May 25, 2004

Mr. David A. Christian
Sr. Vice President and Chief Nuclear Officer
Dominion Nuclear Connecticut, Inc.
Innsbrook Technical Center
5000 Dominion Boulevard
Glen Allen, VA 23060-6711

SUBJECT: RELAXATION OF THE REQUIREMENTS OF ORDER EA-03-009 REGARDING REACTOR PRESSURE VESSEL HEAD INSPECTIONS, RELAXATION REQUEST NO. RR-89-48, MILLSTONE POWER STATION, UNIT NO. 2 (TAC NO. MC0942)

Dear Mr. Christian:

The purpose of this letter is to forward the U.S. Nuclear Regulatory Commission (NRC) staff's final safety evaluation (SE) pertaining to the relaxation of the requirements of Order EA-03-009 regarding reactor pressure vessel (RPV) head inspections.

On February 11, 2003, the NRC issued Order EA-03-009 requiring specific inspections of the RPV head and associated penetration nozzles at pressurized water reactors. Section IV.F of the Order states that requests for relaxation associated with specific penetration nozzles will be evaluated by the NRC staff using its procedure for evaluating proposed alternatives to the American Society of Mechanical Engineers Boiler and Pressure Vessel Code (ASME Code) in accordance with Section 50.55a(a)(3) of Title 10 of the *Code of Federal Regulations*.

By letter dated October 3, 2003, as supplemented on October 10 and 28, November 5, 20, and 21 and December 19, 2003, Dominion Nuclear Connecticut, Inc. (DNC), requested relaxation from the requirements in Section IV.C(1)(b) of the Order for Millstone Power Station, Unit No. 2. The relaxation request was made pursuant to the procedure specified in Section IV.F of the Order.

By letter dated November 21, 2003, the NRC staff authorized DNC's relaxation request based on the NRC staff's review which concluded that:

1) The proposed alternative examination of the CEDM penetration nozzles provides reasonable assurance of the structural integrity of the nozzles.

2) The combined use of ultrasonic testing and dye penetrant testing as proposed demonstrates the integrity of the inspectable portion of the penetration below the J-groove weld, and the results of the crack growth analysis demonstrates that potential cracks emanating from the uninspectable portion of the penetration will not grow into the J-groove weld within one operating cycle.

3) Further inspection of the control element drive mechanism nozzles in accordance with Section IV.C(1)(b) of the Order would result in hardship without a compensating increase in the level of quality and safety. Thus, DNC has demonstrated good cause for the requested relaxation.

The authorization granted by our letter dated November 21, 2003, was provided prior to finalization of the staff's SE in order to support DNC's inspection activities taking place at that time. Enclosed is the staff's final SE to fully document the basis for the staff's decision.

It should be noted that the December 19, 2003, letter was submitted after the NRC authorized DNC's relaxation request from the requirements in Section IV.C(1)(b) of the Order. This letter formally docketed the details of an additional example of supporting analysis. The result of this supporting analysis had been previously discussed with the NRC on November 21, 2003 and December 5, 2003 and was not considered by the NRC staff as a necessary part to be addressed in the final SE. However, to make the final SE complete, the NRC staff subsequently decided to include this information.

As was also discussed in our letter dated November 21, 2003, be aware that when vessel head inspections are performed using ASME Code requirements, acceptance criteria, or qualified personnel, those activities and all related activities fall within the jurisdiction of the ASME Code. Therefore, Order-related inspection activities may be subject to third party review, including those by the Authorized Nuclear Inservice Inspector.

Sincerely,

/RA/

Cornelius F. Holden, Director
Project Directorate I
Division of Licensing Project Management
Office of Nuclear Reactor Regulation

Docket No. 50-336

Enclosure: As stated

cc w/encl: See next page

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As was also discussed in our letter dated November 21, 2003, be aware that when vessel head inspections are performed using ASME Code requirements, acceptance criteria, or qualified personnel, those activities and all related activities fall within the jurisdiction of the ASME Code. Therefore, Order-related inspection activities may be subject to third party review, including those by the Authorized Nuclear Inservice Inspector.

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OFFICE	PDI-2/PM	PDI-2/LA	EMCB/SC*	OGC*	PDI-2/SC	PDI/D
NAME	VNerses	CRaynor	TChan	MYoung	JClifford	CHolden
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cc:

Lillian M. Cuoco, Esquire
Senior Counsel
Dominion Resources Services, Inc.
Rope Ferry Road
Waterford, CT 06385

Edward L. Wilds, Jr., Ph.D.
Director, Division of Radiation
Department of Environmental Protection
79 Elm Street
Hartford, CT 06106-5127

Regional Administrator, Region I
U.S. Nuclear Regulatory Commission
475 Allendale Road
King of Prussia, PA 19406

First Selectmen
Town of Waterford
15 Rope Ferry Road
Waterford, CT 06385

Charles Brinkman, Director
Washington Operations Nuclear Services
Westinghouse Electric Company
12300 Twinbrook Pkwy, Suite 330
Rockville, MD 20852

Senior Resident Inspector
Millstone Power Station
c/o U.S. Nuclear Regulatory Commission
P.O. Box 513
Niantic, CT 06357

Mr. W. R. Matthews
Senior Vice President - Nuclear Operations
Dominion Nuclear Connecticut, Inc.
Rope Ferry Road
Waterford, CT 06385

Mr. P. J. Parulis
Manager - Nuclear Oversight
Dominion Nuclear Connecticut, Inc.
Rope Ferry Road
Waterford, CT 06385

Mr. J. Alan Price
Site Vice President
Dominion Nuclear Connecticut, Inc.
Rope Ferry Road
Waterford, CT 06385

Mr. John Markowicz
Co-Chair
Nuclear Energy Advisory Council
9 Susan Terrace
Waterford, CT 06385

Mr. Evan W. Woollacott
Co-Chair
Nuclear Energy Advisory Council
128 Terry's Plain Road
Simsbury, CT 06070

Ms. Nancy Burton
147 Cross Highway
Redding Ridge, CT 00870

Mr. G. D. Hicks
Director - Nuclear Station Safety and Licensing
Dominion Nuclear Connecticut, Inc.
Rope Ferry Road
Waterford, CT 06385

Mr. S. E. Scace
Assistant to the Site Vice President
Dominion Nuclear Connecticut, Inc.
Rope Ferry Road
Waterford, CT 06385

Mr. Chris L. Funderburk
Director, Nuclear Licensing and
Operations Support
Dominion Resources Services, Inc.
Innsbrook Technical Center
5000 Dominion Boulevard
Glen Allen, VA 23060-6711

Millstone Power Station, Unit No. 2

cc:

Mr. A. J. Jordan, Jr.
Director - Nuclear Engineering
Dominion Nuclear Connecticut, Inc.
Rope Ferry Road
Waterford, CT 06385

Mr. S. P. Sarver
Director - Nuclear Station Operations
and Maintenance
Dominion Nuclear Connecticut, Inc.
Rope Ferry Road
Waterford, CT 06385

Mr. David W. Dodson
Licensing Supervisor
Dominion Nuclear Connecticut, Inc.
Rope Ferry Road
Waterford, CT 06385

SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

RELAXATION OF THE REQUIREMENTS OF ORDER EA-03-009 REGARDING

REACTOR PRESSURE VESSEL HEAD INSPECTIONS AT

MILLSTONE POWER STATION, UNIT NO. 2

DOMINION NUCLEAR CONNECTICUT, INC.

DOCKET NO. 50-336

1.0 INTRODUCTION

On February 11, 2003, the U.S. Nuclear Regulatory Commission (NRC) issued Order EA-03-009 requiring specific inspections of the reactor pressure vessel (RPV) head and associated penetration nozzles at pressurized water reactors. The NRC issued an errata to the Order on March 14, 2003, to correct an administrative part of the Order related to requests for relaxation of the Order requirements.

Section IV.F of the Order states that the NRC may relax or rescind any of the Order requirements upon demonstration by the licensee of good cause. Section IV.F of the Order also states that a request for relaxation of the Order requirements for inspection of specific penetration nozzles shall address the following criteria: (1) the proposed alternative(s) for inspection of specific nozzles will provide an acceptable level of quality and safety, or (2) compliance with this Order for specific nozzles would result in hardship or unusual difficulty without a compensating increase in the level of quality and safety. This section of the Order states that requests for relaxation associated with specific penetration nozzles will be evaluated by the NRC staff using its procedure for evaluating proposed alternatives to the American Society of Mechanical Engineers Boiler and Pressure Vessel Code (ASME Code) in accordance with Section 50.55a(a)(3) of Title 10 of the *Code of Federal Regulations*.

Sections IV.A and IV.B of the Order provide criteria to categorize each plant's RPV head with respect to its susceptibility to primary water stress corrosion cracking (PWSCC). For plants such as Millstone Power Station, Unit No. 2 (MP2), with RPV heads that are categorized as being highly susceptible to PWSCC, Section IV.C(1)(b) of the Order requires that the RPV head penetration nozzles be inspected each refueling outage using either of the following techniques: (1) ultrasonic testing (UT) from two inches above the J-groove weld to the bottom of the nozzle and an assessment to determine if leakage has occurred in the interference fit zone, or (2) eddy current testing or dye penetrant testing (PT) of the wetted surface of each J-groove weld and nozzle base material to at least two inches above the J-groove weld.

By letter dated October 3, 2003, as supplemented by letters dated October 10 and 28, November 5, 20, and 21, and December 19, 2003, Dominion Nuclear Connecticut, Inc. (DNC or the licensee) requested relaxation from the requirements in Section IV.C(1)(b) of the Order for Millstone Power Station, Unit No. 2 (MP2). The relaxation request was made pursuant to the procedure specified in Section IV.F of the Order. Specifically, for inspection of the RPV control element drive mechanism (CEDM) penetration nozzles, DNC requested authorization to use a combination of ultrasonic testing (UT) and dye penetrant testing (PT) on the nozzle base material, and reduced examination coverage below the weld in the non-pressure boundary portion of the nozzle. The relaxation was requested for the fall 2003 refueling outage (RFO) 15 for MP2.

By letter dated November 21, 2003, the NRC staff authorized DNC's relaxation request based on the NRC staff's review. The authorization granted by our letter dated November 21, 2003, was provided prior to finalization of the staff's safety evaluation (SE) in order to support DNC's inspection activities taking place at that time. The following is the staff's final SE to fully document the basis for the staff's decision.

It should be noted that the December 19, 2003, letter was submitted after the NRC authorized DNC's relaxation request from the requirements in Section IV.C(1)(b) of the Order. This letter formally docketed the details of an additional example of supporting analysis. The result of this supporting analysis had been previously discussed with the NRC on November 21, 2003 and December 5, 2003 and was not considered by the NRC staff as a necessary part to be addressed in the final SE. However, to make the final SE complete, the NRC staff subsequently decided to include this information. This additional example analysis, which considers the consequence of a large flaw size in the uninspected zone of the MP2 head, reinforced the conclusion that the operation of MP2 during cycle 16 poses no undue risk to the public health and safety. This provided additional confirmation of the NRC staff's decision to authorize DNC's relaxation request.

2.0 ORDER EA-03-009 RELAXATION REQUESTS FOR EXAMINATION COVERAGE OF REACTOR PRESSURE VESSEL HEAD PENETRATION NOZZLES

2.1 Order Requirements for which Relaxation is Requested

Section IV.C.(1) of Order EA-03-009 requires, in part, that the following inspections be performed every RFO for high susceptibility plants such as MP2:

(a) Bare metal visual examination of 100% of the RPV head surface (including 360 ° around each RPV head penetration nozzle), AND

(b) Either:

   (i) Ultrasonic testing of each RPV head penetration nozzle (i.e., nozzle base material) from two (2) inches above the J-groove weld to the bottom of the nozzle and an assessment to determine if leakage has occurred into the interference fit zone, OR

   (ii) Eddy current testing or dye penetrant testing of the wetted surface of each J-Groove weld and RPV head penetration nozzle base material to at least two (2) inches above the J-groove weld.

The licensee has requested relaxation from Section IV.C.(1)(b)(i) of the Order to perform UT of the RPV head penetration inside the tube from two inches above the J-groove weld to the bottom of the penetration. Specifically, the relaxation is related to UT examination of the bottom portion (threaded area) of all 69 CEDM penetration nozzles.

2.2 Components Covered by the Proposed Relaxation

This relaxation is applicable to the 69 CEDM RPV head penetration nozzles with attached threaded guide funnels for RFO 15 at MP2.

2.3 Licensee's Proposed Alternative Method

The licensee proposes to perform UT examinations from two inches above the weld to below the weld to the extent possible. Nozzles that cannot be examined by UT to at least 0.38 inches below the weld would receive a supplemental outside diameter (OD) PT examination that overlaps with the UT coverage by at least 0.125 inches and extends below the 0.38 inch level below the J-groove weld by at least 0.125 inches. The PT examination will be performed to approximately 0.25 inches above the bottom of the nozzle on the downhill side of the nozzle. The circumferential extent of the PT examination will cover 90 ° on each side of the 0 ° downhill location.

2.4 Licensee's Basis for Relaxation

Section IV.C.(1)(b)(i) of the Order requires UT examination from two inches above the J-groove weld to the bottom of the RPV head penetration nozzle. The licensee stated that compliance with this requirement is difficult because the UT equipment cannot interrogate the bottom inside diameter (ID) of a CEDM penetration nozzle, where the nozzle is internally threaded at the bottom to accept a guide funnel. Each threaded funnel is permanently attached in place with a weld. The length of the threaded region is approximately 1.25 inches at the bottom of the nozzles.

The licensee also stated that there are difficulties related to implementing Section IV.C.(1)(b)(ii) of the Order, which requires eddy current testing (ECT) or PT to obtain the required examination coverage, and difficulties in combining techniques to obtain the required coverage. These difficulties include the following:

> Access to the OD of the nozzles is limited by the adjacent nozzles and attached funnels. The nozzles follow the curvature of the RPV head as do the attached funnels. Spacing between the funnels in the horizontal plane is tight. Consequently, it will make performance of surface examinations on the OD surfaces of the bottom of the nozzles difficult and dose intensive.
>
> PT methods for performing nozzle OD examinations are manually applied and dose intensive. A remote ECT for RPV head penetration nozzle examination remains unavailable at the station, as it has not been qualified by DNC and its vendor for use in the upcoming refueling outage 15 at Millstone Unit No. 2.
>
> The radiation exposure to workers from PT of the wetted surfaces in the manner required by Section IV.C.(1)(b)(ii) of the Order is estimated to be 2.4 Rem per nozzle, or 173 Rem for all 69 CEDM nozzles. Considering the effectiveness of UT examinations, DNC considers that extensive use of PT examinations represents an unnecessary level of exposure.

> The radiation exposure to workers from performance of a supplemental PT of a portion of the nozzle that will augment UT examination coverage is approximated to be 11 Rem for all 69 CEDM nozzles. DNC considers that exposures can be further reduced by using a more discriminating application of the supplemental PT without any adverse impact to the level of quality and safety prescribed by the requirements in the Order.

The licensee's request for the reduction of the examination coverage area is based on a flaw tolerance approach. The licensee noted that its approach will provide an acceptable level of quality and safety with respect to reactor vessel structural integrity and leak integrity. The basis for this approach is provided in "Structural Integrity Evaluation of Reactor Vessel Upper Head Penetrations to Support Continued Operations: Millstone Unit 2," Westinghouse Electric Co., LLC, WCAP-16038-P (Proprietary), Revision 1, August 2003 and WCAP-15813-NP (Non-Proprietary), Revision 0, August 2003.

The licensee stated, as documented in WCAP-16038-P, Revision 1, that for the limiting nozzle location, a postulated axial through-wall flaw at a distance of 0.38 inches from the bottom of the weld, will take 1.9 years of operation to reach the weld. The licensee, therefore, asserts that a UT inspection that includes an area at least 0.38 inches below the weld will support one 18-month period of operation (one refueling cycle) for MP2. The licensee stated that for the nozzles that have UT examination coverage less than 0.38 inches below the weld, a PT examination of these nozzles will be performed.

The licensee stated that according to its analysis, the stresses on the OD surface of the nozzle decrease rapidly as the distance below the weld increases. For the nozzles with limited coverage (intersection angles with the RPV head of 29.1 ° and higher), the hoop stresses were reported by the licensee to be bounded by 33 ksi on the ID and 30 ksi on the OD at 0.38 inches below the weld. This calculation is for an intersection angle of 29.1 °, and at higher intersection angles the stresses are lower.

The licensee states that the change in UT examination coverage that is required by the Order retains an acceptable level of quality and safety because the only portion of the nozzle not fully interrogated is a region near the bottom of each nozzle below the toe of the J-groove weld.

The licensee stated that during its inspection of the 69 CEDM nozzles, there were seven nozzles that had UT examination coverage less than 0.38 inches from the bottom of the J-groove weld. The six nozzles received a PT examination on the OD that overlapped the UT coverage area and extended to approximately 0.25 inches above the bottom of the nozzle end. The one nozzle not PT inspected required repair during the outage. The area that would have been inspected by PT was replaced. The circumferential extent of the PT examination area was limited to 90 ° on each side of the 0 ° downhill location.

2.5 Evaluation

The NRC staff's review of this request was based on criterion (2) of paragraph F of Section IV of the Order, which states:

> Compliance with this Order for specific nozzles would result in hardship or unusual difficulty without a compensating increase in the level of quality and safety.

Within the context of the licensee's proposed alternative examination of the RPV penetration nozzles, the licensee has demonstrated the hardship that would result from implementing examinations to the bottom-end of these nozzles. The hardship identified by the licensee includes the nozzle configuration and the limitation of the UT probe used for nozzle examination. The staff agrees that the nozzles' threaded area that mates with the guide cones makes inspection of these nozzles in accordance with Order EA-03-009 very difficult and would involve a hardship. This evaluation focuses on the issue of whether there is a compensating increase in the level of quality and safety such that additional inspection of these nozzles should be required.

To assess the likelihood of a postulated flaw in the uninspected portion of the nozzle propagating to the pressure boundary, the licensee performed a fracture mechanics analysis. Although Section XI of the ASME Code does not provide guidelines for characterizing postulated flaws for applications similar to the MP2 CEDM nozzle evaluation, good engineering judgement calls for using worst case assumptions, i.e., to assume the existence of the largest flaw that could exist in the uninspected zone considering all engineering principles. Once the postulated initial flaw size is determined, the applied stress intensity factor (applied K) for the postulated crack is calculated to evaluate the crack growth according to an appropriate crack growth rate (CGR) for the Alloy 600 material. The objective is to determine whether the postulated initial flaw will grow to the J-groove weld in one operating cycle. The detailed information can be found in WCAP-15813-P, Revision 1, "Structural Integrity Evaluation of Reactor Vessel Upper Head Penetrations to Support Continued Operation: Millstone Unit 2," and additional information addressing staff concerns can be found in the enclosure of a letter from the licensee dated November 5, 2003. This additional information includes an appropriate description of the stress analysis using finite element method (FEM) modeling of the CEDM nozzle assembly. Further, in letters dated November 20, November 21, and December 19, 2003, supplemental information was provided to extend the scope of the sensitivity analysis on initial flaw sizes and to better characterize the margins associated with the effective full power years (EFPYs) calculated for a postulated flaw to reach the weld bottom for various nozzles under different initial flaw size assumptions.

The staff has evaluated the information regarding the FEM modeling. The licensee's FEM model considers welding processes by simulating melting and solidification of individual welding passes through a combination of thermal and structural models. Heat treatment history has also been considered. This method of calculating residual stresses is consistent with the industry practice and is acceptable to the staff. In addition, the licensee considers all testing and operating loads. The generic stress-strain property for Alloy 600 nozzle material at 600 °F is derived from test data; the actual stress-strain curves used in the stress analysis are based on the generic curve adjusted for temperature differences. Considering the lack of plant-specific data, this engineering approach in modifying the generic stress-strain curve is appropriate. The use of the stress-strain law for an elastic-perfectly plastic model for the Alloy 182 J-groove weld metal may not be a good representation of the material's real behavior. However, it was used to overcome a modeling limitation of the FEM code so that more realistic stresses could result. The November 5, 2003 supplement also indicates that the assumed number of welding passes in the FEM modeling produces conservative stresses and is, therefore, adequate. In summary, the FEM modeling is conservative, and the resulting stresses can be used as input to the licensee's fracture mechanics evaluation.

To assess the consequence of having flaws in the uninspected zone, the licensee, in a series of supplements, documented the results of a sensitivity study assuming a through-wall flaw of length from the top of the uninspected zone (0.38 inch below the J-groove weld) to a point where the applied stress is 0, 10, and 20 ksi in its fracture mechanics evaluation. Since the industry data supporting no crack initiation or growth in areas of Alloy 600 penetrations with stresses less than 20 ksi is not considered conclusive, the staff relies on the information associated with the initial crack lengths defined by 0 and 10 ksi to conduct its evaluation. The flaw length defined by 0 ksi represents the worst possible crack that could exist in the uninspected zone, and the licensee's calculated calendar years for the postulated crack to reach the J-groove weld bottom is 1.6 years, as documented in the November 5, 2003 supplement, assuming an availability factor of 0.9 of the unit in the fuel cycle.

For applied K calculations, the licensee used a model for a through-wall axial flaw in a cylinder under a uniform stress loading defined by the maximum stress along the entire crack face. The licensee provided qualitative assessment of the conservatism associated with using this model. However, the staff found it's important to quantify this conservatism because there is practically no margin in the licensee's calculated calendar year using the licensee's worst-flaw length assumption. The staff first focused on the through-wall crack geometry assumption. To quantify the conservatism, the staff calculated the applied K for a more realistic surface crack with a depth of 50% through-wall using Raju-Newman's solution, "Stress-Intensity Factors for Internal Surface Cracks in Cylindrical Pressure Vessels," as published in ASME Journal of Pressure Vessel Technology, Vol. 102, November 1980, for the limiting case reported in the December 19, 2003 supplement and found the licensee's applied K for a through-wall crack is 31% higher than the staff's for a 50% through-wall surface crack. The staff next focused on the uniform maximum stress assumption. To quantify the conservatism, the staff calculated the applied Ks for an edge crack model and a cracked panel model subjected to a more realistic sloped stress using applied K formulas from the Handbook by Tada, Paris, and Irwin, "The Stress Analysis of Cracks Handbook." The staff found the licensee's applied K for the uniform stress is 64 % higher than the staff's for the edge crack model and 37% to 46% for the cracked panel model with the ratio of the crack size to the panel width ranging from 0.2 to 0.6. These results indicate that the licensee's overestimation of the applied K assuming uniform stresses is about 37%. However, considering the geometric differences between the cracked panel model and the actual CEDM configuration, the staff determines the conservatism to be only 20%. Adding to this value the conservatism from using the through-wall crack geometry assumption, the staff concludes that there is more than 20% conservatism in the licensee's applied K values and calculated EFPYs because the crack growth rate is proportional to applied K with an exponent of 1.16.

Westinghouse used the results from the FEM stress analyses, the assumed initial flaw sizes, the CGR which will be discussed later, and the fracture mechanics methodology described above to predict the crack growth time of the upper crack front of a postulated flaw. The results for CEDM nozzles are expressed in terms of the time, effective EFPYs, needed for a postulated flaw to grow to the J-groove weld from 0.38 inches below the weld for three groups of representative CEDM nozzles. Since the times are calculated based on an acceptable stress analysis and conservative fracture mechanics methodology, the staff accepts the results summarized in the tables of the November and December 2003 supplements, with the understanding that the licensee's calculated values are conservative with respect to the time needed for a postulated flaw to grow from 0.38 inches below the weld to the J-groove weld.

The aforementioned crack growth analysis used the approach recommended by the NRC, and outlined in a letter to Alex Marion at the Nuclear Energy Institute, dated April 11, 2003, with the exception of the crack growth rate, as the criteria to set the necessary height of the surface examination. Therefore, the coverage addressed by this request provides reasonable assurance of structural integrity of the component. However, this analysis incorporates a crack growth formula provided in the Electric Power Research Institute (EPRI) Report, "Material Reliability Program (MRP) Crack Growth Rates for Evaluating Primary Water Stress Corrosion Cracking (PWSCC) of Thick Wall Alloy 600 Material (MRP-55), Revision 1." The NRC staff has completed a preliminary review of the crack growth formula but has not yet made a final assessment regarding the acceptability of the report. If the NRC staff finds that the crack growth formula in industry report MRP-55 is unacceptable, the licensee shall revise its analysis that justifies relaxation of the Order within 30 days after the NRC informs the licensee of an NRC-approved crack growth formula. If the licensee's revised analysis shows that the crack growth acceptance criteria are exceeded prior to the end of the current operating cycle, this relaxation is rescinded and the licensee shall, within 72 hours, submit to the NRC written justification for continued operation. If the revised analysis shows that the crack growth acceptance criteria are exceeded during the subsequent operating cycle, the licensee shall, within 30 days, submit the revised analysis for NRC review. If the revised analysis shows that the crack growth acceptance criteria are not exceeded during either the current operating cycle or the subsequent operating cycle, the licensee shall, within 30 days, submit a letter to the NRC confirming that its analysis has been revised. Any future crack growth analyses performed for this and future cycles for RPV head penetrations must be based on an acceptable crack growth rate formula. The licensee accepted this condition by letter dated October 28, 2003.

The staff finds the relaxation request to be acceptable, because the alternative proposed by the licensee in the relaxation request provides reasonable assurance of structural integrity of the component, and the staff finds that the licensee has demonstrated hardship without a compensating increase in the level of quality and safety, subject to the aforementioned condition.

3.0 CONCLUSION

The staff concludes that the licensee's proposed alternative examination of 69 CEDM RPV head penetration nozzles to a level at least 0.38 inches below the J-groove weld (more area will be covered if possible) on the downhill side of the nozzles provides reasonable assurance of the structural integrity of the RPV head penetration nozzles and welds. Further inspection of the RPV head penetration nozzles in accordance with Section IV.C.(1) of Order EA-03-009 would result in hardship without a compensating increase in the level of quality and safety. Therefore, pursuant to Section IV, paragraph F, of Order EA-03-009, the staff authorizes the proposed relaxation and alternative inspection for all CEDM head penetration nozzles at MP2 for one standard operating cycle (RFO 15), subject to the following condition that was agreed upon by the licensee in letter dated October 28, 2003.

> If the NRC staff finds that the crack-growth formula in industry report MRP-55 is unacceptable, the licensee shall revise its analysis that justifies relaxation of the Order within 30 days after the NRC informs the licensee of an NRC-approved crack growth formula. If the licensee's revised analysis shows that the crack growth acceptance criteria are exceeded prior to the end of the current operating cycle, this relaxation is rescinded and the licensee shall, within 72 hours, submit to the NRC written justification for continued operation. If the revised analysis shows that the crack growth acceptance

criteria are exceeded during the subsequent operating cycle, the licensee shall, within 30 days, submit the revised analysis for NRC review. If the revised analysis shows that the crack growth acceptance criteria are not exceeded during either the current operating cycle or the subsequent operating cycle, the licensee shall, within 30 days, submit a letter to the NRC confirming that its analysis has been revised. Any future crack growth analyses performed for this and future cycles for RPV head penetrations must be based on an acceptable crack growth rate formula.

In addition, when vessel head inspections are performed using ASME Code requirements, acceptance criteria, or qualified personnel, those activities and all related activities fall within the jurisdiction of the ASME Code. Therefore, Order-related inspection activities may be subject to third party review, including those by the Authorized Nuclear Inservice Inspector.

Principal Contributors: A. Keim
S. Sheng

Date: May 25, 2004