LILCO
LONG ISLAND LIGHTING

LONG ISLAND LIGHTING COMPANY
SHOREHAM NUCLEAR POWER STATION
P.O. BOX 604, NORTH COUNTRY ROAD • WADING RIVER, N.Y. 11792

January 6, 1984 SNRC-1003

Mr. Harold R. Denton, Director
Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission
Washington, D. C. 20555

Shoream Diesel Generator
Recovery Program Summary
Shoreham Nuclear Power Station

Dear Mr. Denton:

Enclosed is one (1) copy of the Shoreham Diesel Generator Recovery Program Summary and accompanying appendices. Ten (10) copies of this report and appendices were hand delivered to Mr. Caruso on this date for use by your Staff.

The owners of similar diesel generator units in nuclear service have formed an owners' group. Copies of this report and appendices will be forwarded to all member utilities.

Should you have any questions regarding this program, please do not hesitate to contact this office.

B R McCaffrey

B. R. McCaffrey
Manager, Nuclear Compliance and Safety

JPM/ph
Attachment

cc: R. Caruso
C. Petrone
All Parties

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LMT'D DIST.

SHOREHAM DIESEL GENERATOR RECOVERY PROGRAM SUMMARY

SHOREHAM NUCLEAR POWER STATION

January 6, 1984

SHOREHAM DIESEL GENERATOR RECOVERY PROGRAM SUMMARY

SHOREHAM NUCLEAR POWER STATION

List of Approvals:

M. H. Milligan	Project Engineer
E. J. Youngling	Startup Manager
W. J. Museler	Director - Office of Nuclear

SHOREHAM DIESEL GENERATOR RECOVERY PROGRAM

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I. SUMMARY

Following the fracture of the crankshaft in Diesel Generator #102 at the Shoreham Nuclear Power Station on August 12, 1983, LILCO instituted an extensive recovery program aimed at determining the cause of the failure, correcting it, and ensuring that, in light of the failure, other components would operate reliably in the future. This report outlines all aspects of the Shoreham Diesel Generator Recovery Program. This program, when completed, will provide LILCO and the NRC with reasonable assurance that the Shoreham Diesel Generators will perform reliably and will provide a basis for complete closure of diesel generator issues with the NRC Staff. In addition, it will provide a "model" program for the evaluation and ultimate acceptance of other engines in nuclear service manufactured by Transamerica Delaval Inc. (TDI). LILCO has been designated as the Technical Program Manager of the TDI Diesel Generator Owners' Group Program and will make its findings available to all TDI EDG owners.

A. Background

The Shoreham diesel generators had already undergone an extensive evaluation prior to the crankshaft failure as part of the startup testing and licensing processes. Problems with the Shoreham diesel generators during the Pre-operational Test Program resulted in an extensive Diesel Generator Operational Review Program (DORP) which is discussed in Appendix A. This program evaluated all events which had occurred on the Shoreham Diesel Generators, determined the cause of these occurrences, and provided corrective action where required.

The crankshaft fatigue failure in Diesel Generator #102 and the cracks in the crankshafts of the other two diesel generators required LILCO to (a) determine the cause of the failure, (b) take corrective action, and (c) assess the implications of the failure on other diesel generator components. Failure Analysis Associates (FaAA) of Palo Alto, California was retained to lead the Diesel Generator Recovery effort and was given a broad mandate to investigate fully the cause of the failure and recommend appropriate corrective measures.

B. Shoreham DG Recovery Program

The following are the four main elements of Shoreham's Diesel Generator Recovery Program:

1. Disassembly/Inspection/Repair/Reassembly.

2. Failure Analyses and Corrective Actions for Crankshaft Failures and Other Identified DG Problems.

B. Shoreham DG Recovery Program (Cont'd.)

3. Overall Design Review and Quality Revalidation (DRQR) of the Shoreham Diesel Generators.

4. Expanded Pre-operational Test Program.

LILCO made the decision to remove the diesel generators from the Control Building to perform a comprehensive disassembly, inspection, repair and reassembly of the diesels. As a result of the inspections of the engines, additional areas of concern were indicated. A number of these indications were caused by the original crankshaft failure; others had different causes. Each indication was pursued and remedied. The engines have been reassembled under LILCO's Quality Assurance Program utilizing new and modified components as appropriate and have now been reinstalled in the Control Building for testing and operation.

Failure Analysis Associates performed a design evaluation of the Shoreham crankshafts, including an instrumented test of one of the unbroken crankshafts in an operating engine. As a result of the investigation, FaAA determined that the cause of the crankshaft failure in DG #102 was a design deficiency in the existing crankshafts which subjected them to abnormally high stresses. Available replacement crankshafts for the Shoreham engines were of a larger design, twelve inch diameter connecting rod pins in the new crankshafts versus eleven inch diameter connecting rod pins in the old crankshafts. Using analytical techniques identical to those used to determine the cause of the failure, FaAA determined that the new crankshafts conform to allowable design standards (DEMA Standards) and will provide reliable service at Shoreham.

Similarly, FaAA and other organizations have analyzed other problems identified during the Diesel Generator Recovery Program and determined the appropriate corrective action. The closeout of each individual inspection finding will be appropriately documented.

Due to a combination of factors, including the problems uncovered during the inspection of the Shoreham diesel generators following the crankshaft failure, LILCO instituted an overall Design Review and Quality Revalidation (DRQR) Program aimed at establishing the reliability of the Shoreham diesel generators through further inspection, analyses, and, where necessary, additional corrective actions. The Shoreham DRQR Program addresses plant specific and generic concerns regarding the TDI engines. It includes a review of each

B. Shoreham DG Recovery Plan (Cont'd.)

component to determine its functional requirements and its potential contribution to engine reliability. The program also assesses the need for independent confirmation of the design adequacy or production quality. One hundred sixty-eight of a total of 218 component types have been selected for evaluation. Design Review and Quality Revalidation teams will perform the appropriate analyses and/or inspections. If necessary, these teams will recommend appropriate corrective action. The DRQR Program, involving approximately 30 full-time engineering and technical personnel from LILCO, Failure Analysis Associates, Stone & Webster Engineering Corporation, and other consultants, is currently underway. Figure I-1 illustrates the DRQR organization with LILCO providing overall Program management, FaAA supervising the design review, and SWEC supervising the quality revalidation effort. In summary, the DRQR Program provides a comprehensive framework for evaluating each component of Shoreham's diesel generators, and therefore for NRC closure of the TDI diesel issue.

The final element in the Shoreham Diesel Generator Recovery Program will be the performance of a significantly enhanced Pre-operational Test Program which has been carefully designed to provide further verification of the adequacy of the new Shoreham crankshafts and to demonstrate the overall reliability of Shoreham's diesel generators. As shown in Figure I-2, LILCO's Program goes beyond the minimum regulatory requirements, both in program features and in total operating hours, power levels, and numbers of engine starts. For example, LILCO will run each engine for approximately 300 hours with at least 100 of these hours at full power operation, thereby ensuring that the fatigue resistance of the new crankshafts is adequately demonstrated. A test program limited to NRC requirements would result in only about 70 hours of operation. Further, the overall Pre-operational Test Program will exceed the maximum service that any diesel at Shoreham could be subjected to during an entire operating cycle, even assuming a seven day LOCA during this period. Finally, even though the Shoreham Diesel Generators have had an excellent starting record,[1] LILCO has included an additional 100 starts on one of the engines to demonstrate further the reliability of its diesel generators.

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[1] From March 1983 until the time of the crankshaft failure, the three Shoreham diesel generator units accumulated over 200 consecutive successful starts.

C. Status and Schedule

Figure I-3 provides a summary of the status of the program described above and a schedule for the completion of the remaining activities. As shown, Phase A (Disassembly/Inspection/Repair/Reassembly) is complete and, in fact, all engines have been operated. Phase B (Failure Analysis and Corrective Actions) is rapidly nearing completion. Phase C (Design Review and Quality Revalidation) is well underway with a target completion date of March 12, 1984. Phase D, (Pre-operational Test Program) commenced in late December with a target completion date of February 22, 1984.

D. Diesel Generator Owners' Group Activities

The owners of TDI Diesel Generators have formed a TDI Diesel Generator Owners' Group to resolve the generic TDI Diesel Generator issues. LILCO has been designated as the Technical Program Manager for the Owners' Group Diesel Generator Program.

The program outlined herein, while not required for all engines, has been accepted by the Owners' Group as the basic framework for the resolution of the TDI Diesel Generator issues.

Fig. I-1

DIESEL GENERATOR DESIGN REVIEW QUALITY REVALIDATION PROGRAM

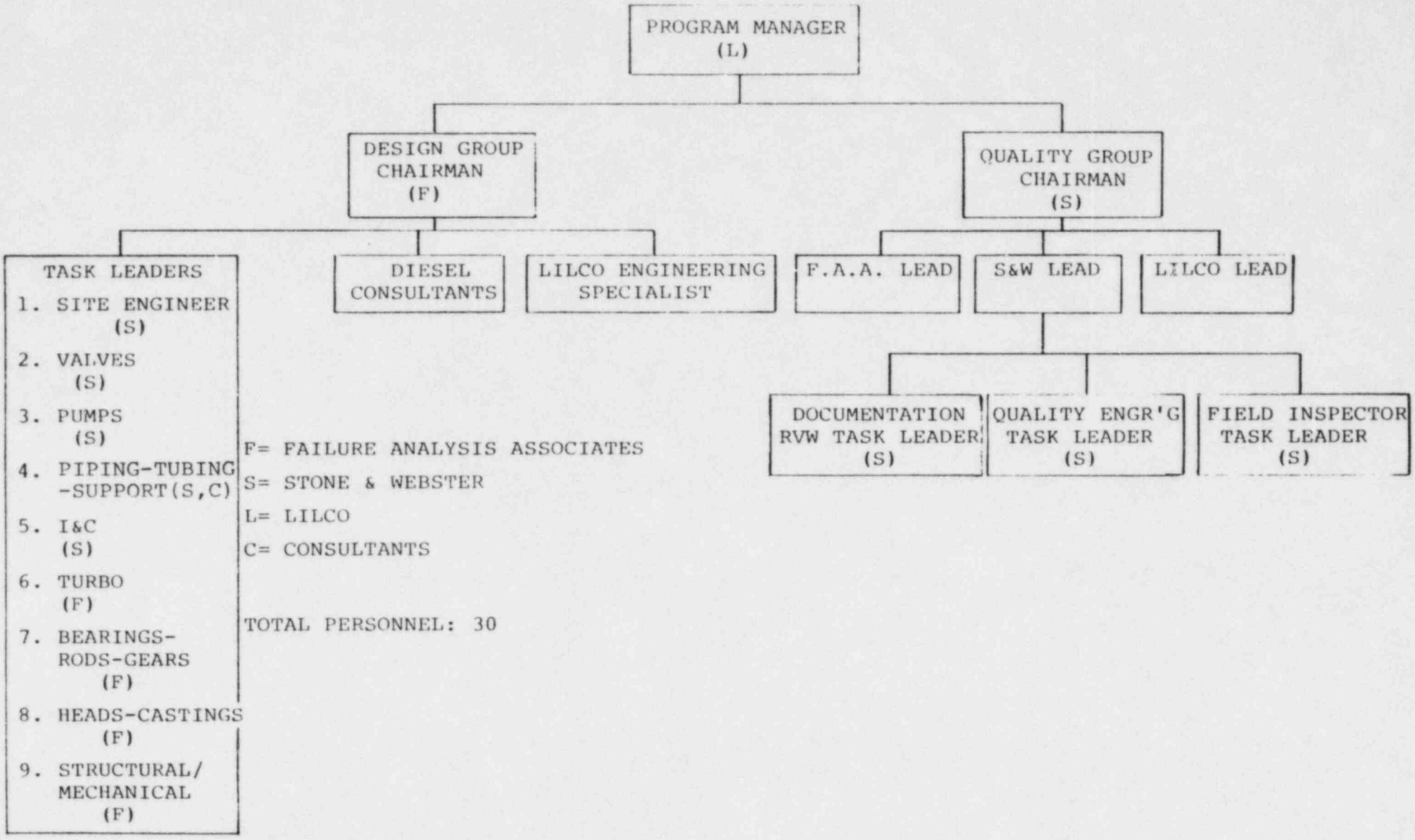


Fig. I-2

SHOREHAM PRE-OPERATIONAL TEST PROGRAM

	NRC REQUIRED PROGRAM	ORIGINAL SNPS PT TEST PROGRAM	EXPANDED RECOVERY PT TEST PROGRAM
Miscellaneous loading, starting, system and electrical tests (as required by Reg. 1.108, SNPS FSAR and IEEE standards).	X	X	X
Integrated electrical test.	X	X	X
Design load and overload tests (22 hr @ 100%; 2 hr @ overload rating).	X	X	X
Qualification tests (23 starts per DG unit)	X	X	X[a]
Detailed vibration and balance tests.		X	X
JTG 72 hr endurance run.		X	X[b]
100 total hours @ $\geq$ 100% load (verification of 10^7 cycle fatigue endurance limit).			X
Crankshaft torsional test (verification of predicted response of replacement crankshafts) (one DG unit only).			X
NDE of crankshafts and inspections of conn rod bearings following PT testing.			X
7-day continuous LOCA/LOOP run.			X
260 total hours of operation, followed by DG maintenance/inspection (surveillance interval cumulative run)			X
100 starts on one DG unit			X
Piston inspections following PT testing			X
Total Hours of Operation (per DG unit)	70	110	296/336[c]
Total Starts (per DG unit)	50	50	65/140[c]

a - For the expanded recovery test program, the 23-start qualification test is part of the 100-start test for one DG unit.

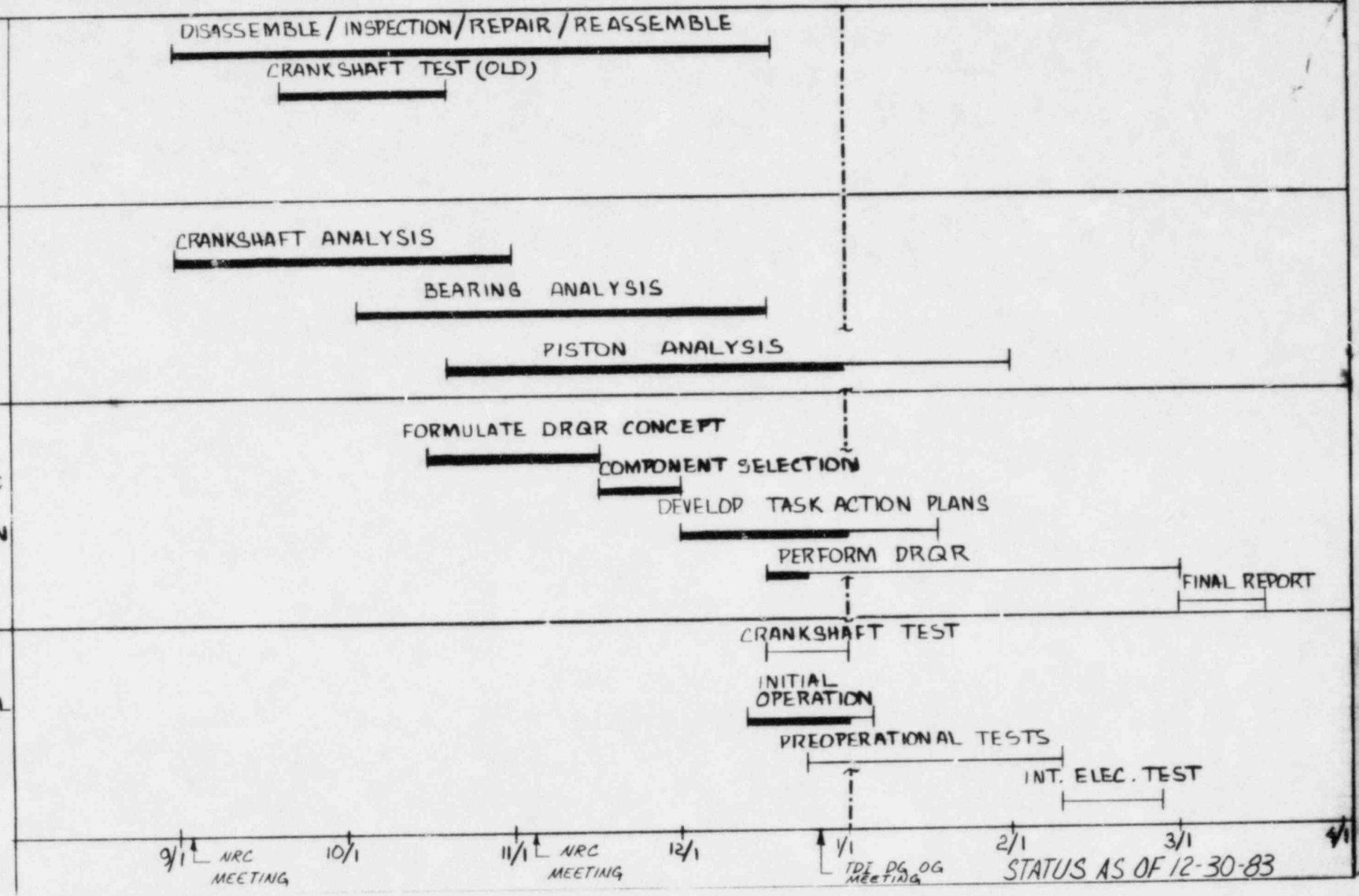
b - For the expanded recovery test program, the JTG 72 hour endurance run is part of the 7-day continuous LOCA/LOOP run.

c - 296 total hours and 65 starts are for two DG units, and 336 hours and 140 starts are for the third DG unit.

SUMMARY SCHEDULE

SHOREHAM DIESEL GENERATOR RECOVERY PROGRAM

FIG. I-3



II. HISTORICAL BACKGROUND

A. Description of Shoreham Diesel Generator Units

The TDI diesel generators supplied for the Shoreham Nuclear Power Station are model DSR-48 diesel engines. The model R engine is a four-stroke-cycle, turbo-charged, after-cooled, in-line diesel engine, built in an 8 cylinder arrangement. Trunk-type pistons, removable wet-type cylinder liners, pressure lubrication and mechanical fuel injection are features of the R engine. A gear-driven starting air distributor provides a timed distribution of pilot air to open the air start valves, permitting the engine to be started cold in a few seconds with a starting air supply.

The Shoreham TDI diesel generators are designed to supply emergency power to vital plant equipment in the event of a complete loss of normal and reserve station auxiliary power. Each engine/generator set is a complete unit, embodying the engine, generator, and basic accessories mounted on a rigid common sub-base. Each engine/generator set is capable of being started either manually, or automatically by electrical signal without local attendance. Auxiliary systems which interface with each skid-mounted engine/generator set include the service water system, combustion air intake and exhaust system, fuel oil transfer system, and the diesel room HVAC system.

According to TDI, the same basic engine as the Shoreham diesel generators has been in production since the early 1950s with the first engine going into service in 1954. The first engine essentially identical to the Shoreham engines went into service in 1969. Delaval has manufactured and sold a total of 97 engines either essentially identical to, or very similar to, the Shoreham diesels. The majority of these engines are already in service. Of the 97 engines, 34 engines are essentially identical to the Shoreham diesels. Collectively, engines either identical to or very similar to Shoreham's diesel generators have accumulated a total of 1,152 operating years of experience. Engines essentially identical to Shoreham's engines have accumulated a total of 115 operating years of experience. The average number of operating years on the 97 Delaval engines mentioned above is 12 years per engine and the average for engines essentially identical to Shoreham's is 3.4 years. Many of these engines are in continuous operation.

B. The Original Diesel Generator Test Program

The diesel generator sets were purchased on May 20, 1974 and were delivered to the site in June 1976. Installation began in 1976 and initial testing commenced on the first engine in October 1981. Initial testing of the second and third

B. The Original Diesel Generator Test Program (Cont'd.)

engines began in March and April 1982, respectively. Construction practices for nuclear Class 1E (safety-related QA Category I) equipment were employed during the installation.

The test program for the emergency diesel generators at Shoreham began at the Delaval factory in Oakland, California. Factory tests performed on the three emergency diesel generators included starting capability tests, high-load runs, load sequencing and load rejection tests. In fact, Emergency Diesel Generator #101 was the engine used by Delaval to qualify the entire R48 series diesel engine for nuclear applications. In this connection, Diesel Generator #101 successfully completed 300 consecutive starts as part of the qualification program.

The emergency diesel generators were delivered to the Shoreham site in 1976 and installed by Construction personnel. Turnover to the Startup organization for testing occurred in August 1980 for DG #102 and in October 1981 for DG #101 and DG #103. The turnover procedure from Construction to Startup included QA inspection of the diesel generators and a formal walkdown and acceptance by the Test Engineers.

The original diesel generator test program was designed to comply with LILCO's commitments in the Shoreham FSAR, including Regulatory Guide 1.108, Revision I (August 1977) concerning diesel generator testing. The test program was carried out in accordance with the requirements of the Shoreham Startup Manual.

The test program for the Shoreham diesel generators used a building block approach starting with the checkout and initial operation tests for individual components. These components were then combined into subsystems and systems and tested again in various functional tests. The diesel generator test program consisted of approximately 135 test packages in the checkout and initial operation phase for all 3 diesel generator units. In addition, 12 flush procedures (four for each diesel generator) were performed on auxiliary systems which supported the diesel generator. Flushes were performed on the lubricating oil system, fuel oil system, jacket water system and air starting system. Following completion of the flushes, 15 functional test procedures (five for each diesel generator) were performed to demonstrate the ability of the diesel auxiliary systems to function properly and to support the complete operation of the diesel generators. These functional tests included demonstrations that standby pumps started at the proper time

B. Diesel Generator Test Program (Cont'd.)

and that the proper pressures and flows were achieved. Functional tests were performed on the lubricating oil system, fuel oil system, jacket water system, air starting system and pneumatic shutdown system.

Upon completion of the above tests, the diesel generators were operated for the first time in October 1981 (DG #102), March 1982 (DG #103), and April 1982 (DG #101). The Pre-operational Test Program, consisting of 12 pre-operational tests (four per diesel engine), started in September, 1982. A mechanical pre-operational test checked various mechanical trips on the diesel engine and the air starting capability of the air start system. Two electrical pre-operational tests demonstrated the electrical trips for the generator and included various high load runs, endurance tests, load sequencing operations and load rejection tests. The final test was the diesel generator qualification test which demonstrated the capability of the diesel generators to complete successfully a total of 69 consecutive starts. On June 24, 1983, the Emergency Diesel Generator Pre-operational Test Program, including all mechanical, electrical, and qualification tests, was completed for all three diesel generators.

During the performance of the DG Pre-operational Test Program, concerns were raised regarding the reliability of the Shoreham diesel generators. In the course of the test program, a number of occurrences took place that required corrective action. These occurrences were analyzed in LILCO's Diesel Generator Operational Review Report which was provided to the NRC in July, 1983. A copy of this report is attached as Appendix A.

In addition to the testing described above, the Shoreham Startup organization, in conjunction with the Plant Staff, performed trial runs of all diesel generator surveillance procedures which must be performed by Plant Staff during the operation of the plant in accordance with Shoreham's Technical Specifications. Finally, although the diesel generators had completed their formal Pre-operational Test Program, one remaining demonstration of diesel generator capability was scheduled prior to fuel load: the Integrated Emergency Core Cooling System and Emergency Diesel Generator Operational demonstration (Integrated Electrical Test). The test program for the diesel generators resulted in a total of 2,182 hours of operation as of August 12, 1983 distributed as follows:

B. Diesel Generator Test Program (Cont'd.)

Emergency Diesel Generator #101 - 646 hours
Emergency Diesel Generator #102 - 718 hours
Emergency Diesel Generator #103 - 818 hours

Following completion of diesel generator pre-operational testing, but prior to the Integrated Electrical Test, LILCO replaced all the cylinder heads originally supplied with the TDI engines with new, improved heads. This corrective action was taken to enhance reliability following the discovery of three leaking cylinder heads. After the replacement of these heads, additional testing was performed. On August 12, 1983, during this testing of Diesel Generator #102, vibrations and sudden erratic load swings were observed. Subsequent visual inspection of the generator revealed that the crankshaft had severed. Inspection of DG #101 and DG #103 revealed cracks in the crankshafts of these diesel generators.

III. PHASE A - DISASSEMBLY/INSPECTION/REPAIR/REASSEMBLY

Following the DG #102 crankshaft failure, LILCO undertook to disassemble, repair, and reassemble each DG unit. The details of this effort are described in the Diesel Generator Master Plan (Appendix B). Specifically, this phase of the Recovery Program consisted of the following elements for each DG unit:

1. Disconnect the engine from the auxiliary equipment in the DG cubicle.
2. Move the DG unit to the turbine deck.
3. Disassemble and inspect the DG unit.
4. Perform any required DG repairs.
5. Reassemble and inspect the DG unit.
6. Move the DG unit back to the DG cubicle.
7. Reconnect the engine to the auxiliary equipment in the DG cubicle.

Each of the above tasks was performed in accordance with approved work documents, including procedures approved by the Joint Test Group (JTG), reviewed by Engineering, and verified by cognizant QA organizations. These procedures were also provided to the NRC. Appendix C contains copies of the procedure used for the disassembly of DG unit #101, the procedure for the inspection of DG #102, and the procedure for reassembly of DG #103. Each procedure is essentially identical for all three engines.

The following organizations were involved in Phase A of the Recovery Program as described above:

Startup personnel
Engineering personnel
Scheduling personnel
Vendor representatives
Plant Staff Maintenance Support personnel
Failure Analysis Associates
Operational Quality Assurance

In addition to these personnel, support from the LILCO Office of Nuclear, as well as the entire Long Island Lighting Company, were available, including the Purchasing, Engineering, Maintenance Services and Quality Assurance Departments. The areas of responsibility for each of the groups involved in the DG Recovery effort are described in Appendix B.

The inspection effort performed during the disassembly and reassembly process encompassed all principal components of the

Emergency Diesel Generators, and included many routine preventative maintenance inspections as well as other supplementary investigations.

These inspections included visual and dimensional checks, and non-destructive examinations (NDE) using a variety of techniques. In appropriate instances, destructive testing was used.

IV. FAILURE ANALYSIS AND CORRECTIVE ACTIONS

Overview

Immediately following the DG #102 crankshaft failure, LILCO initiated efforts to assemble an integrated engineering team with the expertise necessary to conduct an investigation of the DG #102 crankshaft failure, and to assess any generic implications for DG #101 and DG #103. As already noted, Failure Analysis Associates, an engineering and metallurgical consulting firm specializing in the analysis of mechanical, structural and material failures, was selected to lead the investigative effort for the Diesel Generator Crankshaft Failure Analysis report. (Additional detailed information on FaAA qualifications is provided in Appendix D.) FaAA was given a broad mandate to take whatever steps it felt necessary to evaluate fully all possible causes of the crankshaft failure. Additionally, when it became evident that all engines would need crankshaft replacement, an early decision was made by LILCO to investigate any potentially significant deficiencies evidenced during disassembly of the diesels.

The overall failure analysis effort was supervised by LILCO. LILCO Project Engineering personnel provided project management. Stone & Webster Engineering Corporation personnel provided site engineering support, engine removal/disassembly procedures preparation and review, test procedures preparation and review, and vibration test evaluations. LILCO Nuclear Engineering Department personnel provided engineering mechanics and metallurgical engineering support. Transamerica Delaval Incorporated (TDI) Engineering personnel provided both field and home office engineering support.

The inspections of the DG units conducted during this phase identified problems with various DG components. These problems were evaluated on a case-by-case basis and corrective actions were taken. A number of these issues have been described in separate reports, including:

1. Interim FaAA Metallurgical Report on the DG #102 Crankshaft
2. Final FaAA Report on the DG #102 Crankshaft
3. Final FaAA Report on the Replacement Crankshafts
4. Interim FaAA Report on the Connecting Rod Bearings
5. Final FaAA Report on the Connecting Rod Bearings
6. Woodward Failure Analysis Report on the Diesel Generator Governor
7. Parsons Peebles Electric Products Failure Analysis Report on the Generator Rotor

A summary of the more significant issues follows.

Crankshaft

As described above, FaAA was initially retained to investigate the cause or causes of the DG #102 13" x 11" crankshaft failure and its implications for DG #101 and DG #103. FaAA pursued four major evaluation methods: Metallurgical examination; review of original (TDI) design calculations; development of independent and supplemental design calculations; and, dynamic strain/torque engine testing.

These analyses and tests indicated that the DG #102 13" x 11" crankshaft failed in high-cycle torsional fatigue. The application of standard industry torsional analysis methods, augmented by FaAA's detailed calculations of crankshaft torsional response and stress distributions which were confirmed by dynamic engine test measurements performed on DG #101, led to the conclusion that the original TDI crankshaft design was inadequate.

Similar analyses were also performed by FaAA for the replacement 13" x 12" crankshaft design. These analyses have concluded that the new crankshafts will have an unlimited life without fatigue failure from torsional stress.

To confirm the analytical results, dynamic engine testing of the 13" x 12" crankshaft, similar to the tests completed on the 13" x 11" crankshaft in DG #101, will be conducted on DG #103. This testing is expected to be completed in January, 1984.

Connecting Rod Bearings

During disassembly of the Shoreham diesel generators, cracks were observed in four upper connecting rod bearing shells. FaAA conducted metallurgical examinations, finite element analysis, and fracture mechanics analysis of the bearing in order to determine the cause of the 11" bearing failures and the adequacy of the replacement 12" bearing design.

In an interim report, FaAA concluded that the factors which contributed to or caused the bearings to crack were: unsupported, overhung bearing ends, excessive crankpin journal yawing, the presence of voids or pores in the size range of 0.5 to 0.7 mm in the aluminum bearing alloy, and calculated peak oil film pressure loads on the bearings higher than those recommended by a major independent manufacturer of engine bearings. The interim report noted that the new 12" bearing design eliminated the unsupported bearing ends. Also, crankpin journal yawing and

Connecting Rod Bearings (Cont'd)

the calculated peak oil film pressure were reduced in the 12" bearings.

In FaAA's final report on the replacement connecting rod bearings (ref. SNRC-993), the results of finite element stress analysis and fracture mechanics analysis indicated that the changes in the size and design of the 12" bearings reduced the tensile stress by 50 percent of that in the original bearings. The predicted fatigue life of the new bearings is 513,000,000 stress cycles, or 38,000 hours at full load. The replacement bearings are, therefore, adequate to perform their intended service function.

Pistons

As a result of a reported separation of a piston crown from a piston skirt in a TDI engine, LILCO decided to conduct non-destructive examinations of its pistons. Initially, die penetrant examination revealed linear indications near the stud attachment boss region in several piston skirts. Subsequently, all SNPS piston skirts were inspected and linear indications were found in all but one skirt. The affected piston skirts are all of a design type designated by TDI as "AF".

Detailed metallurgical examinations were conducted by FaAA on three piston skirts removed from the Shoreham engines. These examinations concluded that each of the piston skirts contained fatigue cracks, ranging up to 0.3 inch deep by 0.9 inch long, in the region of the stud attachment boss. A detailed summary of the results of the metallurgical evaluations was submitted to the NRC on December 9, 1983 (ref. SNRC-989). On the basis of the metallurgical examination, FaAA concluded that the piston material met the specifications reportedly set by TDI and that the cracks did not result from any defect in the material.

LILCO has replaced all of the piston skirts in all engines with a different and more recent TDI piston skirt design. This design, designated "AE" by TDI, has an increased amount of material in the region of the skirt/crown bolting as well as a revised geometry which will improve the stress distribution. In addition, FaAA is conducting finite element modeling of the old AF and new AE skirt to quantify the expected reduction in the operating stress levels in the skirt/crown attachment boss region. One or more reports on this issue are planned.

Other Investigations

In the course of disassembling and inspecting the Shoreham diesel generators, other deficiencies were noted which warranted evaluation by FaAA or other appropriate organizations. The evaluation of each discrepancy identified is reflected in appropriate documentation (e.g., formal report, memorandum, LDR). For example, disassembly of DG #102 revealed damage to the diesel engine governor. The governor was returned to the manufacturer for investigation of the cause of the damage. The manufacturer concluded that the damage to the governor was caused by increased loading associated with the crankshaft failure.

V. PHASE C - DESIGN REVIEW/QUALITY REVALIDATION

The Design Review/Quality Revalidation (DRQR) Program has been established to conduct a detailed review of the Transamerica Delaval (TDI) engine/generator design and to subject individual engine/generator parts to a rigorous quality revalidation which is capable of providing reasonable assurance that the TDI engines will perform their intended function. The DRQR effort is under the overall supervision of LILCO. The team assigned to the DRQR Program includes representatives from LILCO, FaAA, Stone & Webster, supplemented by diesel engine and other consultants. The DRQR Program objective is to identify important components of the TDI diesel engine and to assure that these components are properly designed and fabricated. Selected components will be subjected to a detailed design and/or quality revalidation review. Any deficiencies identified by the Program will be evaluated and/or corrected as appropriate. Appendix E includes procedure DG-1, "Diesel Generator Design Review and Quality Revalidation Program Description", which provides more details on the Program and its organization.

It is significant to note that, while TDI drawings and certain TDI information is being used as input to the DRQR Program, the actual technical evaluations are being performed independent of TDI thereby providing an independent verification.

The DRQR Program is divided into five major steps:

A. Component Selection
B. Preparation of Task Descriptions
C. Design Review
D. Quality Revalidation
E. Preparation of the Final Report

A. Component Selection

A Component Selection Committee designates the diesel generator components to be subjected to the DRQR Program. Selection is based on the component's function and role in the overall operation of the engine, Shoreham and industry experience, and the engineering judgment and experience of the committee. The selection process includes review of available operating information on TDI diesels to ensure that relevant experience was adequately considered.

As part of the component selection process, components are classified as either type A, B, or C. These classifications are based on the effect of the component's failure on the diesel generator performance. Type A components are those whose failure would result in diesel generator shutdown. Type B components include those whose failure would result in reduced capacity of

A. Component Selection (Cont'd.)

the diesel generator or the eventual failure of a Type A component if not detected. Components whose failure have little bearing on the effective use or operation of the diesel generator are classified as Type C. Following classification, the Committee then specifies appropriate design review and quality revalidation requirements. This information is forwarded to the Design Review Group and Quality Revalidation Group for preparation of task descriptions. Procedure DG-2 "Diesel Generator Component Selection Procedure", (Appendix E), provides additional details of the selection process.

B. Preparation of Task Descriptions

The Design Review Group and Quality Revalidation Group prepare task descriptions to define the reviews, inspections, calculations, etc. that will be performed for each component. The task descriptions include any requirements specified in the selection process as well as a more detailed explanation of the methodology, procedures and standards which apply. This task description provides, as applicable:

1. Primary component function and required attributes,
2. Applicable codes and standards,
3. Alternative codes, standards, or analytical techniques,
4. Analysis or evaluation to be performed to assure satisfactory design,
5. Available verifications of TDI analysis (if any),
6. Final documentation requirements, and
7. Schedule for completion.

Task leaders prepare and complete these task descriptions as described in procedures DG-3, "Diesel Generator Component Design Review Procedure" and DG-4, "Diesel Generator Quality Revalidation Procedure" (Appendix E).

In addition to providing a more detailed outline of the specific review on an individual component, the task descriptions list the information or equipment (such as drawings, design information, NDE equipment, etc.) which are necessary to complete the Design Review or Quality Revalidation.

C. Design Review

Completion of the Design Review in accordance with the task descriptions is the responsibility of the Design Group. Due to the number and diversity of the

C. Design Review (Cont'd.)

components and standards involved, the design review must be tailored to each component, and the Group must utilize their experience and professional judgement where necessary. The actual Design Review may be accomplished using any of the following methods, including: a) an independent calculation performed by the Design Group; b) an independent review of the adequacy, appropriateness or correctness of existing vendor and/or subvendor calculations; c) analysis performed by the Design Group; d) testing specified by the Design Group; or, e) other methods specified and approved in the task descriptions.

Design calculations, when required, are signed by the preparer and the checker to indicate concurrence with the calculation and are individually reviewed. Upon completion, the Component Design Review results shall be filed and summaries submitted for incorporation into the final report.

In addition to completion of the task descriptions, the Design Group has two other important functions. It specifies quality attributes important from a design standpoint (in addition to those identified during the component selection process) which are to be reviewed by the Quality Group. The Design Group also identifies any components which may require corrective action to improve reliability of the diesel generators. This will include appropriate recommendations such as increased frequency of replacement and/or maintenance, or additional in-service inspection. These recommendations may also include Quality Revalidation inspections, tests or reviews.

D. Quality Revalidation

The Component Quality Revalidation Group will be provided with the quality attributes which must be validated. The resulting task description includes applicable component descriptions, attributes to be verified, methodology, acceptance criteria, type of documentation to be provided, and the completion schedule.

Each component to undergo Quality Revalidation will be subject to a documentation review. This process will identify and catalogue all appropriate documentation (such as material test reports, NDE, vendor/subvendor records, etc.) associated with the component. With assistance from Quality Engineering, each document will

D. Quality Revalidation (Cont'd.)

be reviewed for acceptability. These document packages will be available to the Design Group to assist in the engineering review. Important attributes identified by the Design Group, for which acceptable documentation does not exist, will be verified by tests and/or inspections performed by the Quality Group.

Tests or inspections required to be performed on components will be forwarded to Quality Engineering to identify methodology and procedures to be followed. These instructions will be issued to Quality Inspection via a task description. Field inspections and tests will be performed by qualified personnel assigned to Quality Inspection. Depending upon the specified test or inspection, spare parts, or surplus parts may be used in lieu of installed parts as the test/inspection article. Results of inspections and tests will be reviewed by the Design Group as required.

E. Preparation of the Final Report

Upon completion of the DRQR Program, a final report will be issued. The final report will contain the following information:

1. Executive Summary
2. Program Description
3. Methodology for Selecting Components
4. Summary List of Components and Classification
5. Methodology for Component Design Review
6. Result of the Component Design Review
7. Methodology for Component Quality Revalidation
8. Results of Component Quality Revalidation
9. Tabulation and Discussion of any Discrepancies
10. Corrective Actions and Recommendations

Status of Program

The four procedures governing the DRQR Program have been approved and are included in Appendix E. Additionally, the selection of components has been completed (results are included in Appendix F). At present, task descriptions are being prepared, reviewed and approved. This effort was approximately 50 percent complete as of 12/30/83. During the months of January and February, the Design and Quality Groups will implement the task descriptions. A schedule for the completion of the DRQR Program is provided in Appendix G.

VI. PHASE D - QUALIFICATION TESTING

In order to provide added assurance that LILCO's Diesel Generator Recovery effort will result in diesel generators capable of reliable performance, LILCO developed an enhanced Pre-operational Test Program. This test program has been reviewed and approved by cognizant LILCO and SWEC personnel. Failure Analysis Associates representatives have also reviewed the program to verify and confirm the adequacy of various tests to demonstrate reasonable assurance of DG reliability. The expanded Pre-operational Test Program has also been submitted to the NRC. Representatives of NRR have indicated that LILCO's program is acceptable.

This section of the report compares the requirements for diesel test programs, LILCO's original Pre-operational Test Program, and the current expanded Pre-operationalTest Program.

A. Requirements - Shoreham DG Testing

The original test program for the Shoreham TDI diesel generators was designed to meet the requirements specified in the following major documents:

1. Regulatory Guide 1.9, Revision 0
2. Regulatory Guide 1.108, Revision 1
3. IEEE-387-1972
4. SNPS FSAR Section 14.1.3.7.24
5. SNPS Technical Specification 3/4.8.1
6. Specification SH1-89.

The testing required by the documents can be divided into three areas: manufacturer's testing, site testing, and surveillance testing.

Manufacturer's Testing

Manufacturer's testing is performed to verify the operability of the DG units, including the interrelated functional capability of engine components. This testing, performed at the manufacturer's facility, includes engine break-in runs and various qualification tests on each engine, including:

a. Sequential Load Tests
b. Margin Tests
c. Maximum Capability Tests
d. Load Rejection Tests
e. Starting Air System Tests
f. Adjustment and Operation of Alarm and Safety Functions.

A. Requirements - Shoreham DG Testing

Manufacturer's Testing (Cont'd.)

This manufacturer's testing requires, at a minimum, approximately 30 hours of operation per each diesel generator unit (10 to 15 starts), with 10 of the hours being at loads greater than or equal to 100 percent. In addition, the manufacturer's qualification tests performed on a single prototype engine for NRC certification involve an additional 110 hours of operation and 300 starts, with a majority of the hours being at a power level of approximately 50 percent.

Site Testing

Site testing is performed to confirm the operability of the DG units, and to verify the interrelated functional capability of the units with various plant systems once the diesels have been installed at the site. Site testing encompasses functional and pre-operational testing of the DG units including:

a. Starting Tests
b. Load Acceptance Tests
c. Overload Tests
d. Design Load Tests
e. Load Rejection Tests
f. Reliability Tests
g. Electrical Tests (including Integrated Electrical Tests)
h. Subsystem Tests.

The performance of electrical, mechanical, and subsystem tests at the site involves approximately 110 hours of engine operation per unit (50 starts), with 25 of the hours being at 100 percent load, and 5 hours above 100 percent load. This test program was the basis for the initial Pre-operational Test Program performed on the Shoreham TDI DG units prior to the engine crankshaft failures, and was basically identical to the testing program employed by other utilities.

Surveillance Tests

Surveillance tests of the DG units are performed to ensure the availability and operability of the units during plant operational periods, as required by technical specifications.

A. Requirements - Shoreham DG Testing

Site Testing (Cont'd.)

Surveillance testing includes a monthly availability test, and periodic operational tests which include:

a. Starting Tests
b. Load Acceptance Tests
c. Design Load Tests
d. Load Rejection Tests
e. Subsystem Tests.

Periodic DG surveillance tests involve, per plant refueling cycle and per DG unit, approximately 92 hours of engine operation (55 starts), with 88 hours being at a load of 100 percent, and two hours at a load above 100 percent.

B. Original Shoreham DG Pre-Operational Test Program

The completed testing program for the Shoreham TDI diesel generator units included manufacturer's and site testing. Manufacturer's testing of the engines by TDI involved the tests outlined in Section VI.A above, including prototype testing on DG #101.

Site testing on each DG unit began with the check-out and initial operation phase, which included testing of individual DG components under 135 C&IO test packages. This was followed by flush procedures for the DG lube oil system, fuel oil system, jacket water system, and air starting system. Following completion of the flushes, functional tests were also performed on each of these systems, plus the pneumatic shutdown system.

Upon completion of the C&IO tests, flushes, and system

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[1] It should be noted that the minimum NRC requirements for site testing result in 70 total hours of DG operation (50 starts), with 25 of the hours being at 100 percent load and four hours above 100 percent load. The dominant reason for the difference in the total hours of operation between the NRC minimum testing requirements and the Shoreham site testing program (performed prior to DG crankshaft failures), is that the Shoreham Program included a 72 hour endurance run for each DG unit. This endurance test was added by LILCO to verify the operability of the DG units under long-term postulated LOCA/LOOP loads.

B. Original Shoreham DG Test Program (Cont'd.)

functional tests, the pre-operational tests were performed on the DG units. The pre-operational tests included all the specific tests described in Section VI.A. LILCO also performed a 72 hour endurance run on each engine as part of the original test program. The total number of DG starts and hours of operation for the pre-operational testing phase exceeded the expected minimum number of starts and hours of operation, due to this additional test and to DG modifications, reworks, and retests.

At the time of engine disassembly for crankshaft replacement, DG #101 had accumulated 646 hours of operation (541 starts), with 180 hours at 100 percent load. DG #102 had accumulated 718 hours of operation (266 starts), with 254 hours at 100 percent load and 19 hours above 100 percent load. DG #103 had accumulated 818 hours of operation (236 starts), with 249 hours at 100 percent load and 20 hours above 100 percent load.

Planned surveillance testing of the engines was to be in accordance with the requirements outlined in Section VI.A above.

C. Proposed Shoreham DG Recovery Test Program

LILCO's enhanced Diesel Generator Test Pre-operational (Recovery) Program includes the following elements:

1. Hydro testing of DG skid-mounted systems.
2. Checkout and initial operation testing of individual DG components.
3. System flushes.
4. Functional testing of DG systems.
5. Pre-operational testing, including starting tests, design load and overload tests, load acceptance and rejection tests, endurance run, electrical tests, and extensive operation at full load.
6. Detailed vibration and balance tests.
7. Crankshaft and other component inspections following pre-operational testing.
8. Torsional crankshaft tests on DG #103.

This test program includes all the elements of the original Pre-operational Test Program conducted at the site for the DG units (performed prior to DG crankshaft failures), as well as the following enhancements:

a. Hydro Testing of Skid-mounted DG Systems:

This testing was not performed at the site during the

C. Proposed Shoreham DG Recovery Test Program

a. Hydro Testing of Skid-mounted DG Systems (Cont'd.)

original DG test program, but has been added to ensure the integrity of skid-mounted systems following DG disassembly and reassembly during the recovery effort.

b. Crankshaft Torsional Tests on DG #103:

This testing has been added to the DG Recovery Test Program to measure the torsional operating stresses for the replacement crankshafts to provide verification that the stresses are within acceptable limits, as predicted by FaAA. The torsional testing will be completed prior to the commencement of DG #103 pre-operational testing.

c. Crankshaft NDE Inspections:

Following 100 hours of operation at, or above, 100 percent load the diesel generator crankshafts will be inspected using NDE techniques. This testing has been added to the Recovery Test Program to verify that the replacement crankshafts are free from indications after being subjected to the critical number of fatigue cycles.[2]

d. Seven-day Continuous Run:

A seven-day continuous run[3] (168 hours) will be performed on each DG unit under the Recovery Test Program, with the following approximate breakdown of hours at various loads:

Total hours: 168

Hours @ 3900KW (overload rating)	1
Hours @ 3500KW (100% load)	4
Hours @ 2625KW (75% load)	163

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[2] The 100 hours of full load operation during the Recovery Test Program will provide the necessary number of fatigue cycles on the replacement crankshafts to ensure infinite shaft lifetime. The number of critical fatigue cycles has been stated by Failure Analysis Associates to be on the order of 10^7 cycles, as indicated in the FaAA report titled, "EDG Crankshaft Failure Investigation, Shoreham Nuclear Power Station", dated 10/31/83.

C. Proposed Shoreham DG Recovery Test Program

d. Seven-day Continuous Run (Cont'd.)

This test will conservatively simulate the actual operation of each DG unit under potential LOCA/LOOP event loadings. For any operating cycle it is assumed that each DG unit would be required to operate continuously for seven (7) days under the following LOCA/LOOP service loads:[4]

Total hours: 168

Hours @ 3881KW	0.2
Hours @ 3490KW	0.8
Hours @ 2617KW	167.0

Thus, by conservatively simulating DG operation under potential LOCA/LOOP loadings, the ability of the units to function under postulated service conditions will be verified.

e. Refueling Cycle Simulation:

The DG Recovery Test Program is designed to achieve in excess of 260 total hours of DG operation for each unit as follows:

Total hours: 260

Hours @ 3900KW (overload rating)	6
Hours @ 3500KW (100% load)	at least 94
Hours @ 2625KW (75% load)	at least 160

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[3] Under the Recovery Test Program, the seven-day continuous LOCA/LOOP run includes and exceeds the 72 hour endurance run that had been included in the original Pre-operational Test Program.

[4] It should be noted that these assumed 7-day LOCA/LOOP service loads are a conservative combination of actual service loads from the three DG units. Specifically, the portions of the simulation runs at, or above, 100 percent load, will be five times greater in duration, than the actual expected service load durations for the diesel with the highest expected load.

C. Proposed Shoreham DG Recovery Test Program

e. Refueling Cycle Simulation (Cont'd.)

In fact, the total test program is likely to result in at least 296 total hours of operation for two engines and 336.5 hours of operation for a third engine. This expanded testing requirement conservatively simulates the total expected hours of DG operation during any plant refueling cycle. The maximum expected hours of DG operation for any plant refueling cycle, and including a LOCA/LOOP event within that cycle, are:

Total hours: 260

Hours @ 3900KW (overload rating)	2.2
Hours @ 3500KW (100% load)	88.8
Hours @ ≤ 2625KW (≤ 75% load)	169.0

The expected hours of DG operation are the sum of the surveillance test hours that each DG unit would be subjected to during a refueling cycle plus the LOCA/LOOP loadings anticipated in the unlikely event of an accident during such a period.

Each diesel generator will undergo inspections at the end of each plant refueling cycle in accordance with LILCO's maintenance program. Consequently, at the conclusion of the expanded DG Recovery Test Program, the units will also be inspected and various DG maintenance procedures will be performed. Post-testing inspections will include various manufacturer's recommended maintenance inspections and any inspections recommended by the Design Review/Quality Revalidation Program. Thus, by simulating the expected DG operation during a plant refueling period, and then performing major inspections similar to those to be done after such operational periods, the capability of the DG units to function as intended between major inspections will be demonstrated.

f. Starting Tests:

The expanded Recovery Testing Program will perform 100 starts on a single DG unit, allowing no failures in 23 consecutive starts (to meet Regulatory Guide 1.108 reliability requirements), and only one failure in the other 77 starts. The 23 start test will include one hour at greater than 50 percent load, per each DG start. The other 77 starts will include approximately one-half hour at greater than

C. Proposed Shoreham DG Recovery Test Program

f. Starting Tests (Cont'd.)

50 percent load, per each DG start.

This additional 100 start requirement will demonstrate the reliability of the DG units in accordance with the guidelines of IEEE-398-1977. The following considerations support this conclusion:

1. Shoreham is committed to IEEE-398-1972 (as stated in the SNPS-1 FSAR), and this standard does not specifically require a 300 start prototype test. However, DG #101 did undergo a valid 300 start prototype qualification test at the TDI factory. This qualification test on DG #101 engine was also used to qualify other TDI R48 units.

2. The basic design of the Shoreham TDI DG units has not been changed by the crankshaft replacements and subsequent engine reassembly procedures. According to IEEE-387-1977, Section 5.4.2, major design changes (requiring prototype requalification) include: a change in the number of cylinders; a change in the BMEP or cylinder pressure; a change in the engine speed; or a change in the diesel-generator arrangement. None of these changes have been made to the rebuilt Shoreham engines. In addition, by disassembling, repairing, and reassembling the DG units in accordance with JTG approved and QA verified procedures and requirements, a high degree of confidence has been achieved that the engines will be restored to the same or higher level of operational and functional readiness as existed before the shaft failures.

3. IEEE-387-1977 requires 300 starts on a prototype engine, or a minimum of 100 starts on any single engine if the 300 starts are spread over more than one (1) prototype unit (in either case, three failures at most are allowed for the 300 starts). LILCO believes that the original prototype qualification tests for the Shoreham engines are still valid and applicable. However, an additional 100 start test on a single SNPS TDI engine (with at most one failure), will provide an increased level of confidence that the DG reliability levels required by IEEE-387-1977 have been maintained or exceeded.

C. Proposed Shoreham DG Recovery Test Program

g. Piston NDE Examination:

The DG Recovery Test Program will include a series of NDE examinations on a representative number of pistons from each engine following DG testing. This additional inspection requirement will provide assurance that the cracking problem previously experienced with the AF-type pistons has been satisfactorily resolved by installing AE-type pistons of an improved design.

VII. CONCLUSION

As has been described in detail in Sections III through VI LILCO's overall Shoreham Diesel Generator Recovery Program is a comprehensive effort incorporating an integrated combination of inspection, analysis, design review/quality examination and testing. This program is capable of providing reasonable assurance of the ability of the Shoreham Diesel Generators to perform their intended functions.

Several of the major program elements, specifically the Phase I engine disassembly/inspection/repair/reassembly and Phase II failure analysis are nearly complete, and it is expected that the remaining major program elements, Phase III design review/quality revalidation and Phase IV, engine preoperational testing, will be completed by mid-March. While final confirmation of the reliability of the Shoreham diesel generators must await completion of Shoreham's Diesel Generator Recovery Program, the following conclusions are now justified:

1. The cause of the original DG #102 crankshaft failure is understood and has been clearly identified as a design deficiency.

2. The replacement crankshafts presently installed in DG #101, DG #102 and DG #103 have been thoroughly analyzed and have been found to be adequately designed such that they will perform reliably in nuclear service.

3. Other specific engine component deficiencies which were discovered during the Shoreham Phase I engine disassembly/inspection/repair/reassembly program have been thoroughly analyzed and, by replacement either in kind or with redesigned components, as required, the potential for reoccurrence has been minimized.

4. Completion of the Design Review and Quality Revalidation (DRQR) Program, including implementation and closure of program recommendations for component inspections and/or modifications will provide additional confidence in the reliability of the Shoreham diesel generators to perform their intended function.

5. The Recovery Test Program will result in a comprehensive and substantial demonstration of the reliability of the Shoreham diesel generators.