VIRGINIA ELECTRIC AND POWER COMPANY
RICHMOND, VIRGINIA 23261

September 12, 2002

U.S. Nuclear Regulatory Commission
Attention: Document Control Desk
Washington, D.C. 20555

Serial No.	02-491
NL&OS/ETS	R1
Docket Nos.	50-338/339
	50-280/281
License Nos.	NPF-4/7
	DPR-32/37

Gentlemen:

VIRGINIA ELECTRIC AND POWER COMPANY
NORTH ANNA POWER STATION UNITS 1 AND 2
SURRY POWER STATION UNITS 1 AND 2
RESPONSE TO NRC BULLETIN 2002-02 REACTOR PRESSURE VESSEL HEAD AND VESSEL HEAD PENETRATION NOZZLE INSPECTION PROGRAMS

On August 9, 2002 the NRC issued NRC Bulletin 2002-02, "Reactor Pressure Vessel Head And Vessel Head Penetration Nozzle Inspection Programs," requesting information from all PWR addressees concerning their reactor pressure vessel (RPV) head and vessel head penetration (VHP) nozzle inspection programs to ensure compliance with applicable regulatory requirements.

In response to NRC Bulletin 2001-01, Virginia Electric and Power Company (Dominion) performed bare-metal visual examinations of RPV head and VHP nozzles on North Anna Units 1 and 2 and Surry Units 1 and 2. As a result of the visual indications, supplemental under-the-head volumetric and surface examinations were performed on visual indications identified as being a concern. Supplemental NDE of 32 of 65 penetration and/or J-groove welds was performed on the North Anna Unit 1 RPV head. A detailed metallurgical analysis of representative cracks removed from a weld associated with a leaking penetration was performed on the North Anna Unit 2 reactor vessel head. Surry Unit 1 performed supplemental NDE of 16 penetrations. These inspections were performed during scheduled refueling and mid-cycle outages in the Fall of 2001.

Dominion recognizes the potential safety significance of Primary Water Stress Corrosion Cracking (PWSCC) in the reactor vessel head penetration and the ensuing potential for corrosion of the head. We believe that a 100% bare-metal visual inspection of the reactor vessel head every refueling outage provides adequate, early indication of the onset of any PWSCC initiated leakage. Furthermore, we believe that a properly conducted visual inspection ensures that subsequent inspection and corrective actions will be taken to prevent the head wastage observed at Davis Besse and preclude any

A096

associated structural concern. A 100% visual inspection plan also balances the dual concerns of public safety, which is manifest in the uncertainties regarding reactor head leakage/wastage, and radiation worker safety, which is manifest in personnel exposure associated with the plant specific activities to complete the inspection and potential repair of the penetration tubes and J-groove welds. However, given the uncertainty associated with the predicted wastage rates and present absence of NRC acceptable alternatives, we are committing to perform a bare-metal visual and best effort non-visual inspection of the reactor vessel heads at North Anna Units 1 and 2 and Surry Units 1 and 2.

As a result of the compressed schedule to respond to the Bulletin and prepare for the Fall 2002 refueling outage, the proposed inspection plan has been necessarily designed to address North Anna Unit 2. Should additional industry information to justify an alternative scope become available, we intend to reconsider the proposed inspection plan for the other three units and submit a more ALARA balanced alternative.

The attachment to this letter provides the information requested in Bulletin 2002-02 including the immediate plans for inspection of the reactor vessel head and vessel head penetrations for North Anna Unit 2. Following the North Anna Unit 2 outage, this inspection plan will be reviewed to address the specific design and experience of North Anna Unit 1 and Surry Units 1 and 2. If you have any further questions or require additional information, please contact us.

Very truly yours,

Leslie N. Hartz
Vice President – Nuclear Engineering

Attachment

Commitments made in this letter:

1. Perform a bare-metal visual and "best effort" non-visual inspection of the reactor vessel head and vessel head penetrations for the North Anna and Surry units during the next scheduled refueling outage for each unit.

cc: U.S. Nuclear Regulatory Commission
Region II
Sam Nunn Atlanta Federal Center
61 Forsyth Street, SW
Suite 23 T85
Atlanta, Georgia 30303-8931

Mr. M. J. Morgan
NRC Senior Resident Inspector
North Anna Power Station

Mr. R. A. Musser
NRC Senior Resident Inspector
Surry Power Station

Mr. J. E. Reasor, Jr.
Old Dominion Electric Cooperative
Innsbrook Corporate Center
Suite 300
4201 Dominion Blvd.
Glen Allen, Virginia 23060

SN: 02-491
Docket Nos.: 50-280/281 and 50-338/339
Subject: Response to NRC Bulletin 2002-02
Reactor Pressure Vessel Head and
Vessel Head Penetration Nozzle Inspection Programs

COMMONWEALTH OF VIRGINIA)
)
COUNTY OF HENRICO)

The foregoing document was acknowledged before me, in and for the County and Commonwealth aforesaid, today by Leslie N. Hartz, who is Vice President - Nuclear Engineering, of Virginia Electric and Power Company. She has affirmed before me that she is duly authorized to execute and file the foregoing document in behalf of that Company, and that the statements in the document are true to the best of her knowledge and belief.

Acknowledged before me this 12TH day of September, 2002.

My Commission Expires: May 31, 2006.

Vicki L. Hull
Notary Public

(SEAL)

ATTACHMENT

Response to NRC Bulletin 2002-02 Reactor Pressure Vessel Head and Vessel Head Penetration Nozzle Inspection Programs

Virginia Electric and Power Company
(Dominion)
North Anna Power Station Units 1 and 2
Surry Power Station Units 1 and 2

Response to NRC Bulletin 2002-02 Reactor Pressure Vessel Head and Vessel Head Penetration Nozzle Inspection Programs North Anna and Surry Power Stations Units 1 and 2

NRC requested information

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.*

   B. *PWR addressees who do not plan to supplement their programs with non-visual NDE methods are requested to provide a justification for continued reliance on visual examinations as the primary method to detect degradation (i.e., cracking, leakage, or wastage). In your justification, include a discussion that addresses the reliability and effectiveness of the inspections to ensure that all regulatory and technical specification requirements are met during the operating cycle, and that addresses the six concerns identified in the Discussion Section of this bulletin. Also, include in your justification a discussion of your basis for concluding that unacceptable vessel head wastage will not occur between inspection cycles that rely on qualified visual inspections. You should provide all applicable data to support your understanding of the wastage phenomenon and wastage rates.*

Virginia Electric and Power Company (Dominion) Response

Background

In the fall of 2001, in response to NRC Bulletin 2001-01, bare-metal visual inspections were conducted on each of the North Anna and Surry units. Although the focus of the bare-metal visual inspections was the penetrations and the reactor vessel head in the immediate vicinity of each penetration, the surface area between each penetration and the area adjacent to the outer row of penetrations within the ventilation shroud was also observed by the inspectors. Degradation (i.e., wastage of the reactor vessel head base metal) was not observed on the reactor vessel heads, including the area around the penetrations that required repair or evaluation after boric acid residue/deposits were removed. Additionally, the re-inspection of three of the units' reactor vessel heads following cleaning to establish a baseline for future visual inspection activities confirmed that there was no pitting, thinning, or degradation indicative of wastage. Although loose debris was removed with low pressure air, Surry Unit 2 was not re-inspected because of its sufficiently clean as-found condition. The "as-left" condition of each head was documented on videotape. The results of these inspections are documented in our letters Serial No. 01-490C for Surry Units 1 and 2 and Serial Nos. 01-490A and 01-490E for North Anna Units 1 and 2, respectively.

Dominion first committed to perform a bare-metal visual inspection on top of each reactor vessel head at the Surry and North Anna plants in letter, Serial No. 01-490. Further, we committed to continue performing these bare-metal visual inspections at every refueling outage (RFO) until reactor vessel heads are replaced at Surry and North Anna (letter Serial No. 02-168). In addition to performing bare-metal visual inspections, Dominion committed to characterize leaking or suspected leaking penetrations with supplemental non-visual NDE (letter Serial No. 01-490).

In all cases of confirmed leaking penetrations at NAPS Unit 2 and SPS Unit 1, supplemental non-visual (eddy current, ultrasonic and liquid penetrant) examinations performed showed no evidence of ID initiated through wall cracking. Instead, all leaks originated from cracking of the Alloy 182 head buttering layer or J-groove weld. A failure analysis evaluation performed on representative cracks removed from a NAPS Unit 2 penetration J-groove weld indicated that the precursor to cracking was most likely fabrication related pre-existing hot cracking type defects. These fabrication defects may have served as stress concentrators that over time led to PWSCC of the filler metal and then leakage (Reference 13). Cracking of the J-groove weld or buttering will not directly lead to structural failure (rod ejection) because of the wedge formed by the remnant weld. Once cracking in the weld or butter provides a leak path to the annulus, the possibility exists for a circumferential crack to initiate on the penetration OD. However, it is considered unlikely that such an OD crack would grow significantly before boric acid crystals would be detected on top of the reactor vessel head. The possibility of head wastage if one of the J-groove welds was to develop a leak is likewise considered unlikely. Since the maximum width of a weld crack is constrained by the tube interference fit, the maximum leak rate from a weld crack is likely too low to lead to wastage. In support of this, no evidence of head wastage was identified at North Anna and Surry. A summary of the inspection results and corrective actions is provided below.

<u>North Anna</u>

North Anna Unit 1 was shutdown for refueling in September 2001. Visual examination of the reactor vessel penetrations was performed. Several penetrations obscured by boric acid and other debris were examined from under the head. No circumferential cracking or through-wall flaws were identified in the welds or in the tubes of any of the reactor vessel penetrations. However, indications were identified on nine penetrations. One non-service induced flaw (crater crack) and four indications in the butter layer of cladding at the J-groove weld were discovered on one penetration (Penetration 50). The non-service induced flaw was successfully excavated, and since the other four indications were non-recordable, they did not require repair. The indications (which were all on the penetrations' inside diameters) associated with the remaining eight penetrations (i.e., Penetration Nos. 3, 11, 31, 33, 52, 57, 60, 66) were evaluated by fracture mechanics, and it was determined that these indications would not compromise structural integrity. A commitment was made to perform periodic inspection of the indications associated with these eight penetrations during subsequent refueling outages, as required by ASME Section XI, to minimize the probability of a rapidly propagating fracture of the pressure boundary. In addition, voluntary supplemental NDE of 21 additional penetrations and/or J-groove welds was performed with no recordable indications. To facilitate future effective bare-metal visual examinations, existing deposits on the reactor vessel head were pressure washed and the "as-left" condition was documented on videotape.

North Anna Unit 2 was shutdown mid-cycle, in November 2001 to perform bare-metal visual inspections of the reactor vessel head penetrations. The three penetrations suspected of having leaks were examined from under the head. No circumferential cracking or through-wall flaws were identified in the tubes of any of these reactor vessel head penetrations. However, supplemental under the head examinations identified cracking in the area of the welds of the reactor vessel head penetrations. Also, indications on the inner diameter (ID) of the penetrations were identified on the same three penetrations. The ID indications associated with the three penetrations (i.e., Penetration Nos. 51, 62 and 63) were evaluated by fracture mechanics, and it was determined that these indications would not pose a structural integrity concern prior to scheduled head replacement. In addition, a detailed metallurgical analysis of representative cracks, removed from the weld in penetration 62, was performed and documented in WCAP-15777 (Reference 13). The cracking associated with the welds was repaired using an embedded flaw technique, which isolates the Primary Water Stress Corrosion Cracking (PWSCC) flaw from the primary water environment and reestablishes the RCS pressure boundary. To facilitate future effective bare-metal visual examinations, existing deposits on the reactor vessel head were pressure washed and the "as-left" condition was documented on videotape.

<u>Surry</u>

Surry Unit 1 was shutdown for refueling in October 2001. During the refueling outage a bare-metal visual inspection was performed. Based on the results of the bare-metal visual inspection, supplemental under-the-head non-visual NDE examinations were performed for sixteen (16) penetrations. Of these sixteen penetrations, weld defects were removed on four penetrations and six penetrations were repaired. The six penetrations were repaired using a Framatome repair technique, which included partial removal of the penetration tube and establishing a new pressure boundary weld. To enhance the effectiveness of future visual examinations, existing deposits on the reactor vessel head were pressure washed and the "as-left" condition was documented on videotape.

Surry Unit 2 was shutdown mid-cycle in November 2001 to perform a bare-metal visual inspection of the reactor vessel head penetrations. No indication of leakage was identified on any of the Surry Unit 2 reactor vessel head penetrations. Consequently, no additional under the head inspection or repair efforts were required for any of the reactor vessel head penetrations on Unit 2. The Unit 2 head was found sufficiently clean to perform the visual inspection. Any loose debris was easily removed with low-pressure air. No additional cleaning was required or performed. A subsequent bare-metal visual inspection of the reactor vessel head penetrations was performed during the March 2002 refueling outage. Again, no indication of leakage or head wastage was identified. At the conclusion of the inspection, the reactor vessel head was pressure-washed to remove loose debris to establish a baseline condition for future inspections.

Planned Inspection Activities and Information Requested In Accordance with 1.A

Dominion recognizes the importance of performing effective inspections of the reactor pressure vessel heads to identify and promptly repair pressure boundary leakage. Subsequent to the identification of the Davis-Besse head wastage and NRC Bulletin 2001-01, Virginia Electric and Power Company (Dominion) has worked closely with the EPRI's Materials Reliability Program (MRP) to develop a reliable inspection plan that can effectively identify RCS pressure boundary leakage on the reactor vessel head and prevent subsequent reactor vessel head base material degradation/wastage as experienced at Davis Besse.

Dominion has evaluated the current status of North Anna Power Station Units 1 & 2 and Surry Power Station Units 1 & 2 with regard to accrued Effective Full Power Years (EFPY) and Effective Degradation Years (EDY) calculated in accordance with MRP-48 (Equation 2.2) and the results are presented in the table below:

Unit	Prior RVH Exam	Next RFO RVH Exam	RFO No.	EFPY at Next RFO Exam (Years)	EDY at Next RFO Exam (Years)	Planned RVH Replacement
North Anna Unit 1	Sept. 2001	Mar. 2003	16	19.1	21.4	RFO #17
North Anna Unit 2	Nov 2001	Sept. 2002	15	18.2	19.8	RFO #16
Surry Unit 1	October 2001	Apr. 2003	18	21.6	20.5	RFO #19
Surry Unit 2	March 2002	Sept. 2003	18	21.9	20.9	RFO #19

Dominion's responses to Bulletin 2002-01 addressed the adequacy of visual inspection for compliance with the design and licensing basis of the plants. Those responses are still applicable. Additional technical justification for the adequacy of bare-metal visual inspections is provided in this response to Bulletin 2002-02.

The configuration of the North Anna penetrations and the thermal sleeves do not permit the complete inspection of the penetration tube at or above the J-groove weld due to the centering rings on the thermal sleeves. In order to perform complete inspection of the penetrations at North Anna, thermal sleeves would have to be cut out to permit access to the tubes. Both North Anna and Surry have established bare-metal visual inspection programs capable of detecting minor through-wall leakage or head wastage as documented in Dominion letters dated August 31, 2001, November 14, 2001, and January 23, 2002 (Serial Nos. 01-490, 01-490B and 01-490D). As noted above, the Surry and North Anna reactor heads were left in a condition that would permit an effective visual inspection and result comparison during the upcoming refueling outages.

The MRP Inspection Plan has been developed, reviewed, and approved by the PWR utilities (Refs 1 and 2). It presents a technically credible 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 RCS pressure boundary. Furthermore, implementation of the MRP Inspection Plan will assure continued compliance with the Regulatory Requirements cited within NRC Bulletin 2002-02. Bare-metal visual inspections will be performed on the North Anna and Surry reactor vessel head during the next scheduled refueling outages.

It is our experience that a bare-metal visual examination is capable of discovering very small amounts of leakage well before any penetration cracking or head wastage becomes a structural concern. However, given the uncertainty associated with the predicted wastage rate and present absence of NRC acceptable alternatives, Dominion intends to perform a "best effort" non-visual inspection of the reactor vessel heads. Specifically, we intend these "best effort" inspections to include the following NDE:

- For the nine North Anna Unit 2 control rod drive mechanism (CRDM) penetrations that currently do not have thermal sleeves installed, examinations will be performed from the inside diameter of the penetrations using an open housing UT/ET inspection tool. This should provide approximately 100% inspection coverage of the inside surface from about two inches above the J-groove weld to within about 1-inch of the bottom end of the penetration. In addition, the open probe scanner will allow ultrasonic inspection (UT) of the OD surface of the penetration from about two inches above the J-groove weld to about 1/2 inch above the approximate one inch of threads on the OD at the bottom end of the penetration.

- For the balance of the North Anna Unit 2 penetrations (i.e., 56 with thermal sleeves), a "best effort" ET inspection from the ID of the CRDM penetrations will be performed using blade probes. A supplemental examination with UT blade probes will be used to size any crack-like indications discovered by ET. Because of centering rings in the thermal sleeves, inspection coverage of the area of interest is limited using this technique depending on the location of the penetration on the vessel head. In addition, the thermal sleeves may be slightly off center in the penetration, which also limits access to the annulus area between the penetration tube and thermal sleeve. This off centering may also reduce the blade probe coverage on some penetrations. The most extensive inspection coverage is predicted to be from about one to as much as two inches above the top (root) of the J-groove weld for about nine penetrations at the center of the head. For approximately 24 of the most peripheral penetrations, inspection coverage of the J-groove weld could be limited from just above to about 1-1/2-inches above the top of the weld for about 140° of 360° of the penetration circumference. ID inspection coverage for the balance of the penetrations will range between these two extremes. These inspections will provide an assessment of the general condition of the inside surface of the penetrations.

  Some minor ID axial cracking of the North Anna Unit 2 penetrations was noted from previous inspection activities. Very conservative flaw growth calculations were performed for these indications. These calculations of remaining life established that there is not a concern relative to continued operation of the penetration or maintenance of Code allowable structural limits. Through-wall crack growth that would result in leakage is even more remote. As with the previous non-visual examinations of the penetration tubes, any flaws discovered will be evaluated relative to the potential for future flaw growth until the head is replaced, and repairs will be made as appropriate in accordance with procedures detailed in Relief Requests previously submitted to the Commission.

- Because previous inspections at North Anna 2 have conservatively identified leakage through flaws on the J-groove welds as opposed to the penetration base metal, Dominion also intends to perform non-visual NDE of the wetted surface of 61 of the 65 J-groove welds on the North Anna Unit 2 reactor vessel head. An eddy current inspection technique will be employed that was previously used in inspections at North Anna Unit 1 in the Fall of 2001 and subsequently at SONGS, Palo Verde, and D. C. Cook Units 1 and 2. This ET technique will be used for the detection of surface connected flaws and other anomalies on the J-groove weld and its associated butter layer. In addition, for penetrations with thermal sleeves, the OD surface of the penetration below the J-groove weld to within about ½-inch of the one-inch of threads at the bottom end of the penetration will be scanned. Four of the penetrations which are used for thermocouple instrumentation are of such a configuration that eddy current inspection is not possible. Because the only alternative inspection technique for these four penetrations is manual liquid penetrant inspection, which would result in high personnel radiation exposure (estimated to be a minimum of 1 man-rem per penetration) and because the inspection coverage of welds and OD surfaces is already about 94% of the penetrations, these four penetration J-groove welds will not be examined. ET acceptance criteria for the North Anna Unit 2 inspections will be similar to that used at prior weld inspections at North Anna Unit 1, SONGS, D. C. Cook Units 1 & 2, and Palo Verde. Specifically, any reportable ET indication over 9 mm (corresponding to 3 consecutive relevant ET "hits") will be subject to repair. Repairs will be accomplished with the embedded flaw repair technique previously utilized at North Anna 2 to repair three J-groove welds.

- For unacceptable bare-metal visual examination results on the North Anna Unit 2 reactor vessel head penetration, non-visual inspections of the penetration will be performed. The thermal sleeve will be removed from that penetration to allow access for the open tube UT/ET inspection tool. The UT/ET tool will enhance Dominion's ability to detect circumferential cracking on the outside surface of the penetration above the J-groove weld. It will also allow an assessment for potential head wastage at the head to penetration interface for any penetration showing evidence of leakage.

Based on field inspection data, industry sponsored research, and the discussion below, which addresses the 6 concerns raised in NRC Bulletin 2002-02, a 100% bare-metal visual inspection of the reactor vessel head every 18 to 24 months provides adequate assurance of continued structural integrity of the CRDM penetrations and the reactor vessel head relative to penetration cracking and head wastage. The Bulletin states and

Commission has stated in a public meeting of August 23, 2002, that the inspection plan proposed therein is not a dictate and that technically justifiable alternatives may be acceptable. Nevertheless, discussions with the NRC staff have indicated that no alternative inspection plan that does not include at least a "best effort" non-visual inspection program will be considered acceptable. Consequently, Dominion will adopt the inspection plan for the North Anna 2 reactor vessel head and penetrations outlined above. The plan provides additional assurance of the structural integrity of the vessel head and its penetrations for the additional 18 months of operation prior to its replacement.

Similar inspection plans will be employed at North Anna Unit 1 and Surry Units 1 and 2 during the next scheduled refueling outages. However, the inspection plans for these units are subject to change based on North Anna Unit 2 inspection results, information gained during the reactor vessel head inspections performed by the industry throughout the Fall of 2002, improvements in industry understanding of examination technology and crack growth rate, or NRC acceptance of the MRP inspection plan.

<u>NRC Concerns Cited in Bulletin 2002-02</u>

Concern 1:

Circumferential cracking of CRDM penetration 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 penetration nozzles before nozzle integrity is compromised.

Response:

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 reactor vessel heads (Reference 3). A utility workshop was recently conducted to discuss this guidance and lessons learned from recent field experience (including Davis-Besse). Reactor vessel head bare-metal visual inspections at North Anna and Surry are/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 outside diameter (OD) circumferential cracks above the J-groove weld to initiate and grow, a leak path must first be established to the CRDM penetration 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 penetration 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 4). Plant specific top head gap analyses have been performed for a large number of plants, 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 4).

The probability of detecting small CRDM penetration 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 head CRDM penetrations, RPV head thermocouple penetrations, pressurizer heater sleeves, pressurizer instrument nozzles, hot leg instrument nozzles, steam generator drain lines, a reactor vessel hot leg nozzle weld, a power operated relief valve (PORV) safe end and a pressurizer manway diaphragm plate" (Reference 5). To date, no leaking CRDM penetrations 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 (Reference 4).

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 penetrations against failure due to circumferential cracking (Reference 6). 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 penetration 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. Even with these conservative probabilities 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. That is, the change in core damage frequency utilizing the MRP inspection plan is less that 1 E-6. 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 reactor vessel head penetrations with respect to circumferential cracking.

Concern 2:

Cracking of 82/182 weld metal has been identified in CRDM penetration 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.

Response:

Cracks in the J-groove weld do not pose an increased risk regarding nozzle ejection as compared to penetration base metal cracks. 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. 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 penetration has been identified for the first time. This raises concerns about the potential for failure of CRDM penetrations and control rod ejection, causing a LOCA.

Response:

Probabilistic fracture mechanics (PFM) analyses using a Monte-Carlo simulation algorithm were performed to estimate the probability of penetration failure and control rod ejection due to through wall circumferential cracking (Reference 6). 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 penetration 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 the probability of penetration 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 penetration 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 penetration ejection at an acceptably low level indefinitely.

In the extremely unlikely event that penetration 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 8). 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 penetration failure (assuming that failure leads to ejection of the penetration 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 penetration 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 penetration 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.

Concern 4:

The environment in the CRDM housing/reactor vessel 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.

Response:

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 penetration and the reactor vessel 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 environments (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 (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 (Reference 14 - 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 and 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 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.

Response:

The experience at Davis-Besse has clearly demonstrated that effective visual inspection for leakage from CRDM penetration 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 reactor vessel 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 inspection at North Anna and Surry 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 reactor vessel 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.

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 9) clearly identifies the root cause as PWSCC of CRDM penetrations 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 9).

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 3), 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 10).

Subsequent to significant wastage being discovered on the Davis-Besse reactor vessel 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 11) and was previously presented to the NRC (Reference 12).

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 penetrations 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 penetrations penetrate the Davis Besse reactor vessel 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 (Reference 11).

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.

References

1. EPRI Letter MRP 2002-086, "Transmittal of "PWR Reactor Pressure Vessel (RPV) Upper Head Penetrations Inspection Plan, Revision 1, August 6, 2002", from Leslie Hartz, MRP Senior Representative Committee Chairman, August 15, 2002.

2. EPRI Document MRP-75, "PWR Reactor Pressure Vessel (RPV) Upper Head Penetrations Inspection Plan, Revision 1", September 2002

3. EPRI Technical Report 1006899, "Visual Examination for Leakage of PWR Reactor Head Penetrations on Top of the RPV Head: Revision 1", 4/04/02

4. Appendix B of EPRI Document MRP-75 "Probability of Detecting Leaks in RPV Top Head Nozzles," September 2002

5. EPRI TR-103696, "PWSCC of Alloy 600 Materials in PWR Primary System Penetrations", July 1994.

6. Appendix A of EPRI Document MRP-75 "Technical Basis for CRDM Top Head Penetration Inspection Plan," September 2002.

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. 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.

9. Davis-Besse Nuclear Power Station Report CR2002-0891, "Root Cause Analysis Report – Significant Degradation of the Reactor Pressure Vessel Head," April 2002.

10. EPRI Technical report 1007336, "Proceedings of the EPRI Boric Acid Corrosion Workshop, July 25–26, 2002, Baltimore, Maryland, September 2002.

11. Appendix C of EPRI Document MRP-75 "Supplemental Visual Inspection Intervals to Ensure RPV Closure Head Structural Integrity," September 2002.

12. Glenn White, Chuck Marks and Steve Hunt, Technical Assessment of Davis-Besse Degradation, Presentation to NRC Technical Staff, May 22, 2002.

13. Rao, Gutti V. and Bennetch, J., WCAP-15777, "Metallurgical Investigation of Cracking of the Alloy 82/182 J-Groove Weld of the Reactor Vessel Head Penetration Joint at North Anna Unit 2 Station," January 2002.

14. EDF Paper, "Chloride stress corrosion of Alloy 600 in boric acid solutions", P. Berge, D. Noel, J.-M. Gras and B. Prieux - Proceedings of the 8th International Symposium on the Environmental Degradation of Materials - Light Water Reactors, Amelia Island, Florida (August 1997), published by the American Nuclear Society pp. 189 - 199.