58

From: Thomas Wengert
To: McKnight, James
Date: Mon, May 21, 2007 2:20 PM
Subject: Fwd: FirstEnergy Nuclear Operating Company (FENOC) Exponent Failure Analysis Associates' Technical R

Jim,

Have you seen these documents in the DCD? I see that the "cc" indicates that a copy was sent to the "Public Document Room". However, I'm not sure whether the DCD will necessarily receive this document.

I couldn't find these documents in ADAMS. Have you seen these?

Thanks,

Tom
415-4037

CC: Collins, Jay; King, Mike; Mensah, Tanya

H-58

From: John Grobe
To: Eric Duncan
Date: Wed, May 9, 2007 11:09 AM
Subject: Fwd: FirstEnergy Nuclear Operating Company (FENOC) Exponent Failure Analysis Associates' Technical Report

Eric,

You may want to send this to the exponent group

>>> "FERTEL, Marvin" <msf@nei.org> 05/09/2007 10:29 AM >>>
May 9, 2007

Mr. Luis A. Reyes

Executive Director for Operations

U.S. Nuclear Regulatory Commission

Washington, DC 20555-0001

Dear Mr. Reyes:

The FirstEnergy Nuclear Operating Company (FENOC) docketed a May 2, 2007, letter responding to four specific issues raised by the NRC staff regarding the Exponent Failure Analysis Associates' technical report, "Review and Analysis of the Davis-Besse March 2002 Reactor Pressure Vessel Head Wastage Event." In the May 2nd letter, FENOC noted that they provided the Exponent report to NEI with a request that an evaluation be conducted to determine if the report calls into question the adequacy of the industry's operational monitoring or inspection programs or otherwise raise a potential generic safety concern.

Enclosure

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CC: James Caldwell; Mark Satorius

Summary Report
May 2007

Effect of Exponent Analysis of Davis-Besse Reactor Vessel Head Wastage Event On Industry Inspection Programs

Summary Report

Nuclear Energy Institute
1776 I Street, NW, Suite 400
Washington, D.C. 20006-3708

Summary Report
May 2007

Contents

1. Panel Charter and Conclusions

2. Technical Support to the Position that Exponent Analysis does not Invalidate Industry RPV Head Inspection Program

3. References

1. Panel Charter and Conclusions

NEI commissioned an expert panel to review the First Energy Nuclear Operation Company (FENOC) report of December 15, 2006, authored by Exponent, entitled "Review and Analysis of the Davis-Besse March 2002 Reactor Pressure Vessel Head Wastage Event" to determine the potential impact on industry inspection programs for reactor vessel top head nozzles. The two main questions addressed by the panel and conclusions are as follows:

1. *Do the crack growth rates and RPV head wastage mechanisms identified in the Exponent report call into question the adequacy of the industry's operational monitoring and periodic inspection requirements?*

   Panel Response: No, the crack growth rates and RPV head wastage mechanisms identified in the Exponent report do not call into question the industry's monitoring and inspection requirements. Specifically,

   - The reported crack growth rates are near the upper end but within the industry data for PWSCC of Alloy 600 material as documented in MRP-55 [1], and the wastage mechanisms and rates are within the bounds defined by the EPRI Boric Acid Corrosion Guidebook[2] in 1995 and Revision 1 to the guidebook in 2001[3].

   - Industry operational and monitoring programs (NRC EA-03-009[4] and ASME Code Case N-729-1[5]) are capable of preventing the type of condition postulated in the Exponent report.

     - Non-destructive examinations are specified at intervals appropriate to the head temperature and service time to detect cracks in nozzle walls before they grow to leaks.

     - Bare metal visual examinations of the vessel heads are specified at intervals appropriate to the head temperature and service time to detect leaks at an early stage.

     - The combination of NDE and bare metal visual examinations provides protection against large volumes of wastage from occurring.

     - Boric acid corrosion programs meeting the requirements of NRC Generic Letter 88-05[6] have been implemented at all plants. These programs will provide adequate advance warning of leakage and wastage.

     - As a result of the Davis-Besse incident, the industry is far more sensitive to the risk of boric acid corrosion, further decreasing the likelihood of Davis-Besse conditions not being detected and acted on in a timely manner.

2. *Does the information in the Exponent report raise a (new) generic safety concern?*

Response: No, the information in the Exponent report does not raise a new generic safety concern. Specifically,

- The postulated crack growth rates are near the upper end but within the distribution considered for nozzle cracking.
- The postulated head wastage rates are consistent with the upper bounds of boric acid corrosion and subsequent wastage.
- The likelihood of the high stress intensity factors, high crack growth rates and maximum corrosion rates, described in the Exponent report occurring simultaneously is deemed small. Implementation of the inspection requirements contained in the NRC Order EA-03-009, and/or ASME Code Case N-729-1, implementation of an effective boric acid corrosion inspection program per NRC Generic Letter 88-05 and WCAP-15988[7], as well as timely reaction to plant indicators such as area radiation monitor filter clogging, RCS leakage detection, etc., are expected to preclude a gross reactor vessel head wastage event such as that which occurred at Davis-Besse.

Further supporting information to these conclusions are provided in the following section of this report.

- Section 2 provides technical support to the position that the industry periodic inspection programs are adequate to prevent the type of degradation observed at Davis-Besse given that the model and timeline proposed in the Exponent report

2. Technical Support to Position that Exponent Analysis does not Invalidate Industry RPV Head Inspection Programs

The purpose of this section is to provide technical support to the position that the Exponent report "Review and Analysis of the Davis-Besse March 2002 Reactor Pressure Vessel Head Wastage Event" dated December 15, 2006 does not call into question the adequacy of the industry's operational monitoring and periodic inspection requirements for reactor pressure vessel (RPV) top heads in pressurized water reactors (PWRs).

Summary of Exponent Proposed Leakage/Wastage Model

The Exponent proposed model is essentially the same as described in the root cause analysis submitted to the NRC on April 18, 2002 and August 27, 2002[8] with the following main exceptions:

- Leakage from Nozzle 3 occurred over a period of approximately one fuel cycle rather than the approximately 6-8 years in the original root cause report. The more rapid progression of the leak results from the crack growth rate in the Nozzle 3 material being found by test to be up to four times higher than the 75th percentile crack growth rate for Alloy 600 material as described in MRP-55.[1] The leak rate, and boric acid corrosion rate, increased suddenly about October/November 2001 when corrosion in the annulus from an axial crack in the CRDM nozzle uncovered a pre-existing crack through the J-groove weld and increased again when the wastage uncovered the back side of the J-weld..
- Other indications of boric acid leakage (boric acid on the vessel head, containment air cooler cleaning, radiation monitor fouling, etc.) up through 12RFO (2000) were the result of other leaks in containment, and not the result of the CRDM nozzle leaks which caused the large corrosion volume. For example, accumulation of boric acid on the vessel head is attributed to leaking CRDM flange gaskets.
- The sequence of events that occurred in late 2001 leading to the large volume of corrosion was "unexpected and unpredictable."

Does Information in the Exponent Report Represent a New Generic Safety Concern?

The panel tasked with evaluating the Exponent report has concluded that the report does not identify a new generic safety concern. Specifically,

1. Reported Crack Growth Rates
   Exponent states that the crack growth rates of the Davis-Besse CRDM nozzle material were up to four times the growth rate of the MRP recommended 75th percentile crack growth curve reported in MRP-55. While this statement is correct, Figure 2-1 from MRP-55 shows that some of the material specimens in the MRP-55 database had crack growth rates even higher than the Davis-Besse material. Therefore, the Davis-Bess material is considered to be within the bounds of previously evaluated materials.

2. Deterministic vs. Probabilistic Analyses
Industry models for crack growth and wastage are based on probabilistic methods rather than the deterministic analyses performed by Exponent. Probabilistic analysis models and analysis results are reported in MRP-110.[9] These analyses consider the full range of crack growth rates, leak rates and boric acid corrosion rates, including the higher growth rates. Therefore, this is not considered a new, unexpected, or unpredictable occurrence. Probabilistic models were used to establish inspection intervals.

3. Boric Acid Corrosion Rates
Data in the original EPRI Boric Acid Corrosion Guidebook[2] in 1995 showed peak corrosion/wastage rates of up to 10 inches/year for severe cases involving concentrated boric acid or impingement. Therefore, the more recent test data from Argonne, showing corrosion rates of up to 7 inches/year, does not represent a new, unexpected, or unpredictable occurrence. The lower 2-4 inches/year estimated in the Davis-Besse root cause evaluation report was considered a best estimate based on the sum total of available evidence in the spring of 2002.

In summary, industry programs have already addressed the range of conditions hypothesized in the Exponent report.

Current Inspection Requirements for Reactor Pressure Vessel (RPV) Top Heads
In February 2003, the NRC issued EA-03-009 (subsequently revised by Order EA-03-009, Rev 1, in Feb, 2004)[4] establishing interim inspection requirements for RPV heads at pressurized water reactor plants. The industry has subsequently developed alternate requirements for RPV head inspections that have been incorporated into the ASME Boiler and Pressure Vessel Code through Code Case N-729-1.[5] These documents require both nondestructive examinations (NDE) for cracks and bare metal visual examinations (BMV) of the vessel head surface at intervals that were established based on the plant head temperature and operating time, which have been demonstrated statistically to correlate with the occurrence of RPV top head nozzle cracking. The primary intent of the nondestructive examinations is to ensure an acceptably small probability of leaks occurring in the nozzles, while the intent of the bare metal visual examinations is to serve as a backup for the nondestructive examinations. There has also been a significant increase in plants' sensitivity to the potential damage that can result from leakage and far greater attention to changes in the plant unidentified leak rate.

The NRC order establishes three susceptibility categories (high, moderate and low) for RPV heads based on their operating time and temperature, characterized in terms of Effective Degradation Years (EDYs). EDYs correspond to the equivalent operating time of the head if it were to operate at a reference temperature of 600°F. Corrections from the actual head temperature to the reference temperature of 600°F are based on an Arrhenius-type relationship derived from laboratory data. A statistical correlation of RPV top head cracking to EDYs is documented in MRP-105[10]. Plants in the high susceptibility category (> 12 EDYs) must perform NDE and BMVs every refueling outage until they are replaced with heads fabricated with PWSCC-resistant materials. For plants in the moderate category ($12 \geq$ EDYs ≥ 8) BMV is required every outage and NDE every other outage. For plants in the low susceptibility category, BMVs are required every third refueling outage or 5 years, and NDE at least every 4 refueling outages or 7 years. Over time, assuming heads are not replaced, the plants gradually progress to higher categories, with more frequent inspections. As a result of inspection costs, and the need to plan for possible repairs, essentially all plants in the high susceptibility category and many in the moderate category, have replaced or scheduled replacement of their original RPV heads with new heads manufactured with PWSCC-resistant materials. For plants with replaced heads, the order requires an inspection regimen similar to that for low susceptibility plants.

The industry-proposed inspection program, recently issued as Code Case N-729-1[5], also uses a time-temperature Arrhenius correlation to establish Reinspection Years (RIYs). RIYs are similar to EDYs, but are calculated more conservatively, based on laboratory crack growth data correlations (rather than crack initiation). Except for the lowest susceptibility heads (see below), BMVs are required by the Code Case each refueling outage. NDE inspections are required by the Code Case every 2.25 RIYs or eight calendar years, whichever is less. For heads with less than 8 EDYs, the Code Case permits BMVs to be extended to every third refueling outage or five years, which is identical to the NRC order. The Code Case has been published by ASME, and is expected to be accepted by the NRC (with some conditions) in the near future.

In its evaluation of the adequacy of current inspection programs, the panel assumed that all RPV heads in domestic PWR plants will be examined in the future based on either the NRC Order or the ASME Code Case. As a result, the panel concludes that it is highly unlikely, given the above-described inspection regimes and associated head replacements, that a plant would experience the type of significant boric acid corrosion found at Davis-Besse in the future.

Evaluation of RPV Top Head Nozzle Examination Requirements Using Exponent Proposed Crack Growth Rates

As previously noted, the RPV top head safety evaluations, as documented in MRP-110[2], were based on probabilistic predictions of crack growth, using data which encompass the Davis-Besse crack growth rates referenced in the Exponent report.

As additional confirmation of the industry inspection program, deterministic evaluations were performed for specific plants using the crack growth curves proposed by Exponent for the 1/2T Davis-Besse specimens. These calculations were performed for the cases of a relatively high temperature head, an intermediate temperature head, and a low temperature head. The three head temperatures were chosen so as to conservatively bound the heads in each category that remain in service in the domestic PWR fleet. The resulting predictions were then compared to the NDE and BMV examinations required by NRC Order EA-03-009, Rev 1 and ASME Code Case 729-1. Since the current industry requirements are aimed primarily towards discovering cracks before they grow through-wall, the calculations are assumed to start at the approximate limit of NDE detectability rather than the point where an initial leak occurs. A curve for the stress intensity factor versus crack length and a curve for crack growth rate representative of the Davis-Besse Nozzle 3 material were taken directly from the Exponent report.

Table 2-1 below provides a summary of the three cases analyzed, and the associated inspection requirements for each case, based on the NRC Order and the Code Case.

Table 2-1
Description of Case Studies to Evaluate Industry Inspection Requirements

Case	High Temperature Head		Moderate Temperature Head		Low Temperature Head	
Head Temp. (°F)	592		580		561	
Current EFPYs	14.5		25.3		10.8	
Current EDYs	10.5		11.1		2.1	
RFO	Exams per Order	Exams per CC N-729-1	Exams per Order	Exams per CC N-729-1	Exams per Order	Exams per CC N-729-1
0*	BMV+NDE	BMV+NDE	BMV+NDE	BMV+NDE	BMV+NDE	BMV+NDE
1	BMV	BMV	BMV	BMV	None	None
2	BMV+NDE	BMV+NDE	BMV+NDE	BMV	None	None
3	BMV+NDE	BMV	BMV+NDE	BMV+NDE	BMV	BMV
4	BMV+NDE	BMV+NDE	BMV+NDE	BMV	BMV+NDE	None
5	BMV+NDE	BMV	BMV+NDE	BMV	None	BMV+NDE
6	BMV+NDE	BMV+NDE	BMV+NDE	BMV+NDE	None	None
7	BMV+NDE	BMV	BMV+NDE	BMV	BMV	None
8	BMV+NDE	BMV+NDE	BMV+NDE	BMV	BMV+NDE	BMV
9	BMV+NDE	BMV	BMV+NDE	BMV+NDE	None	None

* RFO 0 represents the time of the most recent NDE inspection at which it is conservatively assumed that a crack exists in the nozzle that is just smaller than the limit of NDE detection. This crack would be predicted to reach detectable size immediately after the plant begins operation following that inspection.

Deterministic predictions of crack growth for the three sample cases, using the crack growth rate curve for Davis-Besse Nozzle 3 referenced in the Exponent report are presented in Figures 2-2, 2-3 and 2-4. In each case, the crack growth rate equation was adjusted to the appropriate head operating temperature in accordance with the Arrhenius equation for crack growth (MRP-55 [1]). The figures also show the predicted crack growth in accordance with the MRP-55 75th percentile crack growth law for comparison purposes. Several significant crack sizes are shown as horizontal dashed lines on the figures, corresponding to the crack length at which detection by UT would be expected with high confidence (conservatively assumed = 0.25"), the crack length corresponding to the crack at the top of the weld, at which leakage is predicted, and a crack length of 1.2" above the weld, corresponding to the crack length that was discovered at Davis-Besse in 2002. Finally, vertical arrows are plotted on the figures corresponding to the NDE and BMV inspections that would be required at various refueling outages, per Table 2-1 above. Since inspections required per the NRC Order are somewhat more conservative than those required by Code Case N-729-1, only those required per the Code Case are shown on the figures. This produces the most conservative evaluation of the potential effect of the Exponent crack growth rate, since it corresponds to the least amount of inspection that would possibly be performed in the future. Also for conservatism, the initial baseline inspection was assumed to occur at a time when the postulated crack is just below the UT inspection threshold, and would thus be missed.

Figures 2-2 through 2-4 show that for each hypothetical case an NDE + BMV would be performed shortly after the postulated cracks are projected to reach the top of the welds, such that they would be well above the detection threshold of the ultrasonic NDE, and evidence of leakage would likely be detected by the BMV as well. These exams would be performed, and the cracking detected, well before the crack length approached the size predicted to have caused the severe wastage observed in the Davis-Besse head. These results, plus the conservative bounding nature of the deterministic evaluation, were a major factor in the panel's conclusion regarding adequacy of the current industry RPV top head examination program.

Conclusions

The main conclusions are that the Exponent report has not identified a new generic issue and that current industry inspection programs provide adequate protection against rapidly growing cracks and high rates of boric acid wastage as postulated in the Exponent report.

Figure 2-1
Davis-Besse Crack Growth Rates Relative to MRP-55 Data

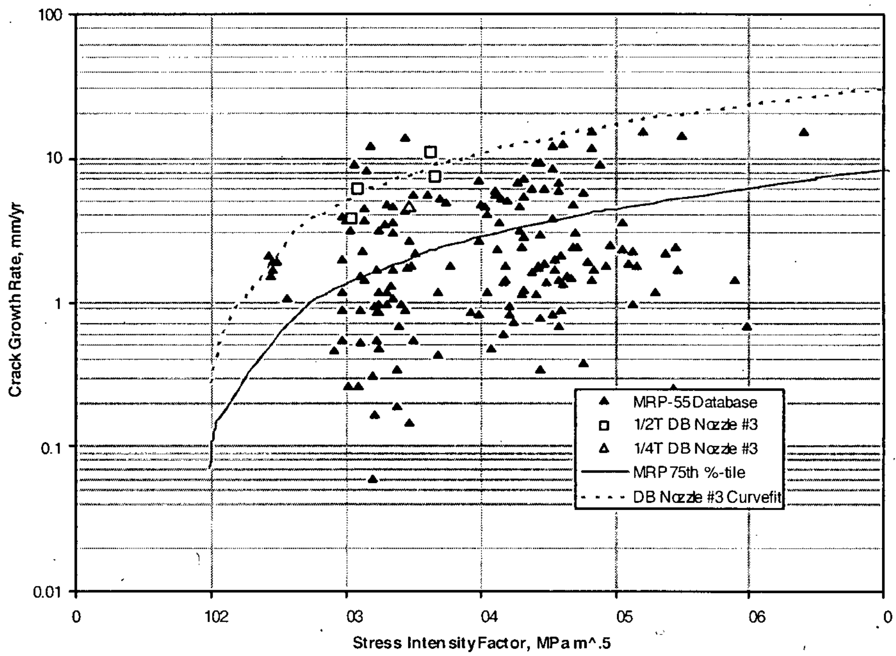


Figure 2-2
Projected Crack Growth and Industry Examination Requirements for a High Temperature Head under Crack Growth Rate Conditions Postulated in Exponent Report

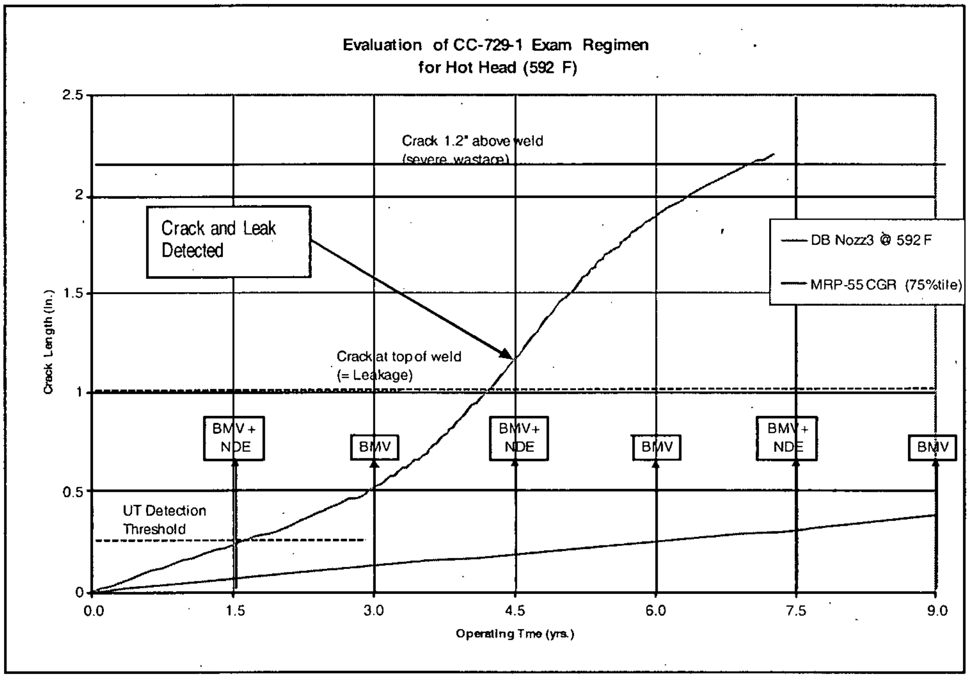


Figure 2-3
Projected Crack Growth and Industry Examination Requirements for a Moderate Temperature Head under Crack Growth Rate Conditions Postulated in Exponent Report

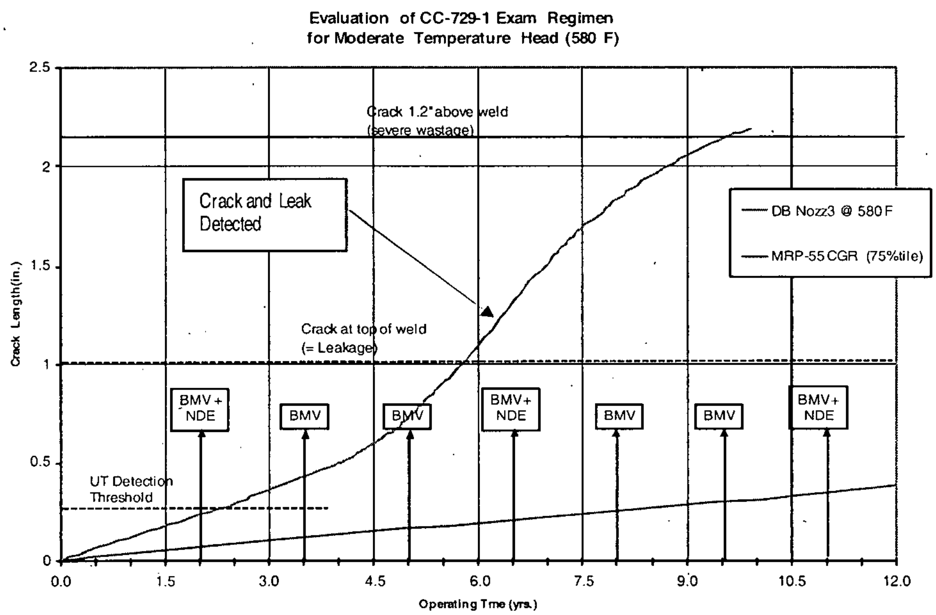
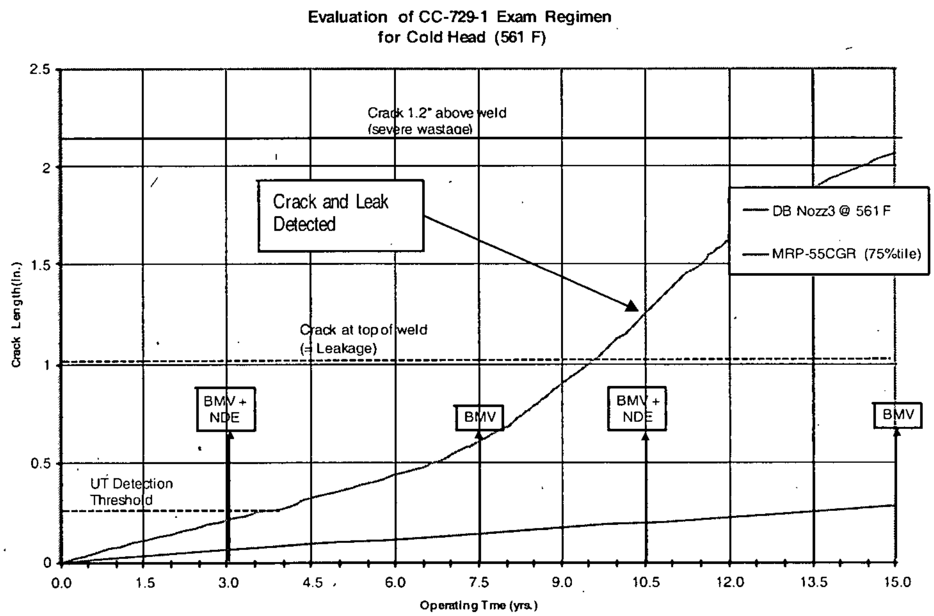


Figure 2-4
Projected Crack Growth and Industry Examination Requirements for a Low Temperature Head under Crack Growth Rate Conditions Postulated in Exponent Report



3. References

1. *Materials Reliability Program (MRP) Crack Growth Rates for Evaluating Primary Water Stress Corrosion Cracking (PWSCC) of Thick- Wall Alloy 600 Materials (MRP-55) Revision 1*, EPRI, Palo Alto, CA: 2002, 1006695.
2. *Boric Acid Corrosion Guidebook: Recommended Guidance for Addressing Boric Acid Corrosion and Leakage Reduction Issues*, EPRI, Palo Alto, CA: 1995, TR-102748.
3. *Boric Acid Corrosion Guidebook, Revision 1: Managing Boric Acid Corrosion Issues at PWR Stations*, EPRI, Palo Alto, CA: 2001, 1000975
4. *Issuance of First Revised NRC Order (EA-03-009) Establishing Interim Inspection Requirements for Reactor Pressure Vessel Heads at Pressurized Water Reactors, Feb. 20, 2004.*
5. *Code Case N-729, Rev. 1, Alternative Examination Requirements for PWR Closure Heads with Nozzles Having Pressure-Retaining Partial-Penetration Welds, Section XI, Division I.*
6. *Boric Acid Corrosion of Carbon Steel Reactor Pressure Boundary Components in PWR Plants*, NRC Generic Letter 88-05, 3/17/1988.
7. *Generic Guidance for an Effective Boric Acid Inspection Program for Pressurized Water Reactors*, Westinghouse, March 2003, WCAP-15988.
8. *Root Cause Analysis Report: Significant Degradation of the Reactor Vessel Head – Revision 1*, First Energy, Davis-Besse Nuclear Power Station, 8/27/2002, CR 2002-0891.
9. *Materials Reliability Program Reactor Vessel Closure Head Penetration Safety Assessment for U.S. PWR Plants (MRP-110): Evaluations Supporting the MRP Inspection Plan*, EPRI, Palo Alto, CA: 2004, 1009807.
10. *Materials Reliability Program Probabilistic Fracture Mechanics Analysis of PWR Reactor Pressure Vessel Top Head Nozzle Cracking (MRP-105), May, 2004*
11. J.F. Hall, *Boric Acid Corrosion of Low Alloy Steel, presented at EPRI Workshop on Primary Water Stress Corrosion Cracking of Alloy 600 in PWRs*, Charlotte, NC, October 9-11, 1991.

NEI

NUCLEAR ENERGY INSTITUTE

Marvin S. Fertel
SENIOR VICE PRESIDENT AND
CHIEF NUCLEAR OFFICER

May 9, 2007

Mr. Luis A. Reyes
Executive Director for Operations
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

Dear Mr. Reyes:

The FirstEnergy Nuclear Operating Company (FENOC) docketed a May 2, 2007, letter responding to four specific issues raised by the NRC staff regarding the Exponent Failure Analysis Associates' technical report, "Review and Analysis of the Davis-Besse March 2002 Reactor Pressure Vessel Head Wastage Event." In the May 2nd letter, FENOC noted that they provided the Exponent report to NEI with a request that an evaluation be conducted to determine if the report calls into question the adequacy of the industry's operational monitoring or inspection programs or otherwise raise a potential generic safety concern.

NEI commissioned an expert panel to conduct an evaluation of the report. The findings and conclusions were reviewed with the NEI Materials Executive Oversight Group (MEOG) responsible for oversight and coordination of the industry programs involving management of materials issues. The MEOG concurred with the expert panel's findings. NEI also briefed the industry Chief Nuclear Officers of the evaluation and its conclusions. NEI provided the following in response to FENOC's request:

1. Do the crack growth rates and reactor pressure vessel (RPV) head wastage mechanisms identified in the report call into question the adequacy of the industry's monitoring and inspection programs?

   Response: No. We believe the industry's materials monitoring programs are sound and will help maintain safe operation of nuclear power plants. The reported crack growth rates are within the industry data for primary water stress corrosion cracking of Alloy 600 materials documented in the EPRI Materials Reliability Program technical report, "Materials Reliability Program Crack Growth Rates for Evaluating Primary Water Stress Corrosion Cracking (PWSCC) of Thick-Wall Alloy 600 Materials (MRP-55)," Revision 1., TR 1006695. Further, the wastage mechanisms and rates are within the bounds described in the EPRI Boric Acid Corrosion Guidebook (TR – 102748).

The industry's operational monitoring and inspection programs as they relate to managing degradation of Alloy 600 nozzles located in the RPV head are capable of preventing the type of conditions postulated the Exponent report.

2. Does the information in the report raise a potential generic safety concern?

   Response: No. The expert panel reviewed the reported crack growth rates and RPV head wastage analyses and concluded there is no new potential generic safety concern. Plant safety is not jeopardized because the postulated crack growth rates are within the distribution considered for nozzle cracking and the wastage rates are consistent with upper bounds of boric acid corrosion. This coupled with the industry's operational monitoring and inspection programs will continue to assure plant safety.

I have enclosed for your information a copy of the expert panel's summary report containing further details supporting the responses summarized above. Please contact me directly or Jay K. Thayer at 202.739.8112, jkt@nei.org should you have any questions.

Sincerely,

Marvin S. Fertel

Enclosure

c: William F. Kane, Deputy Executive Director, NRC
James E. Dyer, Director, NRC
John A. Grobe, Associate Director, NRC
Public Document Room