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October 9, 2002

U. S. Nuclear Regulatory Commission
Washington, DC 20555

ATTENTION: Document Control Desk

SUBJECT: Calvert Cliffs Nuclear Power Plant
Unit Nos. 1 & 2; Docket Nos. 50-317 & 50-318
30-Day Response to NRC Bulletin 2002-02, "Reactor Pressure Vessel Head Penetration Nozzle Inspection Programs"

REFERENCES:
(a) NRC Bulletin 2002-02: Reactor Pressure Vessel Head Penetration Nozzle Inspection Programs, dated August 9, 2002

(b) Letter from Mr. P. E. Katz (CCNPP) to Document Control Desk (NRC), dated August 26, 2002, 15-Day Response to NRC Bulletin 2002-02, "Reactor Pressure Vessel Head Penetration Nozzle Inspection Programs"

The purpose of this letter is to forward Calvert Cliffs Nuclear Power Plant, Inc.'s (CCNPPs) 30-day response to Nuclear Regulatory Commission (NRC) Bulletin 2002-02 (Reference a). Attachment (1) provides the requested information. The Bulletin was issued to:

(1) Advise pressurized-water reactor (PWR) addressees that visual examinations, as a primary inspection method for the reactor pressure vessel (RPV) head and vessel head penetration (VHP) nozzles, may need to be supplemented with additional measures (e.g., volumetric and surface examinations) to demonstrate compliance with applicable regulations.

(2) Advise PWR addressees that inspection methods and frequencies to demonstrate compliance with applicable regulations should be demonstrated to be reliable and effective.

(3) Request information from all PWR addressees concerning their RPV head and VHP nozzle inspection programs to ensure compliance with applicable regulatory requirements.

(4) Require all PWR addressees to provide written responses to this bulletin related to their inspection program plans.

In the discussion section of Bulletin 2002-02, the NRC staff noted six specific concerns about the adequacy of the current industry RPV head and VHP nozzles inspection programs that rely solely on a visual examination as the primary inspection method. We have reviewed the NRC's position and have taken steps to supplement examination of the RPV head and VHP nozzles to address the NRC's concerns.

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Taken together, the supplemental examinations stated herein along with the information provided to address the six NRC concerns ensures continued safe unit operation.

In addition, CCNPP is evaluating long-term plans for RPV head replacement at Calvert Cliffs 1 and 2. As strategies are developed, CCNPP will notify the NRC if its plans result in any changes to the examination practices addressed in this bulletin response.

Please note that we submitted a required 15-day response (Reference b) to provide justification for extending the requested time period from 30 to 60 days. Should you have questions regarding this matter, we will be pleased to discuss them with you.

Very truly yours,

Peter E. Katz

STATE OF MARYLAND :
: **TO WIT:**
COUNTY OF CALVERT :

I, Peter E. Katz, being duly sworn, state that I am Vice President - Calvert Cliffs Nuclear Power Plant, Inc. (CCNPP), and that I am duly authorized to execute and file this response on behalf of CCNPP. To the best of my knowledge and belief, the statements contained in this document are true and correct. To the extent that these statements are not based on my personal knowledge, they are based upon information provided by other CCNPP employees and/or consultants. Such information has been reviewed in accordance with company practice and I believe it to be reliable.

Peter E. Katz

Subscribed and sworn before me, a Notary Public in and for the State of Maryland and County of Calvert, this 9 day of October, 2002.

WITNESS my Hand and Notarial Seal: Michelle D. Hall
Notary Public

My Commission Expires: February 1, 2006
Date

PEK/GT/bjd

Attachment: (1) 30-Day Response to NRC Bulletin 200-02

cc: J. Petro, Esquire
J. E. Silberg, Esquire
Director, Project Directorate I-1, NRC
D. M. Skay, NRC
H. J. Miller, NRC
Resident Inspector, NRC
R. I. McLean, DNR

ATTACHMENT (1)

30-DAY RESPONSE TO NRC BULLETIN 2002-02

Bulletin 2002-02 Requested Information (1)

Within 30 days of the date of this bulletin:*

A. *Pressurized-water reactor [PWR] addressees who plan to supplement their inspection programs with non-visual nondestructive examination [NDE] methods are requested to provide a summary discussion of the supplemental inspections to be implemented. The summary discussion should include effective degradation years [EDY], methods, scope, coverage, frequencies, qualification requirements, and acceptance criteria.*

CCNPP Response

Calvert Cliffs Nuclear Power Plant (CCNPP) Units 1 and 2 reactor pressure vessel (RPV) head and RPV head penetration nozzle inspections will combine both visual and non-visual methods at the next refueling outage.

The Electric Power Research Institute (EPRI) Material Reliability Program (MRP) Inspection Plan and supporting technical basis documents (Reference 2) have been developed by owners and operators of PWR units and have been transmitted to the Nuclear Regulatory Commission (NRC) (Reference 3). The MRP Inspection Plan presents a technically sound inspection regimen that assures to a high degree of certainty that leaks will be detected at an early stage long before wastage or circumferential cracking can challenge the structural integrity of the Reactor Coolant System (RCS) pressure boundary. Furthermore, implementation of the MRP Inspection Plan will assure continued compliance with the regulatory requirements cited within NRC Bulletin 2002-02, since the MRP Inspection Plan addresses the safety aspects of the six concerns identified in the Bulletin. Therefore, CCNPP will implement the MRP Inspection Plan and will comply with its requirements, at a minimum, beginning with the next planned refueling outage (RFO).

As requested in the subject bulletin, CCNPP will supplement the visual inspection with ultrasonic examination of the RPV head penetration base material during the next scheduled RFO for Calvert Cliffs Units 1 and 2. The next RFO for Calvert Cliffs Unit 1 is scheduled to begin in March, 2004 and the next RFO for Calvert Cliffs Unit 2 is scheduled to begin during February, 2003. Penetrant testing of the RPV head penetration nozzle weld will be used to assist in characterization of any leakage indication not confirmed in the nozzle material.

Calvert Cliffs Nuclear Power Plant is also evaluating its long-term plans for RPV head replacement at CCNPP Units 1 and 2. Once those plans and schedules are complete, CCNPP will re-evaluate its commitment with respect to inspection plans. Calvert Cliffs Nuclear Power Plant will notify the NRC if its plans result in any changes to the Bulletin 2002-02 response.

The elements (EDY, methods, scope, coverage, frequencies, qualification requirements, and acceptance criteria) of these inspections are provided below:

1. **Effective Degradation Years**

   Calvert Cliffs Nuclear Power Plant has calculated EDY values for Calvert Cliffs Units 1 and 2 for the next planned RFO according to the methodology described by Equation 2.2 of MRP-48 (PWR Materials Reliability Program Response to NRC Bulletin 2001-01).

* Calvert Cliffs Nuclear Power Plant submitted a required 15-day response that extended the response period from 30 to 60 days (Reference 1).

Calvert Cliffs Unit 1 will have approximately 16.3 EDY at the start of its next RFO in March 2004. Calvert Cliffs Unit 2 will have approximately 15.2 EDY at the start of its next RFO (which is a steam generator replacement outage) in February, 2003.

2. Supplemental Inspection Methods, Scope and Coverage

2.a Ultrasonic Testing of the RPV Head Penetration Base Material

An ultrasonic testing (UT) examination of all of the control element drive mechanism (CEDM), in-core instrument and head vent penetration tube locations will be performed at the next Calvert Cliffs Units 1 and 2 RFOs. The examination scope will include the material starting from approximately 2" above the nozzle to head weld down to the bottom end (to the maximum extent possible) of the respective penetration. The UT examination has been demonstrated to detect both axial and circumferential flaws initiating from the inside diameter or outside diameter (OD) surface of the tube material. Since this UT examination will detect circumferential cracks in the tube, the concern regarding penetration ejection from crack propagation in the tube material is effectively addressed.

2.b UT "Leak Path" Examination

A UT back reflection monitoring examination of the interference fit region above the weld will be performed to determine if a reactor coolant leak has occurred into the annulus causing corrosion in the interference fit region. This UT technique is referred to as a "leak path" examination. In all previous UT examinations of control rod drive mechanism (CRDMs) with known leakage performed by Framatome-ANP, Inc. (FRA-ANP), the CCNPP contracted vendor, a leak path has been observed with the UT scan that corresponded to the known leakage. The UT "leak path" examination provides additional confirmation of the visual results and also addresses the concern of potential wastage resulting from a leak. Therefore, a complete UT examination for detection of axial and circumferential flaws combined with a "leak path" examination addresses the wastage concern resulting from leakage and the potential for a nozzle ejection resulting from a circumferential crack above the weld.

2.c Bare Metal Visual Examination of RPV Head Penetration to RPV Head Surface

A 100% bare metal visual inspection, following insulation removal, as previously identified and described in the response to Bulletin 2001-01 (References 4 and 5) will be performed at the next Calvert Cliffs Unit 2 RFO.

Calvert Cliffs Nuclear Power Plant performed a 100% bare metal visual baseline inspection at Calvert Cliffs Unit 1 in March 2002, and will follow-up with a visual examination of the reactor head at the next RFO. The next Calvert Cliffs Unit 1 examination will be considered a supplemental visual examination on top of the closely conforming rigid insulation as identified in the MRP inspection plan (Reference 2). A bare metal visual examination will be performed at all locations with identified flaws or "leak path" indications from the UT examinations in 2.a and 2.b above, to determine if leakage or degradation has occurred.

The visual examination at both Calvert Cliffs Units is considered "qualified" at all RPV head penetration locations based on a plant-specific finite element analysis. The analysis shows that a gap would exist between each RPV head penetration 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 would provide visual evidence of boron on the head.

2.d Dye Penetrant Testing of the J-Groove Weld Wetted Surface

A dye penetrant (PT) examination will be performed on any RPV head penetration J-groove weld surface to disposition a location that has a relevant external visual indication of leakage that is suspected to originate from the RPV head penetration annulus and can not be confirmed as originating from the tube material by a UT examination.

2.e Potential Interferences

The planned scope of the bare metal visual and UT examinations at Calvert Cliffs is 100% of the RPV head penetrations. However, physical restrictions may exist for some portion of the Calvert Cliffs UT examinations. Specifically, the CEDM penetrations have guide/thermal sleeves with a funneled-end installed inside the CEDM penetration to position the CEDM shaft. There is also a counterbore step above the weld. This results in an annular gap of approximately 0.175" that reduces to 0.123" for inspection using a thin "gap scanning" UT probe. Each sleeve is centered by three expansion points or tabs made in the sleeve above the weld to contact the CEDM penetration. Examination near these expansions with the gap scanning probe may be limited and could affect examination in the area of interest. Actual coverage can only be determined after scanning and imaging the nozzle. Where significant limitations exist that preclude a reasonable determination of the integrity of a nozzle to be made, the limitations will be noted and reported as requested by Bulletin 2002-02 Request 2.A.

3. Supplemental Inspection Frequencies

The additional supplemental examinations described above will each be performed during the next scheduled RFOs for Calvert Cliffs Units 1 and 2.

Calvert Cliffs Nuclear Power Plant expects that the recommended method of performing supplemental exams, vendor specific inspection methods, as well as the inspection frequency may change over the next operating cycle based on the availability of additional inspection results. Calvert Cliffs Nuclear Power Plant will therefore work closely with the NRC, EPRI MRP, and American Society of Mechanical Engineers (ASME) to establish the frequency for performance of these exams during subsequent outages.

4. 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 CRDM nozzle base material and J-groove weld configuration. The CCNPP selected vendor, FRA-ANP, has participated in demonstrations of the UT examination procedures to be used for detection of axially and circumferentially oriented flaws in the RPV head penetration tube material. These procedures and capabilities were demonstrated in blind testing as part of the EPRI MRP, and have been made available to the NRC. The demonstrations have shown the procedures being used will detect both axial and circumferential flaws.

The "leak path" UT technique is a recently developed, FRA-ANP proprietary technology that has no formal industry or ASME qualification program. The basis of the "leak path" UT qualification is derived from empirical data obtained from UT examination of approximately 270 CRDM/CEDM nozzle penetrations to date. In March 2001, FRA-ANP began consistently scanning the nozzle interference fit region during UT examinations. In all subsequent UT examinations of CRDMs with known bare metal visual leakage, and where the interference fit has been scanned, a UT "leak path" has been observed. The "leak path" UT technique has been presented by FRA-ANP to the NRC on three separate occasions. The first meeting occurred on January 23, 2002 at the White Flint NRC offices as part of a pre-outage presentation for a utility specific examination application (ADAMS ML0202403310). The second disclosure of the "leak path" UT technique occurred on January 24, 2002 at the White Flint NRC offices as part of a pre-outage presentation for another utility specific application (ADAMS ML0203806880). Mr. William Bateman, Mr. Allen Hiser, and Mr. Tim Steingass of the NRC were in attendance for both meetings. Subsequent to those meetings the NRC requested another meeting at the FRA-ANP Lynchburg offices to review the "leak path" technique in more detail. That meeting took place on February 12, 2002, which included Mr. Tim Steingass, Mr. Wally Norris, and Dr. Steve Doctor of the NRC.

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

The visual examination personnel and procedures will be qualified in accordance with the vendor's written practice, ASME Section XI, and supplemented by the March 2002 EPRI report (Reference 6).

Dye penetrant examination personnel and procedures will be qualified in accordance with ASME Sections V and XI. Calvert Cliffs Nuclear Power Plant will review and approve all NDE personnel certifications and procedures prior to examinations being performed.

5. **Acceptance Criteria**

The acceptance criteria for the bare metal visual examinations 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 (Reference 6) and will be used as an aid for visual examiners. The acceptance criteria for a supplemental visual inspection at penetrations that have acceptable results from UT examinations identified in 2.a and 2.b above is a minimum detectable condition of any evidence of RCS leakage such as flow emanating from beneath the insulation, bulging insulation, or boric acid accumulation emerging upward through the joints and gaps between adjoining insulation panels from the RPV head surface (Reference 2).

The acceptance of ultrasonic inspections will be determined based on the length, location, and depth of an identified indication. Calvert Cliffs Nuclear Power Plant anticipates that flaws will be removed or evaluated. If the flaws are evaluated, the approach will be to size the flaw, apply the growth rate identified in MRP-55 (Reference 7) to the next inspection interval, and evaluate using ASME Section XI flaw tolerance methods and acceptance criteria as modified by the NRC recommendation letter of November 21, 2001 (Reference 8).

The acceptance criteria for any PT examination of the weld metal will be based on ASME code requirements. However, for PT examination that is performed as a result of positive indication of a leak, the acceptance criteria will be no relevant indications.

Justification for the Inspection Approach above:

In the discussion section of Bulletin 2002-02, the NRC staff noted six specific concerns about the adequacy of current industry RPV head and vessel head penetration nozzle inspection programs that rely solely on a visual examination as the primary inspection method. Calvert Cliffs Nuclear Power Plant has reviewed the NRCs position and has taken steps to supplement examination of the RPV head and VHP nozzles to address the NRC's concerns. Taken together, the supplemental examinations stated herein and the information provided below from the EPRI MRP-75 report (Reference 2) relating to the six NRC concerns ensures that unacceptable wastage or RPV head nozzle ejection will not occur at Calvert Cliffs Units 1 and 2 between refueling outages.

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.

CCNPP Response:

As stated in Section 2.a and 2.b above, a UT examination of all of the RPV head penetration nozzles (subject to the limitations identified) will be performed during the next scheduled Calvert Cliffs Units 1 and 2 RFOs. This UT examination has been demonstrated to detect the presence of circumferential cracks in the RPV head penetration tube material, effectively addressing this concern. Where physical limitations exist that prevent this examination the following justification is provided.

Since the initial industry 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. Recent events at Davis-Besse have not invalidated the fundamental inspection capability requirements previously established as necessary to identify the presence of primary water stress corrosion cracking (PWSCC) and subsequent associated wastage. The effectiveness of inspection techniques continues to be evaluated and improved.

Electric Power Research Institute MRP has published detailed guidance for performing visual examinations of RPV heads (Reference 6). A utility workshop (Reference 9) was recently conducted to discuss this guidance and lessons learned from recent field experience (including Davis-Besse). Reactor pressure vessel head bare metal visual examinations at Calvert Cliffs Units 1 and 2 will 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 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. 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 (Reference 2, Appendix B). Plant specific top head gap analyses have been performed for a large number of plants including Calvert Cliffs, with nozzle initial interference fits 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 (Reference 2, Appendix B).

The probability of detecting small 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 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 (Reference 10)." To date, no leaking (CRDM) nozzles have been discovered by non-visual NDE 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 (Reference 2, Appendix B).

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 (Reference 2, Appendix A). 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 these 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 Alloy 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 material.

CCNPP Response:

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 (Reference 2). 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 by 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 loss-of-coolant accident [LOCA].

CCNPP Response:

As stated in Section 2.a and 2.b above, a UT examination of all of the RPV head penetration nozzles (subject to the physical limitations identified) will be performed during the next scheduled Calvert Cliffs Units 1 and 2 RFOs. These UT exams have been demonstrated to detect the presence of circumferential cracks in the reactor vessel head penetration tube material, effectively addressing this concern. Where limitations exist that prevent this examination the following justification is provided.

Probabilistic fracture mechanics 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 (Reference 2, Appendix A). 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 (Reference 7). 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 effective full power year 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 (Reference 11). The consequences of such an event are similar to that of a small-break loss-of-coolant accident, 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 by the industry to be $1x10^{-3}$. The PFM analyses demonstrate that periodic visual inspections are capable of maintaining the probability of nozzle failure due to circumferential cracking well below $1x10^{-3}$. 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 $1x10^{-6}$ (i.e., $1x10^{-3}$ times $1x10^{-3}$ equals $1x10^{-6}$) 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 ($1x10^{-6}$ per plant year) for changes in plant design parameters, Technical Specifications, etc.

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.

CCNPP Response:

The MRP panel of international experts on stress corrosion cracking (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 (Reference 7). 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-groove 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 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 (Reference 7), which includes a factor of 2x on crack growth rate 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.

CCNPP Response:

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. This case has already been shown for Calvert Cliffs Unit 1 based on the completed Bulletin 2001-01 bare metal inspection results. 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.

As identified in the response to Bulletin 2002-01, the Calvert Cliffs Unit 1 and 2 CEDM and head vent penetration designs utilize a welded connection above the RPV head. The remaining RPV head instrument penetrations utilize a mechanical connection design, which is not prone to leakage. Therefore, boron deposits from these connections are unlikely.

Accordingly, each inspection at Calvert Cliffs 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.

CCNPP Response:

The causes of the Davis-Besse degradation are sufficiently well known to avoid significant wastage. The root cause evaluation performed by the utility (Reference 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 Reference 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 (Reference 6), 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 (Reference 9). Calvert Cliffs Nuclear Power Plant has been active in reviewing this guidance and CCNPP representatives attended the workshop.

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 (Reference 2, Appendix C) and was previously presented to the NRC (Reference 13).

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 cubic inches 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 (Reference 2, Appendix C).

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 (Reference 11). 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 NDEs 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.

Bulletin 2002-02 Requested Information (2)

Within 30 days after plant restart following the next inspection of the RPV head and VHP nozzles to identify the presence of any degradation, all PWR addressees are requested to provide:

A. *The inspection scope and results, including the location, size, extent, and nature of any degradation (e.g., cracking, leakage, and wastage) that was detected; details of the NDE used (i.e., method,* *number, type, and frequency of transducers or transducer packages, essential variables, equipment, procedure and personnel qualification requirements, including personnel pass/fail criteria); and criteria used to determine whether an indication, "shadow," or "backwall anomaly" is acceptable or rejectable.*

B. The corrective actions taken and the root cause determinations for any degradation found.

CCNPP Response to NRC Request 2.A and B

Calvert Cliffs Nuclear Power Plant will provide this response within 30 days after plant restart following the next inspection at Calvert Cliffs Units 1 and 2. This request is a duplicate of the request from Bulletin 2002-01. Accordingly, CCNPP will submit a response to the requests from Bulletin 2002-01 and 2002-02.

REFERENCES

1. Letter from Mr. P. E. Katz (CCNPP) to Document Control Desk (NRC), dated August 26, 2002, 15-Day Response to NRC Bulletin 2002-02, "Reactor Pressure Vessel Head Penetration Nozzle Inspection Programs"
2. "PWR Reactor Pressure Vessel (RPV) Upper Head Penetrations Inspection Plan (MRP-75)," Revision 1, EPRI, Palo Alto, CA: 2002, 1007337
3. Letter from Alex Marion (NEI) to Brian Sheron (NRC), dated September 10, 2002, "EPRI Technical Report 1007337, PWR Reactor Pressure Vessel (RPV) Upper Head Industry RVHP Inspection Program, (MRP-75), Project Number 689"
4. Letter from Mr. C. H. Cruse (CCNPP) to Document Control Desk (NRC), dated September 4, 2001, 30-Day Response to NRC Bulletin 2001-01, "Circumferential Cracking of Reactor Pressure Vessel Head Penetration Nozzles"
5. Letter from Mr. P. E. Katz (CCNPP) to Document Control Desk (NRC), dated June 27, 2002, 30 Days After Plant Restart Responses to NRC Bulletins 2001-01, 2002-01, and Supplement to the 15-day Response to Bulletin 2002-01
6. "Visual Examination for Leakage of PWR Reactor Head Penetrations on Top of RPV head: Revision 1 of 1006296, Includes Fall 2001 Results," Electric Power Research Institute (EPRI), Palo Alto, CA: March 2002, 1006899
7. EPRI Document MRP-55, "Crack Growth Rates for Evaluating Primary Water Stress Corrosion Cracking (PWSCC) of Thick-Wall Alloy 600 Material," July 2002
8. Letter from Jack Strosnider (NRC) to Alex Marion (NEI), dated November 21, 2001, "Flaw Evaluation Criteria"
9. EPRI Report 1007336, "Proceedings: EPRI Boric Acid Corrosion Workshop, July 25–26, 2002 (MRP-77)," September 2002
10. EPRI TR-103696, "PWSCC of Alloy 600 Materials in PWR Primary System Penetrations," July 1994
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. Glenn White, Chuck Marks and Steve Hunt, Technical Assessment of Davis-Besse Degradation, Presentation to NRC Technical Staff, May 22, 2002