March 22, 2011

MEMORANDUM TO: Eric J. Leeds, Director
Office of Nuclear Reactor Regulation

Michael R. Johnson, Director
Office of New Reactors

FROM: Brian W. Sheron, Director ***/RA/***
Office of Nuclear Regulatory Research

SUBJECT: DELIVERY OF FINAL REPORT ON EVALUATION OF FABRICATION-RELATED INDICATIONS IN REACTOR UPPER HEAD PENETRATIONS

The Office of Nuclear Regulatory Research (RES) is pleased to provide the completed deliverable assessing various fabrication-related indications in reactor upper head penetrations. RES initiated this work in response to the Office of Nuclear Reactor Regulation (NRR) User Need 2006-06, "PWSCC of Nickel-Based Alloy Primary Pressure Boundary Components," dated April 21, 2006. This work specifically addresses Task 2 of the user need.

Alloy 52/152 replaced Alloy 82/182 as the preferred weld filler metal for control rod drive mechanism (CRDM) nozzles in the reactor pressure vessel heads (RPVH) for increased corrosion resistance, however, fabrication experience indicates that these alloys are more difficult to weld leading to fabrication-related indications. In some cases, as many as 5 to 22 indications have been identified in these welds. These weld fabrication indications could include slag inclusions and hot cracking and can be quite long (more than 50 mm in length). Hot cracking includes solidification cracking (weld), liquidation cracking, and ductility dip cracking. In addition, large grains could be produced in the welds, and micro-cracks tend to develop in such material. Therefore, micro-cracking in these welds may degrade the integrity of the CRDM nozzle by either by limiting its load-carrying capacity or by leading to occluded regions where primary water stress corrosion cracking (PWSCC) may be more prone thereby increasing the potential for nozzle ejection and loss-of-coolant accident.

To meet this need, RES's Division of Engineering, Component Integrity Branch staff and Engineering Mechanics Corporation of Columbus conducted analyses to study the effect of the multiple indications in these nozzle welds on the integrity of the upper head. The analyses employed sophisticated fracture mechanics and welding residual stress analyses on a variety of nozzle locations. In addition, a stress limit analysis was performed in accordance with Section III of the American Society of Mechanical Engineers Boiler and Pressure Vessel Code that determined the acceptable weld metal loss levels and margins for new RPVH CRDM nozzles.

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The analyses conducted in this investigation demonstrate that the presence of multiple indications, typical of those found in Alloy 52/152 replacement heads, do not greatly influence the integrity of the upper head. Specifically, it was found that these fabrication-related defects only slightly redistributed the weld residual stresses, which acts as the main crack driving force for these indications. In addition, the crack-tip stress intensity factors were in the range where crack growth is possible if the indications were exposed to the environment. However, since these are small embedded defects, and the weld material has low stress corrosion cracking susceptibility, crack growth is not expected to be significant. Finally, if the largest number of indications (22 in this case) were linked together to form one large flaw, analysis results demonstrate that a margin of four on operating loads exists before tube ejection would occur. In fact, limit analysis results suggest that a CRDM nozzle with a single flaw that has a crack area equal to two-thirds of the weld area would still comply with ASME Section III stress limits.

In conclusion, the impact of fabrication-related indications on the integrity of the upper head is small. The main concern stems from tube ejection due to the potential linking or growth of PWSCC. Even though the Alloy 52/152 material has been shown to have limited susceptibility to stress corrosion cracking in PWR environments, the current dataset is limited and PWSCC growth is a possibility. However, as indicated by the limit analysis results, a significant crack would have to occur before ASME Section III stress limits were violated and the margins to rupture were eliminated.

Details of the analysis procedures, results and conclusions can be found in the final report attached to this memorandum.

This memorandum concerns only the delivery of the RES report. The draft report was sent to NRR and NRO for review in December 2009. The NRR staff had the opportunity to review and comment on a draft version of this report, and their extensive comments are incorporated in this version. NRO staff had no comments on the report. This report fulfills the need requested in Task 2 of NRR User Need 2006-06; however, work on other tasks is ongoing

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