FEB 28 1985

Docket No. 50-458

Mr. William J. Cahill, Jr.
Senior Vice President
River Bend Nuclear Group
Gulf States Utilities Company
Post Office Box 2951
Beaumont, Texas 77704
ATTN: Mr. J. E. Booker

Dear Mr. Cahill:

SUBJECT: DRAFT REVIEW AND EVALUATION OF TRANSAMERICA DELAVAL, INC., DIESEL ENGINE RELIABILITY AND OPERABILITY - RIVER BEND STATION

Enclosed, for your information, is a copy of the draft Review and Evaluation of Transamerica Delaval, Inc., Diesel Engine Reliability and Operability technical evaluation report (TER) for River Bend Station. The staff and its contractors have discussed this TER and other previously forwarded requests for additional information during a site visit the week of February 18, 1985.

Sincerely,

Original signed by:

A. Schwencer, Chief
Licensing Branch No. 2
Division of Licensing

Enclosure: As stated

cc: See next page

Distribution:
Docket File
NRC PDR
Local PDR
PRC System
NSIC
LB#2 Reading
FHylton
SStern
LDewey, OELD
ACRS (16)
EJordan
NGrace

*Previous concurrences concurred on by: AS
EW/for

*LB#2/DL/PM	*LB#2/DL	LB#2/DL/BC
SStern:lb	TMichaels	ASchwencer
02/27/85	02/27/85	02/27/85

with comments added

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

FEB 28 1985

Docket No. 50-458

Mr. William J. Cahill, Jr.
Senior Vice President
River Bend Nuclear Group
Gulf States Utilities Company
Post Office Box 2951
Beaumont, Texas 77704
ATTN: Mr. J. E. Booker

Dear Mr. Cahill:

SUBJECT: DRAFT REVIEW AND EVALUATION OF TRANSAMERICA DELAVAL, INC., DIESEL ENGINE RELIABILITY AND OPERABILITY - RIVER BEND STATION

Enclosed, for your information, is a copy of the draft Review and Evaluation of Transamerica Delaval, Inc., Diesel Engine Reliability and Operability technical evaluation report (TER) for River Bend Station. The staff and its contractors have discussed this TER and other previously forwarded requests for additional information during a site visit the week of February 18, 1985.

Sincerely,

A. Schwencer

A. Schwencer, Chief
Licensing Branch No. 2
Division of Licensing

Enclosure: As stated

cc: See next page

River Bend Station

Mr. William J. Cahill, Jr.
Senior Vice President
River Bend Nuclear Group
Gulf States Utilities Company
Post Office Box 2951
Beaumont, Texas 77704
ATTN: Mr. J. E. Booker

cc: Troy B. Conner, Jr., Esq.
Conner and Wetterhahn
1747 Pennsylvania Avenue, N. W.
Washington, D.C. 20006

Mr. William J. Reed, Jr.
Director - Nuclear Licensing
Gulf States Utilities Company
Post Office Box 2951
Beaumont, Texas 77704

H. Anne Plettinger
3456 Villa Rose Dr.
Baton Rouge, Louisiana 70806

Richard M. Troy, Jr., Esq.
Assistant Attorney General in Charge
State of Louisiana Department of Justice
234 Loyola Avenue
New Orleans, Louisiana, 70112

Dwight D. Chamberlain
Resident Inspector
Post Office Box 1051
St. Francisville, Louisiana 70775

Gretchen R. Rothschild
Louisianians for Safe Energy, Inc.
1659 Glenmore Avenue
Baton Rouge, Louisiana 70775

James W. Pierce, Jr., Esq.
P. O. Box 23571
Baton Rouge, Louisiana 70893

Ms. Linda B. Watkins/Mr. Steven Irving
Attorney at Law
355 Napoleon Street
Baton Rouge, Louisiana 70802

Mr. David Zaloudek
Nuclear Energy Division
Louisiana Department of
Environmental Quality
Post Office Box 14690
Baton Rouge, Louisiana 70898

Mr. J. David McNeill, III
William G. Davis, Esq.
Department of Justice
Attorney General's Office
7434 Perkins Road
Baton Rouge, Louisiana 70808

REVIEW AND EVALUATION OF TRANSAMERICA DELAVAL, INC., DIESEL ENGINE RELIABILITY AND OPERABILITY - RIVER BEND STATION UNIT 1

1.0 INTRODUCTION

Gulf States Utilities Company (GSU) is seeking a full power operating license for the River Bend Station (RBS) Unit 1. One matter of concern to the U.S. Nuclear Regulatory Commission (NRC) in considering the request is the operability and reliability (O/R) of the RBS 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 Shoreham Nuclear Power Station (SNPS) in August 1983 as well as by other problems reported by owners of TDI diesels in nuclear and non-nuclear service.

River Bend Station Unit 1 is served by two TDI model DSR-48 diesel engines, designated standby diesel (SD) generator 1A and 1B. These SDs 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 GSU specifies the emergency load as a maximum of 3130 kW under design basis accident conditions coincident with loss of cooling accident (LOCA).

In response to concerns about the operability/reliability (O/R) of TDI engines, GSU has undertaken a comprehensive analysis of all major engine components, has replaced a number of components, and performed engine tests to ensure their O/R.

The Pacific Northwest Laboratory (PNL) has been requested by NRC to review and evaluate GSU's overall efforts to ensure the engines' reliable performance. This technical evaluation report (TER) documents PNL's review and expresses the resulting conclusions and recommendations regarding the capability of the RBS 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 GSU 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 the tests, inspections, and component upgrades undertaken by GSU to prepare the engines for nuclear service.

* Section 4.0 comprises a review and evaluation of GSU's resolution of known problems in 16 engine components identified by the Owners' Group (OG) through a review of TDI engine operating history. Pertinent aspects of the OG and GSU's efforts on other components of concern in the RBS SDs are also included in this section.

* Section 5.0 provides PNL's review of GSU proposed maintenance and surveillance (M/S) program.

* Section 6.0 presents PNL's overall conclusions and recommendations regarding the suitability of the two TDI diesel engines to perform their intended function as emergency standby power sources for the RBS.

1.2 APPLICABILITY OF CONCLUSIONS

To derive the conclusions presented in this report, PNL reviewed the basic documents supplied by GSU, participated in various meetings with GSU and NRC, and observed components of the engines as disassembled for inspection. 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).

GSU has submitted to the NRC revisions for the River Bend Station Final Safety Analysis Report (FSAR). The purpose of these revisions is to establish a qualified load for each of the diesel generators, to provide revised positions on Regulatory Guides (RG) 1.9 and 1.108. These revisions identify 3130 kW as the maximum "qualified load" considered necessary for an engine to support its designated share of the emergency power needs of RBS. Considering the FSAR amendment, 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 TDI engines at RBS for nuclear service are contingent upon final action by NRC on the following PNL recommendations: GSU 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 RBS Phase 2 reviews is anticipated early in 1985. In the opinion of PNL, the reviews of all RBS 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 River Bend.

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 River Bend Station, Unit 1 in September 1984, to observe SD 1A in its reassembled state and SD 1B and its components inspection and preparation for reassembly. PNL met with GSU staff and management on this occasion, as well as in connection with TDI Owners' Group meetings.

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

- R. E. Dodge, PNL project staff
- J. F. Nesbitt, PNL project staff
- B. J. Kirkwood, Covenant Engineering Company, diesel consultant to PNL
- P. J. Louzecky, Engineering Applications Corporation, 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, D. A. Dingee, W. W. Laity, and F. R. Zaloudek; and consultants S. H. Bush, A. J. Henriksen, N. Jaffrey, N. N. Rivera, A. Sarsten, J. V. Webber, L. Wechsler, and A. Wendel. 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 Gulf States Utilities Company to resolve the problems identified in the TDI diesel engines.

2.1 OWNERS' GROUP PROGRAM PLAN

Thirteen nuclear utilities that own generators driven by TDI-manufactured diesel engines have established an Owners' Group (OG) 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 (OGPP) 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 4.0 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 GSU's current request for licensing of River Bend Station-Unit 1 are:

1. Preoperational testing should be performed as discussed in Section 2.3.2 of PNL-5161.
2. The engines should be inspected per Section 2.3.2.1 of PNL-5161 to ensure that the components are sound.

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

2.2 RIVER BEND STATION PLAN

The basic approach followed by GSU in the qualification of their TDI diesels was to disassemble, inspect, upgrade and rebuild each engine and then confirm reliability by testing and post-test inspections. GSU deemed this approach feasible and compatible with the product improvement recommendations of TDI, the testing and inspections performed by other TDI diesel owners, and the engine component reviews conducted by the OG. 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 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 with their engines to late 1983.
- a letter dated May 7, 1984, from Lee Duck (TDI) to John R. Hamilton (GSU) "River Bend Station Unit 1 Diesel Generators S/N 74039/40, P.O. 244.700." This letter formally advised the liner dimensional improvements for job site changes.
- a letter dated May 8, 1984, from Lee Duck (TDI) to John R. Hamilton (GSU) "River Bend Station Unit 1 Diesel Generators S/N 74039/40, P.O. 244.700." This letter transmitted additional liner dimensional improvements.
- a letter dated May 16, 1984, from R. W. Helmick (GSU) to C. L. Ray (TDI OG), "File No. 244.700 Standby Diesel Generator Systems River Bend Station - Unit 1" (RBG-17,838). This letter provides instructions for work of cylinder liners.
- a GSU report dated July 19, 1984 River Bend Station - Unit 1, Docket No. 50-458 (RBG-18,244). This report addresses the program plans for evaluating and testing the standby diesel generators.

- 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.

- GSU report dated October 16, 1984, River Bend Station - Unit 1 Docket No. 50-458 (RBG-19,210). This report presents a revised plan for evaluating and testing the Division I and II SDs and data on the inspection and testing performed to date.

- 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 November 29, 1984 from J. E. Booker (GSU) to Harold R. Denton (NRC) "River Bend Station - Unit 1 Docket No. 50-458" that presents proposed revisions to RBS FSAR.

- an OG report dated December 1984, TDI Diesel Generator Design Review and Quality Revalidation Report - Gulf States Utilities River Bend Station. This 4-volume report documents the DR/QR effort performed on the RBS TDI engines, what was carried over from a lead engine review (Shoreham) and the results of these efforts.

- a LILCO report dated December 3, 1984, TDI Emergency Diesel Generator 103 -Cycle Confirmatory Test/Inspection Report, Shoreham Nuclear Power Station Unit 1 - This report provides LILCO's tests and inspection results for the 10^7-cycle confirmatory test of the EDG 103.

- a GSU report dated December 21, 1984 River Bend Station - Unit 1 Docket No. 50-458 (RBG-19,762) that presents a revised plan for evaluating and testing the Division I and II SDs as well as data on the inspections and testing performed to date.

In addition to reviewing these documents, PNL visited the RBS site to observe engine inspections and to perform a preliminary review of the GSU procedures for component inspection. PNL and its consultants also gained perspective on certain TDI components through participation in TDI engine disassembly and inspections at other nuclear facilities.

3.0 GSU's TESTS, INSPECTIONS, AND COMPONENT UPGRADES

The RBS SDs have been subjected to testing/inspection programs and, as a result, have undergone component upgrades. These programs consist of 1) shop qualification tests, 2) onsite preservice tests and inspections including DR/QR activities, 3) confirmatory testing, 4) post test inspections, and 5) preoperational tests.

A chronological discussion of these tests, inspections, and component upgrades is presented in Sections 3.1 through 3.5. The results and conclusions reported by GSU are documented in Section 3.6. PNL's evaluation of GSU's program is presented in Section 3.7.

3.1 SHOP QUALIFICATION TESTS

According to GSU, the test program for the River Bend SDs began with shop tests at the TDI manufacturing facilities in Oakland, California. These shop tests were performed to verify the operability of the SD units, including the interrelated functional capability of engine components. The shop tests accomplished on both engines included:

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

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

3.2 PRESERVICE TESTS AND INSPECTIONS

The TDI engines were delivered to the RBS in mid 1981. After the installations were completed, GSU initiated a preservice test/inspection effort to verify that the installations were complete and correct and that the manufactured quality of the engines complied with the design requirements.

GSU has reported that as-built installation verification inspections were performed. These included inspections by TDI and major subvendors to TDI, including Electric Products (electric generator), RTE Delta (switchgear), Elliot (turbocharger), and Woodward (governor). In addition, GSU inspected other components based on industry experience.

To verify that auxiliary systems, interlocks, controls and alarms operate in accordance to specifications, GSU has reported that tests were conducted on these components and systems. This included system flushing, hydrostatic testing, relief valve testing for setpoint and seal leakage, initial startup, operation, and performance testing. Also vibration testing of pumps and compressors, performance testing of air dryers, and individual checkout of all electrical components and instrument loops were performed.

Next GSU proceeded on a preservice disassembly inspection program with the purpose to verify the manufactured quality of engine components in support of the OG DR/QR activities. This inspection encompassed 169 components of the TDI DSR-48 diesel engines at RBS Unit 1.

When disassembled for the DR/QR activities, the SD engines at River Bend had been operated for the times and at the loads shown below:

Engine Loads and Hours

Load	Engine Number 1A	1B
zero	1	0
25%	14	5
50%	21	0
75%	11	1
100%	76	31
110%	1	3
Total hours (all loads)	124	40
Number of starts (approx.)	35	35
Test hours at TDI (approx.)	50	50

Details as to the results and conclusions of the RBS DR/QR effort were presented by the OG in the TDI Generator Design Review and Quality Revalidation Report, December 1984.

Pertinent aspects of the preservice tests and inspections including the DR/QR inspections as applicable to generic or crucial engine components are summarized in Section 4.0 of this report.

3.3 CONFIRMATORY TESTS

The purpose of this activity was to verify engine reliability following engine inspection and rebuilding. Tables 3.1 and 3.2 identify the confirmatory tests performed on Engines 1A and 1B, respectively. The testing program did not comply with the requirements of Regulatory Guide 1.108. The number of start tests is less than specified in Regulatory Guide 1.108, Section C.2.a(9), and the overload test described in Regulatory Guide 1.108, Section C.2.a(3) was not conducted.

With respect to the start tests, the program of ten modified starts and two fast starts was considered an adequate demonstration of starting reliability by GSU. Also, GSU did not consider the overload test to be necessary, because the River Bend Station diesels will not be operated above the nameplate rating of 3,500 kW.

TABLE 3.1 Confirmatory Testing Standby Diesel - 1A

Test Objective	Acceptance Criteria	Results
1) Manufacturer recommended test in accordance with TDI SIM #99		
a) initial start, slow idle, no load, (15 min.)	Operating parameters in the normal range Satisfactory crankcase inspection	Satisfactory
b) 450 rpm, no load, (30 min.)	Adjust governor Overspeed trip satisfactory Verify generator differential shutdown Operating parameters in normal range Satisfactory crankcase inspection	Satisfactory
c) Generator phasing	Satisfactory generator electrical checks Set satisfactory crankshaft inspection	Satisfactory
d) 1 hour at 25% rated load	Operating parameters in normal range	Satisfactory
e) 1 hour at 50% rated load	Operating parameters in normal range	Satisfactory
f) 2 hours at 75% rated load	Operating parameters in normal range	Satisfactory
g) return to 25% rated load	Operating parameters in normal range Verify parameters consistent with Step (d)	Satisfactory
h) 4 hours at 100% load (3500 kW), followed by internal engine inspection, turbocharger vibration, bearing cooling & lubrication test	Operating parameters in normal range Crankcase inspection Crankcase web deflector Piston skirt wear Cyliner liner wear Gear set wear Valves & rocker arms wear & clearances Cold compression pressure Generator winding temperature	Satisfactory

DRAFT

TABLE 3.1 (contd.)

Test Objective	Acceptance Criteria	Results
2) Engine timing & adustments. 24 hours at 100% load (power duration may vary).	Smooth operation Cylinder firing pressures in balance Operating parameters in normal range Crankcase web deflection	Satisfactory
3) Crankcase torsional vibration test	Crankshaft stresses with allowable values	Satisfactory
4) Engine performance test. Demonstrate that each diesel operates within design parameters at 100% rated load, & demonstrate starting reliability.	Operating parameters in normal range. All start attempts successful.	
a) 24 hours at 100 % rated load		Satisfactory
b) Ten modified starts (Note 1) to the load required by a loss of offsite power (approx. 75% of rated load) & run for a minimum of 1 hour.		Satisfactory
c) Two fast starts (Note 2) to 100% of rated load, & run for a minimum of 4 hours.		Satisfactory

Notes:

1. A modified start is defined as a start including a prelube period as recommended by the manufacturer and a 3 to 5 minute loading to the specified load level. Modified starts may be conducted with the engine at operating temperature.

2. Fast starts are simulated "black starts" on simulation of an ESF signal with the engine on ready standby status.

TABLE 3.2 Confirmatory Testing Standby Diesel - 1B

Test Objective	Acceptance Criteria	Results
1) Manufacturer recommended test in accordance with TDI SIM #99		
a) Initial start, slow idle, No load, (15 minutes)	Operating parameters in the normal range Satisfactory crankcase inspection	Satisfactory
b) 450 rmp, no load, (30 minutes)	Adjust governor Overspeed trip satisfactory Verify generator differential shutdown Operating parameters in normal range Satisfactory crankcase inspection	Satisfactory
c) Generator phasing	Satisfactory generator electrical shock Set electrical portion of governor	Satisfactory
d) 1 hour at 25% rated load	Operating parameters in normal range	Satisfactory
e) 1 hour at 50% rated load	Operating parameters in normal range	Satisfactory
f) 2 hours at 75% rated load	Operating parameters in normal range	Satisfactory
g) Return to 25% rated load	Operating parameters in normal range Verify parameters consistent with step (d)	Satisfactory
h) 4 hours at 100% load (3500 kW), followed by internal engine inspection, turbocharger vibration, bearing cooling & lubrication test	Operating parameters in normal range Crankcase inspection Crankshaft web deflection Piston skirt wear Cylinder liner wear Gear set wear Valves & rocker arms wear & clearances Cold compression pressure Generator wind temperature	Satisfactory

DRAFT

TABLE 3.2 (contd.)

Test Objective	Acceptance Criteria	Results
2) Engine timing & adustments. 24 hours at 100% load (power duration may vary).	Smooth operation Cylinder firing pressures in balance Operating parameters in normal range Crankcase web deflection	Satisfactory
3) Engine performance test. Demonstrate that each diesel operates within design parameters at 100% rated load, & demonstrate starting reliability.	Operating parameters in normal range. All start attempts successful.	Satisfactory
a) 24 hours at 100% rated load		Satisfactory
b) Ten modified starts (Note 1) to the load required by a loss of offsite power (approx. 75% of rated load) & run for a minimum of 1 hour.		Satisfactory
c) Two fast starts (Note 2) to 100% of rated load, & run for a minimum of 4 hours.		Satisfactory

Notes:

1. A modified start is defined as a start including a prelube period as recommended by the manufacturer and a 3 to 5 minute loading to the specified load level. Modified starts may be conducted with the engine at operating temperature.

2. Fast starts are simulated "black starts" on simulation of an ESF signal with the engine on ready standby status).

3.4 POST-TEST INSPECTIONS

The post-test inspection program was intended to provide a thorough engine inspection without major engine disassembly. Major disassembly was not considered necessary by GSU because of the thoroughness of the preservice inspection and design review program. The purpose of this inspection was to look for potential latent problems not discovered in earlier inspections and tests and verify readiness for further operation. Critical components were inspected by removing access covers and by oil analysis. The oil analysis was the method used to indicate abnormal wear of bushings and bearings and the elemental analysis was the means to identify the component in distress. Visual inspections were relied on to verify nominal wear, absence of discoloration, from overheating, water leakage, and absence of wear products (metal particles) were considered as the means to identify distress conditions in combination with oil analysis. A summary of the engine component groups and post-test inspection results are listed in Table 3.3 (Engine 1A) and 3.4 (Engine 1B).

TABLE 3.3 Post-Test Inspection Summary Standby Diesel - 1A

Part Name	Part Number	Results
Tappets & Guides-Intake & Exhaust	03-345A	Satisfactory
Tappets & Guides-Fuel Tappet Assy	03-345B	Satisfactory
Camshaft Assembly	03-350A	Satisfactory
Camshaft-Supports, Bolting & Gear	03-350C	Satisfactory
Idler Gear Assy Crank to Pump Gear	03-355A	Satisfactory
Cylinder Hd-Bolting & Gaskets	03-360C	Satisfactory
Overspeed Trip - Coupling	03-410C	Satisfactory
Governor Linkage	03-413	Satisfactory
Lube Oil Sump Tank	03-540B	Satisfactory

TABLE 3.4 Post-Test Inspection Summary Standby Diesel - 1B

Part Name	Part Number	Results
Tappets & Guides-Intake & Exhaust	03-345A	Satisfactory
Tappets & Guides-Fuel Tappet Assy	03-345B	Satisfactory
Camshaft Assembly	03-350A	Satisfactory
Camshaft-Supports, Bolting & Gear	03-350C	Satisfactory
Idler Gear Assy Crank to Pump Gear	03-355A	Satisfactory
Idler Gear Assembly	03-355B	Satisfactory
Air Start Valve	03-359	Satisfactory
Cylinder Hd-Bolting & Gaskets	03-360C	Satisfactory
Governor Drive Coupling, Pins & Keys	03-402B	Satisfactory
Governor Linkage	03-413	Satisfactory
Lube Oil Sump Tank	03-540B	Satisfactory

3.5 PREOPERATIONAL TESTS

The purpose or objectives of these tests were:

- to demonstrate the reliability of the standby diesel generator power sources,
- to assure the system is capable of providing standby electrical power during normal and simulated accident conditions,
- to demonstrate the system's ability to pick-up standby loads during simulated accident conditions,
- to demonstrate the operability of the SD auxiliary systems (i.e., fuel oil transfer, starting air supply, etc.)

The types and kinds of tests performed and the overall results were as shown in Table 3.5.

TABLE 3.5 Preoperational Tests Per RBS FSAR

Tests	Results 1A	Results 1B
a) Diesel starting and trip sequence		
b) Auxiliary systems operate per specifications		
c) Interlocks, controls and alarms operate per specifications		
d) • Proper manual and automatic start and operation		
• Voltage and frequency attained within time limits		
e) • Proper response and operation for DBA loading sequence		
• Voltage and frequency attained within time limits		

TABLE 3.5 (contd.)

Tests	Results 1A	Results 1B
f) • Proper operation during load shedding, sequencing, and rejection		
• Loss of largest single load - maintain voltage and frequency		
• Complete loss of load without overspeed		
g) • Full load for 24 hours		
• Voltage and frequency maintained		
• Cooling system operation within limits		
h) Reperform tests (d) and (c) above within 5 minutes after completion of 24-hour load test (g)		
i) • Ability to synchronize with offsite power while loaded		
• Transfer load from diesel to offsite		
• Isolate SD generator and put on standby status		
j) Fuel comsumption rate		
k) Reliability of SD per RG 1.108 (modified)		
l) Capability to supply power within time limits during periodic surveillance testing		
m) Reliability and independence of redundent SD through simultaneous starting during testing per Section 14.2.12.1.44 of FSAR		
n) • Ability to start with minimum air pressure		
• Number of starts from air pressure system without recharging.		

3.6 REPORTED RESULTS AND CONCLUSION

Few problems occured during the operation of the RBS TDI diesel generators. However, it must be recognized that the number of operating hours on either of the two SD has not reached that experienced at a number of other plants. Problems and areas of concern were found on a few engine components during the disassembly and inspection programs.

The TDI Owners' Group has formally reported the results of their DR/QR effort in a four-volume report entitled TDI Diesel Generator Design Review and Quality Revalidation Report - Gulf States Utilities River Bend Station, dated December 1984. Results of tests and inspections performed on the SD at RBS have been reported by GSU in a series of letter reports included in Section 2.0 of this TER. Results and details of the findings at RBS are covered in Section 4.0 on a component basis. Therefore, they are not repeated here.

The conclusions drawn by GSU from the DR/QR effort and the onsite test and inspection activities are:

- As the result of the TDI OG efforts, the problems of the TDI diesel generators are now understood.
- Solutions to these problems have been implemented on the TDI diesels at River Bend.
- The TDI diesel generators at RBS are acceptable for their intended safety related function and they will provide reliable standby power for River Bend Station.

3.7 PNL EVALUATION

In evaluating GSU's engine tests, inspections, and component upgrades, PNL reviewed all available documentation of the tests, inspection results, and engine operating history on the RBS TDI engines. Based on this review, PNL concludes that the inspection program was adequate to identify problems with engine components and that tests were adequate to verify 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. With the exception of the River Bend crankshaft, PNL finds that a sufficient number of hours has been accumulated on other DSR-48 engines to meet the criterion of exposing key engine components subject to high-cycle fatigue stresses to 10^7 cycles at or above the qualified load of the RBS engines.

4.0 COMPONENT PROBLEM IDENTIFICATION AND RESOLUTION

This section documents PNL's review of GSU'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 OG through a review of the operating histories of TDI engines in nuclear and non-nuclear service. Other crucial engine components found to be defective or that were replaced at RBS are also reviewed in this section.

Each 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 OG and GSU. This description is usually followed by PNL's evaluation and conclusion(s).

PNL's conclusions generally incorporate, without stating, the assumed commitment by GSU to the adaptations 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 form the NRC final review of the OGPP concerning these components. The conclusions also reflect PNL's finding, based on a sampling examination of GSU's procedures for dispositioning component inspection findings, that these procedures are adequate with respect to both documentation and engineering consideration.

4.1 ENGINE BASE AND BEARING CAPS

Part No. 03-305-A, C, 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, and the cracks in EDG 103 resulted from improper engine disassembly procedures. Cracks in both U.S. Coast Guard cutters' engine base saddles were considered to be the result of undertorquing.

4.1.4 GSU Status

A LP inspection of the main bearing saddle area between #5 and #6 cylinders (2 surfaces) was performed. The results were satisfactory. In addition to no cracks, there were no indications of excessive wear, erosion or corrosion. A visual inspection of the mating areas on the bearing cap was performed and no indication of fretting was observed.

A visual inspection of the base including the area adjacent to the nut pockets of each bearing saddle for cracks and the #5 main bearing cap mating surfaces for evidence of fretting at each refueling outage is recommended by the OG in the RBS DR/QR report.

4.1.5 PNL Evaluation and Conclusion

PNL believes that the origin of the cracks observed in the Shoreham EDGs was properly diagnosed and that the analysis conducted is appropriate to conclude that similar cracks should not start or propagate in the TDI engines at River Bend.

On the basis of the inspections, diagnostics, and actions taken by GSU and the OG, PNL concludes that the engine base and bearing caps in SD 1A and 1B are acceptable for their intended service, subject to a confirmatory inspection to be performed according to the recommendations noted in the DR/QR report for River Bend.

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 been found 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 Electrical 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 hole-to-stud hole cracks - A stud hole-to-stud hole crack is also oriented vertically, and extends between two cylinder head stud holes of adjacent cylinders. In nuclear applications, these 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 stud holes 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 hole cracks. Furthermore, the original stud hole-to-stud hole crack between cylinders No. 4 and 5 had grown, as documented in the FaAA report referenced above. (The orignial EDG 103 block at SNPS was replaced.)

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.

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 Shoreham's 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 Shoreham 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 hole-to-stud hole 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 (Widmanstaetten graphite) 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 Shoreham EDG 103 block were cut out and subjected to full metallurgical tests of materials, including fractography and metallography, and visual inspection of cracks in couterbore to stud hole, stud hole to shud 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 hole-to-stud hole 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 hole-to-stud hole 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 (the replacement EDG 103 block is a typical gray cast iron, Class 45). Metallurgical tests and photomicrographs demonstrated that Shoreham 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 at Shoreham 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 Shoreham 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 GSU Status

Based on recommendations from TDI and under TDI field service supervision, the cylinder liner support lips (landings) were ground flat with a special tool. Also uniform and larger than original radius was formed on the inside diameter of each of the liner support lips for both of the SDs at River Bend.

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

SD Engine 1A

- Measurements were taken as recorded for all cylinder block liner landings.

- All cylinder block tops were visually inspected in the region adjacent to and between cylinders after 124 hours of operation. No ligament cracks, no stud hole-to-stud hole cracks or stud hole-to-end cracks were found.

- Liquid penetrant test was performed along the top landing surface, fillet radius, and vertical face adjacent to the landing surface for all cylinder block liner landings. The reported results were satisfactory.

- A magnetic particle test was performed on the cylinder head mating surface on top of cylinder blocks 5, 7, and 8 in the areas between stud hole and liner and between adjacent clyinder stud holes. The results were satisfactory.

- No linear indications were found at the stud holes extending into the threads via a visual inspection.

SD Engine 1B

- A dimensional check was made around the cylinder liner and all cylinder block liner landings. The results were ________.

- A ________ ________ test was performed along the top landing surface, fillet radius, and vertical face adjacent to the landing surface for cylinders ________ ________ ______. The results were ______.

- A magnetic particle test was performed on the cylinder head mating surfaces on top of cylinder blocks ______ ______ ____ in the areas between stud holes and liner, and between adjacent cylinder stud holes. The results were ______.

- All cylinder block tops were visually inspected in the region adjacent to and between cylinders after 40 hours of operation. No ligament cracks, no stud hole-to-stud hole cracks or stud hole-to-end cracks were found.

- A metallurgical/microstructural analysis of the cylinder block material was made. This examination indicated the block 1B microstructure was representative of typical gray cast iron, Class 40.

Based on the DR/QR review, and with implementations of routine inspections, the OG concluded that cylinder blocks 1A and 1B at RBS are acceptable for their intended use.

4.2.5 PNL Evaluation and Conclusions

PNL's review of the cylinder blocks at River Bend included consideration of 1) the FaAA design review of the cylinder blocks, 2) test and inspection reports for the GSU engines, 3) the River Bend DR/QR report, and 4) meetings with and plant visits to TDI, TDI engine owners and the OG.

4.2.5.1 Camshaft Gallery Cracks

Evidence available from recent tests and metallurgical investigations strongly suggest that the known camshaft gallery cracks at Shoreham 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 Shoreham's EDG 103 demonstrate that the areas where the camshaft gallery cracks occur are subject to compressive stresses during engine startup, operation, and shutdown. Athough PNL concurs that compressive loads introduced during engine assembly and maintained during operation 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.

During a meeting in September 1984 at River Bend, GSU personnel indicated a visual inspection had been made on the cam shaft gallery areas in October 1983 and no cracks were found. No specifics on this inspection have been provided. GSU also indicated their intention to inspect the cam shaft gallery areas after the initial 24-hour 100% load operational tests. If these inspections have not been performed, adequate and detailed inspections should be done on all of the cam shaft gallery areas of both SD 1A and 1B at River Bend.

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 from SNPS. 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.

Like many other installations, circumferential cracks have not been experienced in the TDI cylinder blocks at RBS. Also the rework performed by GSU on the cylinder lines support lips as well as on the liners proudness height and diameter will reduce the stresses induced in the liner bore of the cylinder block.

4.2.5.3 Ligament Cracks

The inspections performed on the cylinder blocks by GSU, albeit somewhat limited in extent, have not revealed any indications of ligament cracks in either SD 1A or 1B.

PNL believes the analysis presented in the River Bend DR/QR report on the subject cracks is factual and supports the OG recommendation that a material microstructure evaluation be performed on the 1A block at RBS.

4.2.5.4 Stud Hole-to-Stud Hole Cracks

Stud hole-to-stud hole 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 hole-to-stud hole 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 should be much less than that required to produce a stud hole-to-stud hole 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 hole-to-stud hole cracks.

Based on the FaAA analysis of the cracks present in the SNPS blocks and on the GSU inspection results showing the absence of cracks between stud holes of adjacent cylinders, PNL concluded that the cylinder blocks currently installed in SD 1A and 1B are suitable for continued use. This conclusion is subject to verification that no cracks have developed between stud holes of adjacent cylinders in either SD 1A or 1B following each operation of that 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.

In consideration of the above cited analyses and inspections and PNL's examinations of one engine's blocks, PNL concludes that the blocks installed on both SD 1A and 1B are acceptable for the intended service, subject to monitoring for cracks.

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 check).

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 Shoreham crankshafts that had 11-inch diameter crankpins with the 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 OG 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) a 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 report FaAA-84-3-16):

- The TDI calculations of stresses using single orders are appropriate and show that the stresses in the replacment 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 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 program, Dr. Chen concluded that the replacment crankshafts comply with DEMA standard practices at 3500 kW and 3900 kW.

4.3.4 <u>GSU Status</u>

Dimensionally, the crankshafts in the TDI engines at RBS are the same as the Shoreham replacement crankshafts (i.e., 12" diameter crankpins with 3/4-inch fillets). The crankshafts in SD 1A and 1B were made by Elwood City Forge Corporation using a forged slab, hot-twist fabrication process.

During the preservice inspection and the OG DR/QR program on the two TDI diesel engines at RBS, a series of analyses, inspections and NDEs were performed on the crankshafts in SD 1A and 1B.

The following inspections and results were reported by GSU on the crankshafts in SD 1A and 1B:

- Performed visual inspection of eight crankpin journal surfaces for indications of stress. No signs of distress were evident.
- Performed eddy-current inspections of seven crankpin journals. No relevant indications were evident.
- Performed liquid penetrant examinations on eight crankpin journals fillets. No relevant indications were evident.
- Performed fluorescent LP of crankpin and main bearing oil hole entrance regions. The examination of 14 entrance regions and seven holes showed no relevant indications.
- Dental impressions were made on crankpin and main bearing oil holes to a depth of 3-inches (9 on SD 1A and 12 on SD 1B). Some showed tool marks with a depth of 6-mils. This was deemed acceptable as it was within the OG acceptance criteria.
- Performed visual inspection of entrance regions on crankpin and main bearing oil holes (9 on SD 1A and 12 on SD 1B). All showed a polished surface finish.

Tests and results as reported by the OG for the crankshafts in SD 1A and 1B in the River Bend DR/QR that appear to be additional ones not reported by GSU are:

- Performed eddy-current and LP tests on main journals 7, 8, and 9 oil holes. Results were satisfactory.
- Performed eddy-current and LP tests on crankpin journals 5, 6, 7 and 9 oil holes. Results were satisfactory.

As a part of the OG DR/QR program, the adequacy of the RBS crankshafts for their intended use was analyzed and evaluated. As reported by OG:

- A modal superposition analysis of the crankshaft was performed to calculate the nominal shear stresses at each crank pin and main journal location. The pressure loading was obtained from the dynamic test at Shoreham Nuclear Power Station. The modal superposition analysis determined the maximum amplitude of torsional stress to be 7357 psi between cylinder numbers 5 and 6 for a load at 3500 kW. At 3500 kW, the nominal stresses were found not to satisfy the requirements of DEMA, which are less than 5000 psi for a single order, and less than 7000 psi for combined orders.

- The results of the torsiograph test performed on SD 1A (Engine No. 74039) were reviewed, and the natural frequencies and free-end amplitudes of vibration were found to be in agreement with the modal superposition analysis. It was determined that the nominal stresses during steady state conditions at 3130 kW load would satisfy DEMA requirements.

- The TDI Holzer calculations were reviewed by comparing their results with results obtained from the modal superposition analysis. The TDI Holzer calculations were found to be accurate and in agreement with the vibrational analysis.

- The stress levels in the main journal oil holes and crankpin fillets were compared with the endurance limit. The material certification reports for the crankshaft material in engine Nos. 74039 and No. 74040 are within the original design specifications. The factor of safety against fatigue failure in the main journal oil holes and crankpin fillets at 3500 kW load was found to be 1.36 and 1.29, respectively, based on a minimum ultimate tensile strength of 94 ksi for engine serial No. 74039.

Based on the DR/QR review, the OG concluded that the crankshafts in engine serial Nos. 74039 and 74040 are acceptable for their intended function at River Bend provided the engines are run at no greater than a 3130 kW load.

4.3.5 PNL Evaluation and Conclusions

Although the torsiograph tests performed at River Bend apparently were not conducted for underspeed and overspeed conditions at that power level, the results at rated speed provides a level of assurance that actual torisonal stresses at 3130 kW are in compliance with DEMA standards over the limited frequency range and associated speed range to which the SDs at RBS are controlled to.

Subject to the following recommendations on surveillance, PNL concludes that the crankshafts in SD 1A and 1B are acceptable for their intended service, provided that they are not operated at loads in excess of _______ kW.

Because of the limited number of operational hours on these engines the following survillance type activities are recommended:

- 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 SD 1A and 1B 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 SD crankshafts.

- In subsequent refueling outages, two of the three most heavily loaded crankpin journals in each of the two crankshafts should be examined as noted above. The main bearing journal between them should also be examined in this manner.

4.4 IDLER GEAR

Part No. 03-355-B

4.4.1 Component Function

The primary purpose or function of the idler gear is to transmit torque from the crankshaft to the camshaft.

4.4.2 Component History

As a result of the DR/QR reviews, the importance of maintaining the prescribed torque on the idler gear-to-hub bolt has been emphasized.

4.4.3 Component Status

GSU has installed new idler gear locknuts as a TDI recommended product improvement.

4.5 CONNECTING RODS

Part No. 03-340-A

Owners' Group Report FaAA-84-3-13

4.5.1 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.

4.5.2 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 engines in nuclear service.

4.5.3 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 bucking 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.

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.

4.5.4 GSU Status

A number of tests, inspections and NDEs were conducted on the connecting rods at RBS during the preservice inspection and the DR/QR program. Those reported by GSU for both SD 1A and 1B include:

(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.

- Performed a LP inspection of all wrist pin bushings inside diameter surfaces. No indications or surface flaws were found.

- Performed a visual inspection of all upper connecting rod bushing eye oil passages (without removal of bushing). No surface flaws were found.

- Performed eddy current inspection on all connecting rod oil holes. No relevant indications or cracks were found.

Those reported by GSU for SD 1A included:

- Performed material comparitor tests on rods 1, 2 and 3. Results were satisfactory.

- Performed superficial hardness tests on rods 2, 3 and 8. The results were satisfactory.

The OG DR/QR program for the subject components did not include a design review because all EDG CTS experience had already been addressed and the acceptability of the DSR-48 connecting rods was established by the Shoreham DR/QR. However, they did recommend that GSU verify the torque loads on all connecting rod bolts are in accordance with TDI's latest recommended values.

In the Shoreham DR/QR, the OG concluded that the connecting rod assembly is acceptable for its intended purpose.

4.5.5 <u>PNL Evaluation and Conclusion</u>

The PNL reviewers evaluated the Owners' Group report and supplementary information on inline connecting rods. They found that the OG 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 OG were judged to be appropriate.

Both known and postulated cracks in the subject components have been included in the OG analyses. PNL concurs with the OG 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 <u>not</u> acceptable.

PNL reviewed the inspections performed by GSU. Based on these evaluations and reviews, PNL concurs that the connecting rod bolt torque should be verified and concludes that the connecting rods and bushings installed in the River Bend engines are acceptable for the intended service.

4.6 CONNECTING ROD BEARING SHELLS

Part No. 03-340-B

Owners' Group Report FaAA-84-3-1

4.6.1 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 contamination of the oil with water 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.

4.6.2 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 OG criterion for subsurface voids. No other connecting rod bearing shell incidents have been reported on any DSR-4 engines.

4.6.3 Owners' Group Status

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

- journal orbit analysis to determine the pressure distribution in the hydrodynamic oil 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.

4.6.4 GSU Status

Following recommendations and instructions issued by FaAA and approved by the OG, GSU performed various examinations on all 16 bearing shells plus the spares for each engine that included:

- All 40 bearing shells were visually inspected. Only some minor pitting and scratches were noted and the shells were considered to be satisfactory in this respect.
- All 40 of the bearing shells were dimensionally checked. Dimensions were found to be in accordance with the TDI manual.
- All 40 bearing shells were subjected to LP test. No indications were evident.
- Performed radiographic test on all upper and lower connecting rod bearing shells.

The disposition of bearing shells was as follows:

Six of the 16 shells from Engine 1A were rejected.

One shell from the 16 of Engine 1B were rejected.

All of the 8 spare shells were satisfactory.

Of the 33 shells which were found acceptable, 6 bearing shells were dispositioned as suitable for use as lower shells and 27 halves were suitable for either lower or upper shell service.

- After the radiograph inspection, the 33 remaining shells were subjected to an eddy current inspection. No relevant indications were evident.

Based on the review on the bearing shells, the OG recommended that their maintenance be based on the Shoreham DR/QR report as follows:

- Inspect and measure the connecting rod bearing shells to verify lube oil maintenance which affects wear rate. The visual and dimensional inspection of the bearing shells should be conducted at the fuel outage which precedes 500 hours of operation by at least the sum of hours of operation in a LOOP/LOCA event plus the expected hours of operation between outages.

- Perform an x-ray examination on all replacement bearing shells using a procedure with sufficient resolution to implement recommendations for acceptance criteria as documented in the TDI OG connecting rod bearing shell Phase I Report.

The DR/QR program of the OG did not include a design review of the subject components at RBS as they felt the DR/QR efforts on Shoreham and Comanche Peak established the acceptability of bearing shells and the River Bend engine and its operating parameters are essentially the same as Shoreham.

The OG concluded that the connecting rod bearing shells are acceptable for the intended design purpose in the Shoreham DR/QR.

4.6.5 PNL Evaluation and Conclusion

Based on review of the FaAA analyses and on GSU and OG 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.

4.7 PISTON SKIRTS

Part No. 03-341-A

Owners' Group Report FaAA-84-2-14

4.7.1 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 from the skirt 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.

4.7.2 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 the engines in three facilities contained AN skirts. The RBS engines were originally furnished with type AN piston skirts.

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.

4.7.3 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.

4.7.4 GSU Status

A review of piston skirts was included as a part of the OG DR/QR effort as well as in GSU preservice inspections and examinations:

- Performed LP inspection of replacement AE piston skirts in the stud and pin boss areas. No indications were evident.
- Performed visual inspection of AE skirts outside diameter for scuffing and inside surfaces for pitting on SD 1B. No defects were observed.
- Performed visual inspection of SD 1A skirts and crowns outside diameter for scuffing and combustion bowl crown for pitting. Observed no defects.

The OG DR/QR efforts on the subject component did not include a design review because they considered all applicable items had been covered in the Shoreham/Comanche Peak DR/QR reports or the Phase I report on pistons. However, additional inspections on pistons were recommended for GSU's performance.

In the Shoreham DR/QR, it was concluded by the OG that AE type piston skirts were acceptable for the intended design function.

4.7.5 PNL Evaluation and Conclusions

PNL's evaluation of the GSU 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 OG 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 it 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 or River Bend. 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 Shoreham piston skirts following the 746 hour test on EDG 103. Based on 1) the PNL examination of AE piston skirts, 2) the suitability of the AE design as indicated by the above-described experience, 3) the current serviceability of the piston skirts now installed in the Shoreham engines, and 4) the NDT inspection of the AE piston skirts at RBS, PNL concluded that the type AE pistons in the GSU SDs are acceptable for the intended service.

4.8 PISTON RINGS

Part No. 03-341-B

4.8.1 Component Function

These components perform the multi-function of sealing the combustion chamber from the crankcase, allowing heat flow between piston and cylinder liner as well as controlling lube oil consumption and blow by.

4.8.2 Component Status

GSU has installed improved piston rings to reduce the likelihood of liner scuffing during break-in (Muskegan).

4.8.3 PNL Evaluation and Conclusion

Considering test and inspection results on MPR rings at Shoreham, PNL concludes that a change to this type of ring will add to the serviceability of the SD at RBS.

4.9 PISTON-PIN ASSEMBLY

Part No. 03-341-C

4.9.1 Component Function

It is the function of the piston pin to transmit the loads generated by cylinder firing pressures from the piston to the connecting rod as well as permit relative motion between these two components.

4.9.2 Component Status

Due to the presence of unsatisfactory surface defects, seven piston pins from SD 1A and 1B were replaced at RBS. Also for increased reliability, the OG recommended that the piston pin spiral lock ring retainers be replaced with Waldes snap ring retainers at the first refueling outage. GSU has indicated that retainer rings have been exchanged.

4.9.3 PNL Evaluation and Conclusion

Based on the defects observed in the subject pin during the site visit, PNL concurs with GSU's replacement of the defective pins. The change in retainer rings should enhance the functions of the subject component.

4.10 CYLINDER LINERS

Part No. 03-315-C

Owners' Group Report FaAA-84-5-4

4.10.1 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.

4.10.2 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.

4.10.3 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 OG that this could increase hoop stresses in the block, which might lead to block cracks. TDI has approved reducing this fit in the cylinder liner.

4.10.4 GSU Status

As part of GSU's preservice activities and the OG DR/QR program, various efforts have been conducted on cylinder liners at RBS. These include the following:

- Measured bore, length, height, outside diameters and shoulder height on each liner.
- Performed visual inspections of I.D., and top O.D. in contact with cylinder block on all liners.
- One liner with chipped surface was removed from service.
- Two liners found to be out-of-round were reworked back to within specifications and stocked as spares.

- Machined "proudness" thickness or height of liners as required to reduce the protrusion above the cylinder block to a value of 0.001 to 0.002-inches.

- Machined O.D. of liner top flanges as required to reduce liner-to-liner interference fit and stresses.

- All liners were deglazed by crosshatched honing with a Sunnen hone.

- After machining, a dimension check was made on bore, length, O.D. and shoulder height on all of the liners from SD 1A and on liners 4, 5 and 6 of engine 1B.

- After honing, a visual inspection was made over the zone of piston travel for all of the SD 1A's liners and on liners 4, 5 and 6 of Engine 1B.

- Performed a visual inspection on the outside pilot diameter of all liners for SD 1A.

The RBS DR/QR program did not include a design review of this component as all applicable EDG CTS experience was considered in lead engine DR/QR reports (Shoreham/Comanche Peak). For both of these reports, the OG concluded the cylinder liners were acceptable for their intended use. .

4.10.5 PNL Evaluation and Conclusion

At Shoreham, PNL representatives viewed cylinder liners during at least three site visits. The liners that had been in service were glazed and showed some hard rubbing spots. This appearance was considered to be typical of the TDI liners.

PNL representatives also had the opportunity to visually inspect liners removed from the Catawba engines after extended operation. Most showed minor scuffing which was considered to be the result of normal wear and acceptable for additional service. Also, PNL representatives viewed the liners from River Bend's 1B engine during a plant visit. Two of these had some evidence of minor scuffing (streaking).

PNL concludes that the liners in the River Bend SDs are acceptable for their intended service. This conclusion is based upon:

- a review of GSU's actions for both SDs with respect to inspection, remachining, and replacement (as needed)

- PNL's examination of the liners at Shoreham and Catawba after many hours of testing.

- the very good service record for these components.

4.11 CYLINDER HEADS

Part No. 03-360-A

Owners' Group Report FaAA-84-15-12

4.11.1 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.

4.11.2 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 OG 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 and 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.

4.11.3 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.

4.11.4 GSU Status

During GSU's preservice activities and the OG DR/QR program, the following were performed on the cylinder heads at RBS:

- Prior to engine operation at RBS, all of the heads from both SDs were removed, fire deck thickness was measured by UT, all were found to be substandard and were replaced with new cylinder heads. All replacement heads were inspected in accordance to OG criteria and all have a fire deck thickness greater than 0.500-inches between valve seats.

- LP inspections were performed on the exhaust and intake valve seating surfaces for all heads (64 surfaces). Four of sixteen original heads were rejected due to observed cracks in the valve seating surfaces. (Heads 1A, 1B, 5B and 7A and these were included in the heads replaced for other fallacies.)

- MT inspections were performed outside of the valve seat areas on the firing decks of 32 heads. No indications of weld repairs were noted.

Based on a review of the Phase I report and lead engine DR/QR reports, the OG concluded that a design review was not required for cylinder heads at RBS.

Both of the lead engine DR/QR reports (Shoreham/Comanche Peak) included the OG conclusion that the cylinder heads are acceptable for their intended use or function.

4.11.5 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 in nuclear service, and the results of the nondestructive tests performed as part of the component revalidation program and following the 746-hour confirmatory tests of Shoreham's EDG 103. PNL concluded that the cylinder heads currently installed on the two River Bend 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.

4.12 CYLINDER HEAD STUDS

Part No. 03-315-E

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

4.12.1 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 great 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.

4.12.2 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.

4.12.3 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.

4.12.4 GSU Status

The River Bend engines are equipped with the necked-down cylinder head stud design.

In accordance with the latest TDI and OG recommendations the bottom two threads were machined off these studs. This change places the stud threads deeper into the cylinder block and should help distribute the stud load.

Studs from each engine were random sampled and visually inspected for signs of distress, two of the 32 studs from Engine 1A showed nicked threads which were cleaned up. The other studs from both engines were considered satisfactory in their in-situ condition.

A hardness test and material compositor tests were made on four studs from Engine 1A. The results were satisfactory.

Upon installation, the studs in the block for both engines were torqued to 100 ft. lbs. and verified.

4.12.5 PNL Evaluation and Conclusion

PNL concludes that the modified studs now installed on the River Bend SDs 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.
- GSU's action of inspecting and torquing the studs is deemed acceptable.

4.13 PUSH RODS

Part Nos. 03-390-C & D

Owners' Group Report FaAA-84-3-17

4.13.1 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.

4.13.2 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.

4.13.3 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. Nuclear owners have run these versions in actual service beyond 10^7 cycles with no adverse results.

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.

4.13.4 GSU Status

During a recent engine disassembly and inspection program all of the intake and exhaust push rods and push rod connectors were visually examined and it was verified that all were of the friction weld design.

LP tests were performed on the main and connector push rods for cylinder 5A, 3B and 7B. No relevant indications were observed. Also the connector push rods from cylinders 1A, 6A and 7A were penetrant tested with satisfactory results.

4.13.5 PNL Evaluation and Conclusion

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

4.14 ROCKER ARM CAPSCREWS AND DRIVE STUDS

Part No. 03-390-G

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

4.14.1 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. The drive studs plug the rocker lever oil holes.

4.14.2 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.

4.14.3 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.

4.14.4 GSU Status

A magnetic partical inspection for linear indications in the thread root area was made on all the rocker arm capscrews for both engines. No indications were observed.

All drive studs were visually inspected on both engines. The drive studs were found to be properly installed and in good condition.

A material comparitor test was run on four rocker arm shaft capscrews from Engine 1A. The results were satisfactory.

The proper rocker arm shaft bolt torque was verified in accordance with the TDI manual.

4.14.5 PNL Evaluation and Conclusion

PNL concludes that the rocker arm capscrews and drive studs in the River Bend engines are acceptable for the intended service. This conclusion is based on 1) a review of the OG analysis, 2) the favorable checks of materials and design as-installed, 3) the confirmation of installation preloading, and 4) GSU's commitment to perform periodic preload checks.

4.15 TURBOCHARGERS

Part No. MP 020 (Model BCO-90G)

4.15.1 Component Function

The turbochargers on the GSU 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 immedate.

4.15.2 Component Problem History

Various problems have occurred in the turbochargers on TDI 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.

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.

4.15.3 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 reported nozzle ring component failures 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.

4.15.4 GSU Status

Prior to initiating any field testing on the two River Bend engines the turbocharger thrust bearings were inspected and found to be worn. It was concluded that the cause was insufficient pre-lubrication. The bearings were replaced and a pre-lube system installed on the two engines before the start of field test operation. The drip flow system was maintained as a safety measure for emergency starts.

In addition, a visual inspection of the turbocharger thrust bearing for wear and cracking was made on both engines. The bearing thrust end clearance was checked and the 8 bolts holding the nozzle ring were inspected and their torque checked on both SD.

The nozzle ring for the turbocharger on Engine 1A was LP inspected and no cracks in the nozzle ring blades or housing were observed. Also there was not an excessive number of dents in the turbo nozzle ring blades.

4.15.5 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 GSU and the OG. PNL also has examined the prelube system at other plants. Based on these reviews, PNL concludes that the prelube system now installed on the diesels at River Bend 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. 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 suggests that each engine is likely to experience very few, if any, "dry" starts in a given operating cycle.

PNL believes that GSU should implement all of the OG modifications, maintenance and inspection recommendations included in the RBS DR/QR report to add to the turbocharger reliability and performance.

PNL notes that the engines at River Bend will be run at a BMEP of about 200 psi. This engine rating is 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, PNL concludes that the turbochargers on River Bend Engines 1A and 1B are suitable for their intended service.

4.16 JACKET WATER PUMP

Part No. 03-425-A

Emergency Diesel Generator Engine Driven Jacket Water Pump Design Review (SWEC April 1984).

4.16.1 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.

4.16.2 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.

4.16.3 Owners' Group Status

Stone & Webster has investigated the jacket water pumps as installed on the TDI inline and vee engines. They reviewed the River Bend jacket water pumps from the standpoints of mechanical design, material suitability, and hydraulic performance. SWEC recommended that the key on the impeller and shaft be eliminated, and that the impeller be made from ductile iron to the same specifications as the Shoreham impeller.

4.16.4 GSU Status

New water jacket pumps as recommended by the OG Phase I study have been ordered.

4.16.5 PNL Evaluation and Conclusion

The calculations made by Stone & Webster were reviewed and it is concurred that replacing the present pumps with a pump having ductile iron impellers and no keyways is definitely desirable. Based on the Stone & Webster calculations, the new replacement pumps are acceptable for the intended service.

The torque values recommended by the OG for tightening the impeller and gear nuts seem reasonable. If, however, the cotter pin holes do not line up, the nut washer or nut should be reduced in thickness until they do match.

4.17 FUEL INJECTION NOZZLE AND TIP

Part No. 03-365-B

4.17.1 Component Function

The fuel injection nozzle assemblies in use at River Bend are Bendix, Type H4L-40C. Fuel oil under high pressure flows to these assemblies. At the proper pressure, the nozzle opens and fuel sprays into the cylinder through the spray tips which forms the desired spray pattern.

4.17.2 Component Status

GSU has noted their intension of replacing all of the original supplied fuel injector tips having a 140° spray angle with TDIs current production standard tips having a 135° spray angle. This step is to be taken to eliminate fuel spray on cylinder liner walls and to reduce liner wear.

4.17.3 PNL Evaluation and Conclusion

The replacement of 140° tips with 135° tips at RBS will be identical to a change made by others (i.e., LILCO). Based on component inspection results at Shoreham, PNL concludes that this change certainly hasn't detracted from component life and supports its implementation at RBS.

4.18 HIGH-PRESSURE FUEL OIL TUBING

Part No. 03-365-C

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

4.18.1 Component Function

The high-pressure fuel oil tubing carries the fuel oil from the cam-driven fuel injection pumps on the side of the engine 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 and engine load reduction.

4.18.2 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.

4.18.3 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.

4.18.4 GSU Status

The fuel injection tubing (lines) from both engines were eddy current inspected.

Four of the fuel injection tube assemblies from Engine 1A were rejected while the tubing from Engine 1B showed no relevant indications and was considered satisfactory.

The fuel lines were covered with shrouds.

4.18.5 PNL Evaluation and Conclusion

PNL concurs with the OG analysis of the subject tubings. On the basis of 1) the eddy current tests performed to date, 2) the shrouding of the lines, and 3) GSU's commitment to install improved tubing that has been given an auto frettage treatment to improve the fatigue resistance and to check fittings monthly for leakage, PNL concludes that the high-pressure tubing on the RBS engines is acceptable for the intended service. PNL recommends that checks for oil leaks be done only while the engine is not running in order to avoid personnel injury from possible high-pressure spray.

4.19 AIR STARTING VALVE CAPSCREWS

Part No. 03-359

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

4.19.1 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.

4.19.2 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.

4.19.3 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.

4.19.4 GSU Status

The valves and components were inspected and the results are as follows:

- The seating of the valves and valve rings was found to be adequate for both engines except for one starting valve on Engine 1A. This valve had a defective valve seat which was replaced.
- The gasket seal of the valve to cylinder head was verified to be copper and was satisfactory for both engines.
- The locking pin was installed in each lock nut for both engines and was satisfactory.
- Two valve hold down capscrews were checked dimensionally from both engines and complied with TDI requirements.
- The capscrew hold down torque was verified both cold and hot on all cylinders for both engines and was found satisfactory.

4.19.5 PNL Evaluation and Conclusion

The inspections and actions taken by GSU to eliminate potential problems are judged to be adequate to prevent failures. PNL therefore concludes that, with the continued use of GSU installation procedures to control torque of bolts, studs, and screws to specified ranges, these components will not present future problems on the River Bend engines. Thus, PNL concludes these components on SD 1A and 1B are acceptable for their intended service.

4.20 ENGINE-MOUNTED ELECTRICAL CABLE

Part No. 03-688-B

Owners' Group Report SWEC Report of July 1984

4.20.1 Component Function

These cables/wire and terminations are used for connecting auxiliary Class I skid-mounted devices such the Woodward governor/actuator, the Air-Pax magnetic pick-up, and the starting air solenoid. Inappropriate wire/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.

4.20.2 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.

4.20.3 Owners' Group Status

Analyses of the subject wiring, and of the recommended replacements, were conducted by SWEC, both generically and specifically for RBS. All functional attributes of the wiring and terminations were deemed serviceable for the intended service.

4.20.4 GSU Status

The DR/QR report on the subject wiring at River Bend indicates that a visual inspection was made as part of the Phase I effort and no further action was taken or indicated.

4.20.5 PNL Evaluation and Conclusion

Based on the review of the actions taken by the OG, PNL concludes that the subject terminations and cables on SD 1A and 1B are acceptable for their intended service at River Bend.

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.

Gulf States Utilities Company (GSU) has developed a M/S plan for the River Bend Station (RBS). This plan has been presented in Appendix II of the River Bend TDI Diesel Generator Design Review/Quality Revalidation Report (December 1984). However, Appendix II appears to be only marginally complete; it makes repeated references to TDI Instruction Manual volumes and to OG "lead engine DR/QR report(s)" for further details.

The RBS DR/QR lists more maintenance items than will be discussed in this report. Those which are not itemized herein are judged to be beyond the intended scope of this effort, which is focused on components and systems critical to SD operability and reliability and/or with significant failure histories. However, where special attention has been deemed appropriate PNL has added items not listed in the DR/QR. 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 the requisite reliability and operability. However, this report is not intended to supplant Gulf States' M/S plan for RBS, but rather to augment and clarify it.

This section documents PNL's review and evaluation of Gulf States' M/S plan in light of the judgement and recommendations of recognized experts in diesel engine technology. Comments on three aspects of a comprehensive M/S program are presented in the tables and evaluations which follow. These three aspects are:

- key maintenance items
- operational surveillance
- standby surveillance

5.1 KEY MAINTENANCE ITEMS

Components classified as key maintenance items encompass certain engine structural and moving parts. Parts with a failure history, even if they are static and/or nonstructural, are included. Gulf States' proposed M/S plan for these components, as discernible from Appendix II of the RBS DR/QR, is summarized in Table 5.1. Included therein are PNL's comments; these are then amplified (as warranted) in the following subsections.

Where an engine component is not listed in Table 5.1, PNL concurs with the GSU proposed maintenance plan thereon, insofar as it has been expressed in the OG DR/QR report for RBS (or superceded by other GSU proposals). Where an item

TABLE 5.1 Key Maintenance Items for River Bend Station

Item	Gulf States' Proposal	PNL Recommendation
Engine base, incl. bearing caps, bolts and foundation (03-305-A, 305-C, 03-550)	Visual inspection of base, under good lighting, each outage. Particular attention to nut pockets. Solvent clean mating base/cap surfaces after any disassembly. Visual inspection of #5 bearing cap mating surface EDG 1B for fretting (no frequency given).	Concur with GSU. Inspect #5 bearing cap each outage.
	Visual inspection of foundation grout/soleplate bond each outage. Check bolt torque.	Concur with GSU
Cylinder block (03-315-A)	Perform an inspection per DR/QR Report: blocktop at #1A following any operation over 50% load (i.e., over 1750 kW); #1B (and eventually 1A) inspections by formula per FaAA SP-84-6-12(g). No details re: cam shaft gallery.	No details provided by GSU on FaAA SP-84-6-12(g). PNL recommends: a) interim schedule on #1A to be per GSU; b) ongoing schedule on #1A and 1B as per GSU; plus, at first refueling, each unit, c) total inspection for stud hole-to-stud hole and stud hole-to-end cracks; d) remove two heads and LP inspect for ligament and stud hole-to-stud hole cracks; e) remove one cam gallery coverplate and LP inspect for camshaft bearing saddle sturcture cracks; and f) at first two times liners are removed, LP and/or UT inspect for circumferential cracks (see also 5.1.1.1).

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

TABLE 5.1 (contd)

Item	Gulf States' Proposal	PNL Recommendation
Crankshaft (03-310-A)	Measure crankshaft web deflection each refueling outage.	Concur with GSU. To be taken hot and cold.
	Measure crank journal diameters each engine overhaul (equal probably greater than 10 years).	In addition, at first refueling outage LP inspect fillets at crankpin journals 5, 6, & 7, and main journals in between, each engine. At same time inspect oil holes in some journals visually, by fluorescent LP, and by ET. In subsequent refueling outages, reduce to two crankpin and one main journals (see also 5.1.1.2).
Main bearings, incl. thrust bearing ring (03-310-B, 310-C)	Main bearings: inspect, measure thickness; check for misalignment; at first and succeeding alternate refueling outages.	PNL concurs.
	Thrust bearing: check clearance each outage. Visual ring inspection alternate outages.	PNL concurs
Connecting rods; Rod eye bushings (03-340-A)	Inspect and measure connecting rods at 5-year intervals. No plan re: bushings.	PNL concurs. PNL also recommends that preload on connecting rod bolts be checked at each refueling outage. Rod eye bushings should be inspected (each time piston skirts are removed and inspected) for evidence of cracking, "orange peeling" (see also 5.1.1.5).

TABLE 5.1 (contd)

Item	Gulf States' Proposal	PNL Recommendation
Connecting rod bearing shells (03-340-B)	Inspect and measure bearing shells, at refueling outage preceding 500-hours of operation. Perform x-ray examination of all new replacement shells.	PNL concurs. PNL also recommends that a "bump test" for bearing wear be performed at each refueling outage.
Pistons; rings: piston pins (03-341-A,-B,-C)	Inspect and measure skirt and pin and rings each five years. Inspect liners for evidence of ring wear each refueling outage.	PNL concurs
Cylinder liners (03-315-C)	Visual inspection for wear each refueling outage. (Boroscope inspection accepted if heads are not concurrently removed.)	PNL concurs. PNL also recommends that two liners from each engine be measured at each disassembly as means of tracking wear rates.
Cylinder heads (03-360-A)	Visually inspect all cylinder heads each 5 years. Record compression and firing pressures at each outage. Inspect "injector parts" for water leakage monthly. Roll over engine "at appropriate intervals". Inspect valves and valve seats each 5 years.	PNL concurs, with following recommended modifications to the M/S plan: • LP inspect firedeck between exhaust valve seats, and all valve seats, for two adjacent heads at each refueling outage. Select heads such that all are inspected through four refueling outages. • Air-roll before planned starts, and 4 to 8 hours and 4 to 8 to 24 hours after each operation shutdown (see also 5.1.1.4.).

TABLE 5.1 (contd)

Item	Gulf States' Proposal	PNL Recommendation
Cylinder head studs (03-315-E) Rocker arm cap-screws air start valve capscrews	None proposed by GSU	Check preload on 25% of head studs and rocker arm capscrews, and 100% of air start valve capscrews at each refueling outage (see also 5.1.1.5).
Cylinder head sub-covers (rocker arm boxes) (03-362-A)	LP inspection of pedestal tops and machined side (connector pushrod side only) whenever rocker arm shafts are removed.	OG DR/QR for RBS recommends 5-year schedule. PNL concurs with GSU on a 5-year maximum interval.
Push rods (03-390-C,-D)	None proposed by GSU.	PNL concurs, in light of analysis and experience with function-welded design.
Gear train (03-350-C & 355-A,B)	Visually inspect cam gear, idler gears and crankshaft-to-lube oil pump gear each refueling outage. Measure gear backlash at alternate outages.	PNL concurs with GSU, but also recommends inspection of crankshaft to JW-pump gear at same intervals.
Camshaft and bearings (03-350-A,B)	Visual inspection of all cam lobe surfaces each refueling outage. Inspect and measure bearing shells every five years.	PNL concurs. This is particularly important because comparator tests apparently were not run in pre-service DR/QR examination, nor hardener tests on IB cam lobes, all as required to comply with OG plan.

TABLE 5.1 (contd)

Item	Gulf States' Proposal	PNL Recommendation
Governor (03-415-A,-B,-C) and linkage (03-413)	Verify governor control settings monthly. Replace governor drive flex element each outage. Refill oil system; refurbish actuator; inspect servo "O" rings and gaskets; clean and inspect heat exchanger--at five year intervals. Evaluate governor performance (interval not stated). Inspect linkage monthly and lock linkage bolts positively as needed following adjustment.	PNL concurs. Linkage problems are a commmon cause of improper governor/fuel pump performance and PNL recommends rigorous implementation of all manufacturers' instructions.
Overspeed governor (03-410-A-D)	Each refueling outage, check trip setting, shafts and couplings, and magnetic plugs.	PNL concurs. Since the DR/QR report by OG indicates settings have not been calibrated and verified. PNL recommends this be required prior to licensing.
Turbocharger (MD-017)	At each refueling outage, measure vibration, clean impeller and diffuser, measure rotor end play and perform spectrochemical engine oil analysis. At five year intervals, disassemble, inspect and refurbish, including visual and "blue check" inspections of thrust bearings. (NB: thrust bearing inspection is also to be done after each 40 automatic fast starts.)	PNL concurs but also recommends: • inspection of thrust bearing should be after each 40 fast starts and each 100 manual (pre-lube) starts (inclusive of the fast starts in that interval). • spectrochemical analysis should be conducted each 20 fast starts. • inspect nozzle ring, vanes, and rotor blades each refueling outage (or at the time of bearing inspection nearest thereto. (See also 5.1.1.6.) GSU should complete all pre-operational inspections outlined in OG DR/QR.

is listed but no subsection commentary is provided PNL's comments in Table 5.1 are definitive. Where components have been added to the listing of key maintenance items, which were not listed by GSU, it is because in PNL's view, they are important to SD reliability and operability. Their inclusion in an M/S plan is considered consistent with good engine maintenance practice.

5.1.1.1 Cylinder Block

Following any period of operation of SD 1A at greater than 50% load, GSU proposed to perform visual inspections of those portions of the block top that are acccessible between cylinder heads. The purpose of these inspections is to verify the continued absence of detectable cracks between stud holes of adjacent cylinders. 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.

Inspections on EDG 1B are to be performed per formula under FaAA SP-84-6-12(g).

The OG and GSU conducted thorough inspections of block tops of both units in accordance with OG criteria. No indications were found in liner landings, bore-to-stud hole ligaments or between stud holes. (No inspection of camshaft gallery areas is reported.) To the date of October 31, 1984 SD 1A had operated 124 hours, including one hour at 3900 kW and 76 hours at 3500 kW. Similarly, SD 1B had operated 40 hours with 3 hours at 3900 kW and 31 hours at 3500 kW. (The BMEP at 3500 kW is 225 psi; at 3900 kW it is 207.5 psig.) It is not clear whether inspections were made prior to or after these operating hours.

Both block-top and camshaft gallery cracks have been found at SNPS on EDGs essentially identical to RBS SDs. The SNPS units have operated more at 3500 kW and 3900 kW (by a factor of roughly 2X) than those at RBS and some of those with knowledge that cracks already existed. The OG/FaAA report conclusions would indicate that absent any initial block-top cracks, and with materials as designed, the blocks should suffice rated-load operation and not need special inspections.

PNL Recommendations

PNL recommends the following maintenance/inspection patterns.

- Block-Top

  IA - until material is confirmed as equivalent to the grey cast iron of IB, conduct stud hole-to-stud hole and stud hole-to-end inspections (under intense light) following each operation above 50% load.

Both - at first refueling outage conduct visual examination for stud hole-to-stud hole and stud hole-to-end cracks all areas. Remove two heads each unit (as also required by 5.1 1.4 re = heads), and LP inspect for ligament and stud hole-to-stud hole cracks. Absent any deleterious indications (or equivalent indications at Shoreham), no further special inspections needed.

- Cylinder liner landing - An LP and/or UT inspection of the cylinder liner landing should be performed the first two times liners are removed from either of the two 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.

  Because GSU has remachined the liner bore and counterbore areas to reduce fit interference and liner proudness it is not likely that circumferential cracks will develop and a single stage of checking should be sufficient verification.

- Cam gallery - apparently GSU did not make inspection for cam gallery cracks. Such are known to exist in the name model EDGs at SNPS, but have been evaluated as benign (though they are to be monitored). PNL recommends that at the first refueling outage GSU remove one cam gallery cover plate on each engine and inspect by LP for cracks in the accessible camshaft bearing saddle structures. Absent any such cracks no further special attention should be required. If cracks are detected, their length and depth should be recorded and then be monitored again at the next refueling outage, so as to determine growth. If the monitored Shoreham cracks are reported to be growing, the RBS SD should be monitored on a more rigorous schedule and/or procedure, as determined by NRC.

5.1.1.2 Crankshaft

GSU 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 are provided in Section _____.

PNL Recommendations

PNL concurs that GSU take crankshaft deflection readings at every refueling outage. GSU's M/S plan does not prescribe hot and cold deflection measurements or the timing of such measurements. 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. This recommendation reflects the limited margin in crankshaft capability determined by the OG. These would involve three crankpin and two main journals, each engine, at first refueling, and two crankpin and one main journal each outage thereafter. Fillets and oil holes should be inspected.

5.1.1.3 Connecting Rods

GSU 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. Although such a preload check was part of the OG RBS DR/QR Task Description for preoperational inspection of both units, they reported there was no evidence it was done.

PNL also believes that checking rod-eye bushings is good practice in light of evidence in TDI EDG history of some with substantial interdendritic cracks and/or apparent hot spots (evidenced by discoloration). This can be done at any time the pistons are removed and disassembled. GUS has addressed no M/S plans on this component.

PNL Recommendations

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

5.1.1.4 Cylinder Heads

GSU proposes to visually inspect all eight cylinder heads each 5 years. 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 Gulf States' 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, PNL also recommends removal of two adjacent heads and visual and LP inspection of the firedeck at each refueling outage. The valve seats and 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.

5.1.1.5 Cylinder Head Studs, Rocker Arm Capscrews, Air Start Valve Capscrews

GSU 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 OG 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.

5.1.1.6 Turbochargers

GSU proposes to measure turbocharger rotor endplay each outage, to visually inspect the thrust bearing after 40 nonprelubed starts, and to perform a spectrochemical engine oil analysis each 5 years. PNL concurs, with certain qualifications, and also recommends that rotor float be measured and stationary nozzle rings including vanes and capscrews by inspected at each refueling outage.

A recurring problem in the turbochargers on TDI engines at 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, but not assuredly relieved the problem.

The turbochargers on some EDGs have also experienced failed nozzle ring capscrews and lost nozzle ring vanes.

PNL Recommendations

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