

The staff therefore concluded in their SE of March 23, 1995, that PP&L's April 1995 schedule for performing examinations of the SSES-1 core shroud was acceptable and consistent with the recommendations of the BWRVIP.

2.2 Core Shroud Inspection Scope and Examination Results

Pursuant to GL 94-03, PP&L provided the staff with its scope for the examinations of the SSES-1 core shroud on December 19, 1994 (Reference 4). PP&L indicated that the scope of the SSES-1 core shroud examinations would cover examinations of the H3, H4, H5, H6A and H7 welds, with the intent of the examinations being 100% coverage of all accessible weld areas for these welds. The staff acknowledged and accepted the licensee's inspection scope on April 10, 1995 (Reference 5).

The results of PP&L's core shroud examinations are provided in Reference 6. The staff determined that the licensee's implementation of the SSES-1 shroud inspection scope actually exceeded the scope that was approved by the staff on March 23, 1995. This is a conservative inspection approach by PP&L. The staff has reviewed the licensee's core shroud inspection results and determined that, in reporting the results of the SSES-1 core shroud examinations to the NRC, PP&L conservatively added crack growth and NDE uncertainties to the "raw" non-destructive examination (NDE) indication data. These added uncertainties are in accordance with the inspection and flaw evaluation criteria developed by the BWRVIP, and are further discussed in Section 2.3 of this SER (Reference 7)[1]. The staff also determined that the licensee applied the BWRVIP crack proximity rules as the means for determining the effective crack lengths of relevant indications, and confirmed that the effective crack lengths were the ones used as the basis for the licensee's flaw evaluations of the H2, H4, H5 and H6B welds. The crack results for circumferential shroud welds H1 - H9 are summarized in Table 2.2-1 (Attachment 1 to this SE).

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1 The limit load flaw evaluation methods and crack proximity rules contained in Revision 1 of "BWR Core Shroud Inspection and Evaluation Guidelines," dated April 21, 1995, are the same as those contained in the original version of the "BWR Core Shroud Inspection and Evaluation Guidelines," dated Sept. 2, 1994. While the staff has not formally reviewed and accepted the "BWR Core Shroud Inspection and Evaluation Guidelines," Rev. 1, the staff has approved these methods in the original version of the document (See staff "Evaluation of 'BWR Shroud Cracking Generic Safety Assessment Revision 1,' GENE-523-A107P-0794, August 5, 1994 and 'BWR Core Shroud Inspection and Evaluation Guidelines,' GENE-523-113-0894,' September 2, 1994," dated Dec. 28, 1994 [Reference 8].).

2.3 Licensee's Flaw Evaluations of SSES-1 Shroud Welds H1 - H7

The staff determined that the licensee applied the flaw evaluation approach found in the "BWR Core Shroud Inspection and Evaluation Guidelines," Revision 1 as the basis for performing flaw evaluations of the SSES-1 core shroud (Reference 7). This approach applies a limit load evaluation method which is used as means of determining whether the remaining shroud ligaments are structurally acceptable for further operating service. The licensee evaluated the shroud welds under upset and faulted conditions as these conditions constitute the most extreme loading conditions for the SSES-1 core shroud. PP&L performed the flaw evaluations of shroud welds in the circumferential direction. The licensee used the following conservative assumptions as the basis for performing the flaw evaluations of the H2, H4, H5 and H6B circumferential welds.

1. Measured flaw indications from the ultrasonic testing (UT) data were conservatively increased in length in accordance with the criteria for UT uncertainty and tool position uncertainty found in the BWRVIP" BWR Core Shroud Inspection and Evaluation Guidelines" (Reference 7).

2. Measured flaw indications from the UT data were also increased in length by a total of 2.63 inches to account for crack growth at both ends of the crack indication over the next two operating cycles. In this case, the licensee used a bounding NRC accepted crack growth rate of $5X10^{-5}$ in/hr for the adjustment (Reference 7).

3. Flaws that were located within a specified distance of each other were combined in accordance with the proximity rules found in the "BWR Inspection and Flaw Evaluation Guidelines" (Reference 7).

4. Portions of shroud welds that were inaccessible to UT scanning equipment and unable to be examined by UT examination were assumed to be cracked through-wall.

5. All flaw indications were considered to be through-wall flaws.

Linear elastic fracture mechanics methods (LEFM) were not used by the licensee to evaluate the core shroud, because the neutron fluence levels for the H1 - H7 welds were estimated to be less than 3.2×10^{20} nvt at the end of the operating cycle. The need for LEFM methods only becomes important when neutron fluence levels are high enough to result in embrittlement of the internal stainless steel materials (i.e., typically only when the levels are above 1×10^{21} nvt).

In the licensee's flaw evaluations, PP&L used the stress values from the most conservative plant loading conditions as the inputs for performing the limit load evaluations of the H2, H4, H5 and H6B welds. The limit load results for shroud welds H2 and H6B indicate that each of these welds have sufficient remaining ligaments in the circumferential direction to justify operation for two additional cycles of plant service. The results of the flaw evaluations regarding the H4 and H5 welds indicate that each of these welds have sufficient remaining structural ligament to justify operation for one additional cycle of plant service. The results of the licensee's flaw evaluations of the H2, H4, H5 and H6B welds are summarized in Table 2.3-1 (Attachment 2 to this SE).

The licensee did not perform any flaw evaluations of the H1 or H6A welds since the cracks at these welds were all limited to less than 12 inches in total length, respectively. The staff has previously accepted screening criteria proposed by the GE as part of its flaw evaluation methods for assessing circumferential weld cracks (References 9 & 10). In this case, the total amount of cracking at the H1 and H6A welds was significantly less than the screening criteria limits that were proposed earlier GE. The licensee also did not perform any flaw evaluations of the H3, and H7 welds, as the UT results for these welds did not identify any relevant flaw indications.

The staff has noted that the licensee also performed enhanced VT-1 examinations of the H8 and H9 welds. These VT-1 examinations were beyond the scope originally submitted to the staff on Dec. 19, 1994. No relevant indications were identified as a result of the VT-1 examinations of the H8 and H9 welds. The staff has reviewed the licensee's flaw evaluation results for welds H2, H4, H5 and H6B, and has determined that the licensee's results met the acceptance criteria defined in Section 4.0 of the BWRVIP "BWR Core Shroud Inspection and Flaw Evaluation Guidelines," Revision 1 (Reference 7). The staff therefore finds that the results of the SSES-1 core shroud examinations and flaw evaluations are acceptable.

3.0 CONCLUSION

The staff has reviewed the results of the SSES-1 core shroud examinations and flaw evaluations performed by PP&L during 8RIO, and has determined that PP&L has conservatively used the criteria found in the BWRVIP "Core Shroud Inspection and Evaluation Guidelines," Revision 1, as the basis for performing inspections and flaw evaluations of the SSES-1 core shroud (Reference 7). Therefore, the staff concludes that SSES-1 can be safely operated for the next operating cycle without necessitating an immediate repair of the SSES-1 core shroud. PP&L is required to either re-inspect or repair the SSES-1 core shroud during the fall 1996 RIO (No. 9RIO).

Attachments: 1. Table 2.2-1
2. Table 2.3-1

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Date: May 3, 1995

4.0 REFERENCES

1. NRC Generic Letter 94-03, "Intergranular Stress Corrosion Cracking of Core Shrouds in Boiling Water Reactors," dated July 25, 1994.

2. PP&L submittal of the "Susquehanna Steam Electric Station Initial Response to Generic Letter 94-03," dated August 24, 1994.

3. NRC Letter to PP&L regarding "Generic Letter (GL) 94-03, 'Intergranular Stress Corrosion Cracking of Core Shrouds in BWRs,' Pennsylvania Power & Light Company, Susquehanna Steam Electric Station, Units 1 and 2 (TAC Nos. M90112 and M90113)," dated March 23, 1995.

4. PP&L submittal of the "Susquehanna Steam Electric Station Interim Response to Generic Letter 94-03," dated December 19, 1994.

5. NRC letter to PP&L regarding "Susquehanna Steam Electric Station, Units 1 and 2, Interim Response to Generic Letter 94-03, 'Intergranular Stress Corrosion Cracking of Core Shrouds in BWRs,' (TAC Nos. M90112 and M90113)," dated April 10, 1995.

6. PP&L submittal "Susquehanna Steam Electric Station Generic Letter 94-03 Interim Inspection Report," dated April 21, 1995.

7. Boiling Water Reactor Vessel and Internals Project (BWRVIP) "BWR Core Shroud Inspection and Evaluation Guidelines," Revision 1, dated April 21, 1995.

8. NRC Staff "Evaluation of 'BWR Shroud Cracking Generic Safety Assessment Revision 1,' GENE-523-A107P-0794, August 5, 1994 and 'BWR Core Shroud Inspection and Evaluation Guidelines,' GENE-523-113-0894,' September 2, 1994," dated December 28, 1994.

9. General Electric Corporation Report GENE-523-123-0993, Revision 2, "Evaluation and Screening Criteria for the Brunswick 1 Shroud Indications," dated November 1993.

10. NRC letter to Mr. R. A. Anderson, Vice President, Brunswick Nuclear Project, Carolina Power and Light Company, submitting the staff Safety Evaluation regarding "Evaluation and Repair of the Core Shroud Cracks, Brunswick Steam Electric Plant, Unit 1 (TAC No. M87270), January 14, 1994."

Table 2.2-1 Susquehanna Steam Electric Station, Unit 1 - 8RIO Shroud Examination Results

Weld No.	Pct. Cov.	NDE Method	No. Indicat.	Max. Depth	Tot. Cr. Length	Max. Cr. Length
H1	83.2	UT	3	NG	4.6 in.	2.4 in.
H2	83.2	UT	29	NG	54.4 in.	9.1 in.
H3	84.1	UT	NI	NA	NA	NA
H4	82.7	UT	28	0.70 in.	187.5 in.	51.0 in.
H5	72.7	UT	27	0.65 in.	189.9 in.	32.9 in.
H6A	83.9	UT	8	0.25 in.	2.2 in.	11.9 in.
H6B	84.2	UT	19	0.68 in.	65.3	14.3
H7	80.8	UT	NI	NA	NA	NA
H8	NG	VT-1	NI	NA	NA	NA
H9	NG	VT-1	NI	NA	NA	NA

Footnotes: 1. Circumferential crack indications located within a given distance of each other, as delineated by the proximity criteria found in the BWRVIP "BWR Core Shroud Inspection and Evaluation Guidelines," are added together and considered one indication.

Legend: Weld No. - Weld identification number.
Pct. Cov. - Total percentage of circumference covered by inspections.
NDE Method - Non-destructive examination method.
No. Indicat. - No of relevant indications identified by NDE technique.
Max. Depth - Maximum Depth of indications recorded for this location of indications.
Tot. Cr. Length - The sum of the crack lengths of the individual indications at this weld location.
Max. Cr. Length - Crack length of the longest indication at this weld location.
NI - No indications recorded.
NA - Not applicable.
NG - Not given in the results
UT - Ultrasonic Testing.
VT-1 - Enhanced Visual Testing-1 as defined in Section XI of the ASME Code.

ATTACHMENT 1

Table 2.3-1 Results of Limit Load Analyses of the SSES-1 Core Shroud Weld H2, H4, H5 and H6B in the Circumferential Direction

Weld No.	Loading Condition	Membrane Stress	Bending Stress	Min. Allow. Safety Fact. (SF)	Min. Calc. SF
H2	Upset	282 psi	562 psi	2.77	12.91
H2	Faulted	740 psi	1281 psi	1.39	6.97
H4	Upset	265 psi	1385 psi	2.77	4.31
H4	Faulted	696 psi	2113 psi	1.39	2.41
H5	Upset	265 psi	2426 psi	2.77	2.92
H5	Faulted	696 psi	3587 psi	1.39	1.87
H6B	Upset	479 psi	2373 psi	2.77	5.38
H2	Faulted	911 psi	4810 psi	1.39	3.57

Legend: 1. Min. Allow. Safety Fact. (SF) - Minimum Allowable Safety Factor.
2. Min. Calc. SF - Minimum Calculated Safety Factor from Limit Load Analysis

ATTACHMENT 2