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

RESPONSE TO GENERIC LETTER 94-03

BROWNS FERRY NUCLEAR PLANT UNITS 1, 2 AND 3

TENNESSEE VALLEY AUTHORITY

DOCKET NOS. 50-259, 50-260, AND 50-296

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 (GL) 94-03, "Intergranular Stress Corrosion Cracking of Core Shrouds in Boiling Water Reactors," to all BWR licensees (with the exception of Big Rock Point) to address the potential

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for cracking in their core shrouds. GL 94-03 requested BWR licensees to take the following actions with respect to their core shrouds:

- inspect their core shrouds no later than the next scheduled refueling outage;
- perform a safety analysis supporting continued operation of the facility until the inspections are conducted;
- develop an inspection plan which addresses inspections of all shroud welds, and which delineates the examination methods to be used for the inspections of the shroud, taking into consideration the best industry technology and inspection experience to date on the subject;
- develop plans for evaluation and/or repair of the core shroud; and
- work closely with the BWR Owners Group (BWROG) on coordination of inspections, evaluations, and repair options for all BWR internals susceptible to intergranular stress corrosion cracking.

The Tennessee Valley Authority (TVA), the licensee for Browns Ferry Nuclear Plant (BFN), Units 1, 2 and 3, responded to GL 94-03 on August 24, 1994. The licensee's response included a current schedule for inspecting the core shrouds for Units 1 and 2, an assessment of the results from an inspection of the Unit 3 core shroud completed prior to the issuance of the GL 94-03, justification supporting continued operation of BFN Unit 2 (Units 1 and 3 are currently in an outage), and a description of each unit's core shroud. Per the reporting requirements of the generic letter, the licensee submitted the results from the inspection of the Unit 2 core shroud on November 18, 1994. The staff obtained additional information from the licensee during a phone call on December 19, 1994. This Safety Evaluation gives the staff's assessment of the licensee's response to GL 94-03 and their evaluation of the BFN Units 2 and 3 core shroud inspection results.

2.0 INSPECTION AND ASSESSMENT OF BFN CORE SHROUD CRACKING

BFN Unit 1 is currently in an outage with no scheduled date for refuel and subsequent startup. The licensee has indicated that the Unit 1 core shroud will be inspected prior to restart. Inspection results will then be evaluated to justify operation of the unit.

BFN Unit 3 has been in an outage since prior to issuance of GL 94-03. The licensee completed an inspection of the Unit 3 core shroud in July 1994. Since both Unit 1 and 3 have not operated since the generic letter was issued, the licensee did not submit a justification for continued operation (JCO) for these units. On the basis of the inspection results and a structural margin analysis for the Unit 3 core shroud, the licensee determined that Unit 3 can safely resume operation without repair. The staff finds this determination to be acceptable. The licensee has indicated that they will complete a similar analysis to justify a resumption of operation for BFN Unit 1 after an inspection of this unit's core shroud is completed.

TVA completed an inspection of the Unit 2 core shroud in October 1994. On November 18, 1994, the licensee submitted their results from the Unit 2 shroud inspection, in accordance with the generic letter request. The results from the Unit 3 inspection were included in the licensee's original response to GL 94-03. The following is the staff's evaluation of:

1. the licensee's assessment of the potential for core shroud cracking in BFN Units 1, 2 and 3;

2. the inspection scope for the Unit 2 and 3 core shroud examinations completed in July and October of 1994, respectively; and

3. the structural integrity assessment of cracks identified during the inspections.

2.1 Susceptibility of the BFN Core Shrouds to IGSCC

The core shroud cracks which are the subject of GL 94-03, result from intergranular stress corrosion cracking (IGSCC) which is most often associated with sensitized material near the component welds. IGSCC is a time-dependent phenomenon requiring a susceptible material, a corrosive environment, and a tensile stress within the material.

Industry experience has shown that austenitic stainless steels with low carbon content are less susceptible to IGSCC than stainless steels with higher carbon content. BWR core shrouds are constructed from either type 304 or 304L stainless steel. Type 304L stainless steel has a lower carbon content than type 304 stainless steel. During the shroud fabrication process when the sections of the core shroud are welded together, the heating of the material adjacent to the weld metal sensitizes the material. Sensitization involves carbon diffusion out of solution forming carbides at grain boundaries upon moderate heating. The formation of carbides at the grain boundaries depletes the chromium in the adjacent material. Since the corrosion resistance of stainless steel is provided by the presence of chromium in the material, the area adjacent to the grain boundary depleted of chromium is thereby susceptible to corrosion. Increased material resistance to IGSCC will result if the carbon content is kept below 0.035%, as specified for type 304L grade material.

Currently available inspection data indicate that shrouds fabricated with forged ring segments are more resistant to IGSCC than rings constructed from welded plate sections. The current understanding for this difference is related to the surface condition resulting from the two shroud fabrication processes. Welded shroud rings are constructed by welding together arcs machined from rolled plate. This process exposes the short transverse direction in the material to the reactor coolant. Elongated grains and stringers in the material exposed to the reactor coolant environment are believed to accelerate the initiation of IGSCC.

Water chemistry also plays an important role in regard to IGSCC susceptibility. Industry experience has shown that plants which have operated with a history of high reactor coolant conductivity have been more susceptible

to IGSCC than plants which have operated with lower conductivities[1]. Furthermore, industry experience has shown that reactor coolant systems (RCSs) which have been operated at highly positive, electrochemical potentials (ECPs) have been more susceptible to IGSCC than RCSs that have been operated at more negative ECPs[2]. The industry has made a considerable effort to improve water chemistry at nuclear facilities over the past ten years. Industry initiatives have included the introduction of hydrogen water chemistry as a means of lowering ECPs (i.e., making the ECPs more negative) in the RCS. The effectiveness of hydrogen water chemistry in reducing the susceptibility of core shrouds to IGSCC initiation has not been fully evaluated; however, its effectiveness in reducing IGSCC in recirculation system piping has been demonstrated. Browns Ferry does not currently utilize hydrogen water chemistry.

Welding processes can introduce high residual stresses in the material at the weld joint. The high stresses result from thermal contraction of the weld metal during cooling. A higher residual tensile weld stress will increase the material's susceptibility to IGSCC. Although weld stresses are not easily quantified, previous investigation into weld stresses indicate that tensile stresses on the weld surface may be as high as the yield stress of the material. The stress decreases to compressive levels in the center of the welded section.

TVA has reviewed the materials, fabrication and operational histories (water chemistry and on-line years) of the BFN core shrouds and has submitted this information to the staff in their response to GL 94-03. The plant-specific susceptibility factors are summarized below:

- The shell plate materials are constructed using American Society for Testing and Materials (ASTM) A240 Type 304 stainless steel plate. The maximum carbon content is 0.06%. The ring segments were fabricated with an ASTM, A-182 F304 forging. Shroud sections below weld H7 are made with Inconel 600.

- All three BFN units operated with relatively high reactor coolant ionic content levels during the initial years of operation. During the first five cycles of operation the average reactor coolant conductivities for Units 1, 2 and 3 were 0.384, 0.364, and

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[1]Conductivity is a measure of the anionic and cationic content of liquids. As a reference, the conductivity of pure water is ~0.05 μs/cm. Reactor coolants with conductivities below 0.20 us/cm are considered to be relatively ion free; reactor coolants with conductivities above 0.30 μs/cm are considered to have a relatively high ion content.

[2]The electrochemical potential (ECP) is a measure of a material's susceptibility to corrosion. In the absence of an externally applied current, and therefore, for reactor internals in the RCS, the electrochemical potential is equal to the open circuit potential of the material. Industry experience has shown that crack growth rates in reactor internals are low when the ECP $\leq$ ~-0.230 volts.

0.303 µS/cm, respectively. For the entire population of U.S. BWRs, the average for this value is approximately 0.340 µS/cm ranging from 0.123 µS/cm to 0.717 µS/cm.

- BFN Unit 2 accumulated approximately 9 on-line years of operation as of October 1, 1994. Prior to entering their current outages Units 1 and 3 have operated for approximately 6.5 and 5 on-line years, respectively. The BFN core shrouds have low to average operational service in comparison to the majority of U.S. BWRs (range is 3.7 years - 17.8 years).

Based on a review of the above plant-specific susceptibility factors necessary for IGSCC the staff concludes that the BFN core shrouds are likely to contain some cracking; however the extent of any IGSCC should be less than that identified at other BWRs. Inspection results discussed in Section 3.0 below confirm this conclusion for Units 2 and 3. In the report "BWR Core Shroud Inspection and Flaw Evaluation Guidelines" (GENE-523-113-0894, September 1994), the BWRVIP classified the Browns Ferry shrouds as highly susceptible to IGSCC (Category C), and recommended comprehensive shroud inspections. The staff concurs with this assessment.

2.2 Inspection of BFN Unit 2 and 3 Core Shrouds

The licensee completed an inspection of the BFN Unit 2 core shroud on October 22, 1994. Per the reporting requirements of GL 94-03 and Section XI of the ASME Code, the licensee submitted the results from the Unit 2 shroud inspection on November 18, 1994. The results from this inspection confirmed that the Unit 2 core shroud did contain some cracking; however, the cracking was limited. A more detailed discussion of these inspection results is provided in Section 2.2.2 below.

The licensee completed an inspection of the BFN Unit 3 core shroud on July 14, 1994. Results of this inspection were presented to the NRC during a meeting held on August 11, 1994, and were submitted as an enclosure to the licensee's GL 94-03 response. The inspection identified cracking at three weld locations on the Unit 3 core shroud. However, the extent of cracking was limited. The licensee and General Electric completed an analysis which demonstrated that the BFN Unit 3 core shroud has adequate margin to operate for at least one additional cycle.

2.2.1 Scope of Core Shroud Inspections

The licensee used both enhanced visual (VT-1) and ultrasonic test (UT) inspection methods during the inspection of the BFN Unit 3 core shroud. The bulk of the inspection utilized UT techniques. Two UT inspection methods were employed during the inspection, the Smart-2000 system developed by General Electric and suction cup scanners. Weld examination with the Smart-2000 system utilized 45° shear wave (45S) and 60° refracted longitudinal wave (60RL) search units. VT-1 inspections utilized additional lighting methods for improved contrast for flaw detection.

For the inspection of the BFN Unit 2 core shroud, the licensee utilized only UT methods. UT examinations were performed using the General Electric Smart-2000 system and suction cup scanners. Weld examination with the Smart-2000 system utilized 45S, 60RL, and OD creeping wave search units. The OD creeping wave unit is particularly sensitive for the detection of shallow surface flaws. No visual inspection methods were used during the inspection of the Unit 2 core shroud.

The licensee indicated in their submittals that the scope of both inspections covered 100% of the accessible weld length. Inspection procedures were developed in accordance with the Sections V and XI of the ASME Code, NRC/BWROG/EPRI recommendations, and GE SIL-572. Table 1 summarizes the extent of coverage for each weld examined during the core shroud inspection.

Table 1: Extent of Coverage for BFN Units 2 and 3 Core Shroud Inspections

Weld Number	Unit 2		Unit 3	
	Total Length (in.)	Percentage (%)	Total Length (in.)	Percentage (%)
H1	230	33	284	41
H2	439	63	470	68
H3	415	63	544	83
H4	401	61	439	67
H5	401	61	266	40
H6	21	3	28	4
H7	14	2	28	4

The extent of accessible weld for inspection on the BFN core shrouds is comparable to that for other BWRs. The licensee encountered considerable difficulty performing a comprehensive inspection of lower shroud welds (H6 and H7) due to nondestructive evaluation (NDE) equipment accessibility problems. This problem is not unique to the Browns Ferry units. The staff urges all BWR licensees to work with various vendors and the EPRI NDE Center in order to develop improved reliable tooling for inspections of shroud welds which are highly obstructed. Should improved inspections techniques become available, the staff recommends licensees reinspect the lower shroud welds at the earliest opportunity.

2.2.2 Inspection Results

The licensee's inspection of the BFN Unit 2 core shroud examined portions of circumferential welds H1 through H7. Flaws were detected and sized using one or more UT methods. Cracking was identified in or adjacent to three welds: H2, H3, and H5. The indications, however, were minor. The largest linear crack was identified just below the H3 weld. The crack extended just over

four inches in length. The deepest crack measured 0.96 inches. The summary sheet for the examination of this weld noted that the 0.96 inch crack depth was an estimate due to complications involved in sizing this particular flaw. Table 2 summarizes the results of the BFN Unit 2 inspection.

Table 2: BFN Unit 2 Inspection Results

Weld Number	Number of Indications	Total Length of Cracking (in.)	Largest Linear Flaw (in.)	Maximum Flaw Depth (in.)
H1	0	-	-	-
H2	1	1.34	1.34	0.18
H3	3	9.41	4.34	0.8
H4	0	-	-	-
H5	6	9.09	2.9	0.96
H6	0	-	-	-
H7	0	-	-	-

The inspection of the BFN Unit 3 core shroud included an examination utilizing both VT-1 and UT techniques. The VT-1 inspection covered only limited portions of the H6 and H7 welds. No indications were identified during the visual inspection. The UT examination of all the welds found cracking at three different welds: H1, H4, and H5. The extent of cracking at H1 and H4 was minor relative to that at weld H5. Weld H5 contained a total of 26 indications extending 81.7 inches in length around the shroud circumference. Four cracks were identified using the suction cup scanners; the Smart-2000 system identified 22 of the 26 flaws. Nearly one-half of the total crack length on the H5 weld can be attributed to one indication over thirty inches in length. The remaining cracks were all less than five inches. Table 3 summarizes the results from the Unit 3 core shroud inspection.

Table 3: BFN Unit 3 Inspection Results

Weld Number	Number of Indications	Total Length of Cracking (in.)	Largest Linear Flaw (in.)	Maximum Flaw Depth (in.)
H1	5	3.90	1.3	0.56
H2	0	-	-	-
H3	0	-	-	-
H4	1	1.8	1.8	0.57
H5	26	81.7	32.2	0.68
H6	0	-	-	-
H7	0	-	-	-

The inspection of the BFN Unit 2 and 3 core shrouds identified cracking at three welds during each examination. Cracks were detected and sized using UT methods. All cracking is considered minor, with the exception of that identified at the H5 weld location in the Unit 3 core shroud. With the exception of one crack in the H2/H3 ring section in the Unit 2 shroud all flaws were either in the shroud shell plates or in the weld.

2.2.3 Licensee's Assessment of Inspection Results

Cracks identified during the inspections were initially compared to plant-specific screening criteria. The BFN screening criteria is consistent with that established in a document submitted to the NRC by the BWROG, "BWR Core Shroud Evaluation" (GE-NE-523-148-1193), April 5, 1994. This criteria is similar to that approved for use in the inspection of cracking of the Brunswick Nuclear Plant Unit 1 core shroud. With the exception of cracking identified at the H5 weld on the BFN Unit 3 core shroud all indications were below the inspection screening limits.

Cracking identified at the BFN Unit 3 H5 core shroud weld exceeded the inspection screening criteria. The licensee completed an analytical evaluation to assess the residual structural integrity of the H5 weld. The licensee utilized a flaw assessment methodology consistent with that described in the BWROG submittal dated April 5, 1994. Due to the low fluence at the H5 weld, results of a limit load analysis indicate that the Unit 3 core shroud will maintain adequate structural integrity for at least one operating cycle.

The results from the inspection of the BFN Unit 2 core shroud did not identify any cracking exceeding the screening criteria. Nevertheless, the licensee analytically evaluated the strength of the H5 weld using the same methods as done for the same weld on the BFN Unit 3 core shroud. The licensee concluded that the BFN Unit 2 core shroud should maintain adequate structural integrity for at least two operating cycles.

2.2.4 Staff Evaluation of BFN Unit 2 and 3 Core Shroud Inspections

The licensee's response to GL 94-03 included a summary of the inspection of the BFN Unit 3 core shroud, and the licensee's assessment of identified cracks. On November 18, 1994, the licensee submitted the summary and results of the inspection of the BFN Unit 2 core shroud. The staff has reviewed the inspection scope, flaw screening criteria, assessment methodology, and conclusions regarding the significance of cracks found during the inspections.

The scope of both inspections included an examination of 100 percent of the accessible horizontal weld areas. This is consistent with the current staff recommendation for BWRs with core shrouds which are comparably susceptible to IGSCC. Due to difficulty in examining the lower shroud welds, H6 and H7, the licensee was able to inspect less than five percent of the total weld length during both inspections. The inability to examine a significant length of these lower circumferential welds is a problem which is not unique to the Browns Ferry units. Other licensees have encountered similar difficulty during inspection of the lower welds. Efforts are currently underway to address this problem. The staff has urged BWR licensees to work with various

vendors in order to develop improved, reliable tooling for the inspection of such welds.

Should improved inspection techniques become available, the staff recommends that the licensee inspect the lower core shroud welds at the earliest opportunity.

The staff reviewed the inspection screening criteria and flaw evaluation methods which formed the bases for the plant-specific approaches used for the inspection of the BFN Unit 2 and 3 core shrouds and found them acceptable. In addition, the staff reviewed the results of each inspection which describe the length and depth of all identified cracks. All cracking is considered minor with the exception of the flaws identified on the BFN Unit 3 H5 weld. However, the licensee concluded that the Unit 3 core shroud has sufficient uncracked ligament at the H5 weld to maintain adequate structural integrity for at least one additional operating cycle. The staff concurs with this assessment.

The licensee completed an analysis of the limited cracking on the H5 weld for BFN Unit 2 and concluded that the unit can safely operate for at least two operating cycles. The staff does not agree with this conclusion based on the limited information available regarding the condition of the lower core shroud welds. However, the licensee indicated in a phone call on December 19, 1994, that although the analysis concluded the Unit 2 core shroud would maintain adequate structural margin for up to two operating cycles, the licensee has committed to reinspect the core shroud in accordance with the guidance provided by the BWR Vessels and Internals Project (BWRVIP). Currently, the BWRVIP recommends inspecting the BFN core shrouds during each refueling outage. The staff agrees with this recommendation.

3.0 CONCLUSION

The licensee's initial response to GL 94-03 of August 23, 1994, as well as the submittal dated November 18, 1994, indicate that the BFN Unit 2 and 3 core shrouds will maintain sufficient structural margins for at least one operating cycle. The staff concurs with this assessment. The licensee has committed to inspect and assess the condition of the Unit 1 core shroud prior to restart. The staff concludes the schedule for the inspection of the Unit 1 core shroud is acceptable.

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