SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

RELATED TO THE RESPONSE TO GL 94-03

PILGRIM NUCLEAR POWER STATION

BOSTON EDISON

DOCKET NO. 50-293

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

Enclosure

- 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.

Boston Edison, the licensee for the Pilgrim Nuclear Power Station (Pilgrim), responded to GL 94-03 on August 27, 1994. The licensee's response included a schedule for inspection of the core shroud at Pilgrim and a safety assessment to support continued operation through the remainder of the current cycle. In a public meeting on October 4, 1994, and in submittals dated October 7, 1994, October 13, 1994, and October 28, 1994, the licensee provided additional information pertinent to justifying continued operation until the end of the current cycle.

2.0 JUSTIFICATION FOR CONTINUED OPERATION AND SCHEDULE FOR INSPECTION/REPAIR

Boston Edison will perform a preemptive repair during the next refueling outage scheduled for April 1995. The following is the staff's assessment of the licensee's basis for justifying continued operation of Pilgrim.

2.1 Susceptibility of the Pilgrim Core Shroud 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. 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%) makes 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, 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.

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.

Boston Edison has reviewed the materials, fabrication and operational histories (water chemistry and on-line years) of the Pilgrim core shroud and has submitted this information to the staff in its response to GL 94-03.

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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.

[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 core shroud of Pilgrim is susceptible to intergranular stress corrosion cracking (IGSCC) and its susceptibility ranking is considered relatively high among all domestic BWRs. The Pilgrim plant-specific susceptibility factors are summarized below:

(i) All three support rings (upper, central and lower) were fabricated by welding rolled plate segments, followed by machining to size. This form of rings is highly susceptible to IGSCC. The shroud and support rings were made of stainless steel type 304 materials with relatively high carbon content (slightly less than 0.06%).

(ii) The shroud welds were fabricated by submerged arc welding process using ER-308 filler metal, which could have a carbon content as high as 0.08% (maximum). The residual stresses resulting from this welding process are expected to be high.

(iii) Pilgrim operated at high reactor coolant ionic content levels during the initial years of operation. During the first five cycles of operation, the reactor coolant water conductivity at Pilgrim averaged 0.53 μS/cm which is 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).

(iv) Pilgrim has accumulated more than 12.6 on-line years of operation. Thus, the Pilgrim core shroud has longer operational service than the majority of U.S. BWRs (range is 3.7 years - 17.8 years).

Considering the above plant-specific susceptibility factors as well as the industry-wide inspection experiences and the uncertainties in the residual stress profile resulting from fabrication, the staff concludes that significant cracking in the Pilgrim core shroud can not be ruled out.

2.2 Basis for Continued Operation

2.2.1 Licensee's Assessment of Structural Integrity

The results of the licensee's structural evaluation showed that only 5% of the shroud wall ligament is needed to maintain the structural integrity of the core shroud under all design conditions. This evaluation is based on a limit load analysis. The licensee also calculated the crack growth for the remaining period of the current fuel cycle using the GE crack growth Pledge model. Since the initial flaw size is not known, the licensee used the results of a generic crack growth analysis performed by BWROG to provide analysis inputs which bound the conditions for Pilgrim. The generic crack growth analysis was benchmarked with the worst Brunswick crack depth measurements and the results of the analysis predicted that the current crack depth could be up to 80% of the shroud wall thickness. The licensee assumed that, due to low reactor coolant conductivity as a result of implementing hydrogen water chemistry at Pilgrim, the calculated crack growth rate is very small. The licensee stated that the growth in crack depth during the remaining cycle would be less than 0.01 inch (less than 1% of wall thickness) even if a factor of 10 is applied to account for the uncertainties. Therefore, the licensee concluded that sufficient structural margin will be maintained for the current cycle.

2.2.2 Licensee's Consequence Assessment of Shroud Response to Structural Loads

GL 94-03 requested that licensees perform a consequence assessment of the shroud response to design basis loads and their effect on the ability of plant safety features to perform their function assuming 360° through-wall cracking. The licensee's intent of this consequence assessment was to demonstrate that fuel geometry and core cooling would be maintained given the unlikely occurrence of a through-wall failure of any horizontal weld, and to identify whether horizontal weld failures would be detectable. Fuel geometry must be maintained to ensure control rod insertion while core cooling is ensured by proper emergency core cooling system (ECCS) performance. The licensee, considering differential pressures across the shroud head and the shroud support which were determined by the TRACG model, concluded that weld separation greater than two inches during normal operations was detectable. The licensee also stated that the ability to maintain reactivity control, fuel geometry, core cooling, and a refloodable volume was assured with substantial margin although degraded performance was assumed for design basis events. Based on this assessment, the licensee concluded that core shroud separation and/or displacement occurring during normal operations or during anticipated events would have no effect on the primary safety functions of reactivity control and core cooling which are required to mitigate those events.

2.2.3 Staff's Evaluation of Justification for Continued Operation

2.2.3.1 Structural Integrity Assessment

Inspections completed at other BWRs have not identified any 360° circumferential through-wall core shroud cracking. The most significant crack observed to date had sufficient remaining ligament to ensure adequate structural integrity. Furthermore, no BWR has exhibited any symptoms (power to flow mismatch) caused by leakage through a 360° through-wall crack.

In addition, there is a low probability for an initiating event which could potentially challenge the integrity of the core shroud; particularly since there is only a short duration of operation until the licensee implements necessary inspections or repairs. Also, Pilgrim has been operating with hydrogen water chemistry since September 1991 (cycle 9). This measure is beneficial in reducing IGSCC in recirculation system piping. In addition, the recirculation piping was replaced with low carbon stainless steel which is highly resistant to IGSCC. These two measures in conjunction with the short operational time to the scheduled shroud repair date would decrease the probability of initiating a recirculation line break event.

The staff has reviewed BWR core shroud inspection results from a plant considered more susceptible to IGSCC than Pilgrim. Although significant shroud cracking was identified, all welds had sufficient ligament to ensure adequate structural integrity. The staff concludes that any potential core shroud IGSCC at Pilgrim should be bounded by that found at other similar BWRs. In addition, a crack growth evaluation by the licensee to estimate the potential extent of IGSCC utilized realistic estimates of time to initiation and crack growth rates. The methodologies used by the licensee to obtain these values has not been fully evaluated at this time. Benchmark testing is necessary to quantify any error involved in the licensee's calculations. However, considering the small remaining ligament necessary for adequate core shroud structural integrity and industry experience with shroud cracking, the staff concludes that the Pilgrim core shroud should have sufficient ligament at the end of the proposed operating period to preclude failure under all conditions.

Furthermore, the licensee indicated that a number of other vessel internals susceptible to IGSCC such as shroud head bolts, access hole covers, CRD stub tubes and the components associated with jet pump assemblies have been visually inspected at regular intervals, and that no indications have been found.

2.2.3.2 Loads and Consequence Assessment

The staff performed a qualitative assessment of the licensee's consequence assessment. The staff found the submittal to be a relatively complete assessment of the consequences of a MSLB, a RLB with acoustic and blowdown loads, a MSLB plus seismic event, and a RLB plus seismic event with regards to the Pilgrim design. The staff could not entirely verify all the details of the evaluations by the licensee for Pilgrim such as the inherent uncertainties in the TRACG model, the detectability of all postulated failed horizontal welds, and the potential uncertainties of the irregular crack surface of the postulated failed welds. For the main steamline event, the licensee's calculations demonstrated that the top guide would not lift above the fuel, therefore assuring no lateral fuel movement. While this conclusion is reasonable, there may be some small likelihood of top guide lift above the fuel for upper weld locations, due to the inherent uncertainties in the analysis methods, as mentioned above. However, even if this were to occur, the staff concluded that safe shutdown of the reactor should be achieved by the activation of the standby liquid control system (SLCS). Assuming the presence of through wall failures of shroud welds, the other initiating event of concern would be the recirculation line break. The licensee's calculations indicated momentary tipping of the shroud at certain postulated failed weld locations due to the blowdown forces, but no permanent lateral movement. For such shroud response, the staff agrees that adequate core flooding will be maintained since little core/annulus bypass will occur. Modeling the behavior of a cracked shroud to a recirculation line break is quite complex, involving assumptions on crack surface friction and competing forces in the vertical and lateral directions. Therefore, the staff is unable to conclude with high confidence that such lateral motion cannot occur following a RLB.

Lateral motion of less than the thickness of the shroud would only result in small bypass leakages. However, large lateral movement could open up a significant leakage path through the shroud which could possibly prevent adequate 2/3 height core flooding following the RLB. Although the staff could not agree with the licensee's assessment of the RLB with an assumed through-wall crack at the lower shroud welds, the staff has concluded that only the most extreme assumptions with respect to initiating events, crack locations and crack depths would result in unacceptable consequences. Therefore, due to the low frequency of the initiating event, the availability of the SLCS, and the presence of remaining ligament to assure structural integrity, the staff concludes that there is no undue risk to the public health and safety for the approximate four month period of power operation.

3.0 CONCLUSION

Based on the evaluation provided in Section 2, the staff finds that the schedule for the preemptive repair of the core shroud at Pilgrim is acceptable. The staff concludes Pilgrim can continue to be safely operated until their next refueling outage. The bases are: (1) there has been no 360°, through-wall core shroud cracking observed to date in any U.S. BWR that has performed a shroud inspection; (2) all analyses performed by the licensee for Pilgrim show that even if cracking did exist in its shroud, ligaments would remain such that structural integrity would be assured; (3) Pilgrim has not exhibited any of the symptoms (power to flow ratio mismatch) caused by leakage through a 360°, through-wall shroud crack; (4) there is a low probability of occurrence for either steam line or recirculation line breaks; (5) there is only a short duration of operation until a repair is implemented. Other factors include, for example, that Pilgrim has recently replaced recirculation line piping, and has been operating with hydrogen water chemistry, substantially lowering the likelihood for a recirculation line break and somewhat mitigating the potential for IGSCC in the core shroud.

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 repair, the licensee's plans for repairing the shroud.

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