SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

RELAXATION REQUEST FROM ORDER EA-03-009 REGARDING THE

CONTROL ELEMENT DRIVE MECHANISM EXAMINATION

FACILITY OPERATING LICENSE NO. NPF-38

ENTERGY OPERATIONS, INC.

WATERFORD STEAM ELECTRIC STATION, UNIT 3

DOCKET NO. 50-382

1.0 INTRODUCTION

Order EA-03-009, issued on February 11, 2003, requires specific examinations of the reactor pressure vessel (RPV) head and vessel head penetration (VHP) nozzles of all pressurized water reactor (PWR) plants. Section IV, paragraph F, of the Order states that the Director, Office of Nuclear Reactor Regulation, may, in writing, relax or rescind any of the conditions set forth in Section IV, paragraph C, of the Order upon demonstration by the licensee of good cause. In addition, Section IV, paragraph F, of the Order states that requests for relaxation of the Order associated with specific penetration nozzles will be evaluated by the Nuclear Regulatory Commission (NRC) staff using the procedure for evaluating proposed alternatives to the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (Code) in accordance with Title 10 of the *Code of Federal Regulations* (10 CFR) 50.55a(a)(3). Section IV, paragraph F, of the Order states that a request for relaxation regarding inspection of specific nozzles shall address the following criteria: (1) the proposed alternative(s) for inspection of specific nozzles will provide an acceptable level of quality and safety, or (2) compliance with this Order for specific nozzles would result in hardship or unusual difficulty without a compensating increase in the level of quality and safety.

By letter, serial number CNRO-2003-00038, dated September 15, 2003, as supplemented by letters dated September 26, October 2, October 8, and October 24, 2003, Entergy Operations, Inc. (Entergy, the licensee) requested relaxation to implement an alternative to the requirements of Section IV, Paragraph C.(1)(b)(i), of the Order for all control element drive mechanism (CEDM) nozzles at Waterford 3. The September 15, 2003, relaxation request was a complete revision to and supersedes a request made on June 11, 2003. Prior to submitting its September 15, 2003, letter, the licensee provided preliminary information regarding the information contained in its September 15, 2003, letter at a public meeting held at NRC headquarters in Rockville, Maryland on August 14, 2003. (An electronic copy of the August 14, 2003, meeting summary may be found in the Agencywide Documents Access and Management System, accession number ML032410436.)

2.0 RELAXATION REQUEST FOR RPV HEAD CEDM PENETRATION NOZZLES, ORDER EA-03-009

2.1 Order Requirements for which Relaxation is Requested

Section IV.C.(1) of Order EA-03-009 requires, in part, that the following inspections be performed every refueling outage for high susceptibility plants similar to Waterford-3:

(a) Bare metal visual examination of 100% of the RPV head surface (including 360° around each RPV head penetration nozzle), AND

(b) Either:

(i) Ultrasonic testing of each RPV head penetration nozzle (i.e., nozzle base material) from two (2) inches above the J-groove weld to the bottom of the nozzle and an assessment to determine if leakage has occurred into the interference fit zone, OR

(ii) Eddy current testing or dye penetrant testing of the wetted surface of each J-groove weld and RPV head penetration nozzle base material to at least two (2) inches above the J-groove weld.

The licensee has requested relaxation from Section IV.C.(1)(b)(i) of the Order to perform ultrasonic testing (UT) of the RPV head penetration inside the tube from 2-inches above the J-groove weld to the bottom of the penetration. Specifically, the relaxation is related to UT examination of the bottom portion (threaded area) of all 91 CEDM penetration nozzles. The remaining 11 RPV head penetrations consist of 10 incore instrumentation penetrations and 1 RPV head vent line.

By supplement dated October 8, 2003, Entergy requested the relaxation for one operating cycle (operating cycle 13**)** commencing with the startup from the fall 2003 refueling outage at Waterford 3.

2.2 Licensee's Proposed Alternative Method

UT Examination

The licensee states that the inside diameter (ID) surface of each CEDM nozzle (i.e., nozzle base material) shall be ultrasonically examined from two (2) inches above the J-groove weld to 1.544 inches above the bottom of the nozzle. The licensee states that it will also perform an assessment to determine if leakage has occurred into the interference fit zone, as currently specified in Section IV.C(1)(b)(i) of the Order. Figure 1 is from the licensee's September 15, 2003 submittal and shows the inspection areas of a CEDM nozzle as defined by the licensee.

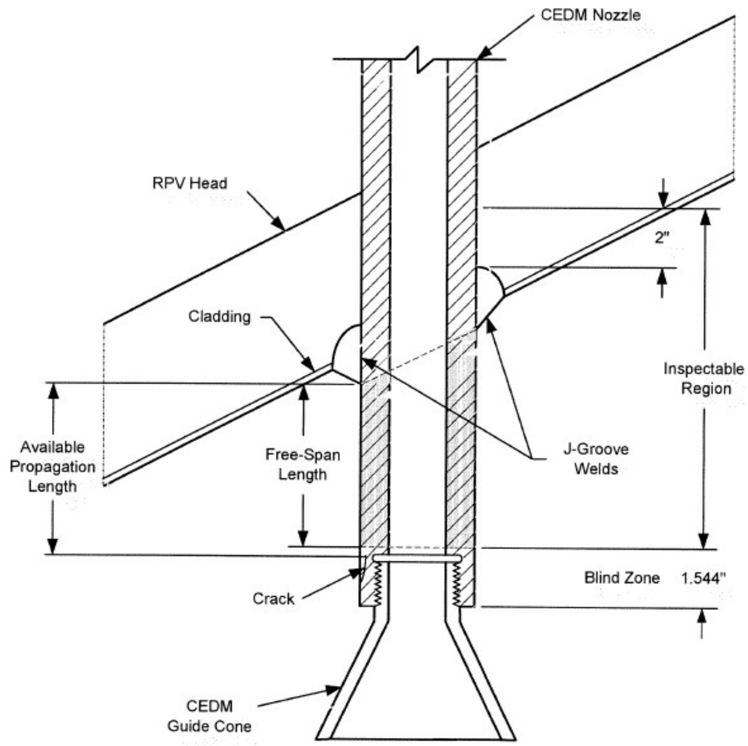

Figure 1

2.3 Licensee's Basis for Relaxation

Nozzle Configuration Limitation

The licensee states that guide cones are attached to the bottom of the Waterford 3 CEDM nozzles via threaded connections and screw into the end of the CEDM nozzles with a welded set screw and two tack welds at the cone-nozzle interface to secure the guide cone to the nozzle. In addition, there is a chamfer at the top of the threaded region that is 0.094 inch in length and the threaded region is 1.25 inches.

The licensee states that meaningful UT data cannot be collected in the threaded area or the chamfer region, since the chamfer region geometry causes sporadic signals. The licensee further states that, once the guide cone is reached, sound cannot pass into the CEDM nozzle base material because of the gap that exists between the guide cone and the nozzle at the threaded connection. This leaves a length of 1.344 inches (1.25 + 0.094) at the bottom of the CEDM nozzle that cannot be inspected by UT examination due to nozzle configuration.

The licensee states that resolving the UT limitations due to nozzle configuration would require eliminating the CEDM nozzle-to-guide cone threaded connection, which would require cutting off the top of the nozzle thread region and changing it to a welded socket design for attachment of the guide cone, and the aforementioned modification would result in a total personnel exposure of 113.75 man-rem and a reduction in the inspection region between the blind zone and the J-groove weld. The licensee states that installing the new guide cones would result in high residual stresses in the weld heat-affected zone, which would increase the probability of PWSCC.

Inspection Probe Limitation Design

The licensee states that, in addition to the limitations of inspecting the chamfer and threaded area of the bottom of the CEDM nozzles, there are limitations regarding the inspection probe's ability to collect data 0.2 inches above the chamfer area. The licensee states that the inspection probe that is to be used for the Waterford 3 CEDM nozzles consists of seven individual transducers. The transducers consist of one pair used for circumferential scanning using time-of-flight diffraction (TOFD), one pair for axial scanning using TOFD, two standard zero-degree scan transducers and one eddy current transducer. These transducers are slightly recessed into the probe holder that must be filled with water to provide coupling between the transducers and the nozzle wall. The licensee indicated that based on prior UT examination experience and a review of UT data from previous inspections, the circumferential-scanning TOFD transducer pair only collects data down to a point 0.200 inch above the chamfer. This makes the total distance at the bottom of the nozzle that cannot be UT inspected equal to 1.544 inches (1.25 in threads + 0.094 inch chamfer + 0.2 inch). The licensee refers to this area as the "blind zone" and states that UT data can not be collected from this area.

Entergy states that it evaluated the feasibility of inspecting the blind zone (ID and OD [outside diameter] surfaces) using the penetrant testing (PT) or eddy current testing (ECT) method as specified in Section IV.C(1)(b)(ii) of the Order. In order to perform a PT examination, it would be required to remove all 91 of the CEDM nozzle guide cones, perform a PT examination and reinstall all 91 CEDM nozzle guide cones, which would result in a total personnel exposure of approximately 227.5 man-rem. The licensee further states that performing a ECT examination, as with a UT inspection, would not yield results in the 1.344-inch threaded region.

In summary, Entergy states that removing the CEDM nozzle guide cones and reinstalling new nozzle guide cones in order to remove the threaded area, or removing and reinstalling the existing nozzle guide cones to conduct additional inspections, would impose hardships and unusual difficulties without a compensating increase in the level of quality and safety.

Crack Growth Analysis

As a result of the aforementioned non-destructive examination (NDE) limitations, the licensee states that it performed an analysis to determine if sufficient free-span length exists between the blind zone and the weld that would allow one operating cycle of crack growth without the postulated crack reaching the reinforcing fillet of the J-groove weld. Because the licensee has never performed a UT examination of the Waterford 3 RPV head penetrations prior to its fall 2003 outage, the licensee used dimensions from Waterford 3 design drawings and actual UT data taken from a sister plant. The licensee states that the sister plant is of a similar Combustion Engineering design rated at 3410 MWt. The licensee's analysis indicates that cracks in the blind zone of the CEDM nozzle will not grow into the welds of any of the 91 CEDM nozzles at Waterford 3 within one cycle of operation based on the assumed nozzle configuration. In the licensee's submittal, it proposed performing augmented surface examinations to nozzles that possess as-built conditions not supported by its analysis or subsequent reanalysis. The licensee proposes that the augmented inspection of the OD surface be performed on the portion of the nozzle that has been determined by analysis as necessary to prevent a crack from reaching the J-groove weld in less than one operating cycle. The licensee's analysis is detailed in Entergy Engineering Report M-EP-2003-004, Rev. 00 "Fracture Mechanics Analysis For The Assessments Of The Potential For Primary Water Stress Corrosion Crack (PWSCC) Growth in Uninspected Regions Of The Control Element Mechanism (CEDM) Nozzles At Waterford Steam Electric Station Unit 3."

In the licensee's October 24, 2003 supplemental letter, it stated that in an effort to identify possible as-found conditions that would require reanalysis, it performed an evaluation of variables that could negatively affect the analysis detailed in Entergy Engineering Report M-EP-2003-004, Rev. 00. The licensee states that the one variable that could negatively affect the original analysis is the distance between the top of the blind zone and the bottom of the weld. The licensee states that to further assess this affect, an iterative analysis using varying lengths between the blind zone and the bottom of the weld was performed to identify the threshold length [free-span length] that would not support one cycle of crack growth and thus require an augmented inspection. The licensee informed the staff on November 4, 2003, that the results of its UT inspections of the CEDM nozzles showed that the as-built nozzle free-span lengths for the Waterford 3 CEDM nozzles exceed the minimum propagation lengths provided in the licensee's October 24, 2003, supplemental letter. The licensee stated that, therefore, no augmented inspections of the CEDM nozzles were performed. The licensee provided via an e-mail the minimum free-span length of all 91 CEDM nozzles on November 4, 2003, (ADAMS accession number ML033140182 and ML033140167). The licensee's information shows that although 9 of 91 CEDM nozzles had less free-span length than originally assumed based on design drawings and UT data from a sister plant, they all had considerably more free-span length than the minimum propagation lengths provided by the letter dated October 24, 2003.

3.0 EVALUATION:

The NRC staff's review of this request was based on criterion (2) of Paragraph F of Section IV of the Order, which states:

> Compliance with this Order for specific nozzles would result in hardship or unusual difficulty without a compensating increase in the level of quality and safety.

Within the context of the licensee's proposed alternative examination of the RPV penetration nozzles, the licensee has demonstrated the hardship or unusual difficulty that would result from implementing examinations to the bottom end of the CEDM nozzles. The hardship identified by the licensee includes the limited access due to nozzle configuration, limitation of the UT probe used for nozzle examination, and radiation exposure to perform UT examination in accordance with the Order. The staff agrees that inspection of the nozzles' threaded areas that mate with guide cones, in accordance with Order EA-03-009, would involve a hardship. The staff's evaluation focuses on the issue of whether there is a compensating increase in the level of quality and safety, such that these nozzles should be inspected despite this hardship.

To assess the likelihood of a postulated flaw in the uninspected portion of the nozzle propagating to the pressure boundary, the licensee performed a fracture mechanics analysis. Although Section XI of the ASME Code does not provide guidelines for characterizing postulated flaws for applications similar to the Waterford 3 CEDM nozzle blind zones, it is reasonable to assume existence of the largest flaw that could exist in the blind zone consistent with engineering principles.

Once the postulated initial flaw size is determined, the applied stress intensity factor (applied K) for the crack is calculated to evaluate the crack growth according to an appropriate crack growth rate (CGR) for the Alloy 600 material. The objective is to determine whether the initial flaw will grow to the J-groove weld in one operating cycle. The stresses required for the applied K calculation are from a stress analysis using finite element method (FEM) modeling of the CEDM nozzle assembly. Evaluation of the technical elements mentioned above is discussed below.

The staff has evaluated the information regarding the FEM modeling. The licensee's FEM model considers welding processes by simulating melting and solidification of individual welding passes through a combination of thermal and structural models. Heat treatment history has also been considered. This method of calculating residual stresses is consistent with the industry practice and is acceptable to the staff. In addition, the licensee considers all test and operating loads. The basic stress-strain properties for Alloy 600 nozzle material and Alloy 182 J-groove weld filler materials use in the stress analysis are modified based on specific material properties from Waterford 3's certified material test reports (CMTR). Considering the lack of plant-specific data (such as the shape of the stress-strain curve), this engineering approach in modifying the generic stress-strain curve is appropriate. Further, the CMTR material property affects the maximum stress of the nozzle more than the generic stress-strain shape does the stress, providing additional support to the licensee's approach. The use of the stress-strain law for an elastic-perfectly plastic model for the Alloy 182 filler metal may not be a good representation of the material's real behavior. However, it was used to overcome a modeling limitation of the FEM code so that more conservative stresses could result. In summary, the FEM modeling is conservative, and the use of resulting stresses from the FEM model as input to the licensee's fracture mechanics evaluation is acceptable.

To assess the consequence of having flaws in the blind zone, the licensee assumed three initial flaw geometries in its fracture mechanics evaluation: an ID elliptical surface flaw 0.04627 inch deep and 0.32 inch long, OD elliptical surface flaw 0.07932 inch deep and 0.32 inch long, and a through-wall flaw of length from the top of the blind zone to a point of hoop stress less than 10 ksi. The licensee assumed the upper crack front for an initial OD or ID flaw to be 0.16 inch ahead of a corresponding through-wall flaw. The staff determines that the licensee's approach of assuming the upper crack front for an initial ID or OD flaw to be 0.16 inch beyond the upper blind zone is conservative, and the assumed initial flaw sizes for the analyzed cases cover all possibilities.

For applied K calculations for ID and OD flaws, the licensee used an influence-function approach based on extensive FEM analyses for thick cylinders with ID and OD surface flaws by S. R. Mettu, et al. (1992). For applied K calculations for through-wall flaws, the licensee used another influence-function approach based on extensive FEM analyses for thick cylinders with through-wall flaws by Christine C. France, et al. (1997). Using formulas for thick cylinders is appropriate because for this application the R/t ratio for the CEDM nozzle is 2.5.

For ID and OD flaws, the licensee calculated the applied K at the crack depth using the stress analyses results, fully considering the variation of stress distribution along the depth direction. Instead of using the conventional approximation approach of estimating the crack growth at the surface based on the aspect ratio of the crack and the applied K at the crack depth, the licensee used an approach of evaluating the applied K at the upper crack front directly using an average stress from the stress analyses results. A detailed evaluation of the licensee's method for ID and OD surface flaws using the "moving average scheme" is not necessary, because the licensee's fracture mechanics results for all three crack geometries indicate that the through-wall flaw assumption is representative and acceptable for all nozzles.

The licensee used the results from the FEM stress analyses, the initial flaw sizes, and the fracture mechanics methodology discussed above to predict the crack growth of the upper crack front of a postulated flaw at the end of an operating cycle. The results of the available propagation length versus the crack growth at the end of one operating cycle based on assumed nozzle configurations are listed in Table 13 in Entergy Engineering Report M-EP-2003-004, Rev. 00, for four groups of representative CEDM nozzles at downhill, uphill, and mid-plane locations for each.

The minimum propagation lengths for various possible free-span lengths, as defined in the licensee's October 24, 2003 supplemental letter, are based on an acceptable fracture mechanics methodology to ensure adequate propagation length for all assumed flaws to grow in one fuel cycle is reasonable. The staff accepts the results summarized in Table 13 of the Entergy Engineering Report mentioned above, and the licensee's letter dated October 24, 2003.

The aforementioned crack growth analysis used the approach described in Footnote 1 of the Order, with the exception of the CGR [crack growth rate], as the criteria to set the necessary height of the surface examination. Therefore, the coverage addressed by this request provides reasonable assurance of structural integrity of the component. However, this analysis incorporates a crack growth formula different from that described in Footnote 1 of the Order, as provided in the Electric Power Research Institute Report, "Material Reliability Program (MRP) Crack Growth Rates for Evaluating Primary Water Stress Corrosion Cracking (PWSCC) of Thick Wall Alloy 600 Material (MRP-55), Revision 1." The NRC staff has completed a preliminary review of the crack growth formula, but has not yet made a final assessment regarding the acceptability of the report. Thus, the alternative should include the following condition: If the NRC staff finds that the crack growth formula in industry report MRP-55 is unacceptable, the licensee shall revise its analysis that justifies relaxation of the Order within 30 days after the NRC informs the licensee of an NRC-approved crack growth formula. If the licensee's revised analysis shows that the crack growth acceptance criteria are exceeded prior to the end of the operating cycle 13, this relaxation is rescinded and the licensee shall, within 72 hours, submit to the NRC written justification for continued operation. If the revised analysis shows that the crack growth acceptance criteria are exceeded during the subsequent operating cycle, the licensee shall, within 30 days, submit the revised analysis for NRC review. If the revised analysis shows that the crack growth acceptance criteria are not exceeded during either the current operating cycle or the subsequent operating cycle, the licensee shall, within 30 days, submit a letter to the NRC confirming that its analysis has been revised. Any future crack growth analyses performed for this and future cycles for RPV head penetrations must be based on an acceptable CGR formula. By letter dated October 2, 2003, the licensee modified its alternative to include this condition.

Augmented inspection

According to the licensee's submittal, of the 91 CEDM nozzles at Waterford 3, all 91 of the nozzles would receive UT coverage of enough nozzle material below the J-groove weld to sustain crack growth of a postulated flaw over one operating cycle based on assumed nozzle configurations. Although the licensee's submittal requested to use an augmented surface examination on nozzles that did not have sufficient free-span length to facilitate one operating cycle of crack growth, the licensee informed the staff on November 4, 2003, that it confirmed that the as-built nozzle configurations showed that sufficient free-span length for one operating cycle of crack growth was available on all 91 CEDM nozzles at Waterford-3. Therefore, augmented inspections were not required for any of the Waterford 3 CEDM nozzles.

Based on the licensee's crack growth analysis, the staff finds that there is reasonable assurance that the growth of flaws initiated from the uninspected portion of the nozzles will not exceed the crack growth acceptance criteria and that the structural integrity of the RPV head, VHP nozzles and welds will be maintained during the next operating cycle. Therefore, performance of UT to the bottom of the CEDM nozzles would result in hardship without a compensating increase in the level of quality and safety.

4.0 CONCLUSION:

The staff concludes that the licensee's proposed alternative examination of the CEDM RPV head penetration nozzles using UT from 2 inches above the J-groove weld to 1.544 inches above the bottom of the CEDM nozzles, provides reasonable assurance of the structural integrity of the RPV head, VHP nozzles, and welds. Further inspection of the CEDM nozzles in accordance with Section IV.C.(1)(b)(i) of Order EA-03-009 would result in hardship or unusual difficulty without a compensating increase in the level of quality and safety. Therefore, good cause has been shown for relaxation of the Order, and pursuant to Section IV, Paragraph F, of Order EA-03-009, and 10 CFR 50.55a(a)(3), the staff authorizes, for one operating cycle commencing with the startup from the fall 2003 refueling outage, the proposed alternative inspection for all CEDM head penetration nozzles at Waterford 3, subject to the following condition:

> If the NRC staff finds that the crack-growth formula in MRP-55 is unacceptable, Entergy shall revise its analysis that justifies relaxation of the Order within 30 days after the NRC informs Entergy of an NRC-approved crack-growth formula. If Entergy's revised analysis shows that the crack growth acceptance criteria are exceeded prior to the end of the operating cycle which follows the current refueling outage, this relaxation is rescinded and Entergy will, within 72 hours, submit to the NRC written justification for continued operation. If the revised analysis shows that the crack growth acceptance criteria are exceeded during the subsequent operating cycle, Entergy shall, within 30 days, submit the revised analysis for NRC review. If the revised analysis shows that the crack growth acceptance criteria are not exceeded during either the upcoming operating cycle or the subsequent operating cycle, Entergy shall, within 30 days, submit a letter to the NRC confirming that its analysis has been revised. Any future crack-growth analyses performed for the upcoming operating cycle and future cycles for RPV head penetrations will be based on an NRC-acceptable crack growth rate formula.

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Date: November 12, 2003