GENE-523-A092-0995
DRF 137-0010-8

Evaluation of the Peach Bottom Unit 3 Core Spray Line

September 1995

Prepared by: Marcos L. Herrera
Marcos L. Herrera, Principal Engineer
Engineering & Licensing Consulting Services

José L. Casillas
José L. Casillas, Principal Engineer
Engineering & Licensing Consulting Services

Reviewed By: S Ranganath
Sampath Ranganath, PhD
Engineering Fellow

Approved By: T. A. Caine for DMK
David Kelly, Manager
Engineering & Licensing Consulting Services

GE Nuclear Energy
175 Curtner Ave
San Jose, CA 95125

IMPORTANT NOTICE REGARDING
CONTENTS OF THIS REPORT

Please Read Carefully

The only undertakings of the General Electric Company (GE) respecting information in this document are contained in the contract between PECO Energy Company and GE, and nothing contained in this document shall be construed as changing the contract. The use of this information by anyone other than PECO, or for any purpose other than that for which it is intended under such contract is not authorized; and with respect to any unauthorized use, GE makes no representation or warranty, and assumes no liability as to the completeness, accuracy, or usefulness of the information contained in this document, or that its use may not infringe privately owned rights.

Table of Contents

EXECUTIVE SUMMARY

An indication was observed in the Peach Bottom Unit 3 core spray pipe sleeve in the vicinity of the fillet weld. This indication was seen by visual inspection from the outside surface. Due to the effects of the crevice, heat affected zone, residual stress and aggressive environment on the inside surface of the sleeve, the indication is assumed to be through-wall. Analyses were performed previously to demonstrate that core spray would still be delivered even if the core spray sleeve were to sever at the current flaw location.

This report examines the structural integrity aspects of this joint in combination with the safety consequences of losing core spray in one loop. Following is a summary of the main features of this issue:

- The observed cracking in the core spray <u>sleeve</u> was likely caused by high weld residual stress, through-wall heat affected zone, crevice condition, and aggressive environment.
- No crack indication on the core spray piping itself at this specific location has been observed at any plant. It is estimated that over 900 visual ISI inspections of these downcomers have been performed in the U.S. BWR fleet.
- A finite element elastic-plastic residual stress evaluation for the Peach Bottom specific design indicates compressive stress on the outside surface of the pipe in the vicinity of the crevice and HAZ. The presence of the compressive stress will inhibit crack initiation at this location.
- Field experience suggests that cracking will be more significant in the <u>sleeve</u>. In fact, based on the shroud head bolt experience which is geometrically similar to the core spray sleeve/pipe configuration, it is reasonable to expect no cracking in the core spray <u>piping</u>.
    - Shroud head bolts have shown cracking in the load carrying member of a creviced configuration. The core spray piping section engaged in the sleeve is not part of the load carrying path.
- The HAZ for the critical core spray <u>pipe</u> cross section likely only penetrates to approximately one-half of the cross-section. Thus, even if crack initiation occurs in the <u>pipe</u>, it is unlikely that significant through-wall cracking would occur.
- Since through-wall cracking in the pipe is not expected, core spray leakage is not expected. Therefore, the impact on the LOCA analysis remains the same, and compliance to the 10CFR50.46 Appendix K criteria is assured.

- Even if leakage through the crack occurred, it would not be sufficient to invalidate the core spray flow used in the licensing basis SAFER/GESTR LOCA analysis.

- The expected Peak Cladding Temperature without core spray credit for one loop will remain low (<1200°F) and comparable to typical Nominal LOCA results.

Based on these observations, it is concluded that cracking in the core spray pipe is not likely to occur and if it did occur it is not likely to affect core spray piping structural integrity. Given the substantial structural margin in the piping (allowable flaw sizes), limited length of through-wall cracking observed in the sleeve, and predicted compressive stress on the outside surface of the pipe, there is a high level of confidence that sufficient structural margin exists for the piping. These conclusions combined with the discussion of system safety margins discussed in Section 3, provide for a high degree of assurance for safe continued operation.

1. INTRODUCTION

In-vessel visual inspection (IVVI) of the Peach Bottom Unit-3 core spray piping revealed an indication on a sleeve in one of the four downcomers. After passing through the nozzle, each core spray pipe passes through a tee-box and then splits in horizontal directions. Each of these horizontal pipes turns downward into a vertical section (downcomers) and eventually penetrate the core shroud above the top guide (See Figure 1-1).

An indication was found in one of the vertical portions of the core spray pipe (there are a total of four vertical downcomers, two per core spray loop) on the outside diameter of the sleeve near the fillet weld (See Figure 1-2). Since the indication was seen on the outside surface, and considering that a crevice exists on the inner surface of the sleeve, it is assumed that the cracking initiated on the inner diameter of the sleeve. The cracking is likely intergrannular stress corrosion cracking (IGSCC) due to the effects of the fillet weld induced heat affected zone (HAZ), residual stress, crevice condition, and aggressive core spray pipe environment.

The indication has been observed to be approximately three inches long on the outside surface of the sleeve. Thus, assuming initiation on the inside surface of the sleeve, it then follows that there is at least three inches of through-wall cracking. Since visual inspection has been performed, part through-wall cracking from the inside surface of the remaining circumference cannot be ruled out. It has been demonstrated that even if the sleeve were to be totally severed at the current flaw location, the pipe would not disengage from the sleeve and thus the core spray delivery would not be disrupted. Since some of the factors which contribute to stress corrosion cracking may be present on the core spray pipe (inner cylinder) at this location, the possibility of crack initiation in the pipe is examined further in this report.

This report evaluates the current core spray pipe condition and justification for continued operation by considering the structural integrity aspects at the location of interest and the evaluation of the safety margins available in the unlikely event of a core spray failure (1 loop out of service). This is demonstrated by presenting the results of a SAFER/GESTR analysis which considers operation of Unit-3 with only one core spray loop in operation, during design basis accident conditions.

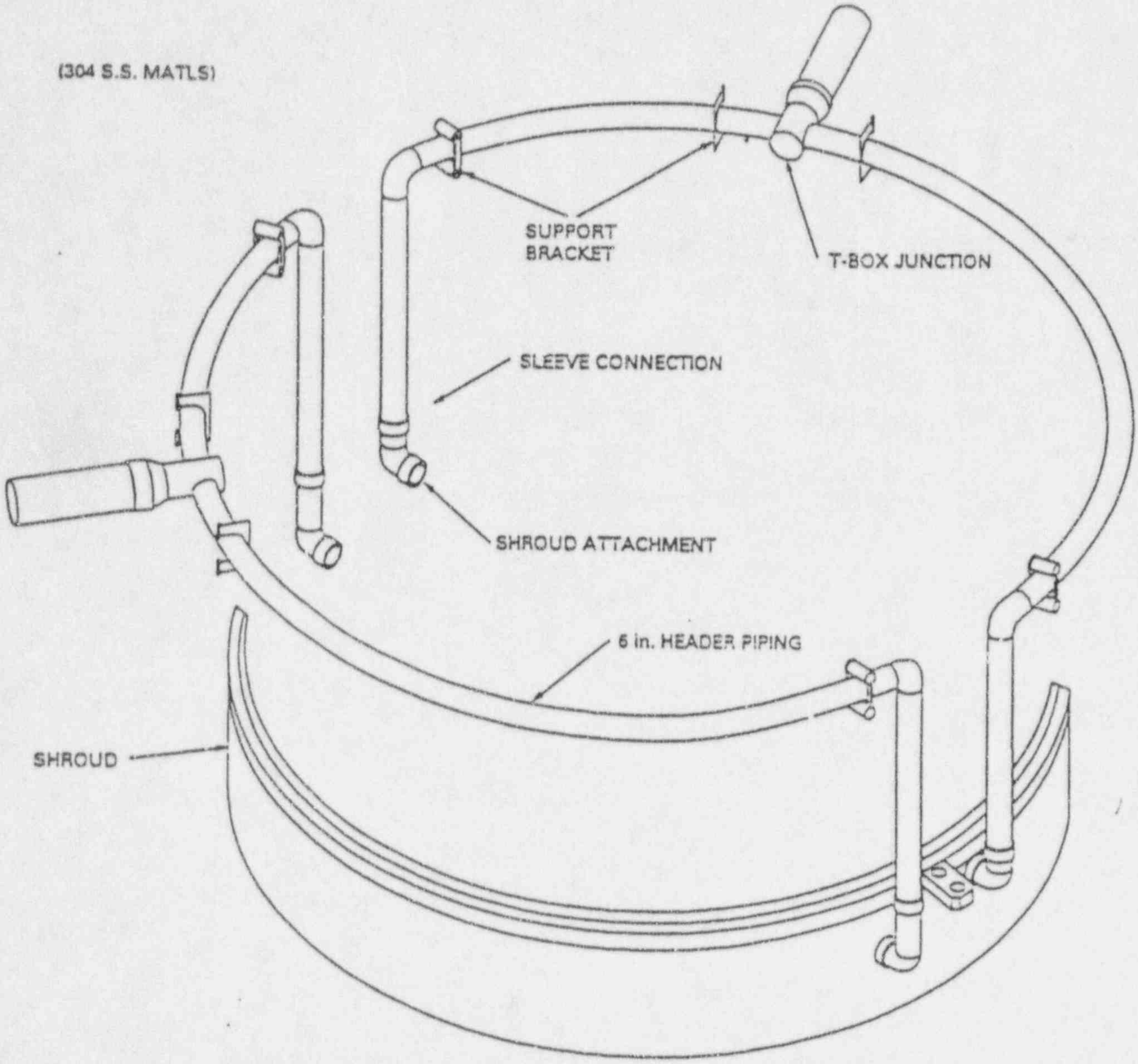

Figure 1-1 - Schematic of Core Spray Piping

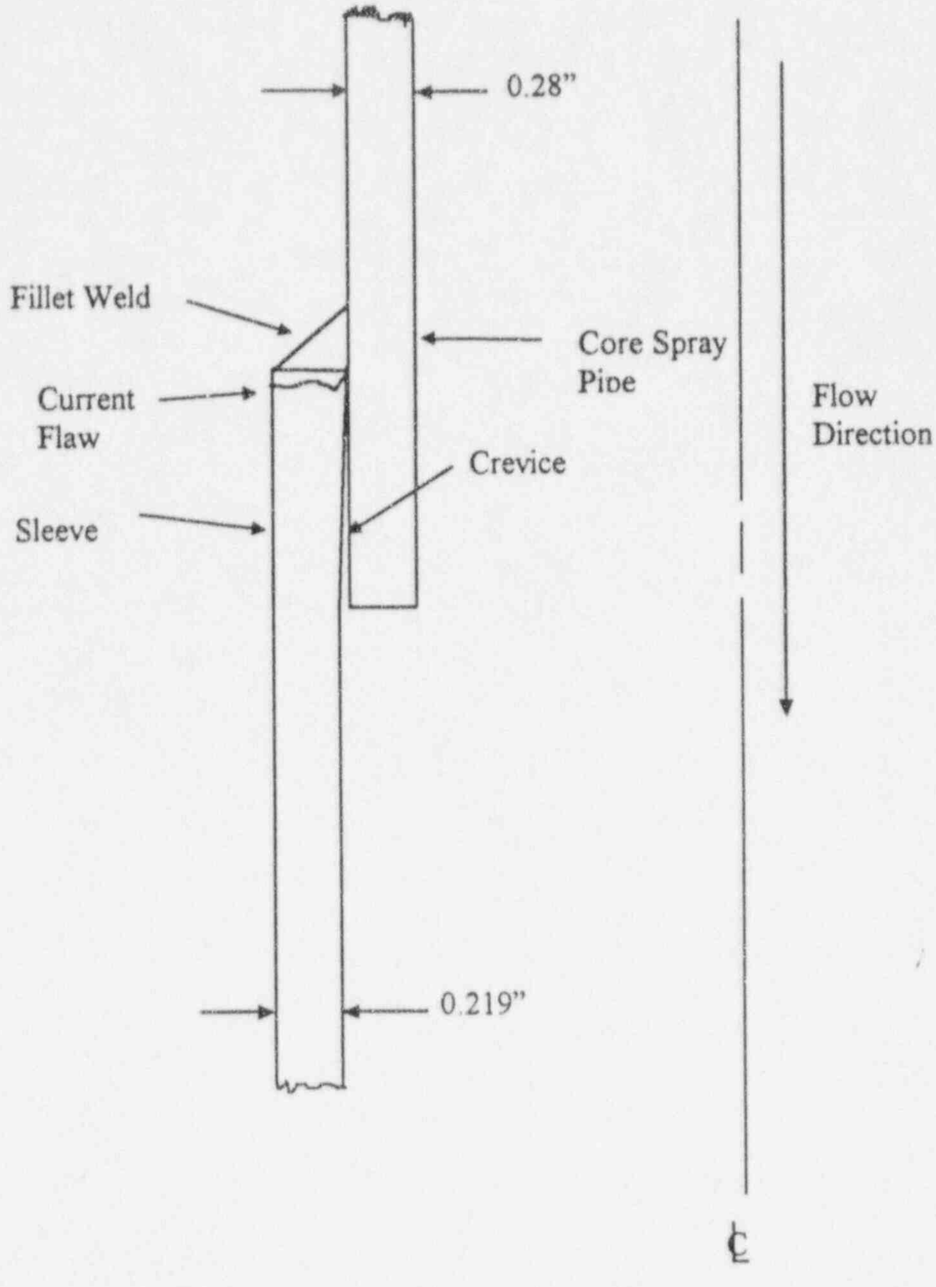

Figure 1-2 - Schematic of Core Spray Line in Vicinity of Observed Cracking

2. STRUCTURAL INTEGRITY CONSIDERATIONS

This section addresses the structural integrity at the location of interest. As mentioned earlier, an indication has been observed on the sleeve (outside diameter cylinder). The core spray pipe, which inserts into the sleeve, is fillet welded to the sleeve. There is a vertical overlap between the core spray pipe and the sleeve (See Figure 2-1). It has been demonstrated that even if the sleeve were to be totally severed at the current flaw location, the pipe would not disengage from the sleeve and thus the core spray delivery would not be disrupted.

Following is a discussion regarding factors that could contribute to or inhibit crack initiation in the core spray pipe. Included in this section is a discussion of the current observed flaw, likely causes and potential for any indications in the core spray pipe including supporting empirical field experience.

2.1 Potential For Cracking In the Core Spray Pipe

This section contains a discussion of the potential for cracking in the core spray pipe. Discussion is presented regarding the key contributors to potential cracking at this location, empirical field experience including a component with similar geometry, and the observed cracking in the sleeve at this location. Finally, based on this information, conclusions are made with respect to the potential for crack initiation in the pipe.

2.1.1 Fillet Weld HAZ and Residual Stress

The fillet weld between the core spray pipe and sleeve will induce weld residual stress and an area of sensitized material. Figure 2-1 shows the geometry of the sleeve to piping junction. Also shown (by the dotted line) is the expected behavior of the HAZ due to the fillet weld. In the sleeve itself (where a crack has been observed) the heat affected zone penetrates through the entire cross-section of the sleeve. Thus, there is a path of susceptible material where a crack could propagate through-wall. However, for the core spray pipe, the HAZ will not penetrate through the entire thickness. Depending on the heat input and other welding parameters, the HAZ depth will vary, but the penetration will likely not be through-wall and is expected to be half the wall thickness. This is illustrated in Figure 2-1.

The residual stress due to the fillet weld is a key parameter in determining the potential for crack initiation in the core spray pipe. Due to the complex geometry of the joint, the residual stress distribution behavior is not obvious. The presence of the crevice makes estimating the residual stress difficult. Based on the design and observation of through-wall cracking in the sleeve, it is likely that there is significant axial residual stress along cross-section A as shown in Figure 2-1. If this were a butt-welded straight pipe, the axial residual stress would be tensile on the inside surface of the sleeve in the vicinity of the crevice. Butt-welded small diameter piping typically exhibits a bending type of axial residual stress distribution. The applied stresses (primary and secondary) in combination with the weld residual stress appear to have been sufficient to cause through-wall propagation of a crack.

A finite element elastic-plastic residual stress analysis was performed to obtain the behavior of the residual stress. The ANSYS finite element program was used to perform this axisymmetric analysis. The Peach Bottom Unit 3 core spray piping specific geometry was used in this evaluation. Two cases were examined which used different sleeve-to-pipe gap dimensions.

The fillet weld application was simulated in a thermal analysis by using the Nugget Area Heating Method (NAH). The NAH method simulates the welding by increasing the temperature of the nodes within the weld to the melting temperature of the material, holding for a short time, then allowing cooldown. Convection boundary conditions were applied to the appropriate surfaces. The gap was simulated in the thermal analysis using air elements. The time dependent results of the thermal analysis was used as input to the stress analysis.

Temperature dependent material properties were used for both the thermal and stress analysis. A bilinear stress-strain curve was used along with the Von Mises yield criterion.

Results of the evaluations indicate that compressive residual stress (in the axial and hoop directions and for both gap cases evaluated) exists on the outside surface of the pipe in the vicinity of the crevice and HAZ. This compressive stress would inhibit crack initiation at this location. It is also interesting to note that the results also predict significant tensile stress on the inside surface of the sleeve which is consistent with the observed crack which is postulated to have initiated on the inside surface of the sleeve at Peach Bottom Unit 3.

2.1.2 Related Field Incidences

There have been other incidences of field cracking which have some similarity to the geometry of interest. Cracking in the creviced Alloy 600 shroud head bolts (SHB) is somewhat similar to the core spray sleeve crack indication. Both Alloy 600 and weld sensitized Type 304 stainless steel are susceptible to IGSCC in the creviced condition.

Cracking was observed in the SHB's in the vicinity of the crevice formed by the connection of a sleeve to the bolt with a fillet weld. In this case, the sleeve is on the outside and the bolt on the inside. The bolt in this case was solid. The sleeve was then fillet welded to the outside surface of the bolt. The bolt was fabricated from Alloy 600 and the sleeve from stainless steel. Figure 2-2 shows a schematic of the SHB geometry in the vicinity of the observed cracking.

Figure 2-2 shows that the cracking in the SHB's was observed in the inner component. However, the inner component is the load carrying component for the shroud head bolt configuration. No cracking has ever been observed in the non-load carrying SHB sleeve. For the core spray pipe case, the load carrying component is the outer sleeve, and the non-load carrying component is the core spray pipe. Based on field experience, it is reasonable to expect any crack initiation to occur in the outer sleeve (consistent with the observed crack). Conversely, field experience suggests that crack initiation in the piping is not expected.

No crack indication on the core spray piping itself at this specific location has been observed at any plant. It is estimated that over 900 visual ISI inspections of these downcomers have been performed in the U.S. BWR fleet.

2.2 Core Spray Pipe Sleeve Indication

The current flaw in the core spray pipe sleeve is likely IGSCC induced by the effects of residual stress, presence of the crevice, heat affected zone (HAZ) and highly oxidizing environment of the core spray piping.

The indication appears to be in the sleeve HAZ as designated by Section A in Figure 2-1. Based on consideration of the environmental, geometric and stress factors at this location, it is likely that the cracking initiated from the inside surface of the sleeve at or near the crevice tip.

An evaluation has been previously performed which determined that even for the limiting condition and complete severance of the sleeve, the pipe would remain engaged in the sleeve, and thus the core spray delivery would not be affected. This evaluation assumed that the present observed indication in the sleeve extended to a fully circumferential through-wall flaw and thus severed the connection between the pipe and sleeve. Also, a flaw evaluation has been performed to determine the allowable through-wall flaw size for the sleeve indications from a structural integrity viewpoint. Results of this evaluation indicate that 270° of circumference through-wall flaw is acceptable and will continue to maintain structural integrity. This result is also applicable to the core spray pipe side of the joint since the wall thickness is actually greater than that for the sleeve. It should be noted that these calculations are based on assuming very conservatively that the indications are joined into one single through-wall flaw. In reality, the flaws if any are likely to be separate indications and if a flaw evaluation were performed which considers the separation, additional structural margin would be found.

Combining these arguments concerning residual stress, applied stress and HAZ characteristics, it is believed that the potential for initiation and propagation of cracking along section B in the core spray pipe is not likely. Also, the integrity of the pipe is maintained even with a through-wall flaw of 270° of the circumference. It should also be noted that due to the low stresses in the pipe, the allowable 360° part through-wall flaw could have a depth of more than 95% of the pipe wall and still maintain structural integrity.

These large allowable flaw sizes are consistent with other evaluations performed for other plants. The applied primary loads on the core spray pipe are relatively low. These are comprised of seismic, flow impingement and deadweight. In addition, the core spray piping is compliant which also contributes to the large through-wall allowable flaw sizes. Based on this allowable flaw calculation, it can be said that the core spray pipe is very flaw tolerant.

2.3 Structural Integrity Considerations Summary

This section concludes the discussion regarding the low potential for cracking in the core spray pipe similar to that observed in the core spray sleeve. Following is a summary of the main features of this issue:

- The observed cracking in the core spray sleeve was likely caused by high weld residual stress, through-wall heat affected zone, crevice condition, and aggressive environment.

- No crack indication on the core spray piping itself at this specific location has been observed at any plant. It is estimated that over 900 visual ISI inspections of these downcomers have been performed in the U.S. BWR fleet.

- A finite element elastic-plastic residual stress evaluation for the Peach Bottom specific design indicates compressive stress on the outside surface of the pipe in the vicinity of the crevice and HAZ. The presence of the compressive stress would inhibit crack initiation at this location.

- Field experience suggests that cracking will be more significant in the sleeve. In fact, based on the shroud head bolt experience which is geometrically similar to the core spray sleeve/pipe configuration, it is reasonable to expect no cracking in the core spray piping.

    * Shroud head bolts have shown cracking in the load carrying member of a creviced configuration. The core spray piping section engaged in the sleeve is not part of the load carrying path.

- The HAZ for the critical core spray pipe cross section likely only penetrates to approximately one-half of the cross-section. Thus, even if crack initiation occurs in the pipe, it is unlikely that significant through-wall cracking would occur.

Based on these observations, it is concluded that cracking in the core spray pipe is not likely to occur and even if it did occur it is not likely to affect core spray piping structural integrity. Given the substantial structural margin in the piping (allowable flaw sizes), current limited through-wall cracking in the sleeve, and predicted compressive stress on the pipe outside surface, sufficient structural margin exist for the piping. These conclusions combined with the discussion of safety consequences (presented in the following section) provide a high degree of assurance for safe continued operation.

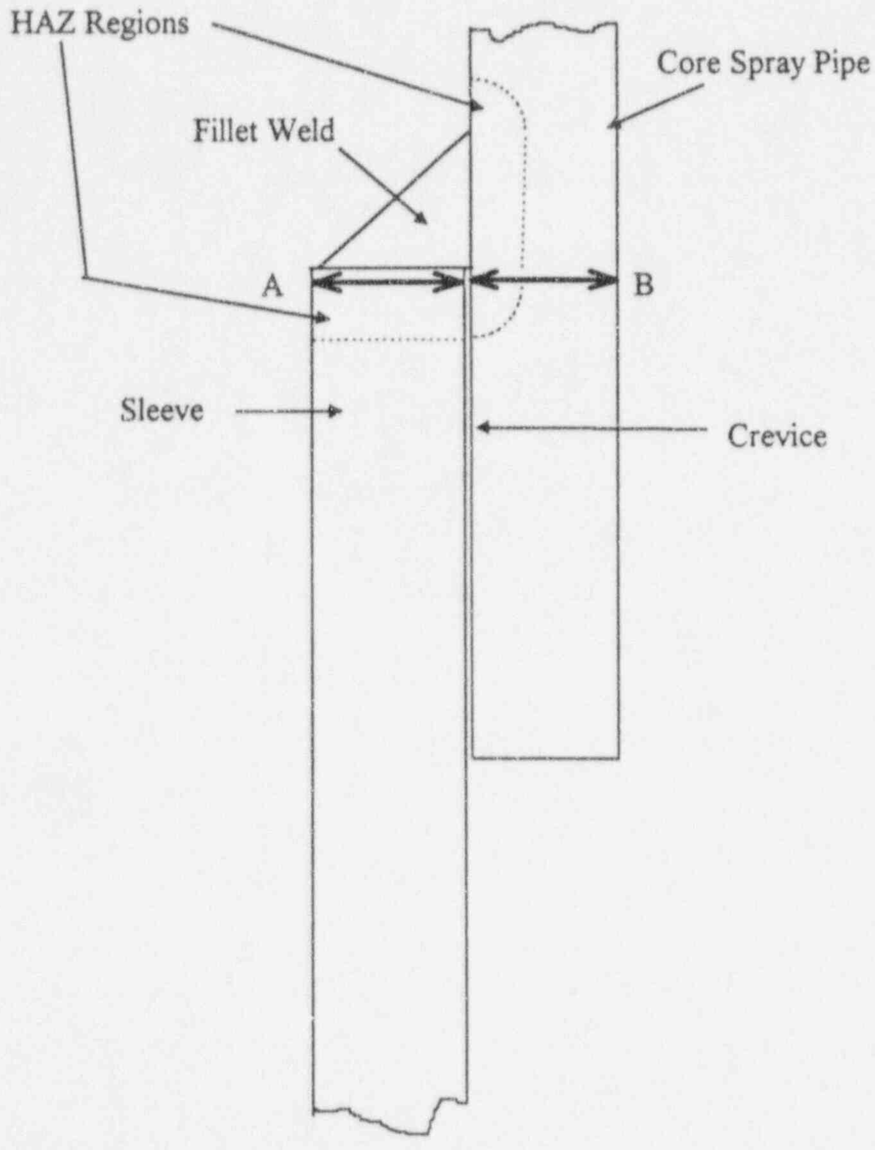

Figure 2-1 - Schematic of Cracked Region in Core Spray Line

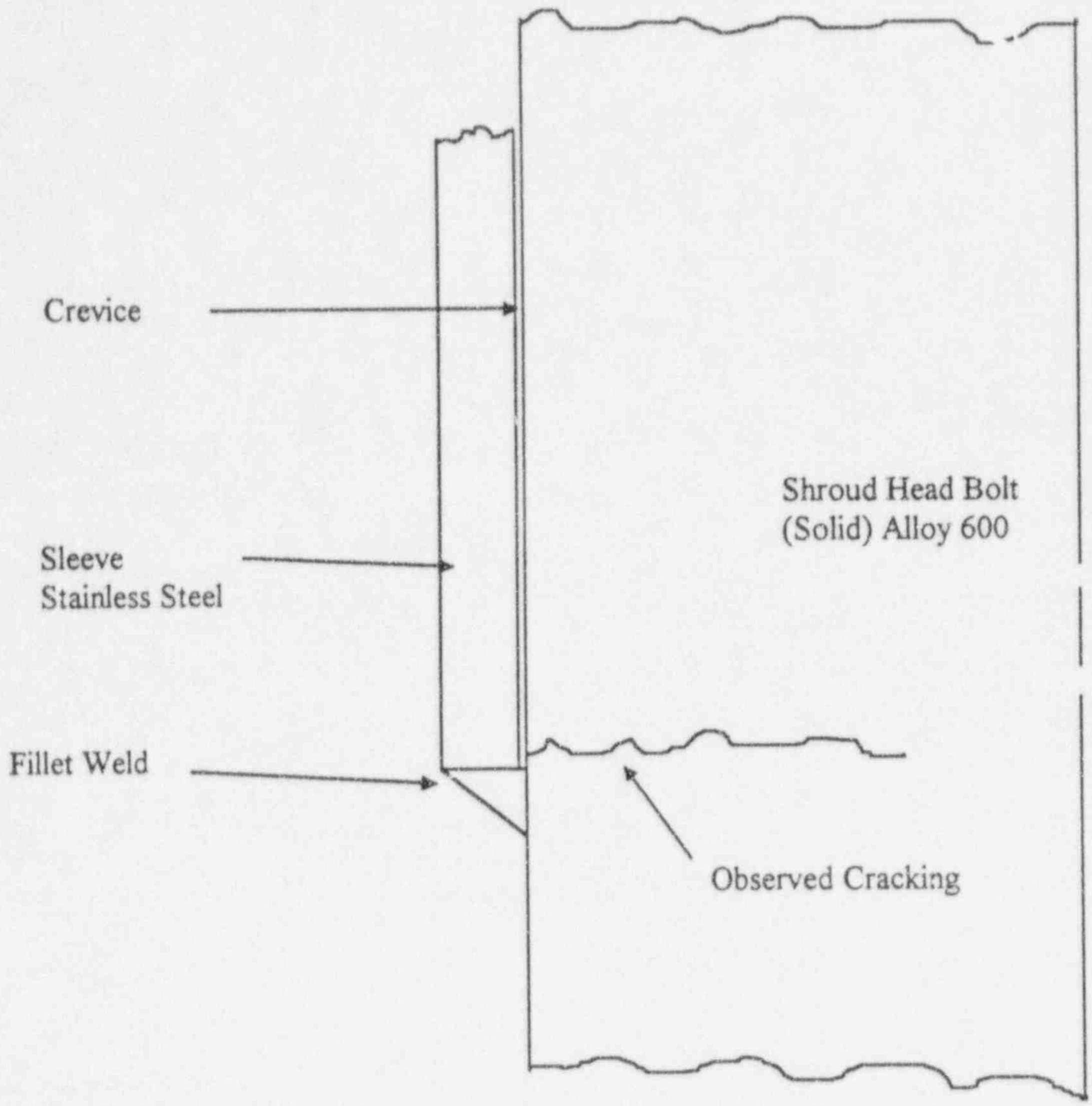

Figure 2-2 - Schematic of Shroud Head Bolt Cracking

3. LOCA EVALUATION

This section addresses the application of the previous Core Spray Line Crack Loss-of-Coolant-Accident evaluation (GENE-637-040-1193) to the current condition as documented in section 2.

The previous assessment included two aspects of the impact of the core spray pipe cracking on the core spray performance. First, it was determined that the amount of leakage through the crack would not be sufficient to invalidate the core spray flow used in the licensing basis SAFER/GESTR LOCA analysis (NEDC-32163P). This conclusion was reached by comparing the core spray flow required by the Technical Specification surveillance against the flow used in the LOCA analysis.

The structural integrity evaluation described in the Section 2, has concluded that no additional core spray leakage is expected. Therefore, the impact on the LOCA analysis remains the same, and compliance to the 10CFR50.46 Appendix K criteria is assured.

Second, further calculations were performed employing the Nominal SAFER/GESTR basis, along with the very conservative assumption of loss of total core spray injection into the reactor vessel through one loop. This calculation showed that the expected Peak Cladding Temperature without core spray credit will remain low (<1200°F) and comparable to typical Nominal LOCA results. The analysis results show a maximum increase of less than 130°F for the total loss of an additional core spray function, which is not significant compared to the PCT Limit of 2200°F. This calculation is applicable to the current core spray condition, as discussed in Section 2, because the very bounding assumption of no core spray injection through one loop was included.

It should also be noted that the core spray leakage monitoring system will detect any excessive leakage prior to failure of the pipe.

3.1 LOCA Evaluation Summary

Therefore, the conclusions of the previous Core Spray Crack LOCA evaluation remain applicable for this assessment. The licensing basis core spray flow is maintained considering the expected core spray crack flow leakage. The impact of a loss of core spray function through one loop does not lead to unacceptably high calculated PCTs.

4. SUMMARY AND CONCLUSIONS

An evaluation has been performed to examine the structural integrity aspects of this joint in combination with the safety consequences of losing core spray in one loop. Following is a summary of the conclusions:

- The observed crack in the core spray <u>sleeve</u> was likely caused by high weld residual stress, through-wall heat affected zone, crevice condition, and aggressive environment.

- No crack indication at this specific location in the core spray piping itself has been observed at any plant. It is estimated that over 900 visual ISI inspections of these downcomers have been performed in the U.S. BWR fleet.

- A finite element elastic-plastic residual stress evaluation for the Peach Bottom specific design indicates compressive stress on the outside surface of the pipe in the vicinity of the crevice and HAZ. The presence of the compressive stress would inhibit crack initiation at this location.

- Field experience suggests that cracking will be more significant in the <u>sleeve</u>. In fact, based on the shroud head bolt experience which is geometrically similar to the core spray sleeve/pipe configuration, it is reasonable to expect no crack initiation in the core spray <u>piping</u>.

    - Shroud head bolts have shown cracking in the load carrying mer[illegible] of a creviced configuration. The core spray piping section engaged [illegible]e sleeve is not part of the load carrying path.

- The HAZ for the critical core spray <u>pipe</u> cross section likely only penetrates to approximately one-half of the cross-section. Thus, even if crack initiation occurs in the <u>pipe</u>, it is unlikely that significant through-wall cracking would occur.

- The structural integrity evaluation, has concluded that no additional core spray leakage is expected. Therefore, the impact on the LOCA analysis remains the same, and compliance to the 10CFR50.46 Appendix K criteria is assured.

- Even if leakage through the crack occurred, it would not be sufficient to invalidate the core spray flow used in the licensing basis SAFER/GESTR LOCA analysis.

- The expected Peak Cladding Temperature without core spray credit for one loop will remain low (<1200°F) and comparable to typical Nominal LOCA results.

Based on the above analysis, it is concluded that crack initiation in the core spray pipe is not likely to occur and if it does occur it is not likely to affect core spray piping structural integrity. Given the substantial structural margin in the piping (allowable flaw sizes), limited length of through-wall cracking observed in the sleeve, and predicted compressive stress on the outside surface of the pipe, there is a high level of confidence that sufficient structural margin exists for the piping. These conclusions combined with the discussion of system safety margins, provide for a high degree of assurance for safe continued operation.