RELATED CORRESPONDENCE

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UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

In the Matter of)
)
LONG ISLAND LIGHTING COMPANY) Docket No. 50-322-1
) (OL)
(Shoreham Nuclear Power Station,)
Unit 1))

TESTIMONY

of

CARL H. BERLINGER

on

Diesel Loads

Q. Have you previously testified/participated at this TDI diesel generator ASLB hearing?

A. Yes, I have and my experience and responsibilities have been previously provided to this board.

Q. The staff has issued a recent Safety Evaluation Report and Supplement dated 12/3/84 and 12/18/84 respectively. What was your responsibility regarding those staff evaluations?

A. I was responsible for the management and coordination of the staff and consultant reviews which were the bases for both of those reports. They were prepared under my supervision and direction. Those SER/SSERs addressed the Shoreham Emergency load requirements and the reliability of the TDI EDGs, respectively.

C. Berlinger

RELATED CORRESPONDENCE

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

December 3, 1984

MEMORANDUM FOR: Thomas M. Novak, Assistant Director
for Licensing
Division of Licensing

FROM: Dennis M. Crutchfield, Assistant Director
for Safety Assessment
Division of Licensing

SUBJECT: SAFETY EVALUATION REPORT - SHOREHAM NUCLEAR POWER STATION EMERGENCY LOAD REQUIREMENTS FOR EMERGENCY DIESEL GENERATORS

The TDI Project Group, Division of Licensing, has completed its review of the emergency service load requirements to be placed on the Shoreham EDGs and the adequacy of these loads relative to the 3300KW "qualified load" rating for these engines. Our review has incorporated SER input from the Power Systems Branch concerning the emergency load requirements for the Shoreham EDGs which was provided by memorandum, L. S. Rubenstein to D. M. Crutchfield, dated November 29, 1984.

Our SER is attached.

Dennis M. Crutchfield

Dennis M. Crutchfield, Assistant Director
for Safety Assessment
Division of Licensing

Enclosure:
SER

cc w/encl:
See next page

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SUPPLEMENTAL SAFETY EVALUATION REPORT
SHOREHAM NUCLEAR POWER STATION
DOCKET NO. 50-322

Introduction and Background

As specified in the original FSAR, Section 8.3.1, the TDI Emergency Diesel Generators at Shoreham have a continuous rating of 3500 KW and an overload rating of 3900KW. These ratings are as defined in IEEE 387-1977.

In testimony presented during the ASLB hearings regarding the Shoreham crankshafts, the staff and its PNL consultants concluded that there was insufficient evidence to either approve or disapprove the crankshaft for operation at engine loads at or above 3500KW continuous rating. The staff testimony suggested, consistent with its generic SER addressing the TDI Owners Group Program Plan dated August 13, 1984, that unlimited fatigue life of the Shoreham crankshafts could be demonstrated by testing an engine for 10^7 engine stress cycles (750 hours). That testing would be conducted at a load at or above the maximum emergency service load. The test load would be designated at the "qualified load" for the engine. Successful completion of such a test would be sufficient to demonstrate the adequacy of the crankshaft for unlimited fatigue life at its "qualified load."

LILCo is expected shortly to submit a test/inspection report demonstrating satisfactory completion of an engine test conducted at 3300KW for 750 hours. Contingent upon successful completion of the test, 3300KW would become the "qualified load" rating for the Shoreham engines. The staff is scheduled to issue an SER addressing the adequacy of the TDI EDGs on December 18, 1984, which will in part include a detailed evaluation of this test/inspection report.

This SER addresses the emergency load requirements to be placed on the Shoreham EDGs and the acceptability of these loads when considered against the 3300KW "qualified load" rating for these EDGs. Information pertaining to the emergency load requirements was submitted by LILCo in letters dated July 3. August 22, September 11, November 19, and November 29, 1984.

Evaluation

In order to reduce the emergency service load requirements, included in Section 8.3.1 of the FSAR, the applicant removed selected loads from the automatic start category. The staff concluded, as indicated in the attached memorandum from O. Parr to M. Srinivasan dated October 12, 1984, that this removal of loads is acceptable. Thus, based on information presented, the staff finds that the total continuous loading for the diesel generator (given a loss of coolant accident concurrent with a loss of offsite power) does not exceed 3300KW. Design features such as alarms have not been provided to assure that the control switch for one of two divisions III service water pumps will remain in the manual mode or the pull to lock position. To obtain the needed assurance, the staff will include a once per shift periodic verification of this switch position in the Shoreham Technical Specifications. Pending revision of the specifications to include this change as well as the change referenced in the attached memorandum, the staff considers this item to be acceptably resolved.

With respect to diesel generator loading when there is only a loss of offsite power (no loss of coolant accident), the applicant implied by letter dated November 19, 1984, that the worst case continuous loading on any one of the three diesel generators is 2786KW. This value was confirmed in the applicant's November 29, 1984 letter. Because 2786KW is below the 3300KW qualified load, the staff considers this item to be acceptably resolved.

The staff has identified a number of short term operating conditions which may cause the Shoreham engines to be loaded above the qualified load rating of 3300KW for brief periods. It has been general industry practice to use the overload rating to justify short term operation (2 hours) at loads exceeding the nameplate continuous rating. The staff has no basis by which to define a "qualified overload" rating (in excess of the qualified load rating) at which the engines can be operated for in excess of two hours out of 24 consecutive operating hours and at which the crankshafts can be shown to have unlimited fatigue life. However, based on consideration of the nature of the short term operating conditions above 3300KW (discussed below), the staff and its PNL consultants have concluded that these conditions are very unlikely to induce a fatigue failure of any of the Shoreham crankshafts. This conclusion is based on the short duration of these operating conditions combined with the assumption that crankshaft inspections will have verified the crankshafts to be initially free of cracks. The redundancy among the Shoreham EDGs provides added assurance that the EDGs will provide the necessary emergency power during LOOP/LOCA events. The staff concludes, however, that in the absence of a "qualified overload" rating, the crackshaft should be periodically inspected to verify the continued absence of cracks.

The 3300KW "qualified" load is to be considered as the only diesel generator rating. Thus, the rated load test required by Section 6.4.3 of IEEE Standard 387-1977 as augmented by R.G. 1.9 and the full load carrying capability test required by position C.2.a(3) of R.G. 1.108 is to be performed at 3300KW. The Technical Specifications for the Shoreham plant will be changed to permit a 3300KW load test (once per 18 months) for 24 hours versus a 3500KW load test for 22 hours followed by 3900KW load test for two hours.

The following items are short term operating conditions identified by the staff which may cause the diesel engine to supply a load greater than its qualified load rating of 3300KW:

1. Inrush current due to starting of large motors will cause very short duration KW spikes (less than one second) that are greater than the 3300KW "qualified load." The applicant was requested by telecon on October 26, 1984, to describe what effect this inrush current had on the diesel engine. The applicant by letter dated November 19, 1984, provided the following response:

> "There is no adverse effect due to inrush current. The phenomena of inrush current (due to starting large motors) causing short duration KW spikes is typical and not unique to the Shoreham diesel generators. In order to minimize the effect of these spikes on the diesels, large motor loads are started in a predetermined sequence. FSAR Table 8.3.1-2 tabulates the various inrush currents and describes the large motor start sequence. Such sequencing allows a spike to occur and to dissipate prior to the start of the next load usually 5.5 to 6 times the full load current but the power factor at that instant is approximately .35 and the net effect on the DG is reduced significantly. The inertia of the flywheel minimizes the effect of these spikes on the diesel due to their short duration. These spikes were considered in FAA's analysis and it was determined that they have no adverse effect on the diesel's capability to perform their intended function. In addition, diesel factory test, preoperational test and periodic operational surveillances (see Technical Specifications Section 4.8.1.1.2.e) have demonstrated and continue to demonstrate the diesel's capability in this area."

The staff agrees with the applicant's assessment that there is no adverse effect due to inrush current. Apart from inertial considerations, the staff also notes that the effect of the electrical transient on the BMEP response of the engine would be further flattened by the fact that the turbocharger cannot respond quickly enough to a full opening of the fuel rack to provide sufficient air to take full advantage of the additional fuel. (This is the cause of engine smoke produced under these conditions.) The electrical spike would be on the order of a hundredth of a second in duration, and in the staff's judgment would not increase the engine BMEP response significantly above that equivalent to engine operation at 3300KW continuous load. Irrespective of the transient BMEP peak, however, the short duration of these transients coupled with the assumption that inspections will have verified the initial condition of the crankshafts as being free of cracks ensures that these transients will not induce a fatigue failure of the crankshafts. The load acceptance test of Section 4.8.1.1.2.e of the Technical Specification will be supplemented such that the voltage and frequency for each load step will be monitored and shown to be within the required design limits specified in R.G. 1.9.

2. By letter dated November 19, 1984, the applicant identified the following loads that are automatically actuated, are intermittent/noncontinuous, and are not considered to be part of the qualified load level:

   a. diesel generator air compressor (12KW)
   b. diesel generator fuel oil transfer pump (0.4KW)
   c. motor operated valves (176KW)

   Based on information presented in Table 8.3.1-1 of revision 34 to the FSAR, the staff concludes that the worst case maximum coincident demand of these loads will be 188.4KW. The 188.4KW, when added to the total maximum emergency service loads tabulated in Table 8.3.1-1A of revision 34 to the FSAR, is 3413.9KW. Because the majority of those loads are automatically actuated motor operated valves, they are short duration loads on the order of one to three minutes. Also, automatic actuated valves do not operate simultaneously; therefore, the actual diesel generator loading should be less than the aggregate value of 3413.9KW but may be greater than 3300KW for one to three minutes. Considering the limited time interval involved and the initial uncracked condition of the crankshafts, this load would be very unlikely to produce a fatigue failure of the crankshafts.

3. In order for the diesel generator to reach its required design basis voltage and frequency limits within the required time of ten seconds, the diesel engine's fuel rack position or fuel setting will move to the wide open position. This wide open fuel setting is greater than the fuel setting which would exist when the diesel generator is delivering steady state power at 3300KW load. Thus, during this ten second plus time period, the diesel engine may be loaded such that its BMEP may be greater than that corresponding to a continuous electrical load of 3300KW. Similarly, when individual loads or a block of loads are connected to the generator, the diesel engine's fuel setting will move towards the wide open position. This fuel setting movement maintains the frequency of the generator within required limits specified in R.G. 1.9. Even though the output of the generator is less than 3300KW, the diesel engine will be loaded for a short time (estimated to be less than 15 seconds) such that its BMEP may be greater than that corresponding to a continuous electrical load of 3300KW. The staff's consultants estimate that the BMEP response could be up to approximately that corresponding to 3800KW. Again, however, considering the short duration of these transients and the initially crack-free condition of the crankshafts, these transients are very unlikely to induce a fatigue failure of the crankshafts.

By letter dated November 19, 1984, the applicant (in response to an October 26, 1984 telecon), indicated that the 3300KW "qualified load" for the diesel generator would be exceeded if one assumed a single operator error. For a loss of coolant accident with a concurrent loss of offsite power, the worst case loading due to a single operator error was identified to be 3583.5KW though no operator action is required to mitigate this event. For a loss of offsite power event only (no loss of coolant accident), the worst case loading due to single operator error was identified to be 3784KW. Plant procedures and training are to be used to prevent an operator error from causing the 3300KW "qualified load" from being exceeded. In addition, the applicant proposed a change in the plant Technical Specification (specifying 3300KW limit) to further aid in keeping the diesel generator loads below its 3300KW "qualified load." The staff will include this proposed 3300KW limit as part of the Technical Specifications. Pending inclusion of this item in the Shoreham Technical Specifications, the staff concludes that there is reasonable assurance that loading of the diesel generator beyond its 3300KW limit will be prevented. However, the staff finds, based on information presented by letter dated November 19, 1984, that the Shoreham plant procedures call for the manual connection of nonsafety loads to the diesel generator. If these nonsafety loads are connected prior to the removal of safety loads, the 3300KW limit may be exceeded. The staff, therefore, concludes that strict adherence to plant procedures is essential to preventing the 3300KW limit from being exceeded. The adequacy of these procedures will be reviewed and reported in a later report. However, it should also be noted that if one assumes a single operator error which would cause the failure of an engine, such an error could only result in the loss of one diesel generator due to overload and the two remaining diesel generators are sufficient to safely shutdown the plant for any postulated event.

Conclusion

A "qualified load" rating of 3300KW adequately envelopes the maximum continuous emergency load requirements associated with LOOP/LOCA events. Although transient and intermittent, non-continuous loads could briefly increase engine loadings slightly above 3300KW, these loads are of such a limited duration that they are not considered as a credible cause of a fatigue failure of the crankshafts during LOOP/LOCA events. The redundancy among the Shoreham EDGs provides added assurance that the EDG will provide the necessary emergency power during such events.

As a precautionary measure, the staff has concluded that the Shoreham EDG crankshafts should be inspected periodically. The staff will address the appropriate inspection interval in a forthcoming SER addressing the adequacy of the Shoreham EDGs which is scheduled for issuance by December 18, 1984. The staff findings are also conditioned to the Technical Specification changes which have been identified above.

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

Docket No.: 50-322

DEC 18 1984

MEMORANDUM FOR: Thomas M. Novak, Assistant Director
for Licensing, DL

FROM: Dennis M. Crutchfield, Assistant Director
for Safety Assessment, DL

SUBJECT: SUPPLEMENTAL SAFETY EVALUATION REPORT - SHOREHAM NUCLEAR POWER STATION UNIT 1 - RELIABILITY OF STANDBY EMERGENCY DIESEL GENERATORS

The TDI Project Group, Division of Licensing, has completed its review of reliability issues relating to the emergency diesel generators at Shoreham Nuclear Power Station Unit 1. Our SSER is attached. We have concluded that the Shoreham EDGs, which were manufactured by Transamerica Delaval, Inc. (TDI), will provide a reliable standby power source of onsite power in accordance with General Design Criteria 17. This conclusion is subject to (1) implementation of an enhanced maintenance/surveillance program, as described in Section 3.5 of the enclosed SSER, (2) special requirements pertaining to any future adverse maintenance inspection findings for the crankshafts and engine blocks, (3) the installation of a distinctive alarm to warn operators when EDG loading exceeds 3300 kw and the completion of appropriate procedures to minimize the possibility of operator error, and (4) implementation by LILCO of any additional actions which the staff finds are necessary as a result of its final review of the Owners Group findings and the Shoreham DRQR program. With respect to Item 4, the staff does not anticipate that any additional actions will be of an urgent nature such that they should necessarily be implemented prior to OL issuance. However, the staff will require that LILCO implement any such actions prior to or during the first refueling outage.

D. M. Crutchfield, Assistant Director
for Safety Assessment
Division of Licensing

Enclosure: As stated

cc w/enclosure:
D. Eisenhut
F. Miraglia
C. Berlinger
E. Murphy
R. Caruso
D. Persinko
M. Miller
T. Michaels
A. Schwencer

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

SUPPLEMENTAL SAFETY EVALUATION REPORT

SHOREHAM NUCLEAR POWER STATION

DOCKET NO. 50-322

1.0 INTRODUCTION

Long Island Lighting Company (LILCO) is seeking a full power operating license for Shoreham Nuclear Power Station Unit 1. One matter which has been of of concern to the U.S. Nuclear Regulatory Commission in considering the request is the reliability of the Shoreham standby emergency diesel generators manufactured by Transamerica Delaval, Inc. (TDI). The reliability of these engines was first brought into question as a result of a major crankshaft failure at Shoreham in August 1983. In response to the NRC concerns, LILCO, with the assistance of the TDI Owners Group, has completed a comprehensive program to verify and enhance the reliability of the Shoreham diesel generators for standby nuclear service.

2.0 BACKGROUND

Shoreham is served by three TDI model DSR-48 diesel engines, designated emergency diesel generator (EDGs) 101, 102, and 103. These EDGs are inline eight-cylinder, four-cycle, turbocharged, aftercooled engines. Each has a nameplate continuous load rating of 3500 KW with an overload rating of 3900 KW, and operates at 450 rpm with a brake mean effective pressure (BMEP) of 225 psig.

2.1 TDI Owners Group

Concerns regarding the reliability of large bore, medium speed diesel generators manufactured by TDI for application at domestic nuclear plants were first prompted by a crankshaft failure at Shoreham in August 1983. However, a broad pattern of deficiencies in critical engine components subsequently became evident at Shoreham and at other nuclear and non-nuclear facilities employing TDI diesel generators. These deficiencies stem from inadequacies in design, manufacture and QA/QC by TDI.

In response to these problems, 11 (now 13) U.S. nuclear utility owners formed a TDI Diesel Generator Owners Group to address operational and regulatory issues relative to diesel generators sets used for standby emergency power. On March 2, 1984, the Owners Group submitted a plan to the NRC which, through a combination of design reviews, quality revalidations, engine tests and component inspections, is intended to provide an in-depth assessment of the adequacy of the respective utilities' TDI engines to perform their safety related function.

The Owners Group Program involves the following two major elements:

1. Phase I: Resolution of 16 known generic problem areas intended by the Owners Group to serve as a basis for the licensing of plants during the period prior to completion and implementation of the Owners Group Program.

2. Phase II: A design review/quality revalidation (DR/QR) of a large set of important engine components to assure that their design and manufacture; including specifications, quality control and quality assurance and operational surveillance and maintenance, are adequate.

The Owners Group Program includes provisions for special or expanded engine tests/inspections, as appropriate, to verify the adequacy of the engines and components to perform their intended functions.

The 16 known problem areas (Phase I issues) identified by the Owners Group include the engine base and bearing caps, cylinder block, crankshaft, connecting rods, connecting rod bearing shells, piston skirts, cylinder head studs, push rods, rocker arm capscrews, turbocharger, jacket water pump, high pressure fuel oil tubing, air start valve capscrews, and engine mounted electrical cable.

The Owners Group has issued reports detailing its proposed technical resolution of each of the 16 Phase I issues. These generic reports analyze the operational history, including failure history, of each of these components. In addition, these reports evaluate the causes of earlier failures and problems, the adequacy of the components to meet functional requirements, and provide recommendations concerning needed component upgrades, inspections, and testing.

The Owners Group has also issued the DRQR (Phase II) report, dated June 29, 1984, for the Shoreham EDGs. This report documents the results of the design review and quality revalidation which was performed on all components critical to the operability and reliability of the engines, including the 16 components identified by the Owners Group as known problem areas. The Owners Group performed the design reviews and identified the component quality attributes to be verified. The actual component inspections to verify the quality attributes were generally performed by LILCO. Engineering dispositions made by LILCO on the basis of the inspection results were reviewed by the Owners Group.

2.2 EDG Experience at Shoreham

The Shoreham EDGs experienced numerous problems during early preoperational testing prior to August 1983 involving excessive turbocharger thrust bearing wear, incorrectly sized air start valve capscrews, jacket water pump failures, cylinder head cracks, engine block cam gallery cracks, ruptured fuel-oil injection lines, and rocker arm capscrew failures.

On August 12, 1983, the EDG 102 crankshaft suffered a complete fracture. At that time, EDG 102 had logged 671 total hours of operation, including 254 hours at 3500 KW and 19 hours at 3900 KW. As a result of this event, an engine teardown and inspection was conducted for all three EDGs. The crankshaft in EDGs 101 and 103, which had logged comparable operating hours to EDG 102, were found to contain cracks. The engine inspections also revealed cracks in four connecting rod bearings, linear indications in all piston skirts (which were of the AF design), cracked bedplates in the areas of the main journal bearings, and indications in the connecting rod rod-eye bushings.

In fall 1983, as part of the crankshaft failure recovery program, LILCO made a number of engine modifications. New crankshafts with larger (12-inch diameter) crankpins were installed; all piston skirts were replaced with the newer, type AE skirts; all cylinder heads were replaced with the newer Group III models; and new connecting rods were installed with the 12-inch (rather than 11-inch) bearing diameter. New connecting rod bearings were installed and rod-eye bushings with relevant indications were replaced.

Subsequent to the crankshaft recovery program in late 1983, LILCO proceeded with additional engine testing and inspections in support of its DRQR program. This included achieving a nominal 100-hour total operation on each engine at or above 3500 KW, followed by a comprehensive engine inspection as part of the DRQR effort in March 1984. The EDGs experienced failures of the turbocharger thrust bearings during this period, and LILCO subsequently implemented a thrust bearing pre-lubrication system to preclude future such failures. In addition to the thrust bearings, a number of other components were replaced during the DRQR inspections including one cylinder liner, several connecting rod bearings, the governor couplings, jacket water pump, and several rod-eye bearings.

At the time of the DRQR inspections, LILCO was aware of cracks in the engine blocks. All three engines were observed to have cracks in the cam gallery area and in the block top ligaments between the cylinder head stud holes and the cylinder head counter-bores. The EDG 103 block also exhibited cracks between stud holes of adjacent cylinders.

In April 1984, during a test at full load, EDG 103 experienced an abnormal load excursion. The engine slowed to 390 rpm, at which time a breaker tripped, removing the electrical load. The engine continued to operate at rated rpm (450) for about 10 minutes, and was then shut down. After the engine was restarted and loaded to 3900 KW, a crack was observed extending down the front of the block from cylinder No. 1, and the engine was again shut down. Reexamination of the block revealed additional stud-to-stud cracks discussed earlier in this section. LILCO decided to replace the block.

Metallurgical examinations of the original EDG 103 block revealed an extensive degenerate graphite microstructure that produced markedly inferior fracture properties. LILCO concluded from metallurgical examinations of the EDG 101 and 102 blocks that they did not exhibit similar degenerate microstructures.

2.3 Confirmatory Test of EDG 103

In testimony presented during the ASLB hearings regarding the Shoreham crankshafts, the staff and its PNL consultants concluded that there was insufficient evidence to either approve or disapprove the crankshaft for operation at engine loads at or above 3500 KW continuous rating. The staff testimony suggested, consistent with its generic SER addressing the TDI Owners Group Program Plan, dated August 13, 1984, that unlimited fatigue life of the Shoreham crankshafts could be demonstrated by testing an engine for 10^7 engine stress cycles (750 hours). That testing would be conducted at a load at or above the maximum emergency service load. The test load would be designated as the "qualified load" for the engine. Successful completion of such a test would be sufficient to demonstrate the adequacy of the crankshaft for unlimited fatigue life at its "qualified load."

In a report dated December 3, 1984, LILCO documented the successful completion of a confirmatory test on EDG 103 to establish 3300 kW as the "qualified load" rating for the Shoreham EDGs. The confirmatory testing on EDG 103 provided additional running hours (525 hours) to accumulate a total of in excess of 740 hours of operation (10^7 stress cycles) at or exceeding 3300 kW. Subsequent NDE inspection of the crankshaft confirmed the absence of cracks in the critical fillet and oil hole locations.

At the request of the NRC, strain gauge measurements were taken in the cam gallery area during the engine test. This data indicated the cam gallery region to be in compression during all modes of engine operation. LILCO considers this data to confirm their earlier conclusions that cam gallery cracks, which are present in all three engines, are benign. LILCO believes these are shrinkage cracks which occurred during the casting process and during subsequent weld repairs.

Inspections of the block top area, which had exhibited no ligament or stud hole to stud hole cracks prior to the test, did not reveal any crack indications.

Post-test inspections were also performed on the connecting rod bearings, wrist pin and wrist pin bushings, turbocharger (thrust bearings, nozzle ring valves and capscrews), front end gears and gear teeth, cylinder liners, and piston skirts.

The cylinder head inspections were in accordance with the October 10, 1984, cylinder head agreement among LILCO, Suffolk County, and the NRC staff for the cylinder head contention. LILCO reported all heads were found to be acceptable; however, one head was replaced in accordance with the settlement agreement because it contained a through wall weld repair in the injector bore area.

The inspection results for the other components inspected were found acceptrable by LILCO. However, two connecting rod bearings were replaced due to damage caused during disassembly. One of these two bearings also contained a small indication on the outside diameter which was within the acceptance criteria.

3.0 EVALUATION

Enclosure 1 to this SER is a Technical Evaluation Report (TER) entitled "Review and Evaluation of Transamerica Delaval, Inc. Diesel Engine Reliability and Operability - Shoreham Nuclear Power Station Unit 1." This TER was prepared by Pacific Northwest Laboratory (PNL) which is under contract to the NRC to perform technical evaluations of the TDI Owners Group's generic program, in addition to plant-specific evaluations relating to the reliability of TDI diesels. PNL has retained the services of several expert diesel consultants as part of its review staff.

The staff concurs with the findings of the PNL TER, and incorporates the TER as part of this Safety Evaluation Report by reference.

This SER and the enclosed TER precede completion of the NRC/PNL review of the proposed generic resolution of the Owners Group Phase I issues and of the total DRQR Program for Shoreham. Final completion of these NRC staff/PNL reviews is anticipated in early 1985. However, the staff and its PNL consultants find that these reviews have progressed sufficiently such that all significant issues warranting priority attention as a basis for issuance of an operating license for Shoreham are adequately resolved.

Conclusions reached in this report are based on staff and PNL review of (1) the Owners Group findings with respect to the resolution of known problem areas and (2) actions taken by LILCO to verify and enhance the reliability of the EDGs including, in particular, actions taken to resolve known problems. These conclusions are subject to (1) implementation of an enhanced maintenance/surveillance program, as described in Section 3.5, to assure that critical components and systems remain in adequate condition, (2) special requirements, as discussed in Section 3.6, pertaining to any future adverse maintenance inspection findings for the crankshafts and engine blocks, (3) the installation of a distinctive alarm to warn operators when EDG loading exceeds 3300 KW and the completion of appropriate procedures to minimize the possibility of operator error, and (4) implementation by LILCO of any additional actions which the staff finds are necessary as a result of its final review of the Owners Group findings and the Shoreham DRQR program. With respect to item 4, the staff does not anticipate that any additional actions will be of an urgent nature such that they should necessarily be implemented prior to OL issuance. However, the staff will require that LILCO implement any such actions prior to or during the first refueling outage.

3.1 LILCO Tests, Inspections, and Component Upgrades

Section 3 of the enclosed TER provides PNL's evaluation of LILCO's comprehensive program of engine testing and inspection, and component upgrades. The NRC staff and PNL have concluded that the testing and inspection program was adequate to uncover problems with engine components and to confirm their ability to meet the load and service requirements. The component upgrades are viewed as responsive to the inspection findings and to the recommendations of the OG. PNL notes that the tests conducted on the Shoreham EDGs have subjected the engines to a number of starts comparable to that expected in actual service for the life of the plant.

3.2 Requalification of Components with Known Problems

Section 4 of the enclosed TER documents PNL's review of LILCO's actions to upgrade and/or requalify the 16 engine components known to have had significant problems (Phase I components). The PNL evaluation also considered the pertinent Owners Group Phase I reports addressing the operating history for each component, Owners Group studies regarding the causes of previous problems and adequacy of the components to meet functional requirements and Owners Group recommendations regarding needed component upgrades, inspections, and testing.

Based on this evaluation, the NRC staff and PNL have concluded that each of the Phase I components currently installed in the Shoreham EDGs is adequate to perform its intended function for the 3300 KW "qualified load" rating of the engine. This includes crankshafts and engine blocks which are discussed in additional detail in Sections 3.3 and 3.4 of this SER. This finding is subject to modifications to the LILCO EDG maintenance and surveillance program as currently defined in Stone and Webster Engineering and Design Coordination Report (E&DCR) No. F-46505. The necessary changes are discussed in Section 3.5 of this SER.

3.3 Crankshafts

LILCO and the Owners Group have concluded that the replacement crankshafts are adequate for the continuous engine nameplate rating of 3500 KW and the 3900 KW overload rating. This conclusion is based on the Owners Group finding that the crankshaft meets the DEMA recommendations and that FaAA calculations indicate a 1.48 margin with respect to fatigue failure.

PNL's evaluation of the crankshafts is provided in Section 4.3 of the enclosed TER. The staff concurs with the PNL findings. The staff and PNL are unable to make unequivocal findings regarding the adequacy of the crankshafts at the 3500 KW continuous, and 3900 kW overload ratings based on the available analytical evidence. However, the recent confirmatory test of EDG 103 which accumulated in excess of 10^7 stress cycles on the crankshaft provides confirmatory information regarding the fatigue resistance of the Shoreham crankshafts for a "qualified load" rating of 3300 kW.

In an SER filed with the ASLB on December 3, 1984, the staff provided its evaluation of the emergency service load requirements to be placed on the Shoreham EDGs relative to the "qualified load" rating of 3300 KW. The staff concluded that the "qualified load" rating of 3300 KW adequately envelops the maximum continuous emergency load requirements associated with LOOP/LOCA events.

The staff found that transient and intermittent, non-continuous loads could briefly increase engine loading above 3300 KW. The staff concluded that these loads are of such a limited duration that they are not considered to be a credible cause of fatigue failures during LOOP/LOCA events. PNL also concurs with this conclusion as indicated in Section 4.3.5 of the enclosed TER.

The staff concurs with the PNL recommendation that, as a matter of normal precaution, the crankshafts should be inspected at the first refueling outage, and at every refueling thereafter. The specifics of the needed periodic maintenance inspections are addressed in Section 3.5 of this SER.

3.4 Engine Blocks

The available evidence from metallurgical investigations strongly indicate that the camshaft gallery cracks, which exist in all three engines, originated from shrinkage stresses associated with the casting process and from subsequent weld repairs and that these cracks have not grown during service. Although strain gauge measurements indicate that the operational stresses in the cam gallery area are compressive, PNL is not fully certain that residual stresses will not cause these cracks to "pop in" when the block is unbolted from the base or that these residual stresses will not lead to crack growth during engine operation (admittedly considered unlikely by PNL and the staff). At PNL's recommendation, therefore (see sections 4.5.2.1 and 5.1.1.2 of the enclosed TER), the staff concludes that these cracks should be monitored as part of the maintenance and surveillance program as is discussed further in Section 3.5 of this SER.

Destructive examinations conducted on the original EDG 103 block indicated circumferential cracks in the cylinder liner counterbore. Such cracks are difficult to detect with conventional NDE techniques. The origin of these cracks is believed to stem from stresses induced by cylinder liner proudness. It is PNL's judgment that any such cracks would be rapidly arrested as they move into the high compressive stress region resulting from the bolt-up of the cylinder head to the block. The staff also notes that the Quality Revalidation Program at Shoreham included dimensional checks to ensure that cylinder liner proudness is minimized. The staff concurs with PNL that any circumferential cracks formed in the liner loading area will not impair engine reliability.

Ligament cracks between the cylinder head stud holes and the cylinder counterbore are known to be present in the EDG 101 and 102 blocks, but were not observed during the recent inspection of the EDG 103 block. These cracks in-of-themselves are not of significant concern; however, such cracks result in increased stress and thus increased potential for cracks between the stud holes of adjacent cylinders. Such "stud-to-stud" cracks are considered more serious than ligament cracks since they can potentially degrade the overall mechanical integrity of the block and its ability to withstand piston firing pressures.

An FaAA analysis has demonstrated that given the existence of ligament cracks and the absence of stud-to-stud cracks prior to a LOOP/LOCA event, even if stud-to-stud cracks were to develop during a LOOP/LOCA event they would not propagate sufficiently during the event to impair engine operability. Based on the FaAA analysis and the results of inspections indicating the absence of stud-to-stud cracks in all three engine blocks, the staff and its PNL consultants conclude that the cylinder blocks for EDGs 101, 102 and 103 are acceptable for continued use. This finding is contingent upon implementation of the maintenance and surveillance program identified in Section 3.5, which includes verifying that no cracks have developed between stud holes of adjacent cylinders for each operation of the engine at or above 50% of qualified load for engines known to have ligament cracks.

3.5 Maintenance and Surveillance

Section 5 of the enclosed TER addresses PNL's review of the applicant's proposed maintenance and surveillance program for the TDI diesels at Shoreham. The program is described in Stone and Webster Engineering and Design Coordination Report (E&DCR) No. F-46505, which is to be incorporated into the TDI Instruction Manual whereby it will be implemented into the Shoreham M/S program. It is the staff's understanding that M/S in the Shoreham DRQR has been incorporated into E&DCR F-46506. Therefore, review of LILCO's M/S program also encompasses TDI and Owners Group recommended maintenance and surveillance procedures.

The PNL review of the proposed maintenance and surveillance program at Shoreham focused on components and systems critical to engine operation and did not include a 100% review of E&DCR F-46505. However, in some instances, PNL has made recommendations where special attention was thought necessary. The review can be divided into four areas which are: (1) major maintenance items, (2) additional recommended maintenance items, (3) operational surveillance, and (4) standby surveillance. In the information provided by the applicant, maintenance and surveillance inspections of certain components that the staff believes should be inspected periodically was not addressed. In other instances, the proposed maintenance or maintenance intervals of certain components was not acceptable to PNL and should be revised by LILCO.

Items requiring maintenance and inspection that were either not included in the applicant's submittals or included but require revisions are:

1. Crankshaft
2. Cylinder block
3. Connecting rod bearing shells
4. Cylinder liners
5. Cylinder heads
6. Studs/Bolts (including conrod bolts)
7. Turbocharger
8. Lube oil sampling and analysis

PNL also made recommendations in Section 5.2 of the enclosed TER concerning other items important to EDG reliability that were either not addressed by the applicant or addressed but should be considered for revision. These items have not been directly related to any known TDI engine failure but are consistent with good practice. As a result, they are presented as comments for consideration by the applicant rather than staff requirements. The applicant should carefully consider the comments provided by PNL for inclusion into the comprehensive maintenance and surveillance program that will be instituted on the TDI engines at Shoreham. PNL comments relate to the following:

1. Fuel injection pump
2. Fuel injection nozzle
3. Fuel oil drip tank
4. Fuel oil filter and duplex strainer
5. Lube oil filter
6. Jacket water system
7. Engine balance

The information provided by the applicant did not include operational surveillance. Monitoring and recording key engine parameters is important because trends in engine performance which are indicative of potential problems can be detected. This detection would permit preventative maintenance to be performed or it may permit an operator to shut down the engine prior to engine damage occurring. PNL's recommended operational surveillance plan is given in Table 5.3 of the enclosed TER.

In Appendix II of the DRQR report and the E&DCR F-46505, the applicant has provided a list of items to be maintained on a daily basis. PNL has reviewed the applicant's standby surveillance program and has noted items that warrant inclusion or revision to the present proposal. These items are:

Item		Staff Guidance
1.	Starting air pressure	Visual check every 8 hours; log every 24 hours
2.	Lube oil temperature in/out	Visual check every 8 hours; log every 24 hours
3.	Jacket water temp. in/out	Visual check every 8 hours; log every 24 hours
4.	Lube oil sump level	Visual check every 8 hours; log every 24 hours
5.	Fuel oil day tank level	Visual check every 8 hours; log every 24 hours
6.	Room temperature	Visual check every 8 hours; log every 24 hours
7.	Annunciator test	Test every 8 hours; log every 24 hours

Item		Staff Guidance
8.	Check alarm clear	Daily
9.	Check compressor air trap operator	Daily
10.	Fuel rack and linkage operation	Lube monthly in addition to current proposal
11.	Keepwarm oil filter differential pressure	Check weekly
12.	Air start admission strainer	Check quarterly

A summary of PNL's complete standby surveillance review is presented in Table 5.4 of the enclosed TER.

Except for the items noted above as comments and not requirements, the staff will require that the applicant modify his existing maintenance and surveillance program to accommodate PNL recommendations. Any deviations from PNL recommendations should be highlighted and justified and receive staff approval. The above modifications and staff approval, if necessary, must be completed prior to exceeding 5% power. Should the applicant deviate from PNL recommendations, the supporting information should be supplied promptly to allow sufficient time for staff review.

3.6 Special Requirements

The staff believes that substantial progress has been made by the TDI Owners Group and the individual applicants/licensees in specifying necessary periodic inspections and acceptance criteria of TDI engine components. The staff concludes that where the results of any inspections do not meet acceptance criteria established by the Owners Group, a thorough review and engineering evaluation should be performed by the individual owner in order to effect a satisfactory disposition. The results of any inspections and the supporting information for disposition of components not meeting established acceptance criteria should be retained by the applicant/licensee in a traceable fashion that allows the staff to audit any results and the disposition of any components. With the exception of the crankshaft and cylinder block, the inspection results and the disposition of any component, in general, are not required to be submitted to the staff for staff review. Any unusual inspection results or occurrences should, however, be reported to the staff in accordance with 10 CFR 50.73.

Because of the importance of the crankshaft, the previous history of crankshaft failure, the uncertainties in the analyses, and the potential for short duration loads that exceed 3300 kW, the staff requires that any unsatisfactory inspection results of the crankshaft be reported to the staff along with the disposition and supporting information for the disposition.

The two issues of concern regarding the block where the staff will require notification of unsatisfactory inspection results are the cracks in the cam shaft gallery and stud-to-stud cracking in the block top. Any detection of crack growth in the cam gallery cracks would negate the current belief by the applicant and the staff that these cracks are benign. Thus, any cam gallery crack growth would precipitate a thorough investigation by the applicant/licensee and a review of those results by the staff. Likewise, the detection of any cracks between studs of adjacent cylinders would represent a situation beyond that which has been analyzed and would require the applicant/licensee to perform the same actions as specified above. The staff will require that an engine be declared inoperable if unsatisfactory inspection results involving the crankshaft, cam gallery crack growth, or cracks between studs of adjacent cylinders are detected. This should be incorporated into the Technical Specifications in a manner that would require prompt notification by the licensee and associated limiting conditions of operation. Licensee resolution to any of these three occurrences must receive staff approval before returning the engine to an "operable" status.

3.7 Technical Specifications, Operating Procedures

As discussed in the SSER provided to the ASLB on December 3, 1984, the plant Technical Specifications will be revised to limit all testing of the Shoreham EDGs to a nominal load not to exceed the 3300 kW "qualified load" level. As was also discussed, the load acceptance test of Section 4.8.1.1.2.e of the Technical Specifications will be supplemented such that the voltage and frequency for each load step will be monitored and shown to be within the required design limits specified in R.G. 1.9.

As discussed in the December 3, 1984 SSER, strict adherence to operating procedures and careful monitoring of EDG loads is necessary to ensure that the EDGs are not operated above 3300 KW. The staff has not received the final procedure that the licensee is relying on to provide assurance that operators will not load the engines above the 3300 KW limit. We cannot, therefore, conclude at this time that such operator errors will not occur. It is well established that operators are more prone to error during times of stress (such as during a LOOP or LOOP/LOCA event). Based on this fact, we are not certain that procedural controls alone can prevent operator errors. We have therefore determined that the licensee should install a distinctive alarm to warn the operators when EDG loads exceed 3300 KW. The staff would review licensee proposals for the design, installation and use of such an alarm in conjunction with its review of the revised EDG operating procedure.

4.0 CONCLUSIONS

The NRC staff concludes that the TDI diesel generators at Shoreham Nuclear Power Station Unit 1 will provide a reliable standby source of onsite power in accordance with General Design Criterion 17. This evaluation is based upon the NRC/PNL review of (1) the Owners Group findings with respect to the resolution of known problem areas and (2) actions taken by LILCO to verify and enhance the reliability of the EDGs including in particular the actions taken to resolve known problems. These findings are subject to the following actions by LILCO.

(1) LILCO should commit to an enhanced maintenance and surveillance program as described in Section 3.5 of this SER prior to plant operation in excess of 5% power.

(2) LILCO should commit to implementing any additional actions which the staff finds to be necessary as a result of its final review of the Owners Group Phase I findings and the Shoreham DRQR program. This commitment should be submitted prior to plant operation in excess of 5% power, although the actions themselves may be implemented anytime up until the first refueling outage. In the absence of such a submittal from LILCO, the staff will impose a license condition requiring staff review and approval prior to restart from the first refueling outage.

(3) LILCO must install a suitable, distinctive alarm to warn operators when the EDG loads exceed 3300 KW, and must provide adequate procedures to minimize the possibiltiy that operators may load the engine above 3300 KW for extended period of time.

Technical Evaluation Report

REVIEW AND EVALUATION OF TRANSAMERICA DELAVAL, INC., DIESEL ENGINE RELIABILITY AND OPERABILITY - SHOREHAM NUCLEAR POWER STATION UNIT 1

December 1984

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Project Title: Assessment of Diesel Engine Reliability/Operability

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FOREWORD

This report is supplied as part of the Technical Assistance Project, Assessment of Diesel Engine Reliability/Operability, being conducted for the U.S. Nuclear Regulatory Commission, Office of Nuclear Reactor Regulation, Division of Licensing, by the Pacific Northwest Laboratory. The U.S. Nuclear Regulatory Commission funded this work under authorization B&R 20-29-40-42-1 FIN No. B2963.

CONTENTS

TABLES

ABBREVIATIONS

ABS	American Bureau of Shipping
ASLB	Atomic Safety and Licensing Board
BMEP	brake mean effective pressure
CFR	Code of Federal Regulations
DEMA	Diesel Engine Manufacturers Association
DR/QR	design review/quality revalidation
E&DCR	Engineering and Design Coordination Report
EDG	emergency diesel generator
ET	eddy-current testing
FaAA	Failure Analysis Associates
FSAR	Final Safety Analysis Report
IACS	International Association of Classification Societies
LILCO	Long Island Lighting Company
LOCA	loss of coolant accident
LOOP	loss of offsite power
LP	liquid penetrant
M/S	maintenance/surveillance
NDE	nondestructive examination
NDT	nondestructive testing
NRC	U.S. Nuclear Regulatory Commission
OG	Owners' Group; the TDI Diesel Generator Owners' Group
OGPP	Owners' Group Program Plan
O/R	operability and reliability
PNL	Pacific Northwest Laboratory
SNPS	Shoreham Nuclear Power Station
SWEC	Stone & Webster Engineering Corporation
TDI	Transamerica Delaval, Inc.
TER	technical evaluation report
UT	ultrasonic testing

REVIEW AND EVALUATION
OF TRANSAMERICA DELAVAL, INC.,
DIESEL ENGINE RELIABILITY AND OPERABILITY -
SHOREHAM NUCLEAR POWER STATION UNIT 1

1.0 INTRODUCTION

Long Island Lighting Company (LILCO) is seeking a full power operating license for the Shoreham Nuclear Power Station (SNPS) Unit 1. One matter of concern to the U.S. Nuclear Regulatory Commission in considering the request is the operability and reliability (O/R) of the SNPS standby emergency diesel-engine generators manufactured by Transamerica Delaval, Inc. (TDI). The O/R of these engines have been brought into question by a major crankshaft failure at SNPS in August 1983 as well as by other problems reported by owners of TDI diesels in nuclear and non-nuclear service.

Shoreham Nuclear Power Station Unit 1 is served by three TDI model DSR-48 diesel engines, designated emergency diesel generator (EDG) 101, 102, and 103. These EDGs are inline 8-cylinder four-cycle, turbocharged, aftercooled engines. Each is nameplate rated for 3500 kW, and operates at 450 rpm with a cylinder brake mean effective pressure (BMEP) of 225 psig. The latest information provided by LILCO specifies the emergency load as a maximum of 3300 kW under design basis accident conditions coincident with a simulated loss of offsite power (LOOP).

In response to the NRC concerns about the SNPS TDI engines, LILCO has undertaken a comprehensive analysis of all major engine components and completed a number of component replacements and engine tests to ensure their O/R. These LILCO actions are described in a number of documents and in testimony before the Atomic and Safety Licensing Board (ASLB).

The Pacific Northwest Laboratory (PNL) has been requested by NRC to review and evaluate LILCO's overall efforts to ensure the engines' reliable performance. This technical evaluation report (TER) documents the PNL review and expresses the resulting conclusions and recommendations regarding the capability of the SNPS TDI diesel engines to serve their intended function.

1.1 ORGANIZATION OF REPORT

This technical evaluation report is organized as follows:

- Section 2.0 provides relevant background information on efforts by both LILCO and the TDI Diesel Generator Owners' Group (an ad hoc group of similar TDI engine owners) to resolve the TDI engine concerns.
- Section 3.0 presents PNL's review and evaluation of LILCO's tests, inspections, and component upgrades undertaken to prepare the engines for nuclear service.
- Section 4.0 comprises a review and evaluation of LILCO's resolution of known problems in 16 engine components identified by the Owners' Group through a review of TDI engine operating history.
- Section 5.0 provides PNL's review of LILCO's proposed maintenance and surveillance (M/S) program.
- Section 6.0 presents PNL's overall conclusions and recommendations regarding the suitability of the three TDI diesel engines to perform their intended function as emergency standby power sources for the SNPS.

1.2 APPLICABILITY OF CONCLUSIONS

To derive the conclusions presented in this report, PNL reviewed the basic documents supplied by LILCO, participated in various meetings with LILCO and NRC, and observed components of the engines as disassembled for inspection following testing. Concurrently, PNL also reviewed various relevant Owners' Group documents and participated in their meetings with NRC, and drafted technical evaluation reports on some elements of the Owners' Group Program Plan (OGPP). In addition, PNL and its consultants participated in the hearing on Docket No. 50-322-OL, extending from September through November 1984, before the Atomic Safety and Licensing Board. Information stemming from these reviews and activities constitutes a major part of the data base from which PNL's conclusions are drawn.

Immediately prior to the preparation of this TER, LILCO submitted to the NRC a Final Safety Analysis Report (FSAR) revision that identifies 3300 kW as the "qualified load" considered necessary for each engine to support its designated share of the emergency power needs of SNPS. In recognition of that FSAR revision, this TER addresses the adequacy of engine components relative to this load limit.

This TER precedes the completion of the final review by PNL and the NRC staff of the Owners' Group Program. Accordingly, the conclusions expressed in this TER about the long-term suitability of the Shoreham engines for nuclear service are contingent upon final action by NRC on the following PNL recommendations. LILCO should commit to NRC to implement all applicable recommendations and requirements identified in the NRC review of the Owners' Group Program. Completion of the ongoing Phase 1 and Shoreham Phase 2 reviews is anticipated early in 1985. In the opinion of PNL, the reviews of all Shoreham-related issues that require priority PNL/NRC attention have progressed sufficiently to consider these issues resolved, subject to the actions discussed in this TER. All recommendations and requirements identified in NRC's review of the Owners' Group Program should be implemented or be fully ready to implement by the end of the first reactor operating cycle. These actions will complete the resolution of the TDI engine issues at Shoreham.

1.3 REPORT PREPARATION

This report is based in part on PNL's review of documents cited in Section 2.0. In addition, the PNL team visited the Shoreham Nuclear Power Station Unit 1 in March, May, and November 1984, for orientation and to observe the EDG 103 inspection following testing. PNL met with SNPS staff and management on these occasions, as well as in connection with TDI Owners' Group meetings and the Atomic Safety and Licensing Board hearing during September through November 1984.

The following PNL staff members and consultants were involved in this review and evaluation, and authored this report:

- D. A. Dingee, PNL project staff
- R. E. Dodge, PNL project staff

- J. F. Nesbitt, PNL project staff
- F. R. Zaloudek, PNL project staff
- A. J. Henriksen, diesel consultant to PNL
- P. J. Louzecky, diesel consultant to PNL.

Others whose contributions were valuable in formulating the conclusions presented herein include PNL Assessment of Diesel Engine Reliability/Operability Project team members J. M. Alzheimer, L. G. Van Fleet, and W. W Laity; and consultants S. H. Bush, B. J. Kirkwood, A. Sarsten, and J. V. Webber (representing Ricardo Consulting Engineers). The report editor was A. J. Currie.

2.0 BACKGROUND

This section presents background information on efforts undertaken by the TDI Diesel Generator Owners' Group and by Long Island Lighting Company to resolve the problems identified in the TDI diesel engines.

2.1 OWNERS' GROUP PROGRAM PLAN

Thirteen nuclear utilities that own diesel generators manufactured by Transamerica Delaval, Inc. have established an Owners' Group to address questions raised by the major failure in one TDI diesel engine at the Shoreham Nuclear Power Station in August 1983, and other problems in TDI diesels reported in the nuclear and non-nuclear industry. On March 2, 1984, the Owners' Group submitted a plan to the U.S. Nuclear Regulatory Commission outlining a comprehensive program to requalify their diesel generator units as standby emergency power sources.

The Owners' Group Program Plan describes a two-phase approach for resolving the known and potential problems in TDI engines:

- Phase 1 addresses the evaluation and resolution of significant known problems in 16 components. These problems were identified by the Owners' Group through a review of the operating histories of TDI engines in nuclear and non-nuclear services.
- Phase 2 entails a comprehensive design review and quality revalidation (DR/QR) to identify critical components of TDI engines in addition to the 16 referred to above, and to ensure that these components are also adequate for their intended service.

The OGPP also describes a program element for special or expanded engine tests and component inspections, as appropriate, to verify the adequacy of the engines and components to perform their intended functions.

At NRC's request, PNL reviewed the OGPP. The results of that evaluation were reported to NRC in PNL-5161, Review and Evaluation of TDI Diesel Generator Owners' Group Program Plan (Pacific Northwest Laboratory June 1984).

Section 4 of PNL-5161 deals with considerations for licensing actions for nuclear stations prior to completion of the implementation of the OGPP. Recommendations in that report relevant to LILCO's current request for licensing of the Shoreham Nuclear Power Station Unit 1 are:

1. The engines should be inspected per Section 2.3.2.1 of PNL-5161 to ensure that the components are sound.
2. Preoperational testing should be performed as discussed in Section 2.3.2 of PNL-5161.
3. The engines should receive enhanced surveillance and maintenance.
4. A "lead engine" as described in Section 2.3.2.2 of PNL-5161 should be tested to 10^7 cycles at "qualified" load to verify the design adequacy of key engine components subject to fatigue stresses, if components of the same design have not already been operated that many cycles under the same or greater load.

The first three recommendations are self-evident; namely, that the engines have sound parts, that appropriate preoperational tests have been satisfactorily completed, and that a suitable program of maintenance and surveillance is established to ensure future performance. The fourth recommendation is included to ensure that all components, including the pistons and crankshaft, have sufficient fatigue resistance to preclude fatigue fracture of these components with concomitant engine failure.

2.2 SHOREHAM NUCLEAR POWER STATION

In its efforts to establish the operability and reliability of the SNPS TDI diesel engines, LILCO has performed engine modifications and has conducted tests and inspections. The utility has provided NRC with documents relevant to these activities. These documents and others that were used in the preparation of this TER are listed below.

- a LILCO report dated August 23, 1983, Shoreham Nuclear Power Station Emergency Diesel Generator 102 Crankshaft Failure Analysis/Recovery - Master Plan - This report describes the steps LILCO will take in investigating the failure of the EDG 102 crankshaft and in determining the generic implications for EDGs 101 and 103.

- a LILCO report dated December 14, 1983, Shoreham Nuclear Power Station Emergency Diesel Generator Recovery Test Program - This report defines the diesel generator test program that will be implemented on the SNPS TDI engines to demonstrate O/R following replacement of the engine crankshafts and reassembly of the engines.
- a LILCO report dated January 6, 1984, Shoreham Diesel Generator Recovery Program Summary - Shoreham Nuclear Power Station - This document outlines all aspects of the SNPS diesel generator recovery program.
- a report entitled Delaval Diesel Generator Operation Experience (handout at TDI Owners' Group meeting, January 26, 1984) - This report outlines the experience of various owners of TDI diesels (including LILCO) with their engines to late 1983.
- An OG report dated June 29, 1984, TDI Diesel Generator Design Review/ Quality Revalidation Report - Shoreham Nuclear Power Station Unit 1 - This 9-volume report documented the comprehensive DR/QR effort performed on the SNPS TDI engines and the results of that effort.
- LILCO Engineering and Design Coordination Report No. F-46505 and attachments dated July 17, 1984 - This report addresses the TDI diesel maintenance/surveillance program.
- an NRC report dated August 13, 1984, Safety Evaluation Report - Transamerica Delaval, Inc. Diesel Generator Owners' Group Program Plan - This report presented NRC staff recommendations for TDI diesel generator test and inspection programs.
- a report by Stone & Webster Engineering Corporation dated August 1984, entitled Survey of Start Experiences and Causes of Unscheduled Shutdowns of Transamerica Delaval Inc. Diesel Engines - This document summarizes data extracted from various diesel generators' logs (including the three engines at SNPS).

- a letter dated October 5, 1984, from J. J. Range (LILCO) to A. R. Dynner (Suffolk County) regarding duplication of photos for Suffolk County - This letter summarizes the status of the discovery made available the week of October 5, 1984, by LILCO pursuant to Suffolk County's September 25 request.
- a letter dated October 5, 1984, from J. J. Range (LILCO) to R. J. Goddard (NRC) transmitting LILCO Deficiency Report Number 1224 including revision and several FaAA preliminary inspection reports.
- a letter dated October 6, 1984, from J. J. Range (LILCO) to A. R. Dynner (Suffolk County) transmitting receiving inspection reports, production routing sheets, etc., for LILCO/TDI engines.
- a letter dated October 9, 1984, from J. J. Range (LILCO) to A. R. Dynner (Suffolk County) transmitting photographs of the cam gallery, engine bed, and main bearing saddles at SNPS.
- a letter dated October 18, 1984, from J. D. Leonard, Jr. (LILCO) to H. R. Denton (NRC), "Confirmatory Testing of TDI Diesel Generators at Shoreham Nuclear Power Station Unit 1, Docket No. 50-322" - This document provides NRC with LILCO's testing protocol for the 10^7-cycle confirmatory tests.
- a letter dated October 22, 1984, from J. Leonard (LILCO) to H. R. Denton (NRC), "Submittal of FSAR Revision Qualified Load - TDI Diesel Generators at Shoreham Nuclear Power Station Unit 1, Docket No. 50-322" - In response to Item 1 of Section 4.6 of the NRC Safety Evaluation Report on TDI OGPP entitled "Interim Basis for Licensing", LILCO has developed a "qualified load" by a combination of analysis and testing utilizing results of a recent preoperational test.
- a LILCO report dated December 3, 1984, <u>TDI Emergency Diesel Generator 103 10^7-Cycle Confirmatory Test/Inspection Report, Shoreham Nuclear Power Station Unit 1</u> - This report provides LILCO's tests and inspection results for the 10^7-cycle confirmatory test of the EDG 103.

- a letter dated December 6, 1984, from B. Germano and M. Herlihy (LILCO) to D. Dingee (PNL), "Load and Engine Hour Telecopy dated 12/5/84 from D. Dingee to B. Germano" - This letter provides engine hours for all three SNPS EDGs following crankshaft replacement to November 4, 1984.

- a letter dated December 7, 1984, from B. Germano (LILCO) to D. Dingee (PNL), "Telecopy dated 12/6/84 from D. Dingee to B. Germano Concerning Regulatory Tests Following DR/QR Inspections" - This letter provides confirmation that LILCO has completed the required qualification tests following EDG 101 and 102 reassembly in the spring of 1984.

- a letter dated December 11, 1984, from B. Germano and M. Herlihy (LILCO) to D. Dingee (PNL), "Load and Engine Hour Data for DG101 and DG102" - This letter summarizes approximate engine data for EDG 101 and 102 from the time following the last crankshaft inspection to the end of the EDG 103 long duration run on November 4, 1984.

In addition to reviewing these documents, PNL visited the SNPS site to observe engine inspections and review a sample of the LILCO procedures for dispositioning component inspection findings. PNL and its consultants also gained perspective on certain SNPS components (crankshaft, piston skirts, cylinder heads, and engine block) through participation in the Atomic Safety and Licensing Board hearing (Docket No. 50-322-OL) over the period extending from September 10 through November 16, 1984. The testimony and exhibits for this hearing are also reference material used in preparation of this TER.

3.0 LILCO TESTS, INSPECTIONS, AND COMPONENT UPGRADES

The SNPS EDGs have been subjected to several testing/inspection programs and, as a result, have undergone several component upgrades. These programs consist of 1) shop qualification tests, 2) onsite preoperational tests, 3) confirmatory tests, and 4) special post-inspection tests. The key inspections include those done on all engines in connection with the DR/QR activities as well as the EDG 103 inspection in November 1984 following the confirmatory tests. Other incidental inspections were also done.

A chronological discussion of these tests, inspections, and component upgrades is presented in Sections 3.1 through 3.4. The results and conclusions reported by LILCO are documented in Section 3.5. PNL's evaluation of LILCO's program is presented in Section 3.6.

3.1 SHOP QUALIFICATION TESTS

According to LILCO, the test program for the Shoreham EDGs began in the early 1970s with shop tests at the TDI manufacturing facilities in Oakland, California. These shop tests were performed to verify the operability of the EDG units, including the interrelated functional capability of engine components. The shop tests accomplished for all three engines included:

- load tests
- air starting system tests
- alarm and safety function tests.

LILCO noted that EDG 101 was used by TDI to qualify the R-48 series engines for nuclear service. This involved successfully completing 300 consecutive starts and operating for 110 hours, mostly at loads above 50% of the engine's rated load.

LILCO reported that the shop tests required a minimum of 30 hours of operation on each EDG; 10 of those hours were at loads equal to or greater than 100% load (3500 kW). In addition, each unit was required to start at least 10 times.

3.2 ONSITE PREOPERATIONAL AND OPERATIONAL TESTS

Onsite preoperational tests were conducted to confirm EDG operability and to verify their functional capability to interface with various plant systems. Tests pursuant to the SNPS FSAR, including NRC Regulatory Guide 1.108 tests, were also conducted.

LILCO has reported that the diesel generators were operated onsite for the first time in October 1981 (EDG 102), March 1982 (EDG 103), and April 1982 (EDG 101). The preoperational test program, consisting of 12 preoperational tests (four per diesel engine), was started in September 1982 and included 1) a mechanical test to check various mechanical trips on the diesel engine and the air starting capability of the air start system; 2) two electrical tests including various high-load rejection tests to demonstrate the electrical trips for the generator; and 3) the diesel generator qualification test, which demonstrated the capability of the diesel generators to successfully complete a total of 69 consecutive starts. On June 24, 1983, LILCO successfully completed the preoperational test program, including all mechanical, electrical, and qualification tests, for all three diesel generators.

In spring 1983, LILCO commenced a cylinder head replacement program in response to minor cooling water leaks that were noted. In mid-August 1983, during testing in conjunction with this cylinder head upgrade program, the crankshaft of EDG 102 fractured. This engine had logged 671 total hours operation, including 254 hours at the rated load of 3500 kW and 19 hours at 3900 kW. At that time, the engine hours logged on EDGs 101 and 103 were comparable to those of EDG 102. An inspection of the EDG 101 and 103 crankshafts also revealed cracks.

Following the EDG 102 crankshaft failure, LILCO initiated an effort to investigate the failure and to assess any generic implications for EDG 101 and 103. This effort included inspections of the diesel engine components in addition to the crankshafts. Several components were found to have problems. LILCO reports that four of the upper connecting rod bearings were cracked; all the AF piston skirts were found to have linear indications; and the governor of EDG 102 was found to be damaged as a result of the crankshaft failure and was returned to the manufacturer. The nature of these findings and their disposition are provided in more detail in Section 4.0 for the 16 components with known problems identified by the OG.

In fall 1983, as part of the crankshaft failure recovery program, LILCO made a number of engine modifications. New crankshafts with larger (12-inch diameter) crankpins were installed; all piston skirts were replaced with AE skirts; all cylinder heads were replaced with the newer Group III models; and new connecting rods were installed with the 12-inch (rather than 11-inch) bearing diameter. New connecting rod bearings were installed and rod-eye bushings with relevant indications were replaced.

During the same time period, LILCO became aware of TDI engines in non-nuclear service with block cracks (marine experiences with the ore-carrier MV Gott and the MV Columbia, a ship belonging to the Alaskan Marine Highway). In response to this and upon advice of their diesel consultants, LILCO conducted dye-penetrant inspections of the cylinder liner landing area. They reported no relevant indications in this area. However, numerous radial/vertical cracks were found in the ligaments between the bore and the stud holes on all SNPS EDGs.

LILCO next proceeded with engine testing and inspections in support of their DR/QR activities. This included achieving a nominal 100-hour total operation on each of the engines at or above the rated load (3500 kW), followed by a comprehensive engine inspection. The inspection that the OG accomplished encompassed 168 components of the SNPS diesel generators. The TDI Owners' Group provided technical recommendations regarding special component inspections. LILCO was responsible for implementing these recommendations and for establishing acceptance criteria where none were established by the Owners' Group. Further details of the DR/QR inspections as applicable to the generic problem components are summarized in Section 4.0 of this report.

This period (fall 1983 through spring 1984) of testing was highlighted by a number of problems with turbochargers (failed nozzle ring capscrews, a lost nozzle ring vane on EDG 103, and failed bearings on all SNPS EDGs). LILCO made suitable repairs and replaced the bearings.

LILCO reported that, during a test in spring 1984, the EDG 103 engine was found to have developed a crack down the front of the block. This block was subsequently replaced with TDI's new-design cylinder block. Microstructural analysis revealed the original block had an extensive degenerate microstructure that produced inferior mechanical properties. Cracks between the cylinder liner bore and cylinder head studs (ligament cracks) were reported in EDGs 101 and 102.

The DR/QR disassembly/inspection also resulted in a number of component replacements: one cylinder liner, several connecting rod bearings, the governor couplings, a number of rod-eye bushings, the jacket water pump, and both turbocharger thrust bearings.

3.3 CONFIRMATORY TESTS

In addition to the above tests and inspections, LILCO undertook confirmatory tests of EDG 103. These tests and the post-test inspections were performed in accordance with NRC staff recommendations described in Safety Evaluation Report - Transamerica Delaval, Inc. Diesel Generator Owners' Group Program Plan issued on August 13, 1984, and in subsequent discussions between NRC and LILCO, documented in LILCO's letter SNRC-1094 dated October 18, 1984. The confirmatory testing on EDG 103 provided additional running hours (525 hours) to accumulate a total of in excess of 740 hours of operation at the load of 3300 kW on the replacement crankshaft. This corresponds to 10^7 stress cycles, generally considered adequate and necessary to confirm long-term life at the tested load.

Inspections following the confirmatory tests included those indicated for each component listed in Table 3.1.

TABLE 3.1. Component Inspections Conducted by LILCO Following Confirmatory Testing of Emergency Diesel Generator 103

Component	Inspection Performed
Cylinder heads	Ultrasonic inspection of firedeck thickness at six specified locations
	Liquid penetrant (LP) inspection of surfaces of intake and exhaust valve seats and the firedeck area between exhaust valves
	Visual inspection to determine if any heads had through-wall weld repairs of the firedeck where the repair was performed from one side only
Engine block	Fluorescent magnetic particle examination and LP examination of the block top and in cam gallery locations where strain gauges had been placed during the confirmatory testing
	Eddy-current (ET) examination in the stud hole region between cylinders No. 4 and 5
Connecting rod bearings	LP examination
Wrist pin and rod-eye bushings	LP examination
Turbocharger	Visual inspection of the thrust bearings, the nozzle ring vanes and capscrews, and the turbocharger mounting flange bolts
	Bearing float evaluation
Crankshaft	LP and ET examinations as appropriate on all fillet areas and all crankshaft oil holes except the main bearings No. 1, 2, 10, and 11
Gears	Visual inspection of accessible front-end gears and gear teeth
Cylinder liners	Visual examination for excessive scuffing
Pistons	LP examination of all piston skirts in the stud/boss region
	Visual inspection of crown-to-skirt contact surface

LILCO reported that all of the inspections listed in Table 3.1 showed acceptable results. Except for two connecting rod bearings (one that was damaged during disassembly and one that had an indication on the outer diameter) and one cylinder head that was found to contain a plug weld, the components were released for reinstallation in the engine.

3.4 POST-INSPECTION TESTING

LILCO has reported that, to demonstrate engine operability after reassembly, they have successfully completed SNPS FSAR testing including Regulatory Guide 1.108 tests for EDGs 101 and 102. They have also completed the following tests on EDG 103 following reassembly after the confirmatory tests:

- ten modified starts to at least 1400 kW, but not to exceed 3300 kW
- two fast starts to 3300 kW; run for a minimum of 4 hours after each fast start
- one 16-hour test at load levels stepping up to and then down from 3300 kW - This includes a total of 4 hours at each of the following loads: 3300 kW, 2625 kW, 1750 kW, and 875 kW.

In addition to the immediate post-inspection operability tests, LILCO will conduct a 3300-kW load test once every 18 months for 24 hours. This test replaces the previously required NRC 18-month load tests consisting of a 3500-kW load for 22 hours and a 3900-kW load for 2 hours as specified in Regulatory Guide 1.108. This change will be incorporated in revisions to the plant technical specifications.

3.5 REPORTED RESULTS AND CONCLUSIONS

Various problems occurred or were noted during the tests conducted on the SNPS engines. Those of significance are summarized in Table 3.2. LILCO reports that all of these problems have been corrected or do not threaten engine reliability or operability.

The TDI Owners' Group has formally reported the results of their comprehensive DR/QR effort in a nine-volume report entitled TDI Diesel Generator Design Review/Quality Revalidation Report - Shoreham Nuclear Power Station

TABLE 3.2. Significant Problems Encountered in Shoreham Emergency Diesel Generators During Testing

Date	Problem
3/81	Excessive turbocharger thrust bearing wear
12/81	Piston modifications to prevent crown separation
9/82	Engine jacket water pump modifications
6/82	Air starting valve capscrews too long for holes
9/82	Engine jacket water pump shaft failed by fatigue
Spring 1983	Cracks in engine cylinder heads
Spring 1983	Cam gallery cracks in all three engines
3/83	Two fuel oil injection lines ruptured
3/83	Engine rocker arm shaft bolt failure
8/12/83	Broken crankshaft; cracks in other two crankshafts
9/83	Cracked connecting rod bearings
9/83	Cracked bedplates in area of main journal bearings
9/83	Unqualified instrument cable
10/83	Cracked AF piston skirts
Spring 1984	Failed turbocharger nozzle ring capscrews and lost turbocharger nozzle ring vane on EDG 103
Spring 1984	Failed turbocharger thrust bearings, all three EDGs
Spring 1984	Cracks between cylinder liner bore and head studs (ligament cracks), EDGs 101, 102, and 103
Spring 1984	Stud hole to stud hole crack in EDG 103
Spring 1984	Deep crack in EDG 103 block from cylinder No. 1 down front of block

Unit 1 dated June 29, 1984. The results of the confirmatory tests were reported in a document published in early December 1984 entitled TDI Emergency Diesel Generator 103 10^7-Cycle Confirmatory Test/Inspection Report, Shoreham Nuclear Power Station Unit 1 (undated). The details of LILCO's findings are discussed in Section 4.0 herein on a component basis. The results are therefore not repeated here.

The conclusion drawn by LILCO from both the DR/QR test/inspections and the confirmatory test/inspections is that all three SNPS EDGs are now suitable to serve their function as standby emergency power sources.

3.6 PNL EVALUATION

In evaluating LILCO's engine tests, inspections, and component upgrades, PNL reviewed all available documentation of the tests, inspection results, engine operating history, and testimony/exhibits from the ASLB hearings on the SNPS TDI engines. Based on this review, PNL concludes that the testing and inspection program is adequate to uncover problems with engine components and to confirm their ability to meet the load and service requirements. The component upgrades are viewed as responsive to the inspection findings and to the recommendations of the OG. PNL notes that the tests conducted on the SNPS EDGs have subjected the engines to a number of starts comparable to that expected in actual service for the life of the plant. PNL finds that a sufficient number of hours (746 hours or 10^7 cycles) has been accumulated on EDG 103 to meet the criterion for proving the absence of high-cycle fatigue in the crankshaft.

4.0 REQUALIFICATION OF COMPONENTS WITH KNOWN PROBLEMS

This section documents PNL's review of LILCO's actions to upgrade and/or requalify the 16 engine components known to have had significant problems (termed Phase 1 components). These components were previously identified by the Owners' Group through a review of the operating histories of TDI engines in nuclear and non-nuclear service.

Each Phase 1 component is discussed individually. The discussions are presented in a sequence reflective of component location within, on, or about the engine. The sequence generally progresses from bottom to top; that is, structural components, power train components, ancillary and auxiliary systems and components, on-engine and then off-engine.

Each component is described in terms of its function, operating history, and status as determined by the TDI Owners' Group and LILCO. This description is followed by PNL's evaluation and conclusion(s).

PNL's conclusions generally incorporate, without stating, the assumed commitment by LILCO to the modifications to their maintenance and surveillance program that are described in Section 5.0 of this TER, as well as the utility's commitment to appropriately implement the applicable recommendations and requirements resulting from the NRC final review of the OGPP concerning these components. The conclusions also reflect PNL's finding, based on a sampling examination of LILCO's procedures for dispositioning component inspection findings, that these procedures are adequate with respect to both documentation and engineering considerations.

4.1 ENGINE BASE AND BEARING CAPS

Part No. 03-305-A and 03-305-D

Owners' Group Report FaAA-84-6-53

4.1.1 Component Function

The engine base itself supports the crankshaft and upper structures, and carries the thrust of the cylinder combustion loads to the main bearings. The shaft is bedded in half-circle bearings set within "saddles" in the base. The bearing caps are structural members that hold the upper bearing shells in place over the shaft main journals while also absorbing the upward, reciprocating piston inertial loads. The studs and nuts hold the cap and therefore the shaft in place. A failure of base, cap, or bolting would allow shaft gyration or misalignment, potentially leading to shaft fracture and seizure, sudden engine stoppage, and possible ignition of crankcase vapors.

4.1.2 Component Problem History

Four incidents of cracking have occurred in the engine base saddles of inline DSR-4 engines, causing this component to be evaluated as a generic issue:

- SNPS EDG 102, reported following an inspection in September 1983
- SNPS EDG 103, reported following an inspection in September 1983
- U.S. Coast Guard cutter Westwind (a TDI DSR-46 engine)
- U.S. Coast Guard cutter Northwind (a TDI DSR-46 engine).

4.1.3 Owners' Group Status

Failure Analysis Associates (FaAA), a consultant to the Owners' Group, analyzed the base, bearing saddles, bearing caps, nut pockets, and bolting/ nuts. FaAA conducted a finite element analysis to determine stresses acting on critical sections of the bearing saddle under lateral loading from the crankshaft. The loads were determined from a journal orbit analysis. The bearing cap, through-bolts, bearing studs, and nuts were similarly analyzed. The studs and bolts were tested for hardness.

FaAA concluded that the base assembly components have the strength necessary to operate at full rated load for indefinite periods, provided that all components meet manufacturer's specifications, that they have not been damaged, that mating surfaces are clean, and that proper bolt preloads are maintained.

The Owners' Group concluded that the cracks in the engine base saddle of SNPS EDG 102 were due to the crankshaft failure. The cracks in EDG 103 resulted from improper engine disassembly procedures. Cracks in both U.S. Coast Guard cutters' engine base saddles were the result of undertorquing.

4.1.4 LILCO Status

Cracks were found in the main bearing saddles of EDG 102 and EDG 103 during an inspection (September 1983). FaAA evaluated these cracks and concluded that the EDG 102 cracks resulted from the crankshaft failure and those in EDG 103 were caused by improper engine disassembly procedures. In September 1983 the engine base saddle for EDG 101 was also inspected and no cracks were noted. However, because no inspection requirement or instruction existed at that time, no records were made. LILCO concluded, based on the analytical testing and inspection cited in Section 4.1.3 above, that adequate margins of safety for ultimate and fatigue loading exist for the main bearing saddles. Based on the finite element analysis, also cited in Section 4.1.3, they further concluded that the existing cracks in EDG 102 and 103 bearing saddles will not propagate. They also concluded that adequate safety margins exist against failure of the through-bolt and bearing cap bolt nut pockets. Periodic inspection (at alternate refueling cycles) via fluorescent-dye penetrant of the EDG 101, 102, and 103 bearing saddles is to be done to verify that cracks will not initiate and that existing cracks will not propagate.

4.1.5 PNL Evaluation and Conclusion

PNL notes that no cracks were found in EDG 101. PNL believes that the origin of the cracks observed in EDGs 102 and 103 was properly diagnosed and that the analysis conducted is appropriate to conclude that those cracks will not propagate in service. PNL also concurs with the periodic inspections planned to verify that the cracks will not grow.

On the basis of the inspections, diagnostics, and actions taken by LILCO, PNL concludes that the engine base and bearing caps in EDGs 101, 102, and 103 are acceptable for their intended service, subject to a confirmatory inspection to be performed according to the OGPP recommendations noted in Section 5.0 of this TER.

4.2. CYLINDER BLOCK

Part No. 03-315-A

Owners' Group Report FaAA-84-5-4

4.2.1 Component Function

The cylinder block, which is bolted to the engine base, provides structural support for the cylinder liners, cylinder heads, camshaft and valve assemblies, and other miscellaneous components. It also serves as the outer boundary for the engine coolant. The block is subjected to both mechanical and thermal stresses resulting from the combustion processes. Structural failure of the block could lead to inadequate support of components that confine combustion pressures, and thereby result in a sudden engine shutdown.

4.2.2 Component Problem History

Cracks have been reported in cylinder blocks of both DSR-4 (inline) and DSRV-4 ("V") engines in nuclear and non-nuclear applications. Several types of cracks have occurred in cylinder block tops. Cracks have also occurred in the camshaft galleries of inline engines, in the vertical wall just above the camshaft bearing supports. The following is a summary of the types of cracks and the engines in which they have been found.

1. Ligament cracks - A ligament crack is oriented vertically and extends between the counterbore for the cylinder liner landing and a cylinder head stud hole. Numerous cracks of this type have been identified in the top surfaces of the Shoreham EDG 101, EDG 102, and original EDG 103 engine blocks. Crack maps for the three blocks are presented in FaAA-84-5-4, Design Review of TDI R-4 and RV-4 Series Emergency Diesel Generator Cylinder Blocks and Liners.

   Ligament cracks have also been reported by FaAA in the marine and stationary installations listed below. These engines have operated with such cracks from 6,000 to 28,000 hours.

TDI Engine Series	Installation
DSR-4	Copper Valley Electric Corporation
DSR-4	MV Trader
DSR-4	MV Traveler
DSRV-20-4	Homestead, Florida
DSRV-16-4	MV Gott
DSRV-16-4	MV Columbia

2. Stud-to-stud cracks - A stud-to-stud crack is also oriented vertically, and extends between two cylinder head stud holes of adjacent cylinders. In nuclear applications, stud-to-stud cracks have been identified only in the original block for the Shoreham EDG 103 engine. Following replacement of the crankshaft in that engine and an engine test of 100 hours at or above the nameplate rating of 3500 kW, a crack was discovered that extended between two adjacent studs on the exhaust side of cylinders No. 4 and 5. Later, after EDG 103 had experienced an abnormal load excursion while being operated at full load, and had then been operated for a brief period (less than two hours) at 3900 kW, reexamination of the engine block revealed additional between-stud cracks. Furthermore, the original stud-to-stud crack between cylinders No. 4 and 5 had grown, as documented in the FaAA report referenced above. (The original EDG 103 block was replaced, as discussed later in this section.)

3. Circumferential cracks - Cracks of this type are found in the corner formed by the cylinder liner landing and the cylinder liner counterbore. They may extend circumferentially around the landing and downward into the block. Such cracks were discovered in the original EDG 103 block through destructive metallurgical examinations, which revealed a maximum crack depth of approximately 3/8 inch. Because of the relatively sharp corner where these cracks occur, they are difficult to identify through nondestructive tests. PNL anticipates that similar cracks may occur in the EDG 101 and 102 blocks, because

of the relatively high stress concentration associated with the geometry of the cylinder liner landing.

4. Cam gallery cracks - This type of crack appears as a horizontal indication in the upper radius of a camshaft bearing support, and extends in essentially a horizontal plane toward the engine jacket cooling water system. Cracks of this type have been discovered in the cam galleries of the EDG 101, EDG 102, original EDG 103, and replacement EDG 103 cylinder blocks. Weld repairs that are essentially cosmetic in nature were performed on the cam gallery cracks in the first three blocks. These repairs did not involve complete removal of the crack; furthermore, additional cracking occurred between the weld "nuggets" and the base material in all three blocks. The cam gallery cracks in the replacement EDG 103 block are much shallower than those in the other blocks.

Another crack of a type that differed from those described above appeared in the original EDG 103 block after the following sequence of events. During a test at full load, EDG 103 experienced an abnormal load excursion. The engine slowed to 390 rpm, at which time a breaker tripped, removing the electrical load. The engine continued to operate at rated rpm (450) for about 10 minutes, and was then shut down. After the engine was restarted and loaded to 3900 kW, a crack was observed extending down the front of the block from cylinder No. 1, and the engine was again shut down. Reexamination of the block revealed additional stud-to-stud cracks discussed earlier in this section. LILCO decided to replace the block.

Metallurgical examinations of the original EDG 103 block by FaAA revealed an extensive degenerate graphite microstructure that produced markedly inferior mechanical properties. FaAA concluded from metallurgical examinations of the EDG 101 and 102 blocks that they did not exhibit similar degenerate microstructures.

Several indications were discovered in the DSRV-16-4 engines at Comanche Peak that also differ from the types of cracks described above. These indications are oriented vertically and extend radially into the block from the cylinder liner landing and cylinder liner counterbore. Through metallurgical examinations, FaAA identified these cracks as interdendritic shrinkage or porosity resulting from the casting process. They have not been found in any other TDI engines in nuclear service.

4.2.3 Owners' Group Status

Because no cracks other than those found in the Comanche Peak engines have been reported for any other TDI engines in nuclear service, all efforts have been directed toward determining the significance of the various cracks in the SNPS engine blocks.

To this end, FaAA on behalf of the OG conducted an investigation that consisted of 1) an analysis of loads on the block that influence fatigue and fracture and 2) a stress analysis to estimate the levels of stresses caused by these loads, as input to their fracture and fatigue life evaluation.

The load analysis considered the combined effects of 1) the preload on the cylinder head studs, 2) the load distribution between the head and the block, 3) the load between the head and liner, and 4) the thermal and pressure loads between the liner and the block. These loads were used as input to the stress analysis to provide estimates of the stress levels in the block.

The stress analysis included strain-gauge testing on EDG 103 at various loads and types of starts, as well as two- and three-dimensional finite element analyses of the top of the block. The finite element analyses were used to 1) analyze the stresses in the ligament resulting from firing pressure, 2) obtain the ratio of stresses in the ligament resulting from thermal expansion, 3) determine the radial stress distribution on the inside surface of the block resulting from a uniform pressure on the inside surface of the liner for both the cracked and uncracked ligament, and 4) determine the effect of varying the liner-to-block radial clearance. The results of the finite element analyses were used to gain insight on the distribution of stresses and to determine scaling factors to relate stresses at gauge locations to those at the crack initiation sites.

In addition, sections of the original EDG 103 block were cut out and subjected to full metallurgical tests of materials, including fractography and metallography, and visual inspection of cracks in counterbore to stud hole, stud hole to stud hole, and counterbore radii and camshaft gallery areas. Metallurgical tests were also conducted on samples from EDG 101 and 102 blocks.

FaAA findings are summarized as follows:

- Initiation of cracks in the ligament between stud hole and liner counterbore is predicted to occur after accumulated operating hours at high load and/or engine starts to high load. These cracks are benign because the cracked section is fully contained between the liner and the region of the block top outside the stud hole circle. Field experience is consistent with both the prediction of ligament cracking and the lack of immediate consequences. These cracks are not expected to extend below the cylinder liner counterbore landing (approximately 1.5 inch deep.)
- The presence of ligament cracks between stud holes and liner counterbore increases the stress and the probability of cracking between the stud holes of adjacent cylinders such that stud-to-stud cracks are predicted to initiate after additional operating hours at high load and/or engine starts to high load. The deepest measured crack in this region was originally estimated to be approximately 5.5 inches deep, but later, when a cutout section was available for measurement, determined to be 3.9 inches deep. This did not degrade engine operation or result in stud loosening.
- The apparent rate of propagation of cracks between stud holes in the original EDG 103 block at SNPS, when compared with LOOP/LOCA requirements, indicates that blocks with ligament cracks are predicted to withstand a LOOP/LOCA event with sufficient margin, provided that 1) inspection shows no stud-to-stud cracks prior to the event and 2) the specific block material of EDG 103 is shown to be sufficiently less resistant to fatigue than typical gray cast iron, Class 40. Metallurgical tests and photomicrographs demonstrated that EDG 101 and EDG 102 block material had the appearance and ultimate tensile strength of typical gray cast iron, Class 40. However, the material of the EDG 103 original block was found to be of a degenerate

graphite composition with ultimate tensile strength much inferior to that of typical gray cast iron, Class 40.

- The block tops of engines that have operated at or above rated load should be inspected for ligament cracks. Engines such as those at Catawba and Grand Gulf that are found to be without ligament cracks can be operated without additional inspection for combinations of load, time, and number of starts that produce less expected damage than the cumulative damage prior to the latest inspection. The allowable engine usage without repeated inspection can be determined from cumulative damage analysis.
- The blocks of engines that have been operated without subsequent inspection of the block top should conservatively be assumed to have ligament cracks for the purpose of defining inspection intervals.
- For blocks with known or assumed ligament cracks, the absence of detectable cracks between stud holes of adjacent cylinders should be established by eddy-current inspection before the engine is returned to emergency standby service after any period of operation at or above 50% of rated load. If crack indications are found, removal of the adjacent heads and detailed inspection of the block top are necessary. In addition, it is necessary to ensure that the microstructure of the block top does not indicate inferior mechanical properties.
- Engines that operate at lower maximum pressure and temperature than those in the SNPS engines may have increased margins against block cracking that could allow relaxation of block top inspection requirements. Modifications to other parameters such as increased liner-to-block radial clearance and reduced liner protrusion above the block (proudness) will reduce stresses, and site-specific analyses of such modifications could also permit relaxation of inspection requirements.
- The cracks in the cam gallery of the EDG 101 and 102 blocks and the EDG 103 replacement block are shrinkage cracks that originated during

the cooling-down period after the blocks were cast, while they were still in the mold. During operation the areas in question are under continuous compressive stress and, thus, pose no problems due to crack growth.

4.2.4 LILCO Status

As part of the DR/QR program, LILCO assembled and reviewed the component documentation including the Owners' Group evaluation of the component described in the previous section. They also performed a series of dimensional checks and NDT examination of the block that are summarized as follows.

Engine 101

- A liquid penetrant test was performed on the cylinder liner landing along the top landing surface, fillet radius, and vertical face adjacent to the surface on cylinders No. 1 through 8. Indications of landing cracks were reported and reviewed by FaAA. Based on operating experience, FaAA judged these indications to be normal and to have no impact on the safe operation of the engine.
- Liquid penetrant and ultrasonic tests were performed in the area of the cylinder block stud holes. These tests revealed linear indications in the landing area of the stud hole counterbore for cylinders No. 1, 2, 3, 4, and 6. The indications were reviewed by FaAA and, on the basis of experience, judged to not compromise safe operation of the engine.
- Visual, liquid penetrant, and ultrasonic tests of cylinder block liner landings performed in conjunction with a 100-hour test revealed indications on cylinders No. 3, 4, 5, 7, and 8. Indications were reviewed, and judged to be normal and to have no impact on the function of the seating surface.
- Eddy-current tests were performed on the cylinder block in the area between the cylinder head studs. No relevant indications were reported.

- Measurements were taken to establish the as-built dimensions of all cylinder block liner landings, and recorded.

Engine 102

- Liquid penetrant tests were performed on the cylinder liner landing along the top landing surface, fillet radius, and vertical surface adjacent to cylinders No. 1 through 8. Linear indications were found, which, after review, were judged to not compromise the safe operation of the engine.
- Visual and eddy-current tests were performed prior to and after the 100-start test. The locations of all indications were reported to FaAA, who judged them to be not detrimental.
- Liquid penetrant tests were performed around the head stud bolt circle on top of the block. Ligament cracks were reported to FaAA, who judged them to be not detrimental.
- Eddy-current tests were performed on the cylinder block in the stud-to-stud areas between the cylinders, and no relevant indications were revealed.
- Liquid penetrant tests were performed on cam gallery saddles No. 3 and 5, revealing linear indications. The indications were reported to FaAA, who judged them to be not detrimental.
- The dimensions of the cylinder block liner landings were verified.

Engine 103 Replacement Cylinder Block (following the 746-hour confirmatory test)

- Fluorescent magnetic particle examination of the block top surface revealed no recordable indications. Eddy-current examination of the four adjacent stud holes between cylinders No. 4 and 5 revealed no recordable indications.
- Prior to the endurance run, liquid penetrant and magnetic particle examinations of cam saddles No. 2 and 8 and the areas adjacent to the bolts were performed and indications mapped. A surface resistance probe was used to measure the depth of the indications. These

examinations were repeated following the confirmatory testing. Comparisons of the results of these tests established that these indications did not grow as a result of the testing.

- Prior to the endurance run, strain gauges were placed in critical areas of the camshaft gallery. Adjacent tie rods were loosened and the strain gauges were adjusted to zero. Next, the tie rods were retorqued to their proper values, and the strain gauges registered compressive stress. The strain gauges were monitored and readings were recorded at varying load conditions. At no time during operation did the readings indicate tensile stresses.

The replacement block for EDG 103 is a typical gray cast iron, Class 45. Ultimate tensile strength has been checked and proven to be normal. Class 45 is superior to Class 40 gray cast iron. Therefore, the replacement block for EDG 103 is of a superior strength material to that of EDG 101 or 102.

On the basis of the review of the design review documentation and the results of the testing and inspections summarized above, LILCO concluded the cylinder blocks for EDGs 101, 102, and 103 are acceptable for their intended function at SNPS.

4.2.5 PNL Evaluation and Conclusions

PNL's review of the SNPS EDGs included consideration of 1) the FaAA design review of the cylinder blocks, 2) inspection reports for the SNPS engines, and 3) the testimony exhibits of the applicant, intervenor, FaAA, and NRC given at the ASLB hearing. The implications of the observed camshaft gallery, ligament, circumferential, and inter-stud hole cracking observed in both nuclear and non-nuclear applications were considered.

4.2.5.1 Camshaft Gallery Cracks

Evidence available from recent tests and metallurgical investigations strongly suggests that the known camshaft gallery cracks originated during the casting and subsequent cooldown of the cylinder blocks, and that the cracks have not grown since that time. Strain-gage measurements taken by FaAA on EDG 103 demonstrate that the areas where the camshaft gallery cracks occur are subject to compressive stresses during engine startup, operation, and shutdown.

Although PNL concurs that compressive loads introduced during engine assembly should prevent growth of the cam gallery cracks, PNL is less certain of the level of residual stresses in the vicinity of the cracks and the consequences of those stresses when compressive loads are reduced or removed. The residual stresses could conceivably lead to crack "pop in" when a block is unbolted from its base. It is also conceivable (although admittedly unlikely) that the unknown residual stresses, combined with reduced compressive stresses during engine operation, could exceed the imposed compressive stresses at the crack tip and lead to crack growth during operation. Therefore, PNL is of the opinion that monitoring of crack behavior is indicated for the camshaft galleries of EDG 101 and 102. PNL's recommendations, and reasons for not recommending that EDG 103 also be monitored, are presented in Section 5.1.1.2.

4.2.5.2 Circumferential Cracks in Liner Bore

Circumferential cracks in the liner counterbore and counterbore landing were observed in the Shoreham engines and in other engines in non-nuclear applications. These cracks were not analyzed in the FaAA original design review; however, they were later dealt with by both visual examination of cracks in the cutout section of the original EDG 103 block. PNL believes that the FaAA analysis of the origin of cracks, namely stresses induced by cylinder liner proudness, is correct.

Further, FaAA's finite element analysis of the area reveals that the above-described region of high tensile stresses is immediately surrounded by a region of high compressive stresses resulting from the bolt-up of the cylinder head to the block. Therefore, it is PNL's judgment that any cracks formed in the cylinder liner counterbore and landing would be rapidly arrested as they move into the region of compressive stress, and will not represent any hazard to engine reliability. This judgment was supported by the results of sectioning of the circumferential crack that had propagated only 1/8 to 3/8 inch into the block even though this block had degraded mechanical properties. Further confirmation that such cracking is benign is furnished by operating experience; there are no records of any nuclear or non-nuclear engine failing because of cracks of this type.

4.2.5.3 Ligament Cracks

PNL concludes that, provided the ligament cracks in cylinder blocks for EDG 101 and EDG 102 are properly monitored as indicated in Section 5.0 of this TER, they will not impair service during an eventual LOOP/LOCA event. This conclusion is based on review of FaAA analyses, including three-dimensional finite element analysis, LILCO's DR/QR, and the fact that, although numerous reports on cylinder block ligament cracks exist from TDI DSR-4 and DSRV-4 engines in operation, there are no reports on these cracks rendering an engine nonfunctional.

4.2.5.4 Stud-to-Stud Cracks

Stud-to-stud cracks are considered more serious than ligament cracks because they degrade the overall mechanical integrity of the block and its ability to withstand firing pressures and piston side thrust. The analysis performed by FaAA indicated that, once ligament cracks occur, the stresses in the stud-to-stud region increase, providing a greater potential for cracking in this region. From cumulative damage analyses, FaAA determined that approximately the same amount of accumulated damage would be required to form stud-to-stud cracks following the formation of ligament cracks as would be needed to originally cause the ligament cracks themselves. Furthermore, the amount of damage that would be caused by operation during a LOOP/LOCA accident would be much less than that required to produce a stud-to-stud crack greater than 4 inches deep. Therefore, FaAA concluded that a block was able to meet its intended function if tests showed the absence of stud-to-stud cracks.

Based on the FaAA analysis of the cracks present in the SNPS blocks and on the LILCO inspection results showing the absence of cracks between studs of adjacent cylinders, PNL concluded that the cylinder blocks currently installed in EDGs 101, 102, and 103 are suitable for continued use. This conclusion is subject to verification that no cracks have developed between stud holes of adjacent cylinders in EDGs 101 and 102 following each operation of the engine at 50% of qualified load or above. If cracks are found, further analysis should be made to determine the suitability of the block for continued service. Because the absence of ligament cracks in the block of EDG 103 was confirmed following the completion of the confirmatory tests, inspection for inter-stud cracks is not necessary. However, it is recommended that the block of EDG 103 be reinspected for ligament cracks at intervals based on the formula described in the report FaAA-85-5-4.

In consideration of the above cited analyses and inspections and PNL's examinations of the blocks, PNL concludes that the blocks installed on EDGs 101, 102, and 103 are acceptable for the intended service, subject to monitoring of cracks as noted above.

4.3 CRANKSHAFT

Part No. 03-310-A

Owners' Group Report FaAA-84-3-16

4.3.1 Component Function

The crankshaft receives the reciprocating power strokes from the cylinders (via the pistons and connecting rods), converts them to rotary motion, and transfers the shaft power to the generator. It also drives the gear train that operates the camshaft, which, in turn, operates the cylinder-head valves, fuel injection pumps, governor, etc. The crankshaft is supported by journal bearings mounted in the engine base. The crankshaft begins as a forged steel billet, which is subsequently formed into the crankshaft configuration by a further process of forging and twisting, after which it is machined. By means of holes drilled throughout the crankshaft, pressurized oil is picked up from the main journal bearing supply points and transmitted to connecting rod bearings, wrist pins, undersides of the pistons, and other parts.

The crankshaft is subject to a variety of very complex stress fields. These include direct and torsional shear stresses and bending stresses due to the piston thrusts; inertial effects of reciprocating masses; torsional, axial and flexural vibration stresses; bending stresses due to overhung flywheel; bending stresses due to wear-down in main journal bearings; and variation in external support alignments. These nominal stress combinations are augmented in local stress fields due to the stress-raising influence of oil holes and crankweb/journal transition zones. Residual stresses due to forging and heat treating procedures, operating conditions, and operating accidents also affect the final stress spectrum. The machined surfaces of the crankshaft journals and crankpins are subject to damage from oil impurities, bearing deterioration, and excessive heat. Therefore, crankshaft failures may occur. At worst, a crankshaft may actually fracture (through fatigue) and separate, leading to immediate engine shutdown and probable significant conjunctive damage to other components. Precursory damage leading to failure (such as cracking) can sometimes be prevented via surveillance and maintenance (e.g., periodic crankshaft deflection checks).

4.3.2 Component Problem History

In August 1983, the SNPS EDG 102 crankshaft fractured during plant preoperational tests. This fracture occurred at the crankpin journal of cylinder No. 7, separating the crankshaft into two pieces. The fracture involved the web connecting the No. 7 crankpin journal to the adjacent No. 9 main bearing journal. Inspection revealed severe cracking in the crankshafts of the other two SNPS engines. Independent studies performed by FaAA and the Franklin Research Center subsequently determined these failures to be due to torsional vibrations. No other torsional failures of DSR-48 crankshafts have been reported.

The original crankshafts that had 11-inch diameter crankpins with 1/2-inch fillets were subsequently replaced with new crankshafts having 12-inch diameter crankpins with 3/4-inch fillets.

4.3.3 Owners' Group Status

The OG initiated an extensive investigation of the causes of the SNPS crankshaft failure. FaAA and SWEC were retained by LILCO to carry out intensive inspections, and analytical and experimental investigations. The NRC requested that the Franklin Research Center provide an independent review. The conclusion of these investigations was that the crankshaft failed from torsional vibration stresses resulting from operation too near a critical speed.

The Owners' Group next evaluated the adequacy of the replacement Shoreham crankshafts. This was performed by FaAA and consisted of 1) reviewing TDI calculations of stresses from single torsional vibration modes and SWEC torsiograph tests on both the old and new crankshafts to verify that the new crankshafts did meet Diesel Engine Manufacturers Association (DEMA) standards and 2) performing a fatigue analysis of the crankshaft to determine the factor of safety against fatigue. In addition, TDI obtained certification from the American Bureau of Shipping (ABS) for sizing of the crankpins, journals and webs.

The analysis of the factor of safety against fatigue failure consisted of 1) torsional dynamic analysis to compute the nominal stresses at each crank throw, 2) a three-dimensional finite element analysis to determine local stresses in the crankpin fillet, 3) stress measurements at the points of maximum stress indicated by the finite element analysis, and 4) a determination of the factor of safety by comparing the measured stresses with the endurance limit for the failed Shoreham crankshaft.

FaAA reached the following conclusions (which are documented in FaAA-84-3-16):

- The TDI calculations of stresses using single orders are appropriate and show that the stresses in the replacement crankshafts are below DEMA recommendations for single orders of torsional vibration.
- The SWEC torsiograph tests show that the stresses in the replacement crankshafts are below DEMA-recommended limits for both single and combined orders of torsional vibration at 3500 kW (100% load) and at 3800 kW. A linear extrapolation to 3900 kW also shows compliance.
- Calculations of torsional stresses over the range within five percent above and below rated speed (450 rpm) at 3500 kW show compliance with DEMA within the accuracy of the analysis. These stresses were calculated by FaAA using the modal superposition method together with harmonic data obtained by SWEC at 3500 kW and 450 rpm.
- On the basis of an endurance limit established for the failed crankshafts and scaled to account for the higher ultimate tensile strength of the replacement crankshafts, together with stress levels computed from strain gauge data, the factor of safety against fatigue failure of the replacement crankshafts is 1.48 for operation at 3500 kW. This factor of safety does not account for the beneficial effects of shotpeening, and is even greater if the shotpeening of the Shoreham crankshafts is considered.
- The replacement crankshafts are suitable for unlimited operation in the emergency diesel generators at SNPS at the nameplate engine rating of 3500 kW and at the two-hour-per-24 hour rating of 3900 kW.

Other evaluations of the adequacy of the replacement crankshafts were performed for LILCO by Dr. Franz F. Pischinger, president of FEV (Research Society for Energy, Technology and Internal Combustion Engines) and a professor at the University of Aachen in West Germany; and by Dr. Simon K. Chen, owner and president of Power and Energy International, Inc., a private consulting firm in Beloit, Wisconsin. Dr. Pischinger independently reviewed the work performed by FaAA on the crankshafts, and he compared the design of the crankshafts against the Kritzer-Stahl design criteria. He concluded that the crankshafts should have unlimited life for operation at 3500 kW, and that the crankshafts should be able to operate at 3900 kW for a minimum of 600 hours. Using 12 orders of vibration and harmonic coefficients based on data from Lloyd's Registry of Shipping standards ("Guidance Notes on Torsional Vibration Characteristics of Main and Auxiliary Oil Engines," 1976), and the TORVAP computer program, Dr. Chen concluded that the replacement crankshafts comply with DEMA standard practices at 3500 kW and 3900 kW.

4.3.4 LILCO Status

The replacement crankshafts installed by LILCO were manufactured by the West German firm of Krupp Stahl, A.G. using a forged slab, hot-twist fabrication process. Nondestructive examinations performed by Krupp included ultrasonic testing (to detect subsurface flaws) and magnetic particle inspection (to detect surface and near-surface flaws). Krupp's inspections revealed no relevant indications.

The fillet areas of two of the three replacement crankshafts were shotpeened by TDI before these crankshafts were shipped to LILCO. They were repeened for LILCO by Metal Improvements Company, Inc., when receipt inspection revealed that the original shotpeening did not meet LILCO requirements. Before the repeening was performed, the crankshafts were subjected to magnetic particle testing and liquid penetrant testing of the fillets. These inspections showed that no relevant indications were introduced in the first shotpeening. The third crankshaft was shipped directly from Krupp to LILCO, and shotpeened by Metal Improvements Company.

As part of LILCO's DR/QR program for the engines, the three crankshafts were reinspected in the areas of highest torsional stress after each crankshaft had been operated for approximately 300 hours, including approximately 100 hours at 3500 kW and above. The reinspection of each crankshaft involved high-resolution eddy-current testing and liquid penetrant testing of the crankpin journal fillets of cylinders No. 5, 6, 7, and 8. No rejectable indications were found.

On October 22, 1984, LILCO submitted a Final Safety Analysis Report (FSAR) amendment to the NRC staff for a "qualified" engine load of 3300 kW (i.e., the maximum emergency load that would be imposed on any of the three engines under design-basis accident conditions). In a letter to the NRL staff dated October 18, 1984, LILCO described the protocol for a 740-hour confirmatory test of the EDG 103 engine at the qualified load of 3300 kW. The test was completed early in November 1984.

Inspections performed by LILCO following the test referred to above included 1) liquid penetrant testing of all crankshaft fillet areas and external radii of oil holes except for fillets and oil holes at main bearings No. 1, 2, 10, and 11; 2) eddy-current inspection for evaluation of all recordable indications; and 3) eddy-current inspection of oil holes to three inches from the journal surface except oil holes in main bearing journals No. 1, 2, 10, and 11. (The latter journals, which are not the most highly loaded, were not accessible for inspection because the cylinder block remained installed on the engine base.) All recordable liquid penetrant indications were evaluated by LILCO and found to be nonrelevant.

Summarized in Table 4.1 are the loads and corresponding hours accumulated on all three engines following the installation of the new crankshafts. This information was provided by LILCO.

TABLE 4.1. Loads and Engine Hours

	Engine Number		
	101	102	103
Total hours (all loads)	611	557	1323
Approx. hours at 3300 kW	0	0	525
Approx. hours at 3500 kW	147	117	119
Approx. hours at load greater than 3500 kW	99	68	101
Approx. hours at 3900 kW	6.5	7.5	7
Number of starts	216	250	319

4.3.5 PNL Evaluation and Conclusion

PNL reviewed the post-test inspection OF EDG 103 following the endurance test described above. The purpose of the review was to determine, through an independent audit of the condition of key engine components, whether or not they exhibited any evidence of abnormal behavior under the conditions imposed during the test. This audit was performed by consultants under contract to PNL who have extensive experience in diesel engine technology, and by a PNL specialist in nondestructive testing. PNL's findings on the crankshaft are documented in a report dated December 3, 1984, for the Atomic Safety and Licensing Board. In summary, PNL's consultants found nothing in their visual inspections of the crankshaft journals and the corresponding bearing shells that would be indicative of crankshaft deficiencies. Furthermore, no rejectable indications were found in the nondestructive examinations witnessed by PNL's NDT specialist.

PNL's consultants also performed independent reviews of the adequacy of the replacement crankshafts relative to DEMA standard practices and to the rules established by several classification societies for marine engines. Although TDI was not obligated to follow rules of marine classification societies in the design of the Shoreham engines, such rules provide a conservative basis for an independent evaluation. The results of PNL's reviews are summarized as follows:

- DEMA

  Prof. Sarsten, a PNL consultant from the Norwegian Institute of Technology at Trondheim, Norway, used a computer program called COMHOL to calculate torsional stresses for single orders and for the sum of 24 orders of vibration. His analysis employed the same harmonic data used by FaAA. His results predict that the crankshaft stresses meet DEMA standards for single orders, but exceed DEMA standards for the sum of orders at 3500 kW. At 3300 kW, his results predict that the crankshaft torsional stresses are below DEMA limits for the sum of orders over the speed range of 5% below rated speed through 5% above rated speed, except for that portion of the speed range above 466 rpm. His results predict that stresses exceed the DEMA limit of 7000 psi by a maximum of approximately 250 psi at 473 rpm (at 3300 kW).

- American Bureau of Shipping

  PNL consultants confirmed that crankshaft web dimensions satisfy ABS rules. However, torsional stresses predicted by PNL consultant A. Sarsten for single and combined orders at 3500 kW (approximately 3600 psi and approximately 7100 psi, respectively) exceed limits calculated by TDI (3357 psi and 5035 psi, respectively) that would be allowed under the 1984 ABS rules.

- International Association of Classification Societies

  Ricardo Consulting Engineers of England calculated the factor of safety of the Shoreham replacement crankshafts for PNL according to the proposed rules of the IACS. For 3200 kW, 450 rpm, and a maximum cylinder pressure of 1650 psi, the calculated factor of safety was 0.926 in comparison to the IACS-proposed minimum of 1.1.

- Det Norske Veritas

  Allowing for the stationary application of the Shoreham engines and for an estimated influence of shotpeening, this classification society in Oslo, Norway, concluded that the crankshaft safety margin would not be adequate for loads exceeding 3200 kW.

PNL has the following comments on the various analyses of the replacement crankshafts and the recently-completed endurance test of EDG 103:

- In light of the conflicting results of the analyses performed for LILCO and the analyses performed independently for PNL, the analytical evidence alone does not provide a sufficient basis for concluding that the crankshafts are adequate for the qualified load of 3300 kW.
- The crankshafts for the Shoreham engines do not have to meet any or all of the requirements of the various marine classification societies. Even if a crankshaft does not meet such rules, it may still perform adequately. The rules of the classification societies contain inherent conservatisms that reflect the rigors and uncertainties of marine service. Furthermore, the rules are often subject to interpretation and discussion with the classification society, and approval does not necessarily depend on strict compliance with the rules.
- The results of the EDG 103 test completed in November 1984 provide important and, in PNL's view, definitive information regarding the fatigue resistance of the Shoreham crankshafts for service at 3300 kW. The test duration of 746 hours at the rated engine speed of 450 rpm corresponds to just above 10^7 crankshaft stress cycles at or above the qualified load in a 4-cycle engine. This number of cycles is generally accepted as sufficient to demonstrate high-cycle fatigue resistance in metal structures, provided that no cracks develop under the conditions imposed during the test. The post-test examinations of the EDG 103 crankshaft demonstrated that it had completed the test with no indications of cracking.

On the basis of the following considerations, and subject to the recommendations for surveillance discussed later in this section, PNL concludes that the replacement crankshafts for EDG 101, EDG 102, and EDG 103 are acceptable for their intended service, provided that they are not operated during engine tests at loads in excess of the qualified load of 3300 kW[a]. The primary considerations on which this conclusion is based are as follows:

- The torsiograph tests performed for LILCO by SWEC as discussed earlier in this section provide experimental evidence that the crankshaft torsional stresses are essentially in compliance with DEMA standards at 3500 kW and the rated engine speed of 450 rpm. Although torsiograph tests were not conducted for underspeed and overspeed conditions at that power level, the results at rated speed provide a level of assurance that actual torsional stresses at 3300 kW are likely to be essentially in compliance with DEMA standards over the limited frequency range and associated speed range to which the EDGs are controlled at Shoreham.

- Ultrasonic tests of the crankshafts during manufacture revealed no significant subsurface defects. Magnetic particle, eddy-current, and liquid penetrant examinations performed on several occasions prior to installation of the crankshafts in the engines and following operation of all three crankshafts at load levels to 3500 kW have revealed no rejectable indications.

- The 746-hour endurance test of the EDG 103 engine at or above the qualified load of 3300 kW and the absence of any rejectable indications on critical crankshaft surfaces following that test provide definitive evidence of the fatigue resistance of the design under the conditions imposed during the test.

(a) In a report filed with the ASLB on December 3, 1984, the NRC staff identified several transient conditions under which the SNPS diesel generators could be loaded for brief periods (a few seconds to a few minutes) above the qualified load of 3300 kW during an emergency. It is PNL's understanding that these transient loads would not exceed 3900 kW. Recognizing that the engines have operated for many hours at loads above 3300 kW (see Table 4.1), that inspections following such operation have revealed no defects in the crankshafts, and that the duration of any transient loads above 3300 kW will be very brief relative to the hours already accumulated, PNL concludes that the transients will not jeopardize the operability of the engines.

- The three engines have comparable engine load histories above 3300 kW as shown in Table 4.1.

In light of the results of the analyses performed for PNL by Ricardo Consulting Engineers and by Det Norske Veritas as summarized earlier in this section, PNL has concluded that it would be prudent to examine certain high-stress areas of all three crankshafts periodically to confirm that no cracks develop in service. These examinations should include the nondestructive tests listed below. If these examinations reveal nothing of significance, LILCO may wish to propose a change in the examinations to NRC.

- During the first refueling outage, the fillets of the three crankpin journals (Nos. 5, 6, and 7) subject to the highest stresses should be examined with liquid penetrant and, as necessary, eddy current in the crankshafts of both the EDG 101 and 102 engines. The fillets in the two main journals between these three crankpins should also be examined in this manner. In addition, the oil holes in these crankpin and main bearing journals should be examined in the manner used in the most recent examination of the EDG 103 crankshaft. These inspections are not considered necessary for the EDG 103 crankshaft at the first refueling outage because of the inspection performed on this crankshaft in November 1984.
- In subsequent refueling outages, two of the three most heavily loaded crankpin journals in each of the three crankshafts should be examined as noted above. The main bearing journal between them should also be examined in this manner.

4.4 CONNECTING RODS

Part No. 03-340-A

Owners' Group Report FaAA-84-3-13

4.4.1 Component Function

The primary function of the connecting rod is to transmit the engine cylinder firing force from the pistons and piston pin through the rod to the crankshaft such that the reciprocating motion of the pistons induces rotation and output torque of the crankshaft. The connecting rod must have sufficient column buckling strength and fatigue resistance to withstand the cylinder firing forces and inertial loads. The wrist pin bushing (or rod-eye bushing) and the crankpin bearings are contained by the connecting rod. The flexure of the rod must be such that the bearings are not unacceptably distorted. The passages within the rod must remain unblocked to provide cooling and lubrication to the bearings and pistons. Sufficient clamping force must be maintained by the bolts on the connecting rod cap to prevent relative motion of the components The rod cap bolts must support the necessary preload without yielding, fracture, or unacceptable thread distortion. The wrist pin bushing must support the cylinder firing forces and inertial forces.

4.4.2 Component Problem History

Only one inservice failure of connecting rods in TDI DSR-48 series engines has been reported. This failure consisted of a longitudinal split through the oil hole in a DSR-46 engine at Glennallen, Alaska (Copper Valley Electric Corporation). Reportedly, this crack was initiated from fatigue. The failure report supplied by TDI did not identify the origin of the crack; however, no material abnormalities were reported. This engine had operated for over 8000 hours and, for part of that time, at much higher peak firing pressures (1975 psi) than those measured for the Shoreham engines (1680 psi).

4.4.3 Owners' Group Status

The adequacy of the TDI inline connecting rods was addressed by FaAA for the Owners' Group. The objectives of their efforts were to assess the structural integrity of connecting rods in TDI model DSR-48 engines in standby emergency diesel generator sets at Shoreham, River Bend, and Rancho Seco nuclear power stations, and to determine the connecting rods' suitability to perform their required function.

The Owners' Group evaluation considered four major parts of the inline connecting rod assembly: the rod-eye bushing, the rod eye, the connecting rod bearing housing and cap, and the connecting rod itself. The rod-eye bushing, which is of the same design as those in the V-engines, was analyzed because linear indications have been found in the bronze bushings during field inspections. Journal orbit analyses, metallurgical evaluations, and stress and fracture mechanics analyses were performed. The rod-eye end of the connecting rods was evaluated by stress and fracture mechanics analyses, which included assumed surface flaws. The connecting rod bearing housing and cap were evaluated by stress and fatigue analyses. The connecting rod itself was analyzed for buckling stability.

The connecting rod is attached to the crankpin bearing cap with four bolts extending entirely through the connecting rod. Prestressing of these bolts creates compressive stresses in the connecting rod itself and tensile stresses in the bolts. The two extreme loading conditions, firing stroke and exhaust stroke, were considered. The stresses in the bolts and connecting rods were determined for the two load cases, and the fatigue crack propagation in the bolts was investigated because they were the most critically stressed component. A critical crack depth of 0.133 inch was determined at the thread root. While cracks in the root of the bolt threads are not permitted, the analysis showed that a crack as large as the critical crack could be tolerated and would not propagate. Fatigue was determined not to be a problem.

The buckling stability of the connecting rod was assessed under the maximum cylinder firing pressure. The margin factors of 6.28 for yielding and of 5.72 against lateral buckling of the connecting rod were determined.

Wrist pin bearing performance was analyzed using a journal orbit analysis computer program. The oil pressure profiles imposed on the rod-eye bushing under piston firing and inertial loads were determined. A peak oil film pressure of 97,400 psi was predicted to occur at the bottom of the bushing due to power stroke. A peak oil film pressure of 5000 psi(a) was also predicted by FaAA to occur at the top of the bushing due to the inertial effects of the exhaust stroke. These two cases provided input to a rod-eye bushing stress analysis.

The calculated circumferential stresses and the oil film pressures were used as input to a fracture mechanics analysis. This fracture mechanics model indicated that bushing defects would not propagate if they originate on the outside diameter. The model also indicated that bushing defects on the inside diameter will not propagate unless they originate within ±15 degrees from the bottom center. Even if inside diameter (ID) defects are within ±15 degrees of the bottom center, they are predicted not to propagate unless the crack faces are exposed to the full range of oil film pressure. Because of the compressive hoop stress in the bushing, it was considered unlikely that the crack faces would separate and allow oil pressure to be exerted.

In conjunction with the rod-eye bushing stress analysis, the rod eye itself was analyzed with the same finite element and curved beam models and for the same load cases. The stress range calculated was below the fatigue initiation stress range for the rod material. Because of the possibility of pre-existing defects, as in the case of the Glennallen failure, the threshold crack size for fatigue was estimated by a fracture mechanics analysis using conservative values for the threshold range of stress intensity factor. A 0.043-inch deep flaw was determined to be the critical crack depth for the maximum tensile stress range (calculated) for load case 1. For load case 2, the maximum critical crack depth of 0.04 inch at the rod eye was determined.

The Owners Group could find no explanation for the one reported rod eye fatigue failure. However, fracture mechanics analyses indicate that fatigue cracks could propagate from a 0.04-inch deep surface discontinuity at the intersection of the oil hole with the bore of the rod eye. Such discontinuities on the smoothly polished surfaces were felt to be readily apparent on visual examination.

(a) The FaAA value reported in FaAA-84-3-13, page 2-4, was 500 psi. This was corrected by G. Derbalin (LILCO) in a telephone conversation with D. Dingee (PNL) on December 9, 1984.

Based on their evaluations the OG concluded that the inline DSR-48 connecting rod is adequate for its intended purpose, provided there are no bushing defects in the region within 15 degrees on either side of the bottom dead center of the bushing.

4.4.4 LILCO Status

Rod-eye bushings in the replacement connecting rods for all three SNPS EDGs were inspected prior to the startup testing. Linear indications were found by liquid penetrant testing on all rod-eye bushings and were determined to be casting defects. These indications were found on both the inside and outside diameter of the bushings. Similar indications were also found in new, unused bushings. No fatigue growth of these cracks was noted after 100 hours' operation at full load. The linear indications were determined to be the result of interdendritic shrinkage or porosity. No service-induced fatigue extension of the casting defects was observed.

Metallurgical evaluations were performed on several bushings. A chemical analysis performed on one of the bushings removed from a SNPS engine showed the bushing composition to be within the range for the specified bronze alloys, C93200 or SAE 660.

As a result of the DR/QR inspection, all the following wrist pin bushings, which had indications of cracks within ±15 degrees of the bushing bottom, were replaced:

- EDG 101 - bushings in connecting rods 1, 2, 3, 4, 6, and 8
- EDG 102 - bushings in connecting rods 1, 3, and 8
- EDG 103 - bushings in connecting rods 1, 3, and 5.

Following the 746-hour confirmatory test on EDG 103, all wrist pin bushings were again inspected with liquid penetrant. None of the bushings showed any porosity. They did show slight wear patterns and some light scratches.

In addition to the bushings, LILCO also confirmed the condition of the rod-eye, the rod bolts and the connecting rod itself. The connecting rods were inspected at TDI with liquid penetrant with a LILCO inspector present. This inspection considered the whole connecting rod including the rod eye. The connecting rod bolts were inspected at TDI and subsequently inspected visually at SNPS prior to rod assembly. LILCO confirmed that the connecting rods currently installed in the Shoreham EDGs did not contain any cracks or discontinuities that could lead to fatigue failure.

As a result of these inspections of the connecting rod and wrist pin bushing, LILCO believes that these components are acceptable for their intended design function.

4.4.5 PNL Evaluation and Conclusions

The PNL reviewers evaluated the Owners' Group report and supplementary information on inline connecting rods. They found that the Owners' Group examined the appropriate significant failure modes (namely, the cracks in the rod-eye bushing; fatigue in the rod eye itself; fatigue and possible pretension loss in the connecting rod bolts; stiffness and buckling of the connecting rod; and size of the oil cooling holes and path). The bounding load cases of exhaust stroke inertial loads and firing pressure loads were correctly used in the analyses. The analytical methods used by the Owners' Group were judged to be appropriate.

Both known and postulated cracks in components have been included in the Owners' Group analyses. PNL concurs with the Owners' Group position that linear indications are acceptable in the rod-eye bushing so long as they do not occur within ±15 degrees of the bottom center, because the indications are in compression. PNL also concurs that cracks larger than 0.046 inch deep in the rod eye or 0.133 inch at the root of the bolt threads are not acceptable.

PNL also reviewed the inspections performed by LILCO: 1) inspection of the connecting rods and bushings for signs of distress; 2) liquid penetrant test on all wrist pin bushings; 3) determination of the connecting rod and cap material; 4) determination of the hardness of the connecting rod and caps; and 5) the TDI/LILCO inspection procedures for the rod eyes and bolts. Based on these evaluations and reviews, PNL concludes that the connecting rods and bushings installed in the Shoreham engines are acceptable for the intended service.

4.5 CONNECTING ROD BEARING SHELLS

Part No. 03-340-B

Owners' Group Report FaAA-84-3-1

4.5.1 Component Function

The connecting rod bearings interface the connecting rods with the crankshaft. They are of cast aluminum alloy with a thin babbitt overlay, and are furnished in two identical halves. They are lubricated under pressure, and a substantial flow of oil proceeds through machined channels in the shells from the drilled crankshaft oil holes to the passageways within the connecting rods and on to the pistons and intervening bearing surfaces. The upper bearing half is subject to the piston firing loads and is therefore more susceptible to failure.

Failure can occur through inadequate oil flow or pressure, excessive or unplanned loadings, structural anomalies (from design or manufacture), or fatigue and erosion of the babbitt layer in crucial areas. Bearings are also subject to particle, chemical, or water contamination of the oil, or improper oil selection for the duty, either of which can lead to degradation and failure. The failure mechanism usually is gradual, and its onset generally can be detected by prudent surveillance of oil and filter conditions. However, a substantial structural problem, excessive cylinder loads, or heavy water contamination can lead to rapid failure. This can affect the crankshaft journals, sometimes with irreparable results.

In light of the severe conditions affecting bearings, the need for replacement is not uncommon. However, in customary service, bearing life generally is measured in multiples of 10^4 hours, given reasonable service conditions.

4.5.2 Component Problem History

Five incidents of cracking in the SNPS EDG connecting rod bearing shells have been reported. All but one occurred during operation with the original 11-inch crankshafts and were discovered during disassembly after the crankshaft failure on EDG 102. A number of bearings, other than the cracked ones, have also been replaced because of inservice conditions or nonconformance with the Owners' Group criterion for subsurface voids. No other connecting rod bearing shell incidents have been reported on any DSR-4 engines.

4.5.3 Owners' Group Status

Failure Analysis Associates analyzed the connecting rod bearing shells for the Owners' Group. The analyses, which encompassed both 11-inch and 12-inch diameter shells, included:

- journal orbit analysis to determine the pressure distribution in the hydrodynamic film
- finite element analysis to determine the stress distribution in the connecting rod bearing shell
- fracture mechanics analysis to determine the resistance to fatigue cracking
- computation of acceptance criteria using radiographic NDE
- evaluation of babbitt adhesion.

Based on their analyses, FaAA concluded that the cracking of the four 11-inch diameter bearing shells was due to bearing shell overhang causing undue bending stresses. They attributed the crack in the 12-inch bearing shell to excessive voids in the subsurface of the bearing shell in the area of the crack. The overall conclusion was that, provided they conform to the manufacturer's specifications and meet the criterion for subsurface voids developed by FaAA, the bearings are suitable for the intended service.

4.5.4 LILCO Status

Following recommendations and instructions issued by FaAA and approved by the Owners' Group, LILCO performed radiographic and liquid penetrant examinations on all 16 bearing shells in each engine.

The crankpin bearing shells for EDGs 101, 102, and 103 were inspected after the nominal 100-hour test, which was run to support the DR/QR activities. The crankpin bearings for EDG 103 were again inspected after the 746-hour endurance test.

The results of these inspections are as follows:

- EDG 101 - All the crankpin bearings were found to be satisfactory and reusable except the upper shells for cylinders No. 7 and 8, which were replaced because they did not meet the OG criterion for subsurface voids. The lower shells for cylinders No. 4 and 6 were approved for use as lower shells for 300 hours of running. The shells for cylinder No. 5 were interchanged, the lower shell being approved by FaAA for 300 hours of use as a lower bearing shell. Analysis relevant to the use of lower shells No. 4, 5, and 6 for 300 hours of operation was provided by FaAA in a letter dated March 3, 1984, from C. H. Wells (FaAA) to P. Martin (LILCO).
- EDG 102 - The crankpin bearing shells for this engine were found in satisfactory condition except the upper shells for cylinders No. 2, 5, and 8 and the lower shells for cylinders No. 5 and 8, which were replaced because they did not meet the OG criterion for subsurface voids.
- EDG 103 - All except two crankpin bearing shells for this engine were found to be satisfactory. The lower shell for cylinder No. 2 was damaged in handling; the upper shell for cylinder No. 6 had a small surface inclusion on its outside surface. Both were replaced.

4.5.5 PNL Evaluation and Conclusion

Based on review of the FaAA analyses and LILCO inspection reports, and on a number of visual inspections conducted by PNL consultants, PNL concludes that the connecting rod bearing shells are acceptable for the service intended. The above conclusion is based on the condition that if the bottom bearing shells No. 4, 5, or 6 for EDG 101 should exceed the allowable 300 hours of operation during the first refueling cycle, they must be replaced prior to starting the cycle.

4.6 PISTON SKIRTS

Part No. 03-341-A

Owners' Group Report FaAA-84-2-14

4.6.1 Component Function

The piston (an assembly that includes the piston crown, piston skirt, rings, piston pin, etc.) receives the thrust of inertia and combustion and transfers it to the connecting rod. The cast steel crown is subject to the direct combustion pressure and thermal conditions. The skirt, made of ductile iron, actually transfers the load to the piston pin/connecting rod and guides the reciprocating motion of the piston within the cylinder. Such a two-piece piston structure is relatively common to large, modern, high-output engines.

In general, failure is most apt to result from excessive pressure and thermal stresses of both high-cycle and low-cycle character. Durability is affected by material selection, fabrication quality, and design characteristics. A crown separation will require immediate shutdown; it is likely to lead quickly to serious cylinder, head, and rod damage, and to piston seizure, with adverse impact on the crankshaft and possible crankcase explosion. Hence, adequate attachment of crown to skirt is necessary.

4.6.2 Component Problem History

TDI has utilized several skirt designs, including types AH, AN, AE, and modified type AF, in their R-4 series engine. Most early engines for nuclear service were furnished with type AF and AH skirts, although one plant had AN skirts. The SNPS engines were originally furnished with 23 modified type AF piston skirts and one type AN skirt.

The modification to the type AF skirt, performed by TDI in 1981, consisted of spot-facing each of the four bosses through which the studs extend to secure the piston crown and replacing the originally supplied spherical washer set with two stacks of Belleville washers. This spot-finishing reduced the height of the stud attachment bosses from 2 inches to approximately 0.25 inch. During an early inspection of the SNPS piston skirts, all 23 of the type AF piston skirts were found to contain linear indications in one or more of the skirt-to-crown attachment bosses. The single type AN piston did not exhibit these indications. Subsequent metallurgical examinations of these indications revealed that they were fatigue cracks. Similar cracks were observed in the type AF piston skirts at Mississippi Power & Light (MP&L) Company's Grand Gulf Nuclear Station. LILCO subsequently replaced all 24 piston skirts in the Shoreham EDGs with type AE skirts of the latest design. This type AE design restores half the original height of the attachment bosses and incorporates one stack of Belleville washers instead of two. In addition, the piston bosses are wider and more smoothly blended into the skirt wall.

Prior to their use at Shoreham, one of the major sources of experience with the type AE piston skirt was the experimental TDI R-5 engine. In this engine, the type AE piston skirts were observed to contain no cracks, even after 622 hours at a peak firing pressure of approximately 2000 psi.

4.6.3 Owners' Group Status

The TDI Owners' Group experimentally and analytically evaluated both the type AF and type AE piston skirts. The OG first evaluated the cracked type AF skirts to assess the nature of the problem. This evaluation revealed that the observed cracking was the result of fatigue. Subsequently, both skirt types were experimentally tested for stress in a static hydraulic test, and these stresses were evaluated by finite element analysis of the skirt only. Then, the thermal stresses in the piston crown were evaluated by finite element analysis, and their effect on the stresses in the skirt determined. Finally, a fatigue and fracture analysis was performed.

It was concluded that the type AF skirts would crack in service at TDI nameplate rating, but the cracks would not grow once they move out of the highly stressed region near the boss. For type AE skirts, the analysis indicated that cracks may initiate at high loads but will not grow. On these bases, the OG concluded that the modified type AF skirts are adequate for service, provided that they are 100% inspected for cracks in the stud boss area prior to use and that they are inspected periodically. Recommendations for operating load levels and inspection intervals were to be made on a plant-by-plant basis. Furthermore, the OG concluded that the type AE piston skirts as currently installed in the SNPS EDGs were adequate for unlimited life.

4.6.4 LILCO Status

As part of the component revalidation process, LILCO assembled and reviewed the component documentation including 1) the Owners' Group evaluation of the component described in the previous section and 2) NDT evaluations of the skirts performed prior to placing them into service. The utility also performed a series of NDT tests and inspections; these are summarized below.

- EDG 101, in February/March 1984 - A liquid penetrant examination of the piston attachment bosses was performed on piston skirts No. 5, 7, and 8. Piston skirts No. 5 and 7 were found to be satisfactory. A nonrelevant indication was found on piston skirt No. 8. An eddy-current test was performed on the piston skirt attchment bosses on piston skirts No. 5, 7, and 8, and all three skirts were found to be satisfactory. Dimensions of the piston groove height, ring height, and piston pin bore diameter were confirmed for cylinders No. 5, 7, and 8. Piston skirts No. 5, 7, and 8 were visually inspected and signs of scuffing were observed. The pistons were cleaned and reinstalled.
- EDG 102, in February/March 1984 - A liquid penetrant test was performed on the piston skirt attachment bosses for cylinders No. 5, 6, 7, and 8. Satisfactory results were obtained. Eddy-current tests were performed on the skirts of pistons No. 5, 6, 7, and 8 in the same area. The results were reported as satisfactory. Visual inspections were performed of the outside diameter of the skirts on pistons No. 5, 6, 7, and 8. Unsatisfactory conditions were corrected and the pistons were reinstalled.
- EDG 103, in March 1984 - A liquid penetrant examination was performed at the piston skirt attachment bosses for bolt attachment to the crown on pistons No. 5, 7, and 8. The test revealed that all areas examined were satisfactory. An eddy-current examination was performed on pistons No. 5, 7, and 8 in the same area. The regions inspected were found satisfactory. Dimensions of the piston groove height, ring height, and piston pin bore diameter were confirmed for

pistons No. 5, 7, and 8. A visual inspection of the skirt outside diameter was performed and the piston skirt was returned to service.

- EDG 103, in May/June 1984 - Pistons No. 1 through 8 were visually inspected. A light carbon deposit was found on the outside edge of the crown and down to the top ring on all pistons. No "unusual" scuffing or scratching was noted on the outboard portions of the pistons and piston skirts.
- EDG 103, in November 1984 (following completion of the 746-hour endurance test at 3300 kW) - All eight cylinder liners were inspected; no scuffing was found. Breakaway torque for crown-to-skirt attachment bolts revealed no degradation of original torque values. Liquid penetrant tests of the piston skirt at the crown-to-skirt attachment bosses revealed no recordable indications. No eddy-current evaluations were required because no indications were found. Visual inspection of crown-to-skirt contact areas for excessive and abnormal fretting revealed only minor, normal operational fretting in several small areas. Specific activities performed by PNL representatives in conjunction with this inspection and the conclusions reached by these representatives are addressed in a report to the ASLB dated December 14, 1984.

Based on their review of component documentation and test results, LILCO concluded that no adverse indications exist relevant to the integrity of the AE piston skirts currently installed in the SNPS EDGs; hence, these piston skirts are acceptable for their intended design function.

4.6.5 PNL Evaluation and Conclusions

PNL's evaluation of the SNPS EDG piston skirts is limited to the type AE pistons, because this is the piston skirt type currently installed in the engines.

The primary conclusion of the Owners' Group analysis of the type AE piston skirts was that cracks may initiate but will not grow. PNL reviewed this analysis and found the stress field in the region of the stud bosses so complex that is was difficult to conclude with any degree of certainty whether cracks would initiate or not, and, if they did initiate, whether they would grow or not. However, available operating experience appears to support the conclusion that this piston type is suitable for its intended function.

This operating experience was obtained from both the TDI R-5 test engine and from the SNPS EDG 103 confirmatory test. In the R-5 engine, two type AE piston skirts were installed and the engines tested for 622 hours at 514 rpm and a peak firing pressure of 2000 psi, about 20% higher than that expected at Shoreham. The type AE piston skirts used in this test were not quite identical to the same type AE skirts used at Shoreham. However, they were sufficiently comparable to conservatively extrapolate the results to the Shoreham engines. The 622 hours of operating time in the R-5 engine were equivalent to 9.6×10^6 stress cycles in the type AE skirts. This number of cycles very closely approaches the fatigue limit for long-term operability of a mechanical design. Therefore, this R-5 test engine experience gives considerable confidence that the type AE skirt design is adequate. The other experience was obtained in EDG 103 during the 746-hour endurance test at 3300 kW. This test subjected the piston skirts to in excess of 10^7 stress cycles; subsequent nondestructive testing revealed no apparent crack initiation. The successful completion of this test without occurrence of apparent fatigue of the piston skirts provides considerable confidence in the suitability of the skirt design for the intended function.

PNL also visually inspected all the piston skirts identified in Section 4.6.4 above. Based on 1) the LILCO procedure for handling inspection findings, 2) the PNL examination of many of the piston skirts, 3) the suitability of the design as indicated by the above-described experience, 4) the current serviceability of the piston skirts now installed in all three engines as confirmed by the component revalidation tests for all three EDGs, and 5) the NDT inspection of EDG 103 following the confirmatory test, PNL concluded that the type AE pistons in the SNPS EDGs are acceptable for the intended service.

4.7 CYLINDER LINERS

Part No. 03-315-C

Owners' Group Report FaAA-84-5-4

4.7.1 Component Function

Engines of this size and character are designed with individual, removable cylinder liners, which fit inside the cylinder block. The liners contain the pistons and are capped at the upper end by the cylinder head. Thus, they act as containment for the firing forces, subject to the stress and heat thereof, and the reciprocating travel of the pistons. The outer surfaces are cooled by jacket water circulating within the block. The lower end is sealed against an opening in the block with O-rings. The upper end has an external, circumferential ledge, which seats on the block's "liner landing." The head is gasketed and bolted in compression against the upper liner annulus, to seal in the high-pressure combustion gases. The liner is of nodular iron, selected for its strength, castability, and durability against the rubbing action of the pistons and rings.

Liners generally do not fail, but they can be adversely affected by inadequate or inappropriate lubrication, the forces and heat of the combustion processes, the character of the pistons and rings, and the quality of fuels and oils. Failure most often is in the form of scoring by broken rings or carbon deposits, or "scuffing" by the action of the piston on the cylinder walls, due to one or more of the factors mentioned. If such conditions are severe enough, a piston will seize and cause significant damage to liner, head, and connecting rod, and even to the crankshaft. A crankcase explosion can result.

4.7.2 Component Problem History

Only one incident of cylinder liner "failure" in nuclear service is known. This failure occurred in 1982 at Grand Gulf when a piston crown separated from the skirt during testing of the Division II engine and marred the liner.

4.7.3 Owners' Group Status

The OG included considerations of liners in their study of cylinder blocks. Two concerns were uncovered:

- The TDI design calls for the liner to protrude slightly above the top deck of the block, to ensure a tight, compressive fit against the head and gasket. However, this produces bending moments in the head and substantial shear stresses on the cast iron liner landing of the block. Both aspects are suspect in some of the real or incipient failures in those components. TDI has approved remachining to reduce the protrusion, termed "proudness".
- The design also calls for a tight fit between the outer ring of the liner ledge and the matching counterbore of the block. There is some concern by the Owners' Group that this could increase hoop stresses in the block, which might lead to block cracks. TDI has approved reducing this fit in the cylinder block.

4.7.4 LILCO Status

The bores of all cylinder liners were inspected by the Owners' Group for dimensions, signs of interior wear, scoring, scuffing, or cracking.

Cylinder liner No. 7 on EDG 101 showed a crack existing from the top edge of the liner down 2-5/32 inches on the inside surface. A metallurgical examination suggested that the crack was not related to service loading. This liner was replaced.

Cylinder liner No. 5 on EDG 102 showed evidence of scuffing. It was brush deglazed and reused. Liner No. 7, however, was found pitted and was replaced.

EDG 103, in which both the liner landing height and outside diameter were remachined to reduce bending and hoop stresses, was dismantled for inspection following the recent 10^7-cycle endurance test. The cylinder liners were not removed from the block. Evidence of liner surface spot glazing was found. Following the inspection, all liners were deglazed by honing per TDI instructions. The deglazing was witnessed by a TDI representative.

LILCO concludes that the liners in EDGs 101, 102, and 103 are suitable for nuclear standby service.

4.7.5 PNL Evaluation and Conclusion

PNL representatives viewed the liners from EDG 101 in March 1984 and those from EDG 103 in June and November 1984. The liners were glazed and showed some hard rubbing spots. However, their appearance was typical of liners that had been in service. The liners did not appear to have any scuffed surfaces or other defects that could not be removed by deglazing.

PNL concludes that the liners in all SNPS EDGs are acceptable for their intended service. This conclusion is based upon:

- a review of LILCO's actions for all EDGs with respect to inspection, remachining, and replacement (as needed)
- PNL's examination of the liners from EDGs 101 and 103
- the good service record for these liners.

4.8 CYLINDER HEADS

Part No. 03-306-06-0F

Owners' Group Report FaAA-84-15-12

4.8.1 Component Function

The cylinder heads cap the cylinders and, with the cylinder liners, provide the enclosure needed to direct the combustion forces against the pistons. In the TDI engine design, each cylinder uses a separate cylinder head assembly. The bottom surface of the cylinder head, facing the piston, is called the firedeck. There is also a top deck to enclose the internal water cooling passages and an intermediate deck that provides structural rigidity to the assembly. The cylinder head assembly contains two inlet valves, two exhaust valves, a fuel injector, air starting valve, and a test cock.

Each head is bolted to the cylinder block by means of eight studs extending through the head from the block. On top of the cylinder heads are two more components: the subcover or rocker box, which supports the valve actuating mechanism, and a light top cover.

The TDI DSR-4 heads are cast from an alloy steel. The casting cores that produce the complex system of internal water, air and exhaust gas passages are large and are difficult to hold in place during the casting process. They can shift during manufacture, causing uneven and/or incomplete sections, and can lead to a variety of flaws or indications, some of which can be repaired during subsequent manufacturing processes.

Cylinder head deficiencies that have been experienced have tended to be mostly superficial linear indications with inconsequential results. However, some deficiencies have led to warpage or cracks. The latter, if through the jacket water passages, can result in the leakage of water into the affected cylinder when the engine is inoperative, and the introduction of combustion gases into the cooling jackets during operation. If an attempt is made to start an engine with water present in one or more cylinders, severe structural damage can result.

4.8.2 Component Problem History

Numerous failures of TDI cast steel cylinder heads have been reported in both nuclear and non-nuclear applications. For identification, TDI cylinder heads have been classified by the Owners' Group as belonging to one of three groups. Group I heads include all those cast prior to October 1978. Group II heads were cast between October 1978 and September 1980. Group III heads were cast after September 1980. The distinction among groups involves both design changes to facilitate better casting control and improvements in quality control. Most instances of cracked heads have involved Group I heads. Only five instances of cracks resulting in water leaks have been reported in heads of Groups II and III, and these have all been in marine applications. Most of these cracks were observed to have originated at the stellite faced valve seats.

The most recently reported head failure of a TDI nuclear EDG occurred at Mississippi Power & Light (MP&L) Company's Grand Gulf Nuclear Station. A 2-inch through-wall crack occurred in the right exhaust port casting surface between the valve seat area and the exhaust valve guide in their Division I diesel engine. This crack allowed water from the cooling jacket to enter a cylinder; the presence of this water was detected during the "barring-over" of the engine with the cylinder cocks open. The specific head group classification of this head was not reported. However, the affected head was supplied with the engine and had undergone 1500 hours of operation, including 335 hours at 100% load (7000 kW, 225 BMEP) and 31 hours at 110% load. MP&L believes that this was a unique, isolated event.

4.8.3 Owners' Group Status

Failure Analysis Associates performed mechanical and thermal stress calculations for the Owners' Group to determine if these heads are suitable for the intended service. The results indicated that heads from all three groups would be suitable. However, FaAA recommended that Group I and II heads be inspected for cracks using liquid penetrant and magnetic particle testing. They also recommended that the firedeck thickness be determined by ultrasonic testing. For Group III heads, sample inspection as described for Groups I and II was recommended. For all three groups, FaAA recommended that the engine be rolled over before manual start with the cylinder cocks open to assure that no water was leaked into the cylinders.

4.8.4 LILCO Status

The SNPS EDGs originally were supplied with Group I heads. During early operation, leaks developed in three heads. These were attributed to casting defects resulting from the coring and mold design or lack of stress relief. All heads were subsequently replaced with Group III heads. The replacement heads were operated for at least 300 hours, including 100 hours at or above 3500 kW load. Many were inspected by nondestructive testing in the DR/QR program as summarized below.

- EDG 101 - A liquid penetrant test was performed on the exhaust and intake valve seats and firedeck area between exhaust valves on cylinders No. 5, 7, and 8 following about 100 hours of full power operation. The surface integrity of the inspected area was found to be satisfactory.
- EDG 102 - A liquid penetrant test was performed on the exhaust and intake valve seats and the firedeck area between the exhaust valves on cylinder heads No. 5, 7, and 8 following about 100 hours of full power operation. The inspected area was found to be satisfactory. A visual inspection for signs of cracking was performed in the valve seat area with the valves in place on all four valves of all eight cylinder heads. No evidence of cracking was noted.
- ENG 103 - Liquid penetrant tests were performed on cylinders No. 5, 7, and 8 following about 100 hours of full power operation. Head No. 7 was found to be satisfactory. Indications on heads No. 5 and 8 were dispositioned for engineering action. A visual examination was performed of the firedeck on cylinder heads No. 1, 2, 3, 4, 6, 7, and 8 for indications of surface damage. Heads No. 1 and 6 were found to be satisfactory. Observations regarding cylinder heads

No. 2, 3, and 4 were resolved by engineering action. Superficial surface abrasions observed on heads No. 7 and 8 also were resolved by engineering.

The thickness of the firedeck of the heads of all three engines was verified by ultrasonic techniques.

Following the 746-hour confirmatory test of EDG 103 at the qualified load of 3300 kW, additional inspections were performed on the cylinder heads. These inspections included 1) ultrasonic inspection of the firedeck at six locations to verify that minimum thickness requirement of 0.400 inch was met, 2) surface inspection (either liquid penetrant or magnetic particle) of intake and exhaust valves to verify their freedom from unacceptable surface defects, and 3) a determination if any heads had through-wall weld repairs of the firedeck where the repair was performed from one side only. Based on the results of these inspections, LILCO concluded:

> With one exception the cylinder heads passed the confirmatory tests. The one exception was head No. 4, which, although having performed satisfactorily and having passed both ultrasonic and liquid penetrant inspections, was replaced due to having been plug-welded in the fuel injector area.

As a result of the design review of the cylinder heads performed by FaAA for the Owners' Group, a review of existing documentation on the cylinder heads, and the results of the above tests, LILCO concluded that the cylinder heads are acceptable for their intended function at SNPS, provided that the engine barring-over procedure is conducted at "appropriate intervals" after shutdown and before manual starting.

4.8.5 PNL Evaluation and Conclusions

PNL reviewed the FaAA mechanical and stress analyses of the TDI cylinder heads, the service history of the Group III heads currently installed on all three SNPS EDGs, and the results of the nondestructive tests performed as part of the component revalidation program and following the 746-hour confirmatory tests of EDG 103. PNL concluded that the cylinder heads currently installed on all three SNPS engines are acceptable for the intended service, provided that the engine is air-rolled at appropriate intervals with open cylinder cocks after and before planned operation to verify the absence of cracks that may allow water leakage into the cylinder. It is recommended that this procedure be performed 4 to 8 hours, and again 24 hours, after any operation and, thereafter, prior to any planned start. If leakage is indicated by the ejection of water or steam from any of the open cylinder cocks during air-rolling, the affected head should be removed, inspected, and replaced, if defective.

4.9 CYLINDER HEAD STUDS

Part No. 03-315-E

Owners' Group Report Emergency Diesel Generator Cylinder Head Stud Stress Analysis (SWEC March 1984).

4.9.1 Component Function

Eight studs per cylinder are used to bolt the heads to the cylinder block. Together they transmit the power load from the head to the block and ensure a required preload on the cylinder head gasket.

Head bolts are not normally found to yield or break; however, these occurrences are possible, due to faulty design, materials, or fabrication, or excessive firing pressure. Fatigue failure is a greater concern, given reasonable operating conditions. This will occur if preload is insufficient and the bolts go through many cycles of loading. Once a bolt yields or breaks, its neighbors must carry increased burden, and the head is unevenly stressed. This generally results in escaping combustion gases, with the attending hazards of heat and fire, as well as physical and metallurgical damage to head and block.

4.9.2 Component Problem History

To date, no cylinder head stud failure has been reported in the nuclear industry. However, some isolated failures have been reported in the non-nuclear field. The cause has not been established.

TDI has employed two basic stud designs recently. One is of straight shank diameter, and there has been concern that its tight fit within the block stud opening, coupled with inadequate preload, could put side thrusts on the block and contribute to block fractures. A second design uses a necked-down shank. This design not only avoids any possible stud-to-bore contact, but reduces the preload needed to maintain positive stresses during the firing cycle.

4.9.3 Owners' Group Status

Stone & Webster Engineering Corporation (SWEC) has analyzed both the old design studs and new necked-down studs developed by TDI to minimize potential cylinder block cracking. SWEC has concluded that both stud designs are adequate for the service intended, provided proper stud preload is applied.

4.9.4 LILCO Status

The SNPS engines are all equipped with studs of the necked-down design. No failures have been noted and no studs have been replaced. In connection with the DR/QR inspection effort the bolts were checked on a sampling basis on all engines for 1) visible signs of distress, 2) dimensional conformance to specifications, and 3) material hardness and compaction. In addition, on EDG 102, the breakaway torque was measured following 100 starts. All sampling tests were completed without any rejectable indication.

4.9.5 PNL Evaluation and Conclusion

PNL concludes that the studs now installed on the SNPS EDGs will be acceptable for the intended service. This conclusion is based on the following findings resulting from PNL's evaluation:

- The SWEC analysis has satisfactorily demonstrated the stud design is adequate.
- No failures of cylinder head studs have occurred in TDI engines in nuclear service to date.
- LILCO's action of inspecting and torquing the studs is deemed acceptable.
- LILCO has confirmed to NRC that these bolts were installed with proper preloading.

4.10 PUSH RODS

Part Nos. 03-390-C & D and 03-390-04-AB

Owners' Group Report FaAA-84-3-17

4.10.1 Component Function

Push rods transmit the cam action from the camshaft on the engine side to the intake and exhaust valves in the head. One main rod extends from the camshaft to the subcover where it acts directly on the intake valve rocker lever. The second main rod transfers cam action to an intermediate rocker in the subcover and on through an intermediate (connector) push rod to the exhaust valve rocker arms. They are subject to high-acceleration compressive forces and cylinder pressures on the valves as they respond to the cams. Fundamentally, these are steel tubes with rounded ends, to fit the various mating sockets.

A failure would, at the least, reduce valve action and, thus, cylinder performance. Total inoperability of a cylinder could result, but would not necessarily lead to immediate engine shutdown. Because these components are always in compression, failure modes are limited, assuming reasonably good design.

4.10.2 Component Problem History

TDI push rods originally had tubular steel bodies fitted with forged and hardened steel end pieces, attached by plug welds. An estimated 2% reportedly developed cracks in or around the plug welds. A "ball-end" push rod design introduced later consisted of a tubular steel body with a high-carbon steel ball fillet-welded to each end. This design proved to be prone to cracking at the weld. A third design, consisting of a tubular steel body friction-welded on each end to a forged plug having a machined, hemispherical shape, was then introduced. This third configuration is referred to as the friction-welded design.

4.10.3 Owners' Group Status

Because industry (both nuclear and non-nuclear) had expressed concern about the continued integrity of TDI push rods, the TDI Owners' Group included the component in the known generic problem category for specific study and resolution. Failure Analysis Associates performed stress analyses as well as stress tests to 10^7 cycles on samples of both the plug-welded and the friction-welded push rods, at conditions simulating full engine nameplate loading. No sign of abnormal wear or deterioration of the welded joints or ends was observed. Other nuclear owners have run these versions in actual service beyond 10^7 cycles with no adverse results. The 746-hour test on SNPS EDG 103 was completed successfully without any observed push rod failures.

FaAA concluded from their analyses and tests that both the plug-welded and friction-welded designs are adequate. They provided stipulations for inspection and action, including destructive examination of a random sample.

4.10.4 LILCO Status

Originally the SNPS EDGs contained push rods of the fillet-welded ball-end design. Subsequently, the main push rods were replaced with those of the forged-head plug-welded design and the connector rods with those of the friction-welded design.

The component revalidation included visual inspection, LP inspection, and metallurgical analysis and hardness test of the rods on the three engines. From the results, LILCO concluded that the installed push rods are acceptable for their intended use. LILCO's conclusion is supported by the findings of the FaAA analysis.

4.10.5 PNL Evaluation and Conclusion

PNL reviewed and concurred with the FaAA report. PNL also reviewed documentation of LILCO's actions and noted the favorable record of push rods in extended service elsewhere. On these bases, PNL concludes that push rods of both the plug-welded and the friction-welded designs are acceptable for their intended service.

4.11 ROCKER ARM CAPSCREWS

Part No. 03-390-G

Owners' Group Reports Emergency Diesel Generator Rocker Arm Capscrew Stress Analysis (SWEC March 1984, July 1984).

4.11.1 Component Function

The rocker arm capscrews bolt in place the rocker arm shaft in the subcover assemblies. They transmit camshaft rolling loads, valve spring loads, and residual cylinder pressure forces from the rocker arm shaft to the cylinder heads. They are made from fairly standard bolting materials. A failure would weaken or cancel the restraints on a rocker shaft and cause malfunction of intake or exhaust valves. Reduced engine output would result.

4.11.2 Component Problem History

Rocker arm capscrew failures due to improper bolt preload have been reported at SNPS. There have been no reports of similar failures elsewhere.

4.11.3 Owners' Group Status

Stone & Webster Engineering Corporation performed stress analyses of both the original capscrew design with a straight shank (the type that failed at SNPS) and a newer design incorporating a necked-down shank. SWEC has concluded that both designs are adequate for the service intended. SWEC attributed the failure at SNPS to insufficient preload.

4.11.4 LILCO Status

The DR/QR report states that, prior to April 1984, all rocker arm capscrews in the SNPS engines were replaced with the newer, necked-down design. A sample of these capscrews was inspected in connection with the Shoreham DR/QR and found to be of the correct design material and hardness. The bolts were installed with the specified 365-ft/lb preloads. LILCO concluded on the basis of the analysis and inspections that the capscrews are acceptable for their intended service.

4.11.5 PNL Evaluation and Conclusion

PNL concludes that the rocker arm capscrews in all SNPS engines are acceptable for the intended service. This conclusion is based on 1) a review of the OG analysis, 2) LILCO's actions to replace all bolts, 3) the favorable checks of materials and design as-installed, 4) the confirmation of installation preloading, and 5) LILCO's commitment to perform periodic preload checks as described in Section 5.0 of this TER.

4.12 TURBOCHARGERS

Part No. MP 017 (Model BCO-90G)

Owners' Group Report FaAA-84-6-56

4.12.1 Component Function

The turbochargers on the LILCO TDI DSR-48 engines are Model 90G units manufactured by the Elliott Company. One turbocharger per engine provides pressurized air to the cylinders for combustion of more fuel than would be possible with a "normally aspirated" engine. The turbochargers consist principally of a turbine, driven by engine exhaust gases, directly driving an air compressor wheel or impeller. The associated housing ducts the air and exhaust to and from the rotors; the exhaust inlet guide vanes direct the exhaust gases toward the turbine wheel blades. Turbine speed changes with engine load (i.e., gas volume, pressure, and temperature), with maximum speed depending on specific turbine selection and design parameters.

Because close tolerances and high rotating speeds are necessary for efficiency, and because temperature levels can approach 1200°F at the exhaust inlet, all components are sensitive to temperature, pressure, structural loads (vibrations), and contaminants or particles in the gas and air streams. The radial and thrust bearings require particular care and lubrication.

Vanes and blades are sometimes lost due to heat and vibration, or fractured by impact of particles, such as bolt heads, fractured vanes, or valves. Undue stresses or vibration from connected exhaust piping or inappropriate supports can cause rotor wear at stator interface. Inadequate bearing lubrication (and the cooling the oil provides) can lead to bearing failure. Depending on the severity of the situation, diesel engine shutdown can come quickly, but usually is not immediate.

4.12.2 Component Problem History

Various problems have occurred in the turbochargers on TDI DSR-4 engines in nuclear service. The principal problem has been the rapid deterioration of the combination turbine thrust/radial bearing, which has occurred at the Shoreham, Comanche Peak, Catawba, and San Onofre nuclear plants. There also have been problems regarding missing exhaust inlet vanes, missing or broken capscrews joining the vane disc to the turbocharger at the inlet, and broken capscrews and welds in the support mounts. At Shoreham, capscrew failures have been reported in EDG 101, and lost nozzle vanes have occurred in EDG 103.

Because nuclear EDGs have, to date, had unusual quick-start requirements--and are tested extensively to assure reliability for such duty--the owners and TDI investigated the failure parameters early in the history of such service. It was recognized that the bearing and bearing lubrication systems inherent in the 90G design were not adequate to provide lubrication of the bearing thrust pads and rotor thrust collars under fast startup conditions to high loads. TDI initiated two steps of modifications in an attempt to address this problem; one instituted and modified the oil drip system and the second provided for manual prelubrication prior to planned starts.

4.12.3 Owners' Group Status

On behalf of the Owners' Group, FaAA undertook an extensive study of causes of reported failures in nuclear service. The net result was an affirmation of inadequate startup lubrication. Briefly, the resulting recommendations were:

- Retain and use a "drip system" that directs a small flow of oil toward the bearings at all times in standby, but increases the flow of oil to 0.35 gph. (Higher flows are apt to flood past the bearing into the exhaust manifolds and create fire risk at startup.)
- Provide and use an auxiliary prelubrication pump to direct substantial flow to the bearings immediately prior to planned startups.
- Maintain oil filtration at 10 microns or better and utilize spectrochemical and ferrographic oil analysis regularly.
- Enhance bearing inspection programs. At least one bearing should be inspected at a station following every 100 starts of any nature. Inspection should also be done following 40 starts without manual prelube.

In a separate study, FaAA also considered the various nozzle ring component failures that have been reported in Elliott 90G turbochargers. They concluded that, on the basis of operating experience, these types of failures do not affect the operation of the turbocharger and, therefore, do not compromise the ability of the EDGs to perform their intended function. They did, however, recommend that the engine operation be monitored to ensure that exhaust gas temperatures do not exceed maximums specified by Elliott.

4.12.4 LILCO Status

As a result of LILCO's engine start tests, the turbocharger thrust bearings were wiped and had to be replaced. LILCO subsequently instituted the drip system and later the prelube bearing oiling system.

In early 1984 after the new crankshafts were installed in the engines, the turbochargers were disassembled for inspection subsequent to the 100-hour engine qualification test. All three units were thoroughly inspected and the thrust bearing in each turbocharger was again replaced.

In addition to replacing the thrust bearings, LILCO made the following repairs to the turbochargers:

- EDG 101 - replaced oil seal and snap ring, and staked inlet casting plugs, as welds were found cracked
- EDG 102 - staked inlet casting plugs, as welds were found cracked
- EDG 103 - replaced oil seal and snap ring, and staked inlet casting plugs, as welds were found cracked.

In addition to these efforts, LILCO has committed to the OG plan calling for inspection of the turbocharger thrust bearings if any engine experiences 40 fast starts (starts without manual prelubrication of the bearings) or 100 total starts.

The turbocharger on EDG 103 was disassembled for inspection following the 746-hour crankshaft test. The turbocharger was found in good condition. The thrust bearing did show a few slight circumferential dirt scratches across its face, which were judged to be of no consequence by LILCO and PNL consultants. In addition to the 10^7-cycle test, EDG 103 had made 319 starts prior to the turbocharger inspection.

Based on their having made the cited changes and implementing the OG/FaAA recommendations listed in Section 4.12.3, as well as the recent inspections and the fact that the exhaust temperature is measured, LILCO concludes these turbochargers now installed will adequately perform their intended function.

4.12.5 PNL Evaluation and Conclusions

PNL has reviewed the FaAA report referenced above, the results of the Owners' Group meeting with representatives of FaAA, the Owners' Group, NRC, and PNL, and the inspection data presented by LILCO. PNL also has examined the prelube system at other, similar plants. Based on these reviews and on the recent inspection of the EDG 103 turbocharger, PNL concludes that a similar prelube system now installed on the diesels at SNPS will provide sufficient additional lubrication to augment the protection of the turbocharger bearings during planned fast starts. Further, in PNL's view, the few unplanned fast starts that may occur without prelube during a given operating cycle will not lead to bearing failure prior to scheduled maintenance of the bearing (see Section 5.1.1.9). According to Failure Analysis Associates, as confirmed in a telephone conversation between PNL (W. Laity) and FaAA (T. Thomas) on July 20, 1984, the shortest known time-to-failure of a turbocharger thrust bearing subjected to "dry" starts (for which no forced bearing prelubrication was provided) occurred at SNPS. That bearing experienced at least 62 "dry" starts before failure. The new operating procedure instituted at SNPS suggests that each engine is likely to experience very few, if any, "dry" starts in a given operating cycle.

PNL also notes that LILCO has established a planned program of relevant maintenance and surveillance and, at the next refueling outage, has agreed to implement the OG recommendations for inspections. LILCO has also committed to comply with OG recommendations regarding capscrews, vanes, and mounting and supports that may result from the Shoreham DR/QR effort.

PNL notes that the engines at SNPS will be run at a BMEP of about 213 psi. This engine rating is slightly below the TDI full load BMEP of 225 psi. This reduces the pre-turbine exhaust temperature, which is beneficial to the turbocharger.

On the bases of the above considerations and the recent inspection of the EDG 103 turbocharger, including the PNL consultant examination, PNL concludes that the turbochargers on SNPS EDGs 101, 102, and 103 are suitable for their intended service.

4.13 JACKET WATER PUMP

Part No. 03-425-A

Owners' Group Report Supplement to Emergency Diesel Generator Engine Driven Jacket Water Pump Design Review (SWEC July 1984).

4.13.1 Component Function

The engine driven jacket water pump furnishes water to the engine jackets (i.e., the cylinder block surrounding the liners, the heads, the coolers, and the exhaust manifold). Water is also circulated through the turbocharger water jackets. The pump is a typical centrifugal pump, driven from the front-end gear.

Without the water pump (or an emergency backup), the engine would quickly shut down due to excessive temperatures. Such pumps generally are trouble-free, but occasionally develop problems of shaft seals, bearings, and drive mechanisms.

4.13.2 Component Problem History

The jacket water pumps at Shoreham have encountered one significant problem: a pump shaft failure. This led to redesign of the method of attaching the impeller to the shaft. There is no history of other jacket water pump failures.

4.13.3 Owners' Group Status

Stone & Webster has investigated the jacket water pumps as installed on the TDI inline and vee engines. They reviewed these jacket water pumps from the standpoints of mechanical design, material suitability, and hydraulic performance. SWEC found the pump as modified at SNPS is acceptable, with the recommendation that the proper torque be used for holding both the gear and impeller on the shaft taper.

4.13.4 LILCO Status

A water pump at SNPS sustained a broken shaft. The failure was analyzed to be caused by a stress concentration at a keyway. SNPS obtained a new jacket water pump in which the keyway was eliminated; the impeller in this new pump is now held to the tapered shaft with a preloaded lock nut. The modified design was reviewed by SWEC, who stated it was satisfactory.

In connection with the Shoreham DR/QR effort, the jacket water pump for EDG 102 was subjected to:

- visual inspection for signs of distress or excessive wear or pitting of both the drive and driven gears
- verification of bearing surface contact between impeller and shaft
- liquid penetrant examination on the contact surface of the impeller and gear to shaft, shaft taper, impeller, and gear bore
- verification of material and hardness of shaft and impeller
- visual inspection of the clearance or wear rings for evidence of galling or wear
- dimensional checks of the shaft.

LILCO has reported all results to be satisfactory. No comparable inspections or tests were conducted for EDGs 101 or 103.

During the inspection of EDG 103 after 746 hours of operation at a load of 3300 kW, the water pump was examined in place in the engine. The water pump seal showed no leaks, and the water pump drive and drive gear showed no wear or pitting pattern.

Based on the OG design review studies and the inspections listed above, LILCO has concluded that the jacket water pumps are acceptable for their intended function at SNPS.

4.13.5 PNL Evaluation and Conclusion

On the basis of the redesign of the impeller/shaft attachment, and the fact that all SNPS EDGs are equipped with this new design, PNL concludes that these pumps are acceptable for their intended service.

4.14 HIGH-PRESSURE FUEL OIL TUBING

Part No. 03-365-C

Owners' Group Report Emergency Diesel Generator Fuel Oil Injection Tubing (SWEC April 1984).

4.14.1 Component Function

The high-pressure fuel oil tubing carries the fuel oil from the cam-driven injection pumps on the engine sides to the injector nozzles (spray nozzles) in the heads. This oil is under pulsating and quite high pressure (~500 psi to 15,000 psi once each cycle); hence, any flaws in the steel tubing or fittings used, or any breaks caused by vibration or other factors, will release an oil spray in high-pressure bursts, with consequential personnel and fire risks.

4.14.2 Component Problem History

High-pressure fuel tubing leaks have developed during preoperational engine testing on SNPS and Grand Gulf engines. No other failures in nuclear applications have been reported.

4.14.3 Owners' Group Status

SWEC analyzed the failed high-pressure fuel tubing and concluded that the failures originated in inner surface flaws that were introduced during fabrication. If, through eddy-current inspection, the inner surface condition of new tubing is found to be within the manufacturer's specification, SWEC has concluded the high-pressure tubing is suitable for the service intended. It was also recommended, however, that all future replacement lines be of a superior material and be "shrouded" with a sock to protect against open oil sprays in the event of future leakages.

The OG also has reviewed the compression fittings and concluded that they are adequate, provided that the injection lines are properly installed. The OG recommends that inspections for fuel leaks near the compression fittings be performed while the engine is running.

4.14.4 LILCO Status

In March 1984, following a series of tubing failures, all of the fuel oil injection tubing was replaced with new, high-pressure, shrouded tubing. The ends of this tubing were eddy-current inspected to detect flaws greater than 0.003 inch, which is less than the flaw size determined by the OG to be critical for propagation.

4.14.5 PNL Evaluation and Conclusion

PNL concurs with the OG analysis of the critical flaw size. On the basis of 1) the actions taken by LILCO to replace all tubing, 2) the successful ET, and 3) LILCO's commitment to check tube fittings monthly for leakage. PNL concludes that the high-pressure tubing on all SNPS engines is acceptable for the intended service. PNL recommends that checks for oil leaks be done only while the engine is not running.

4.15 AIR STARTING VALVE CAPSCREWS

Part No. 03-359

Owners Group Report Emergency Diesel Generator Air Start Valve Capscrew Dimmension and Stress Analysis (SWECo March 1984).

4.15.1 Component Function

These capscrews serve to hold the air start valves in place in the cylinder head. A failure, or an inappropriately long capscrew, will prevent the air starting valve assembly from seating securely in the head. The consequences of being incorrectly secured are the loss of power in one cylinder due to escaping combustion gases.

4.15.2 Component Problem History

No actual failures of these capscrews have been reported. However, on May 13, 1982, TDI reported a potential defect due to the possibility of the 3/4-10 x 3-inch capscrews "bottoming out" in the holes in the cylinder heads, resulting in insufficient clamping of the air start valves.

4.15.3 Owners' Group Status

SWEC and TDI both have recommended that the 3-inch capscrews be either shortened by 1/4 inch or replaced with 2-3/4-inch long capscrews.

4.15.4 LILCO Status

Two TDI upgrades associated with the air start valves have been implemented at Shoreham. They are 1) installation of new 2-3/4-inch capscrews and 2) installation of new gaskets.

In conjunction with the SNPS DR/QR, a number of inspections were performed to verify that the capscrews for all three engines are of correct material and length, bolt holes are clean and lubricated, the locking pin is in the valve arm lock nut, the O-ring and grooves are in good condition, and the gasket seal to the cylinder head is of the proper material. Material testing of the capscrews was also performed. Other visual inspections were conducted for corrosion and deterioration. LILCO confirmed that all capscrews were torqued to OG recommendations.

On the basis of the modifications, inspections, and maintenance plans, LILCO concludes that the air start valves, capscrews, and gaskets for all engines are suitable to serve their intended function.

4.15.5 PNL Evaluation and Conclusions

The inspections and actions taken by LILCO to eliminate potential problems are judged to be adequate to prevent failures. PNL therefore concludes that, with the continued use of LILCO's installation procedures to control torque of bolts, studs, and screws to specified ranges, and LILCO's recommended maintenance procedures, these components will not present future problems on the SNPS engines. Thus, PNL concludes these components on EDGs 101, 102, and 103 are acceptable for their intended service.

4.16 ENGINE-MOUNTED ELECTRICAL CABLE

Part No. 03-688-B

Owners' Group Report SWEC Report of April 1984

4.16.1 Component Function

These cables serve the Woodward governor/actuator and the Air-Pax magnetic pick-up, both mounted on the engines. Inappropriate cable materials, not able to withstand the temperature or service environment, could lead to short circuits, with adverse impact on the component functions and possible risk to personnel.

4.16.2 Component Problem History

Two defective cables were recorded by TDI in a 10 CFR 21 report. Also, a TDI Service Information Memo warned of potentially defective engine-mounted cables.

4.16.3 Owners' Group Status

Analyses of the subject wiring, and of the recommended replacements, were conducted by SWEC, both generically and specifically for SNPS. The replacement cable and terminations were deemed serviceable for this duty.

4.16.4 LILCO Status

LILCO has evaluated the wiring and terminations used on all three SNPS engines. The terminal components and blocks were found to be within specifications. The insulated wires associated with the crankcase vacuum fans and the standby air supply solenoid valves were replaced to meet operating temperature requirements. All wiring and cables now installed are of acceptable flame-retardant construction and meet specified current and thermal requirements.

On the basis of the evaluations and changes implemented, LILCO concludes that the engine-mounted electrical cable and terminations used at SNPS are suitable to serve their intended function.

4.16.5 PNL Evaluation and Conclusion

Based on the review of the actions taken by LILCO, PNL concludes that the subject terminations and cables on EDGs 101, 102, and 103 are acceptable for their intended service at SNPS.

5.0 PROPOSED MAINTENANCE AND SURVEILLANCE PROGRAM

In PNL's review of the TDI Diesel Engine Owners' Group Program Plan (PNL-5161, June 1984), maintenance and surveillance (M/S) is identified as "a key aspect of the overall effort for establishing TDI engine operability and reliability". NRC also recognizes the importance of a comprehensive M/S program and has provided guidelines for the development of such a program in the NRC staff SER dated August 13, 1984.

Long Island Lighting Company has developed an M/S plan for the Shoreham Nuclear Power Station. The plan is presented in the Stone & Webster Engineering and Design Coordination Report (E&DCR) No. F-46505, which is to be incorporated into the TDI Instruction Manual whereby it will be implemented into the Shoreham M/S Program. E&DCR F-46505 includes, as an attachment, the Suggested Maintenance Schedule from the TDI Operation, Maintenance and Instruction Manual, Model DSR-48 Diesel Engine. Subsequent references to the LILCO M/S plan in this TER will, therefore, also encompass TDI's recommended maintenance and surveillance procedures. LILCO's M/S plan is also partially reproduced in Appendix II of the Shoreham TDI Diesel Generator Design Review/Quality Revalidation Report (June 29, 1984), although LILCO has indicated that this appendix is subordinate to E&DCR F-46505.

E&DCR F-46505 lists many more maintenance items than will be discussed in this report. Those that are not itemized here are judged to be beyond the scope of this effort, which is focused on components and systems critical to engine operation and/or with failure histories. However, PNL has added a few items where special attention is deemed appropriate. Specifically, recommendations for M/S are provided when, in the opinion of PNL consultants, their inclusion in an overall M/S plan is important to ensuring operability and reliability. This report is not intended to supplant LILCO's M/S plan, but rather to augment and clarify it.

This section documents PNL's review and evaluation of LILCO's M/S plan in light of the opinions and recommendations of recognized experts in diesel engine technology. Comments on four aspects of a comprehensive M/S program are presented in the subsections that follow. The four aspects are:

- major maintenance items
- proposed additional maintenance items
- operational surveillance
- standby surveillance.

5.1 MAJOR MAINTENANCE ITEMS

Components classified as major maintenance items include engine structural and moving parts. Parts with a failure history, even if they are static and/or nonstructural, also are included. LILCO's proposed M/S plan for these components is summarized in Table 5.1.

5.1.1 PNL Evaluation and Recommendations

PNL found that LILCO's proposed M/S plan does not identify several important components and systems requiring periodic maintenance. In addition, PNL consultants recommended that LILCO's maintenance procedures for several items be revised.

PNL recommends that LILCO add procedures for the following components to its M/S plan:

- main bearing shells
- studs/bolts.

PNL also recommends modifications to the LILCO M/S plan for the following commponents:

- crankshafts
- cylinder blocks
- connecting rod bearing shells
- cylinder liners
- cylinder heads
- turbochargers.

PNL recommendations for M/S of these components are presented in Table 5.1 for comparison with LILCO's M/S plan. Where the two recommendations diverge substantively, explanation for the difference is provided in the subsections that follow.

TABLE 5.1. Major Maintenance Items for Shoreham Nuclear Power Station[a]

Item	LILCO Proposal	PNL Recommendation
Crankshaft	Check and record crankshaft deflections.	Concur with LILCO. Measure web deflection, hot and cold, once each refueling. EDG 101 and EDG 102: Inspect crankpin journals No. 5, 6, and 7 and the main bearing journals between them at the first refueling outage, using LP and ET as appropriate. Also inspect the oil holes in these journals. EDG 101, 102 and 103: During the second and subsequent refueling outage, inspect two of the three crankpin journals subject to the highest stresses (No. 5, 6, and 7) and their oil holes, using LP and ET as appropriate. Perform this inspection on each engine.
Cylinder Blocks	Perform a visual and eddy-current inspection of the cylinder block, paying close attention [to the areas] between stud holes of adjacent cylinders prior to returning the engines to emergency standby service after any period of operation greater than 50% load.	Concur with LILCO. In addition, visually inspect daily during any period of continuous operation and inspect under intense light while operating monthly. At each refueling outage, inspect top surface of block exposed by removal of two heads. LP recommended with UT as appropriate. Monitor behavior of several representative cam gallery cracks in EDG 101 and 102. Alternative approaches and frequency discussed in Section 5.1.1.2.

(a) Refer to Section 4.0 for additional details on Owners' Group designated generic issues.

TABLE 5.1. (contd)

Item	LILCO Proposal	PNL Recommendation
Cylinder Blocks		Perform LP and/or UT inspection of cylinder liner landing at any time a liner is removed.
Connecting Rods	None provided	Check preload on connecting rod bolts at each refueling outage.
Main Bearing Shells	Check at alternate refueling outages. (method unspecified)	Concur with LILCO
Connecting Rod Bearing Shells	Inspect and measure connecting rod bearing shells every 5 years.	Concur with LILCO
	Perform an x-ray examination on new bearing shells to acceptance criteria developed by Owners' Group prior to installation.	Concur with LILCO
	Bump test for bearing wear at each refueling outage.	Concur with LILCO.
		Replace lower bearing shells No. 4, 5,and 6 on EDG 1 at first refueling, or sooner per FaAA recommendations (300 operating hours).
Pistons	Inspect and measure skirt and piston pin every 5 years (TDI inspection and maintenance form No. 5-D-10)[a]	Concur with LILCO
Cylinder Liners	Perform a boroscopic inspection of liners for potential progressive wear at each refueling outage.	Concur with LILCO
		Measure/record dimensions at each disassembly.

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[a] Included in Shoreham DR/QR report, but not in E&DCR F-46505.

TABLE 5.1. (contd)

Item	LILCO Proposal	PNL Recommendation
Cylinder Heads	Visually inspect cylinder heads (all eight cylinders) at each refueling outage.	Concur with LILCO
		Inspect firedeck between exhaust valve seats and all valve seats for two adjacent heads with LP at each refueling outage. Select heads such that all heads are inspected every four refueling outages.
Cylinder Heads		Air-roll before planned starts, and 4 to 8 and 24 hours after each shutdown.
Valve Gear/ Lifters	Visually inspect camshafts, tappets, rollers, rocker arms, push rods, and valve springs, and adjust lifter, at each refueling outage.	Concur with LILCO
Head Studs, Air Start Valve Capscrews, Rocker Arm Bolts	None provided[(a)]	Check preload on 25% of head studs, 100% of air start valve capscrews and 25% of rocker arm bolts at each refueling.
Gear Train	Visually inspect cam, idler, and crankshaft to jacket water pump gear for chipped or broken teeth, excessive wear, pitting, or other abnormal conditions during alternate refueling outages.	Concur with LILCO
	Measure gear backlash at each refueling outage.	Concur with LILCO

(a) LILCO does propose to remove and inspect the air start valves at each refueling outage and would therefore retorque all air start valve capscrews.

TABLE 5.1. (contd)

Item	LILCO Proposal	PNL Recommendation
Turbochargers	Measure rotor endplay monthly until confidence is established.	Concur with LILCO, but also record measurements and monitor for trends.
	Inspect thrust bearing after 40 nonprelubed starts.	Concur with LILCO, except inspect after 40 nonprelubed starts or after 100 starts (inclusive), whichever occurs first.
	Perform spectrochemical ferrographic engine oil analysis quarterly or after 20 starts.	Concur with LILCO
		Inspect nozzle ring and check rotor float at each refueling outage.
"Y" Strainers in Starting Air System	Inspect monthly.	Concur with LILCO
	Replace filter element at each refueling outage.	Concur with LILCO
Lube Oil Sampling and Analysis	Check lubricating oil with a viscosimeter for fuel oil dilution. Send a sample of oil to laboratory for analysis monthly.	Concur with LILCO; sample from lube oil filter inlet monthly or every 24 hours running.
Lube Oil Sampling and Analysis	Drain lubrication oil system and clean sump tank at every refueling outage. Depending on the results of lube oil analysis, refill with new oil.	Concur with LILCO.
		Sample from bottom of sump (check for water) monthly.
Air Start Valves	Remove, clean, and inspect at each refueling outage.	Concur with LILCO
	Inspect the piston cap guide housing sliding surfaces at each refueling outage.	Concur with LILCO
	Ensure that the refrigerant dryer is working properly daily.	Concur with LILCO

TABLE 5.1. (contd)

Item	LILCO Proposal	PNL Recommendation
Base Assembly	Perform a fluorescent dye liquid penetrant inspection of the linear indications present on the bearing saddles during alternate refueling outages.[a]	Concur with LILCO
Fuel Injection Tubing	Check tubing for leaks at fittings monthly.	Concur with LILCO. PNL recommends that leakage inspection and corrections be made with the engine stopped.

(a) The Shoreham DR/QR report calls for magnetic particle examination. PNL concurs with E&DCR F-46505, which specifies liquid penetrant examination of the base assembly.

5.1.1.1 Crankshaft

LILCO proposes to measure crankshaft deflections at each refueling outage. PNL concurs and recommends in addition certain NDE examinations of the crankshaft at refueling outages.

In light of the analyses performed for PNL by Ricardo Consulting Engineers and by Det Norske Veritas, PNL concludes that it would be prudent to examine certain high-stress areas of the crankshaft at each refueling outage. The areas to be examined and the examination methods and frequency are provided in Section 4.3.5.

PNL Recommendations

PNL concurs that LILCO take crankshaft deflection readings at every refueling outage. LILCO's M/S plan does not prescribe hot and cold deflection measurements or the timing of such measurements. PNL recommends the following instructions be added to LILCO's M/S plan. The hot deflection measurements should be taken immediately after the 24-hour preoperational testing, so as to reflect representative operational foundation temperatures. The hot checks should be initiated within 15 to 20 minutes after shutdown, and completed as rapidly as possible, preferably within 1/2 hour, starting with the last throw of the engine (generator end). Such a schedule, although strenuous, is deemed achievable. If the crankshaft deflection readings are outside the acceptable range, the foundation bolts should be checked for proper preload.

PNL also recommends that crankshaft journals be LP inspected whenever corresponding bearings are being inspected.

5.1.1.2 Cylinder Block

Following any period of engine operation at greater than 50% load, LILCO proposes to perform visual and eddy current inspections of those portions of the block top that are accessible between cylinder heads. The purpose of these inspections is to verify the continued absence of detectable cracks between stud holes of adjacent cylinder. PNL concurs with this proposal (with the clarification that 50% load is 50% of the "qualified" load), but recommends that additional surveillance and maintenance procedures also be performed.

Cracks known to exist in the cylinder blocks of the three Shoreham EDGs are described in Section 4.2.2. These include ligament cracks in EDG 101 and EDG 102, cam gallery cracks with weld overlays in those same engines, and cam gallery cracks in EDG 103.

PNL Recommendations

PNL recommends that the visual examinations proposed by LILCO be augmented with daily visual examinations when the engine is in continuous operation, and with a visual examination under intense light when the engine is operated monthly.

PNL recommends the following nondestructive examinations for each cylinder block in addition to the eddy-current inspections proposed by LILCO:

- Block top - During each refueling outage, the portion of the block top exposed by removal of two of the cylinder heads (for inspections discussed in Section 5.1.1.6) should be examined for any new cracks that may develop into stud-to-stud cracks. This inspection should also identify any new ligament cracks in the exposed areas of the top surface, and any changes detectable through surface examination of known ligament cracks. For any new cracks and/or changes in known cracks that extend from stud holes, the studs should be removed to gain better access to the holes, and the depth of the cracks along the counterbores should be measured. PNL recommends that LP be used to perform these examinations, and that UT be used as appropriate to better define the extent of any new cracks or changes in known cracks.
- Cylinder liner landing - An LP and/or UT inspection of the cylinder liner landing should be performed at any time a liner is removed from any of the three engines, to determine if circumferential cracks have developed. PNL recognizes that liners are likely to be removed only infrequently, and does not recommend removal of a liner for the sole purpose of this inspection. If a circumferential indication is found, an attempt should be made to characterize the depth and length through appropriate nondestructive tests. PNL also recognizes that

these cracks are difficult to identify unequivocally through nondestructive tests due to the relatively sharp corner where they may occur.

- Cam gallery - Several representative cracks in the camshaft bearing saddles of EDG 101 and EDG 102 should be monitored to determine if long-term changes are observed that would be indicative of crack propagation under transient conditions of engine startup and shutdown, and during engine operation. PNL recommends that the second camshaft bearing saddle inboard of each end of the engine be selected for monitoring. PNL does not recommend monitoring the cam gallery cracks in EDG 103, because the known cracks in the replacement block are much shallower than those in EDG 101 and EDG 102 and have not been repair welded.

  The monitoring should focus on crack behavior, rather than on measurement of stresses in the vicinity of a crack. (Representative stresses in the area of interest were measured in the replacement EDG 103 block by FaAA in October 1984.) This could be accomplished through any of several alternative approaches. One approach would be to install strain gages to monitor changes in crack opening and/or in crack length. The gages could be monitored during monthly engine tests. If no changes indicative of crack growth were observed in such tests over a period of 6 months, the frequency of testing could be reconsidered. The monitoring could be discontinued if no changes were observed over one refueling cycle.

  An alternative approach would be to monitor crack depth periodically with an appropriate surface probe. Depth readings measured in this manner lack accuracy, but would probably be sufficient to show any significant change in crack depth. Because access covers would have to be removed to expose the cracks, the engine would not be immediately available for emergency service. To obtain the desired information with minimal disruption of engine availability, it would be sufficient in the opinion of PNL to take the depth measurements approximately every 3 months through one refueling cycle. The monitoring could be discontinued at the end of that period if no changes indicative of crack growth were observed.

In the event the block of either EDG 101 or EDG 102 is unbolted from its base during the time the cam gallery cracks are being monitored, measurements should be taken to determine whether or not crack "pop-in" occurred as a result of the relaxation of compressive stresses in the cam gallery.

5.1.1.3 Connecting Rods

LILCO has not addressed the inspection of the connecting rod bolt preload. PNL recommends that the preload on all connecting rod bolts be checked at each refueling outage.

PNL believes that it is good practice to inspect the preload on the connecting rod bolts periodically. Checking the bolt preload during regularly scheduled outages is a simple procedure and is easily justifiable on the basis of the potential damage to the engine that could result from the loss of these bolts.

PNL Recommendation

PNL recommends checking all connecting rod bolts' preload at each refueling outage.

5.1.1.4 Connecting Rod Bearing Shells

LILCO proposes to inspect and measure the connecting rod bearing shells every 5 years and to "bump" test for bearing wear at each refueling outage. PNL concurs and recommends replacement of the lower bearing shells No. 4, 5, and 6 in EDG 101 before they accumulate a total service of 300 hours.

The Owners' Group design review report (FaAA-84-3-1) concluded that the bearings were adequate at site loads for the lifetime of expected usage. Based on these findings, LILCO has proposed inspection of these bearings every 5 years and to bump test all connecting rod bearings at each refueling outage.

LILCO has also identified three connecting rod bearing shells that have minor defects. These bearing shells are installed in the lower position of crank journals 4, 5, and 6 of EDG 101. PNL believes that these bearing shells are acceptable for operation through the first refueling outage, provided that the total operating hours accumulated on any of these bearings do not exceed 300 hours, as recommended by FaAA (C. H. Wells) in a memo to LILCO (P. Martin) dated March 24, 1984.

PNL Recommendations

PNL concurs with LILCO's plan. PNL also recommends replacing lower bearing shells No. 4, 5, and 6 of EDG 101 at the first refueling outage, subject to the 300-hour limitation discussed in the preceding paragraph.

5.1.1.5 Cylinder Liners

LILCO proposes to perform a boroscopic inspection of the liners for potential progressive wear at each refueling outage. PNL concurs and recommends a recorded dimensional check at every disassembly.

Because liner wear provides an important indication of engine reliability and operability, it should be monitored whenever reasonably possible.

PNL Recommendation

PNL concurs that all liners should be visually inspected by boroscope at each refueling outage. In addition, two of the liners from each engine should be measured for wear at every disassembly, and the dimensions recorded for trend analysis.

5.1.1.6 Cylinder Heads

LILCO proposes to visually inspect all eight cylinder heads at each refueling outage. PNL concurs, but recommends further that two heads from adjacent cylinders be LP inspected at valve seats and firedeck at each refueling outage. In addition, PNL recommends that the engines be air-rolled before all planned starts, 4 to 8 hours after each shutdown, and 24 hours after each shutdown.

Air-rolling the engine will expel any accumulation of water in the cylinder, which would most likely be the result of a cracked cylinder head or liner. Substantial water accumulation in a cylinder could cause severe damage to head, piston, crankshaft, or bearings on engine startup. Detection and expulsion of water in the cylinder liners is essential to ensuring engine operability.

PNL Recommendations

PNL concurs with LILCO's plan and, in addition, recommends a schedule for air-rolling as follows:

- an initial air-roll at least 4 hours (but not over 8 hours) after engine shutdown
- a second air-roll approximately 24 hours after shutdown
- thereafter, an air-roll immediately prior to any planned engine operation.

In view of the potential for crack initiation noted in Section 4.8, PNL also recommends removal of two heads and visual and LP inspection of the firedeck at each refueling outage. The firedeck should be inspected between exhaust valves. The heads to be inspected should be selected such that all heads are inspected every four refueling outages.

5.1.1.7 Head Studs, Air Start Valve Capscrews, Rocker Arm Bolts

LILCO has not addressed head studs, air start valve capscrews, and rocker arm bolts in their M/S plan. PNL recommends that these items be inspected for proper preload at each refueling outage as specified below.

Loss of preload on cylinder head studs, rocker arm capscrews, and air start valve capscrews can adversely affect engine operability if it goes unnoticed. Because of their operational history, these items are included on the Owners' Group list of components with significant known problems. Thus, these components warrant regular maintenance and surveillance.

PNL Recommendations

PNL recommends that the preload be checked on a sample of 25% of the head studs and rocker arm capscrews at each reactor refueling outage. However, because the air start valve capscrews are more susceptible to relaxation (due to the associated soft metal gaskets), PNL recommends that they all be checked at each refueling outage.

5.1.1.8 Turbochargers

LILCO proposes to measure turbocharger rotor endplay monthly until confidence is established, to visually inspect the thrust bearing after 40 nonprelubed starts, and to perform a spectrochemical engine oil analysis quarterly or after 20 starts. PNL concurs, with certain qualifications, and also recommends that rotor float be measured and stationary nozzle rings including vanes and capscrews be inspected at each refueling outage.

A recurring problem in the turbochargers on TDI engines at Shoreham and at other TDI installations has been thrust bearing wear. A modification to the lubrication system to provide minimal lube oil to the thrust bearing during engine standby proved to be inadequate. Subsequent modifications to the system have increased bearing prelubrication, which has substantially mitigated the thrust bearing wear.

The turbochargers on the Shoreham EDGs have also experienced a failed nozzle ring capscrew and a lost nozzle ring vane.

PNL Recommendations

PNL recommends that LILCO's M/S plan be modified to include visual thrust bearing inspection after 40 nonprelubed starts or after 100 starts (inclusive), and to include rotor float measurement and stationary nozzle ring including vanes and capscrews at each refueling outage.

5.1.1.9 Lube Oil Sampling and Analysis

LILCO proposes to check the lube oil with a viscosimeter and send a sample of oil to the laboratory for analysis monthly. LILCO also proposes to drain and clean the sump tank at each refueling outage. PNL concurs with LILCO's plan and recommends, in addition, a monthly inspection for water.

Proper maintenance and surveillance of the lubrication oil is desirable not only to ensure proper lubrication of moving engine components, but also to obtain diagnostic information from which engine wear can be inferred. The oil samples to be analyzed should, therefore, be taken from the lube oil filter inlet. Because water will sink in oil, a sample should also be taken from the bottom of the sump tank to detect the presence of water.

PNL Recommendations

PNL concurs with LILCO's plan to take the lube oil samples from the filter inlet with the engine running. PNL further recommends that monthly samples be taken from the bottom of the sump tank to check for the presence of water.

5.2 ADDITIONAL MAINTENANCE ITEMS

In addition to the major maintenance items discussed in Section 5.1, certain other engine components and maintenance procedures warrant inclusion in a comprehensive M/S plan. These include:

- fuel injection pump
- fuel injection nozzle
- governor oil change
- air intake filter
- fuel oil drip tank
- fuel oil filter and duplex strainer
- lube oil keep warm filter
- lube oil filter
- heat exchangers
- jacket water system flush
- engine balance
- governor drive coupling

5.2.1 Rationale

These additional maintenance items also are important to EDG reliability and operability although they have not been related directly to any TDI engine failure to date. In PNL's opinion, their inclusion in an M/S plan is consistent with good practice. The items are presented here as recommendations/ suggestions.

5.2.2 PNL Evaluation

PNL reviewed the available LILCO documentation to determine if the 13 items noted above were included in the utility's proposed M/S plan. The first two columns of Table 5.2 summarize PNL's findings.

PNL's recommendations are summarized in the third column of Table 5.2. Explanatory notes are included where necessary to augment these

TABLE 5.2. Recommended Additional Maintenance Items for Shoreham Nuclear Power Station

Item	LILCO Plan	PNL Recommendation	Note
Fuel injection pumps	Not included	Verify calibration and operation at every third refueling.	(1)
Fuel injection nozzles	Not included	Check "popping" pressure and spray pattern at every refueling outage.	(2)
Governor oil change	Drain, flush, refill, and vent actuator oil system with oil from a clean container, ensuring that appropriate cleanliness procedures are followed, at each refueling outage.	Concur with LILCO	
Air intake filter	Inspect air intake filter every 3 to 6 months. Replace as required.	Concur with LILCO	
Fuel oil drip tank	Not included	Check monthly, clean as required.	
Fuel oil filter and duplex strainers	Change filter elements at each refueling outage.	Concur with LILCO; also change filters if there is a 20-psi pressure drop across filter.	
	Record strainer differential pressure monthly; clean or replace if pressure drop is greater than 5 psi.	Concur with LILCO	
Lube oil keepwarm filter	Change filter elements at each refueling outage or when filter differential pressure reaches 10 psid.	Concur with LILCO	
Lube oil filter	Manually cycle lube filter and strainer monthly.	Also change with 20-psi pressure drop across filter.	
Jacket water heat exchanger	Flush daily.	Concur with LILCO	
	Inspect tubes, tube protectors and tube sheets for corrosion and fouling at each refueling outage.	Concur with LILCO	

TABLE 5.2. (contd)

Item	LILCO Plan	PNL Recommendation	Note
	Inspect and clean lantern ring at each refueling outage.	Concur with LILCO	
	Replace packing ring at each refueling outage.	Concur with LILCO	
Lube oil heat exchanger	Inspect for leakage at neoprene packing daily.	Concur with LILCO	
	Inspect tube, tube protectors and tube sheets for corrosion and fouling at each refueling outage.	Concur with LILCO	
	Replace packing rings at each refueling outage or when packing becomes hard or when leakage at the packing is noted and cannot be stopped by tightening.	Concur with LILCO	
Jacket water system flush	Not included	Flush system at alternate refuelings.	
Engine balance	Not included	Record firing peak pressure and exhaust temperatures and adjust per TDI manual at each refueling.	
Governor drive coupling	Check that coupling is tight on shaft at each refueling outage.	Concur with LILCO	
	Replace the present neoprene elastomeric inserts in Koppers coupling.	Concur with LILCO	

NOTES

(1) Fuel injection pumps on the LILCO engines have not been a source of problems. Due to the precision and close-tolerance nature of the fuel injection pumps, they can be damaged easily during a disassembly, thus requiring replacement of parts when otherwise unnecessary. Fuel injection pumps can be checked for proper operation and calibration at any reliable diesel service center; faulty or questionable pumps can then be put aside for disassembly. It is important to note that the same test should be performed on all pumps if they have been disassembled. The pumps should also be recalibrated after disassembly.

(2) Fuel injection nozzles are similar to injection pumps, in that very close tolerances are encountered; thus, they are also susceptible to damage during maintenance inspection. Proper testing of the nozzles for leakage, "popping" pressure, and spray pattern would give a complete indication of the status of each nozzle. Then, only nozzles giving questionable results would need to be disassembled. The same tests should still be performed on all nozzles after reassembly, should they be disassembled.

PNL recommends checking "popping" and closing pressure and spray pattern of all fuel injection nozzles at every refueling outage. Should operating surveillance (i.e., cylinder exhaust temperature) indicate a potential fuel injection nozzle problem, the suspect nozzle should be tested and, as necessary, disassembled.

ecommendations. In PNL's opinion, the recommendations presented in Table 5.2 should be considered in finalizing LILCO's M/S plan for the Shoreham plant.

5.3 OPERATIONAL SURVEILLANCE PLAN

A third aspect of M/S is operational surveillance, which refers to the parameters to be monitored and/or recorded during engine operation. This typically includes temperatures and pressures at key locations in and about the engine, as well as cumulative parameters such as engine hours and tachometer readings.

5.3.1 Rationale

Operational surveillance is necessary to ensure safe and efficient operation of the diesel engine. By monitoring and recording key engine parameters, trends in degradation can be detected, allowing timely preventive maintenance. Trend monitoring may also prevent major engine damage by providing early warning to allow engine shutdown prior to damage.

5.3.2 PNL Recommendations

PNL has not received a detailed operational surveillance plan from LILCO. Recognizing the importance of operational surveillance as indicated above, PNL's recommended surveillance plan is provided in Table 5.3. Justification for several of the included parameters when the recommendations are not obvious is provided in the subsections that follow.

5.3.2.1 Pre-Turbine Exhaust Temperature

Pre-turbine exhaust temperature is valuable because:

- The individual cylinder exhaust pyrometer reports only a time average of highly variable function.
- The turbine inlet temperature may be higher than any cylinder exhaust because of more hot puffs per time, and also because of possible exothermal reactions in the exhaust manifold.
- Blades and nozzle rings may be damaged by temperatures above the manufacturer's limit, which Elliott states is 1200°F.

TABLE 5.3. Recommended Operational Surveillance Plan for Shoreham Nuclear Power Station

Item	PNL Recommendations
Lube oil inlet pressure	Log hourly
Lube oil to turbocharger pressure	
Fuel oil to engine pressure	
Fuel oil filter differential pressure	
Air manifold pressure	
Lube oil filter differential pressure	
Jacket water pressure (inlet and outlet)	
Crankcase vacuum	
All cylinders exhaust temperature	
Exhaust temperature at turbine inlet	
Lube oil temperature (inlet and outlet)	
Jacket water temperature (inlet and outlet)	
Tachometer	
Hour meter	
Generator load	
Air manifold temperature	
Fuel oil transfer pump strainer differential pressure	Log hourly unless strainer is auto/duplexed and alarmed
Starting air pressure	Check hourly
Fuel oil day-tank level	Check hourly
Air manifold	Drain condensate every 4 hours of engine operation
Visual inspection for leaks	Monthly or after 24 hours' operation

5.3.2.2 Air Manifold Temperature

Air manifold temperature indicates the effectiveness of the turbocharger aftercooler, and its efficiency is dependent on water flow and temperature and on fouling. The effects of elevated air manifold temperatures are reduced maximum load and less efficient combustion. Although the potential for such problems is less at the low engine loads, it is considered prudent to monitor and trend the air manifold temperature.

5.3.2.3 Fuel Oil Transfer Pump Strainer Differential Pressure

This pressure should be monitored continuously and recorded hourly unless the pump is automatically valved duplex with alarm to protect fuel feed.

5.3.2.4 Starting Air Pressure

This pressure must be monitored to ensure sufficient pressure is available for restart at all times.

5.3.2.5 Fuel Oil Day-Tank Level

This level must be monitored to ensure fuel availability.

5.4 STANDBY SURVEILLANCE PLAN

In Appendix II of the Shoreham DR/QR report, LILCO has provided a list of specific items to be maintained on a daily basis. In addition, the attachment to E&DCR F-46505 contains several pages from the TDI Instruction Manual that specify maintenance procedures to be followed.

5.4.1 Rationale

Standby surveillance is important to ensuring the operability of the diesel engines. The parameters monitored on an engine in standby status are intended to indicate the engine's preparedness to start rapidly and accept load. The two factors that contribute most to this are engine temperature and lubrication. By keeping the engine warm and all oil passages pressurized, the time lag associated with load acceptance is minimized. In addition, a ready supply of quality compressed air is required for starting the engines.

5.4.2 PNL Evaluation

PNL reviewed LILCO's proposed standby surveillance plan and found that the proposal covers a number of items considered important to monitoring engine condition while on standby status. However, several important items were not included in LILCO's proposal. For other items, PNL consultants' recommendations differ from those of LILCO. In general, justification for these recommendations is based on engineering judgment.

Recommended items to be included in a standby M/S plan are presented in Table 5.4. The information in this table is not intended to supplant any maintenance procedure recommended by the manufacturer, but rather to provide additional perspective in developing an integrated M/S plan.

Two points regarding the keepwarm lube oil filter are important:

1. Entrained water or bacteria (in the absence of bactericide use) will tend to plug some filter media (or weaken others), and so would gradually increase pressure drops.
2. The continuous keepwarm flow through the filters will (purposefully) continuously filter the oil, with gradual buildup of contaminants in the media; the material scavenged out thereby itself helps filter even finer particles as time continues.

Thus, it remains valid to monitor oil filter pressure drop during standby. The changes are slow enough that a weekly check is deemed sufficient.

In conclusion, it appears that the LILCO standby surveillance plan needs to be formalized as a separate entity within the overall M/S program for Shoreham. PNL recommends that the plan include the items and time intervals listed in Table 5.4.

TABLE 5.4. Recommended Standby Surveillance Plan for Shoreham Nuclear Power Station

Item	LILCO Proposal	PNL Recommendation
Starting air pressure	None provided	Visual checks every 8 hours. Log every 24 hours.
Lube oil temperature in/out	Daily[(a)]	↓
Jacket water temperature in/out	Daily[(a)]	↓
Lube oil sump level	Daily	↓
Fuel oil day-tank level	None provided	↓
Room temperature	↓	↓
Annunciator test	↓	Test every 8 hours. Log every 24 hours.
Check alarm clear	↓	Daily
Check compressor air trap operation	↓	Daily
Fuel rack and linkage operation	Daily	Concur and lube monthly.
Governor oil level	Daily	Concur with LILCO
Inspect for leaks	Daily, with detailed inspection monthly	Concur with LILCO
Check freedom of air butterfly valve and cylinder	Monthly	Concur with LILCO
Keepwarm oil filter differential pressure	None provided	Check weekly
Test jacket water for pH, conductivity, corrosion inhibitor	Monthly	Concur with LILCO
Air start distributor filter	Monthly	Concur with LILCO
Air start admission valve strainer	None provided	Check quarterly

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(a) Both in and out temperatures are to be measured.

6.0 OVERALL CONCLUSION

This section presents PNL's overall conclusion regarding the capability of the Shoreham EDGs to perform their intended function as emergency standby power sources.

6.1 GENERAL CONCLUSION

PNL and its consultants conclude that EDGs 101, 102, and 103 at the Shoreham Nuclear Power Station are suitable for nuclear standby service at the "qualified" load of 3300 kW, subject to the following comments.

- PNL recommends that the NRC staff obtain a commitment from LILCO to implement the maintenance and surveillance recommendations documented in Section 5.0 of this report. In the revised surveillance and maintenance plan, LILCO should retain all of the provisions currently proposed by the utility that are not addressed in Section 5.0. LILCO's commitment should be a prerequisite for a license from NRC.
- Recognizing that this report precedes the final review by NRC of the Owners' Group Program Plan, PNL recommends that the NRC staff obtain a commitment from LILCO to implement all relevant recommendations and requirements identified in the NRC review. This commitment should be obtained as a prerequisite for licensing, and all relevant actions should be completed by LILCO before or during the first refueling outage, insofar as this is practicable.

6.2 BASIS FOR CONCLUSION

PNL based this conclusion on reviews of 1) the TDI Owners' Group Program Plan, 2) LILCO's actions to resolve generic and plant-specific problems and to upgrade the Shoreham EDGs, 3) the results of engine testing (including requalification and confirmatory testing), and 4) the results of associated engine inspections.

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UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

In the Matter of)
)
LONG ISLAND LIGHTING COMPANY) Docket No. 50-322-1
) (OL)
(Shoreham Nuclear Power Station,)
Unit 1))

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