UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION REGARDING CORE SHROUD WELD EXAMINATIONS DURING THE 1998 REFUELING OUTAGE AND ASSOCIATED FLAW EVALUATIONS NIAGARA MOHAWK POWER CORPORATION NINE MILE POINT NUCLEAR STATION, UNIT NO. 2 DOCKET NO. 50-410

1.0 INTRODUCTION

By letter dated July 9, 1998, as supplemented September 21, 1998, Niagara Mohawk Power Corporation (NMPC) submitted, for NRC review, the results of its ultrasonic examination (UT) of the core shroud welds during the 1998 refueling outage (RFO6) at Nine Mile Point Nuclear Station, Unit No. 2 (NMP2) and the associated evaluation for the detected flaws. The examination included accessible area of all eight shroud horizontal welds and six of the vertical welds. No cracking was found for the vertical welds, but significant cracking was detected for horizontal welds H4 (the crack length was 71.45% of the weld circumference), H5 (42.5% of the circumference), and H7 (40.85% of the circumference). Only minor cracking was observed for welds H1, H2, H3, and H8, and no cracking was observed for H6. NMPC's analytical flaw evaluation is intended to demonstrate that NMP2 can be safely operated, without repair or intermediate inspection, for at least the operating cycle that follows RFO6.

2.0 EVALUATION

The NMP2 shroud material is SA-240 Type 304L plate. The shroud thickness is 2 inches. Weld designations are shown in attached Figure 1-1 (extracted from NMPC's submittal dated July 9, 1998).

2.1 NMPC

Since no flaw indications were found in the vertical welds, NMPC only evaluated the detected circumferential flaws in the horizontal welds. NMPC applied limit load analysis to all eight horizontal welds. The limit load analysis is consistent with that of Appendix C of Section XI of the American Society of Mechanical Engineers Boiler and Pressure Vessel Code (ASME Code). The results indicated that for the limiting weld, H4, the calculated safety factor is 5.13, which exceeds the ASME Code's required value of 2.77 by a significant margin.

To account for the effect of embrittlement on three (H3, H4, and H5) of the eight welds in the beltline region (with estimated peak fluence greater than $3X10^{20}$ n/cm^2), NMPC also applied the linear elastic fracture mechanics (LEFM) methodology consistent with the methodology in the report by the Boiling Water Reactor Vessel and Internals Project, BWRVIP-01, Revision 1, "BWR Core Shroud Inspection and Flaw Evaluation Guidelines," dated March 1995 (also referred to as GENE-523-113-0894, Rev. 1) to horizontal welds H3, H4, and H5. The LEFM methodology

applied to weld H3 is for a through-wall crack, which is directly from BWRVIP-01, Revision 1. The LEFM methodologies applied to welds H4 and H5 contain new equations for two additional crack geometries--a compound crack (i.e. a combination of 360° part through-wall crack and a through-wall crack) and a 360° part through-wall crack. The applied stress intensity factor ("applied K") equation for the compound crack was modified from the equation for a simple compound crack from the "Ductile Fracture Handbook," Volume 2 (Electric Power Research Institute's Research Project 1757-69), dated October 1990. The applied K equation for the 360° part through-wall crack was from American Society for Testing and Materials (ASTM) STP 590 (1974), "Stress Intensity Factor Solutions for Continuous Surface Flaws in Reactor Pressure Vessels." The LEFM results indicated that for the limiting case of treating the crack in weld H4 as a compound crack, the calculated safety factor was 2.96, which exceeds the required value of 2.77. This calculation was based upon a K_{Ic} value of 150 ksi(in)^{½}, an initial crack depth of 0.5 inch, a UT uncertainty of 0.108 inch, and a crack growth of 0.85 inch (the result of using the bounding growth rate of $5X10^{-5}$ inch/hour for 17000 hours). Based upon the results from limit-load and LEFM analyses, NMPC concludes that all horizontal welds meet the structural margin requirements for continued operation for at least one fuel cycle following RFO6.

2.2 NRC Staff

NMPC's flaw evaluation for the detected flaws in the horizontal welds of the NMP2 core shroud was based upon BWRVIP-01, Rev. 1, as presented in NMPC's letters of July 9 and September 21, 1998. The evaluation employed limit-load analysis and LEFM analysis. The NRC staff determined that NMPC's use of the limit load analysis for all welds and the LEFM analysis for the welds in the beltline region are appropriate because the methodologies were selected according to the guidelines (based upon fluence levels) established in BWRVIP-01, Revision 1. This report was approved by the NRC staff on June 16, 1995. Further, the NRC staff determined that the limit load analysis is acceptable because it is in accordance with Appendix C of Section XI of the ASME Code. The NRC staff also examined the LEFM analysis and has the following comments, which may be considered as supplements to the NRC staff safety evaluation that was issued June 16, 1995, regarding BWRVIP-01, Revision 1.

2.2.1 Safety Factor

Paragraph IWB-3640, "Evaluation Procedures and Acceptance Criteria for Austenitic Piping," of Section XI of the ASME Code requires a safety factor of 3 for normal operating conditions and a factor of 1.5 for emergency and faulted conditions when the evaluation procedure is based upon applied stress. NMPC's LEFM analysis used a safety factor of 2.77, the same as that specified in Appendix C of the ASME Code, Section XI, for the limit load analysis. The NRC staff determined that NMPC's evaluation was based upon applied stress. However, because the core shroud is not a pipe, although NMPC adopted most of the evaluation procedures and acceptance criteria in Appendix C and Paragraph IWB-3640 to evaluate the core shroud, the safety factor of Paragraph IWB-3640 does not directly apply. Considering that the core shroud material is highly ductile and LEFM is very conservative for this type of material, the NRC staff accepts the safety factor of 2.77 for NMPC's LEFM methodology.

2.2.2 Applied K for the Compound Crack

NMPC applied A. Zahoor's solution from the "Ductile Fracture Handbook," Volume 2, to calculate the applied K for the compound crack. This solution is applicable to geometries with a radius-to-thickness ratio (R/t) ranging from 5 to 10. Hence, the applicability of this equation to the present case of a core shroud with R/t of 50 needs to be established. To this end, NMPC submitted additional information on September 21, 1998, indicating that the finite element method duplicated the results using Zahoor's solution within a few percent. The NRC staff finds NMPC's additional information to be acceptable. Consequently, the NRC staff accepts Zahoor's applied K solution for a compound crack in this application.

2.2.3 Fracture Toughness

In Generic Letter (GL) 90-05, "Guidance for Performing Temporary Non-code Repair of ASME Code, Class 1, 2, and 3 Piping," the NRC staff endorsed a fracture toughness value of 135 ksi(in)^{½} for austenitic stainless steel. This is based upon the lower-bound value used in Paragraph IWB-3640. NMPC used a value of 150 ksi(in)^{½} based upon the test data of two irradiated specimens documented in BWRVIP-01, Revision 1. The NRC staff finds this to be acceptable because using the value representative of the core shroud material is more appropriate than using the lower-bound value for a wide range of stainless steels for pipes.

2.2.4 Additional Conservatism

The NRC staff recognizes an additional conservatism associated with NMPC's limiting case (with a calculated safety factor of 2.96). In the limiting case, NMPC assumed that all weld segments that were not examined because they were not accessible contained through-wall cracks. If these inaccessible areas were assumed to have part through-wall cracks like those in the inspected portion of the H4 weld, the calculated safety factor would be 6.80. Since it is highly unlikely that all inacessible areas have through-wall cracks when the inspected areas only indicated part through-wall cracks, there is a significant conservatism associated with this assumption for the limiting case.

3.0 CONCLUSION

Based upon its review of NMPC's submittals, the NRC staff concludes that the limit-load analysis meets the rules of the ASME Code. As discussed in Sections 2.2.1 to 2.2.4 above, the NRC staff further concludes that the LEFM analysis meets the intent of the rules of the ASME Code. Since the predicted final flaw depth at the end of the operating cycle (1.458 inches) has a calculated safety factor of 2.96, which exceeds the required safety factor of 2.77, the NRC staff agrees that continued operation, without repair or intermediate inspection of the NMP2 core shroud, is acceptable for at least one operating cycle after RFO6.

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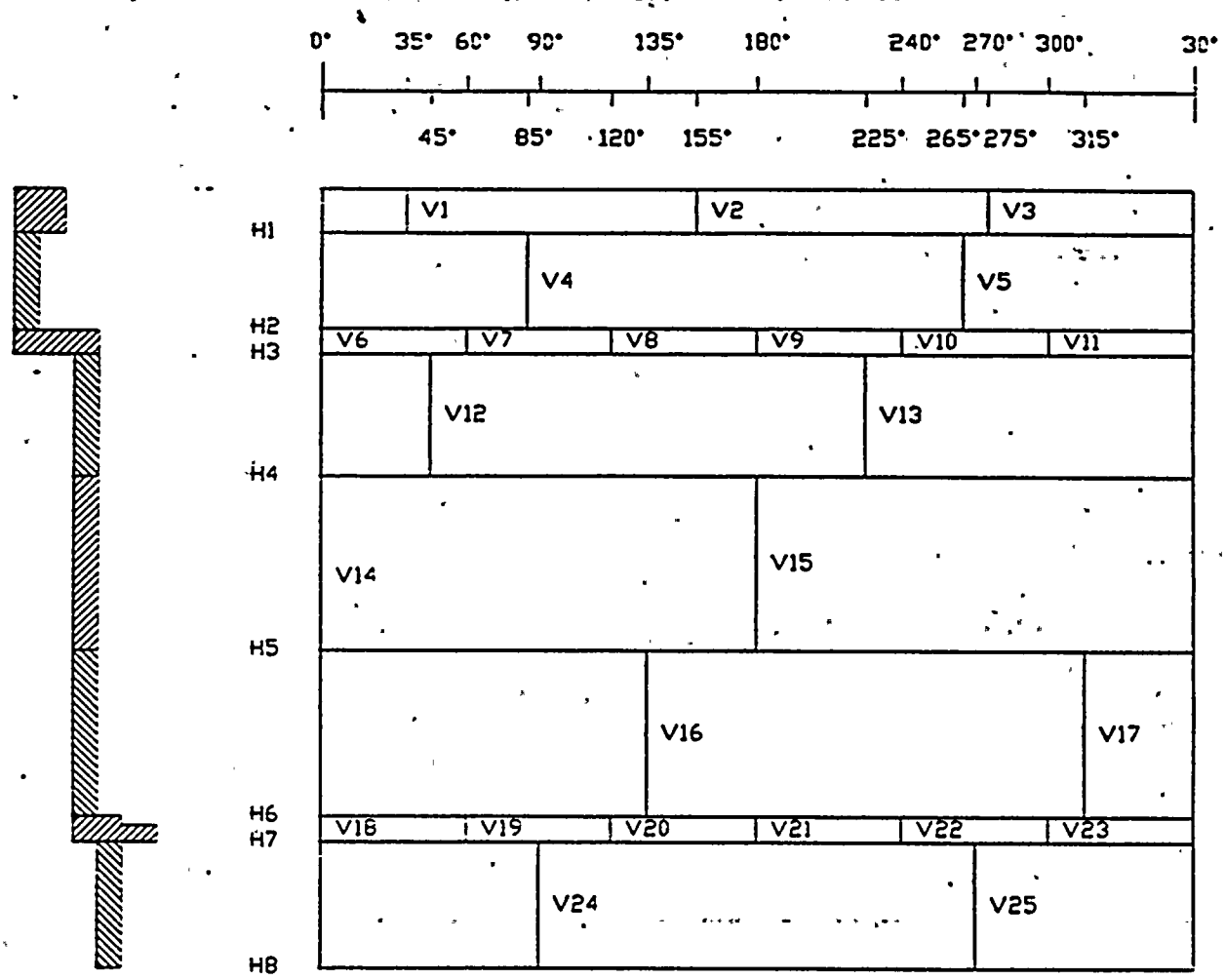

Figure 1-1 Weld Designations Used in NMP2 Shroud Cracking Evaluation (Weld azimuths are typical, and may not be located exactly as specified in above figure)