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

RESPONSE TO GENERIC LETTER 94-03

PEACH BOTTOM ATOMIC POWER STATION, UNIT 3

PECO ENERGY COMPANY

DOCKET NO. 50-278

1.0 BACKGROUND

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

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BWR licensees (with the exception of Big Rock Point, which does not have a core shroud) to address the potential for cracking in their core shrouds. GL 94-03 requested BWR licensees 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 BWROG on coordination of inspections, evaluations, and repair options for all BWR internals susceptible to intergranular stress corrosion cracking.

The PECO Energy Company (PECO), the licensee for the Peach Bottom Atomic Power Station, Unit 3 (PBAPS 3), responded to GL 94-03 on August 24, 1994 (Reference 1). Part of the licensee's response included PECO's inspection scope for the planned re-inspections of the PBAPS 3 core shroud, which were scheduled for refueling outage (RFO) 3R010 in the fall of 1995. PECO provided additional information regarding the 3R010 shroud inspection plans in a letter dated June 16, 1995.

The licensee previously completed an inspection of the PBAPS 3 core shroud during the refueling outage 3R09 during the fall of 1993. The General Electric Nuclear Energy Division formally submitted the examination results and assessment of core shroud structural integrity to the NRC by letter dated December 3, 1993. PECO amended the results and assessment by letter dated March 14, 1994. The NRC staff's review of the results of PECO's inspection and assessment is documented in a safety evaluation dated February 6, 1995.

2.0 EVALUATION OF THE LICENSEE'S RESPONSE TO GL 94-03

PECO scheduled and performed comprehensive inspections of the PBAPS 3 core shroud during the unit's RFO 3R010, which commenced in September, 1995. The following gives the staff's assessment of the susceptibility of the PBAPS 3 core shroud, the scope of the inspection completed during RFO 3R010, and the licensee's assessment of identified cracking.

2.1 Susceptibility of the PBAPS 3 Core Shroud to Intergranular Stress Corrosion Cracking (IGSCC)

The core shroud cracks which are the subject of GL 94-03, result from 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. 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 0.030%, as specified for type 304L grade material.

Currently available inspection data indicates 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)

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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 μs/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.

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 10 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.

PECO has reviewed the materials, fabrication and operational histories of the PBAPS 3 core shroud and has submitted this information to the staff in their response to GL 94-03. The PBAPS 3 plant-specific susceptibility factors are summarized below:

- The shroud support, top guide support, and core support plate rings are fabricated from two welded 304 stainless steel, forged ring segments, with carbon contents of ~0.030%. The shroud shell region was fabricated by welding rolled 304 stainless steel plates together. The carbon content of the PBAPS 3 shroud plates are in the range of 0.050 - 0.065%.
- Welding of the shroud plates and rings for circumferential welds H1 - H6 was accomplished by submerged arc welding using ER308 filler metal. Welding of the bi-metallic weld, H7, was accomplished by gas metal arc welding using filler metal 82. Weld residual stress levels resulting from these fabrication processes are high.
- PBAPS 3 operated at high reactor coolant ionic content levels during the initial years of operation. The initial 5-year average coolant conductivity for PBAPS 3 was 0.695 μS/cm, which is considerably higher than the average for other U.S. BWRs (where the conductivities range from ~0.123 μS/cm to 0.717 μS/cm, and average ~ 0.340 μS/cm).

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[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 ≤ ~-0.230 volts.

- PBAPS 3 had, at the time of the August 24, 1994 response to GL 94-03, operated for 11 cumulative years at full power, which is slightly above the median for U.S. BWRs (range is 3.7 years - 17.8 years, with a median of 10.8 years).

A review of the plant-specific factors which increase the potential for IGSCC in BWR core shrouds reveals that PBAPS 3 initially operated at high reactor coolant conductivity during the first five cycles of operation. In addition, the carbon content of the material which comprises the PBAPS 3 core shroud is relatively high. On these bases, the Boiling Water Reactor Vessels & Internals Project (BWRVIP) has classified the PBAPS 3 core shroud as a susceptible Category "C" shroud. The staff has also determined that the PBAPS 3 core shroud is susceptible to IGSCC, and therefore concludes that the BWRVIP's susceptibility assessment is acceptable. This conclusion is supported by the identification of moderate cracking during the 1993 and 1995 shroud inspections. The 1995 PBAPS 3 inspections are discussed further in the following section.

2.2 Inspection of the Peach Bottom Unit 3 Core Shroud

By letter dated November 3, 1995, PECO submitted the PBAPS 3 core shroud inspection scope, examination results and their flaw evaluation.

2.2.1 Scope of Core Shroud Inspection

The PBAPS 3 shroud examinations were performed using ultrasonic testing (UT) methods developed by the General Electric Corporation (GE). The UT examinations used GE's Smart-2000 Data Acquisition System and the GE OD Tracker and suction cup scanners. The extent of the planned UT examinations included all accessible portions of circumferential shroud welds H1 - H7. The UT examinations were performed using three UT transducers, a 45° shear wave transducer, a 60° longitudinal wave transducer, and a creeping wave transducer which was used to pick up surface indications. The licensee indicated that it had completed the following PBAPS 3 core shroud UT examinations:

- 84.5% of the length (583") of weld H1,
- 84.5% of the length (583") of weld H2,
- 89.5% of the length (583") of weld H3,
- 89.2% of the length (580") of weld H4,
- 90.8% of the length (591") of weld H5,
- 80.1% of the length (506") of weld H6,
- 89.6% of the length (565") of weld H7.

2.2.2 Core Shroud Examination Results

The following summarizes the cracking identified at each weld during the examination of the PBAPS 3 core shroud.

- H1 Weld - The examination detected 7 indications by UT using 45°S/60°RL transducers, totalling 27.95 inches, with a maximum length of 5.38 inches and a maximum depth of 0.73 inches at Indication #7;

- H2 Weld - Examinations were negative for indications;

- H3 Weld - 10 indications were detected by UT using 45°S/60°RL transducers, totalling 203.41 inches, with the maximum length being 53.21 inches at Indication #6 and a maximum depth of 0.85 inches at Indication #5;

- H4 Weld - 36 indications were identified, totalling 186.71 inches, with the maximum length of 27.11 inches at Indication #18 and one indication (#18) with a depth size greater than 50% through wall;

- H5 Weld - 9 indications were identified, totalling 44.53 inches in length as detected by UT using 45°S/60°RL transducers, with a maximum length of 9.11 inches at Indication #3 and a maximum depth of 0.23 inches at Indication #3;

- H6 Weld - Examinations were negative for indications;

- H7 Weld - Examinations were negative for indications.

Interference from core spray downcomer piping and lifting lugs limited access to the shroud welds to less than 100% of the total weld length. The licensee's inspection plan is consistent with the staff's position recommending a 100% inspection of all accessible shroud weld areas.

2.2.3 Assessment of the PBAPS 3 Core Shroud Inspection Results

Flaws identified in welds receiving a comprehensive examination during the fall 1995 RFO were evaluated in accordance with the methodology outlined in the "BWR Core Shroud Inspection and Flaw Evaluation Guidelines" (Reference 2). These guidelines closely follow the flaw evaluation guidelines found in Section XI of the ASME Code. The staff has reviewed the BWRVIP evaluation guidelines and approves of the use of the quantitative assessment methods.

The licensee's evaluations were based on the following assumptions and conditions:

- All as-found indications were assumed to be through-wall, which removed the necessity for depth characterization. Additionally, any areas inaccessible to inspection were assumed to contain through-wall indications over their entire lengths.

- For the H2, H6 and H7 welds, in which no indications were found, the areas inaccessible to inspection were assumed to contain through-wall indications.

. As-found crack lengths were adjusted for crack growth, non-destructive examination uncertainties, and crack proximity factors in accordance with the guidelines in Reference 2.

Inspection results were compared to the initial screening criteria and were subsequently evaluated for safety margins using limit load methodology found in Reference 2. The inspection results of the H3 and H4 welds were also subject to evaluation using linear elastic fracture mechanics methods to account for high neutron fluences which are common at these weld elevations.

For all postulated loadings the licensee showed that the loadings conditions for the as-found conditions in welds H1 - H7 were less than the ASME Code stress intensity allowables. The licensee's evaluations of the PBAPS 3 core shroud indicate that the shroud will maintain its structural integrity even under the most severe loading conditions for a given shroud weld location. The staff has reviewed the licensee's methodology, and has determined that the licensee's method of evaluating the PBAPS 3 core shroud is acceptable and that the licensee's evaluation results justify operation of the PBAPS 3 unit for the next operating cycle.

3.0 CONCLUSIONS

Based on a review of the PBAPS 3 core shroud materials, fabrication processes and operating history, the staff previously concluded that the licensee's core shroud is susceptible to IGSCC. PECO completed an examination of the PBAPS 3 core shroud during refueling outage 3R010. The licensee's evaluation of the PBAPS 3 core shroud indicates that the PBAPS 3 core shroud will maintain sufficient structural margins to justify operation of the PBAPS 3 reactor for another operating cycle without necessitating a modification of the PBAPS 3 core shroud.

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4.0 REFERENCES

1. Letter from G. A. Hunger, Jr., PECO, to the U.S. Nuclear Regulatory Commission, forwarding the "Peach Bottom Atomic Power Station, Units 2 and 3, Limerick Generating Station, Units 1 and 2, Response to Generic Letter 94-03, 'Intergranular Stress Corrosion Cracking of Core Shroud in Boiling Water Reactors," dated August 24, 1994.

2. "BWR Core Shroud Inspection and Flaw Evaluation Guidelines," GENE-523-113-0894, Revision 1, March, 1995.