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SOUTHERN COMPANY
Energy to Serve Your World℠

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

Ladies and Gentlemen:

Response to NRC Bulletin 2002-02, "Reactor Pressure Vessel Head and Vessel Head Penetration Nozzle Inspection Programs" for Vogtle Electric Generating Plant, Units 1 and 2

Southern Nuclear Operating Company (SNC) has evaluated the expected status of Vogtle Electric Generating Plant (VEGP) Units 1 and 2 with regard to accrued Effective Full Power Years (EFPY) and Effective Degradation Years (EDY) calculated in accordance with EPRI Material Reliability Project (MRP)-48 (Equation 2.2). The results are presented in the following table referenced to the next scheduled outage for each unit:

Unit	As of Next RFO	EDY
1	9/14/03	2.66
2	10/06/02	2.23

The SNC 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 the inspections is provided in this response to Bulletin 2002-02.

SNC previously committed in a letter dated March 28, 2002, to perform a 100 percent bare metal visual inspection of Units 1 and 2. The inspection of Unit 1 was completed in March 2002 during the tenth refueling outage as reported in a letter dated May 15, 2002. The inspection of Unit 2 is scheduled for October 2002 during the ninth refueling outage as reported in letters dated March 28, 2002 and August 14, 2002.

The MRP Inspection Plan has been developed, reviewed, and approved by the PWR utilities (References 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.

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Therefore, SNC will implement the MRP Inspection Plan and will comply with its requirements beginning with the conduct of the next planned 100 percent bare metal visual inspection of Unit 2 in October 2002. The MRP Inspection Plan encompasses the inspection commitments SNC made in its responses to Bulletin 2001-01 and Bulletin 2002-01, but is more rigorous.

Accordingly, SNC offers the following responses as justification for continued reliance on visual examinations as the primary method to detect degradation in the reactor pressure vessel head. Included in these responses are discussions on the reliability and effectiveness of visual examinations as they relate to the six concerns cited in Bulletin 2002-02 and the basis for concluding that unacceptable wastage will not occur between refueling outages.

Mr. J. T. Gasser states he is Vice President of Southern Nuclear Operating Company and is authorized to execute this oath on behalf of Southern Nuclear Operating Company, and to the best of his knowledge and belief, the facts set forth in this letter are true.

Please contact this office if there are any questions.

Sincerely,

Jeffrey T. Gasser

Jeffrey T. Gasser

Sworn to and subscribed before me this 5th day of September, 2002.

Glenda C. Spinks

Notary Public

My commission expires: 11/10/02

JTG/BHW

Enclosure

cc: <u>Southern Nuclear Operating Company</u>
Mr. G. R. Frederick
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Mr. L. A. Reyes, Regional Administrator
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Enclosure

Response to NRC Bulletin 2002-02, "Reactor Pressure Vessel Head and Vessel Head Penetration Nozzle Inspection Programs" for
Vogtle Electric Generating Plant, Units 1 and 2

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.

Response 1:
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 primary water stress corrosion cracking (PWSCC) and subsequent associated wastage. The effectiveness of inspection techniques continues to be evaluated and improved.

The EPRI MRP has published detailed guidance for performing visual examinations of reactor pressure vessel (RPV) heads (Ref. 3). 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 Vogtle Electric Generating Plant (VEGP) Units 1 and 2 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 control rod drive mechanism (CRDM) annulus region from the inner wetted surface of the RPV 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 (Ref. 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 (Ref. 4).

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 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." (Ref. 5) 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 (Rev. 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 nozzles against failure due to circumferential cracking. (Ref. 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 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. Even with this conservative probability of detection assumptions, the PFM analyses show that visual inspections 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.

Response 2:
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 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.

Response 3:
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. 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 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. 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 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. 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 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.

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.

Response 4:
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 (Ref. 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:

(a) Back diffusion of oxygen is too low compared to counterflow of escaping steam (two independent assessments based on molecular diffusion models were examined).
(b) Oxygen consumption by the metal walls would further reduce its concentration.
(c) Presence of hydrogen from leaking water and diffusion through the upper head results in a reducing environment.
(d) 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.
(e) Corrosion potential will be close to the Ni/NiO equilibrium, resulting in primary water stress corrosion cracking (PWSCC) susceptibility similar to normal primary water.

2. The most likely crevice environment is 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; however, 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) should conservatively cover possible acceleration of PWSCC, even up to a high-temperature pH of around 9.

For larger leakage rates that 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:

(a) Alloy 600 is very resistant to transgranular SCC (material design basis).
(b) High levels of oxygen <u>and</u> chloride are necessary for intergranular cracking to occur at all.
(c) 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 a 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. 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 5:
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 inspection at VEGP Units 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.

During the visual inspection conducted on Unit 1 during March 2002, Level III certified VT-2 visual examination personnel viewed each of the examinations performed. The Level III personnel were cognizant of boric acid corrosion problems experienced at other utilities and reviewed examples of boric acid corrosion provided in EPRI Report 1006296, Revision 1, "Visual Examination for Leakage of PWR Reactor Head Penetrations," January 30, 2002. The persons performing the examination looked for boric acid residue in the area around the annulus between the penetration stalk and the penetration hole in the RPV closure head. Boric acid in this area could be indicative of a through-wall leak in the Inconel penetration stalk or attachment weld on the underside of the RPV closure head weld. Any boron accumulation on the RPV closure head that could result in corrosion of the head was recorded for evaluation.

The general condition of the RPV closure was very good, with some slight debris and/or foreign objects noted. There was no apparent evidence of boric acid residue from active leakage in the vicinity of any of the head penetrations at the interface between the RPV closure head and the penetration stalks. Several locations had small white spots on the penetration stalk above the penetration to RPV closure head interface, a condition that is not unusual for locations that have been vented or disassembled in the past. Following the examination, the RPV closure head was washed to remove the noted boric acid residue, debris, and/or foreign objects from the head.

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.

Response 6:
The causes of the Davis-Besse degradation are sufficiently well known to avoid significant wastage. The root cause evaluation performed by the utility (Ref. 9) 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. 9).

The industry has provided utilities with guidance for inspecting the top of the RPV head to ensure that conditions approaching that which existed at Davis-Besse will not occur. Visual inspection guidelines have been provided (Ref. 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 (Ref. 10).

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 in the basis for the MRP Inspection Plan (Ref. 11) and was presented to the NRC (Ref. 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 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 a 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 determined 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 that $1x10^{-3}$ 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. 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 duration 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," August 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," August 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," August 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. Proceedings: EPRI Boric Acid Corrosion Workshop, July 25–26, 2002, Baltimore, Maryland, to be published by EPRI.
11. Appendix C of EPRI Document MRP-75 "Supplemental Visual Inspection Intervals to Ensure RPV Closure Head Structural Integrity," August 2002.
12. Glenn White, Chuck Marks, and Steve Hunt, Technical Assessment of Davis-Besse Degradation, Presentation to NRC Technical Staff, May 22, 2002.