ENCLOSURE 3

SAFETY EVALUATION BY THE OFFICE OF
NUCLEAR REACTOR REGULATION

INDIANA - MICHIGAN POWER COMPANY
D.C. COOK UNIT 2

DOCKET NO.: 50-316

EVALUATION OF THE CRACKING OF THE STEAM GENERATOR NOZZLE TO REACTOR COOLANT PIPING WELDS

I. INTRODUCTION

During the 1988 refueling outage the licensee, Indiana - Michigan Power Company, replaced the four Westinghouse Series 51 steam generators at D. C. Cook Unit 2. Extensive cracking occurred during the welding of the reactor coolant piping to the replacement nozzles. The staff considered the cracking to be a signficant event because of the number and depth of repair excavations. This report provides the staff's evaluation of this issue.

On November 7, 1986 the licensee submitted a topical report entitled "Steam Generator Repair Report" addressing the safety-related aspects associated with the replacement. The staff evaluated this document and prepared a SER dated January 20, 1988. The staff's evaluation emphasized the original tube degradation mechanism, the objectives of the design improvements, materials selection for internal components and the new performance characteristics. Replacement programs had been successfully completed at several plant sites. The staff's review was based on the licensee's assertion that the replacement steam generators would be similar in design and would be functionally the same as the original units. The licensee also stated that the original design configuration and installation requirements would be used when components and piping are reinstalled. This eliminated any modifications that would require changes to the original design analysis.

II. SUMMARY OF SEPTEMBER 19, 1988 MEETING

A meeting was held between the staff and the licensee on September 19, 1988 to discuss the cracking of the steam generator nozzle to reactor coolant elbow

welds. The licensee described the joint configuration, materials of construction, welding process, degree of cracking, nondestructive examination and corrective action. The problem was related to the inability to properly tie-in the weld beads at the nozzle side wall leading to separation of metal at the fusion line between the nozzle butter deposit and the adjacent weld bead. The D. C. Cook replacement project was the first use of the flux cored arc welding (flux core) process to apply the stainless steel butter on the cast carbon steel nozzle during fabrication. The field welds were made with manual gas tungsten arc welding (GTAW) root passes and filled with an automatic GTAW process. The difficulty encountered was in obtaining complete fusion along the buttering interface when welding progressed above the change in joint bevel. Sporadic weld pool behavior and poor wetting were observed when the gas tungsten arc weld was made over the flux core deposited buttering. Visually observable cracking occurred on the nozzle side of the joint due to poor fusion at the nozzle caused by the tight joint access, poor wetting, and the force of gravity. The poor fusion created a notch at the interface between the weld metal and nozzle buttering from which a crack propagated as a result of shrinkage stresses in the deposited layer.

The licensee's position is that the flux core process is equivalent to other flux processes and no ASME Code or regulatory restrictions exist that prohibit the use of the process for cladding or buttering. The licensee assembled an experienced team to assess the entire welding process. As a result of this evaluation, the welding procedure was modified to change the technique, i.e., different electrode angle and welding sequence. To reduce shrinkage stresses in the joint, bead width was reduced by eliminating torch oscillation and depositing stringer beads. Bead sequencing was changed to start each layer at the nozzle side of the joint first and progress towards the elbow side. These welding technique changes relieved the surface cracking by reducing shrinkage stresses in the weld joint. The tight joint access continued to cause lack of fusion defects after the cracking problem was solved. The lack of fusion defects were embedded in the weld, occurred in the middle 1/3 of the thickness of the weld joint, and is required to be repaired by ASME Section III. Before the September 19, 1988 meeting all known defects had been removed and the structural welding was essentially completed. The licensee concluded that final nondestructive testing would demonstrate that the welds meet all applicable Codes and, therefore, the welds would be acceptable for service.

III. ADDITIONAL INFORMATION PROVIDED BY THE LICENSEE

The licensee provided additional supporting documentation in a letter dated October 28, 1988. Three samples were taken from different welds and sent to Edison Welding Institute for metallurgical analysis. The samples from number 1 hot leg contained one face of a crack fracture surface and 308L buttering material. Scanning electron microscopic examination revealed evidence of ductile rupture throughout the fracture surface. A microhardness traverse across the sample correlated to acceptable strength levels for 308L deposit, and a bend test revealed no signs of embrittlement. The microstructure was normal with no sign of degradation or ferrite dissolution. Sufficient theoretical basis and documented research exist to conclude that the heat of the repair activities do not degrade the microstructure. The analytical data from the Edison Welding Institute investigation supports the conclusion that cracking originated at the fusion line and propagated due to tensile overload.

Two relatively large all-weld metal samples were removed from number 3 cold leg and number 4 hot leg for chemical analysis as a result of Code-acceptance radiography. The results showed no evidence of chemical elements contamination as a contributing factor in the welding difficulty. Metallurgical analysis by the Edison Welding Institute revealed normal microstructures with no signs of degradation, and microhardness traverses across the samples correlated to acceptable strength levels for 308L deposit. Further, the service temperature is far below the range in which ferrite dissolution would occur during the steam generator lifetime.

The Edison Welding Institute provided an explanation for the sporadic weld pool behavior and poor wetting noted earlier. This behavior is not uncommon with gas tungsten arc welding over deposits made by a flux-bearing process, such as flux-

core, shielded metal arc, or submerged arc welding. Flux entrapped in the microstructure of these deposits is remelted and acts on the gas tungsten arc welding pool to impede weld pool fluid flow and wettability. Welding technique changes compensated for these conditions. Metallurgical evaluation indicated that the 308L buttering material was not a primary cause of cracking.

The licensee concluded that a thorough investigation has been made of the potential causes of the welding difficulties encountered. This investigation revealed no evidence of metallurgical degradation and no reason to expect anything but the full mechanical properties of these weld joints. Numerous informational radiographs have been taken during the construction and detected indications have been removed. Repairs have been completed on all steam generator nozzle to reactor coolant elbow welds, which have been accepted by ASME Section III radiography. Section XI ultrasonic examination is in progress. In addition to the investigative efforts and Code-required examinations described above, supplementary examinations to conclusively demonstrate the integrity of these weld joints have been undertaken.

IV. STAFF EVALUATION

The steam generator replacement project was accomplished based on a topical report, which the staff reviewed. The welding was performed in accordance with the requirements of Section III, Section IX and Section XI of the ASME Code, 10 CFR 50, and state of Michigan Boiler Law and Rules and Regulations. The weld filler metals and electrodes were ordered in accordance with Section II and Section III of the ASME Code.

A. Site Inspection

The staff decided that a site visit was necessary to evaluate additional details of the welding problem. Region III personnel and representatives from NRR participated in this inspection. Technical support was provided by two consultants from Brookhaven National Laboratory and Parameters, Inc. The staff's

consultants trip reports are included as Appendices 1 and 2. The staff addressed the topics of welding and nondestructive testing during the period between September 20 - 22, 1988.

Welding Issues

The objectives of the staff's visit were to assess the licensee's welding process, evaluate the flux core butter, determine the influence of hydrostatic test cap and identify any generic issues. Westinghouse conducted a limited survey for the licensee of recent industrial experience with nuclear steam generator construction and replacement projects. Similar automatic GTAW equipment was used. Lack of side wall fusion defects occurred adjacent to the nozzle butter at other sites. The basic welding problems encountered at D. C. Cook were not unique, although the flaws observed in the past were less severe. The licensee's corrective measures included some of the approaches used at other projects.

The hydrostatic testing cap was removed at the site by plasma arc cutting, the weld preparation remachined and nondestructively examined. The final joint geometry, dimensions, materials of construction, and welding methods for the replacement nozzle to pipe weld are typical for this application and are illustrated in Appendix 1, Figures 2 and 4. The weld joint is a compound bevel single-U groove weld oriented in the 6G position. One apparent difference is the flux core process was first used to apply the stainless steel butter deposit. Appendix 1 describes the construction codes, the material specifications, the nominal chemical analysis of both the components and filler materials, and the welding parameters.

During installation the steam generator channel head assembly was aligned with the polar crane, tack welded in place to the piping and the approximately 3/8" root pass completed with manual GTAW. Restraints and fixtures were not used. The polar crane was then disconnected for other plant tasks. Inside diameter cosmetic grinding was required on some of the GTAW root reinforcement. Welding continued with the automatic GTAW system. Acceptable weld fill was obtained through

the 22.5 degree bevel portion of the joint with the manual and automatic GTAW (see figure 4). Significant cracking and difficulty welding were first encountered at the 12.5 degree transition point of the weld bevel and the flux core to automatic GTAW interface. [The hydro cap had been removed from this region.] The extent and predominate location of the cracking are illustrated in Appendix 1. The flaws were observed visually and detected with in-process liquid penetrant testing and radiography.

The licensee concluded that the probable root cause was improper technique due to the electrode angle not allowing proper side wall fusion and the use of excessive electrode weave. Corrective action including reducing the weave and using stringer beads with the first stringer weld applied to the flux core face. Manual GTAW overlay of the flux core bevel face was also used before automatic GTAW in an attempt to reduce the cracking. Weld defects were removed by grinding and repaired with the shielded metal arc welding (SMAW) process.

The licensee lost control of the welding process in late August 1988 that resulted in significant cracking and numerous repair excavations. The staff agrees that the licensee's evaluation of the predominate cause of the welding problem has merit; the staff found that other factors also contributed to the severity of the welding difficulty. The deficiencies identified are discussed in Appendix 1. The staff did not find an inherent problem with the flux core butter. If this were the case, weldability problems should have been observed along the entire nozzle side wall. As part of the remedial effort, a manual GTAW overlay was applied over the flux core butter deposit prior to automatic GTAW. Although this action did not resolve the cracking problem, the GTAW overlay did reduce the possible contribution from the flux core process and the hydro cap to the welding problems.

<u>Nondestructive Examinations</u>

The objectives of the audit of the licensee's radiography were to determine the effectiveness of the examination method and to assess the results of modifications to the welding procedure. As general practice during welding informational radiographs were taken of repairs and at roughly 1/3 fill, 2/3 fill and full weld fill before the final Code-acceptance radiographs. The staff's review of the in-process radiographs showed that some exposures revealed cracked in areas where none had existed on a prior exposure with no metal added. This phenomenon was due to a shift in source position from shot to shot. The radiographers were not careful while setting up the exposure; thereby, the indications were masked in the density break on one exposure and, due to shift in position, would be readily visible on the next exposure. In some cases there was a much as a ½ inch shift. Tungsten inclusions that appeared on some exposure were used to determine this condition. The methodology used to make this conclusion is described in Appendix 2.

Tables with the chronology of repairs for each weld based on radiographic data are shown in Appendices 1 and 2. At the time of the NRC inspection Code-acceptance radiography had not been completed. "T" film was used for the in-process exposures. The staff determined that "T" film would be preferable for the accep-tance exposures instead of "AA" film, which is less sensitive. In order to support its position concerning the integrity of the welds, the licensee per-formed two radiographs oriented along the 12.5° joint prep angle. This was done to provide maximum detectability of any planar indications on the nozzle side of the joint. After reviewing these exposures the staff determined that radiography with the Code-acceptance technique and the optimum angle, using "T" film, would display all radiographically rejectable indications.

The licensee conducted ultrasonic testing to supplement the weld repair and to develop plant-specific procedures. ASME Section XI requires that the inner 1/3 of the weld be examined. The D.C. Cook ultrasonic testing was augumented to include the entire weld volume to examine the excavation region. Accessibility was optimized by (1) inside diameter (ID) surface conditioning, (2) no counter-bore interference and (3) an outside diameter (OD) surface weld buildup. Technique performance verification was demonstrated at the plant on the cast stainless steel elbows by ID through transmission and observation of inside sur-face geometric reflectors. The O. D. surface buildup was machined to reduce transducer lift-off. The examination procedure requires the recording of all reflectors, other than geometric, regardless of amplitude.

The staff determined that a comprehensive technical approach was used by the licensee to develop a plant-specific ultrasonic testing procedure. The contoured weld buildup resulted in an external surface finish that is superior to most applications in the industry. However, the licensee did not correlate the ultrasonic testing with cracks prior to excavation to show that the instrumentation was capable of detecting and recording flaws adjacent to the nozzle butter. The staff found that the licensee's ultrasonic testing method should be demonstrated to be effective for the detection of significant flaws in the mid-plane region.

B. Supplemental Examinations

Licensee's Description

In the letter dated October 28, 1988 the licensee summarized the conclusions of his investigation, described the supplemental examinations conducted after the NRC site inspection and defined his plans for inservice inspection. During fabrication almost 100 in-process informational radiographs were taken in addition to the final Code-acceptance radiography. All Unit 2 nozzle to reactor coolant elbow welds were also radiographed at an angle oriented along the 12.5 degree joint prep to provide maximum detectability of any planer indications on the nozzle side of the joint. The licensee concludes that this extensive radiography provides a high level of assurance that relevant radiographic indications were detected and repaired. In addition to the Section XI ultrasonic examination on each nozzle to elbow weld performed after construction, the licensee committed to perform a second Section XI ultrasonic examination of all welds after hydrostatic and pre-operational testing. This will subject the welds to one pressure/temperature cycle and the subsequent ultrasonic examination will serve as the official Section XI preservice baseline.

On October 15, 1988, a very thin, 3/4" long radiographic indication was detected on number 3 cold leg. Before the indication was removed, various ultrasonic transducers were characterized on this indication based on amplitude response, signal-to-noise ratio, and screen presentation. Superior performance was obtained using a 45°, 1 MHz, dual element (two ½" x 1" crystals), fixed roof angle, refracted longitudinal wave transducer. At Code scanning levels, this indication produced a 50% DAC (Distance Amplitude Correction) peak amplitude response with a signal-to-noise ratio of better than 4:1. 50% DAC is a recordable indication by ASME Section XI criteria.

When ultrasonic transducer characterization was completed, the size of the indication was quantified by a cycle of grinding/penetrant test/photograph/depth measurement. A layer of roughly 1/16" was removed by grinding during each cycle. Using this method, the indication was determined to have a through-wall dimension of 1/4", maximum length of 7/8", at a depth of 1-1/8" from the outside diameter. According to ASME Section XI, 1983 Edition plus Summer 1983 Addendum, this indication is subsurface and has a through-wall dimension to component thickness ratio (a/t) of 4.5%. The allowable preservice inspection planar indication size in Table IWB-3514-2 is less than a/t = 7.8%. Therefore, the ultrasonic technique to be used on the steam generator nozzle to reactor coolant elbow welds has demonstrated capability to detect in-situ reflectors which are smaller than Code allowable size. This gives a high level of confidence that the ultrasonic examination technique provides a valid assessment of the integrity of the installed welds for preservice and inservice inspections. Ultrasonic testing performed in the future will be conducted with this technique. The inservice inspection program for the 10 year interval following installation will be front loaded to the maximum extent permitted by ASME Section XI. Four steam generator nozzle to reactor coolant elbow welds will be examined during the first period of the interval (at the next scheduled refueling outage), two during the second period, and two during the third period.

As an additional qualification of the ultrasonic examination technique, the licensee has completed design of a mock-up block. The licensee plans to have this block fabricated from the same cast carbon steel and stainless steel material specifications as the nozzle and elbow, and 308L buttering will be applied to the cast carbon steel. The block will have two sets of side-drilled holes at 1/4T, 1/2T, and 3/4T, and two 0.3" deep by 0.06" wide ID notches. Five ID cracks will be induced ranging from less than the ASME Section XI allowable size to greater than the allowable size.

Staff Discussion

The staff has evaluated the licensee's nondestructive examination and finds the overall program to be acceptable. The rejectable defects found after the staff's site inspection provided an opportunity for the licensee to evaluate the metallurgical properties of the weldment and to optimize the transducer selection. Radiography and ultrasonic testing are complementary volumetric techniques, each intended to detect different types of flaws. The radiography is intended to detect fabrication conditions. The licensee conducted both optimum angle and Code-acceptance radiography on each of the completed welds.

Ultrasonic testing is normally intended to detect service-induced degradation originating from the inside diameter surface (lower 1/3 examination). The replacement steam generators permitted ID access to demonstrate penetration of the cast stainless steel elbows and to resolve geometric reflectors. As a result of the welding problems, the licensee installed a contoured weld buildup on the external surface and expanded the scope of examination to the full weld volume in order to examine the mid-plane region adjacent to the nozzle butter. The licensee will perform two ultrasonic examinations prior to returning the plant to service. The licensee is fabricating a mockup for additional development. This mockup will permit the licensee to confirm that the ultrasonic testing used during the inservice inspection is also effective for the detection of inside diameter flaws.

Some welds were subjected to an unusual number of major excavations. The licensee's metallurgical analyses and the staff independent evaluation does not indicate that the mechanical strength or fracture toughness properties of the welds were significantly affected by the repair process. Therefore, the staff finds that the licensee's plan to perform the first inservice inspection of these welds at the next refueling outage is acceptable.

V. CONCLUSION

Based on the results of this evaluation, the staff reached the following conclusions:

1. The automatic flux core arc welding process for applying the butter deposit was not a prime contributor to the problems encountered performing the nozzle to primary pipe elbow weld.

2. The welding and field removal of the nozzle hydrostatic test cover plate was not a major contributing factor to the welding problem.

3. The licensee experienced significant difficulties with the control of the welding parameters. The licensee resolved the problems, modified the welding procedure and repaired the welds.

4. The steam generator nozzle to primary piping welds are acceptable for service based on the nondestructive examinations that were performed.

5. The mechanical properties of the completed welds were not significantly affected by the repair process.

6. The nondestructive testing in accordance with the scope described in the licensee's October 28, 1988 letter will provide adequate assurance that defects that could cause a loss of structural integrity will be identified. The best available ultrasonic testing instrumentation and techniques should be used during scheduled inservice inspections. The licensee should continue with the design and fabrication of mockup in order to optimize the examination procedure. The licensee should demonstrate the effectiveness of the ultrasonic testing procedure before the first refueling outage.