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FINAL REPLY:

Mario V. Bonaca, ACRS

TO:

Chairman Diaz

FOR SIGNATURE OF : ** GRN ** CRC NO: 03-0332

Travers, EDO

DESC:

Vessel Head Penetration Cracking and Reactor Pressure Vessel Degradation

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UNITED STATES
NUCLEAR REGULATORY COMMISSION
ADVISORY COMMITTEE ON REACTOR SAFEGUARDS
WASHINGTON, D.C. 20555-0001

May 16, 2003

The Honorable Nils J. Diaz
Chairman
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

SUBJECT: VESSEL HEAD PENETRATION CRACKING AND REACTOR PRESSURE VESSEL DEGRADATION

Dear Chairman Diaz:

During the 502nd meeting of the Advisory Committee on Reactor Safeguards, May 8-9, 2003, we met with representatives of the NRC staff regarding pressurized water reactor (PWR) vessel head penetration (VHP) cracking and reactor pressure vessel degradation. This matter was discussed with members of the EPRI Materials Reliability Program (MRP) at the 500th ACRS meeting, March 6-8, 2003, and with the MRP and NRC staff during a joint Materials and Metallurgy and Plant Operations Subcommittee meeting, April 22-23, 2003. During our reviews we had the benefit of the documents referenced.

This topic was addressed in our previous reports dated July 23, 2001, and June 20, 2002. This report expands on technical concerns raised in these previous reports.

CONCLUSIONS AND RECOMMENDATIONS

(1) The action plans, developed to address the recommendations of the Lessons Learned Task Force (LLTF), define the work needed to provide a sound technical basis for assessing industry's development of a proactive life management methodology for materials degradation in PWR vessel head penetrations.

(2) The LLTF action plans need to be augmented in some areas:

- (a) Cracking prediction algorithms that address pressure vessel penetrations other than those in the vessel head
- (b) Flaw Evaluation Guidelines for vessel head penetrations
- (c) Qualification criteria for vessel head penetration inspection techniques
- (d) Other degradation modes for high-chromium nickel-base alloys

(3) Although we support cooperation with other organizations in collecting the required data, the staff must analyze the data independently.

DISCUSSION

The NRC issued a series of Bulletins (2001-01, 2002-01, 2002-02) and finally an Order (EA-03-009) in February 2003 to deal with the various materials degradation phenomena that have been observed in PWR VHPs. The Order mandated interim inspection requirements (technique, location, and frequency) that would be operative until revised inspection requirements could be defined in 10 CFR 50.55a. These actions were based on engineering judgment informed by available data.

The EPRI MRP is developing a proactive life management methodology for the various degradation modes. The program involves: (a) identification of potential degradation modes, (b) development of inspection techniques, (c) specification of inspection intervals, and (d) a safety assessment. The NRC needs to develop the capability to evaluate this methodology. The LLTF action plans lay the groundwork for such a capability in the areas of stress corrosion cracking, boric acid corrosion, barrier integrity, and inspection.

There are several technical challenges that are not fully addressed in the current LLTF action plans.

The metric "Effective Degradation Years" used by the industry and NRC for prioritizing inspections of VHPs is based solely on operating temperature and time. As we have pointed out in previous reports, the prioritization algorithm is incomplete because it does not take into account stress and material parameters. However, this algorithm is adequate for prioritizing VHP inspections for the near future because the material and stress conditions in this particular configuration seem sufficiently similar.

Different prioritization algorithms will be needed for other penetrations (such as the pressure vessel bottom head or pressurizer) where markedly different residual stress profiles are expected. Given the potential cracking event in the bottom head at South Texas Project Unit 1, prioritization algorithms for these other penetrations should be developed now.

Management of boric acid corrosion of low-alloy steel in the VHP subassembly using the inspection schedule required by the Order should be adequate to detect the cracking which is the precursor to the boric acid corrosion. However, it remains a concern that corrosion rates on the order of one inch per year in the low-alloy steel at Davis-Besse were unpredicted. This lack of prediction capability could be of concern if the inspection methodology failed to detect a crack just before the crack penetrated to the annulus between the control rod drive mechanism (CRDM) tube and the pressure vessel. Thus, a specific objective of the LLTF action plans should be the development of a predictive capability for boric acid corrosion under the specific system conditions relevant to the VHP geometry and operating conditions. In order to efficiently resolve this issue, there should be adequate attention to the fundamental aspects of this degradation phenomenon.

The recently revised Flaw Evaluation Guidelines issued by the NRC for disposition of cracks in vessel head subassemblies are acceptable, but there are concerns regarding the details, which will need to be addressed. For instance, (a) there is no guidance about the residual

stress profile that is needed in the calculation of stress intensity, and (b) there is no justification given for the choice of the (75th percentile 50% confidence) curve fit of the crack propagation rate vs. stress intensity data for Alloy 600 as the crack disposition relationship (rather than the "95/50" curve used in the earlier guideline), and the impact this has on the uncertainty in predicted crack depths at the end of an inspection period.

The industry will be changing their materials of construction for vessel head penetration to more "stress corrosion resistant" alloys (Alloys 690,152, and 52). There is evidence, largely from abroad, that such resistance, originally seen in the laboratory, is experienced in plant operation. However, there are insufficient stress corrosion data to enable the NRC to analyze quantitatively the improvement in resistance to cracking in VHPs utilizing these new alloys. Until these data are available there should be no relaxation in the inspection requirements for new reactor vessel heads imposed by the current Order.

The use of the Flaw Evaluation Guidelines will require determination of the size of cracks in the VHP subassembly as a function of the crack location and orientation. It is not clear from the industry presentations at the subcommittee meeting that the various inspection techniques can provide adequate crack sizing capability (i.e., resolution, repeatability, probability of detection). The LLTF action plans objectives state that revised inspection guidelines will be developed following examination of VHP inspection results and evaluation of current methodologies for determining leakage probability, non-destructive testing, etc. This is a crucial area in the control of VHP head degradation.

The LLTF action plans do not include an assessment of other modes of degradation in the high-chromium nickel-base alloys such as Alloys 182 and 82, and the replacement Alloys 690, 152, and 52. For instance, the fracture toughness of these alloys can be lowered under specific conditions of temperature and exposure, and this known phenomenon might be of significance during cooling accident situations and in the definition of flaw acceptance criteria. Furthermore, the weld alloys, such as Alloy 52, have a known propensity to crack during welding fabrication. The NRC should be in a position to analyze these scenarios.

As in many of the nuclear-related fields, there has been an attrition over the past decade in the experimental and analytical capabilities needed to resolve the above challenges in a timely manner. Thus, it is appropriate that industry and NRC have cooperative programs to collect data. It is important to emphasize that the NRC must develop and retain its own independent analytical capability.

Dr. William J. Shack did not participate in the deliberations on this matter.

Additional comments by ACRS members Dana A. Powers and Thomas S. Kress are presented below.

Sincerely,

Mario V. Bonaca
Chairman

Additional Comments by ACRS Members Dana A. Powers and Thomas S. Kress

Our colleagues have noted in this report that the assurance of the integrity of pressure boundaries in nuclear power plants will rely on inspection methods for the foreseeable future. Current technologies for inspection of reactor pressure boundaries have very limited capabilities. Though we do not at all impugn the efforts by EPRI and commercial firms to optimize these technologies, the truth is that these methods are cumbersome to apply, have low probabilities of detecting flaws and cracks, do not provide adequate characterizations of the sizes and orientations of cracks and flaws, and do not provide indications of the rates of crack growth. There are great needs for innovations in technologies for more convenient inspection of pressure boundaries, higher probabilities of detection, better characterization of flaws and cracks and indications of crack growth. These needs for better technology extend beyond the nuclear community into many if not most industrial areas. The NRC should join with others to solicit and stimulate the Government and the private sector to innovate more useful methods for the inspection of metal structures.

References:

1. Letter dated April 11, 2003, from Richard Barrett, Office of Nuclear Reactor Regulation, NRC, to Alex Marion, Nuclear Energy Institute, Subject: Flaw Evaluation Guidelines.
2. U.S. Nuclear Regulatory Commission, Subject: Davis-Besse Reactor Vessel Head Degradation Lessons-Learned Task Force Report, September 30, 2002.
3. U.S. Nuclear Regulatory Commission Bulletin 2001-01, "Circumferential Cracking of Reactor Pressure Vessel Head Penetration Nozzles," August 3, 2001.
4. U.S. Nuclear Regulatory Commission Bulletin 2002-01, "Reactor Pressure Vessel Head Degradation and Reactor Coolant Pressure Boundary Integrity," March 18, 2002.
5. U.S. Nuclear Regulatory Commission Bulletin 2002-02, "Reactor Pressure Vessel Head and Vessel Head Penetration Nozzle Inspection Program," August 9, 2002.
6. U.S. Nuclear Regulatory Commission Order EA-03-009, "Issuance of Order Establishing Interim Inspection Requirements for Reactor Pressure Vessel Heads at Pressurized Water Reactors," February 11, 2003.