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

RELATED TO CORE SHROUD CRACKING

COMMONWEALTH EDISON COMPANY

AND

IOWA-ILLINOIS GAS AND ELECTRIC COMPANY

DRESDEN NUCLEAR POWER STATION, UNIT 3

QUAD CITIES NUCLEAR POWER STATION, UNIT 1

DOCKET NOS. 50-249 AND 50-254

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EXECUTIVE SUMMARY

In April 1994, the Commonwealth Edison Company (ComEd or the licensee) informed the U.S. Nuclear Regulatory Commission (NRC) that inspections conducted as part of their inservice inspection program had detected cracking in the circumferential welds of the core shrouds of Dresden, Unit 3, and Quad Cities, Unit 1, boiling water reactors (BWRs). The core shroud in a BWR is a cylindrical shell within the reactor vessel that provides a partition to channel reactor coolant flow through the reactor core. In addition, the core shroud provides a refloodable volume for safe shutdown cooling and provides lateral support for the fuel assemblies. The shroud is not part of the reactor pressure boundary and the loads on it during normal operation are very small. Stress corrosion cracks were detected near several of the welds in the core shrouds of both units. The largest cracks extended completely around the circumference in the lower elevation of the shroud cylinder, but these cracks were not through-wall. The licensee provided the NRC with documentation and analyses to support returning Dresden, Unit 3, and Quad Cities, Unit 1, to operation for 24 months and 18 months, respectively, without repair of the cracked shrouds.

The NRC staff has evaluated ComEd's submittals to determine if the plants' licensing basis would still be satisfied while operating with cracked shrouds. ComEd provided documentation to demonstrate that the cracked shrouds could maintain margins against failure as specified in Section XI of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (Code) for the normal operating and postulated accident loads specified in the plants' Updated Final Safety Analysis Report (UFSAR). Based on our review of ComEd's analyses, and our own independent analyses, the staff has concluded that the cracked shrouds would satisfy ASME Code margins against failure for 15 months of operation above cold shutdown. Satisfying the ASME Code specified margins against failure provides reasonable assurance that the shrouds will remain intact, even under postulated licensing basis and beyond licensing basis accident loading. This conclusion was based on assuming a bounding initial crack size and applying a conservative growth rate for the crack in service, disallowing any enhancement of the structural integrity by the presence of an inside diameter fillet weld, and assessing the structural integrity of the core shrouds for seismic loads and loads associated with postulated breaks of the main steamline or the recirculation line piping.

As indicated above, the NRC staff has concluded that the core shrouds would remain intact for 15 months of operation above cold shutdown, even under postulated accident conditions. However, in order to acquire further insight into the significance of core shroud cracking, the staff requested ComEd to provide a safety assessment assuming a 360° through-wall crack in the lower elevation of the core shroud. The NRC staff also independently performed an assessment of the risk of this postulated condition. A realistic assessment of core damage frequency would require estimating the frequency of initiating events of concern coupled with the probability of a complete failure of the H5 weld and the probability that systems required to mitigate the consequences of those scenarios would not be available. Events of potential safety significance are a large loss-of-coolant accident and a main steamline break. The occurrence of such events is very low (i.e., 10^{-4} to 10^{-5}/reactor year).

The conditional probability of complete failure of the H5 weld and the failure to mitigate the consequences of these events is expected to be much less than one. Therefore, the frequency of core damage is expected to be significantly lower than 10^{-4} to 10^{-5}/reactor year (RY). The staff assessment is clearly conservative in that the assumed cracking, 360° through-wall, is significantly more at the end of 15 months of operation and conservative assumptions were used to account for uncertainties in the loads and the resultant dynamic effects of the core shroud for postulated accidents.

Although the licensee's assessment supports operation for a period longer than 15 months, the staff's evaluation has identified some uncertainties in ComEd's analyses. These uncertainties are described in the staff's safety evaluation. To account for these uncertainties, conservative estimates have been used in the staff's analyses. In addition, the staff gives no credit in its evaluation for any enhancement to the structural integrity of the shroud by the presence of the inside diameter fillet weld at H5. Therefore, the staff's evaluation only approves a 15 month operational period. The staff considers the resolution of the identified uncertainties important for fully understanding and assessing the safety significance of the core shroud issue. Thus, the licensee has been requested to provide additional information in these areas.

While the NRC staff's evaluation concludes that operation above cold shutdown with a cracked shroud for 15 months is acceptable, the staff has also concluded that licensee action is necessary to ensure long-term structural integrity for the core shroud. The licensee has indicated that over the next 6 months, plans for a permanent repair of the entire core shroud will be developed.

Based upon the above, the staff has concluded that operation of Dresden, Unit 3, and Quad Cities, Unit 1, for a period of 15 months above cold shutdown does not pose an undue risk to the public health and safety.

1.0 INTRODUCTION AND BACKGROUND

In April 1994, Commonwealth Edison Company (ComEd or the licensee) informed the NRC that inspections conducted as part of their inservice inspection program had identified cracking in the 2" thick core shroud for both Dresden, Unit 3, and Quad Cities, Unit 1. Figures 1 and 2 show the configuration of the core shroud at Dresden and Quad Cities and the location of the welds. The core shroud in a boiling water reactor (BWR) is a cylindrical assembly within the reactor vessel that provides a partition to properly channel reactor coolant circulation through the reactor core. In addition, the core shroud provides a refloodable volume for safe shutdown cooling and also provides lateral support for the fuel assemblies to maintain control rod insertion geometry.

The cracks in the core shrouds at Dresden, Unit 3, and Quad Cities, Unit 1, were discovered by the licensee during visual inspection (VI) of the core shroud during the Spring 1994 refueling outages. The VIs were performed by the licensee in accordance with the inspection criteria discussed in the licensee's March 31, 1994, submittal. The licensee's inspection criteria were consistent with the recommendations contained in General Electric Company's (GE) Rapid Information Communication Service Information Letter (RICSIL) 054, "Core Support Shroud Crack Indications," that was issued as a result of cracking previously discovered in the core shroud of a foreign-owned GE BWR.

The licensee's initial VIs of the Dresden, Unit 3, and Quad Cities, Unit 1, core shroud revealed a circumferential crack at horizontal weld H5. This was based upon an examination of 100% of all accessible areas on the outside diameter (OD) of the weld's circumference. The licensee determined that the flaw existed in all examined areas. Depth characterization by ultrasonic testing (UT) indicated that the maximum crack depth at the H5 weld was 0.84" for Dresden, Unit 3, and 0.57" for Quad Cities, Unit 1. All other welds at both Dresden, Unit 3, and Quad Cities, Unit 1 (H1, H2, H3, H4, H6 and H7) were examined and visually qualified for acceptability.

To further corroborate the UT results, the licensee removed material (boat) samples from the H5 weld location at Dresden, Unit 3, and Quad Cities, Unit 1. Comparison of the UT examination findings against the results of the boat samples indicated that detectability for shallow flaws had not been reliably achieved and that the UT had underestimated the depths of the deeper flaws.

On May 26, 1994, the licensee met with the NRC and described the ongoing core shroud inspections at Dresden and Quad Cities and provided preliminary results of the inspections. In the meeting, the licensee stated that the following three options were being pursued based on the preliminary results of the inspections:

1. Restart of Dresden, Unit 3, and Quad Cities, Unit 1, without making repairs to the H5 weld at this time, but providing adequate justification for operation based on an analytical evaluation of each weld in the core shroud in accordance with ASME Section XI, IWB-3142.4.

2. One cycle of operation with a temporary repair of the H5 weld.

3. Permanent repair of the shroud prior to restart from the current refueling outage.

By letter dated June 6, 1994, in response to a request for additional information (RAI) from the NRC dated May 6, 1994, the licensee described the method, scope, and results of the inspections performed on the core shrouds at Dresden, Unit 3, and Quad Cities, Unit 1.

Based on further inspections and analyses, by letter dated June 13, 1994, the licensee indicated that additional time would be necessary to properly design and qualify a permanent repair for the shrouds and, therefore, they had chosen to restart both Dresden, Unit 3, and Quad Cities, Unit 1, without making repairs to the core shrouds at this time and proposed to justify operation through analyses. The June 13, 1994, analyses were submitted to the NRC for review and approval prior to restart of Dresden, Unit 3, and Quad Cities, Unit 1, in accordance with 10 CFR 50.55a and ASME Section XI, IWB-3144(b). By letters dated June 13 and 14, 1994, the licensee provided supplemental information to the June 13 analyses. By letter dated June 23, 1994, the NRC requested additional information concerning the analyses. By letters dated June 24, June 25 (superseded by letter dated July 8, 1994), June 28, June 30, July 12, July 15, 1994, and July 20, 1994, the licensee provided responses to the RAI. By a second letter dated June 30, 1994, ComEd provided an Integrated Evaluation Report which summarized: (1) ComEd's effort to resolve the cracked core shrouds issue, (2) the analytical information provided to the NRC, and (3) its plans and schedules for future actions.

2.0 EVALUATION

The following is the NRC staff's evaluation of the licensee's June 13, 1994, analyses and all supplemental information. The evaluation addresses the following areas:

1. Construction of the core shrouds at Dresden, Unit 3, and Quad Cities, Unit 1. (Section 2.1)

2. Analysis of the inspection and metallurgy results from the core shroud inspections at Dresden, Unit 3, and Quad Cities, Unit 1. (Section 2.2)

3. Evaluation of loading conditions on the core shroud. (Section 2.3)

4. Analysis of the licensee's flaw assessment. (Section 2.4)

5. Consequence evaluation of a postulated 360° through-wall crack at weld H5 and probabilistic risk perspective. (Section 2.5)

6. Future licensee and NRC actions. (Section 2.6)

7. Conclusions. (Section 3.0)

2.1 Construction of the Core Shrouds

The core shroud and the location of the welds, are illustrated in Figures 1 and 2. The core shroud separates the core region from the downcomer annulus, which contains the jet pumps, and assures that feedwater flow is directed down the downcomer annulus, through the jet pumps, through the lower plenum, and up through the core region.

The core shrouds at Dresden, Unit 3, and Quad Cities, Unit 1, measure 17.5 feet in diameter and are approximately 20 feet tall. The core shrouds are 2" thick and are constructed of plate, welded to segmented support rings.

The materials used to fabricate the core shroud are as follows:

- material specification - American Society for Testing and Materials (ASTM) A-240 Type 304 stainless steel plate. Carbon content varies from 0.044 to 0.063, depending on the heat number, and

- filler material specification - ASTM Type E308 and ER-308.

The core shrouds for Dresden and Quad Cities were fabricated by Williamette. No significant fabrication differences were identified between units.

The top flange ring subassemblies were fabricated from four strip segments (4.5" x 6.5") abrasively cut from plate, roll formed, and welded end-to-end to form the rough ring assembly. Therefore, the end-grain surfaces of the rolled segments in the completed assembly are exposed to the reactor coolant environment. Machining of all ring surfaces was required to achieve the finished 4" x 6" cross section.

The top guide ring was fabricated from six arc segments (3" thick) that were cut from plate materials. The arc segments were welded end-to-end to form the ring assembly. The end-grain surfaces of the rolled segments are exposed to the reactor coolant environment at the vertical surfaces, which are more susceptible to crack initiation of the ring. The finished cross section of the ring (2.5" thick) indicates machining of all surfaces.

The core support plate ring was fabricated from six arc segments (4.5" thick) that were cut from plate materials. The arc segments were welded end-to-end to form the ring assembly. The end-grain surfaces of the rolled segments are exposed to the reactor coolant environment at the vertical surfaces of the ring. The finished cross section of the ring (4" thick) indicates machining of all surfaces. This ring forms a ledge that supports the core shroud cylinder and the lower core support plate (see Figures 1 and 3).

The shell subassemblies were all made of three 2" plate sections that were rolled to curvature and joined by vertical welds.

The bottom of the core shroud is welded to the ledge at the bottom of the downcomer annulus upon which the jet pumps sit. The shroud is further supported by shroud support legs welded to the bottom head of the reactor vessel.

The steam separators and the dryers are mechanically attached to the core shroud at the ledge region near the top of the core, above the core spray spargers. The core top guide structure, which provides lateral support for the fuel assemblies and assures that the core geometry is maintained to allow for control rod insertion, is supported by a second ledge below the core spray spargers. The spray header for the core spray system is contained within and supported by the core shroud, and the connecting piping enters through the vertical portion of the core shroud above the top guide support ring (ledge).

Figure 3 shows a detail of the H5 weld geometry for the core shrouds at Dresden, Unit 3, and Quad Cities, Unit 1.

2.2 Results from Nondestructive Examination and Metallography

The staff has reviewed the information provided by ComEd on the inspection procedures and analysis methodology employed by the licensee in carrying out visual and ultrasonic examinations of the Dresden, Unit 3, and Quad Cities, Unit 1, core shroud welds. In addition, the staff has also reviewed the results from ultrasonic examinations of the core shrouds and metallographic examinations performed on material (boat) samples taken from both the Dresden, Unit 3, and Quad Cities, Unit 1, facilities.

2.2.1 Visual Inspection Methodology and Results

By letter dated March 31, 1994, ComEd provided the methodology used in the in-vessel VI of the Dresden, Unit 3, and Quad Cities, Unit 1, core shroud welds. The method called for an enhanced ASME Code, Section XI, visual examination by qualified Level II and Level III personnel. The examiners were required to detect a .001" (1 mil) wire at the inspection surface to ensure required sensitivity. By letter dated June 25, 1994, the licensee provided information describing the area of each weld to be examined by VI techniques with the intent of meeting the visual screening criteria described in the Boiling Water Reactor Owner's Group (BWROG) "BWR Core Shroud Evaluation," (GENE-523-48-1193) dated April 5, 1994.

Based on the amount of cracking discovered, the scope of the licensee's VIs was expanded significantly beyond the original inspection plan. The final scope and results of the VIs of the Dresden, Unit 3, and Quad Cities, Unit 1, core shroud welds were submitted to the NRC by letter dated June 6, 1994. A summary of results is given in Tables 1 and 2. The staff has concluded that the scope of the VIs was adequate.

This paragraph discusses some generic observations resulting from the VIs at Dresden, Unit 3, and Quad Cities, Unit 1. Although the final scope of the licensees VIs for these two units was acceptable to the staff, the original methodology supporting the inspection pattern specified by the licensee in their March 31, 1994, submittal, Section 2.0, was inadequate. Table 1 of Section 2.0 in each document established an inspection scope that would limit inspections to a "minimum required inspection length per uncracked region" to demonstrate adequate structural margin. The staff has concluded that this strategy of minimum inspection is not a prudent way to conduct an examination. Furthermore, the staff finds that the methodology originally proposed by the licensee for their expansion of the inspection after cracking was found to be inadequate. The staff has concluded that the entire weld should be visually examined to ascertain the extent of cracking, thereby providing a good baseline for future evaluation. Visual examination to establish the existence of a minimum sound ligament does not provide a comprehensive characterization of the condition of the shroud for future inspections. Additionally, given the extensive cracking observed during the VI of both the Dresden, Unit 3, and Quad Cities, Unit 1, core shroud welds, the staff has informed the BWROG that the original screening requirements in the BWROG submittal and those used by the licensee need to be modified for future inspections. This is due to the discovery of cracks at weld locations other than those which had previously been considered to be limiting. The occurrence of both inside and outside diameter cracks may also make it necessary to require VI from both surfaces of some core shroud welds or to require reliable ultrasonic examination when only the outside diameter is accessible to VI techniques.

2.2.2 Ultrasonic Inspection Results

Ultrasonic inspection methods were employed at Dresden, Unit 3, and Quad Cities, Unit 1, to inspect shroud welds H2, H5, H6 and H7. Ultrasonic testing examination was employed if VI of the inside diameter surface of the shroud weld was not possible due to structural impediments or if the weld failed the screening criteria for VI.

The ultrasonic examinations were performed using a variety of techniques. The first technique employed by the licensee was used at Dresden, Unit 3, on the H5 weld at six locations to perform flaw depth evaluation. This method made use of manually-operated, pole-mounted 60° and 70° refracted longitudinal (RL) wave transducers. The results of this technique indicated a maximum estimated crack depth of 1.55".

Subsequent ultrasonic testing made use of an automated tracking system developed by GE to inspect welds H2, H5, H6 and H7. This automated tracking system carried two types of transducers. The first type was a 45° shear wave transducer used to detect the presence or absence of a flaw in a particular area. The transducers of the second type permitted examination by a 60° RL pitch-catch method intended to be used in crack tip diffraction for flaw depth sizing. A summary of the flaw depth sizing from this system was submitted to the NRC by letter dated June 6, 1994, and is presented for Dresden, Unit 3, and Quad Cities, Unit 1, in Tables 3 and 4, respectively. The maximum flaw depth recorded at the H5 weld location based on the 60° RL wave inspection was 0.84" for the Dresden, Unit 3, shroud and 0.57" for the Quad Cities, Unit 1, shroud. The licensee has also suggested that due to the geometry (see Figure 6) involved in the 45° shear wave inspection, the observance of a strong back wall reflection from the toe of the fillet weld at the H5 location on the inside diameter indicates that no crack propagating from the outside diameter can have a depth greater than 1.24", since a crack would result in a loss or attenuation of the back wall reflection. The reliability of the ultrasonic results are discussed in the following section.

2.2.3 Metallography Results from the Boat Samples

In order to more fully investigate the cracking observed at the H5 weld location, material (boat) samples were removed from the shroud by electrical discharge machining (EDM). Two boat samples were removed from the outside diameter surface of the H5 welds at both Dresden, Unit 3, and Quad Cities, Unit 1. The samples from Dresden, Unit 3, were removed after the ultrasonic examination was completed. The samples removed from Quad Cities, Unit 1, were removed prior to ultrasonic examination, therefore, the metallographic examinations of these samples were compared to the UT results from the immediate adjacent areas. The results of the crack depth sizing from the metallographic inspection of the boat samples are compared to the automated tracker ultrasonic results in Table 5.

The comparison in Table 5 indicates that significant discrepancies exist between the ultrasonic and metallographic results. The result from Dresden, Unit 3, sample 1, shows that the ultrasonic examination undersized the existing crack by 0.310". The result from Quad Cities, Unit 1, sample 2, indicates that the ultrasonic examination may have undersized the existing crack by 0.300". The staff believes that these discrepancies are due to the tightness and fineness of the intergranular stress corrosion cracking (IGSCC) in the region near the crack tips. The tightness of the cracks may cause only low levels of acoustic impedance mismatch (AIM) near the crack tips. The staff has concluded that these AIM levels may not be sufficient to cause an ultrasonic indication either through direct reflection or through crack tip diffraction. Furthermore, it has not been demonstrated that low levels of AIM would be sufficient to result in the masking or attenuation of a back wall reflection via a 45° shear wave.

The metallographic examination in areas adjacent to the H5 welds in all of the boat samples confirmed the cracking to be IGSCC. As mentioned in the preceding paragraph, the cracks were observed to be extremely branched at the crack tips and very fine. The nature of the cracking indicates a reduction in the stress intensity as the cracks propagate deeper into the shroud. The metallographic results showed that all surfaces of the core support rings had a significant amount of cold-work present due to machining during shroud fabrication. The residual stresses due to this cold-working were significant and could have contributed to accelerated flaw nucleation. The weld residual stresses are probably the dominant driving force for crack propagation since the normal operating loads are low. Results submitted by the licensee in the June 25, 1994, letter using the GE nugget cooling finite element model showed that peak values of the weld residual stress occur near the outside diameter of the shroud.

The application of the UT and metallographic results in determination of a flaw depth to use in the crack assessment is addressed in Section 2.4.2.1.

2.3 Evaluation of Loading Conditions

This section provides the staff's review of the licensing basis loads for Dresden, Unit 3, and Quad Cities, Unit 1, to determine their adequacy for the structural integrity assessment of the cracked core shroud discussed in

Section 2.4 and for the consequence and risk assessments discussed in Section 2.5

The applicable licensing basis pressures, loads and load combinations for the shroud are defined in the Dresden and Quad Cities Updated Final Safety Analysis Reports (UFSAR). In its submittal of June 25, 1994, the licensee provided free body diagrams of the shroud, depicting the loads and points of application on the shroud. The licensee also defined properties, loads, stresses, and combined stresses in the wall of the shroud. The licensee has determined the minimum required ligament for the shroud under all loading conditions. These analyses have included all licensing basis loads and, in addition, have considered additional load combinations that are more severe than what is defined in the Dresden and Quad Cities UFSARs. These included load combinations involving MSLB plus an SSE and RLB plus an SSE used in evaluating the limiting crack size and the consequence of a postulated 360° through-wall crack at the H5 location. These load combinations are not required as a design basis for the Dresden and Quad Cities plants. In addition, the probability of occurrence of these events is considered to be very low as discussed in Section 2.5.4. These load combinations are however included in the licensing basis for plants of more recent vintage. ComEd has considered them in the present evaluation to examine the safety margins which exist for various scenarios.

The staff reviewed the resulting stresses in the shroud due to the individual loadings, discussed below. Stresses due to combined loadings were also evaluated to determine the governing (maximum) tensile stress in the shroud wall. The licensee used a combination of stresses due to dead load, buoyancy, main steamline break (MSLB) pressure, and seismic safe shutdown earthquake (SSE) as the governing load combination for evaluation of the limiting flaw size. The staff concurs with this determination on the basis of its review of the applicable load combinations, discussed above. However uncertainties have been identified by the staff in the licensee's determination of the RLB blowdown loads discussed in Section 2.5.2.2. The staff's conclusion regarding the governing load combination involving MSLB plus an SSE, stated above, is contingent upon the assessment that the uncertainties in the determination of the RLB blowdown loads are bounded by a factor of two. In the event the RLB blowdown loads are determined to be greater than the present estimated value by a factor of two, this load combination involving RLB plus an SSE, would become the governing load combination for evaluation of the limiting flaw size.

There is a difference in the loading conditions between the Dresden and Quad Cities plants. This is primarily due to differing calculational methods used in the transient loading analysis of the two plants. Since the Quad Cities thermal-hydraulic calculations used to determine faulted condition loads were performed more recently, and the two plants are essentially identical, the staff believes it more reasonable and conservative to use the Quad Cities loading conditions to evaluate bounding flaws and consequences.

2.3.1 Normal Operations & Transient Condition Loading

During normal operations, the loading conditions in the Dresden and Quad Cities UFSARs are used for this analysis. They consist of: (1) dead loads which include the weight of the shroud and reactor pressure vessel (RPV) internals, (2) buoyancy loads which have been calculated on the basis of the average density of shroud components, and (3) uplift loads due to normal operating and upset pressure differentials (7 psi for Dresden, and 8 psi for Quad Cities). Normal operational loads and transient condition loads are all bounded by licensing basis event loads.

The stresses which occur as a result of the maximum possible combination of loadings encountered during normal operations, including dead loads plus operating basis earthquake (OBE) loads, are within the stress criteria of ASME Section III, Class A Vessel.

Additional loading conditions of a pressure regulator failure (open), a recirculation flow control failure, and inadvertent actuation of the automatic depressurization system were evaluated. Assessments by the licensee indicate that the loads from these events were of insufficient magnitude to displace the shroud. The staff reviewed these loads and agrees with this conclusion.

2.3.2 Licensing Basis Events

The licensing basis faulted events analyzed in the UFSAR include the main steamline break, the reactor recirculation line break, and the licensing basis earthquake. These are discussed in the following sections. In addition, certain load combinations such as the main steamline and reactor recirculation line breaks, in combination with a licensing basis earthquake, were used by the licensee to evaluate the bounding flaw size and consequences of a postulated 360° crack at the H5 weld location. These loading conditions, which are beyond the licensing basis, are discussed in 2.3.3.

The staff has performed an independent assessment of the loads by: (1) reviewing previous work done for pressurized water reactors (PWR) blowdown loads summarized in NUREG-0609, "Asymmetric Blowdown Loads on PWR Primary Systems - Resolution of Generic Task Action Plan A-2," for applicability to the BWR acoustic loads analysis, (2) reviewing main steamline break calculations, and (3) performing independent analysis of the loads for a recirculation line break. The independent calculations were performed using a TRAC model of the Dresden/Quad Cities downcomer and steam dome region. The model has 13 axial levels and eight theta sectors with eight of the axial levels over the core barrel region. The water in the downcomer is assumed to be 10 degrees Kelvin (K) subcooled and the system pressure is set at 7 Mega Pascal (MPa). This model can provide a rough estimate of the acoustic loads and a good estimate of the blowdown loads that are generated in a recirculation line break. Both instantaneous and 25 millisecond (ms) break opening times were studied in the acoustic load analysis.

The primary stresses resulting from licensing basis accident loadings such as MSLB, a reactor recirculation line break (RLB) and an SSE are within the stress criteria of ASME, Section III, Class A Vessel. The primary stresses and primary plus secondary stresses were examined on a rational basis taking into account elastic and plastic strains. These strains are limited to preclude failure by deformation, which could compromise the engineered safeguard features or prevent safe shutdown of the reactor.

2.3.2.1 Main Steamline Break

The licensee provided analyses for an MSLB event. The internal pressures on the shroud head associated with the MSLB (20 psid) are used in the evaluation and applied as a uniform pressure on the entire shroud head area. The MSLB pressure differentials were computed from the RETRAN computer code, which were derived from the Dresden and Quad Cities UFSAR. The staff agrees that RETRAN is generally acknowledged to provide an adequate simulation for applications similar to this. Additionally, the staff reviewed similar BWR calculations, performed using the TRAC and RELAP5 codes, to assess the licensee's estimated loading. The licensee's loads bounded those from the TRAC and RELAP5 calculations. Therefore, the staff finds the licensee's loading values acceptable.

2.3.2.2 Reactor Recirculation Line Break

For the reactor RLB loss-of-coolant accident (LOCA), the blowdown and acoustic loads associated with the RLB LOCA have been calculated. The acoustic loading is a highly dynamic shock loading that acts for a short time interval and results from the propagation of pressure waves after the break opens. The calculation of acoustic loads requires a dynamic calculation that tracks pressure wave propagation throughout the system. The blowdown loads are quasi-steady forces that result from the quasi-static pressure distribution around the downcomer after the initial acoustic loads have dampened out. These can be estimated with a static calculation.

The acoustic loads were calculated by the licensee using the time history load profile in the UFSAR and by proportioning the total load between the sections of the shroud above and below the H5 weld. Based on the relative geometry of the shroud, 75% of the total load was assumed to act upon the portion of the shroud above H5. The blowdown loads were calculated by the licensee using a potential flow analysis to determine a net lateral force acting above H5.

The acoustic loads provided by ComEd are calculated by the WHAM computer code and backed up by several different hand calculations to conclude that the short duration acoustic load from the RLB event would result in minimal movement of the shroud in the event of a postulated 360° through-wall crack. The staff believes that the WHAM code is appropriate for this use and is known to be conservative, provided the models have been constructed correctly. The WHAM models and assumptions were not provided to the staff, and have been requested. Absent details of the licensee's WHAM analysis, the staff attempted to identify the upper bound of acoustic loads. A review of similar calculations for PWRs in NUREG-0609 indicates that the acoustic loads may be significantly higher than the loads provided by ComEd. Due to this estimate showing increased acoustic loading, the staff performed independent simplified calculations with TRAC. These analyses gave loads about 10 times higher for the instantaneous break opening calculation and about seven times higher for the 25 ms break opening time. These assessments do not credit attenuation of the acoustic wave by the jet pump structure in the downcomer region, but are utilized by the staff in its safety assessment as a bounding value. ComEd has been requested to provide detailed modelling information in order to confirm their calculated loads.

For the purpose of this assessment, the contribution of acoustic loads was negligible since the fundamental frequency of the cracked shroud is substantially lower than the characteristic frequency of the acoustic impulse. The licensee has determined that due to the considerable mismatch between the characteristic frequency of the acoustic impulse and the fundamental frequency of the shroud, the structural response of the shroud would be greatly deamplified relative to the input excitation. On this basis, the effect of the acoustic loads on the structural response of the shroud would be negligible and consequently, the uncertainties in the WHAM model and the magnitude of acoustic loads are not germane to the present evaluation. Therefore, the licensee has not included the acoustic loads in their analyses to determine the minimum-required ligament size and consequence assessment of the shroud with a postulated 360° through-wall crack at the H5 weld when subjected to licensing basis, as well as beyond licensing basis accident loads.

The staff concurs with the licensee's assessment and on the basis of its independent evaluation, concludes that the acoustic loads need not be included in determining the structural response of the shroud. The staff's review to validate the magnitude of the acoustic loads, however, will continue, since these loads may be pertinent for other structural evaluations such as permanent repair options.

The asymmetric blowdown pressure distribution over the shroud was calculated by the licensee using potential flow theory. The force was calculated by summing the products of the pressure and area perpendicular to the blowdown direction over each 10° circumferential segment above the H5 weld. The moment was similarly calculated by multiplying the product of the normalized force and area for each segment times it vertical moment arm and summing the moments in each segment. Conservatively, the blowdown load was applied above the H5 weld, whereas the actual load should impact the shroud below the H5 weld.

The staff finds that there is significant uncertainty with the loads calculated using the potential flow theory. The licensee provided no information to benchmark or demonstrate that this calculational method is bounding for this application. In addition, one assumption used in the 2-dimensional (2-D) calculation appeared to be non-conservative; the absence of jet pumps would lower the velocities, raising the pressure differential, in the flow field and remove flow resistance that would increase the pressure differential between the break location and the opposite side of the shroud. A scoping calculation utilizing TRAC was performed by the staff that includes flow area blockages and head losses due to the presence of the jet pumps. These calculations provided loads and tipping moments that were approximately twice as large as the loads calculated by the licensee. The staff concludes that the licensee's loads are not conservative. Therefore, ComEd has been requested to perform a more detailed computer calculation that takes into account the flow area blockages and losses due to the jet pumps. In performing this safety assessment, the staff used blowdown loads that are increased by a factor of two above that reported by the licensee.

2.3.2.3 Safe Shutdown Earthquake Loads

The original licensing basis seismic design analyses for Dresden were based on a spectra from the El Centro earthquake of 1940. The original licensing basis seismic analyses for Quad Cities were performed using the Golden Gate Park spectra from the San Francisco earthquake of 1957. In addition, a reevaluation of the seismic design was performed using the Housner earthquake spectrum.

In the core shroud evaluation, the licensee performed two seismic analyses using the current licensing basis SSE at both Dresden and Quad Cities. Quad Cities UFSAR specifies the 1957 Golden Gate Park S80°E time history (normalized to 0.24g ZPA) as the licensing basis SSE. It also states that structures should be analyzed against El Centro and Housner ground response spectra if their characteristic modes included frequencies below a specified limit. The seismic analysis for Quad Cities was performed by subjecting a model of the Quad Cities reactor building to the licensing basis SSE free field acceleration time history specified above. Since the structural model of the reactor building with the shroud intact did not contain modes with low enough frequencies where the El Centro and Housner spectra would be expected to govern the response in the lower frequency range, the licensee determined that the Golden Gate Park time history was the most limiting seismic input motion for this analysis. The seismic analysis for Dresden was based on subjecting the structural model of the reactor building to an El Centro N-S time history anchored at 0.2g ZPA. The vertical UFSAR seismic design loads were calculated by multiplying the self weight with the vertical accelerations (0.133g SSE for Dresden and 0.16g SSE for Quad Cities). The structural seismic model is a mathematical, stick model consisting of beam elements and lumped masses. The model represents the actual reactor building and drywell and includes details of the RPV and internals. The model also accounts for the dynamic interaction between the turbine and reactor buildings. Based on its review, the staff finds the licensee's seismic analysis acceptable. The shroud's seismic SSE stresses were utilized in the staff's limit load analysis discussed in Section 2.4.2.4.

For evaluation of the seismic loads for the case of a postulated 360° through-wall crack in weld H5, a parametric seismic analysis similar to the above (based on the Quad Cities model) was performed by the licensee, using the licensing basis SSE loads, except that the analytical model of the shroud was modified to account for the degraded condition of the H5 weld location. The seismic maximum relative displacement between the RPV and the shroud for the case of an assumed 360° through-wall crack at weld H5 was obtained from a base support time history analysis of the Quad Cities structural east-west seismic model. The time history analyses were performed using the GE computer program SAP4G07 which is considered to be appropriate for such applications. Two bounding analyses were performed to account for the assumed 360° through-wall crack at H5. The shroud was considered to be pin-connected at the weld elevation in the first analysis and roller-connected in the second analysis.

In the first case, only shear could be transferred across the cracked weld. In the second case, neither shear nor moment could be transferred across the cracked weld. For both cases, very soft springs were assumed in the analysis, added between the RPV and the shrouds, resulting in essentially zero change in the eigendata set for the uncracked model. The soft springs assumption is required to rid the model of the singularities introduced by the assumed pinned-connected and roller-connected conditions in the shroud at the H5 weld elevation. The resulting SSE forces in these springs were also divided by the soft springs stiffness to obtain the relative displacements between the RPV and the shroud at the top guide and the core support plate locations. Based upon our review, the staff finds the licensee's methodology for the seismic analysis of the cracked shroud acceptable. The staff questioned the basis for considering the Golden Gate time history as the limiting seismic input in this evaluation since the predicted shroud displacement could be exceeded due to the significant reduction in frequency of the degraded shroud and the higher acceleration levels at the lower frequency range if the Housner or El Centro ground response spectra were used in such evaluation. The licensee performed a preliminary assessment of the staff's concern and concluded that the increase in the shroud's displacement as a result of using other seismic input spectra would not be significant due to the very low frequency of the degraded portion of the shroud in relation to the supporting structure (reactor vessel and support). Thus, the maximum differential displacement of the core shroud would not be appreciably higher than the maximum ground displacement of the limiting seismic input. The licensee concluded that maximum differential shroud displacement would be less than an upper bound of 2". The staff found the licensee's preliminary assessment to be reasonable; however, the staff requested ComEd to provide additional detailed analyses to substantiate its preliminary conclusion as discussed in section 2.6. Results from the seismic analysis considering a 360° through-wall crack were used for the assessment of the shroud's response discussed in Section 2.5.

2.3.3 Beyond Licensing Basis Loads

The licensee's safety assessment with a postulated through-wall crack at the H5 weld and loadings beyond the licensing basis (MSLB plus an SSE, RLB plus an SSE) involved determination of shroud movement both in the upward and lateral directions and its potential impact on the core spray lines and control rod insertability. In these analyses, usually stresses do not exceed the yield stress of the material. However, if they did exceed this limit, energy absorption capacity was determined and compared to the energy input from the most-severe loadings. The criterion of demonstrating functionality was used in these evaluations. In the analyses to determine effects of the shroud's drop, conservation of linear momentum was applied to determine the effective impact velocity of the shroud. This velocity was used to determine the impact force and stress on the shroud and shroud support legs, assuming that the shroud support legs take the full dynamic load from the shroud lift and subsequent drop and that the load is distributed equally. Elastic buckling calculations were performed for the shroud support legs and the stresses in the support legs were limited to the elastic limit of the shroud support leg material. Based upon its review, the staff finds the licensee's methodology for assessing beyond licensing basis loads acceptable.

2.3.4 Summary

On the basis of its review, the staff finds that the licensing basis pressure loads, dead loads and load combinations are consistent with the applicable sections of the Dresden and Quad Cities UFSARs.

Loading combinations more severe than those defined in the Dresden and Quad Cities UFSAR were used. The licensee concluded that of the various loading combinations, the MSLB plus an SSE is the governing event for flaw evaluation. Given the licensee's loads calculated for the recirculation line break, the staff agrees with the licensee that the load combination of MSLB plus SSE is the bounding load for use in the flaw evaluation and has used this combination based on Quad Cities loads to determine the limiting flaw size discussed in Section 2.4. It is the staff's view that this conclusion is contingent upon the assessment that the uncertainties in the determination of the RLB blowdown loads are bounded by a factor of two.

Other loading combinations, as discussed above, have been used to evaluate the consequences of a postulated 360° through-wall crack in the shroud at the H5 weld location. While some uncertainties have been identified in the licensee's calculations, the licensee's load development methodology and load combinations are considered to be reasonable. The results of this evaluation are discussed in Section 2.5.

2.4 Flaw Assessment of Weld H5

The assessment of the flaws observed in the Dresden, Unit 3, and Quad Cities, Unit 1, core shroud welds was based on two different sets of visual criteria and a flaw evaluation using limit load analysis of cracks as characterized by UT. Initially, the licensee compared the results from the VI of each weld with established visual screening criteria to determine if additional analysis was required to demonstrate structural integrity. Welds which required additional analysis were examined by ultrasonic testing. Flaws which exceeded the screening limits were evaluated by the licensee based on: (1) the loading combinations discussed in Section 2.3, which may exceed the actual licensing loads, (2) the flaw geometries, (3) the current flaw depths, and (4) the crack growth rate. The licensee's analysis was compared against an independent staff analysis to determine its adequacy in justifying full power operation of Dresden, Unit 3, and Quad Cities, Unit 1, based upon the amount of ligament expected to remain at the weld location.

2.4.1 Visual Screening Criteria

Two sets of visual screening criteria have been submitted to the NRC. The first set consisted of licensee-specific submittals for Dresden and Quad Cities. These included "Evaluation and Screening Criteria for the Dresden 2 and 3 Shrouds," (GENE-523-05-0194), and, "Evaluation and Screening Criteria for the Quad Cities Unit 1 and 2 Shrouds," (GENE-523-02-0194), dated March 31, 1994. The other generic set "BWR Core Shroud Evaluation" (GENE-523-148-1193), was submitted by the BWROG in April 1994.

2.4.1.1 <u>Licensee Visual Screening Criteria</u>

In the March 31, 1994, letter, the licensee sought to establish an analysis method similar to that outlined in Section XI of the ASME Code for the comparison of measured flaw lengths observed in a weld to code acceptable flaw lengths. For the purpose of analyzing VI results, any flaw which was observed was considered to be through-wall and proximity criteria based on ASME Code, Section XI, Subarticle IWA-3300 of the 1989 edition were used. Any areas of the weld which were not inspected by VI were assumed to contain through-wall cracks. The allowable through-wall flaw length at each weld location in each plant was calculated based on postulated loading conditions by both linear-elastic fracture mechanics (LEFM) and the limit load techniques in ASME Code, Section XI, Subsubarticle IWB-3640. The results of the analysis are presented in Columns 1 and 2 of Table 6 for both the Dresden, Unit 3, and Quad Cities, Unit 1, facilities. The flaw lengths defined by the LEFM analysis for welds H4 and H5 are for effective single flaw lengths as defined by the proximity rules, while the limit load values are representative of the total combined flaw length for the given weld.

2.4.1.2 <u>BWROG Visual Screening Criteria</u>

The methods used to develop the BWROG visual screening criteria as presented in GENE-523-148-1193 are consistent with those used by the licensee. The BWROG criteria also imposes an additional limit with respect to the distribution of the flaws at a weld location and the limit load analysis. The BWROG submittal adds, "the cumulative flaw length cannot be more than one-fourth of the limit load allowable flaw length in any 90° sector of the shroud." This indicates that for limit load analysis based on the postulated loading conditions, the limit on the flaw length in any 90° sector would be that listed in Column 3 of Table 6 for each plant. The staff has concluded that the application of the additional conservatism given in the BWROG submittal on the effective cumulative flaw length allowable in any one 90° sector is justified.

2.4.1.3 <u>NRC Assessment of Indications Using Visual Screening Criteria</u>

After accounting for degradation due to continued crack growth and including the conservatism of the BWROG criteria, welds H1, H2, H3, H4, H6 and H7 at both Dresden, Unit 3, and Quad Cities, Unit 1, are within the bounds established by the respective limit load analyses for each weld. Weld H5 fails the VI screening criteria at both plants, since flaws were detected on the outside diameter in all locations where VI was performed. This also implies that, based on the VI alone, the flaw at H5 in each shroud would have to be assumed to be a 360° through-wall failure of the weld. The licensee subsequently performed ultrasonic inspection on the H5 weld location to provide a flaw depth evaluation suitable for use in a structural integrity analysis of the Dresden and Quad Cities units.

The staff also notes that the H3 weld location in the Dresden, Unit 3, shroud was very close to exceeding the screening criteria as established in the BWROG submittal for the sector between 105° and 195° based upon the observed inside diameter flaws. Although presently acceptable, the staff has also concluded that additional inspection of the H3 location during future inspections will be important in assessing the structural integrity of the Dresden, Unit 3, core shroud.

2.4.2 Evaluation of the H5 Weld Location

The evaluation conducted by the licensee for the H5 weld location has been reviewed by the staff. The staff has also conducted an independent evaluation of the structural integrity of the weld. The methodology of the staff and licensee evaluations were consistent, although different values have been assumed in each for various parameters. The analysis carried out by the staff and the results of both analyses are discussed below. The staff's analysis is based upon information provided from both Dresden, Unit 3, and Quad Cities, Unit 1, and the values selected for the analysis bound both facilities.

2.4.2.1 Establishment of the Bounding Crack Depth

The staff has determined that based on the information supplied by the licensee, five independent methods may be used to attempt to establish a bounding crack depth for the current outside diameter flaws at the H5 weld location. These methods, as discussed below, include: (1) crack growth based on GE PLEDGE model results; (2) the manual pole-mounted ultrasonic transducer results; (3) the ultrasonic flaw sizing results based on the automated 60° RL inspection; (4) a geometrical argument proposed by ComEd based on the automated 45° shear wave examination; and (5) results based on the modeling of the weld residual stress profile.

The staff has used results from the GE PLEDGE models for Dresden, Unit 3, and Quad Cities, Unit 1, in establishing a bounding crack depth. These are provided as Figures 4 and 5, respectively, and were included in the licensee's June 13, 1994, submittals. Based on the licensee's submittal of June 25, 1994, which confirmed 14.4 effective full power years (EFPY) of operation for Quad Cities, Unit 1, and the assumption that the IGSCC cracking nucleated after 3 EFPY, the bounding flaw depth was determined to be 1.32" based on a realistic crack growth rate of 1.32×10^{-5} inches/hour obtained from the Quad Cities data. Some uncertainty exists in the depth calculation based on plant water chemistry for the early years of operation as well as the actual time for crack initiation. The staff also noted that the assumption of crack initiation after 3 EFPY is inconsistent with the threshold operating time for crack initiation of six to eight years stated in other industry documents. The assumption of an earlier initiation time would result in slower crack growth rates when bench marking crack growth models against operating data.

As presented in Section 2.2.2, the values for the bounding flaw depth based on the various methods of ultrasonic inspection are as follows: manual pole-mounted ultrasonic inspection, 1.55"; automated 60° RL inspection with a 0.310" uncertainty, 1.15"; automated 45° shear wave inspection, 1.24". Since only a small sampling of the shroud was done with the manual system, the uncertainty in its results is not known and based on the other data its results may overestimate the actual crack size by a significant margin. The establishment of uncertainties via the boat sample metallography, which have been included above, provides additional credibility for the 60° RL results.

The results of the weld residual stress intensity profile submitted in the June 25, 1994, letter were based on the GE nugget cooling finite element model. As the residual stresses in the weld are relieved by crack propagation, the expected crack growth rate decreases and the mode of degradation shifts from IGSCC to intergranular corrosion as a result of the reduction in the driving force. The residual stress profile indicates that this driving force diminishes significantly at depths between 1.10" and 1.30" from the outside diameter of the shroud.

Based on the considerations above, the staff concluded that using a bounding crack depth for outside diameter flaws of 1.30" would provide an appropriate level of conservatism for the analysis of the structural integrity of the weld. The licensee chose to use the 1.24" result from the 45° shear wave geometry as its bounding initial crack depth.

2.4.2.2 Establishment of the Bounding Flaw Geometry

The licensee's calculations were based upon a minimum material thickness of 3.0" that a crack must traverse before reaching through-wall. The material thickness included the 2.0" shroud barrel wall thickness and the 1.0" leg fillet weld on the inside diameter at the H5 location. The minimum required ligament thickness calculated by the licensee was 0.060" for Dresden, Unit 3, and 0.120" for Quad Cities, Unit 1. The licensee's methodology is based on the limit load approach in Section XI of the ASME Code. To justify the appropriateness of the limit load analysis for determining the stress distributions associated with the H5 weld, ComEd performed a finite element analysis of the cracked region. The results of the finite element analysis were not amplified by stress intensification factors, since the model incorporated the shroud's geometrical discontinuities, including the crack length, and the minimum wall thickness required for satisfying the assumption of membrane loading. On this basis, the licensee concluded that the limit load analysis was appropriate. This is evaluated by the staff in Section 2.4.2.4.

The geometry used by the licensee in its analysis of the H5 weld location may be found in Figure 6. The licensee's approach to the concerns of crack growth and subsequent remaining ligament made use of an initial 3" material thickness through the core support plate for flaw propagation. Their analysis takes full credit for the existence of a 1" fillet weld on the inside diameter of the H5 weld with no provision for the generation of an inside diameter flaw.

The results of the ultrasonic examinations for the H5 weld locations at Dresden, Unit 3, and Quad Cities, Unit 1, have shown that the majority of the flaws present nucleated from the outside diameter of the core support plate. However, the ultrasonic examination at Quad Cities, Unit 1, indicated the presence of a flaw in the upper heat affected zone (HAZ) on the inside diameter of the H5 weld location at the toe of the fillet weld. This indication suggests that conditions favorable to the nucleation and propagation of IGSCC may exist at the inside diameter of the H5 weld in both units. The presence of a significant amount of cold-work on the core support ring would indicate that the residual surface stresses necessary for flaw nucleation would, in fact, be greater for the lower HAZ. Furthermore, based on the geometry used in the ultrasonic inspections, the staff has concluded that flaws in the upper HAZ would be more readily identified than those in the lower HAZ.

Based on these considerations and the uncertainty present in the results of the ultrasonic examination, the staff has concluded that the assumption of cracking in the lower HAZ of the internal fillet weld is prudent. The staff concluded, based on the size of the inside diameter flaw from the Quad Cities inspection, the uncertainty in the automated ultrasonic scanner supported by the boat samples, and the weld residual stress profile that a value of 0.55" would bound inside diameter flaws in the lower HAZ. Additionally, the licensee has not provided documentation to confirm the 1" dimension of weld fillet. In the licensee's response on June 25, 1994, the licensee states, "Fillet dimensions were verified by following a quality control path of specification, written welding and inspection procedures, and by inspection verification and approval." Therefore, while the staff recognizes that in a weld of this type, the existence of a fillet is to be expected, due to the unresolved issue of inside diameter cracking and due to the indeterminate thickness of the fillet, no credit was given to the weld fillet in the staff's analysis. The bounding crack geometry used in the staff analysis was a single crack propagating from the outside diameter of the shroud into a total material thickness of 2".

2.4.2.3 Analysis of Crack Growth

The crack growth rates used in the licensee's analysis are based on results generated by the GE PLEDGE model of IGSCC. Based on the results, as depicted in Figures 4 and 5, the licensee used IGSCC growth rates of 1.24×10^{-5} inches/hour for Dresden, Unit 3 and 1.32×10^{-5} inches/hour for Quad Cities, Unit, 1. The staff's position on crack growth rate assumptions for licensing purposes has been to use a crack growth rate of 5×10^{-5} inches/hour. The staff has concluded that the use of this crack growth rate is appropriate for the analysis of the structural integrity of the core shroud, based on experience with IGSCC in BWR piping applications as summarized in NUREG-0313, Revision 2, "Technical Report on Material Selection and Processing Guide Lines for BWR Coolant Pressure Boundary Piping."

The application of the 5×10^{-5} inches/hour crack growth rate to the bounding crack geometry has been analyzed for both units. An assessment of the remaining ligament is made in Section 2.4.2.4.

2.4.2.4 Limit Load Analysis

The resultant forces and moments at each weld location for welds H1 through H7 were determined by appropriate combinations of dead load, seismic and faulted condition loads on the shroud. An axisymmetric shell model with a fixed base at the H8 location was used for this analysis. The primary stresses in the shroud wall at each weld location were obtained by adding the membrane stresses due to axial loads, P_m, to the bending stresses due to seismic and asymmetric loads, P_b. Utilizing the maximum primary tensile stresses (P_m+P_b), a limit load analysis was performed to determine the minimum ligament size required. The methodology for this analysis is discussed in an ASTM publication, "Engineering Methods for the Assessment of Ductile Fracture margin in Nuclear Power Plant Piping," S. Ranganath and H. S. Mehta, 1983. The safety factors were used in accordance the ASME, Section XI, Appendix C, Subsection C-3320, requirements. As discussed in Section 2.3 the governing load combination used for this analyses was a MSLB event in combination with an SSE. On the basis of the limit load analysis the minimum required ligament was determined to be 0.12".

The appropriateness of the use of the limit load methodology was verified by a finite element analysis of the H5 weld region. A finite element model was developed that represented the H5 weld geometry in sufficient detail, so that stresses from the applied loading could be assessed across the remaining ligament and compared to the stresses used in the limit load evaluations. The purpose of the finite element analysis was to ensure that minimal stress intensification effects were present in the region due to the offset geometry or the presence of a deep flaw, thus validating the limit load methodology.

The finite element model was developed by the licensee using the ANSYS computer code and comprised of 2-D, axisymmetric, isoparametric solid elements. The H5 weld region was modeled in detail, including the fillet weld, the core plate support ring, and enough of the upper and lower shroud cylindrical portions so that end effects were not significant in the region of interest.

The licensee applied uniform boundary tensile load ($P_m + P_b$) to the upper end of the model. This boundary load represented the contribution of the shroud segment above the upper end of the model, and was derived from the screening criteria primary loads (GE Report "Evaluation and Screening Criteria for the Dresden 2 and 3 Shrouds," GENE-523-05-0194, Revision 0, W.F. Weitze, GE Nuclear Energy, March 1994). As stated earlier, the governing loads were the result of a faulted event of a main steamline break in combination with an SSE. With an ASME Code safety factor of 1.4, this represents the maximum combined primary membrane plus bending stress at a section 50" above the H5 weld. At this location it is estimated that the local bending effects due to fixity are sufficiently attenuated. Since sustained stresses induced by primary loads are the only loads required for limit load evaluation, secondary stresses (e.g., thermal, welding residual, local bending) were not considered. Furthermore, since the wall stresses remained elastic in the finite element model of the shroud with an assumed 0.25" remaining wall ligament, it was considered appropriate for determining the limit load for Dresden, Unit 3, and Quad Cities, Unit 1, shrouds.

The resulting shroud axial stress distribution in the region of interest and a linearized stress profile through the remaining ligament cross section indicates that the average axial membrane stress is approximately 10,000 psi, which is consistent with calculations based on force equilibrium considerations. This average stress is significantly less than the allowable stress of $3S_m$ = 50,700 psi. A review of the stress profile in the remaining ligament confirms that even for very large crack depths, minimal stress intensification effects are present in this region due to the offset geometry or the presence of deep flaws. The model incorporated a shroud height above the core support plate that exceeds the decay length of the discontinuity moments at the shell restraint.

The licensee employed limit load methodologies consistent with ASME Code, Section XI, Subsubarticle IWB-3640, to demonstrate the structural integrity of the H5 weld location in Dresden, Unit 3, and Quad Cities, Unit 1, shrouds for resumption of full-power operation. Additionally, the licensee submitted finite element modeling (FEM) results to support the use of limit load analysis in lieu of LEFM for the geometrically discontinuous H5 weld location. The staff has concluded that given the high value of fracture toughness associated with 304 stainless steel, the low neutron fluence at the H5 weld location, and the results of the FEM, the use of limit load analysis is appropriate.

The limit load analysis provided by the licensee with regard to Quad Cities, Unit 1, is bounding with respect to Dresden, Unit 3. The results of the licensee's analysis indicted that a minimum remaining ligament of 0.120" was required to maintain shroud structural integrity under all loading conditions postulated in Section 2.3. The staff's independent analysis confirms the licensee's assessment. However, as discussed in Section 2.4.2.1, the staff does not agree with the licensee's bounding initial crack depth and initial section thickness available for crack growth. Therefore, the staff performed an independent evaluation using a bounding outside diameter flaw of 1.30" combined with a crack growth rate of 5×10^{-5} inches/hour and an initial section thickness of 2" (discounting the fillet weld). Based on this independent evaluation, the staff has concluded that at the end of 15 months of power operation above cold shutdown, the remaining uncracked thickness of the core shroud would be greater than the required minimum thickness. In evaluating the 15 months of operation, the time spent in cold shutdown need not be counted. This is because the corrosion rates due to IGSCC in cold shutdown are significantly less than the rates encountered during power operations.

In accordance with the licensing basis for the Dresden and Quad Cities units, the staff has also considered the allowable time of operation if only the bounding seismic loads from the Quad Cities FSAR were imposed. Due to the relative magnitudes of the loads generated by a MSLB event versus those by a SSE event, the consideration of SSE loads alone did not change the staff's conclusion on the acceptable period of power operation.

2.4.3 Summary

The staff has determined that the margins to failure required by the ASME Code, Section XI, and the requirements of 10 CFR 50.55a will be satisfied for the operation of Dresden, Unit 3, and Quad Cities, Unit 1, for up to 15 months of operation above cold shutdown.

2.5 Consequence Evaluation of a Postulated 360° Through-Wall Crack at Weld H5

Even though the H5 weld is expected to remain intact, the licensee assessed the potential consequences of a complete failure of the H5 weld. This evaluation provides additional perspective on available safety margins and defense in depth. The licensee's potential structural loads on the core shroud during normal, transient and accident conditions that were evaluated by the staff in Section 2.3, were utilized by the licensee to determine the possible displacement of the shroud given the unlikely occurrence of a complete through-wall failure of the shroud at the H5 weld location. The staff's conclusions regarding the consequences of these loading conditions given a through-wall failure of the shroud at the H5 weld location, are discussed below for the various operational regimes of concern.

2.5.1 Normal Operations and Transient Conditions

The licensee provided an assessment of normal operating conditions and leakage assuming a postulated 360° through-wall crack at the H5 weld. The results and conclusions are consistent with results given in the Dresden and Quad Cities UFSARs. The licensee concluded that the weight of the core shroud above the H5 location is sufficient to preclude shroud movement under all normal operating conditions. With an assumed gap at the crack location of 0.002" around the entire circumference, and the normal operating pressure drop across the upper shroud of 7 psid and 8 psid at Dresden and Quad Cities, respectively, the resultant leakage from the core shroud would be approximately 30 and 35 gpm for Dresden and Quad Cities. The licensee has concluded that leakage flow of this magnitude would have no consequence on plant operation. The staff agrees with this assessment. However, the leakage would not be detectable and, therefore, a 360° through-wall crack at the H5 weld location would not be detectable during normal operation.

Additional loadings during transient conditions were evaluated by ComEd. These transients included pressure regulator failure (open), recirculation flow control failure, and inadvertent actuation of the automatic depressurization system. The licensee indicated that the loads from these events were of insufficient magnitude to displace the shroud. The loads were evaluated by the staff in Section 2.3.1. The staff agrees with the licensee's conclusion.

2.5.2 Licensing Basis Events

The licensee has evaluated the significance of a postulated 360° through-wall crack at the H5 location during licensing basis events. The three scenarios of concern are the MSLB, the RLB, and the SSE. Each scenario is discussed in further detail below.

2.5.2.1 Main Steamline Break

The postulated MSLB event is significant in that this event would result in a large upward load on the shroud, and potential upward shroud motion could impact the ability of the control rods to insert and the ability of the core spray system to perform its safety function.

As discussed in Section 2.3.2.1 above, the staff reviewed the loads provided by the licensee for the MSLB scenario which were calculated using the RETRAN computer code, and has concluded that they are acceptable. Using these calculated loads, ComEd determined the shroud movement that would be expected to occur during the MSLB. The maximum lift of the core shroud was calculated by developing a simplified equation of motion for the severed shroud subject to an uplift pressure. This varying uplift pressure was determined by considering the leakage of single phase flow through the H5 weld opening. The results of this calculation indicated that a 4" vertical lift of the shroud is expected during the MSLB for Quad Cities, and no shroud motion is expected for Dresden. The difference between the Dresden and Quad Cities resultant shroud motion is due primarily to differing calculational methods of the MSLB loads for the two plants. Since the Quad Cities calculation was performed more recently and since the two plants are essentially identical, the staff believes it is more appropriate to evaluate the Quad Cities results which are more limiting. The calculation of shroud response was reviewed and confirmed by the staff. The method used by the licensee and the licensee's calculated results were found by the staff to be acceptable. Therefore, the staff finds the licensee's conclusion, that the MSLB loads would result in an expected vertical shroud motion of 4", to be acceptable.

The licensee has concluded that all safety functions would be maintained for the MSLB scenario. This includes control rod insertion, the core spray function, and the ability to reflood and cool the core. The licensee has indicated that the calculated 4" vertical lift would not result in failure of the core spray riser or sparger. However, the core spray spargers at both Dresden, Unit 3, and Quad Cities, Unit 1, are known to be cracked, and the licensee has not provided an assessment of the impact of potential shroud motion during MSLB on core spray spargers that are cracked. For this reason, the staff is assuming that the core spray sparger will fail during the MSLB, and that the core spray function will not be maintained. While no spray function would be provided, the flow from the damaged core spray system would still be injected into the vessel. Even with significant shroud bypass leakage, the capability of the emergency core cooling system (ECCS) to reflood the reactor vessel is not impacted, as there is no loss of coolant from the lower vessel. Therefore, the staff concludes that long-term core cooling is assured.

While the staff agrees with the licensee's conclusion that core cooling will not be affected, the staff does not agree with the licensee's conclusion that control rod insertion could not be potentially affected. This is discussed in further detail as follows.

The staff questioned the effect of the impact of the core shroud when it lowers after the 4" vertical lift. The licensee provided preliminary calculations performed by GE that indicated that no buckling, in either the shroud or the shroud support legs, would occur due to the impact of the shroud dropping back down. The staff considers the GE calculations to be preliminary and not adequately detailed. More detailed analyses are needed for the staff to fully evaluate the structural integrity of the shroud support structure from shroud drop impact loads. If buckling in the shroud or the shroud support legs were to occur, the safety systems response could be impacted.

The impact of the shroud after the 4" vertical lift and subsequent buckling could potentially impact the ability of the control rods to be inserted. In this case, the standby liquid control system (SLCS) would be available to shut down the reactor. The SLCS flow is injected into a line which penetrates the reactor vessel through a stub tube in the bottom of the vessel beneath the core plate. As discussed above, low differential pressures and low bypass leakage through a postulated through-wall crack in the shroud would not affect the flow path of the SLCS. With the boron provided by the SLCS system assumed to be distributed throughout the vessel, including the core and annulus region, the SLCS is expected to shut down the reactor. The staff recognizes, however, that SLCS would require manual initiation. The plant emergency operating procedures direct operators to manually initiate SLCS in the event that the rods do not fully insert.

In summary, while the licensee has concluded that there would be no impact on the safety systems response for this scenario, the staff has concluded that control rod insertion and core spray function could potentially be impacted. However, the staff has also concluded in this case that the SLCS system would shut down the reactor and that the ECCS would be capable of reflooding the reactor vessel, thereby providing long-term core cooling. This scenario is discussed from a risk perspective in Section 2.5.4.

2.5.2.2 <u>Recirculation Line Break</u>

For the postulated RLB event, the significant concern with a postulated through-wall crack in the shroud at the H5 location is the ability to reflood the reactor vessel to two-thirds core height. This is because the asymmetric loads that would be applied to the shroud during the event could result in a lateral or tipping motion of the shroud. Shroud motion of this nature could result in an opening of the shroud and shroud bypass leakage. Significant shroud bypass leakage could defeat the standpipe effect of the jet pumps, which provides the two-thirds refloodable volume, and would, thus, defeat the ability to reflood the core to two-thirds core height, and to provide adequate core cooling.

The licensee's analysis of this event concluded that there would be no significant consequences during the RLB assuming a 360° through-wall crack at the H5 weld location. Their results indicate that no shroud movement is anticipated for the RLB, and that the safety systems response, including the integrity of the refloodable volume, control rod insertion, and ECCS response, would not be impacted. The analyses which were used to determine the shroud response were based on the calculated loads on the shroud during the RLB event. These loads were provided by ComEd and include two distinct components: acoustic load and blowdown load. The blowdown load was calculated to produce a concentrated force on the shroud less than one-tenth of the magnitude of the acoustic load concentrated force, but its duration is longer. These loads have been reviewed by the staff, and the results of this review are provided in Section 2.3.2.2.

The acoustic load, determined using the WHAM code, is calculated to produce a horizontal differential pressure across the shroud for about 0.020 seconds. The conclusion from the licensee's preliminary calculations was that the maximum lateral displacement is well below 0.09" (the product of the computed velocity times the application time). In this preliminary calculation, however, the significant deamplification of the acoustic impulse, due to a mismatch between the characteristic frequency of the acoustic impulse and the fundamental frequency of the shroud, was not considered. As discussed in more detail in Section 2.3.2.2, the acoustic loads will not have a measurable contribution to shroud movement. Therefore, the staff has concluded that acoustic loads need not be included in determining the structural response of a severely degraded shroud.

The asymmetric blowdown loads resulting from an RLB, continuing past the duration of the acoustic shock loads, were calculated by the licensee using potential flow theory. This is a hand calculation for an idealized flow field, and is discussed in further detail in Section 2.3.2.2. The licensee has concluded that blowdown produces loads that are a factor of 15 below the loads necessary to tip the shroud; this conclusion assumes a peak moment of 500 inch-kips (from their 3-dimensional potential flow calculation) compared to the 7500 inch-kips restoring moment assumed for Dresden. The staff believes a more conservative estimate would be a 3 to 1 factor, obtained by comparing the 1060 inch-kips peak tipping moment from their 2-D potential flow calculation with the 3700 inch-kips restoring moment from the Quad Cities calculation. This is because the difference between the Dresden and Quad Cities restoring moment as presented by ComEd is due primarily to differing calculational methods for the two plants. Since the Quad Cities calculation was performed more recently and since the two plants are essentially identical, the staff believes it is more appropriate to use the Quad cities restoring moment to estimate the conservatism in these calculations.

Conservatively, the blowdown load was applied above the H5 weld, whereas the actual load should impact the shroud below the H5 weld, and the licensee concluded that no shroud motion and, therefore, no impact on the safety systems response would result. Given the blowdown loads that the licensee has calculated with the potential flow theory, the staff has reviewed and confirmed the licensee's calculation of the shroud response. As discussed in Section 2.3.2.2, however, the staff has concluded that there are significant uncertainties in the blowdown load calculation, and that the loads could be a factor of two higher than those calculated by ComEd. This increase in the blowdown loads would result in a reduction in the margin to shroud motion from a 3 to 1 factor to a 1.5 to 1 factor.

Because of the uncertainties in the calculations of the blowdown loads, the staff has independently assessed the consequences of shroud bypass leakage on adequate core cooling, in the event that significant shroud motion results from the RLB loads. The results of this assessment indicate that the consequences of a significant crack opening (larger than approximately 1 to 3 square feet) could result in core damage if the core spray function is also defeated by core shroud movement, as the bypass flow from an opening of this area would exceed the capability of the ECCS to reflood the core. The availability of core spray may provide spray cooling even if the core can not be reflooded to two-thirds core height; however, this has not been confirmed by licensee evaluation. In addition, there are significant questions regarding the availability of core spray given its degraded condition and the impact of potential shroud motion. Significant shroud bypass leakage may also limit the effectiveness of SLCS to shut down the reactor.

It should be noted that occurance of significant shroud bypass leakage would require several occurrences, including a 360° through-wall crack, a recirculation line break, and resulting loads from the recirculation line break being large enough to cause a significant opening in the core shroud. All of these conditions are considered by the staff to be highly unlikely. A discussion of the probabilistic risk perspective is provided in Section 2.5.4 below.

2.5.2.3 Seismic Conditions

In the event of a postulated 360° through-wall crack, shroud motion could also result from SSE loads. However, without a concurrent loss of coolant from the reactor vessel, core cooling would not be adversely impacted.

As discussed in section 2.3.2.3, there were staff questions regarding the seismic loads presented by the licensee. The licensee has provided a preliminary evaluation which bounds this uncertainty by stating that the seismic loads will result in a shroud displacement of less than 2". The licensee has concluded that even if the shroud displacement is increased to 2", there will be no adverse consequences associated with an SSE. The licensee's conclusion is based on information provided by GE which concludes that the control rods will insert given a postulated 2" shroud displacement. The staff finds this preliminary evaluation to be acceptable, pending confirmation by the licensee.

2.5.3 Beyond Licensing Basis Scenarios

The licensing basis of Dresden and Quad Cities does not include combined seismic and accident loads; however, the licensee did provide an evaluation of the shroud response to these loading conditions given a postulated 360° through-wall failure of the shroud at the H5 location. These scenarios are discussed below.

2.5.3.1 SSE in combination with MSLB

For a postulated combined MSLB and SSE event, the shroud would be lifted due to the effects of the full dynamic load and subsequently dropped for both Dresden (2") and Quad Cities (8"). The kinetic energy at impact from the shroud dropping from a height of 2" and 8" was calculated. The downward displacements resulting from these impact velocities were determined by using a single-degree-of-freedom model to simulate the lower shroud and support legs. From the results of these analyses, GE has calculated that the stresses will be very low in the Dresden shroud during the drop, and the stresses are both within the elastic limit and well below the elastic buckling load. No buckling was predicted for the Dresden shroud support legs. For Quad Cities, the stresses are calculated to be below the load for which any buckling may occur in the shroud, but buckling of the support legs can not be ruled out.

The staff considers the GE calculations to be preliminary and not adequately detailed. More detailed analyses are needed for the staff to fully evaluate the structural integrity of the shroud support structure from shroud drop impact loads. If buckling in the shroud or the shroud support legs were to occur, the safety systems response could be impacted. The impact of the shroud after the 8" vertical lift and subsequent buckling could impact the ability of the control rods to be inserted. In this case, the SLCS would be available to shut down the reactor, as discussed in Section 2.5.2.1 for the MSLB scenario.

As was concluded for the MSLB scenario, Section 2.5.2.1, the staff is assuming that the core spray sparger will fail during the MSLB, and that the core spray function will not be maintained. While no spray function would be provided, the staff assumes that the flow from the damaged core spray system would still be injected into the vessel. When the shroud lowers following the 8" maximum vertical lift, there will not be a large pressure differential across the crack in the shroud, and bypass leakage will be low. Therefore, the staff concludes that the flow from the core spray system, in addition to the flow provided by other ECCS systems will reflood the reactor vessel, thereby assuring long-term core cooling.

2.5.3.2 SSE in combination with RLB

During postulated combined SSE and RLB events, in addition to the concerns regarding two-thirds core coverage that were discussed above for the RLB case in Section 2.5.2.2, a concern arises that the core shroud movement may result and displace the upper guide structure such that the control rods may be incapable of being fully inserted following the event. GE noted that because of the design of the internals, the maximum shroud movement that may occur would be about 4" laterally. During such movements, the fuel rods would be contacting the vertical portions of the core shroud surrounding the core.

GE believes that the control rods are likely to insert even with a postulated four-inch lateral movement of the upper guide structure. There is sufficient flexibility in the connection between the control rods and the drives to accommodate this displacement. General Electric supported this assertion by noting it had performed rod insertions using fuel assemblies bowed by approximately 2.5" at the core center. For these experiments, control rod insertion occurred to within a few inches of complete insertion even with this bowing. It is GE's position that these tests represent a far more extreme condition than that which would occur for the estimated lateral displacement of the upper guide structure.

Because of the large driving force provided by the scram accumulators, GE believes that control rod insertability will be maintained. GE estimates that the control rods have sufficient force to possibly even lift the assemblies off the lower core support, but the control rods would be maintained within the core volume and a coolable geometry would be maintained. While GE's assessment may be correct, in the staff's view, there is inadequate data to fully assess whether control rod insertion can be achieved during the lateral displacements postulated above (up to 4"), particularly if RLB blowdown loads are determined to be in excess of the licensee's present estimate by a factor of three. Therefore, the staff has concluded at this time that boron injection may be necessary to assure shut down for the combined SSE and RLB scenario. As discussed in Section 2.5.2.2, because of uncertainties in the licensee's blowdown load calculations, the staff has concerns that the core may not be reflooded and that the SLCS will not be able to shut down the reactor following an RLB due to significant shroud bypass leakage. The staff's conclusions would also apply to this scenario, SSE in combination with RLB. This scenario, however, is very unlikely, as discussed in the probabilistic risk perspective in the following section.

2.5.4 Probabilistic Risk Perspective

Even though a 360° through-wall H5 weld failure is not expected to occur (see Section 2.4), an evaluation of the potential core damage contribution of operating with a cracked shroud was performed by the staff. Core damage frequency (CDF) could be represented by the following equation: [CDF = (Initiating Event Frequency) x (Probability of Complete H5 Weld Failure) x (Probability of Mitigating System and Recovery Feature Failures (if applicable))]. The staff's assessment assumed a shroud failure occurred, although the probability of such a failure is clearly much less then one based upon the staff's flaw evaluation. Given the conservative estimates used for crack depth and crack growth rates discussed in Section 2.4, the H5 weld will have large structural integrity margins for main steamline and recirculation line breaks. Furthermore, the staff assumed failure of some mitigating and recovery features. Therefore, the assessment performed below is conservative to assess the potential scope of the safety concern, since the CDF reduction factor due to the known strength remaining in the weld and contributions from all mitigating/recovery features are not reflected in the quantification. For this risk perspective, five limiting initiating events are considered concurrent with a postulated 360° through-wall shroud crack at the H5 weld. The events considered are an SSE, an MSLB, an RLB, an SSE coincident with an MSLB, and SSE coincident with an RLB.

In performing this assessment, the staff considered the following information derived from the licensee's individual plant examination (IPE).

	DRESDEN 2&3 IPE	QUAD CITIES 1&2 IPE
CORE DAMAGE FREQUENCY/RY	1.85E-5	1.20E-6
SSE FREQUENCY/RY (*)	5.00E-5	2.20E-5
MSLB FREQUENCY/RY	1.00E-4	1.00E-4
LARGE LOCA/RY	3.00E-4	3.00E-4

*mean estimate of the safe shutdown earthquake peak ground acceleration frequency

While the staff has not completed its review of the licensee's entire IPE, the staff did review the event frequencies used in the IPE for reasonableness in the evaluation. The SSE frequency in the table is consistent with the EPRI study ("Probabilistic Hazard Evaluation at Nuclear Plant Sites in the United States," (EPRI NP-4726) 1988). The large loss-of-coolant accident (LLOCA) initiator frequency (utilized in the Dresden/Quad Cities IPEs for RLB frequency) is also consistent with the data from the National Reliability Evaluation Program (NREP) and other IPEs, i.e., Brunswick and Peach Bottom 2. The MSLB frequency presented in the table above is the Dresden/Quad Cities IPE value which was used to quantify the MSLB main steam isolation valve (MSIV) failure scenario for assessing steamline breaks downstream of the outboard isolation valve and is consistent with the Brunswick IPE. This value is expected to bound MSLB contribution for piping segments inboard of the MSIVs, due to the longer runs of non-Class I piping comprising the outboard sections. The LLOCA frequency of 3.0E-4/yr includes all of the breaks including; MSLB, RLB, multiple safety relief valve (SRV) failures, feedline break and others. Even though the Dresden/Quad Cities IPEs used 3.0E-4/RY for quantification of RLB sequences, the staff believes that the RLB initiator frequency is 1.0E-4 or less.

To gain additional insight on this initiator frequency, the licensee was asked toreassess the likelihood of RLB and provide additional justification for the RLB initiating event probability.

On July 12, 1994 ComEd submitted a Safety Assessment of the Reactor Recirculation Piping. In this evaluation, ComEd stated that a more representative RLB frequency would have an upper bound of 1E-5/RY, due to the many factors that reduce the likelihood of pipe breaks associated with IGSCC, as well as preclude pipe failures due to other rupture modes. These factors include the presence of leak detection instrumentation to provide indication of potential leakage from a cracked pipe, replacement of the IGSCC degraded recirculation piping at Dresden, Unit 3, repair with weld overlays and stress relief as necessary, and improved hydrogen water chemistry at Quad Cities, Unit 1. This assessment also notes operating experience statistical studies which supported a probability of a large double-ended guillotine break being less then 1E-5 per reactor year. The licensee also applied the IPE methodology to assess the recirculation line break frequency, and reported the results as 1.7E-5/RY for all the large bore piping and 5.6E-6/RY for the suction piping, which gives the large asymmetric loads of concern.

The staff could not judge the quantitative impact of all the factors identified by the licensee related to RLB probability. However, the1941Xstaff believes the frequency is likely to be in the rae of 1.0E-4 to 1.0E-5/RY. Therefore, the icensee's assessment supports use by the staff of an RLB initiator of 1.0E-4/RY rather then the 3.0E-4 originally presented in the Dresden/Quad Cities IPEs. The staff also notes that the CDF reported in the IPE is for internal initiators only, and seismic induced core damage is not included. Further, shroud cracks in conjunction with or coincident with a seismic, MSLB or RLB are not considered in the IPE study. Results of the staff risk perspective, utilizing the above data, is discussed below.

2.5.4.1 <u>SSE Risk Perspective</u>

In Section 2.5.2.3 the staff evaluated, in a deterministic fashion, the consequences of an SSE, given a through-wall crack in the H5 weld. This evaluation concluded that control rod insertion, core reflood, core spray, and SLCS would not be affected by the small movement expected. Therefore, other independent failures, or earthquakes larger than the SSE, must be assumed before core damage would occur. As a result, the staff concludes that this event is not likely to become limiting as a result of shroud cracking.

For the combined accidents, SSE would have to occur coincident with an MSLB or a RLB. If these events were treated independently, this can be expressed as: CDF = (SSE) x (Probability of RLB or MSLB occurring on same day as SSE) x (Probability of Failed Shroud), which is quantified as CDF = (5.0E-5/RY) x (1E-4)/365 x (Probability of Failed Shroud). This very small frequency would not account for the possibility of a direct or indirect seismically induced LOCA. Much of the piping in question is seismically qualified and even non-seismic steamline piping would be expected to remain intact when subjected to seismic design basis loads. Therefore, the likelihood of a direct seismically induced LOCA is quite small. A study, "Probability of Failure in BWR Reactor Coolant Piping" (NUREG/CR-4792 Volume 2) estimated a direct seismically induced reactor coolant piping LOCA to be approximately 1E-7/RY. Volume 4 of this study indicated a related indirect induced LOCA contribution (due to support failures) of approximately 2E-8/RY for the Brunswick Plant, showing that the direct contribution is limiting. While these studies were not specifically focused on this Dresden/Quad Cities situation, they do provide meaningful insights. Thus, the staff concludes the seismically induced LOCAs are much less likely than the independent frequencies of either RLB or MSLB which are evaluated below. Therefore, accounting for a seismically induced LOCA the staff estimated RLB risk (found below to be more limiting than MSLB) is given by the expression: Combined RLB/SSE CDF = (1E-7)/RY x (Probability of Shroud Failure). This is well below the CDF contribution from random RLB discussed below, quantified as 1E-4/RY not accounting for shroud failure.

2.5.4.2 MSLB Risk Perspective

The consequences of an MSLB are discussed in Section 2.5.2.1. The vertical lifting of the shroud is calculated to be 4" for this event, assuming a 360° through-wall crack of the H5 weld. The potential impact of the shroud falling back and buckling the shroud support legs could displace the lower core support structure and prevent control rod insertion. As the core refloods following blowdown, reactivity control would need to be provided by the SLCS. This can be expressed as CDF = (Frequency of MSLB) x (Probability SLCS Failure) x (Probability of Shroud Failure). The NUREG-1150 model for Peach Bottom and the draft of a revised ASP model for Peach Bottom was reviewed to provide insights on the probability of mitigating a failure of control rod insertion. This probability is estimated to be on the order of 1.0E-1. This is dominated by human error to initiate SLCS or failure to restore SLCS after maintenance or test. Core damage frequency, given this scenario would be: CDF = (1E-4)/RY x (.1) x (Probability of Shroud Failure). The frequency of this sequence is, therefore, conservatively estimated to be 1.0E-5/RY, not crediting the low likelihood of shroud failure.

2.5.4.3 RLB Risk Perspective

In evaluating the risks for RLB, the uncertainty in blowdown loads, pending completion of additional confirmatory analyses by the licensee, was reflected by assuming that RLB forces could cause shroud movement. As discussed in Section 2.5.2.2, significant shroud movement or core damage is not expected given the calculated blowdown loads predicted by preliminary staff calculations. However, if the loads are large enough to tip the core shroud, it is possible that the crack opening would be large enough to exceed the ECCS pump flow and a core refloodable volume would not be maintained. Even if reflood is possible, SLCS inventory may partially bypass the core preventing shutdown. Further, due to the presence of cracks in the spray sparger, the staff does not have assurance that the sprays would be operable following an RLB. This can be expressed as CDF = (Frequency of RLB) x (Probability of Shroud Failure) x (Probability of Core Spray Failure). In this case, the core damage probability could be conservatively estimated as the RLB initiating event frequency, or 1.0E-4/RY, which does not credit the low probability of shroud failure or possible success of mitigating features, e.g., core spray. While this would dominate CDF contribution given a postulated weld failure, it demonstrates that even when evaluated with a number of conservatisms, the risk contribution is fairly low.

2.5.4.4 Overall Risk Perspective

A realistic assessment of core damage frequency would require estimating the frequency of initiating events of concern coupled with the probability of a complete failure of the H5 weld and the probability that systems required to mitigate the consequences of those scenarios would not be available. Events of potential safety significance are a LLOCA and a MSLB. The occurrence of such events is very low (i.e., 1.0E-4 to 1.0E-5/RY). The conditional probability of complete failure of the H5 weld and the failure to mitigate the consequences of these events is expected to be much less than one. Therefore, the frequency of core damage is expected to be significantly lower than 1.0E-4 to 1.0E-5/RY. This risk estimate supports the conclusion that operation of Dresden, Unit 3, and Quad Cities, Unit 1, for the 15 months of power operation above cold shutdown, will not pose undue risk to the public health and safety.

2.5.5 Summary

The staff's conclusions for a postulated 360° through-wall crack at the H5 weld are as follows:

- During normal operation and transients, the weight of the shroud assembly will maintain the shroud's position within the reactor internals, and control rod insertion and core cooling will be maintained.

- During a postulated MSLB accident, the vertical differential pressure is expected to lift the shroud, and may fail the core spray sparger. Even with significant shroud bypass leakage and failure of the core spray sparger, the capability of the ECCS to reflood the reactor vessel is not impacted as there is no loss of coolant from the lower vessel. Therefore, the staff concludes that long-term core cooling is assured. The consequences of the core shroud lift and drop and resulting impact have not been fully evaluated by the licensee in the calculations provided. A more detailed analysis has been requested from the licensee (see Section 2.6). Control rod insertion may be prevented, however, and the SLCS may be necessary for reactivity control.

- A postulated RLB accident, is not calculated to result in significant movement and, therefore, control rod insertion and core cooling are assured. However, uncertainties remain in the licensee's blowdown load calculations, and the licensee must confirm these calculations. If the blowdown loads are more than three times as large as those calculated by the licensee, the resultant core shroud movement may not ensure a refloodable core volume and core cooling and SLCS function may not be assured for this scenario.

- An SSE event was calculated to momentarily tip the shroud less than 2" at the top, with no lateral movement or lifting; however, control rod insertion and core cooling are expected to be maintained.

- A realistic assessment of core damage frequency would require estimating the frequency of initiating events of concern coupled with the probability of a complete failure of the H5 weld and the probability that systems required to mitigate the consequences of those scenarios would not be available. Events of potential safety significance are a LLOCA and an MSLB. The occurrence of such events is very low (i.e., 1.0E-4 to 1.0E-5/RY). The conditional probability of complete failure of the H5 weld and the failure to mitigate the consequences of these events is expected to be much less than one. Therefore, the frequency of core damage is expected to be significantly lower than 1.0E-4 to 1.0E-5/RY. Thus, operation of Dresden, Unit 3, and Quad Cities, Unit 1, for the next 15 months does not pose undue risk to the public health and safety.

2.6 Future Actions

In the licensee's June 25, 1994, letter and the June 30, 1994, Integrated Evaluation Report, ComEd committed to establish 6-month administrative operating periods for both Dresden, Unit 3, and Quad Cities, Unit 1, following restart from their current refueling outages. In the 6-month periods, ComEd has committed to finalizing all analyses to justify continued operation for the entire fuel cycle.

In addition, ComEd has committed to reinspect and/or repair the core shrouds at Dresden, Unit 3, or Quad Cities, Unit 1, at the end of the 6-month administrative operating period if the results of the continuing evaluation indicate a reduction in operating margins below acceptable levels.

Based on the staff's review and independent evaluation, ComEd is requested to provide the following additional confirmatory analyses:

1. a computerized 3-dimensional asymmetric depressurization analysis for the recirculation line break, including assumptions and entry level conditions,

2. the WHAM calculations for the recirculation line break, including assumptions and entry level conditions, and

3. a detailed analysis of shroud movement, following postulated events, assuming a 360° through-wall crack, including all assumptions, entry level conditions, calculational techniques, and conservatisms. In the evaluation of seismic considerations, the analysis should be based on the most limiting seismic input motion (i.e., Golden Gate Park, time history, and El Centro, and Housner).

ComEd has committed to submit this information to the NRC by December 15, 1994, for review.

3.0 <u>CONCLUSIONS</u>

During current refueling outages, ComEd discovered cracking in the circumferential welds in the core shrouds at Dresden, Unit 3, and Quad Cities, Unit 1. By letter dated June 13, 1994, ComEd concluded, based on its analyses, that the cracked core shrouds could maintain margins against failure as specified in Section XI of the ASME Code for 24 months for Dresden, Unit 3, and for 18 months for Quad Cities, Unit 1. The licensee has provided additional information in response to requests by the NRC staff. Section 4.0 of this Safety Evaluation (SE) provides a detailed listing of all correspondence provided by ComEd.

The staff evaluated ComEd's June 13, 1994, submittal and all supplemental documentation in accordance with 10 CFR 50.55a to determine if the degraded shrouds have adequate safety margins to meet the requirements of the ASME Code. The staff also evaluated the potential risks associated with cracked shroud operation that were not considered as part of the original licensing basis.

During the staff's review, uncertainties were identified in the following parts of ComEd's analyses:

1. the sizing of the crack in the H5 weld;

2. the recirculation line break load analysis; and

3. core shroud movement under postulated accident loads assuming complete failure of the H5 weld.

The staff's independent evaluation used conservative assumptions to account for the uncertainties identified in ComEd's analyses; however, as discussed in Section 2.6 of this SE, ComEd is requested to provide confirmatory analyses to the NRC by December 15, 1994.

While, based on its assessment, ComEd has proposed operation for a full cycle, considering the uncertainties identified above, coupled with the staff disallowing any enhancement of the structural integrity of the shroud by the presence of the inside diameter fillet weld at H5 in its analysis, the staff's conservative evaluation has concluded that the cracked shrouds will satisfy

ASME Code margins against weld failure for 15 months of operation above cold shutdown. Satisfying the ASME Code margins against failure provides reasonable assurance that the core shrouds at Dresden, Unit 3, and Quad Cities, Unit 1, will remain intact, even under postulated licensing basis and beyond licensing basis accident conditions.

As indicated above, the NRC staff has concluded that the core shrouds would remain intact for 15 months of operation above cold shutdown, even under postulated accident conditions. However, in order to acquire further insight in to the significance of core shroud cracking, the staff requested ComEd to provide a safety assessment assuming a 360° through-wall crack in the lower elevation of the core shroud.

The NRC staff also independently performed an assessment of the risk contribution of this postulated condition. A realistic assessment of core damage frequency would require estimating the frequency of initiating events of concern, coupled with the probability of a complete failure of the H5 weld and the probability that systems required to mitigate the consequences of those scenarios would not be available. Events of potential safety significance are a LLOCA and a main steamline break. The occurrence of such events is very low (i.e., 10^{-4} to 10^{-5}/RY). The conditional probability of complete failure of the H5 weld and the failure to mitigate the consequences of these events is expected to be much less than one. Therefore, the frequency of core damage is expected to be significantly lower than 10^{-4} to 10^{-5}/RY.

The staff assessment is clearly conservative in that the assumed cracking, 360° through-wall, is significantly more extensive than anticipated, and conservative assumptions were used to account for uncertainties in the loads and the resultant dynamic effects of the core shroud for postulated accidents. This risk estimate supports the conclusion that operation of Dresden, Unit 3, and Quad Cities, Unit 1, for the 15 months of power operation above cold shutdown, will not pose undue risk to the public health and safety.

ComEd has indicated that over the next 6 months, plans for a permanent repair of the entire core shroud will be developed. These plans should be discussed with the staff at the earliest opportunity.

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Dated: July 21, 1994

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July 15, 1994, from P. Piet (ComEd), to W. Russell (NRC), Confirmatory Analysis for Main Steamline Break Related to the Core Shroud Cracking Issue

July 20, 1994, from P. Piet (ComEd), to W. Russell (NRC), Calculations of the Seismic Displacement

<u>Meetings</u>

May 26, 1994, meeting between ComEd (Lyster, et al.) and NRC staff (Taylor, Russell, et al.)

June 21, 1994, meeting between ComEd (Williams, et al.) and NRC Staff (Capra, Rubin, et al.)

June 27, 1994, meeting between ComEd (Williams, et al.) and NRC Staff (Strosnider, Capra, Hermann, Wichman, et al.)

FIGURE 1
DRESDEN AND QUAD CITIES
CORE SHORUD STRUCTURAL CONFIGURATION

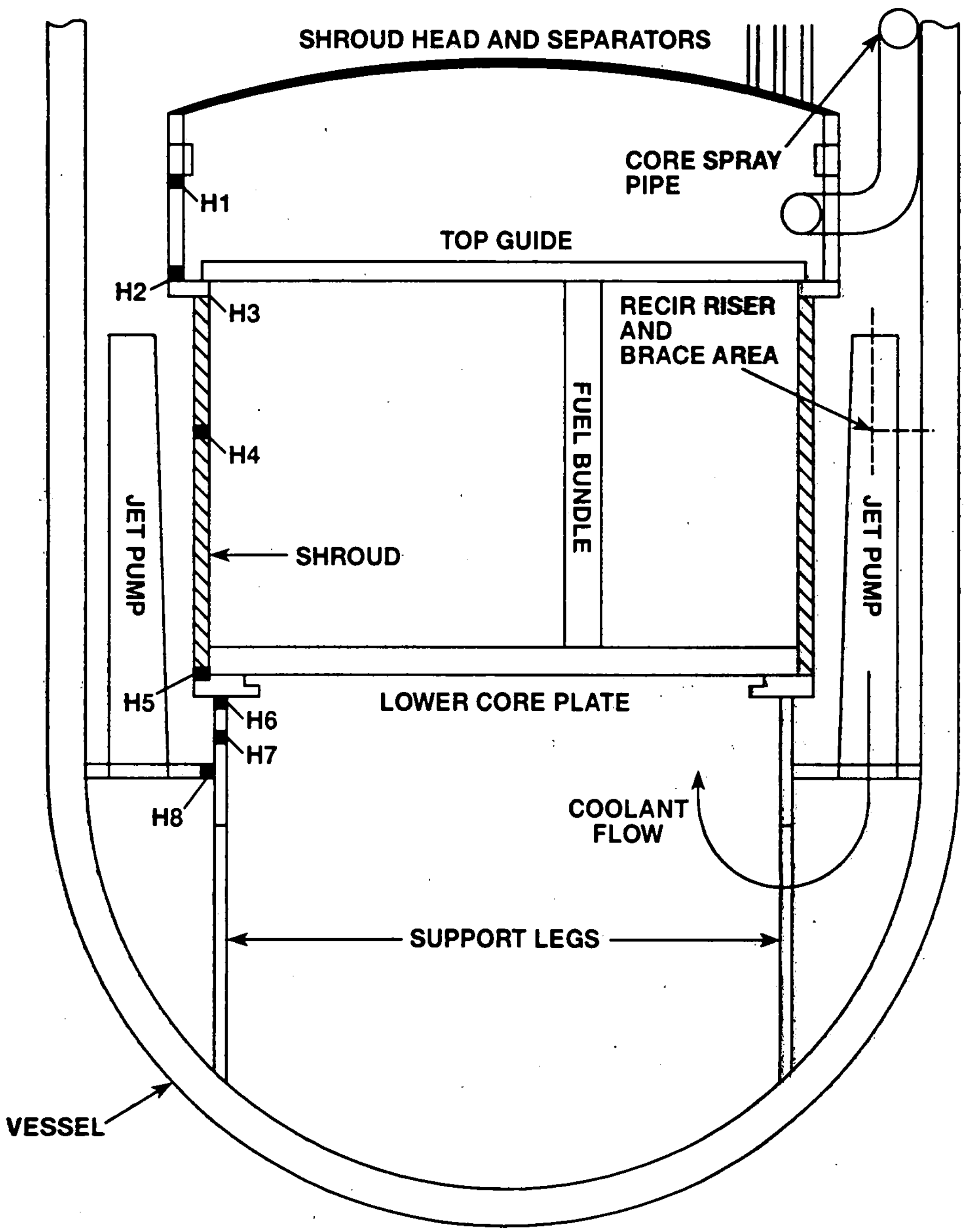


FIGURE 2
CORE SHROUD WELD LOCATIONS

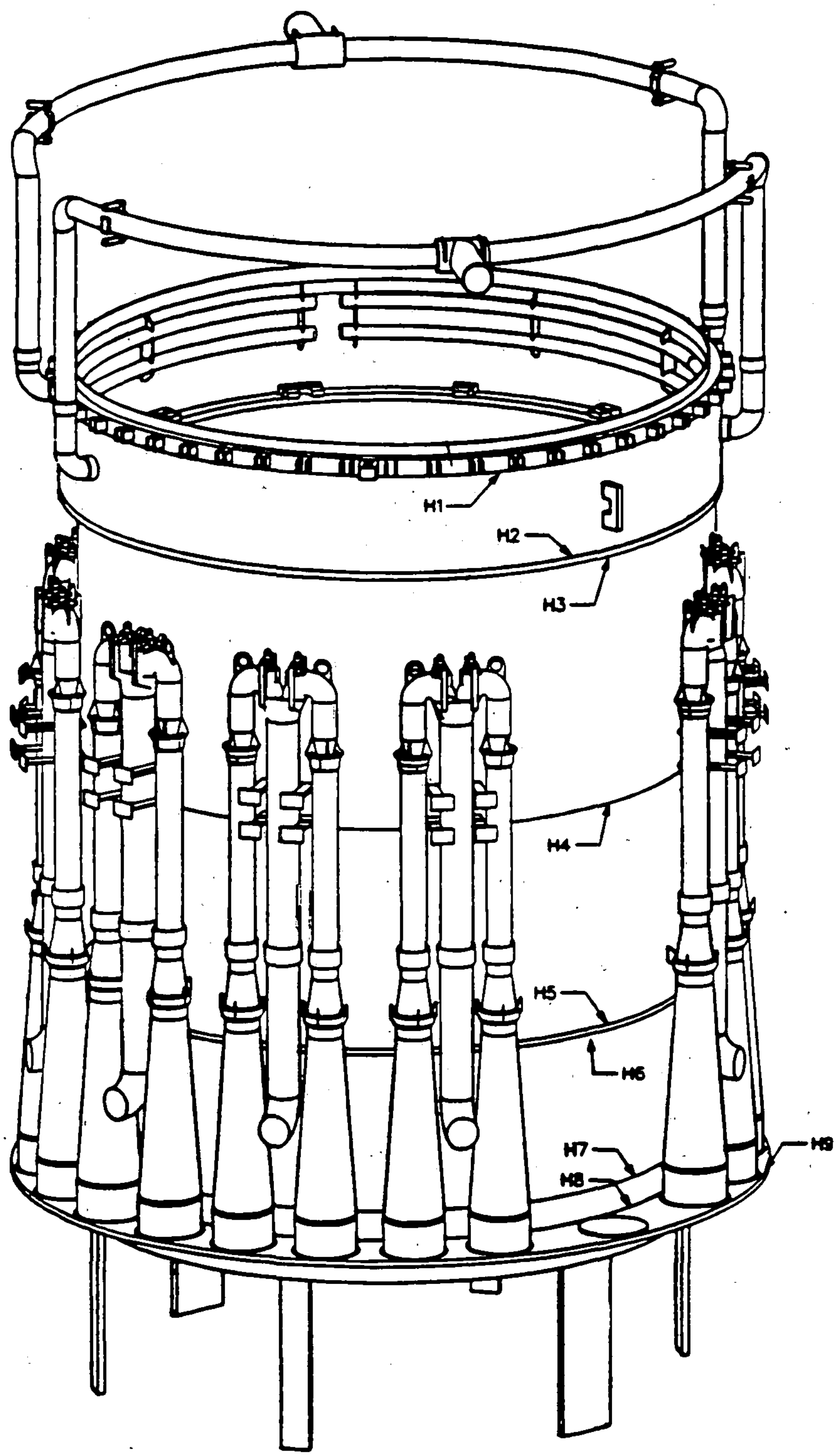
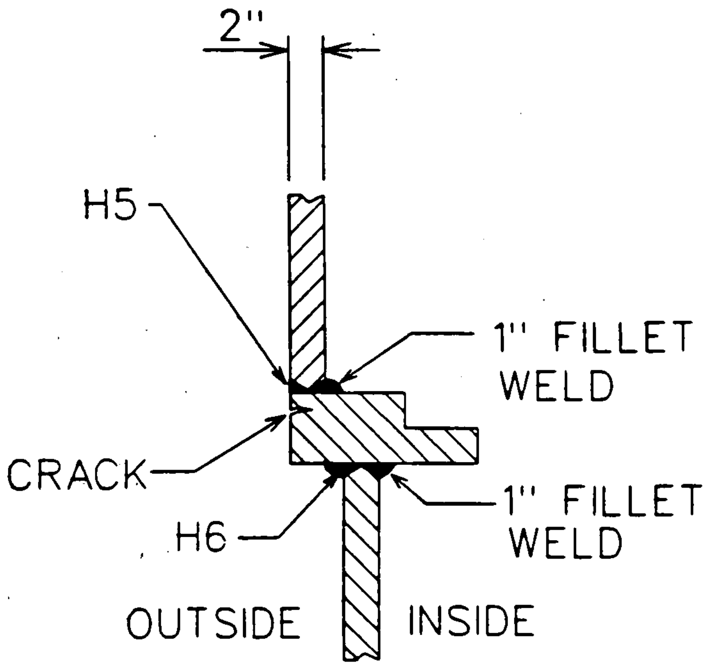
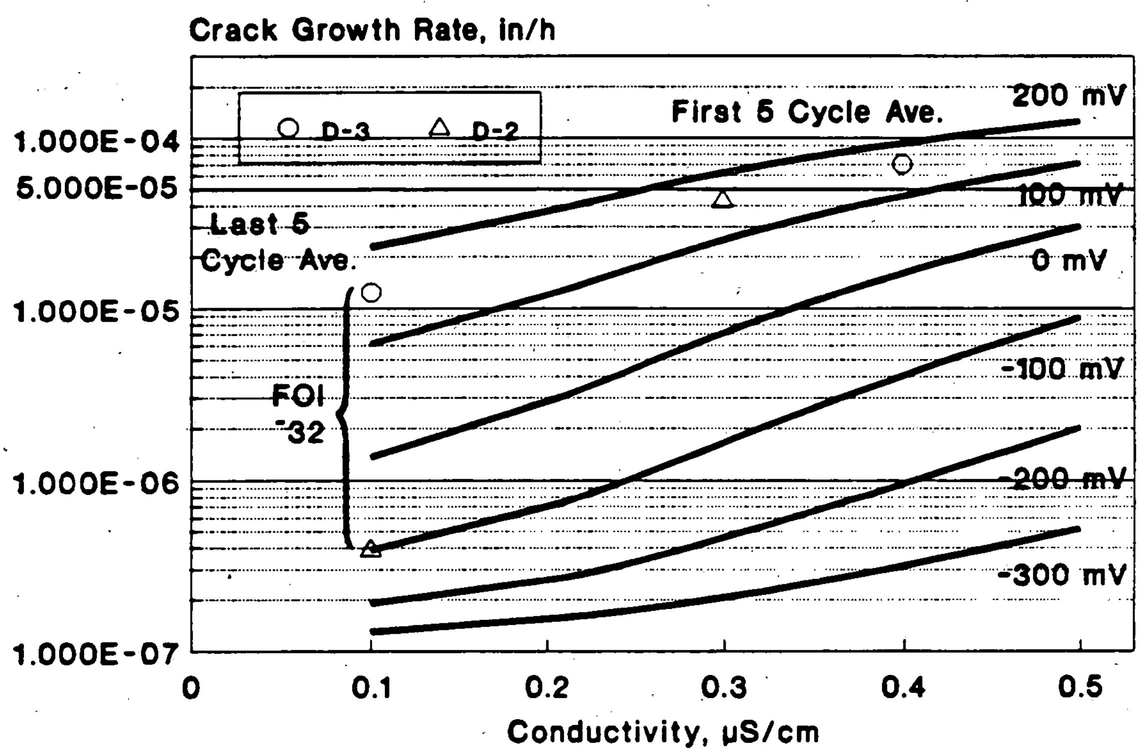


FIGURE 3
DETAIL OF H5 WELD



DETAIL - WELDS TYPE H5

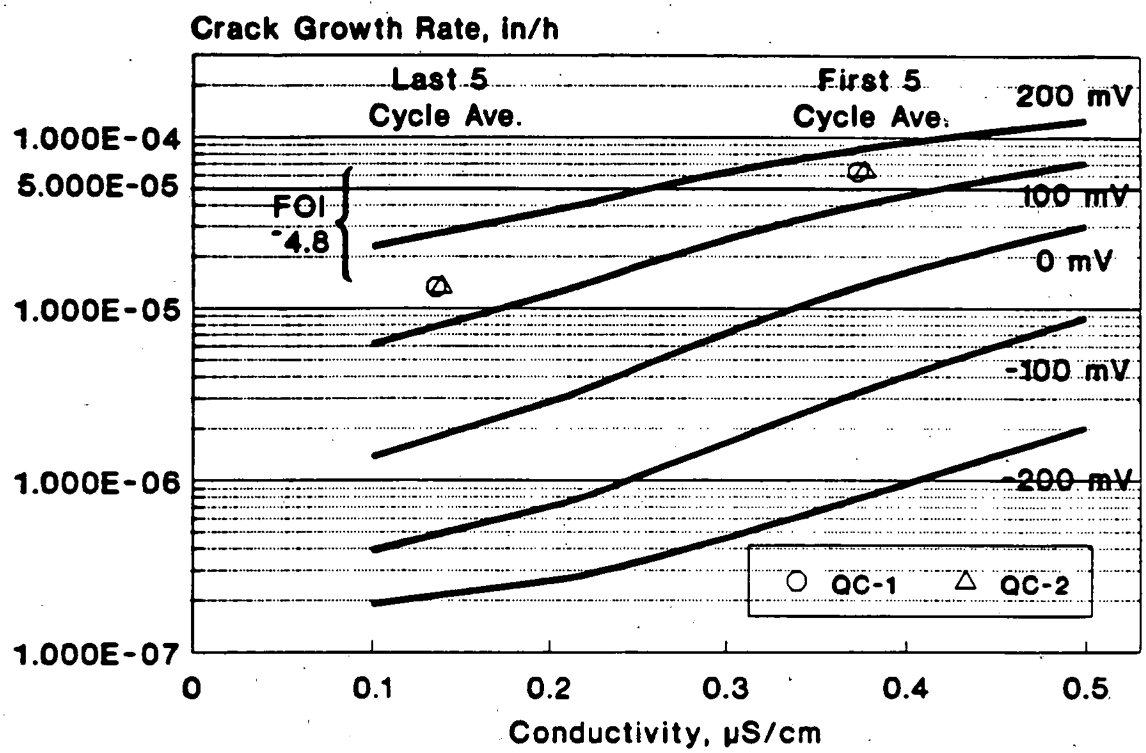
FIGURE 4
PLEDGE MODEL PREDICTION FOR DRESDEN, UNIT 2/3



PLEDGE: 15 C/cm2, 20ksi√in

D2SGR20C

FIGURE 5
PLEDGE MODEL PREDICTION
FOR QUAD CITIES, 1/2



PLEDGE: 15 C/cm2, 20ksi√in

QC12GR20

FIGURE 6
DEFINITION OF "CRACK FREE" EXCLUSION ZONE

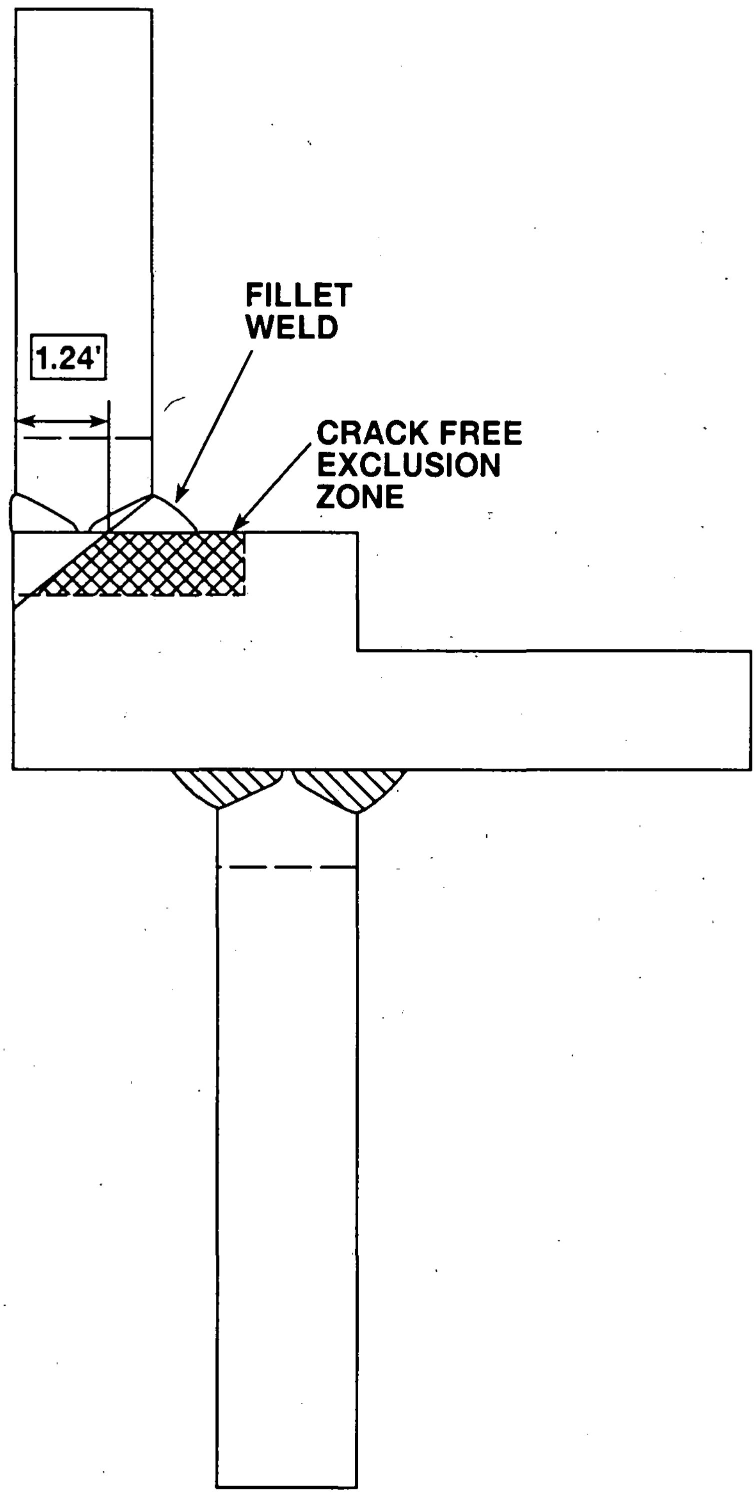


TABLE 1
DRESDEN UNIT 3
SHROUD VISUAL INSPECTION STATUS
Page 1 of 4

WELD #	SURFACE	AREA EXAMINED	INSPECTION RESULTS	QUALIFICATION STATUS
H1	O.D.	44° - 54° (19")	LINEAR CIRC INDICATION ~ 2" IDENTIFIED IN UPPER HAZ at 52°.	QUALIFIED VISUALLY
		136° - 144° (15")	NO INDICATIONS IDENTIFIED	
		226° - 234° (15")	NO INDICATIONS IDENTIFIED	
		316° - 330° (27")	LINEAR CIRC INDICATION ~ 2" IDENTIFIED IN UPPER HAZ BEHIND JET PUMP 20 (315°), OUTSIDE INSPECTION ZONE.	
H2	O.D.	38° - 54° (31") (38° - 42° LOWER HAZ ONLY)	NO INDICATIONS IDENTIFIED	QUALIFIED VISUALLY
		136° - 144° (15")	NO INDICATIONS IDENTIFIED	
		226° - 234° (15")	NO INDICATIONS IDENTIFIED	
		316° - 323° (14")	LINEAR CIRC INDICATION < 1" IN LOWER HAZ AT 320°	
H3	O.D.	0° - 20° (36")	NO INDICATIONS IDENTIFIED	QUALIFIED VISUALLY
		90° - 106° (29")	NO INDICATIONS IDENTIFIED	
		180° - 196° (29")	NO INDICATIONS IDENTIFIED	
		265° - 284° (34")	NO INDICATIONS IDENTIFIED	
H3	I.D.	0° - 31° (60")	NO INDICATIONS IDENTIFIED	QUALIFIED VISUALLY
		40° - 68° (50")	NO INDICATIONS IDENTIFIED	
		90° - 112° (40")	LINEAR CIRC INDICATION ~12" LONG IN LOWER HAZ FROM 105° TO 112°	

TABLE 1
DRESDEN UNIT 3
SHROUD VISUAL INSPECTION STATUS

WELD #	SURFACE	AREA EXAMINED	INSPECTION RESULTS	QUALIFICATION STATUS
H3 (CONT'D)	I.D. (CONT'D)	121° - 170° (88")	LINEAR VERTICAL INDICATION IN UPPER HAZ ~ 1" AT 140° LINEAR CIRC INDICATION ~77" LONG IN LOWER HAZ FROM 121° TO 164°	QUALIFIED VISUALLY
		173° - 180° (13")	LINEAR CIRC INDICATION ~13" LONG IN UPPER HAZ FROM 173° TO 180°	
		180° - 200° (36")	LINEAR CIRC INDICATION ~4" LONG IN LOWER HAZ FROM 190° TO 192°	
		200° - 215° (27") (LOWER HAZ ONLY)	NO INDICATIONS IDENTIFIED	
		218° - 245° (49") (LOWER HAZ ONLY)	2 LINEAR CIRC INDICATIONS ~4" LONG IN LOWER HAZ FROM 218° TO 220° AND 225° TO 227°	
		270° - 295° (45") (LOWER HAZ ONLY)	LINEAR CIRC INDICATION ~18" LONG IN LOWER HAZ FROM 278° TO 288°	
		313° - 323° (18") (UPPER HAZ ONLY)	LINEAR CIRC INDICATIONS ~18" LONG IN UPPER HAZ FROM 313° TO 323°	
		324° - 331° (13")	LINEAR CIRC INDICATIONS ~13" LONG TOTAL IN UPPER HAZ FROM 325° TO 331° LINEAR CIRC INDICATION ~8" LONG IN LOWER HAZ FROM 327° TO 331°	
		332° - 341° (16")	LINEAR CIRC INDICATION ~6" LONG IN LOWER HAZ FROM 338° TO 341°	

TABLE 1
DRESDEN UNIT 3
SHROUD VISUAL INSPECTION STATUS

WELD #	SURFACE	AREA EXAMINED	INSPECTION RESULTS	QUALIFICATION STATUS
H4	O.D.	43° - 57° (25")	NO INDICATIONS IDENTIFIED	QUALIFIED VISUALLY
		135° - 151° (29")	NO INDICATIONS IDENTIFIED	
		220° - 234° (25")	LINEAR CIRC INDICATION < 1" IN LOWER HAZ AT 227°	
		315° - 325° (18")	LINEAR CIRC INDICATION < 1" IN UPPER HAZ AT 318°	
H4	I.D.	10° - 25° (27")	NO INDICATIONS IDENTIFIED	QUALIFIED VISUALLY
		44° - 55° (20")	NO INDICATIONS IDENTIFIED	
		96° - 115° (34")	2 LINEAR VERTICAL INDICATIONS < 1" IN LOWER HAZ AT 114°	
		134° - 152° (32")	LINEAR CIRC INDICATION < 1" IN LOWER HAZ AT 146°	
		188° - 205° (30")	NO INDICATIONS IDENTIFIED	
		226° - 238° (22")	LINEAR CIRC INDICATION < 1" IN UPPER HAZ AT 230°	
		275° - 295° (36")	NO INDICATIONS IDENTIFIED	
		316° - 329° (23")	4 LINEAR VERTICAL INDICATIONS < 1" IN UPPER HAZ AT 320°	
H5	O.D.	100% OF ACCESSIBLE AREA, WHICH CONSISTS OF ~ 40% OF THE WELD CIRCUMFERENCE.	LINEAR CIRC INDICATION IN LOWER HAZ FOR 100% OF THE AREA EXAMINED (ASSUMED TO BE ESSENTIALLY 360°). VERIFIED TO BE A CRACK USING INFORMATIONAL UT.	FAILED SCREENING CRITERIA.

TABLE 1
DRESDEN UNIT 3
SHROUD VISUAL INSPECTION STATUS

WELD #	SURFACE	AREA EXAMINED	INSPECTION RESULTS	QUALIFICATION STATUS
H6	O.D.	46° - 54° (14")	LINEAR VERTICAL INDICATION < 1" IN UPPER HAZ AT 47°	QUALIFIED VISUALLY
		76° - 84° (14")	NO INDICATIONS IDENTIFIED	
		143° - 151° (14")	NO INDICATIONS IDENTIFIED	
		166° - 174° (14")	NO INDICATIONS IDENTIFIED	
		224° - 235° (20")	NO INDICATIONS IDENTIFIED	
		256° - 264° (14")	NO INDICATIONS IDENTIFIED	
		316° - 324° (14")	NO INDICATIONS IDENTIFIED	
		346° - 354° (14")	NO INDICATIONS IDENTIFIED	
H7	O.D.	15° - 115° (17")	LINEAR CIRC INDICATION < 1" IN UPPER HAZ AT 20°	QUALIFIED VISUALLY
		105° - 115° (17")	NO INDICATIONS IDENTIFIED	
		135° - 147° (21")	NO INDICATIONS IDENTIFIED	
		196° - 204° (14")	NO INDICATIONS IDENTIFIED	
		286° - 292° (10")	NO INDICATIONS IDENTIFIED	
		325° - 335° (17")	NO INDICATIONS IDENTIFIED	

TABLE 2
QUAD CITIES UNIT 1
SHROUD VISUAL INSPECTION STATUS
Page 1 of 4

WELD #	SURFACE	AREA EXAMINED	INSPECTION RESULTS	QUALIFICATION STATUS
H1	O.D.	42° - 49° (13")	NO INDICATIONS IDENTIFIED	QUALIFIED VISUALLY
		132° - 139° (13")	NO INDICATIONS IDENTIFIED	
		222° - 229° (13")	NO INDICATIONS IDENTIFIED	
		322° - 329° (13")	NO INDICATIONS IDENTIFIED	
H2	O.D.	42° - 49° (13")	NO INDICATIONS IDENTIFIED	QUALIFIED VISUALLY
		132° - 139° (13")	NO INDICATIONS IDENTIFIED	
		222° - 229° (13")	NO INDICATIONS IDENTIFIED	
		322° - 329° (13")	NO INDICATIONS IDENTIFIED	
H3	O.D.	100% (651")	NO INDICATIONS IDENTIFIED	QUALIFIED VISUALLY
H3	I.D.	100% (638")	LINEAR CIRC INDICATION ~ 10" LONG IN LOWER HAZ FROM 85° - 90°	QUALIFIED VISUALLY
			LINEAR CIRC INDICATION ~ 3" LONG IN LOWER HAZ FROM 90° - 92°	
			LINEAR CIRC INDICATION ~ 6" LONG IN LOWER HAZ FROM 148° - 152°	
			LINEAR CIRC INDICATION ~ 9" LONG IN LOWER HAZ FROM 160° - 165°	
			LINEAR CIRC INDICATION ~ 11" LONG IN LOWER HAZ FROM 187° - 193°	

TABLE 2
QUAD CITIES UNIT 1
SHROUD VISUAL INSPECTION STATUS

WELD #	SURFACE	AREA EXAMINED	INSPECTION RESULTS	QUALIFICATION STATUS
H3 (CONT'D)	I.D. (CONT'D)	100% (638")	LINEAR CIRC INDICATION ~ 35" LONG IN UPPER HAZ FROM 185° - 205°	QUALIFIED VISUALLY
			LINEAR CIRC INDICATION ~ 17" LONG IN LOWER HAZ FROM 205° - 215°	
			LINEAR CIRC INDICATION ~ 17" LONG IN LOWER HAZ FROM 250° - 260°	
			LINEAR CIRC INDICATION ~ 60" LONG IN LOWER HAZ FROM 225° - 260°	

TABLE 2
QUAD CITIES UNIT 1
SHROUD VISUAL INSPECTION STATUS

WELD #	SURFACE	AREA EXAMINED	INSPECTION RESULTS	QUALIFICATION STATUS
H4	O.D.	75° - 85° (19")	NO INDICATIONS IDENTIFIED	QUALIFIED VISUALLY
		140° - 175° (62")	NO INDICATIONS IDENTIFIED	
		255° - 265° (19")	NO INDICATIONS IDENTIFIED	
		320° - 355° (62")	NO INDICATIONS IDENTIFIED	
H4	I.D.	83° - 97° (23")	NO INDICATIONS IDENTIFIED	QUALIFIED VISUALLY
		173° - 187° (23")	NO INDICATIONS IDENTIFIED	
		260° - 280° (35")	TWO INDICATIONS ~ 1/2" LONG EACH IN LOWER HAZ AT 260° AND 277°	
		355° - 15° (35")	NO INDICATIONS IDENTIFIED	
H5	O.D.	15° - 25° (17")	NUMEROUS, RANDOM LINEAR INDICATIONS (CIRC AND AXIAL) WERE OBSERVED BELOW THE WELD IN AREAS INSPECTED; NO INDICATIONS WERE IDENTIFIED ON THE UPPER SIDE OF THE WELD. UT INSPECTIONS AT SIX LOCATIONS VERIFIED PRESENCE OF CRACKS WITH DEPTHS UP TO 1.20".	FAILED SCREENING CRITERIA.
		45° - 55° (17")		
		75° - 85° (17")		
		105° - 115° (17")		
		135° - 175° (72")		
		195° - 205° (17")		
		225° - 235° (17")		
		255° - 265° (17")		
		285° - 295° (17")		
		320° - 355° (60")		

TABLE 2
QUAD CITIES UNIT 1
SHROUD VISUAL INSPECTION STATUS

WELD #	SURFACE	AREA EXAMINED	INSPECTION RESULTS	QUALIFICATION STATUS
H6	O.D.	15° - 25° (17")	NO INDICATIONS IDENTIFIED	QUALIFIED VISUALLY
		75° - 85° (17")	NO INDICATIONS IDENTIFIED	
		105° - 115° (17")	NO INDICATIONS IDENTIFIED	
		135° - 175° (70")	NO INDICATIONS IDENTIFIED	
		195° - 205° (17")	NO INDICATIONS IDENTIFIED	
		255° - 265° (17")	LINEAR CIRC INDICATION ~ 7" LONG IN UPPER HAZ FROM 257° - 261°	
		286° - 295° (16")	NO INDICATIONS IDENTIFIED	
		320° - 355° (60")	NO INDICATIONS IDENTIFIED	
H7	O.D.	41° - 49° (13")	NO INDICATIONS IDENTIFIED	QUALIFIED VISUALLY
		135° - 170° (60")	NO INDICATIONS IDENTIFIED	
		296° - 304° (13")	NO INDICATIONS IDENTIFIED	
		320° - 355° (60")	NO INDICATIONS IDENTIFIED	

TABLE 3
DRESDEN UNIT 3
SHROUD ULTRASONIC EXAMINATION STATUS

WELD #	AREA SCANNED	FLAW LENGTH	MAX FLAW DEPTH	MINIMUM REMAINING LIGAMENT	WELD SIDE	EXAMINATION SUMMARY
H2	16° - 74.5° (112")	8 FLAWS - 15.6" TOTAL 4 FLAWS - 24.8" TOTAL	.75" .56"	2.25" 1.44"	LOWER UPPER	EXAMINATION COVERED ALL ACCESSIBLE AREAS, OR ≈ 534" (77%) OF THE TOTAL 691" WELD LENGTH. THE SUM OF THE LOWER HAZ INDICATIONS RECORDED EXTEND FOR A TOTAL LENGTH OF 114.5". THE SUM OF THE UPPER HAZ INDICATIONS RECORDED EXTEND FOR A TOTAL LENGTH OF 63.5". VISUAL WELD QUALIFICATION CORROBORATED BY UT RESULTS.
	76° - 102° (50")	6 FLAWS - 3.4" TOTAL 2 FLAWS - 8" TOTAL	.46" .37"	2.54" 1.63"	LOWER UPPER	
	106° - 151° (86.5")	4 FLAWS - 21.7" TOTAL 3 FLAWS - 9" TOTAL	.71" .39"	2.29" 1.61"	LOWER UPPER	
	188° - 191° (6")	1 FLAW - 5.1"	.61"	2.39"	LOWER	
	218.5° - 253.5° (67")	6 FLAWS - 18.6" TOTAL 5 FLAWS - 10" TOTAL	.70" .71"	2.30" 1.39"	LOWER UPPER	
	256° - 280° (46")	1 FLAW - 1.5" 1 FLAW -1. 8"	.38" .20"	2.62" 1.80"	LOWER UPPER	
	286° - 12.5° (166")	19 FLAWS - 48.8" TOTAL 4 FLAWS -9.9" TOTAL	.61" .32"	2.39" 1.68"	LOWER UPPER	
H5	31° - 52.5° (39")	NO RECORDABLE INDICATIONS				EXAMINATION COVERED ALL ACCESSIBLE AREAS, OR ≈ 271" (41.5%) OF THE TOTAL 651" WELD LENGTH. THE SUM OF THE INDICATIONS RECORDED EXTEND FOR A TOTAL LENGTH OF 127.5".
	113.5° - 170.5° (103")	129° - 144° (27")	.45"	2.55"	LOWER	
		150° - 158° (14")	.30"	2.70"	LOWER	
	214.5° - 237.5° (42")	225° - 237.5° (23")	.47"	2.53"	LOWER	
	297.5 - 345.5° (87")	310.5° - 345° (63.5")	.84"	2.16"	LOWER	

TABLE 3
DRESDEN UNIT 3
SHROUD ULTRASONIC EXAMINATION STATUS

<table>
<tr><th>WELD #</th><th>AREA SCANNED</th><th>FLAW LENGTH</th><th>MAX FLAW DEPTH</th><th>MINIMUM REMAINING LIGAMENT</th><th>WELD SIDE</th><th>EXAMINATION SUMMARY</th></tr>
<tr><td rowspan="4">H6</td><td>147° - 153° (10.5")</td><td>NO RECORDABLE INDICATIONS</td><td></td><td></td><td></td><td rowspan="4">EXAMINATION COVERED 4 ACCESSIBLE AREAS AT THE ACCESS HOLE COVERS, OR ≈ 42" OF THE 650" WELD LENGTH. NO RECORDABLE INDICATIONS WERE IDENTIFIED.

VISUAL WELD QUALIFICATION CORROBORATED BY UT RESULTS.</td></tr>
<tr><td>169.5° - 175.5° (10.5")</td><td>NO RECORDABLE INDICATIONS</td><td></td><td></td><td></td></tr>
<tr><td>327° - 333° (10.5")</td><td>NO RECORDABLE INDICATIONS</td><td></td><td></td><td></td></tr>
<tr><td>349.5° - 355.5° (10.5")</td><td>NO RECORDABLE INDICATIONS</td><td></td><td></td><td></td></tr>
<tr><td rowspan="4">H7</td><td>147° - 153° (10.5")</td><td>NO RECORDABLE INDICATIONS</td><td></td><td></td><td></td><td rowspan="4">EXAMINATION COVERED 4 ACCESSIBLE AREAS AT THE ACCESS HOLE COVERS, OR ≈ 42" OF THE 650" WELD LENGTH. THE SUM OF THE INDICATIONS RECORDED EXTEND FOR A TOTAL LENGTH OF 7.9"

VISUAL WELD QUALIFICATION CORROBORATED BY UT RESULTS.</td></tr>
<tr><td>169.5° - 175.5° (10.5")</td><td>NO RECORDABLE INDICATIONS</td><td></td><td></td><td></td></tr>
<tr><td>327° - 333° (10.5")</td><td>NO RECORDABLE INDICATIONS</td><td></td><td></td><td></td></tr>
<tr><td>349.5° - 355.5° (10.5")</td><td>2 FLAWS - 7.9" TOTAL</td><td>.42"</td><td>1.83"</td><td>LOWER</td></tr>
</table>

TABLE 4
QUAD CITIES UNIT 1
SHROUD ULTRASONIC EXAMINATION STATUS

WELD #	AREA SCANNED	FLAW LENGTH	MAX FLAW DEPTH	MINIMUM REMAINING LIGAMENT	WELD SIDE	EXAMINATION SUMMARY
H2	336° - 76° (192")	341° - 342° (3") OD	0.20"	1.80"	UPPER	THE EXAMINATION COVERED ~ 539" (77.9%) OF THE TOTAL 691" WELD LENGTH. THE SUM OF THE INDICATIONS RECORDED EXTEND FOR A TOTAL LENGTH OF 139" (20.1%). VISUAL WELD QUALIFICATION CORROBORATED BY UT RESULTS.
		350° - 356° (11") OD	0.20"	1.80"	UPPER	
		6° - 7° (1") ID	0.25"	1.55"	UPPER	
		6° - 17° (21") OD	0.20"	1.55"	UPPER	
		19° - 28° (17") OD	0.20"	1.80	UPPER	
		25° - 26° (1")	0.32"	2.68"	LOWER	
		66° - 75° (17") OD	0.20"	1.80"	UPPER	
	81° - 106° (48")	NO RECORDABLE INDICATIONS				
	111° - 153° (81")	111° - 116° (10") 0D	0.20"	1.80"	UPPER	
		122° - 125° (6") OD	0.20"	1.80"	UPPER	
		127° - 128° (0.5") OD	0.20"	1.80"	UPPER	
		129° - 130° (1") OD	0.20"	1.80"	UPPER	
		144° - 145° (1") OD	0.20"	1.80"	UPPER	
		149° - 152° (5") ID	0.20"	1.80"	UPPER	
	219° - 286° (129")	250° - 252° (3") ID	0.30"	1.70"	UPPER	
		263° - 264° (1")	0.35"	2.65"	LOWER	
		278° - 281° (5") ID	0.25"	1.75"	UPPER	

TABLE 4
QUAD CITIES UNIT 1
SHROUD ULTRASONIC EXAMINATION STATUS

WELD #	AREA SCANNED	FLAW LENGTH	MAX FLAW DEPTH	MINIMUM REMAINING LIGAMENT	WELD SIDE	EXAMINATION SUMMARY
H2 (CONT)	291° - 331° (77")	296° - 298° (4") OD	0.20"	1.80"	UPPER	THE EXAMINATION COVERED ~ 539" (77.9%) OF THE TOTAL 691" WELD LENGTH. THE SUM OF THE INDICATIONS RECORDED EXTEND FOR A TOTAL LENGTH OF 139" (20.1%). VISUAL WELD QUALIFICATION CORROBORATED BY UT RESULTS.
		303° - 306° (6") OD	0.20"	1.80"	UPPER	
		308° - 310° (3") ID	0.20"	1.80"	UPPER	
		312° - 317° (10") ID	0.35"	1.65"	UPPER	
		317° - 322° (9") OD	0.20"	1.46"	UPPER	
		319° - 321° (3") ID	0.34"	1.46"	UPPER	

TABLE 4
QUAD CITIES UNIT 1
SHROUD ULTRASONIC EXAMINATION STATUS

WELD #	AREA SCANNED	FLAW LENGTH	MAX FLAW DEPTH	MINIMUM REMAINING LIGAMENT	WELD SIDE	EXAMINATION SUMMARY
H5	126° - 181° (99")	NO RECORDABLE INDICATIONS				THE EXAMINATION COVERED ~ 207" (31.8%) OF THE TOTAL 651" WELD LENGTH. THE SUM OF THE INDICATIONS RECORDED EXTEND FOR A TOTAL LENGTH OF 27" (4.1%).
	224° - 233° (16")	NO RECORDABLE INDICATIONS				
	306° - 338° (58")	327° - 328° (2") ID	0.25"	1.75"	UPPER	
	344° - 360° (29")	345° - 347° (4")	0.39"	2.61"	LOWER	
		349° - 361° (21")	0.57"	2.43"	LOWER	
H6	141° - 147° (11")	145° - 146° (2") ID	0.25"	1.75"	LOWER	THE EXAMINATION WAS PERFORMED IN FOUR (4) ACCESSIBLE LOCATIONS WHICH COVERED ~ 42" (6.7%) OF THE TOTAL 631" WELD LENGTH. VISUAL WELD QUALIFICATION CORROBORATED BY UT RESULTS.
	163° - 169° (11")	NO RECORDABLE INDICATIONS				
	328° - 334° (11")	NO RECORDABLE INDICATIONS				
	343° - 349° (11")	NO RECORDABLE INDICATIONS				
H7	141° - 146° (9")	NO RECORDABLE INDICATIONS				THE EXAMINATION WAS PERFORMED IN FOUR (4) ACCESSIBLE LOCATIONS WHICH COVERED ~ 42" (6.7%) OF THE TOTAL 631" WELD LENGTH. VISUAL WELD QUALIFICATION CORROBORATED BY UT RESULTS.
	163° - 169° (11")	NO RECORDABLE INDICATIONS				
	328° - 334° (11")	NO RECORDABLE INDICATIONS				
	343° - 349° (11")	NO RECORDABLE INDICATIONS				

TABLE 5
COMPARISON OF ULTRASONIC AND METALLOGRAPHIC RESULTS

Boat Sample Identification	Max. Crack Depth Ultrasonic Examination	Max. Crack Depth Metallographic Inspection	Discrepancy
Dresden #1 153° Location	0.300 inches	0.610 inches	0.310 inches
Dresden #2 324° Location	0.520 inches	0.640 inches	0.120 inches
Quad Cities #1 154° Location	No identification	0.285 inches	Not applicable
Quad Cities #2 342° Location	0.390 inches	0.690 inches	0.300 inches

TABLE 6
ALLOWABLE THROUGH-WALL FLAW LENGTH

Weld Identification	Limit Load Total Flaw Length (Dresden/Quad)	LEFM Single Flaw Length (Dresden/Quad)	Limit Load 90° Quadrant Flaw Length (Dresden/Quad)
H1	571/541 inches	Not Given	142/136 inches
H2	565/532 inches	Not Given	141/133 inches
H3	532/501 inches	Not Given	133/126 inches
H4	505/466 inches	489/281 inches	126/117 inches
H5	484/438 inches	326/183 inches	121/110 inches
H6	453/407 inches	Not Given	113/102 inches
H7	435/388 inches	Not Given	108/97 inches