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

RELATED TO THE PROPOSED REPAIR FOR THE CORE SHROUD

COMMONWEALTH EDISON COMPANY

AND

IOWA-ILLINOIS GAS AND ELECTRIC COMPANY

QUAD CITIES NUCLEAR POWER STATION, UNITS 1 AND 2

DOCKET NOS. 50-254 AND 50-265

1.0 BACKGROUND

In Boiling Water Reactors (BWRs) the core shroud is a stainless steel cylinder within the reactor pressure vessel (RPV) that provides lateral support to the fuel assembly. The core shroud also serves to partition feedwater in the reactor vessel's downcomer annulus region from cooling water flowing through the reactor core. The RPV, core shroud and other RPV internals are designed to accomplish three basic safety functions:

- provide a refloodable coolant volume for the reactor core to assure adequate core cooling in the event of a nuclear process barrier breach;
- limit deflections and deformation of internal safety-related RPV components to assure that control rods and Emergency Core Cooling Systems can perform their safety functions during anticipated operational transients and/or design basis accidents;
- assure that the safety functions of the core internals are satisfied with respect to safe shutdown of the reactor and proper removal of decay heat.

In 1991, cracking of the core shroud was visually observed in a foreign BWR. The crack in this BWR was located in the heat-affected zone of a circumferential weld in the mid-core shroud shell. The General Electric Company (GE) reported the cracking found in the foreign reactor in Rapid Information Communication Services Information Letter (RICSIL) 054. GE identified the cracking mechanism as intergranular stress corrosion cracking (IGSCC).

A number of domestic BWR licensees have recently performed visual examinations of their core shrouds in accordance with the recommendations in GE RICSIL 054

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or in GE Services Information Letter (SIL) 572, which was issued in late 1993 to incorporate domestic experience. The combined industry experience from plants which have performed inspections to date indicates that both axial and circumferential cracking can occur in the core shrouds of GE designed BWRs, and that extensive cracking can occur in circumferential welds located both in the upper and lower portions of BWR core shrouds. The cracking reported in the Brunswick Unit 1 core shroud was particularly significant since it was the first time that extensive 360° core shroud cracking had been reported by a licensee in a domestic BWR. The 360° core shroud crack at Brunswick Unit 1 was located at weld H3 which joins the top guide support ring to the mid-core shroud shell. Information Notice 93-79 was issued by the NRC on September 30, 1993, in response to the observed cracking at Brunswick Unit 1.

The cracks reported by the Commonwealth Edison Company (ComEd) in the Dresden Unit 3 and Quad Cities Unit 1 core shrouds were of major importance, since they signified the first reports of 360° cracking located in lower portions of BWR core shrouds. These 360° cracks are located at core shroud weld H5, which joins the core plate support ring to the middle core shroud shell in both the Dresden and Quad Cities Units. Information Notice 94-42 and its Supplement were issued by the NRC on June 7, and July 19, 1994, to alert other licensees of the core shroud cracking discovered at Dresden Unit 3 and Quad Cities Unit 1.

On July 25, 1994, the NRC issued Generic Letter (GL) 94-03 (Reference 1) to all BWR licensees (with the exception of Big Rock Point, which does not have a core shroud) to address the potential for cracking in their core shrouds. GL 94-03 requested BWR licensees to take the following actions with respect to their core shrouds:

- inspect the core shrouds no later than the next scheduled refueling outage;
- perform a safety analysis supporting continued operation of the facility until the inspections are conducted;
- develop an inspection plan which addresses inspections of all core shroud welds, and which delineates the examination methods to be used for the inspections of the core shroud, taking into consideration the best industry technology and inspection experience to date on the subject;
- develop plans for evaluation and/or repair of the core shroud and work closely with the BWR Owners Group (BWROG) on coordination of inspections, evaluations, and repair options for all BWR internals susceptible to intergranular stress corrosion cracking.

By letters dated January 16, (Reference 2), March 3, (Reference 3), and March 22, 1995 (Reference 4), ComEd responded to GL 94-03 by submitting the details of the planned repair of the Quad Cities Units 1 and 2 core shrouds. Part of the licensee's response included ComEd's plans for inspection of the

Quad Cities Unit 2 core shroud during the upcoming refueling outage and plans for a repair that involves a permanent modification. ComEd advised the staff that the modification will encompass the entire set of circumferential welds in the core shroud and will involve the installation of four (4) restraint assemblies in the annulus region around the core shroud.

2.0 EVALUATION

2.1 Scope of the Modification Design

The scope of this safety evaluation (SE) focuses on the circumferential welds in the core shroud, since the only significant cracking of BWR core shrouds has been associated with these welds. The staff is currently not aware of any extensive cracking of vertical seam welds in BWR core shrouds. As stated in Reference 28, ComEd also inspected the vertical welds and determined that there were no reportable indications. Industry experience of cracking in these welds has been limited to relatively small lengths (less than 3 inches with one exception where a 15 inch crack was observed).

The Quad Cities core shroud repair has been designed to restrain the core shroud head, the top guide support ring, the core and core plate support ring, and to prevent upward displacement of the core shroud during postulated accident conditions. The modification has been designed as an alternative to the requirements of the ASME Boiler and Pressure Vessel (B&PV) Code pursuant to 10 CFR 50.55a(a)(3)(i). It is designed to structurally replace the circumferential welds from the H1 weld at the top of the core shroud to the H7 weld at the bottom of the core shroud (see Figure 1 for identification of the core shroud welds). The Quad Cities core shroud repair design therefore provides structural integrity for, and takes the place of, all circumferential welds which are subject to cracking in the Quad Cities core shrouds. ComEd has also stated that the repair is designed for 40 years, including 30 effective full power years. This indicates that the design of the repair accounted for the remaining life of the plant plus possible life extension beyond the current operating license.

Details of the modification are contained in a number of GE proprietary reports which were reviewed by the staff. These are contained in References 2 through 4.

2.2 Core Shroud Repair Modification Description

The design of the Quad Cities Units 1 & 2 core shroud repair consists of four (4) tie rod stabilizer assemblies, which are installed 90° apart in the core shroud/reactor vessel annulus, between attachment points at the top of the core shroud flange and toggle support assemblies attached to the core shroud support plate. Each tie rod stabilizer assembly consists of upper, middle and lower spring assemblies connected by a solid rod. The rod provides the vertical load transfer from the core shroud head flange to the core shroud support plate attachment and supports the spring assemblies. The upper spring assembly provides lateral load support at the top guide elevation from the core shroud to the RPV. The lower spring assembly provides lateral support from the core shroud at the core plate support ring elevation to the RPV. The middle spring assembly provides lateral support for the mid sections of the core shroud and increases the natural frequency of the tie rod stabilizer to reduce flow induced vibration. Each cylindrical section of the core shroud between welds H1 through H7 is prevented from unacceptable lateral motion by these tie rod stabilizer assemblies.

The upper spring assemblies of the tie rod stabilizer assemblies are attached to the core shroud head flange by means of brackets which are installed into slots machined in the flange. The lower end of the tie rod stabilizer assemblies are attached to pins in toggle assemblies which are bolted into holes cut into the core shroud support plate. Hook devices on the lower spring assemblies allow attachment to the toggle assemblies. The tie rod stabilizer assemblies provide vertical restraint to the core shroud. The springs limit the lateral displacements of the core shroud during horizontal dynamic loading in the postulated event of a 360° through-wall failure of one or more of the circumferential welds, so as to ensure control rod insertion. Together, the tie rod stabilizer assemblies and the lateral restraints resist both vertical and lateral loads resulting from normal operation and design accident loads, including seismic loads and postulated pipe ruptures.

The tie rod stabilizer assemblies are installed with a small vertical preload such that the core shroud is in compression during cold shutdown conditions. The coefficients of thermal expansion of the components of the tie rod stabilizer are smaller than those of the core shroud such that the compressive preload on the core shroud increases as the reactor reaches operating conditions. The combined spring constant of the tie rod stabilizer assemblies and the core shroud together was designed to provide a total vertical preload at operating conditions which will assure no separation of any or all failed circumferential welds from H1 through H7 during normal plant operation. Vertical separation for any and all welds is precluded except for the postulated design events addressed in Section 2.4.6 of this SE. Similarly, the upper, middle and lower spring assemblies are installed with a small preload during cold shutdown. During normal operation, the lateral expansion of the core shroud and the spring assemblies due to thermal growth is greater than that of the RPV, providing additional preload and support for the core shroud. This preload will restrict the lateral core shroud displacements during postulated accident conditions within acceptable limits, and assure prompt rod insertion during these conditions.

During the week of May 7, 1995, members of the NRC Region III staff visited the Quad Cities site to observe portions of the core shroud repair activity. No discrepancies were identified or reported.

2.3 Structural Evaluation

2.3.1 Core Shroud and Tie Rod Stabilizer Assemblies

The repair of the core shroud using the tie rod stabilizer assemblies have been designed to the structural criteria specified in the Quad Cities Updated Final Safety Analysis Report (UFSAR) (Reference 7). The seismic analyses were performed in accordance with the methods described in the UFSAR. All of the loads and load combinations specified in the UFSAR which are relevant to the core shroud were included in the design. The tie rod stabilizer assemblies were designed using the ASME Code Section III, 1989 Edition, Subsections NB and NG as a guide (Reference 5). The original ASME Code Section III (1965 Edition with June 30, 1966, Addenda thru Summer 1965) for the design and construction of the RPV did not have design requirements for core support structures. The additional loads placed on the RPV by the stabilizer assemblies have been evaluated to the original design Code.

ComEd evaluated all load combinations required by the UFSAR for normal, upset, emergency, and faulted conditions which include: normal (dead weight (DW) plus normal operating temperature), thermal upset, Operating Basis Earthquake (OBE), Design Basis Earthquake (DBE), Main Steam Line Break (MSLB) Loss of Coolant Accident (LOCA), and Recirculation Line Break (RLB) LOCA loads. All internal loads including those due to the two faulted load combinations of DBE plus LOCA were combined by absolute summation. A three-dimensional finite element analysis model was developed for the stress analysis of the core shroud and the tie rod stabilizer assemblies (References 10 and 11). The analysis was performed using the commercial finite element program ANSYS (Reference 12). The use of ANSYS for modelling of the core shroud and the tie rod stabilizer assemblies is acceptable to the staff. ComEd evaluated the dynamic nature of the DBE, RLB and MSLB LOCA loads on the repaired core shroud structure. The RLB LOCA lateral loading fluctuates with time, but the initial acoustic loading has an input frequency much greater than the core shroud frequency content such that there is very little response due to the initial acoustic loading. ComEd determined that the portion of the RLB loading following the acoustic portion is relatively constant which would result in a static load with no amplification, and that the RLB loads were bounded by the MSLB loads for the design of the stabilizer.

The limiting upset loading condition event which ComEd evaluated is the cold feedwater transient which is classified as an upset loading condition. During this transient, due to injection of cold feedwater into the core shroud annulus, a maximum temperature difference of 133°F between the hot core shroud and the cooler tie rod stabilizer assembly components could exist. This would cause an increase in the tensile load on the stabilizer and an increase in the compressive load on the core shroud. ComEd evaluated this condition and determined that the stresses in the stabilizer and in the core shroud for this condition would be both less than the ASME Code upset allowable stress and less than the material yield stress, thus preventing permanent deformation, which is acceptable. ComEd also determined that this event is the only case which produces any fatigue in need of consideration. For this event, the maximum calculated fatigue usage was found to be insignificant compared to the allowable usage and is, therefore, acceptable.

ComEd has also investigated the effects of radiation on the repair design. Specifically, ComEd determined that the fast flux levels on the stabilizer are low compared to levels which could degrade material properties. Further, the service temperature for this application has no significant effect on the degradation of the repair materials.

The NRC staff has reviewed the methodology and results of the stress analysis of the core shroud and tie rod stabilizer assembly and has determined it meets the appropriate criteria to assure core shroud structural integrity and, therefore, is acceptable.

2.3.2 Evaluation of Postulated Critical Weld Failures

ComEd evaluated an enveloping combination of postulated cracked/uncracked welds to define the worst case for the core plate and top guide displacements to ensure control rod insertion and safe shutdown during the assumed normal, upset, emergency and faulted conditions required by the UFSAR. Each postulated through-wall cracked weld was modelled as a hinge or roller to determine the limiting displacement. In References 8 and 14, ComEd provided the maximum allowable transient and permanent displacements of the core plate and top guide. The staff agrees that these maximum displacements are reasonable and therefore acceptable. The predicted worst case lateral transient deflection of the core plate support ring during a DBE is 0.80 inch which is less than the allowable limit of 1.12 inches. The worst lateral transient displacement of the top guide support ring is 1.92 inches during an DBE which is less than the allowable limit of 3.6 inches.

The limiting loads in the tie rod stabilizer assemblies and the limiting loads in the upper, middle and lower springs occur for different assumed core shroud crack combinations (Reference 8). The limiting loads in the tie rod stabilizer assemblies occur under the Golden Gate Park (GGP) DBE plus operating pressure, assuming a through-wall crack in weld H4 when it behaves as a hinge. The limiting loads in the radial direction on the upper and lower springs occur under the Housner DBE plus operating pressure where it is assumed that all horizontal welds in the core shroud are cracked and represented as hinges. The limiting load in the radial direction on the middle spring occurs under the Housner DBE plus MSLB LOCA where it was assumed that all horizontal welds in the core shroud are cracked and represented as hinges except for H1, which was represented as a roller. The middle spring is designed to prevent radial deflections of the core shroud from exceeding acceptable limits. The upper and lower springs are similarly designed to prevent the radial deflection of the top guide support ring and the core plate support ring from exceeding acceptable limits.

The tie rod stabilizer assembly preload prevents the vertical separation of the core shroud at all potential crack locations during normal operation. The critical cracked weld locations are for H2 and H3 since the failure of these welds has a significant effect on the vertical stiffness of the core shroud due to the greater deflections in the top guide support ring when vertical loads are applied. ComEd also included the effect of a postulated failure of the H5 and H6 welds on the vertical core shroud stiffness. The most severe consequences are determined to occur if these welds are postulated to be initially intact but fail subsequently in operation. For this scenario, ComEd's calculations indicate that there is sufficient preload to prevent weld separation due to the change in rigidity of the core shroud structure. ComEd determined that the tie rod stabilizer assembly cold preload could be reduced to zero due to the application of the core shroud head weight when it is installed if the core shroud stiffness is reduced the maximum amount. However, since the mechanical cold preload is only a small part of the total hot operating preload, there will be no separation at any welds during normal operation. The staff has reviewed ComEd's evaluation and finds it reasonable and acceptable.

In References 26 and 28 ComEd reported that the maximum expected vertical separation of the H7 weld at the 180° azimuth would be 0.450 inch for the postulated DBE plus dead weight plus operating pressure and temperature load combination. This displacement is momentary since the tie rod stabilizer assemblies and the weight of the core shroud and the internals will close the gap once the event is over. This value was based on the maximum tie rod stabilizer assembly load determined from the GGP DBE plus normal pressure analysis considering weld H4 cracked as a hinge (Reference 8). ComEd also stated in Reference 14 that the core spray piping does not provide significant restraint to the core shroud vertical movement during this load combination, and that this piping will remain operable for this postulated single occurrence. We find these results reasonable and acceptable.

2.3.3 Seismic Analysis

A two-dimensional linear elastic dynamic analysis (Reference 8) of a coupled structural stick models of the Turbine Building, the Reactor Building, the RPV and the reactor internals subjected to horizontal seismic excitation was performed consistent with the original design methods and the original analysis in the UFSAR. Both East-West and North-South seismic models were analyzed. With the exception of the nuclear core and the core shroud (including the repair hardware), these models were identical to the original seismic models. The nuclear cores of Units 1 and 2 were updated to the projected Cycle 14 configuration. The seismic models incorporated the tie rod stabilizer assemblies and the core shroud with postulated 360° thru-wall cracks. The tie rod stabilizer assemblies were modeled as an equivalent rotational spring and incorporated into the stick model, and these were assumed to resist the horizontal seismic loading acting on the core shroud. However, due to the postulated cracked welds, the structural behavior of the core shroud is non-linear, with different mass and stiffness characteristics causing the dynamic properties of the core support shroud and the tie rod stabilizer assemblies to vary, depending on the particular load combination and the postulated cracked weld configuration. To permit the application of linear elastic analysis, the core shroud was represented by a number of stick models, in which the critical cracked welds were represented by hinges or rollers. For the emergency loading condition of DBE plus operating pressure, the maximum load in the highest loaded tie rod stabilizer assembly was determined if the core shroud was postulated to be cracked at the H4 weld, and this weld was represented as a hinge. For the faulted loading condition of DBE and MSLB LOCA, the maximum load in the highest loaded tie rod stabilizer assembly was determined if the core shroud was postulated to crack at the H3 weld, and the H3 weld was assumed to be represented by a roller. Seismic analyses were performed considering these loading conditions and core shroud models as bounding cases. These analyses were performed using the GE proprietary computer program SAP4G07 (Reference 9) that has been accepted for this application.

The seismic analysis for the OBE and DBE is based on time history ground motion input. Two horizontal earthquake time histories were applied to the structural model at the mat foundation and used to generate DBE seismic design loads for the core shroud repair: 1) a synthetic time history whose response spectrum envelopes the Housner seismic response spectrum, and 2) the S80E component of the 1957 Golden Gate Park earthquake time history. Both time histories have a normalized peak ground acceleration of 0.24g. These time histories were used for consistency with the original design as stated in the UFSAR. The material damping ratios (corresponding to percent of critical damping) were taken from the UFSAR. These damping ratios are the same for both OBE and DBE conditions. The seismic analyses were performed for the DBE condition only, and the OBE seismic loads were taken as half of the DBE loads.

In order to account for uncertainties in the seismic input and modelling of the core shroud repair, ComEd included some conservatism in the time history input ground motion for the artificial Housner and Golden Gate Park earthquakes. The response spectra from both of these time histories envelope the smoothed Housner UFSAR spectra used as a target. ComEd stated that the duration of the synthetic Housner time history was increased to 40 seconds which increases the energy content of the input ground motion.

Forces and moments due to vertical seismic loading were calculated by using the vertical zero period acceleration (ZPA) equal to 0.16g (2/3 of 0.24g) for DBE as the multiplier of the dead weight which is also consistent with the original design methods. The seismic design loads which were used for the design and analysis of the repair hardware was bounded by the higher of the Housner or Golden Gate Park responses. The peak horizontal and vertical seismic loads were combined by absolute summation with other loads in the core shroud and the repair hardware analyses.

The staff has reviewed the methodology and results of the seismic analysis of the core shroud and the repair hardware, and has found them to be plausible and in accordance with current seismic analysis practice, and therefore acceptable.

2.3.4 Evaluation of RPV Components

ComEd performed an evaluation (Reference 13) of the core shroud support plate stresses in the vicinity of the tie rod stabilizer bolt attachments with the H8 weld both cracked and uncracked, using a detailed finite element model and the ANSYS code. ComEd also computed the effect of the additional loads from the core shroud repair on the original RPV design, including the core shroud support legs (References 19 and 20). The stresses were evaluated for the combined loading of weight, pressure differential and the tie rod stabilizer loading, resulting from the specified operating, emergency and faulted conditions. The stresses were shown to be within the ASME Code allowable stresses. A fatigue analysis was also performed which showed that the usage factor resulting from the upset thermal condition is minimal. The staff has reviewed these results and finds them reasonable and acceptable.

During the installation of the core shroud repair hardware on Quad Cities Unit 2, pockets were cut in the core shroud head flange to accommodate the upper support spring assemblies. During this cutting operation, one of the pockets was cut too deep, and the cut transversed through the remaining wall of the core shroud head flange. GE issued a non-conformance report and a Field Deviation Disposition Request (FDDR) as a result of this installation deficiency. In Reference 21, GE reported the structural evaluation of the stresses in the core shroud head flange with through-wall holes in the pockets, and justification for the disposition of the FDDR as "Accept As-Is." GE demonstrated that the maximum stresses in the core shroud meet the ASME Code stress allowables when subjected to a bounding conservative loading condition of the maximum differential pressure under a MSLB combined with the asymmetric loads due to a RLB and a DBE. GE also determined that due to the geometrical configuration of the upper supports and the clamping effect of the core shroud head, the pressure acting on the support through the hole will not cause the support to be pushed out of the pocket. GE has therefore concluded that the operation of the plant would not be impaired without a repair to the pocket. The staff concurs with this conclusion.

ComEd also addressed the core plate preload clamping force adequacy against lateral sliding relative to the core plate support ring under horizontal DBE seismic forces and resultant vertical loading due to dead weight, buoyancy, vertical DBE and the pressure difference induced by MSLB LOCA (Reference 13). The results indicate that the clamping force is adequate to resist sliding, and that no wedges are needed to prevent sliding. The staff has reviewed these results and finds them reasonable and acceptable.

2.3.5 Potential for Flow-Induced Vibration

ComEd also evaluated the potential for flow-induced vibration by calculating the lowest natural frequency of the tie rod stabilizer and the highest vortex shedding frequency due to the water flow in the core shroud annulus. ComEd found that the lowest natural frequency of the tie rod stabilizer assemblies is 37.8 Hertz while the maximum vortex shedding frequency is 4.6 Hertz. Therefore, ComEd determined that there would be essentially no resulting flow-induced vibration fatigue of any of the tie rod stabilizer assembly components. The staff finds these results reasonable and acceptable.

2.3.6 Loose Parts Considerations

ComEd stated that all components of the tie J stabilizer assemblies will be locked in place with mechanical devices and that loose pieces cannot occur without the failure of a locking device. Further, ComEd determined that if a tie rod stabilizer assembly were to fail during normal operation, the leakage through any through-wall cracks would increase but would not be detectable. If the failed tie rod stabilizer assembly part came completely loose, it could fall onto the core shroud support plate or be swept into the recirculation pump suction line. ComEd stated that the consequences of such a loose part would be consistent with other postulated loose parts. In Reference 25, ComEd committed to submit a "Reinspection Plan" of the Quad Cities Unit 2 core shroud hardware approximately nine months following restart of Quad Cities Unit 2. If ComEd's tie rod stabilizer assembly inspection results, following the first fuel cycle of operation, indicate that further measures are necessary to assure that the tie rod stabilizer assemblies (or parts thereof) will not become loose or detached during plant operation, ComEd will be required to augment the inservice inspection plan to address these additional measures.

ComEd stated that full-scale mock ups, which actually represent the plant core shroud and vessel configuration, have been used to qualify and train personnel for the stabilizer assembly installation task. To install the stabilizer, it is necessary to cut and hone holes in the core shroud support plate and to cut notches in the core shroud head flange using the electric discharge machining (EDM) process. The EDM equipment collects about 95% of the swarf generated during the machining. ComEd evaluated the impact which the remaining metal particles/filings would have on reactor operation, and determined that the suspended particles will be carried away to the reactor water cleanup (RWCU) system where they will be removed and will not increase any short- or long-term degradation of the control rod drive (CRD) or recirculation pump wear.

2.3.7 ComEd 10 CFR 50.59 SE of Core Shroud Repair

In Reference 4, ComEd provided its 10 CFR 50.59 SE of the core shroud repair (Reference 27). In accordance with 10 CFR 50.59, ComEd determined that no unreviewed safety question will result and no Technical Specification revision will be involved as a result of the implementation of the core shroud repair. The staff agrees with this determination, and concludes that no license amendment, pursuant to 10 CFR 50.90, is necessary.

2.3.8 Conclusion

ComEd has demonstrated that the maximum stresses in the core shroud and the tie rod stabilizer assemblies resulting from operating, upset thermal and emergency and faulted accident conditions meet the corresponding ASME Code-allowable stresses. The staff has reviewed the referenced documents, and has determined that the results are reasonable and in general agreement with design and analysis practices employed in support of other core shroud repairs reviewed by the staff. Based on the foregoing discussion, the staff therefore concludes that the proposed core shroud repair modification is acceptable from a structural standpoint.

2.4 Systems Evaluation

2.4.1 Introduction

The intent of the ComEd core shroud modification design documents for Quad Cities Nuclear Power Station Units 1 and 2, dated January 16, 1995, was to demonstrate that fuel geometry and core cooling would be maintained given the unlikely occurrence of a through-wall failure of any horizontal weld during normal operations and design basis events with the core shroud repair installed. Fuel geometry must be maintained to ensure control rod insertion while core cooling is ensured by proper emergency core cooling system (ECCS) performance. The ComEd submittals provided analyses of the principal effects and issues of operating the plant with postulated circumferential core shroud welds cracked and tie rod stabilizer assemblies installed. Some of the conditions analyzed by ComEd included tie rod stabilizer assembly induced leakage, core shroud weld crack leakage, downcomer flow characteristics, lateral displacement of the core shroud, and vertical separation of the core shroud. The staff has reviewed these portions of the ComEd submittals, compared the results to the revised consequence assessment without the core shroud repair dated December 14, 1994 (Reference 15), and provided an evaluation of ComEd's findings in the following discussion.

2.4.2 Tie Rod Stabilizer Assembly System Induced Leakage

As discussed above, the installation of the tie rod stabilizer assemblies requires the machining of eight holes through the core shroud support plate using the EDM process. ComEd estimates that a small amount of core flow leakage will occur through the clearance slots. The total calculated leakage from the installation of the tie rod stabilizer assemblies was estimated to be 0.12% of core flow (350 gpm) at 100% rated power and 108% rated core flow (References 14 and 22). The staff does not consider this leakage rate to be significant with regards to total core flow and therefore, it is acceptable.

The installation of the tie rod stabilizer assemblies also requires the machining of eight slots or pockets into the core shroud head flange in order to install the long upper supports. The core shroud head flange is located above the H1 weld which is the uppermost weld on the core shroud and is above the top guide. At this location, core flow is considered to be two-phase flow. The pockets were to be machined into the core shroud head flange leaving 0.5 inches of core shroud head flange material at the back of the pocket. As discussed in Section 2.3.4, on April 27, 1995, ComEd informed the staff that the EDM process burned through the back of the core shroud head flange at the fourth pocket location. ComEd concluded that the burnthrough resulted in a hole at the back of the core shroud head flange that will allow two-phase flow leakage from the core upper plenum to the downcomer annulus. ComEd performed an analysis and estimated that the additional leakage due to the hole was 0.03% of core flow at 100% rated power and 108% rated core flow (Reference 21). ComEd concluded that full-power operation with the hole in the core shroud head flange and the tie rod stabilizer assemblies installed is acceptable. The staff evaluated the effect of the hole with regards to bypass leakage. The combined total leakage from the hole in the core shroud head flange and the clearance slots in the core shroud support plate is estimated to be 0.15% of core flow (438 gpm) at 100% rated power and 108% rated core flow (Reference 21). The staff does not consider this leakage rate to be significant with regards to total core flow and therefore, is acceptable.

At Quad Cities, the ECCS consists of the single-train high pressure coolant injection (HPCI) system, the automatic depressurization system (ADS), the two-train core spray (CS) system, and the two-train low pressure coolant injection (LPCI) system. The staff notes that the leakage from the core shroud support plate and the core shroud head flange to the downcomer annulus does not affect the performance of the above systems. Therefore, the ECCS performance is not affected by the physical installation of the tie rod stabilizer assembly system.

2.4.3 Core Shroud Weld Crack Leakage

The tie rod stabilizer assemblies are installed with a cold preload to ensure that no vertical separation of any or all cracked horizontal welds will occur during normal operations. Vertical separation, if sufficiently large, could compromise fuel geometry and control rod insertion. For Quad Cities, a maximum vertical separation of 15 inches is required for the top guide to clear the top of the fuel channels. Without the repair, ComEd estimated that the vertical separation during normal operation was 0.9 inches for the H3 weld location, assuming 360° through-wall weld failure (Reference 15). With the repair, ComEd stated that the preload on the tie rod stabilizer assemblies will not allow vertical separation of failed welds during normal operations. The staff notes that, with or without the repair, the estimated vertical separation during normal operations will not affect the fuel geometry, and therefore, control rod insertion is not precluded. However, a small leakage path could exist due to existing through-wall core shroud weld cracks. ComEd conservatively modeled the crack to provide a 0.001 inch leakage path per weld, H1 through H8 (Reference 22). ComEd estimated that the total leakage from all welds, H1 through H8, having postulated 360° through-wall cracks was approximately 150 gpm (0.05% of core flow) at 100% rated power and 108% rated core flow (Reference 14). Although core shroud crack leakage is unlikely due to the preload on the tie rod, ComEd concluded that there are no consequences associated with the repair installed based on these small leakages during normal operations. The staff acknowledges that the total leakage is insignificant and will not affect the performance of the ECCS.

2.4.4 Downcomer Flow Characteristics

ComEd analyzed the available flow area in the downcomer with the four tie rod stabilizer assemblies installed. ComEd stated that the size of the tie rod stabilizer assemblies are small compared to the size of the jet pump assemblies and thus, the tie rod stabilizer assemblies are not expected to significantly affect the flow characteristics in the downcomer. However, since the downcomer annulus is smaller at the top of the core shroud with other existing obstructions such as the core spray lines, ComEd evaluated the flow blockage area at one elevation of the upper core shroud restraint of the tie rod stabilizer assembly. This realistic calculation demonstrated that the installation of the tie rod stabilizer assemblies will decrease the available downcomer flow area by approximately 2 percent at the top of the core shroud (Reference 14). The staff requested ComEd to perform a more conservative calculation using the plan view of the upper core shroud restraint assembly and existing downcomer hardware. ComEd's second analysis demonstrated that the installation of the tie rod stabilizer assemblies will decrease the available downcomer flow area by approximately 10.6 percent (Reference 23). The staff reviewed both downcomer flow calculations which accounted for the core spray piping, miscellaneous bolts, lugs, and brackets, and the upper support and spring of the tie rod stabilizer assemblies. The staff notes that, consistent with design requirements, the upper core shroud restraint assembly is much larger than any other previous General Electric repair design and that the 10.6 percent decrease in downcomer flow area is comparable with repair designs reviewed by the staff for other facilities. Based on ComEd's analyses, the staff concluded that the installation of the tie rod stabilizer assemblies will not have a significant impact on the downcomer flow characteristics. Additionally, ComEd provided the corresponding pressure drop to the decrease in downcomer flow area. ComEd demonstrated that the increase in pressure drop due to the installation of tie rod stabilizer assemblies is less than 0.02 psi which is considerably less than the system pressure drop during normal operations. Based on this information and information from other reviews of similar core shroud repairs, the staff concluded that the increase in the pressure drop is insignificant. Therefore, the staff agrees with ComEd that the installation of the tie rod stabilizer assemblies should not affect the recirculation flow of the reactor.

2.4.5 Potential Lateral Displacement of the Core Shroud

ComEd also evaluated the maximum lateral displacement of the core shroud at the core plate and top guide under normal operations and load combinations such as DBE, MSLB, and RLB, assuming 360° through-wall cracks at any weld location. Lateral displacement of the core shroud could damage core spray lines and could produce an opening in the core shroud, inducing core shroud bypass leakage and complicating recovery. Maximum permanent displacements of the core shroud are limited by the restoring force of the lateral springs and was calculated to be minimal for normal and worst case accident scenarios. This lateral displacement is significantly less than the 2 inch thickness of the core shroud, and accordingly, the separated portions of the core shroud would remain overlapped during worst case conditions. Additionally, a permanent lateral displacement of the top guide or core plate to the actual magnitude shown in the submittal will not significantly increase the scram time as demonstrated in Reference 16. Therefore, the staff has concluded that the maximum lateral displacement of the core shroud would not result in significant leakage from the core to the downcomer region following an accident scenario and the ability to reflood the core to 2/3 core height would not be precluded.

2.4.6 Potential Vertical Separation of the Core Shroud

ComEd evaluated the maximum vertical displacement of the core shroud assuming 360° through-wall cracks at any weld above or below the core plate during a MSLB, DBE, and a MSLB plus DBE. These postulated events would result in a large upward load on the core shroud which could impact the ability of the control rods to insert and the ability of the core spray system to perform its safety function. As stated above, a maximum vertical separation of 15 inches is required for the top guide to clear the top of the fuel channels. Without the repair, ComEd calculated that the maximum vertical separation would be 9.3 inches during a MSLB, assuming 360° through-wall weld failure of the H3 weld location (Reference 15). With the repair installed, the maximum vertical separation during a MSLB is limited to 0.210 inches at the H6 location and 0.132 inches at the H1 through H5 locations, assuming 360° through-wall failure of any of the respective welds (Reference 14 and 26). This separation is limited by the tie rod stabilizer assemblies and should not impact the core spray system. ComEd analyzed the effect of 360° through-wall cracks in horizontal welds during a MSLB plus a DBE. ComEd stated that this combination event would result in a maximum momentary separation at the 180° azimuth (i.e. tipping of the core shroud) of 0.408 inches at the H7 weld (Reference 26). In addition, the largest vertical separation was calculated to be 0.450 inches at the H7 location during a DBE (Reference 26 and 28). The staff acknowledges that the ECCS performance and control rod insertion should not be impacted by any of the cases of momentary separation. Therefore, based on this assessment, the staff concluded that postulated separation during a MSLB, DBE or a MSLB plus DBE event would not preclude any of the systems from performing their safety functions.

2.4.7 Conclusion

The staff has evaluated ComEd's SE of the consequences of the proposed core shroud repair. The staff has found that the proposed repair should not impact the ability to insert control rods, the performance of the ECCS, particularly the core spray system, or the ability to reflood and cool the core. The staff concluded that the proposed repair does not pose adverse consequences to plant safety, and therefore, plant operation is acceptable with the proposed core shroud repair installed.

2.5 Materials, Fabrication and Inspection Considerations

2.5.1 Materials and Fabrication

ComEd stated in Reference 6 that Type 316 or 316L austenitic stainless steel, Type XM-19 stainless steel and nickel-based (Ni-Cr-Fe) alloy X-750 materials were selected for the fabrication of core shroud tie rod stabilizer components. These materials have been used for a number of other components in the BWR environment and have demonstrated good resistance to stress corrosion cracking by laboratory testing and long term service experience. Welding is not designed in the fabrication and the installation of the core shroud tie rod stabilizer for the purpose of minimizing its susceptibility to IGSCC. The spring supports and some connecting components are made from alloy X-750. The alloy X-750 material was selected for these components because of the requirements of higher material strength and lower coefficient of thermal expansion than that of the core shroud material (Type 304 stainless steel). The tie rod stabilizer assemblies were made of Type XM-19 stainless steel in a solution annealed condition with a carbon content less than 0.04%. The remaining connecting components in the tie rod stabilizer assemblies were made from either Type 316/316L austenitic stainless steel with a carbon content not more than 0.02%.

ComEd selected Type XM-19 instead of Type 304 or 316 stainless steel for the fabrication of tie rod stabilizer assemblies because Type XM-19 material has higher resistance to sensitization, higher allowable stress and a slightly lower coefficient of thermal expansion which would increase the thermal pre-load. ComEd stated that Type XM-19 was extensively tested in the mid-1970's, with the results published in Reference 17. The test results showed that Type XM-19 material has good resistance to sensitization and IGSCC. The solution annealed Type XM-19 material has been used in BWR environments with successful experience for over 20 years. The material was used for piston or index tubes in the control rod drive mechanisms and in a number of bolting applications for the core shroud head, top guide and flow deflector.

Type 316/316L austenitic stainless steel and solution annealed alloy Type XM-19 are acceptable ASME Code Section III materials. The alloy X-750 was procured to American Society for Testing and Materials (ASTM) Standard B637, Grade UNS N07750 material (bars and forging) requirements. The heat treatment of alloy X-750 includes solution annealing at 1975°F ±25°F for 60 to 70 minutes, followed by forced air cooling, and age hardening at 1300°F ± 15°F for a minimum of 20 hours, followed by air cooling. The equalization heat treatment at 1500°F to 1800°F was prohibited because this heat treatment will produce a microstructure that would make the alloy X-750 material susceptible to IGSCC.

Type 316/316L austenitic stainless steel was procured to ASTM A-479, A-182 or A-240 with a maximum carbon content of 0.020%. The procured materials were water quenched from solution annealing at 2000°F ±100°F. ComEd stated that all Type 316/316L components were generally re-solution annealed after final fabrication.

The Type XM-19 stainless steel materials were procured to ASTM specification A182, A240, A412 or A479. The materials were solution annealed at 1950°F to 2050°F, followed by forced air cooling to a temperature below 500°F in 20 minutes or less. The staff finds that the process of air-cooling from the solution annealing temperature is not consistent with the Boiling Water Reactor Vessel and Internals Project (BWRVIP) guidelines as provided in Reference 24, where water quenching from the solution annealing temperature is specified. ComEd has committed in Reference 25 that additional information will be submitted to NRC by September 25, 1995, to support the long term use of air-cooled XM-19 materials. If the submittal does not provide sufficient information to resolve the issue, ComEd has also committed to submit a plan for conducting further stress corrosion testing of the materials to demonstrate that the air cooled XM-19 materials have adequate resistance to stress corrosion cracking in a BWR environment.

All procured XM-19 and Type 316/316L stainless steel materials were tested for sensitization in accordance with ASTM Standard A262, Procedures A or E, to ensure the materials were not sensitized. The maximum hardness of the procured materials and completed parts were specified in the GE Fabrication Specification (Reference 18). The threaded areas of Type XM-19 tie rod stabilizer assembly components were re-solution annealed after final machining to remove the surface cold work effect. The cold work resulting from machining is known to promote IGSCC. ComEd stated that the re-solution annealing was carried out by induction heating at a power level of 100 kw and a frequency of approximately 8 khz, and that the induction heating process was qualified using heat treated 316L stainless steel threaded sections. GE has performed metallographic examination of the induction heated pieces. The result of the examination showed that a very thin machined skin layer (0.0001 to 0.0002 inch) on the threads was completely recrystallized and that a limited grain growth from an original grain size of 9 to 7.5 to 6 had occurred.

To preclude intergranular attack (IGA) as a result of high temperature annealing or pickling treatment, ComEd required IGA testing per GE E50YP11 specification to be performed for each heat and heat treat lot of materials after annealing or pickling. ComEd stated that neither pickling nor exposure to any acid environment is permitted during the manufacturing of the repair components. In lieu of IGA testing, a minimum of 0.03 inches may be removed from all surfaces after the last exposure to high temperature annealing as a control of IGA.

ComEd indicated that tie rod stabilizer assembly components are generally rough machined to within 0.10 inch of final size and skim passes are used to achieve the final dimensions. Coolant and sharp tools were used in the machining. The final machined surface finish is generally specified to be 125 root mean square or better. ComEd also indicated that a Nickel-Graphite antiseize thread lubricant will be used in the installation of tie rod stabilizer assemblies. Controls of lubricant impurities were provided in the GE Specification (Reference 24), where impurities limits were specified for halogens, sulfur and nitrates. ComEd stated that machined components that were not solution annealed after machining, were metallographic and microhardness evaluated on test samples to verify that the surface condition after final machining has very shallow cold work depth. The acceptance criteria for machined surfaces as stated in Reference 18 were that the total depth of surface cold work shall not exceed 0.003 inches (by microhardness) and the heavily deformed, feature-less surface layer shall not exceed 0.0003 inches in depth (by metallography).

The staff has reviewed ComEd's submittal regarding the proposed core shroud repair and concludes that the selected materials and fabrication methods for the tie rod stabilizer assemblies are acceptable, considering ComEd's commitment to address the stress corrosion cracking of XM-19 materials, as discussed above. The staff has concluded that operation of the plant is acceptable until this commitment is satisfied, since the potential degradation of the air-cooled materials is expected to be small during the interim operating period.

2.5.2 Pre-modification and Post-modification Inspection

ComEd's pre-modification inspection plan for Quad Cities Unit 2 to support the repair installation consisted of inspection of vertical welds, ring segment welds, H-8 and H-9 welds and repair attachment locations, and was reviewed by the staff. Some of the core shroud pre-modification inspection was performed after the completion of the repair installation. The selection of the welds and the scope and limitation of the inspection are briefly summarized below. ComEd stated that the inspection plan for Quad Cities Unit 1 will be submitted at a later date to support its fourteenth refueling outage, which is scheduled for the spring of 1996.

(1) Ultrasonic examination (UT) was performed on six (6) vertical welds (V14 through V19) of the core shroud (3 vertical welds between each pair of the horizontal welds of H3/H4 and H4/H5), using the General Electric (GE) area scanner system. The UT area scanner consisted of three transducers (45 degree shear, 60 degree RL and surface creeping wave). About 30% of each vertical weld (approximately 27 inches) was examined.

(2) Enhanced visual examination was performed on the remaining six (6) vertical welds which are accessible at the outside diameter (OD) surface. For vertical weld V26, 100% (55 inches) of the weld was inspected, and about 12" was inspected for each of the vertical welds V5, V6, V7, V27, and V28.

(3) Enhanced visual examination was performed on the core shroud head flange ring, top guide support ring and the core plate support ring. Because of the machined surface condition, the segment welds in the three rings (4 welds on core shroud head flange ring, 6 welds on top guide support ring and 6 welds on core plate support ring) could not be visually located. Therefore, all accessible surface areas of the three rings were inspected to ensure the coverage of the ring segment welds. For the core shroud head flange ring, 72% of the OD surface and 100% of the

inside diameter (ID) surface and top surface were inspected; and for the top guide support ring and core plate support ring, 100% and 55% were inspected, respectively, on the OD surface and bottom surface.

(4) Enhanced visual examination was performed on H-8 weld from the jet pump annulus region at the four repair assembly locations (20°, 110°, 200°, and 290° Azimuth). The H-8 weld connects the core shroud support plate to the core shroud support ring. Approximately 10 inches of H-8 weld at each repair location were inspected.

(5) Enhanced visual examination was performed on H-9 weld from the jet pump annulus region at the four repair assembly locations. The H-9 weld connects the core shroud support plate to the reactor vessel. Approximately 12 inches of H-9 weld at each repair location were inspected.

(6) Enhanced visual examination of repair assembly attachment locations before and after cutting or polishing operations. Each end of the four tie rod stabilizer assemblies was attached at the core shroud head flange and the core shroud support plate, respectively.

ComEd reported that the following indications were found by enhanced visual examination (a) one indication (3/4 inch in length) at the core shroud head flange ring was located in the heat affected zone (HAZ) of the fillet weld which connects the steam dam to the flange and, (b) six (6) circumferential indications (51 inches in total length with the longest indication about 24 inches) and three (3) axial indications (1/4 inch to 1/2 inch in length) at the core plate support ring were located in the HAZ and weld toe of the horizontal weld H5. The indication associated with the fillet weld is small and would not affect the structural integrity of the core shroud head flange. The weld H5 will be structurally replaced by the core shroud tie rod stabilizer assemblies.

ComEd has not yet finalized its reinspection plan for the core shroud and the tie rod stabilizer assembly components. The staff recommends that ComEd's reinspection plan should consider the following (1) the plant specific repair design requirements, (2) the extent and the results of the baseline inspection performed during pre-modification inspection, (3) the threaded areas and the locations of crevices and stress concentration in the tie rod stabilizer assemblies, (4) the development of an effective method to locate the ring segment welds to ensure that a successful inspection of the segments welds could be performed during reinspection, and (5) BWRVIP reinspection guidelines when they are established. In Reference 25, ComEd committed to submit the Quad Cities Unit 2 core shroud hardware "Reinspection Plan" for the core shroud and repair assemblies by March 15, 1996. This schedule is approximately nine months after restart of Quad Cities Unit 2. The schedule is based on the current activities necessary to complete the core shroud repair on Dresden Unit 2 (scheduled to begin in June 1995), and to prepare for the implementation of the core shroud repair on Quad Cities Unit 1 (scheduled to begin in February 1996). The NRC staff will review ComEd's reinspection plans when submitted. Since the core shroud and the tie rod stabilizer assemblies are generally classified as ASME Code Class B-N-2 components (core structural support), the reinspection plan will be required to be incorporated into the plant in-service inspection (ISI) program after NRC approval.

The staff has reviewed ComEd's pre-modification inspection plan and results. The staff concludes that the inspection performed by ComEd is acceptable to support the planned core shroud repair.

3.0 CONCLUSION

The proposed core shroud repair has been designed as an alternative to the requirements of the ASME Boiler and Pressure Vessel Code, Section XI, pursuant to 10 CFR 50.55a(a)(3)(i). Based on a review of the core shroud modification hardware from structural, systems, materials, and fabrication considerations, as discussed above, the staff concludes that the proposed modifications of the Quad Cities Units 1 and 2 core shrouds are acceptable and, subject to the submittal of the inservice inspection program and the successful performance of the accelerated stress corrosion testing, will not result in any increased risk to the public health and safety.

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