UNITED STATES
NUCLEAR REGULATORY COMMISSION
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SAFETY EVALUATION OF THE RESPONSE TO GL 94-03

FOR DUANE ARNOLD ENERGY CENTER

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CENTRAL IOWA POWER COOPERATIVE
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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 to all BWR licensees (with the exception of Big Rock Point) to address the potential for cracking in their core shrouds. GL 94-03 requested BWR licensees to take the

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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 that addresses inspections of all shroud welds, and that 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 BWROG on coordination of inspections, evaluations, and repair options for all BWR internals susceptible to intergranular stress corrosion cracking.

IES Utilities Inc., the licensee for the Duane Arnold Energy Center (DAEC), responded to GL 94-03 on August 24, 1994. The licensee's response included a current schedule for inspecting the DAEC core shroud, justification supporting continued operation of the plant, a description of the shroud, and a discussion of past core shroud inspection results. This Safety Evaluation gives the staff's assessment of the licensee's response to GL 94-03.

2.0 JUSTIFICATION FOR CONTINUED OPERATION AND SCHEDULE FOR INSPECTION

IES Utilities Inc. has scheduled an inspection of the DAEC core shroud for the current refueling outage. The following is the staff's assessment of the licensee's basis for justifying continued operation of DAEC from July 25, 1994, the date of issuance of GL 94-03, until the scheduled inspection date.

2.1 Susceptibility of the DAEC Core Shroud to IGSCC

The core shroud cracks that 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 phenomena 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. The formation of carbides at the grain boundaries upon moderate heating (sensitization) is hindered for type 304 stainless steels with carbon contents below 0.03%. BWR core shrouds are constructed from either type 304 or 304L stainless steel. The slightly lower carbon content of type 304L (< 0.035%) make it less prone to develop IGSCC.

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, electro-chemical 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.

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.

The licensee has reviewed and submitted information related to the DAEC core shroud materials and fabrication methods. The following is a brief summary of this information.

- material specification - American Society for Testing and Materials (ASTM) A-240 Type 304L stainless steel plate.

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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.

- The DAEC core plate support rings were fabricated from welded plate sections.

Since the DAEC core shroud was fabricated with low carbon type 304 stainless steel, it is less likely to develop IGSCC than shrouds with higher carbon content materials. However, the welded core plate support rings increase the potential for IGSCC initiation in the ring sections. The staff concludes that the DAEC is susceptible to IGSCC, but to a lesser degree than core shrouds at other U.S. BWRs.

2.2 Operational History

In response to GL 94-03 the licensee submitted information regarding the operational history of the DAEC. The following briefly summarizes the factors related to core shroud IGSCC.

- DAEC operated at moderate reactor coolant ionic content levels during the initial years of operation. During the first five cycles of operation, the reactor coolant water conductivity at DAEC averaged 0.333 μS/cm which is near the average for 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).

- DAEC has accumulated a total of 13.5 on-line years of operation. Thus, the DAEC core shroud has more operational service than the majority of U.S. BWRs (range is 3.7 years - 17.8 years).

- The licensee began operating with hydrogen water chemistry at DAEC in 1987. Although the potential benefits of such a measure are not fully quantified at this time, such programs have been shown to be successful in reducing IGSCC in recirculation system piping.

Because of the moderate reactor water conductivity during the first five cycles of operation and the relatively long operational history, the possibility exists that DAEC core shroud contains some IGSCC. However, the extent of any cracking should be less than that observed in other previously inspected BWR core shrouds.

2.2 Basis for Continued Operation

In response to GL 94-03, the licensee submitted a justification for continued operation (JCO) based on the core shroud material's susceptibility to IGSCC and the absence of observed cracking in previous limited inspections of the shroud. The following summarizes the staff review of the licensee's response.

As discussed in Section 2.1, the core shroud at DAEC is constructed with type 304L stainless steel. The higher resistance to IGSCC of this material compared with type 304 stainless steel decreases the likelihood that extensive cracking will be observed upon inspection.

The water conductivity during the first five years of operation was in the moderate range in comparison with other BWRs. Although it is anticipated that some cracks may have initiated during these years, the low carbon content of the shroud material would tend to inhibit early IGSCC initiation.

During refueling outage (RFO) 11 in 1990, the licensee performed a limited inspection of the accessible portions of several vertical shroud welds and a single horizontal weld in the beltline region of the core. The visual inspection with one mil wire resolution did not identify any shroud cracking. Additional horizontal and vertical welds were inspected later in 1993 (RFO 12). No crack-like indications were observed. However, due to the limited scope of past inspections, the possibility of significant cracks in the shroud cannot be discounted.

The staff has reviewed the inspection results for other BWRs with core shrouds more susceptible to IGSCC and notes that there has been no instance where a 360° through-wall crack existed in any plant that was inspected. Further, no BWR has exhibited any symptoms (power to flow mismatch) caused by leakage through a 360° through-wall crack. All analyses performed by licensees for higher susceptibility plants show that even if cracking did exist, ligaments would exist to assure structural integrity. In addition, there is a low probability for an initiating event that could potentially challenge the integrity of the core shroud, and there was only a short duration of operation until the licensee implements the necessary inspections or repairs.

3.0 CONCLUSION

The staff concludes that while significant cracking cannot be entirely ruled out, the DAEC core shroud should have retained adequate structural margin for safe operation until the current refueling outage. The conditions relevant to IGSCC initiation and growth for the DAEC core shroud are bounded by conditions at other BWRs. Thus, the extent of IGSCC in the DAEC core shroud will likely be bounded by cracks identified at these other plants, and all of these cracks had sufficient ligament to maintain structural integrity. The staff has reviewed the licensee's basis for justifying continued operation of the DAEC until the current refueling outage, and has determined that the licensee's materials-based JCO is acceptable.

4.0 OUTSTANDING ISSUES/FUTURE ACTIONS

In accordance with the reporting requirements of GL 94-03, the licensee shall submit to the NRC, no later than 3 months prior to performing the core shroud inspections, both the inspection plan and the licensee's plans for evaluating and/or repairing the shroud based on the inspection results. In addition, results should be provided to the NRC within 30 days from the completion of the inspection.

The licensee indicated in their response that they may adjust their core shroud inspection schedule and scope per guidance from the BWR Vessel & Internals Project (BWRVIP). At present, the NRC has not approved the inspection guidelines proposed by the BWRVIP. Considerable differences remain with regard to the recommended scope of core shroud inspections. The staff cautions the licensee against modifying their plans according to BWRVIP recommendations that have not undergone review and approval by the NRC. Should the licensee opt to install a preemptive repair in lieu of performing a comprehensive core shroud inspection, the only required inspection is that mandated in the staff approval of the repair option.

It should be noted that the industry is currently encountering difficulty in performing comprehensive inspections of lower shroud welds due to non-destructive examination (NDE) equipment accessibility problems. The staff urges licensees to work with various vendors and the EPRI NDE Center in order to develop improved reliable tooling for inspections of shroud welds that are highly obstructed.

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