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

ENCLOSURE

SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

SOUTHERN CALIFORNIA EDISON COMPANY

SAN ONOFRE NUCLEAR GENERATING STATION UNIT 1

DOCKET NO. 50-206

1.0 INTRODUCTION

In a letter dated January 13, 1989, the Southern California Edison Company (the licensee) submitted report FaAA-84-12-14 Revision 1.0, entitled "Evaluation of Transient Conditions on Emergency Diesel Generator Crankshafts at San Onofre Nuclear Generating Station Unit 1" (San Onofre 1). The report summarized the results of inspection, testing and analyses performed on the emergency diesel generator crankshafts at San Onofre 1. Additional information regarding crankshaft transient response of the emergency diesel generators was provided in a letter from the licensee dated May 31, 1989.

In another letter dated June 19, 1989, the licensee requested that engine start-stop cycles in which engine speed does not exceed 200 rpm not be counted towards meeting license condition number 3.L(1). License condition number 3.L(1) requires that the number of start-stops on each diesel engine be limited to no more than fifty between successive inspections of the crankshaft oil holes.

2.0 DISCUSSION

As a result of eddy-current inspection in the crankshaft main journal oil hole regions of Diesel Generator 1 (DG1) in July and August, 1984, and of DG2 in October, 1984, cracks were observed in DG1 main journal oil hole numbers 8, 9, and 10 and in DG2 main journal oil hole number 9. All cracks were removed either by drilling the oil hole to a larger diameter or by grinding and polishing the blend radius. DG1 and DG2 had approximately 740 and 450 starts, respectively.

The eddy current probe calibration was performed on a 20 mil deep, 40 mil long, 10 mil wide notch, which was machined to simulate a crack-life defect. The magnitude of the eddy current signal received from the cracks in the oil holes varied from 36 percent to 300 percent of the calibration standard. Based on the drill size utilized to remove the cracks, the maximum crack depth in each oil hole varied from 63 mils to 250 mils. Several cracks extended for at least 3 inches.

Torsiograph test data from three fast starts, two slow starts, and six coastdowns of the San Onofre 1 DG1 were used to determine the free-end response, the cylinder pressure and the nominal torsional stress on each main journal. The licensee's torsional analysis indicates that the highest level of vibration occurred during fast starts and the level of vibration varied depending on the initial starting position of the crankshaft. The fast start with cylinder 10RB (right bank) at BDC (bottom dead center) in its exhaust stroke produced the highest level of vibration, producing a maximum nominal torsional stress of 20.79 ksi in main journal 10. The stresses in main journals 8 through 12 are nearly as high as in 10.

The licensee performed a low cycle fatigue analysis to determine the cumulative damage for cycles of starts-stops. The licensee analysis indicates that 95 starts-stops would produce a cumulative damage of 0.8 in main journal number 10. However, due to the scatter in low cycle fatigue data, the number of start-stops required to initiate a flaw is not known with a high degree of certainty.

The licensee performed a fracture mechanics analysis to predict the amount of crack propagation. In this analysis the licensee used two different crack geometry models and four different load histories. An edge crack with one degree of freedom (1DOF) under a univariate stress field had a higher propagation rate than the other model evaluated. Based on the long shallow nature of the cracks observed in the oil holes, the licensee indicated that the 1DOF model represents a realistic model.

The load histories are identified as "Best Case," "Worst Case," "Slow Start," and "Average." One cycle in each case consists of a start, two hours of steady state operation at full load (6000 KW) and a coastdown. The vibration during steady state and coast down was assumed the same for each case. The variable in the four cases was the amount of vibration during the start of the DG. The licensee indicates that the crack propagation versus load history for the 1DOF model with "Average" case loads correlates well with field experience at San Onofre 1. For this case, a crack is predicted to grow from 5 mils to 18 mils in depth in approximately 520 cycles. A crack is predicted to grow from 10 mils to 18 mils in depth in approximately 150 cycles. For the "Average" case, the vibration during a start was the average of 10 starts in which the crankshaft's initial position is altered by 72 degrees, thereby covering two revolutions of the crankshaft.

For the "Worst Case" the vibration during a start was assumed to be the values predicted for a fast start with cylinder 10RB at BDC in its exhaust stroke. For this case with the 1DOF models, a crack is predicted to grow from 5 mils to 18 mils in depth in approximately 320 cycles and from 10 mils to 18 mils in depth in approximately 100 cycles.

The licensee's fatigue crack growth analysis indicates full power steady state loads do not contribute to crack proprogation until the crack has propogated to a depth of 18 mils. At this depth rapid crack propogation occurs. Hence, 18 mils of crack growth represents the life of the DG crankshaft.

The fatigue growth rate utilized in the fatigue crack growth analysis was derived from crack growth data available for low strength, medium carbon steel in an air environment. The crankshafts were forged from vacuum degassed, medium carbon, low strength steel. The licensee indicates that the oil environment of the engine would not be considered a corrosive environment and is expected to be more benign than the air environment of the test data.

The crack growth rate utilized by the licensee tends to be near the lower bound of the available data. Hence, it could produce non-conservative growth rates for the crankshaft material.

The licensee's conclusion about the benign oil environment is generally correct for the crankshaft material. However impurities such as sulfides are known to cause rapid crack propagation

The report contained the following conclusions and recommendations:

(a) Stress cycles during startup and coastdown are above the endurance limits.

(b) It is safe to operate the engine with cracks up to 18 mils deep.

(c) If the oil hole regions are inspected so that 10 mil deep cracks can be detected, then the number of starts-stops to propagate a crack from 10 mils to 18 mils deep represents the effective life of the crankshaft.

(d) Inspections should be performed at outages so that the inspection interval is approximately 50 starts-stops.

(e) When cracks are detected they should be removed.

(f) Initially, main journals 4 through 12 should be inspected. During future inspections a smaller number could be inspected as long as no cracks are found.

3.0 STAFF CONCLUSIONS

(a) Based on the licensee's fatigue crack growth analysis, 18 mils of crack growth represents the effective life of the crankshaft. This is a reasonably conservative estimate, since cracks as deep as 1/4 inch have been observed.

(b) The information provided in the report on calibration of the eddy current probe and drill size to remove the cracks is insufficient to determine whether cracks 10 mils deep can be detected by the licensee's eddy current inspection with a high degree of confidence.

(c) An inspection interval of 50 starts-stops is acceptable provided the licensee can demonstrate that the eddy-current inspection technique is capable of detecting 10 mil deep cracks with a high degree of confidence.

(d) Engine start-stop cycles with engine speed less than 200 rpm need not be counted towards meeting license condition 3.L(1) provided the licensee can demonstrate that the stresses induced in the crankshaft at startup and coast down are less than the steady state values.

(e) Since cracks as deep an 1/4 inch were reported, it is possible impurities in the oil, which result from engine operation or oil manufacture, may have contributed to crack initiation and propagation.

(f) License condition 3.L(1) will prevent cracks in the oil holes from causing fracture of the DG crankshafts until the next refueling outage.

RECOMMENDATIONS

(a) Prior to the next refueling outage the licensee must demonstrate that the eddy current inspection procedure is capable of detecting 10 mil deep flaws.

(b) If the licensee can not demonstrate that the eddy current inspection procedure is capable of detecting 10 mil deep flaws, the licensee should replace the crankshafts with a design that is not susceptible to cracking.

(c) The licensee should review his DG oil maintenance procedures to ensure impurities in the oil do not contribute to initiation and propagation of cracks in the oil holes.

Principal Contributor: Barry Elliot

Date: November 21, 1989