Nuclear Management Company, LLC
Point Beach Nuclear Plant
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NRC 2002-0082

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U.S. Nuclear Regulatory Commission
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Point Beach Nuclear Plant, Units 1 and 2
Dockets 50-266 and 50-301
License Nos. DPR-24 and DPR-27
NRC Bulletin 2002-02: Reactor Pressure Vessel Head And Vessel Head Penetration Nozzle Inspection Programs – 30-Day Response

On August 9, 2002, the Nuclear Regulatory Commission (NRC) transmitted Bulletin (BL) 2002-02, "Reactor Pressure Vessel Head and Vessel Head Penetration Nozzle Inspection Programs." The NRC required that specific information be provided within 30 days of the date of the Bulletin. NRC staff subsequently stated that the 30-day response was due September 12, 2002. In accordance with this requirement, Nuclear Management Company, LLC (NMC) is providing the attached 30-day response for Point Beach Nuclear Plant (PBNP), Units 1 and 2.

This letter contains new commitments that are discussed in the attachment.

I declare under penalty of perjury that the foregoing is true and accurate. Executed on September 12, 2002.

A. J. Cayia
Site Vice-President

cc Regional Administrator, USNRC, Region III
NRC Resident Inspector – PBNP
Project Manager, PBNP, USNRC, NRR

CAT/kmd
Attachment

A096

NRC 2002-0082
ATTACHMENT

NUCLEAR MANAGEMENT COMPANY, LLC
POINT BEACH NUCLEAR PLANT, UNITS 1 AND 2
DOCKETS 50-266, AND 50-301

30-DAY RESPONSE TO NRC BULLETIN 2002-02

On August 9, 2002, the Nuclear Regulatory Commission (NRC) transmitted Bulletin (BL) 2002-02, "Reactor Pressure Vessel Head and Vessel Head Penetration Nozzle Inspection Programs" (Ref 1). The NRC requested that specific information be provided within 30 days of the date of this Bulletin. NRC staff subsequently stated that the 30-day response was due September 12, 2002. Nuclear Management Company, LLC (NMC) is providing the following in response to this Bulletin with respect to Point Beach Nuclear Plant (PBNP), Units 1 and 2.

Requested Item 1.A

(1). Within 30 days of the date of this bulletin:

A. PWR addressees who plan to supplement their inspection programs with non-visual NDE methods are requested to provide a summary discussion of the supplemental inspections to be implemented. The summary discussion should include EDY, methods, scope, coverage, frequencies, qualification requirements, and acceptance criteria.

Response

The PBNP Unit 1 and 2 reactor pressure vessel (RPV) head and vessel head penetration (VHP) nozzle inspection program will combine both visual and non-visual methods during the next scheduled refueling outages. The next refueling outage for PBNP Unit 1 is scheduled for September 2002. The next refueling outage for PBNP Unit 2 is scheduled for September 2003.

The elements (effective degradation year (EDY), methods, scope, coverage, frequencies, qualification requirements, and acceptance criteria) of these supplemental examinations are described below.

1. Effective Degradation Year Discussion

Pressurized water reactors (PWRs) have been ranked for the potential of primary water stress corrosion cracking (PWSCC) at the RPV top head nozzle using a time-at-temperature model. This time-at-temperature calculation is normalized to a reference temperature of 600°F, with the result termed effective degradation years. The methodology is described in MRP-48, "PWR Materials Reliability Program Response to NRC Bulletin 2001-01" (Ref. 2).

The PBNP Unit 1 and 2 EDY values are listed in MRP-48 as 13.5 and 14.9, respectively. MRP-48 included effective full power year (EFPY) data only through February 2001. NMC has estimated that the EDY value will be 14.5 at the start of the next PBNP Unit 1 refueling outage. NMC has estimated that the EDY value will be 16.6 at the start of the next PBNP Unit 2 refueling outage. These estimates have been derived using equation 2.2 of MRP-48.

These EDY values place both Point Beach Units in the >12 EDY category of the "Example Supplemental Inspections" Table of BL 2002-02.

2. Supplemental Inspection Methods, Scope and Coverage

NMC will conduct supplemental inspections of the VHP nozzle base material and interference fit region above the J-groove weld at PBNP Unit 1 and 2 as described herein. Since a non-destructive examination (NDE) vendor has not been selected for the PBNP Unit 2 Fall 2003 outage, any changes to the specific details of the proposed examinations will be provided to the NRC no later than 3 months prior to the start of that outage.

A Ultrasonic Testing (UT) of the VHP Nozzle Base Material

PBNP Units 1 and 2 will be in the >12 EDY category of BL 2002-02 "Example Supplemental Inspections" Table at the start of the next refueling outage. As such, this testing will be performed during the next scheduled refueling outage for Unit 1 and Unit 2.

PBNP Units 1 and 2 have fifty (50) total VHPs each, including forty-nine (49) control rod mechanism housings and one head vent nozzle. Thirty-three (33) of the 49 control rod mechanism housings contain thermal sleeves and are to be examined using an ultrasonic blade probe. Sixteen (16) of the control rod mechanism housings and the head vent nozzle will be examined using rotating probe UT, because they do not contain thermal sleeves and have an open bore. The targeted examination scope will include the VHP tube material for a distance starting approximately one (1) inch above the weld down to the bottom end (to the maximum extent possible) of the respective penetration. Scanning will be performed in order to detect both axial and circumferential indications initiating from the ID or OD surface of the CRDM tube material. Since this UT exam will detect circumferential cracks in the tube material, the concern for penetration ejection from crack propagation in the tube material is effectively addressed.

Since a NDE vendor has not been selected for the PBNP Unit 2 Fall 2003 outage, the possibility for changes exists relative to detailed implementation of the UT examination of the VHP nozzle base material. However, method, scope, coverage, frequency, qualification requirements, and acceptance criteria are expected to remain the same.

B. UT "Leak Path" Examination of Interference Fit Region

A UT back reflection monitoring examination of the interference fit region above the J-groove weld will be performed. The purpose of this examination is to determine if a reactor coolant leak into the annulus region between the VHP tube and the RPV head has occurred and corroded the interference fit. This UT technique is referred to as a "leak path" examination. In all UT examinations of VHP nozzles with known leakage since March 2001, the contract vendor for PBNP Unit 1, Framatome, has been able to observe indication of a leak path through the interference fit. The targeted examination scope will include the VHP tube material for a distance starting approximately two (2) inches above the weld down to the weld. This UT leak path examination will further supplement the above-head 100% bare metal visual examination results, as well as, provide assurance that RPV head wastage has not occurred in the interference fit region as a result of a leak. These supplemental UT techniques provide assurance that a leak from the J-groove weld or VHP base material will not go undetected. Therefore, a complete UT examination for detection of axial and circumferential flaws combined with a leak path examination address the wastage concern resulting from leakage and the potential for a nozzle ejection resulting from a circumferential crack above the weld

NMC plans to perform the UT "leak path" examination during the next scheduled refueling outage for PBNP Units 1 and 2. Since a NDE vendor has not been selected for the next PBNP Unit 2 scheduled refueling outage, NMC will provide details of any changes to the planned examination to the NRC no later than 3 months prior to the start of that outage.

C. Potential UT Examination Limitations

NMC will examine as much of the selected examination region as possible, within the capabilities of the NDE equipment and any geometrical limitations. The extent of examination coverage is not known with certainty for this UT examination, since this is the first time that this NDE method and vendor has been utilized to perform UT inspection of 100% of the nozzles in a 2-loop Westinghouse RPV head. The examination volume may be limited due to interference with centering pads on the thermal sleeves and the maximum reach of the UT tool.

The upper end of the examination region may be slightly limited near the periphery of the head due to the UT blade tool stroke limitation. The UT tool has a maximum reach of approximately eleven (11) inches from the bottom of the nozzle. Near the center of the head, the UT blade tool stroke will be limited due to the presence of the centering pads on the OD of the thermal sleeve. The centering pads can limit blade probe travel, because the pads effectively close the gap at those locations. The pads at the center nozzle location are approximately 1.5 inches above the top of the J-groove weld. Since the pads for all the thermal sleeves are on the same plane, the distance between the pads and the top of the J-groove weld will increase as the distance to the center of the head increases. As a result coverage of the examination volume will improve closer to the periphery of the head. There are no expected interferences for scanning the open nozzles. Actual coverage can only be determined after scanning and imaging the nozzle. Actual coverage achieved for each nozzle will be documented and reported on the examination data sheets or NDE report.

D. Dye Penetrant (PT) Testing of J-Groove Weld Wetted Surface

PT examinations will be performed on the J-groove weld wetted surface as required to help resolve discrepancies between UT cracking indications and leakage indications. NMC will perform, for both PBNP Unit 1 and 2, a PT examination on J-groove weld wetted surface for all VHPs that have relevant visual indication of leakage that is suspected to originate from the RPV head penetration annulus and can not be confirmed as originating from the VHP nozzle base material by UT examination. A PT examination will also be performed on the RPV head penetration weld surface, at any location that a UT of the tube and leak path exam cannot be performed, and bare metal visual information is not available to confirm the absence of a leak.

E. 100% Bare Metal Visual Examination of VHP to RPV Junction at Top of RPV Head

NMC committed to perform a 100% bare metal visual inspection of the VHP to RPV junction at top of RPV head in response to NRC Bulletin 2001-01 and NRC Bulletin 2002-01 (Ref. 3 and 4). PBNP Unit 1 will perform a 100% bare metal visual examination of the VHP to RPV junction during the next scheduled refueling outage. PBNP Unit 2 recently completed a 100% bare metal visual examination of the VHP to RPV junction during the Spring 2002 refueling outage.

For future refueling outages, NMC will perform a supplemental visual examination, as identified in the MRP inspection plan, through access holes installed in the shroud and insulation. Plant specific top head gap analyses have been performed for a large number of plants, with nozzle initial interference fit ranging from 0.000 to 0.0034 inches (Ref. 5). These analyses have confirmed the presence of a physical leak path in essentially all nozzles under normal operating pressure and temperature conditions. MRP-48 reports that the interference fit ranges from 0.5 – 1.5 mils and 0.0 – 3.0 mils for PBNP Unit 1 and 2, respectively. Thus, a gap is expected to exist between each RPV head control rod mechanism housing and the RPV steel during operation to allow a leak to communicate with the top surface of the reactor vessel head. Therefore, a visual examination with no evidence of boric acid leakage addresses the concern that wastage has not occurred on the top of the head or in the nozzle annulus, since any leak is expected to provide visual evidence or boron on the head.

3. **Supplemental Inspection Frequency**

The additional supplemental examinations described above will each be performed during the next scheduled refueling outage for PBNP Units 1 and 2.

NMC has not determined an appropriate examination frequency for ultrasonic testing of the VHP nozzle base material and UT "leak path" examination of the interference fit region beyond the next refueling outage. It is expected that the recommended method of performing supplemental examinations, as well as the frequency, will change over the next operating cycle based upon inspection results at other nuclear plants. NMC will therefore work closely with the NRC, EPRI MRP, and ASME to establish an acceptable frequency for performance of these exams during subsequent outages.

The supplemental visual examinations of the VHP to RPV junction at top of RPV head will be performed each scheduled refueling outage.

4. **Supplemental Inspection Qualification Requirements**

Currently, a qualification program, similar to the ASME Section XI, mandatory Appendix VIII, "Performance Demonstration For Ultrasonic Examination Systems", does not exist for testing of the VHP nozzle base material and J-groove weld configuration. The NMC selected vendor for PBNP Unit 1, Framatome, has participated in a demonstration of the UT examination techniques to be used for detection of axial and circumferentially oriented flaws in the RPV head penetration tube material. These techniques and capabilities were demonstrated in blind testing as part of the EPRI MRP and have been open to the NRC for observation and review. The demonstration has shown the procedures being used will detect and characterize both axial and circumferential flaws.

The "leak path" UT technique is a recently developed, Framatome ANP proprietary technology that has no formal industry or ASME qualification program. The basis of the "leak path" UT qualification is from empirical data obtained from UT examination of approximately 270 VHP nozzle penetrations to date. In all previous UT examinations of VHPs since March 2001 with known bare metal visual leakage, and where the interference fit has been scanned, a UT "leak path" has been observed. Framatome ANP has presented the "leak path" UT technique to the NRC on three separate occasions.

The technical basis of the technique is described in a Framatome ANP proprietary document titled "Reactor Vessel Head Penetration Leak Path Qualification Report," dated February 6, 2002. Due to the proprietary nature of the document, Framatome ANP is willing to meet with NRC personnel for further discussions on the technique and experience to date and to support any review necessary.

Dye Penetrant examination personnel and procedures will be qualified in accordance with ASME Sections V and XI.

The bare metal visual examination personnel and procedures will be qualified in accordance with the employer's written practice, ASME Section XI, and supplemented by EPRI Report 1006296, Revision 1, "Visual Examination for Leakage of PWR Reactor Head Penetrations on Top of RPV Head". Visual examination results will include photographs of suspect areas as a minimum.

Personal utilized to perform these supplemental examinations will be certified in accordance with employers' written practices. NMC will review and approve all NDE personal certifications prior to examinations being performed.

5. <u>Supplemental Inspection Acceptance Criteria</u>

The acceptance criteria used for the ultrasonic inspections will be determined based on the length, location and depth of an identified indication.

It is anticipated that all flaws will be removed or evaluated. If a flaw is evaluated, the approach will be to size the flaw, apply the growth rate(s) identified in MRP-55 (Ref. 6) to the next inspection interval, and use the ASME B&PVC flaw tolerance methods consistent with those specified in IWB-3640 of Section XI.

The acceptance criteria for any dye penetrant inspections of the weld metal will be based on the original construction code. However, for PT inspections that are performed as a result of a positive indication of a leak, the acceptance criteria will be zero indications. The acceptance criteria for the bare metal visual inspections is no evidence of leakage coming from the RPV head penetration at the intersection of the bare metal head. Typical indications of RPV penetration leakage are identified in the March 2002 EPRI report (Ref. 7) and will be used as an aid for visual examiners.

Summary of RPV Head and CRDM Penetration Inspection Program

In the discussion section of Bulletin 2002-02, the NRC staff noted a number of concerns about the adequacy of current industry RPV head and VHP inspection programs that rely on visual examination as the primary inspection method. NMC has reviewed these concerns and has taken steps to supplement examination of the RPV head and VHP nozzles to demonstrate compliance with applicable regulations. Taken together, the supplemental examinations stated herein, and the information provided below relating to the six concerns cited in Bulletin 2002-02, provide reasonable assurance that unacceptable wastage and penetration ejection will not occur, and circumferential cracking in VHPs will not go undetected at PBNP Units 1 and 2. This conclusion is valid even if any unforeseen NDE limitations occur.

NMC is also evaluating long-term plans for RPV head replacement at PBNP Units 1 and 2. Once those plans and schedules are complete, NMC may re-evaluate our commitment with respects to inspection plans. NMC will notify the NRC if our plans result in any changes to the BL 2002-02 response.

Concern 1: Circumferential cracking of CRDM nozzles was identified by the presence of relatively small amounts of boric acid deposits. This finding increases the need for more effective visual and non-visual NDE inspection methods to detect the presence of degradation in CRDM nozzles before nozzle integrity is compromised.

Observation: A UT examination of all of RPV head penetration nozzles (subject to the limitations identified) will be performed during the next scheduled PBNP Unit 1 and 2 refueling outages. These UT exams will be able to detect the presence of circumferential cracks in the RPV head penetration tube material, effectively addressing this concern. Where limitations exist that prevent this examination, the following justification is provided.

Since the initial discovery of circumferential cracks above the J-groove weld in 2001, visual inspection techniques and approaches employed have been dramatically improved and a heightened sense of awareness exists for the range in size and appearance of visual indications that must be further investigated. Non-visual techniques similarly have and continue to evolve to more effectively examine the penetration tube and associated welds for evidence of cracks. Nothing in the recent events at Davis-Besse has altered the fundamental inspection capability requirements previously established as necessary to identify the presence of PWSCC and subsequent associated wastage. The effectiveness of inspection techniques continues to be evaluated and improved.

EPRI MRP has published detailed guidance for performing visual examinations of RPV heads (Ref. 7). A utility workshop was recently conducted to discuss this guidance and lessons learned from recent field experience (including Davis-Besse). RPV head bare metal visual inspections at PBNP Unit 1 and 2 are scheduled to be performed and documented in accordance with written procedures and acceptance criteria that comply with the guidance of the MRP Inspection Plan. Evaluations and corrective actions will be rigorous and thoroughly documented.

In order for outside diameter (OD) circumferential cracks above the J-groove weld to initiate and grow, a leak path must first be established to the CRDM annulus region from the inner wetted surface of the reactor vessel head (RVH). If primary water does not leak to the annulus, the environment does not exist to cause circumferential OD cracking. Axial cracks in the CRDM nozzles or cracks in J-groove welds must first initiate and grow through wall. Experience has shown that through wall axial cracks will result in observable leakage at the base of the penetration on the outer surface of the vessel, even with interference fits. Alloy 600 steam generator drain pipes at Shearon Harris (1988) and pressurizer instrument nozzles at Nogent 1 and Cattenom 2 (1989) were all roll expanded but still developed leaks during operation (Ref. 5). Plant specific top head gap analyses have been performed for a large number of plants, with nozzle initial interference fit ranging from 0 to 0.0034". These analyses have confirmed the presence of a physical leak path in essentially all nozzles under normal operating pressure and temperature conditions. (Ref. 5).

The probability of detecting small control rod drive mechanism (CRDM) leaks by visual inspections alone is high. "Visual inspections of the reactor coolant system pressure boundary have been proven to be an effective method for identifying leakage from primary water stress corrosion cracking (PWSCC) cracks in Alloy 600 base metal and Alloy 82/182 weld metal. Specifically, visual inspections have detected leaks in reactor pressure vessel (RPV) head CRDM nozzles, RPV head thermocouple nozzles, pressurizer heater sleeves, pressurizer instrument nozzles, hot leg instrument nozzles, steam generator drain lines, a RPV hot leg nozzle weld, a power operated relief valve (PORV) safe end and a pressurizer manway diaphragm plate." (Ref. 9). To date, no leaking (CRDM) nozzles have been discovered by non-visual NDE examinations except for the three nozzles at Davis-Besse where leakage would have been detected visually had there been good access for visual inspections and the head cleaned of pre-existing boric acid deposits from other sources (Ref. 5).

Finally, as described under Concern 3 below, detailed probabilistic fracture mechanics (PFM) analyses have been performed to demonstrate the effectiveness of visual inspections in protecting the CRDM nozzles against failure due to circumferential cracking. (Ref. 10). Even though the above discussion illustrates that visual inspections performed in accordance with MRP recommendations have a high probability of detecting through-wall leakage, a very low probability of detection was assumed in the PFM analyses. The PFM analyses assume only a 60% probability that leakage will be detected if a CRDM nozzle is leaking at the time a visual inspection is performed. Furthermore, if a nozzle has been inspected previously, and leakage was missed, subsequent visual inspections are assumed to have only a 12% probability of detecting the leak that was previously missed. Even with this conservative probability of detection assumptions, the PFM analyses show that visual inspection every outage reduces the probability of a nozzle ejection to an acceptable level for plants with 18 or more EDY. Visual inspections of plants with fewer than 18 EDY in accordance with the MRP inspection plan will maintain the probability of nozzle ejection for these plants more than an order of magnitude lower than that for the greater than 18 EDY plants.

In summary, the industry has responded to the need to detect small amounts of leakage by increased visual inspection sensitivity, increased inspection frequencies, and improved inspection capabilities. Small amounts of leakage can be detected visually and it has been shown that timely detection by visual examination will ensure the structural integrity of the RPV head penetrations with respect to circumferential cracking.

Concern 2: Cracking of 82/182-weld metal has been identified in CRDM nozzle J-groove welds for the first time and can precede cracking of the base metal. This finding raises concerns because examination of weld metal material is more difficult than base metal.

Observation: A UT "leak path" examination of the interference fit region above the J-groove weld and 100% bare metal visual examination of the VHP to RPV junction at top of the RPV head (subject to the limitations identified) will be performed during the next scheduled refueling outage for PBNP Units 1 and 2. These supplemental examinations will be able to detect the presence of a leak in the J-groove weld, effectively addressing the concern. Additionally, since a NDE vendor has not been selected for the next PBNP Unit 2 scheduled refueling outage, NMC will provide details of any changes to the planned examination to the NRC no later than 3 months prior to the start of that outage.

Cracks in the J-groove weld do not pose an increased risk regarding nozzle ejection as compared to penetration base metal cracks. Cracking that is completely within the weld metal, even if 360° around the nozzle, will not lead to ejection since the portion of the weld that remains attached to the outside surface of the nozzle will not be able to pass through the tight annular fit. J-groove weld cracks that initiate and grow through-wall will leak the same as cracks in the penetration base metal. Therefore, weld cracks pose a similar risk as cracks in the base material and are equally detectable by visual examination as well as the supplemental inspections identified above. Although higher crack growth rates have been observed in laboratory testing of weld metal, the industry model of time-to-leakage includes plants that have had weld metal cracking as well as base metal cracking. The visual examination frequencies from the MRP Inspection Plan have been conservatively established based on the risk informed analyses considering leakage due to both weld metal and base metal cracking.

Concern 3: Through-wall circumferential cracking from the outside diameter of the CRDM nozzle has been identified for the first time. This raises concerns about the potential for failure of CRDM nozzles and control rod ejection, causing a LOCA.

Observation: A UT examination of all of RPV head penetration nozzles (subject to the limitations identified) will be performed during the next scheduled PBNP Units 1 and 2 refueling outages. These UT exams will be able to detect the presence of circumferential cracks in the RPV head penetration tube material, effectively addressing this concern. Where limitations exist that prevent this examination or for future refueling outages that involve only a bare metal visual examination the following justification is provided.

Probabilistic fracture mechanics (PFM) analyses using a Monte-Carlo simulation algorithm were performed to estimate the probability of nozzle failure and control rod ejection due to through wall circumferential cracking (Ref. 10). The PFM analyses conservatively assume that, once a leak path has extended to the annulus region, an OD circumferential crack develops instantaneously, with a length encompassing 30° of the nozzle circumference. Fracture mechanics crack growth calculations are then performed for this initially assumed crack, using material crack growth rate data from EPRI Report MRP-55 (Ref. 6). The parameters used in the PFM model were benchmarked against the most severe cracking found to date in the industry (B&W Plants) and produced results that are in agreement with experience to date. The analyses were used to determine probability of nozzle failure versus EFPY for various head operating temperatures. Analyses were then performed to estimate the effect of visual and non-visual (NDE) inspections of the plants in the most critical inspection category, using the conservative assumption discussed above (see Concern #1 response) for probability of leakage detection by visual inspection. These analyses demonstrate that performing visual inspections significantly reduces the probability of nozzle ejection, and that performing such examinations on a regular basis (in accordance with the inspection schedule prescribed in the MRP Inspection Plan) effectively maintains the probability of nozzle ejection at an acceptably low level indefinitely.

In the extremely unlikely event that nozzle failure and rod ejection were to occur due to an undetected circumferential crack, an acceptable margin of safety to the public would still be maintained (Ref. 11). The consequences of such an event are similar to that of a small-break LOCA, which is a design-basis event. The probability of core damage given a nozzle failure (assuming that failure leads to ejection of the nozzle from the head) has been estimated to be 1×10^{-3}. The PFM analyses demonstrate that periodic visual inspections are capable of maintaining the probability of nozzle failure due to circumferential cracking well below 1×10^{-3}. Therefore, the PFM analyses demonstrate that the resulting incremental change in core damage frequency due to CRDM nozzle cracking can be maintained at less than 1×10^{-6} (i.e., 1×10^{-3} times 1×10^{-3} equals 1×10^{-6}) per plant year, through a program of periodic visual examinations performed in accordance with the MRP inspection plan. This result is consistent with NRC Regulatory Guide 1.174 that defines an acceptable change in core damage frequency (1×10^{-6} per plant year) for changes in plant design parameters, technical specifications, etc.

Not withstanding this work performed by EPRI MRP Alloy 600 Task Group, NMC recognizes the seriousness of the potential for through-wall cracking from the outside diameter of the CRDM nozzle and has therefore elected to conduct 100% UT examination of all of CRDM nozzles during the next scheduled PBNP Units 1 and 2 refueling outages. These UT exams will detect through-wall circumferential cracking from the outside diameter of the CRDM.

Concern 4: The environment in the CRDM housing/RPV head annulus will likely be more aggressive after any through-wall leakage because potentially highly concentrated borated primary water may become oxygenated. This raises concerns about the technical basis for current crack growth rate models.

Observation: The MRP panel of international experts on SCC (including representatives from ANL/NRC Research), prior to the Davis-Besse incident, gave extensive consideration to the likely environment in the annulus between a leaking CRDM nozzle and the RPV head and revisited this issue subsequently (Ref. 6). When revisited, the relevant arguments remain valid for leak rates that are less than 1 liter/h or 0.004 gpm, which plant experience has shown to be the usual case. The conclusions were

1. An oxygenated crevice environment is highly unlikely because:
    - Back diffusion of oxygen is too low compared to counterflow of escaping steam (two independent assessments based on molecular diffusion models were examined).
    - Oxygen consumption by the metal walls would further reduce its concentration.
    - Presence of hydrogen from leaking water and diffusion through the upper head results in a reducing environment.
    - Even if the concentration of hydrogen was depleted by local boiling, coupling between low alloy steel and Alloy 600 would keep the electrochemical potential low.
    - Corrosion potential will be close to the Ni/NiO equilibrium, resulting in PWSCC susceptibility similar to normal primary water.

2. The most likely crevice environments are either hydrogenated steam or PWR primary water within normal specifications and both would result in similar, i.e. non-accelerated, susceptibility of the Alloy 600 penetration material to PWSCC.

3. If the boiling interface happens to be close to the topside of the J-weld, itself a low probability occurrence, concentration of PWR primary water solutes, lithium hydroxide and boric acid, can in principle occur. Of most concern here would be the accelerating effect of elevated pH on SCC, but calculations and experiments show that any changes are expected to be small, in part because of the buffering effects of precipitates. A factor of 2x on the crack growth rate (CGR) conservatively covers possible acceleration of PWSCC, even up to a high-temperature pH of around 9.

For larger leakage rates, which could lead to local cooling of the head, concentration of boric acid, and development of a sizeable wastage cavity adjacent to the penetration, the above arguments no longer directly apply. However, limited data (Berge et al., 1997) on SCC in concentrated boric acid solutions indicate that

- Alloy 600 is very resistant to transgranular SCC (material design basis).
- High levels of oxygen <u>and</u> chloride are necessary for intergranular cracking to occur at all.
- The effects are then worse at intermediate temperatures, suggesting that the mechanism is different from PWSCC.

The above considerations show that there is no basis for assuming that any post-leakage, crevice environment in the CRDM housing/RPV head annulus would be significantly more aggressive with regard to SCC of the Alloy 600 penetration material than normal PWR primary water, irrespective of the assumed leakage rate and/or annulus geometry. The current industry model (Ref. 6), which includes a factor of 2x on CGR to cover residual uncertainty in the composition of the annulus environment, remains valid.

Concern 5: The presence of boron deposits or residue on the RPV head, due to leakage from mechanical joints, could mask pressure boundary leakage. This raises concerns that a through-wall crack may go undetected for years.

Observation: The experience at Davis-Besse has clearly demonstrated that effective visual inspection for leakage from CRDM nozzle and weld PWSCC requires unobstructed inspection access and that the head surface be free of pre-existing boric acid deposits. Accumulations of debris and boric acid deposits from other sources can interfere with a determination as to the presence or absence of boric acid deposits extruding from the tube-to-head annulus. Therefore, to effectively perform a visual examination of the RPV head outer surface for penetration leakage, such deposits and debris accumulations must be carefully inspected, removed, and the area re-inspected. Evaluation may show that it is necessary to perform a non-visual examination to establish the source of the leakage.

Accordingly, each bare metal visual inspection at PBNP Unit 1 and 2 will be conducted with a questioning attitude and any boric acid deposit on the vessel head will be evaluated to determine its source in accordance with existing industry guidance, supplemented by the most recent industry experience at the time of the inspection. These requirements are incorporated in the visual inspection guidance contained in the MRP Inspection Plan. Implementation of these requirements will preclude the cited condition of a through-wall crack remaining undetected for years.

Concern 6: The causative conditions surrounding the degradation of the RPV head at Davis-Besse have not been definitively determined. The staff is unaware of any data applicable to the geometries of interest that support accurate predictions of corrosion mechanisms and rates.

Observation: The causes of the Davis-Besse degradation are sufficiently well known to avoid significant wastage. The root cause evaluation performed by the utility (Ref. 12) clearly identifies the root cause as PWSCC of CRDM nozzles followed by boric acid corrosion. The large extent of degradation has been attributed to failure of the utility to address evidence that had been accumulating over a five-year period of time (Figure 26 of Ref. 12).

The industry has provided utilities with guidance for vessel top head visual inspections to ensure that conditions approaching that, which existed at Davis-Besse, will not occur. Visual inspection guidelines have been provided (Ref. 7), and a workshop was conducted to thoroughly review industry experience, regulatory requirements, leakage detection, and analytical work performed to understand the causes of high wastage rates (Ref. 13).

Subsequent to significant wastage being discovered on the Davis-Besse RPV head, the industry has performed analytical work to determine how a small leak such as seen at several plants can progress to the significant amounts of wastage discovered at Davis-Besse. This work is referenced within the basis for the MRP Inspection Plan (Ref. 14) and was previously presented to the NRC (Ref. 15).

The analytical work shows that the corrosion rate is a strong function of the leakage rate. Finite element thermal analyses show that leak rates must reach approximately 0.1 gpm for there to be sufficient cooling of the RPV top head surface to support concentrated liquid boric acid that will produce high corrosion rates. The leak rate is in turn a strong function of the crack length. The effect of crack length above the J-groove weld on crack opening displacement and area has been confirmed by finite element modeling of nozzles including the effects of welding residual stresses and axial cracks. Leak rates have been calculated using crack opening displacements and areas determined by the finite element analyses and leak rate models based on PWSCC cracks in steam generator tubes.

Cracks that just reach the annulus through the base metal or weld metal will result in small leaks such as those that produced small volumes of boric acid deposits on several vessel heads at locations where the CRDM nozzles penetrate the RPV head outside surface. These leaks are typically on the order of 10^{-6} to 10^{-4} gpm. There is no report of any of these leaks resulting in significant corrosion. A leak rate of 10^{-3} gpm will result in the release of about 500 in^3 of boric acid deposits in an 18-month operating cycle, which will be detectable by visual inspections.

The time for a crack to grow from a length that will produce a leak rate of 10^{-3} gpm to a leak rate of 0.1 gpm has been estimated by deterministic analyses based on the MRP crack growth models to be 1.7 years for plants with 602°F head temperatures. Probabilistic analyses show that there is less than a 1×10^{-3} probability that corrosion will proceed to the point that the inside surface cladding of the head would be uncovered over a significant area before the wastage would be detected by supplemental visual inspections as required under the MRP Inspection Plan. During the transition from leak rates of 10^{-3} gpm to 0.1 gpm, loss of material will be by relatively slow processes (Ref. 14).

The ability to detect leakage prior to the risk of structural failure is illustrated by Figure 26 of the Davis-Besse root cause analysis report. There was visual evidence of boric acid deposits on the vessel head for five years prior to the degradation being detected. Guidance provided in the MRP Inspection Plan would not permit these conditions to exist without determining the source of the leak, including nondestructive examinations if necessary.

Therefore, while the exact timing of the event progression at Davis-Besse cannot be definitively established, the probable durations can be predicted with sufficient certainty to conclude that a visual inspection regimen can ensure continued structural integrity of the RCS pressure boundary.

Commitments

The following list identifies those actions committed to by NMC in this document regarding supplemental inspections of the current reactor vessel heads. Any other statements in this document are provided for information purposes and are not considered to be commitments.

1. NMC will conduct supplemental ultrasonic examinations of the VHP nozzle base material during the next scheduled refueling outage for PBNP Units 1 and 2, currently scheduled for September 2002 and September 2003, respectively.

2. NMC will conduct a supplemental ultrasonic leak path examination of the interference fit region of VHP nozzles during the next refueling outage for PBNP Unit 1 and 2, currently scheduled for September 2002 and September 2003, respectively.

3. NMC will perform a PT examination on the J-groove weld wetted surface of all VHPs for PBNP Units 1 and 2 during the next scheduled refueling outage for each unit under the following scenarios:

   - If relevant visual indication of leakage suspected to originate from the VHP annulus is observed and cannot be confirmed as originating from the VHP nozzle base material by UT examination; or
   - When UT of the tube and leak path exam cannot be performed and bare metal visual examination is not available to confirm the absence of a leak.

4. NMC will perform a supplemental visual examination of the VHP to RPV junction at the top of the current RPV heads by examining through access ports during each future refueling outage for PBNP Unit 1 and 2.

5. NMC will provide details to the NRC regarding any changes to the planned PBNP Unit 2 RPV head and VHP penetration inspection program no later than three months prior to start of the Fall 2003 refueling outage.

References

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3. NMC Letter dated January 3, 2002, "Revised Response to NRC Bulletin 2001-01, "Circumferential Cracking of Reactor Pressure Vessel Head Penetration Nozzles".
4. NMC Letter dated April 18, 2002, "Revised Response to NRC Bulletin 2002-01, "Reactor Pressure Vessel Head Degradation and Reactor Coolant Pressure Boundary Integrity"
5. Appendix B of EPRI Document MRP-75, Technical Report 1007337, "Probability of Detecting Leaks in RPV Top Head Nozzles," September 2002
6 EPRI Document MRP-55, "Crack Growth Rates for Evaluating Primary Water Stress Corrosion Cracking (PWSCC) of Thick-Wall Alloy 600 Material", July 2002.
7. EPRI Technical Report 1006899, "Visual Examination for Leakage of PWR Reactor Head Penetrations on Top of the RPV Head: Revision 1", 4/04/02
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9. EPRI TR-103696, "PWSCC of Alloy 600 Materials in PWR Primary System Penetrations", July 1994.
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11. Walton Jensen, NRC, Reactor Systems Branch, Division of Systems Safety and Analysis (DSSA), Sensitivity Study of PWR Reactor Vessel Breaks, memo to Gary Holahan, NRC, DSSA, May 10, 2002.
12. Davis-Besse Nuclear Power Station Report CR2002-0891, "Root Cause Analysis Report – Significant Degradation of the Reactor Pressure Vessel Head," April 2002.
13. Proceedings: EPRI Boric Acid Corrosion Workshop, July 25–26, 2002, Baltimore, Maryland, to be published by EPRI.
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15. Glenn White, Chuck Marks and Steve Hunt, Technical Assessment of Davis-Besse Degradation, Presentation to NRC Technical Staff, May 22, 2002.