APPENDIX B

U.S. NUCLEAR REGULATORY COMMISSION
REGION IV

Inspection Report: 50-498/94-16
50-499/94-16

Licenses: NPF-76
NPF-80

Licensee: Houston Lighting & Power Company
P.O. Box 1700
Houston, Texas

Facility Name: South Texas Project Electric Generating Station, Units 1 and 2

Inspection At: Matagorda County

Inspection Conducted: May 2-6, 11, and 13, 1994

Inspectors: P. A. Goldberg, Reactor Inspector, Division of Reactor Safety

Accompanied by: J. R. Rajan, Mechanical Engineer, Division of Engineering
Office of Nuclear Reactor Regulation

Approved: C. J. Paulk, Acting Chief, Engineering Branch 6-10-94
Date

Inspection Summary

Areas Inspected (Units 1 and 2): Nonroutine, announced inspection of the licensee's actions concerning standby diesel generator spurious starts, failed fuel injection pump hold down bolts, Standby Diesel Generator 22 piston failure corrective actions, Unit 2 standby diesel generator final system readiness review report, and standby diesel generator operation with one or two cylinders inoperable.

Results (Units 1 and 2):

- Licensee's actions to resolve the standby diesel generator fuel injection pump hold down stud problem was progressing satisfactorily. The licensee had replaced the hollow studs on the three Unit 2 diesels with solid studs. The licensee was in the process of generating a plan for replacement of the Unit 1 studs (Section 1.1).

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- Station Problem Report No. 940864, which documented the standby diesel generator fuel injection pump hold down stud failures, was considered to be well done and comprehensive; however, a loose hold down stud found earlier on Standby Diesel Generator 22 had not previously been documented on a station problem report. The failure to have initiated corrective action on initial identification was a violation (Section 1.1).

- Licensee actions to resolve the spurious start issue was progressing. The spurious starts were not considered to be safety significant (Section 1.2).

- The licensee's actions concerning the piston failure on the No. 22 standby diesel generator were considered satisfactory (Section 1.3).

- The Unit 2 final system readiness review report was considered acceptable (Section 1.4).

- Staff action to review standby diesel generator operability with 18 or 19 of 20 cylinders operating was closed. The staff concluded the diesels at South Texas Projects were adequately balanced to preclude excessive engine stresses if the diesels were required to carry design rated loads with up to two cylinders inoperable and provided that there was only steady state operation or decreasing load (Section 1.5).

<u>Summary of Inspection Findings:</u>

- Violation 499/9416-01 was opened (Section 1.1).
- Inspection Followup Item 498;499/9416-02 was opened (Section 1.2).

<u>Attachment:</u>

- Attachment - Persons Contacted and Exit Meeting

DETAILS

1 INTRODUCTION

Both units at the South Texas Projects facility were shutdown in early February 1993, as a result of numerous broad scope problems identified by the NRC and the licensee. At the time of this inspection, Unit 2 was still shutdown. This inspection was conducted to review South Texas Project's actions concerning spurious starts of the standby diesel generators (SDGs) and failed SDG fuel injection pump hold down studs.

1.1 Failure of SDG Number 22 Fuel Injection Pump Hold Down Studs

NRC Inspection Report 50-498/93-44; 50-499/93-44 documented nine failures of the SDG fuel injection pump hold down studs. The SDG manufacturer, Cooper Bessemer, had designed the studs hollow to provide a mechanical fuse in the event of a high pressure fuel system malfunction. If a high pressure pump were to seize or a hydraulic lock occur, the studs were designed to break to prevent damage to engine components. After the ninth failure, the licensee determined that the root cause had been inadequate preload on the bolts which had caused the studs to loosen and eventually fail. For corrective action, the licensee implemented the recommendations outlined by Cooper Bessemer in their Engineering Standard No. 123. These recommendations included the lubrication of the stud threads, lock nut threads, and the mating surfaces prior to installation adding the run down torque for the lock nuts to the total torque. This action was taken to provide proper prestress of the fasteners. The licensee had replaced all bolts and locking nuts in accordance with Cooper Bessemer Engineering Standard No. 123 recommendations in December of 1993.

Around March 28, 1994, prior to the April 14, 1994, 6L fuel injection pump failure, the licensee found a loose hold down stud on the 2L fuel injection pump on SDG No. 22. The four fuel injection pump hold down studs were replaced on a service request since relaxation of the stud indicates potential degradation of the stud and was a significant precursor to stud failure. No station problem report (SPR) was generated. The licensee documented the loose stud nut on SPR No. 940864 after the 6L injector pump failure. The inspectors concluded that by not writing a SPR, the licensee had lost an opportunity to analyze the studs and determine the cause of failure. Criterion XVI, Appendix B of 10 CFR 50, requires that, in the case of significant conditions adverse to quality, measures shall assure that the cause of the condition is determined and corrective action is taken to preclude repetition. Station Procedure OPG03-ZX-0002, "Correction Action Program," Revision 4, required that any person associated with South Texas Projects who identified a deficiency of significant deficiency was responsible for initiation a SPR in accordance with the requirements of the procedure. Licensee did not determine the cause of the loose stud nut or initially take corrective action. The inspectors identified this as a violation (498;499/9416-01).

On April 14, 1994, the fuel injection pump on SDG No. 22 at cylinder 6L was ejected from its position due to the failure of the four hollow hold down studs which held the pump to the fuel injection pump pedestal. The hollow studs failed during post maintenance testing of SDG No. 22. In addition, the licensee reviewed surveillance inspection documents and found the 2L cylinder on SDG No. 22 had been detected in March 1994 to have had a loose hold down stud nut. The licensee reviewed the history of hold down stud failures and determined that a total of 12 failures had occurred at the South Texas Project, with 8 out of the 12 occurring to SDG No. 22.

The inspectors reviewed SPR No. 940864, dated April 14, 1994, which documented the injection pump stud failure. The SPR was determined to contain a history of the hold down stud failures, an event analysis, and a detailed root cause analysis. Corrective actions included replacing the hollow studs and elastic stop nuts with solid studs, heavy duty nuts and Belleville washers. All replacements had been completed for the three Unit 2 diesels. The licensee was preparing a plan for the installation of the solid studs in the Unit 1 diesels. The licensee contacted Cooper Bessemer concerning installation of the solid studs. Cooper Bessemer responded by stating that a solid stud would give rise to a commercial risk, however, they judged that risk to be small. The inspectors concluded that the SPR was well done and comprehensive.

A metallurgical examination of the failed studs by the licensee indicated that the failure was similar to the past failures, two studs showed fatigue related failure and they all showed tensile shear. The licensee contracted MPR Associates, Failure Prevention Incorporated International, and the manufacturer, Cooper Bessemer, to assist in the failure root cause analysis. Calculations were performed to evaluate the margins of safety in the hollow stud design and the proposed solid stud design (Calculation No. MC-6440). The design of the fasteners for the fuel injection pump mounting was analyzed using operating and design basis loads, which were provided by the manufacturer. As part of the evaluation, fastener preloads were calculated. The basic approach taken in this analysis was to extend and incorporate existing analytical results from previous calculations and to analyze the proposed design to confirm its adequacy under design basis conditions.

The licensee has identified three causal factors which influenced failure of the hollow studs. These were related to the installation methods, manufacturing tolerances, and design margins. The licensee considered the hollow stud design adequate but marginal, and was replacing the hollow studs with a fastener arrangement which included the use of solid studs with a Belleville washer to provide adequate preload.

1.1.1 Installation-Related Practices

Installation-related practices were suspected to contribute to the loss of stud preload which lead directly to the high cyclic stress failure of the studs. The licensee examined embedment of the stud in the joint under cyclic loads, torquing practices which did not specify a torquing sequence, and use of Loctite, which may have compressed under load.

1.1.2 Manufacturing

The licensee considered manufacturing tolerances such as stud dimensions, hole dimensions, and thread manufacturing methods. The licensee reported that some hollow studs had machined threads rather than rolled, which resulted in an approximate 20 percent reduction in strength according to the licensee. Checks of stud dimension by the vendor was stated by the licensee to be a go/no-go gage check of the inside diameter on between 10 percent to 20 percent of the run population. The inspectors observed that other critical tolerances, such as eccentricity of the hole drilled in the hollow studs and the minimum wall thickness, did not appear to have been determined. Deformation of the stud hole was found in one instance to allow installation of the stud at an angle and resulted in stud deformation.

1.1.3 Design Margin

The original material used for the hollow studs was AISI 1045. In 1984, Cooper Bessemer changed the material to ASTM 193 Grade B-7 hollow studs with a thinner wall thickness. During this inspection, the inspectors determined that both the old and the new hollow studs were kept in the same storage bin at the South Texas Projects facility with the same part number. Initially there was some concern about material control. However, the inspectors reviewed a 1987 letter from Cooper Bessemer that stated the parts were compatible and interchangeable. In addition, the inspectors determined that there was some traceability for the studs used. The service request documented both the stud part number and receiving report number which lead to the purchase order number and the stud material.

The inspectors reviewed Calculation MC-6440, which quantified the design margin in the studs based on measurements of stud root diameter, and minimum and maximum wall thickness taken during metallurgical examination. The licensee's summary of the calculation stated that ten different cases were run with varying stud root diameter, nut factor, and material properties. For the case in which nominal values and AISI 1045 material were used, the design margin to yield from initial preload was calculated to be only 1.26. For the nominal case, using the new materials properties, the margin was only 1.36. In each of the other cases, when dimensions were varied, the calculated design margin was less than that for the nominal cases. Given that there was some uncertainty in the calculations due to assumptions made and measurement inaccuracies, there was still considerable difference between the vendor-supplied margin and that calculated. The lack of additional design margin with the hollow studs was concluded, by the licensee, to provide a strong motivation to go to a solid stud conservative configuration which provided higher margins.

The cyclic operational loads on the bolts were primarily generated during pump operation as the pump fluid pressure cycled between 241 kPa (35 psi) to 7.6 MPa (1100 psi). This resulted in operating loads of over 40 kN (9000 lbs) along the axis of the bolts. These loads have been conservatively calculated.

1.1.4 New Stud Design Compared to Previous Hollow Stud Design

MPR Associates performed a fatigue evaluation of the hollow studs (AISI 1045 material with a 0.99 cm (0.391 in) center hole, and the studs delivered after 1984, A193 Grade B-7 material with a 1.07 cm (0.422 in) center hole) and compared it to fatigue stresses in solid studs of the A193 Grade B-7 material. The analysis assumed a loose joint with no preload. Failure by fatigue was not predicted for the hollow studs if the alternating loads were assumed to be evenly distributed However, with uneven distribution of loads, fatigue failure was probable. The predicted maximum stresses in the solid studs were determined to be half the calculated stress in the hollow studs. Confirmatory calculations performed by the licensee indicate that the amount of relaxation which could be tolerated in the solid stud design was more than twice as much as in the hollow stud design and the pumps could operate indefinitely with one of the four studs completely unloaded in the solid stud arrangement. Preload stress must remain in excess of operating loads to preclude fatigue failure. An applied preload stress of 207 MPa (30 ksi) could result in an actual preload stress of 145 MPa (21 ksi) due to margins of error in the torque application technique. In the new solid stud design, a Belleville washer provided preload. With a minimum preload, the stress in the solid stud design was well above the operating stress. By comparison, the preload stress in the hollow stud arrangement needed to be maintained at about 48 MPa (65 ksi). The operating load in the hollow stud design was calculated to be approximately 11.1 kN (2500 lbs) per stud, and the operating stress was about 207 MPa (30 ksi). Thus, a relaxation of about 3 mils was enough to unload the stud during a portion of the load cycle. With the new design, relaxation of 3 mils would leave the Belleville washers compressed by 9 mils, giving a spring force of 22.2 kN (5000 lbs), or nearly twice the operating load. The effect of relaxation resulted in cyclic fatigue of the studs.

In the hollow stud design, the licensee calculated the combined stress due to preload and operating loads to be about 745 MPa (108 ksi). Thus, even with nominal dimensions, the peak stress could exceed yield stress of the material for a portion of the stress cycle. With worst case dimensions, the maximum ultimate tensile strength could be exceeded. With the solid stud design, the sum of the prestress and operating stresses on the studs were well below yield stress, even after allowing for variations in preload. The required compression of the Belleville washer to equal the operating load was 5 mils, allowing a substantial available margin for accidental relaxation. Since loss of preload had been identified as a primary cause of failure, the solid stud design with Belleville washers offered a wide margin of safety.

Other evaluations performed by the licensee included analyses to determine the effect of seizure of the push rod due to a hydraulic lock. The marginal design of the hollow studs was intended to prevent damage to the camshaft during such an event. The solid stud fastener would presumably exert a much higher force on the camlobe prior to failure. Since keyed camlobes were also not expected to fail due to loading from a seized push rod, there was a high likelihood of damage to the camshaft. For the South Texas Project SDGs, however, there was an interference fit between the camshaft and the camlobes. The licensee's calculations indicated that, in the event of a hydraulic lock, the camfollower was likely to break this interference fit without damaging the camshaft. The inspectors observed minimal operational data to support the calculation. The inspector was informed that there were two other Cooper Bessemer sites with the solid studs.

1.2 Standby Diesel Generator Spurious Starts

NRC Inspection Reports 50-498;499/93-44 and 50-498;499/93-55 discussed the spurious start issues which had been occurring to the SDGs. NRC Inspection Report 50-498;499/93-55 closed out Inspection Followup Item 498;499/9344-01, which concerned the resolution of the spurious starts. At that time, the licensee had determined the cause of the spurious starts was the failure of the varistors and installation of relays without surge suppression in the control circuitry that caused voltage spikes. The voltage spikes degraded the transistor's operational characteristics and resulted in intermittent transistor operation. In addition, the licensee concluded that the transistor may have degraded due to high control cabinet temperatures. The corrective actions included replacing the affected varistors and transistors, installing fans in the control cabinets, and establishing preventive maintenance for the varistors.

On April 29, 1994, SDG No. 21 was started by a signal whose origin was unknown. The licensee, in the process of investigating the spurious start, determined that a high frequency noise was being emitted from the direct current power source. They believed that this noise was causing the spurious starts. The licensee developed a modification to install noise filters on the SDG's control power supply. As of May 13, 1994, the filters had been installed on SDG No. 21. The plan for installing the filters on the other five diesels had not been completed.

The inspectors did not consider the spurious starts to be a safety significant issue since the starts were caused by the normal start circuit and not the safety circuit. The diesels remained capable of emergency start. The inspectors identified the final resolution of the SDG spurious starts as an inspection followup item (498;499/9416-02).

1.3 SDG NO. 22 Piston Failure

In March 1994, during an 18-month surveillance inspection of SDG No. 22, the licensee found a section of the bottom edge of the 4R piston skirt missing. After disassembly of the cylinder, the licensee found that the tin overlay on the pistons was essentially gone, the piston had score marks on both the thrust and nonthrust sides and the liner was heavily scored. The licensee initiated SPR No. 940551 to document the investigation, determine the root cause of the failure, and to provide corrective actions. The licensee postulated that a potential root cause of the piston fracture could have been foreign material creating scuffing of the piston skirt against the lower liner thrust side which led to a condition of local heating, tin transfer and loss of the lubrication. The inspector observed that other initiating mechanisms may have led to the failure of SDG No. 22. The licensee has a program in place to continue to monitor engine performance and perform additional inspections for SDG No. 22 as discussed below.

The corrective actions included inspecting the diesel and repairing any damage. All of the pistons and liners were examined. The licensee replaced five pistons and four liners. After installation, the licensee performed a 175 hour special test on the engine and inspected the pistons and liners at the beginning and completion of the test. No out of specification conditions were found. The only item noted was a 620.5 kPa (90 psi) increase in the 4R cylinder firing pressure. However, the firing pressure remained within the allowable range. The licensee stated that they intended to perform a videoscopic inspection of the cylinders every 6 months and then perform a dimensional inspection in 18 months. In addition, the cylinder firing pressure will be monitored every 3 months. The inspectors concluded that the licensee's actions should advise them of any degradation to the engine.

1.4 Unit 2 Final System Readiness Review Report

The inspectors reviewed the Unit 2 final system readiness review report dated May 9, 1994. This report contained all of the items which were to be completed prior to startup of Unit 2 and items being deferred to after startup. The inspectors reviewed the items that were being deferred and found that most of these items were software items. Most of the hardware items had been completed. The inspectors concluded that the report was acceptable.

1.5 Operation With One Or Two Cylinders Inoperable

Section 4.6 of NRC Inspection Report 50-498/499/93-44 included a discussion of the licensee's assertion that each of the SDGs at the South Texas Project facility could carry design-rated load (5500 KW) with up to two of its 20 cylinders inoperable.

The inspectors reviewed the licensee's position and concluded that the SDGs could, in concept, carry design-rated load with as few as 18 cylinders without excessive engine stresses. However, the inspectors conclusion would only be valid if the engines were balanced, and the cylinder failures occurred only after all loads had been sequenced on to the SDGs (i.e., the SDGs would not be required to accept and accelerate any additional loads with less than 20 cylinders operating).

During the review of this issue, the inspectors reviewed engine balance data which showed that cycle-to-cycle firing pressures on any given cylinder were varying by as much as 896 kPa (130 psi) in an unpredictable manner. Given this apparent erratic operation, the inspectors were not able to establish that the SDGs were balanced.

Subsequent to the above inspectors' review, the licensee determined that the erratic operation of the SDGs at South Texas Project was due to electronic governor "hunting" when the SDGs were paralleled with offsite power. This hunting, and associated large cycle-to-cycle cylinder firing pressure variations, would not occur in an actual emergency because the SDGs would not be paralleled with offsite power. Based on this, the inspectors concluded the SDGs at South Texas Project were adequately balanced to preclude excessive engine stresses if the SDGs were required to carry design-rated load with up to two cylinders inoperable. This inspector's conclusion was validated by cylinder firing pressure data which indicated a cycle-to-cycle standard deviation on the order of 20 percent maximum high to low deviation previously observed. Cycle-to-cycle cylinder pressure variations in this lower range were consistent with a balanced engine.

The above discussion resolves the issue of SDG operability with up to two cylinders inoperable (i.e., the SDGs would be operable provided that the SDGs would only see steady state or decreasing load). It is still the inspectors' position that the SDGs would not be able to accept and sequence on large loads with less than 20 cylinders operable, and therefore, must be considered inoperable in any circumstances other than steady state or decreasing load.

ATTACHMENT

1 PERSONS CONTACTED

1.1 Licensee Personnel

* M. Berg, Manager, Design Support
* J. Blevins, Supervisor
* C. Boudreaux, Construction Engineering Specialist
* D. Clifford, Diesel Project Manager
* T. Cloninger, Vice President Nuclear Engineering
* M. Coughlin, Staff Engineer
* D. Fisher, Supervisor, Diesel Section
* J. Groth, Vice President, Nuclear
* H. Hesidence, Independent Safety Engineering Group
* W. Humble, Manager Reliability Engineering
* C. Johnson, Manager South Texas Project Activities
* J. Johnson, Supervisor Quality Assurance
* T. Jordan, Manager, Systems Engineering
* M. Kanavus, Manager, Mechanical/Civil
* A. Kent, Manager Mechanical Fluids
* L. Martin, Nuclear Assurance
* G. Parkey, Unit 2 Plant Manager
* S. Thomas, Manager, Design Engineering Department
* G. Walker, Manager, Public Information
* L. Walker, Licensing Engineer

Cooper Bessemer

* A. Lambert, Consultant, Cooper Bessemer

1.2 NRC Personnel

* W. Johnson, Chief, Project Section A, Division of Reactor Projects

In addition to the personnel listed above, the inspectors contacted other personnel during this inspection period.

2 EXIT MEETING

An exit meeting was conducted on May 5, 1994. During this meeting, the inspectors reviewed the scope and findings of the report. The licensee acknowledged the inspection findings documented in this report. Additional telephone calls were held with Mr. Fisher and others on May 11 and 13, 1994. The licensee did not identify as proprietary any information provided to, or reviewed by, the inspectors.