March 09, 2012

MEMORANDUM TO: Mirela Gavrilas, Chief
Corrosion and Metallurgy Branch
Division of Engineering
Office of Nuclear Regulatory Research

FROM: C.E. (Gene) Carpenter, Jr., Sr. Materials Engineer ***/RA/***
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SUBJECT: SUMMARY OF PUBLIC MEETING WITH INDUSTRY REGARDING PWROG'S BORIC ACID CORROSION TEST PROGRAM

On Wednesday, February 29, 2012, the U.S. Nuclear Regulatory Commission (NRC) staff met with industry representatives to discuss the final results of the Pressurized Water Reactor Owners' Group (PWROG) research on boric acid corrosion (BAC). The meeting was held at the NRC's headquarters building, and included teleconferenced participants from both the Pacific Northwest National Laboratory (PNNL) and Électricité de France (EDF). Attendees, including those who participated by telephone, are listed in Attachment 1. Presentation materials are included in Attachments 2 – 5.

The industry had initiated research into BAC in 2004 following the discovery in 2002 of significant wastage to Davis Besse's reactor pressure vessel (RPV) top head due to primary coolant leakage around a control rod drive mechanism (CRDM). The purpose of this research was to improve understanding of the fundamental mechanisms that cause BAC, perform mockup testing under prototypical plant conditions to develop data to be used to address BAC, and to investigate the impact of BAC on bottom-mounted instrument (BMI) nozzles. The PWROG is using the BAC test data and recent operating experience to update the Boric Acid Corrosion Guidebook (MRP-58).

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The major conclusions from the BAC program were presented by William Sims, Entergy (see Attachment 2, "Boric Acid Corrosion Testing Program: Industry Perspectives," for additional details of this portion of the meeting). Test results have led the PWROG to conclude that:

1. current inspection intervals are adequate to detect possible corrosion before it becomes a safety issue;

2. current visual inspection methods are a reliable technique for detection of leakage, even at low flow rates; and,

3. a 0.01 gallon per minute (GPM) will result in 3 cubic inches ($in^3$) or less wastage, which the PWROG believes is not structurally significant.

It should be noted that the staff has not reviewed these results, and reserves judgment about their validity.

Rick Reid of EPRI then presented an overview of the BAC testing program (see Attachment 3, "Boric Acid Corrosion Testing Program Overview"), describing the four tasks that comprised the testing program. Task 1, heated crevice tests, was intended to quantify corrosion rates likely to occur in the early stages of a CRDM nozzle leak. The results, reported in the PWR Materials Reliability Program's (MRP) report "Reactor Vessel Head Boric Acid Corrosion Testing (MRP-163), Task 1: Stagnant and Flow Primary Water Tests" (publically available on the EPRI website), included the following conclusions:

- Rapid corrosion does not occur at the conditions evaluated under this task;

- Beginning of fuel cycle chemistry slightly more aggressive (~0.10 mm/yr (4 mpy) versus ~0.03 mm/yr (1 mpy));

- Corrosion rate under the test conditions is not sensitive to test temperature changes; and,

- Galvanic coupling of the low-alloy steel (LAS) to Alloy 600 does not result in significant increases to the corrosion rate for the conditions tested.

Task 2, jet impingement tests, investigated corrosion of low-alloy steel by primary water jet impingement. This task, described in MRP-164, Rev 1, "Reactor Vessel Head Boric Acid Corrosion Testing" (publically available on the EPRI website), had the following findings:

- Heat flux, water chemistry, flow rate, jet velocity and oxygen are important parameters affecting LAS corrosion;

- Damage due to jet impingement is minimal;

- Corrosion rates are markedly higher at higher coolant boron to lithium ratios (lower pH) and higher levels of dissolved oxygen; and,

- Corrosion rates due to jet impingement varied significantly – 0.002 to 0.2 $in^3$/yr.

Task 3, separate effects tests, investigated the separate effects of chemistry, temperature, and sample configuration on corrosion rates. This task, described in MRP-165 (publically available on the EPRI website), had the following findings:

- pH is the most significant parameter affecting corrosion rates – temperature, galvanic coupling, crevice geometry, and oxygen are secondary effects;
- Slurries of hydrated molten boric acid can corrode LAS at rates up to 5 in/yr;
- Dynamic concentration tests indicated that molten boric acid mixtures are unlikely to retain the moisture necessary for high corrosion rates; and,
- Lithium concentration could change corrosion rates by 10X or greater.

Task 4, full-scale mockup testing, performed full-scale CRDM BAC tests with prototypic geometries, materials, thermal-hydraulic conditions and primary coolant chemistries. The results were documented in MRP-266, "Full-Scale CRDM Mockup Boric Acid Corrosion Testing," which has not been made publically available. The staff requested that the PWROG provide this report to the staff for informational purposes.

Ryan Jones, Dominion Engineering, then discussed the implications of the BAC test program (see Attachment 4, "Implications Assessment of BAC Test Programs"). He discussed how the modeling addressed thermal-hydraulic analyses, thermal analyses, dry-out calculations, and wastage rate estimates. Computational fluid dynamics models were utilized to simulate the flow within the mockup annulus, and the MRP-110 safety assessment model indicates that Code-allowable stresses would not be exceeded given a leaking nozzle and periodic bare-metal visual examinations. He described how wastage volumes were determined from safety assessment models and compared to the mock-up testing, and the results were:

- wastage rates observed during the full-scale tests support the wastage rates used in the safety assessment model; and,
- wastage rates observed during the full-scale tests are representative, and are expected to be bounding and decrease with time as: (1) the annulus opens, (2) flow velocities decrease, and (3) there is reduced back pressure to promote moisture retention.

The effectiveness of visual inspections was evaluated utilizing a probability of detection (POD) curve that estimated the probability of visually detecting a given volume of boric acid deposits. The conclusions were that:

- Based on the full-scale mockup tests, both the volumetric wastage rate and effectiveness of visual examination to detect a leak support the modeling elements used in the technical analyses of the safety assessments; and,
- The current inspection requirements are conservative and adequate such that a leaking nozzle would be detected and addressed before resulting in structurally significant wastage.

Glenn White, Dominion Engineering, then discussed the revisions made to the BAC Guidebook based on this testing (see Attachment 5, “Boric Acid Corrosion: Revision to BAC Guidebook”). This second revision to the guidebook updates plant experience, and is expected to be issued in 2012. Originally issued in 1995 (EPRI TR-104748), the updated Guidebook will include BAC test summaries and conclusions regarding BAC mechanisms and corrosion rates based on operating experience and research since 2000; the understanding of effect of oxygen on BAC rate revised based on testing since 2003 (for low pH, the effect of oxygen is modest); and, updated summaries of industry guidance on related topics. The Guidebook is intended to provide utilities with practical information to support BAC control programs and provide guidance for assessments of whether components can be left in service with continuing leakage or degradation[1]. It also presents available data on BAC rates of other materials used in the reactor building and in the balance of plant that are potentially exposed to borated water (e.g., stainless steels, copper alloys).

The BAC guidebook is a key reference to WCAP-15988-NP, Rev. 1, “Generic Guidance for an Effective Boric Acid Inspection Program for Pressurized Water Reactors,” dated February 2005, which requires that each US PWR utility have a BAC Control Program (BACCP) that addresses 11 specific elements. Revision 2 to WCAP-15988 is being developed and is expected to be issued later in 2012. The staff requested that the PWROG provide the revised BAC Guidebook and WCAP-15988, Rev. 2, to the staff for informational purposes when they are issued.

The members of the public were then offered an opportunity to ask questions or make any statements, but none were forthcoming.

The staff thanked the meeting participants, and informed the PWROG representatives that if there were any additional questions arising from this meeting, the staff would request either follow-on information or another meeting. The meeting was then adjourned.

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[1] It should be noted that General Design Criteria 14, found in Appendix A of Title 10 to the *Code of Federal Regulations*, Part 50 (10 CFR Part 50, Appendix A, GDC 14) requires that “the reactor coolant pressure boundary shall be designed, fabricated, erected, and tested so as to have an extremely low probability of abnormal leakage, of rapidly propagating failure, and of gross rupture.” As such, the BAC Guidebook supports regulatory requirements.

The Guidebook is intended to provide utilities with practical information to support BAC control programs and provide guidance for assessments of whether components can be left in service with continuing leakage or degradation[2]. It also presents available data on BAC rates of other materials used in the reactor building and in the balance of plant that are potentially exposed to borated water (e.g., stainless steels, copper alloys).

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