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

SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

RELATED TO REVISED FEEDWATER NOZZLE ANALYSIS

DETROIT EDISON COMPANY

ENRICO FERMI NUCLEAR POWER PLANT, UNIT 2

DOCKET NO. 50-341

1.0 INTRODUCTION

On July 29, 1992, Detroit Edison Company (DECo) provided for NRC review a revised feedwater nozzle analysis for Fermi-2. The revised analysis was a response to the NRC request on August 21, 1991, that required DECo to re-evaluate the original feedwater nozzle analysis before restart of Cycle 4, which began November 4, 1992. The request stemmed from the staff review of the original analysis submitted on November 2, 1989. The analysis showed that a postulated 0.25 inch deep crack would grow to a depth of 1.0 inch in 8.9 years, which did not meet the crack growth criterion in Generic Letter (GL) 81-11. Generic Letter 81-11 requires crack growth to be no greater than 1.0 inch in 40 years.

The feedwater is distributed through spargers that deliver the flow evenly to assure proper jet pump subcooling and help maintain proper core power distribution. An essential part of the sparger is the thermal sleeve, which projects into the nozzle bore and is intended to prevent the impingement of cold feedwater on the hot nozzle surface. The incoming feedwater (340°F to 435°F) is colder than the reactor vessel (about 545°F) and is much colder (about 100°F) during startup and shutdown when feedwater heaters are not in service. Turbulent mixing of the hot water returning from the steam separators and dryers and the incoming cold feedwater causes thermal stress cycling of the nozzle bore unless it is protected by the thermal sleeve.

In the late 1970's, inspections at BWR plants disclosed cracks in feedwater nozzles for those plants that have loose-fit sparger/thermal sleeve design. For those loose-fit thermal sleeves, bypass leakage past the juncture of the thermal sleeve and nozzle safe end is the primary source of cold water impinging upon the nozzle bore The frequency of thermal cycling caused by turbulent mixing led to metal fatigue and crack initiation.

Once a crack is initiated, it grows under stresses of lower frequency but higher amplitude than those encountered during turbulent mixing. These stresses are generated by the intermittent flow of cold feedwater into the vessel during startup and shutdown and during hot standby conditions when feedwater is added to maintain reactor water level. The frequency and magnitude of these stresses depend on whether such feedwater additions are modulated smoothly or are made by an on-off flow control system. Stress

cycles also are caused by pressure changes during startup. The large, low frequency thermal and pressure stresses are additive. Such cycling can propagate any small thermal fatigue cracks deep into the nozzle wall if remedial measures are not taken.

In November 1980, the NRC issued NUREG-0619, "BWR Feedwater Nozzle and Control Rod Drive Return Line Nozzle Cracking," recommending BWR owners to remove feedwater nozzle cladding, install modified sparger/thermal sleeve, change operating procedures, modify the feedwater control system with a low-flow controller, and follow NRC's inspection program.

Comments received from General Electric (GE) and BWR owners since the publication of NUREG-0619 note the difficulty in meeting the requirements for a low-flow controller having the six characteristics described in GE report NEDE-21821-A. The comments noted that an existing controller may not meet the six characteristics, yet the feedwater system may still in fact meet the criterion of the crack growth analysis (0.25 inch crack growing to less than 1.0 inch in 40 years) from which the characteristics were derived. The staff recommended the use of the low-flow controller to eliminate on/off feedwater operation and to preclude greater than 25°F mixture peak-to-peak temperature variations during steady demand. The low-flow controller will reduce the low cycle fatigue which, in turn, reduces crack growth.

On February 20, 1981, the NRC issued GL 88-11 to amend NUREG-0619 and to allow for a plant specific fracture mechanics analysis in lieu of replacing the existing controller. The analysis must show that stresses from controller temperature and flow profiles, when added to those resulting from the other crack growth phenomena, such as startup and shutdown cycles, do not result in the growth of a postulated 0.25 inch crack in the feedwater nozzle to more than one inch during the 40-year life of the plant. The analysis should be submitted as part of the reporting requirements specified in NUREG-0619.

2.0 EVALUATION

Fermi-2 uses a GE triple-sleeve sparger which has an improved interference fit thermal sleeve design. The vessel was manufactured with unclad feedwater nozzles. Fermi-2 uses a plant-specific low-flow controller which is different from the one recommended in the GE study. Instead of replacing the existing controller with a GE controller, DECo opted for the plant-specific fracture mechanics analysis as recommended in GL 81-11.

Generic Electric performed both original and revised feedwater nozzle analyses for DECo which consists of thermal cycle definition, plant operating history, finite element analysis, and crack growth analysis. The difference between the two analyses is in the thermal cycle definition and plant operating history. In the revised analysis, thermal cycles were based on plant operating data whereas in the original analysis thermal cycles were assumed because actual data were unavailable.

Thermal cycles for feedwater nozzles can occur as a result of 50 different normal and upset events. General Electric condensed these events to three basic type; startup, shutdown, and SCRAM to low and high pressure hot standby

followed by a return to full power. The revised analysis used three SCRAM events and eight startup/shutdown events taken from Fermi-2 strip charts during the period from April 1990 to June 1991.

The plant operating history delineates an accounting of the number of thermal cycles from the past and projects the expected number of additional transients before end-of-life. The startup, shutdown, and SCRAM cycles from 1986 to 1990 were 28, 28, and 53, respectively. These cycles were projected to 40 years with a total of 648 cycles of startups, shutdowns, and SCRAMs. The licensee stated that the number of cycles accounted for in the revised analysis is conservative because there tends to be more cycles in earlier years of plant operation than later, due to operator learning effects.

A finite element analysis was performed to develop temperature distributions and thermal and pressure stresses for use in the crack growth analysis. The finite element code, ANSYS, was used to develop a two-dimensional, axisymmetric model of the feedwater nozzle. The lengths of the nozzle safe end and pressure vessel section were each modeled to at least 2.5√Rt (2.5 times √Rt), where R is the radius and t is the thickness of the nozzle. This modelling assured that end effects did not influence the stresses in the nozzle corner region. The heat transfer coefficients for a triple thermal sleeve sparger design were used assuming seal number one failed. Pressure stresses were calculated based on a 1000 psi pressure. A scaling factor was applied to the pressure stresses because the two-dimensional finite element model cannot perfectly model the three dimensional characteristics near the nozzle corner.

From the pressure and thermal stresses, a third-order polynomial curve-fit technique was used to generate stress intensity factors. To simulate a three-dimensional nozzle corner crack, the stress intensity factors were calculated based on the average of magnification factors for a semi-circular crack and a quarter-circular crack.

General Electric used the fatigue crack growth rate data for low alloy steel from the 1989 edition of Appendix A to Section XI of the American Society for Mechanical Engineers (ASME) Code to calculate crack growth. For each thermal cycle, the maximum and minimum stress intensity factor and the number of occurrences were calculated. From this, the stress intensity factor range and the corresponding R-ratio (minimum stress intensity factor divided by maximum stress intensity factor) were calculated for each cycle. Using this information and the crack growth data in the ASME Code, the incremental crack growth was calculated for each cycle. The crack size was updated and the procedure was repeated for all cycles until all events had been analyzed. This process was repeated 59 times (648 events/11 events) to project crack growth for the entire 40-year plant life.

The revised analysis result shows that a postulated 0.25 inch crack would grow to one inch in 38.3 years. The result is very close to, but does not satisfy, the crack growth criterion in GL 81-11.

The staff determined that the analysis method is acceptable. The licensee stated that the thermal cycle projections used in the revised analysis are still conservative. The licensee believes that if projections were based on more years of plant operation, the analysis would have predicted the crack growth to no greater than one inch in 40 years. However, the staff needs to confirm this assessment. Therefore, the staff requires that DECo re-evaluate the crack growth analysis when more operating thermal cycle data are available and submit the analysis for NRC review six months before the end of 12 operating years.

On June 4, 1981, DECo committed to inspect the feedwater nozzles in accordance with the schedule and type of non-destructive examination in Table 2 of NUREG-0619. The inspection will monitor the structural integrity of the feedwater nozzles in case cracks develop in the interim.

3.0 CONCLUSION

The staff has determined that the analysis method is acceptable. However, the analysis results still do not satisfy the crack growth criterion in GL 81-11. The staff requires that DECo re-evaluate the crack growth analysis when more operating thermal cycle data are available and submit the analysis for NRC review six months before the end of 12 operating years.

The licensee has committed to follow the feedwater nozzle inspection schedule and examination specified in Table 2 of NUREG-0619. The inspection will monitor the structural integrity of the feedwater nozzles in case cracks develop in the interim.

The staff concludes that the results of the analysis demonstrate integrity of the feedwater nozzles and that public safety will be maintained pending the future assessment of operating data.

Principal Contributor: J. Tsao

Dated: December 8, 1992