June 22, 2001

Mr. Alex Marion, Director
Engineering
Nuclear Energy Institute
1776 I Street, N.W., Suite 400
Washington, D.C. 20006-3708

SUBJECT: TRANSMITTAL OF STAFF QUESTIONS RELATED TO STAFF REVIEW OF MRP-44, PART 2 “PWR MATERIALS RELIABILITY PROGRAM INTERIM ALLOY 600 SAFETY ASSESSMENTS FOR U.S. PWR PLANTS (MRP-44), PART 2: REACTOR VESSEL TOP HEAD PENETRATIONS,” TP-1001491, PART 2, INTERIM REPORT, MAY 2001

Dear Mr. Marion:

By electronic mail (e-mail) dated May 25, 2001, the NRC staff forwarded to Mr. Jack Bailey, Chair of the EPRI Materials Reliability Program (MRP), a set of questions that the staff requested to be addressed in the June 7, 2001, public meeting with the staff regarding the MRP-44, Part 2 report on pressurized water reactor (PWR) vessel head penetrations (VHPs) cracking issues. By e-mail dated May 29, 2001, the staff forwarded to Mr. Bailey a revised set of questions, which added questions on interference fit classification and a loose parts assessment. These questions were made publicly available prior to the meeting in ADAMS and were posted on the NRC web site for this issue ("Generic Activities on PWR Alloy-600 Weld Cracking," at http://www.nrc.gov/NRC/REACTOR/ALLOY-600/index.html).

During the June 7, 2001, public meeting, you requested that these questions be formally submitted to the industry through the Nuclear Energy Institute (NEI), as the regulatory interface for the MRP. Per this request, the attached provides the questions forwarded prior to the subject meeting, and also includes several additional questions that arose during the meeting.

If you have any question regarding this letter, please contact Mr. Jack Strosnider of my staff at 301-415-3298.

Sincerely,

/RA/
Brian W. Sheron, Associate Director
for Project Licensing and Technical Analysis
Office of Nuclear Reactor Regulation

Enclosure: As stated

cc: See next page

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NRC STAFF REVIEW OF MRP-44, PART 2
"PWR MATERIALS RELIABILITY PROGRAM INTERIM ALLOY 600
SAFETY ASSESSMENTS FOR U.S. PWR PLANTS (MRP-44), PART 2:
REACTOR VESSEL TOP HEAD PENETRATIONS," TP-1001491, PART 2,
INTERIM REPORT, MAY 2001

The staff has reviewed TP-1001491, Part 2, "PWR Materials Reliability Program Interim Alloy 600 Safety Assessments for US PWR Plants (MRP-44), Part 2: Reactor Vessel Top Head Penetrations," and has developed the following comments.

<u>Section 3:</u> <u>Reactor Vessel Closure Head Penetration Configurations, Fits and Leakage</u> <u>Detectability</u>

1. Appropriate consideration of the interference fit incorporated into the initial fabrication of the vessel head penetrations (VHPs) is important in evaluating the ability of visual leakage detection methods (e.g., boric acid walkdowns) to accurately identify through-wall degradation at the subject locations. While the recent instances of cracking in several VHPs at ANO-1 and Oconee Units 2 and 3 indicate that it is possible to detect through-wall flaws caused by primary water stress corrosion (PWSCC) based on boric acid walkdowns that can look under the insulation, the information provided in Section 3 of the MRP-44, Part 2 report does not support the conclusion that these events were "bounding" (i.e., that, for a similar size through-wall flaw at some other facility, an equivalent or greater amount of leakage would be expected).

2. In order to better understand the leakage potential of PWSCC at VHP locations, and to assist in understanding how comparisons can be made to the leakage potential for VHPs at other facilities, the staff request additional information detailing the precise interference fits (as opposed to a range of values) for the VHPs which leaked at ANO-1 and Oconee.

3. The staff notes that, based on information in ASME Code Section II, Part D, the coefficient of thermal expansion for Alloy 600 is slightly greater than that for low alloy vessel steels throughout the temperature range of interest (70 °F to 600 °F). This would lead to the conclusion that the magnitude of the interference fit would grow as the vessel was heated up from room temperature to operating temperature. Further, internal pressurization of the VHP nozzle may be expected to further expand the nozzle into the vessel head penetration. Other potential effects related to RPV head distortion at pressure, flange rotation, and/or vessel head penetration ovalization are not discussed in Section 3.0. Address how these factors may affect central and peripheral VHPs differently. Provide additional information to support your statement that "...analyses show that the initial fit tends to open up at operating temperature and pressure." Provide details on the finite element analysis (FEA) of the RPV head used to support this statement, including modeling assumptions, boundary conditions and results.

4. Assuming a leak path by way of a through-wall flaw in the CRDM nozzle into the annular region of the RPV head and then up and out onto the RPV head, provide a detailed description of any predictive modeling of this scenario which has been performed, or is planned. Specific attention should be given to the evaluation of the expected leakage from VHPs having potentially greater interference fit values. Based on the information provided in the MRP-44, Part 2 report, such a modeling effort, appropriately benchmarked against the information provided in response to item (2) above, could be used (along with accurate crack growth data) to evaluate the leakage from any VHP. This could demonstrate whether leakage could occur prior the growth of such a flaw to a size that could challenge primary system integrity.

5. Provide additional technical justification, based on a consideration of the physical processes involved, as to why boric acid crystal and/or corrosion product plugging should not be considered when evaluating the potential leakage from the VHPs. This additional information should consider the potential for substantial plugging of the assumed leak path based upon different specific crack morphologies, different interference fits, and/or different operational stresses, which could lead to potentially smaller effective crack opening areas.

6. At a public meeting on June 7, 2001, at NRC headquarters, the industry representatives described visual examinations conducted under the insulation at several PWRs. Provide any photographic documentation that can serve to demonstrate the expected conditions, accessibility and inspectability of the RPV head for such arrangements.

<u>Section 4:</u> <u>Time-at-Temperature Comparisons and Plant Inspection Status</u>

1. The simplified ranking model proposed in the subject report is based on the consideration of plant operating time and head temperature. In calculating the operating time at equivalent temperature, an Arrhenius equation was used with an activation energy of 50 kcal/mole. The staff notes that this 50 kcal/mole value is based on the evaluation of PWSCC in steam generator tubes. The staff is continuing to evaluate whether or not this value is acceptable given the mechanistic nature of the cracking observed in the CRDM penetrations. Discuss the sensitivity of the relative plant susceptibility rankings to the selection of a specific activation energy value, and whether a range of activation energy values would be more appropriate.

2. Based on your simplified ranking model, all U.S. PWRs are assigned into one of eight assessment groups relative to the time it takes, in effective full power years (EFPYs), to reach equivalency to Oconee Unit 3. The number of plants in each group, including a summary of their inspection status, was provided in Figure 4-1. In order for the staff to complete its review of this information, identify by name which plants are in each of the assessment groups and provide the head temperature, operating time (in EFPY), effective degradation years based on your model, and interference fit classification for each facility.

Also provide, on a plant-by-plant basis, a review of the inspection history (i.e., when were inspections conducted, how were the inspections performed and scope thereof, what were the results, etc.) for each facility and a schedule of each facility's upcoming refueling outages.

3. In Table 2-1, a summary of worldwide CRDM nozzle PWSCC experience was provided. Provide the rankings, by use of the model proposed in your report, of those foreign PWRs experiencing cracking in their CRDM nozzles. Discuss the reliability of your simplified model when benchmarked against the inspection results of the foreign PWRs.

4. In the subject report, the recommended inspection of nine plants for fall outage 2001 is based on consideration of the 25 plants in the first three assessment groups that have equivalent time at temperature to be within 10 EFPY of the Oconee 3 condition. Explain the basis for selecting the 10 EFPY cut off criteria for near-term inspection. Additionally, provide justification for not selecting for re-inspection plants with high rankings that were only partially inspected in the past.

5. In the last sentence of the "Summary" section of Section 4, it is stated that "[s]ince the Oconee units lead the industry in effective time at temperature, and 10 EFPYs margins [have] been added to account for uncertainties when planning inspections, there is assurance that significant cracking at any of the US PWRs will be detected before there is any significant impact on plant safety." The staff notes that, in the subject report, the potential crack growth rate (CGR) in the affected nozzles was not discussed. The Alloy 600 and Inconel 182 CGRs are affected by a number of factors (e.g., surface cold work, residual stresses resulting from welding, operating stresses, component geometry and material properties - strength and sensitization), in addition to operating temperature. Explain what technical basis was used for establishing the assumed CGR for the circumferential CRDM nozzle cracking. Provide a detailed justification, based on this assumed CGR, as to why the proposed inspection plan (based on operating time and temperature) will provide adequate assurance that significant cracking will be detected in U.S. PWRs prior to having an impact on plant safety.

6. Discuss the potential for additional measures, such as acoustic monitoring, for monitoring the RPV head and detecting leakage.

<u>Section 5:</u> <u>Structural Margin for Circumferential Cracks above J-Groove Weld</u>

1. The staff noted that, in the subject report's evaluation of structural margins, no consideration was apparently given to the impact of CGR on the margins. Explain what impact the assumed CGR would have on the assessment of structural margins. In particular, explain how long Oconee Unit 3 could have operated based on the assumed CGR before it reached a critical flaw size.

2. Discuss the effect that potential contaminants, such as organics and fabrication fluids, could have on the crack initiation and CGR of circumferential flaws in Alloy 600 nozzle material.

3. At a public meeting on June 7, 2001, at NRC headquarters, the industry representatives described finite element analyses (FEA) for circumferential cracks in peripheral CRDM nozzles. Provide details of the FEA modeling assumptions (such as symmetry, boundary conditions and residual stresses), the resultant stresses, and the applied stress intensity factors. How do these parameters change (e.g., stress redistribution) with crack growth in the nozzles?

Risk-Informed Review

1. Discuss the factors affecting the likelihood, consequence, and compensatory measures for a potential CRDM LOCA, including:

   a. the probability of having undetected circumferential flaws (e.g., the fit-up between the CRDM nozzle housing and the RPV head being sufficiently tight that there is too little evidence of boron crystal deposits to be detectable using a VT-2 visual examination);

   b. the potential likelihood of CRDM nozzle housing rupture due to undetected circumferential cracks propagating to a critical flaw size (discussion should include installation/repair stresses and weld history, age and temperature history, and chemistry excursions); and,

   c. the potential likelihood of CRDM ejection following a postulated rupture.

2. Discuss the accident progression given a CRDM ejection following a postulated rupture including, but not limited to, the likelihood of core uncovering, ATWS, and/or disrupted geometry. As part of this discussion, provide a detailed explanation of plant system response to such an event. This discussion should focus on mitigating or compensatory measures and core damage prevention strategies in the event of assembly ejection, ATWS, and LOCA scenarios. The discussion should also include consideration of secondary effects (e.g., insulation blown off by LOCA blocking recirculation system, collateral damage on adjacent CRDMs caused by the ejected CRDM, etc.).

Loose Parts Assessment

1. At a public meeting on April 12, 2001, industry representatives described an evaluation of loose parts, wherein circumferential cracking of the CRDM nozzle below the weld could link two or more axial cracks to form a loose part. Discuss the potential generation and consequences of loose parts generated from degradation of CRDM nozzles.

Inspection Capabilities

1. Discuss the industry's ability to perform volumetric non-destructive examinations (NDE) of the VHPs such that flaws originating either from the inside or outside diameter (ID or OD) of the nozzle housing, or through the J-grove weld to the RPV head, can be detected.

2. Discuss the industry's ability to perform volumetric NDE of multiple PWR's VHPs prior to January 1, 2002. Include in this discussion a realistic estimate of how many units could be so inspected, the time associated with performing this inspection, and any other costs (i.e., dose, outage duration, replacement power, etc.) associated with conducting such an inspection assuming performing it during a scheduled outage during this time frame, or in an unscheduled outage.

3. Discuss the industry's ability to perform a visual examination of the upper PWR head sufficient to detect evidence of leakage from the VHPs prior to January 1, 2002. Include in this discussion a realistic estimate of how many units could be so inspected, the time associated with performing this inspection, and any other costs (i.e., dose, outage duration, replacement power, etc.) associated with conducting such an inspection assuming performing it during a scheduled outage during this time frame, or in an unscheduled outage.