April 4, 2007

Alex Marion, Executive Director
Nuclear Energy Institute
Nuclear Operations and Engineering
1776 I Street, N.W.
Washington, DC 20006-3708

Dear Mr. Marion,

In a February 14, 2007, letter from Jay Thayer, Nuclear Energy Institute (NEI) to J.E. Dyer, U.S. Nuclear Regulatory Commission (NRC), industry proposed performing advanced finite element fracture mechanics analyses to address NRC staff concerns that rupture could occur without prior evidence of leakage (ML070600674). On March 20, 2007 the Electric Power Research Institute provided results of a draft calculation to the Expert Review Panel for Advanced Finite Element Analysis (FEA) Crack Growth Calculations. This calculation was prepared for industry by Dominion Engineering, Inc., and represents the completion of Phase I draft calculations. The purpose of the Phase I calculation is to apply the updated crack growth software to the analysis for the same weld geometry, piping load inputs, and welding residual stress distribution assumed in the previous calculations for the Wolf Creek flaws. The updated crack growth software allows the crack profile to be governed by the stress intensity values along the crack front without the mathematical constraint of an elliptical crack shape. The Phase II calculations will further investigate the viability of through-wall leakage prior to rupture for pressurizer nozzle dissimilar metal butt welds.

U. S. Nuclear Regulatory Commission (NRC) staff from the Office of Nuclear Reactor Regulation, the Office of Nuclear Regulatory Research (RES) and RES' contractor participated in a conference call with the industry Expert Panel to discuss this calculation on March 20, 2007. During this conference call the NRC staff provided comments on the calculation and discussed their concerns. The NRC staff have prepared the enclosed information to document these concerns.

In an effort to provide industry with additional information to evaluate the basis for these concerns, the NRC staff are preparing a technical basis document, which we will endeavor to provide prior to the next teleconference with the Expert Panel on April 9, 2007. The NRC staff regards resolution of these concerns to be of the utmost importance as they will potentially affect the NRC staff's evaluation and conclusions regarding the results of the Phase II calculations. We anticipate having future communications with industry to discuss the enclosed concerns and the forthcoming technical basis document. In order to continue to progress toward a timely NRC staff decision on the advanced finite element analyses, industry needs to evaluate and respond to these concerns by April 23, 2007.

We look forward to continuing to work with industry on this project.

Sincerely,

R/A

Michele Evans, Director
Division Of Component Integrity
Office of Nuclear Reactor Regulation

Enclosure:
Concerns with Industry's Phase I Wolf Creek Calculation

cc: A. Marion, NEI
J. Thayer, NEI
C. King, EPRI
G. Wilkowski, EMCC
C. Harrington, EPRI
D. Weakland, MRP
J. Gasser, MRP
D. Rudland, EMCC

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/RA/

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Concerns Regarding Industry's Phase I Wolf Creek Calculations

1. The industry incremented the crack growth in the analyses based on constant increment of crack growth in the length direction for the majority of the analyses. This constraint caused the times for the crack extension at the surface and depth to be different. Even though these differences are small, over the entire time period the sum of the differences could be substantial. This difference could bring into question the validity of the crack shape at leakage. Growing the crack along the crack front by a constant time increment seems more logical and more representative of the crack growth physical characteristics. We suggest further investigation into the crack increment calculation is warranted.

2. In Figure 11 of industry's Phase I calculations on the evolution of the stress intensity factors, a discontinuity occurred after the second increment of crack growth, and appears to occur at the same stress intensity for each of the remaining steps. Industry's response to a question on this observation during the March 20, 2007, teleconference was unclear, but industry indicated they believed the response was real. We suggest further investigation into the mesh density or the crack increment calculation is warranted. It is recognized that this effect is probably secondary in nature.

3. A significant result from these analyses was that the surface crack grew to 360 degrees before becoming through-wall. This effect was driven by the higher residual stresses at the inside diameter (ID) surface. In addition, the shape of the final defect at the location of maximum stress was highly driven by the magnitude of the bending stress relative to the ID welding residual stress. For similar residual stresses with lower bending moments, a critical 360-degree surface crack is likely to occur. Industry needs to address this issue in the analysis matrix for Phase II.

4. The last comment relates to the calculation of critical crack sizes which affect the calculation for the time to rupture. In the Phase I results, industry used a limit-load analysis with the weld metal flow stress to estimate the critical through-wall crack size; then industry used that cross-sectional cracked area to draw conclusions about the stability of the leaking surface crack. In addition, industry did not evaluate the displacement-controlled stresses in this stability calculation, arguing that these stresses would be relieved by the plasticity and change in compliance due to the large crack. From reviewing past full-scale pipe testing results, it is the NRC staff's view that in conducting critical crack size analyses, industry must address the following concerns.

    a. The location of the crack in a dissimilar weld can change the fracture response. If the crack is close to the safe-end then the lower strength of the stainless steel safe-end should be used. If the crack is in the center of the weld or closer to the ferritic nozzle side, the effective flow stress would be slightly higher than using the safe-end strength but much lower than using the weld metal strength properties. Hence, if the location of the crack in the weld is not known, then the conservative assumption is to use the lower safe-end strength properties. This fact is supported by both analyses and experiments.

b. Elastic-plastic fracture mechanics should be considered since in the NRC analyses, this condition controlled for some crack geometries. For an idealized circumferential through-wall crack as used in industry's failure analysis, the NRC staff's detailed finite element elastic-plastic analyses and pipe tests showed that failure stress would be below that predicted by limit-load analyses even when using the stainless-steel base-metal strength properties in the limit load analysis. For a circumferential surface flaw, the experiments and analyses suggest that limit-load using the lower strength properties would be appropriate. Finally, for a complex or compound crack, i.e., a long surface crack that penetrates the wall thickness for a short length, full-scale pipe tests have shown that the failure stress would be significantly below limit load. This crack shape is similar to the flaw found in the Duane Arnold safe end. The results also indicate that secondary stresses can lead to rapid severance of pipes containing complex cracks. Consequently, there can be significant non-conservatism in the industry's fracture analysis.

c. For large cracks, especially surface and complex cracks, the plasticity is localized to the area surrounding the crack, and therefore the secondary loads will not be relieved by a change in compliance. If the crack is large enough so that the rest of the pipe system remains elastic, then these secondary stresses will act as a primary stress. If the failure stresses are above yield of the uncracked pipe, there will be a gradual reduction of the importance of secondary stresses, but this is material and pipe-system geometry dependant. This condition may begin to relieve some of these loads, but total relief will not occur until there is large scale plasticity in the uncracked pipe loop. This secondary stress effect on fracture response is consistent with the ASME Section III design rules that offer a warning about Local Overstrain due to a weakened pipe cross section. There are full-scale pipe system tests with different amounts of thermal expansion stress that illustrate this fracture behavior in NUREG reports and technical papers.