May 4, 2007

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SUBJECT: ASSESSMENT OF EXPONENT REPORT PROJECT NUMBER BN63097.001, "REVIEW & ANALYSIS OF THE DAVIS-BESSE MARCH 2002 REACTOR PRESSURE VESSEL HEAD WASTAGE EVENT," TO ENSURE CURRENT REACTOR PRESSURE VESSEL HEAD INSPECTION REQUIREMENTS ARE ADEQUATE TO PREVENT SIGNIFICANT HEAD WASTAGE.

In a March 20, 2007, letter, FirstEnergy Nuclear Operating Company (FENOC) provided to the U.S. Nuclear Regulatory Commission (NRC), for the staff's information, copies of Exponent Failure Analysis Associates and Altran Solutions Corporation (jointly referred to as "Exponent") Report Project Number BN63097.001, "Review & Analysis of the Davis-Besse March 2002 Reactor Pressure Vessel Head Wastage Event." The report contains analyses performed for FENOC by Exponent concerning the Davis-Besse reactor pressure vessel (RPV) head wastage event found in March 2002. The assumptions in the report led to the conclusion that the time line of the Davis-Besse RPV head wastage was much shorter than previously reported in the FENOC root cause report on the event, issued in April 2002. The purpose of this assessment is to determine whether current RPV head inspection requirements would ensure the structural integrity of RPV heads given the conclusions of the Exponent Report.

Based on our assessment of the report, NRC staff reconfirmed that current RPV head inspection requirements under the First Revised NRC Order EA-03-009, dated February 20, 2004, are adequate to identify primary water stress corrosion cracking prior to development of significant head wastage as stated by the Exponent Report scenario. The staff's assessment is enclosed.

Enclosure:
Assessment of Exponent Report

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Enclosure:
Assessment of Exponent Report

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ASSESSMENT OF EXPONENT FAILURE ANALYSIS ASSOCIATES AND ALTRAN SOLUTIONS CORPORATION REPORT PROJECT NUMBER BN63097.001, "REVIEW & ANALYSIS OF THE DAVIS-BESSE MARCH 2002 REACTOR PRESSURE VESSEL HEAD WASTAGE EVENT"

1.0 INTRODUCTION

In February 2002, FirstEnergy Nuclear Operating Company (FENOC), the licensee of the Davis-Besse Nuclear Power Plant (Davis-Besse), shut down Davis-Besse for a refueling outage. During this outage, FENOC planned to perform a visual inspection of the outer surface of the Davis-Besse reactor pressure vessel (RPV) head to look for signs of boron deposits, and to perform an ultrasonic inspection of all associated vessel head penetration (VHP) nozzles. Through this inspection, FENOC identified a large cavity, approximately football sized and shaped, in the RPV head base material adjacent to VHP nozzle number 3. For the majority of the cavity, the RPV head had approximately six inches of low-alloy pressure vessel steel corroded away leaving only the stainless steel cladding. By letter dated April 18, 2002, FENOC submitted to the US Nuclear Regulatory Commission (NRC) "Root Cause Analysis Report: Significant Degradation of the Reactor Pressure Vessel Head," which provided a time line of events which could have led to the formation of the large cavity in the RPV head. The root cause report stated that the large cavity was formed due to boric acid corrosion of the low alloy steel head material. The root cause report found that the corrosion began as early as 1996 and continued over the next five years to cause the cavity.

By letter dated March 20, 2007, FENOC provided, for the NRC staff's information, Exponent Failure Analysis Associates and Altran Solutions Corporation (jointly referred to as "Exponent") Report Project Number BN63097.001, "Review & Analysis of the Davis-Besse March 2002 Reactor Pressure Vessel Head Wastage Event." Exponent was contracted by FENOC to prepare this report in an arbitration case involving Nuclear Electric Insurance Limited, the industry insurance organization that provides insurance to nuclear plant owners and operators. The conclusions of this report differ from FENOC's Root Cause Report submitted on April 18, 2002. One of the principal conclusions of the Exponent Report states the large wastage cavity discovered in March 2002 at Davis-Besse was principally caused by an accelerated attack of the RPV head low alloy steel material which began in the October to November time frame of 2001. The Exponent Report asserts that accelerated corrosion and erosion rates caused the majority of the RPV head wastage found at Davis-Besse in March 2002, and that this process occurred in a four to five month period.

The purpose of this assessment is to determine whether current RPV head inspection requirements would ensure the structural integrity of RPV heads given the conclusions of Appendixes A, B and C within the Exponent Report. This assessment does not evaluate whether the assumptions, logic, analysis and conclusions of the Exponent Report are correct. A detailed review of each assertion by the Exponent Report authors is beyond the scope of this assessment.

2.0 REGULATORY REQUIREMENTS

The First Revised NRC Order EA-03-009, "Interim Inspection Requirements for Reactor Pressure Vessel Heads at Pressurized Water Reactors," dated February 20, 2004 (Order), provides the current regulatory requirements for RPV head and associated VHP nozzle inspections for all U.S. pressurized water reactors (PWR). The Order inspections were developed to identify primary water stress corrosion cracking (PWSCC) in susceptible VHP nozzle materials and their associated J-groove welds, as this form of degradation could lead to control rod drive mechanism ejection or RPV head wastage. The Order establishes a PWSCC susceptibility rating for each RPV head in service, as determined by a calculation of the number of effective full power years (EFPY) of operation weighted by estimated operational RPV head temperature. This susceptibility rating is called effective degradation years (EDY). The Order then establishes four PWSCC susceptibility categories as defined by certain conditions detailed in the following table.

Susceptibility Category	Conditions
High	(1) Plants with a calculated value of EDY greater than 12, OR (2) Plants with an RPV head that has experienced cracking in a penetration nozzle or J-groove weld due to PWSCC.
Moderate	Plants with a calculated value of EDY less than or equal to 12 and greater than or equal to 8 AND no inspection findings requiring classification as High.
Low	Plants with a calculated value of EDY less than 8 AND no inspection findings requiring classification as High.
Replaced	Plants with a replaced RPV head AND with a calculated value of EDY less than 8 AND no inspection findings requiring classification as High.

Inspection frequency requirements are based upon the susceptibility category of the RPV head. Licensees with RPV heads in the High susceptibility category are required to perform bare metal visual (BMV) examinations of the RPV head surface and volumetric (typically ultrasonic testing) and/or surface (typically eddy current or dye penetrant) examinations of the VHP nozzles each outage. Licensees with RPV heads in the Moderate susceptibility category are required to perform BMV examinations of the RPV head surface or volumetric and/or surface examinations of the VHP nozzles each outage, alternating the inspection type each outage. Licensees with RPV heads in the Low and Replaced susceptibility category are required to perform BMV examinations of the RPV head surface every three outages or five years, whichever is limiting, and volumetric and/or surface examinations of the VHP nozzles every four outages or seven years, whichever is more limiting. Licensees with RPV heads in the Low susceptibility category are also required to perform initial baseline volumetric and/or surface examinations of the VHP nozzles by February 11, 2008.

3.0 EXPONENT REPORT TIME LINE

The Exponent Report's time line for the development of the head wastage found at Davis-Besse in March 2002, is primarily based upon various assumptions and a calculational flaw evaluation of through-wall flaws identified by volumetric examination of VHP nozzle number 3. In the Exponent Report, the cracks were calculated to grow until the VHP nozzle material crack extended through-wall and leakage initiated. This process is estimated by the Exponent Report to take 3.2 years as shown in Figure 7 of Appendix B of the report. The Exponent Report then used a computation fluid dynamics code to predict the corrosion/erosion effects in this annulus region using various assumptions. The Exponent Report concludes that accelerated corrosion/erosion rates reached after October/November 2001 led to the majority of the wastage cavity formation found in March 2002.

The Exponent Report states that the key moment in this corrosion/erosion process is when the through-wall PWSCC flaw in the VHP nozzle grows to a length above the J-groove weld, in which the upper point of the flaw reaches a point of equal elevation as the bottom of the corrosion cavity formed in the RPV head wall in the annulus region. Therefore, the time line to initiation of this key moment is dependent on the growth of the PWSCC flaw in the VHP nozzle above the J-groove weld. In Figure 10 of Appendix B of the Exponent Report, estimated growth time in EFPY is provided for the PWSCC flaw in the VHP nozzle to extend from the top of the weld, when leakage would have initiated, to a point 1.2-inches above the weld, which corresponds to the volumetric data identifying the flaw in the as-found condition in February 2002. According to Figure 10, the flaw growth took approximately 2.3 EFPY.

The Exponent Report concludes based on its assumptions and analysis methodology that the time line for the formation of the wastage cavity as found on the Davis-Besse RPV head in March 2002, is approximately five and a half years. The time line starts with the initiation of PWSCC flaws in both the VHP nozzle and J-groove welds which take 3.2 years to grow to a point of initiation of leakage. The next step in the time line is the growth of the PWSCC flaw in the VHP nozzle to a point at which accelerated corrosion/erosion rates begin, which is 2.3 EFPY minus a conservative estimate of five months of operation (~ 0.4 EFPY). Finally, the last section of the time line consists of the remaining five months of operation, during which the majority of the wastage cavity is formed. To be conservative, EFPY is equated to years for this NRC staff assessment. Therefore, based on the Exponent Report assumptions and analytical approach the total conservative time line from initiation of the PWSCC flaw to the time at which the RPV head wastage was found is estimated to be 5.5 years, and the conservative time line from initiation to the beginning of the accelerated corrosion and erosion is estimated as 5.1 years.

4.0 STAFF ANALYSIS

The Davis-Besse RPV head was calculated to have an estimated 19.2 EDY at the time of the finding of the wastage cavity in March 2002. The 19.2 EDY estimated value was provided in Table 4.4 of a Materials Reliability Program (MRP) Report, MRP-110, "Materials Reliability Program Reactor Vessel Closure Head Penetration Safety Assessment for U.S. PWR Plants (MRP-110)," dated April 2004 (ML041680506). Under the current regulatory requirements of

the Order inspection regime, this EDY value would have placed Davis-Besse in the High PWSCC susceptibility category, and would have required a volumetric examination in 2002 to detect PWSCC if the Order was in effect at that time.

A further examination of the Exponent Report time line shows that crack initiation is stated to have begun in late 1996. Between late 1996 and March 2002, there were two refueling outages at the Davis-Besse plant. The first being in 1998 and the second being in 2000. The staff conservatively estimated EDY values for the Davis-Besse RPV head for these outages as 16.8 EDY for the 2000 refueling outage, and 14.5 EDY for the 1998 refueling outage. In both refueling outages, the Davis-Besse RPV head would have been in the High PWSCC susceptibility category, if the current regulatory requirements of the Order would have been in place. Under the requirements of the Order's High PWSCC susceptibility category, volumetric and/or surface examination of the VHP nozzle material would have been performed during each of these outages. These examinations would have identified the PWSCC flaw prior to formation of the wastage cavity found at Davis-Besse in March 2002.

Based on the results of current inspections performed pursuant to NRC requirements, the staff has reasonable assurance that PWSCC flaws of a size hypothesized in the Exponent Report that could cause excessive RPV head wastage are not present in operating reactors. All current High and Moderate PWSCC susceptibility category plants have performed volumetric examinations of their VHP nozzles within the past two and a half years. Where indications of PWSCC were found, all have been repaired, or the RPV head has been replaced.

Of the twenty-three Low PWSCC susceptibility plants, one plant has replaced its RPV head and nineteen others have performed volumetric examinations of all of their approximately 1400 Low PWSCC susceptibility VHP nozzles within the past three years. One VHP nozzle was identified as having two indications which may be due to PWSCC. These indications were found during the writing of this assessment and further testing of a material sample of one of the indications is expected. Based on the NRC staff's current knowledge of this finding, these indications did not result in leakage through the reactor coolant pressure boundary. Of the three remaining plants in the Low PWSCC susceptibility category, all have performed bare metal visual examinations of their RPV head surface to identify leakage from VHP nozzles or associated J-groove welds, and no leakage due to PWSCC has been identified. The baseline volumetric inspections for the these three plants will be performed as follows: two in the Fall 2007 outage season, and the last in the Spring 2008 outage season.

One plant, Davis-Besse, is in the Replaced category with an RPV head using alloy 600 VHP nozzles, and this RPV head has been in service for only three years. Further a bare metal visual examination was performed in 2006 with no indications of leakage. All other plants in the Replaced category have had their original RPV heads manufactured with alloy 600 VHP nozzles replaced with RPV heads with alloy 690 VHP nozzles, which are reported to be resistant to PWSCC as set forth in MRP Report number 111, "Materials Reliability Program Resistance to Primary Water Stress Corrosion Cracking of Alloys 690, 52 and 152 in Pressurized Water Reactors (MRP-111)," (ML041680546). Therefore, the flaws as stated in the Exponent report would not be expected. These inspection results provide reasonable assurance that significant PWSCC flaws of a size to support the stated corrosion and erosion rates of the Exponent Report do not currently exist in operating PWR plants with alloy 600 VHP nozzles in their RPV heads.

A review of the Order inspection frequencies was performed to provide reasonable assurance that the PWSCC flaws required for enhanced corrosion and erosion rates, as described by the Exponent Report, would be identified prior to significant head corrosion. Based on the assumptions and analysis approach described in the Exponent Report, it states that the majority of the wastage cavity was formed from October/November 2001 through February 2002. The report further states that the conditions necessary for the accelerated wastage required approximately 5.1 years of crack growth.

The NRC staff used the Exponent Report conservative time line for wastage in a general analysis of all PWRs in the U.S. fleet. The NRC's use of this time period for a generic analysis of other facilities is conservative due primarily to the following considerations: (1) the Exponent Report uses a higher crack growth rate for the specific material used at Davis Besse; (2) the Exponent Report hypothesizes the simultaneous initiation and growth of two flaws joining together to cover the extent of cracked area necessary to support the Exponent Report's conclusions; and (3) the Exponent Report uses an estimated Davis-Besse RPV head temperature which is the highest in the U.S. PWR fleet supporting a higher crack growth rate.

This time period of crack growth would allow identification of these flaws under the inspection requirements of the Order, as follows:

- Plants in the High PWSCC susceptibility category would perform volumetric and/or surface examinations of the VHP nozzles and bare metal visual examinations of the RPV head surface at least twice through this period. Volumetric inspections of this frequency for plants in the High PWSCC susceptibility category would identify the flaws as described in the Exponent Report prior to RPV head wastage.

- Plants in the Moderate PWSCC susceptibility category would perform volumetric and/or surface examinations of the VHP nozzles at least once through this period. Volumetric inspections of this frequency for plants in the Moderate PWSCC susceptibility category plants would identify the flaws as described in the Exponent Report prior to RPV head wastage.

- Plants in the Low PWSCC susceptibility category would perform volumetric and/or surface examinations only once every seven years. However, the Exponent Report analysis was performed for the highest operational RPV head temperature in the U.S. PWR fleet. Temperature has a significant impact on crack growth rates of PWSCC in alloy 600 material, as the crack growth rate can vary by a factor of four along the range of operational RPV head temperatures for the U.S. PWR fleet. All Low PWSCC susceptibility category plants have operational RPV head temperatures in the lower third of this range. Therefore, factoring in the lower temperature impact to the development of the proposed flaws in the Exponent Report, the time for sufficient cracking to develop to lead to enhanced corrosion and erosion rates of the RPV head, conservatively increases by a factor of at least three. Hence, more than 10 years of unidentified crack growth in a VHP nozzle in a RPV head with a Low PWSCC susceptibility would be required prior to the development of RPV head wastage as stated in the Exponent Report. Therefore, we conclude that volumetric inspections of this frequency for Low PWSCC susceptibility plants would identify the flaws as described in the Exponent Report prior to RPV head wastage.

- In the Replaced category, all plants, except for Davis-Besse, have replaced their original RPV heads manufactured with alloy 600 VHP nozzles with RPV heads with PWSCC resistant alloy 690 VHP nozzles installed. Therefore, the flaws as stated in the Exponent report would not be expected.

- In the Replaced category, Davis-Besse is unique in that the current Davis-Besse RPV head is the former cancelled Midland Plant RPV head, and it is manufactured with alloy 600 VHP nozzles. As a Replaced category plant, volumetric inspections would only be required every seven years. The estimated RPV head temperature for Davis-Besse is the highest in the U.S. PWR fleet, therefore a similar evaluation as was used with the Low PWSCC susceptibility category inspection frequency would not be valid. However, because this replaced RPV head was put into service in 2004, it has accumulated only an estimated 4 EDY. According to the time line laid out by the Exponent Report, the NRC staff estimates that the original Davis-Besse RPV head had accumulated 12.4 EDY of degradation time prior to a crack initiating on the VHP nozzle surface. By letter dated March 11, 2004, from M. Bezilla to the NRC, Serial Number 3033, FENOC has committed to perform additional inspections of the new Davis-Besse RPV head that go beyond the Order requirements for the Replaced category of the Order, until the replaced RPV head reaches 8 EDY or is replaced as well. Due to the relatively young age of the new RPV head, PWSCC is not expected to occur. However, if PWSCC does initiate, with BMV inspections of the RPV head surface each outage and volumetric inspection within the next two outages, cracking or leakage as described in the Exponent Report would be identifiable prior to significant RPV head wastage.

Based on the preceding evaluation, NRC staff finds that the current RPV head inspection requirements under the First Revised NRC Order EA-03-009, dated February 20, 2004, are adequate to identify PWSCC prior to development of the conditions necessary to support the Exponent Report scenario for the significant RPV head wastage found at Davis-Besse in 2002.

5.0 CONCLUSION

The Exponent Report, commissioned by FENOC, proposes a time line of events that proceeded to, and concluded with, the formation of the RPV head wastage found at Davis-Besse in March 2002. This assessment is not a validation of the basis statements or the conclusions of the Exponent Report. The purpose of this evaluation is to evaluate whether current requirements are adequate to ensure safety.

The current NRC regulatory requirements for U.S. PWR RPV head and associated VHP nozzle inspection are provided in the First Revised NRC Order EA-03-009. Given the Exponent Report's time line of events necessary to cause the significant head wastage at Davis-Besse, the NRC staff continues to find the requirements of the Order remain sufficient to detect RPV head degradation issues before they propagate into significant wastage.