Docket No. 50-440 50-441 Official Exh. No. 5

In the matter of PNPP

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PNL-5411

Technical Evaluation Report

A Review of the Operability and Reliability of Transamerica Delaval, Inc., Diesel Generators at Perry Nuclear Power Plant Unit 1

February 1985

Prepared for
the U.S. Nuclear Regulatory Commission
Division of Licensing
Office of Nuclear Reactor Regulation
under Contract DE-AC06-76RLO 1830
NRC FIN B2963

Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
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PNL-5411

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Project Title: Assessment of Diesel Engine Reliability/Operability

NRC Lead Engineer: C. H. Berlinger

Pacific Northwest Laboratory
Richland, Washington 99352

PACIFIC NORTHWEST LABORATORY

PROJECT APPROVALS

W. W. Laity Date Feb. 22, 1985

W. W. Laity, Project Manager
Pacific Northwest Laboratory

WDRichmond Date 2-22-85

W. D. Richmond, Chairman
Senior Review Panel
Pacific Northwest Laboratory

FOREWORD

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

CONTENTS

ABBREVIATIONS

ASLB	Atomic Safety and Licensing Board
BMEP	brake mean effective pressure
CEI	Cleveland Electric Illuminating Company
DEMA	Diesel Engine Manufacturers Association
DR/QR	design review/quality revalidation
EDG, EDGs	emergency diesel generator(s)
ET	eddy current
FaAA	Failure Analysis Associates
FSAR	final safety analysis report
LOCA	loss of coolant accident
LOOP	loss of offsite power
LP	liquid penetrant
MP	magnetic particle
M/S	maintenance/surveillance
NRC	U.S. Nuclear Regulatory Commission
OCRE	Ohio Citizens for Responsible Energy
OG	TDI Diesel Generator Owners' Group
PNL	Pacific Northwest Laboratory
PNPP	Perry Nuclear Power Plant
SNPS	Shoreham Nuclear Power Station
SWEC	Stone & Webster Engineering Corporation
SwRI	Southwest Research Institute
TDI	Transmerica Delaval, Inc.
UT	ultrasonic testing

A REVIEW OF THE OPERABILITY AND RELIABILITY
OF TRANSAMERICA DELAVAL, INC., DIESEL GENERATORS
AT PERRY NUCLEAR POWER PLANT UNIT 1

1.0 INTRODUCTION

The Cleveland Electric Illuminating Company (CEI) is seeking an operating license for its Perry Nuclear Power Plant (PNPP) Unit 1 from the U.S. Nuclear Regulatory Commission (NRC). This action is opposed by the Ohio Citizens for Responsible Energy (OCRE) in a contention submitted to the Atomic Safety and Licensing Board (ASLB). OCRE questions the reliability of emergency diesel generators (EDGs) supplied by Transamerica Delaval, Inc. (TDI), based on problems with TDI engine components at the Shoreham Nuclear Power Station (SNPS) and at other nuclear and non-nuclear installations.

The Pacific Northwest Laboratory (PNL) is providing technical support to the NRC staff in addressing questions regarding the adequacy of TDI diesel generators as emergency power sources for safety-related nuclear systems. The scope of PNL's effort encompasses reviews of TDI engine-related information submitted to NRC by the TDI Diesel Generator Owners' Group (OG) and by individual licensees, and reviews of disassemblies and inspections of TDI engines at nuclear power plants.

At the request of NRC, PNL performed a brief technical review of the TDI engines installed at PNPP. This report documents the PNL review, which was conducted over the period from February 11 through February 14, 1985. Participants in the review included D. A. Dingee of the PNL staff and three diesel engine consultants who are under contract to PNL: A. J. Henriksen, B. J. Kirkwood, and P. J. Louzecky.

This review is not intended to provide definitive final evaluations of the operability and reliability of the TDI engines at PNPP. Rather, the intent is to provide NRC with preliminary technical guidance regarding the status of the TDI engines at PNPP relative to similar TDI engines at other nuclear power plants.

1.1 REVIEW SCOPE

The following documents relevant to the TDI engines at PNPP were addressed in this review:

- reports prepared by the TDI Diesel Generator Owners' Group on the 16 components with known problems addressed in Phase I of the Owners' Group Program
- the TDI Diesel Generator Design Review and Quality Revalidation (DR/QR) Report dated December 1984, which was prepared for the Perry Nuclear Power Plant by the TDI Diesel Generator Owners' Group
- PNPP inspection reports supporting the DR/QR report
- the Perry Nuclear Power Plant TDI Diesel Generator Program Plan submitted as an enclosure to a letter dated January 17, 1985, from M. R. Edelman of CEI to B. J. Youngblood of NRC
- an affidavit dated January 28, 1985, of J. C. Kammeyer of Stone & Webster Engineering Corporation (SWEC), describing the formation and structure of the TDI Diesel Generator Owners' Group and the principal elements of the Owners' Group Program Plan
- an affidavit dated January 31, 1985, of C. D. Wood III of Southwest Research Institute (SwRI) describing SwRI's review and critique of Owners' Group reports and related materials on the 16 components addressed in Phase I of the Owners' Group Program, from the standpoint of their applicability to the TDI engines at PNPP
- an affidavit dated February 1, 1985, of E. C. Christiansen of CEI, describing implementation of the Owners' Group Program Plan at PNPP
- an affidavit dated February 1, 1985, of G. R. Leidich of CEI, describing TDI diesel engine testing and inspection at PNPP.

This review was performed in the context of PNL's overall effort in providing technical support to the NRC staff. Participants in this review have been involved in all aspects of this effort, including reviews of Owners' Group reports on resolution of known problems (Phase I of the Owners' Group Program Plan), reviews currently in progress of DR/QR reports for several nuclear power

plants (Phase II of the Owners' Group Program Plan), and reviews of disassemblies and inspections of TDI engines comparable to those installed at PNPP. These reviewers have also participated in discussions of engine-related issues with representatives of the Owners' Group and its consultants (Stone & Webster Engineering Corporation and Failure Analysis Associates). As part of this review, the PNL representatives have met with PNPP technical staff to discuss the status of PNPP's TDI engines, and have reviewed supporting technical information provided by PNPP. At the time this report was prepared, however, the PNL representatives had not visited PNPP.

1.2 REPORT ORGANIZATION

Following a summary of background information on the TDI engines at PNPP (Section 2 of this report), the overall conclusions drawn by PNL from this review are presented (Section 3). Next, the following topics are addressed as they pertain to PNPP's engines: components with known problems addressed by the Owners' Group (Section 4), design review/quality revalidation of engine components (Section 5), surveillance and maintenance plans (Section 6), and engine testing and inspection (Section 7).

2.0 BACKGROUND

Two standby emergency diesel generators manufactured by TDI are installed at PNPP Unit 1 to carry emergency service electrical loads. Each engine is a TDI model DSRV-16-4, with 16 cylinders arranged in two banks in a V-type engine block. The engines are coupled to General Electric generators. Each engine-generator set is rated for continuous operation at 7000 kW and 8750 kVA at a 0.8 power factor, with a short-term overload rating of 7700 kW. As reported by Edelman (January 17, 1985), the maximum load on the EDGs predicted in the PNPP Final Safety Analysis Report (FSAR) would be 5634 kW for a loss of offsite power (LOOP) and 4668 kW for a LOOP combined with a loss of coolant accident (LOCA). These predicted loads have not yet been verified by measurements.

The TDI diesel generators at PNPP are the same model as those installed in several other nuclear power plants (e.g., Catawba, Grand Gulf and Comanche Peak). PNL project staff and consultants have reviewed disassemblies and inspections of the latter engines, and submitted technical evaluation reports on them to NRC in connection with licensing actions. The results of these previous reviews were considered in the conclusions and recommendations documented in this report.

The EDGs were delivered to PNPP in 1978 and installed in 1981. At the time of this review, preoperational tests of the EDGs at PNPP had not yet been performed. However, pre-shipment tests performed at TDI included operation of the Division 1 engine for about 12 hours and the Division 2 engine for 10 hours at varying loads to 110% rated load.

Pursuant to recommendations of the Owners' Group, the Division 1 and 2 engines were disassembled and inspected in late 1984 and early 1985 as part of the design review and quality revalidation effort. The DR/QR encompassed 171 components. CEI reported only two notable concerns. One was that two rocker arms on the Division 1 engine and eight on Division 2 had come into contact with a swivel pad, indenting the rocker arm forgings. CEI concluded that this problem was caused by improper adjustment at the factory. The second

was that the eddy-current inspection of oil holes in the crankshaft revealed excessive machining marks. According to CEI, this was resolved by polishing the affected area.

CEI requested Southwest Research Institute, San Antonio, Texas, to conduct an independent review of the 16 components addressed in Phase I of the Owners' Group Program Plan. The SwRI review is summarized in the affidavit of Wood (January 31, 1985). SwRI concluded that the 16 components in the PNPP engines are of satisfactory design and will perform their intended functions. Further, SwRI concluded that the TDI engines at PNPP will perform reliably as emergency power sources for safety-related systems. The SwRI conclusions are dependent upon CEI implementation of all relevant OG and SwRI recommendations.

3.0 CONCLUSIONS AND RECOMMENDATIONS

This section presents the overall conclusions reached by the PNL representatives who participated in the review of the TDI engines at PNPP Unit 1. These conclusions depend, in part, on a comparison of the PNPP engines with TDI engines of the same model at the Comanche Peak Steam Electric Station. The latter engines are the most appropriate basis for comparison for two reasons: they were the "lead" 16-cylinder engines for the design review/quality revalidation performed as Phase 2 of the Owners' Group Program, and they were previously reviewed by PNL in support of the Comanche Peak licensing schedule. PNL concluded that the Comanche Peak engines are suitable for nuclear standby service, subject to certain actions including implementation of all relevant recommendations and requirements identified in the ongoing NRC review of the Owners' Group Program.[a]

Of the 171 components addressed in the Owners' Group DR/QR report on PNPP's TDI engines, 11 were reported by CEI to differ from similar components in the Comanche Peak engines. PNL reviewers consider EDG differences that affect only one of these components--the crankshaft--to warrant further attention. All of the other components are considered suitable for full-load operation.

Pending completion of the torsiograph test planned by CEI for a PNPP engine and a review of the results, PNL does not have an adequate basis for drawing conclusions on the adequacy of the crankshaft. PNL comments on the crankshaft are summarized as follows and addressed in more detail in Section 4.3:

- The torsiograph test should include not only variable load tests but variable speed tests to identify any critical frequencies that may exist at speeds near the rated speed and under conditions of startup and shutdown. The significance of any such critical frequencies

(a) Pacific Northwest Laboratory. September 1984. Review and Evaluation of Transamerica Delaval, Inc., Diesel Engine Reliability and Operability - Comanche Peak Steam Electric Station Unit 1. PNL-5234, Richland, Washington.

should also be examined relative to the effects of load acceptance and shedding (e.g., through the engine speed range from startup to possible overspeed upon load rejection).

- If the fourth-order critical frequency is determined through the torsiograph test to occur at a speed near (or within) the allowable range recommended by the Owners' Group for steady operation, it may be necessary to establish special surveillance requirements to control engine timing, balance, and speed to alleviate the effects of the critical frequency. For example, such special requirements would be necessary if the fourth-order critical occurred at 438 rpm, which would be within 2 rpm of the minimum speed of 440 rpm recommended by the Owners' Group.

- The results of the torsiograph test should be compared with test results for other 16-cylinder engines in nuclear service, to ascertain whether the torsional systems are sufficiently similar that extended testing performed on another engine (e.g., at Catawba) might be applicable to the engines at PNPP. Crankshaft stresses calculated on the basis of the torsiograph data should also be evaluated against applicable criteria. NRC should be informed of the results and conclusions of the torsiograph test and analysis, and the basis for the conclusions.

- Depending on the outcome of the torsiograph test and analysis, further testing may be called for to qualify the crankshaft. The approach recommended in PNL's review[a] of the Owners' Group Program Plan is to operate an engine at the load chosen by the utility as the "qualified" load for enough time (approximately 750 hours at 450 rpm) to accumulate 10^7 stress cycles on the crankshaft. Such a test should be followed by appropriate nondestructive examinations to detect any abnormalities that might indicate crankshaft deficiencies. NRC representatives should be notified in advance of any inspections.

(a) Pacific Northwest Laboratory. June 1984. Review and Evaluation of TDI Diesel Generator Owners' Group Program Plan. PNL-5161, Richland, Washington.

Although PNL's review of the DR/QR report for Comanche Peak has not yet been completed, sufficient progress has been made for PNL to conclude that the overall approach is adequate for the intended purpose. That portion of the PNPP DR/QR covering the 16 components addressed in Section 4 of this report was also reviewed by PNL and found to be acceptable, as discussed in Section 5. The results of this latter review, together with the similarity of the components in the Comanche Peak and PNPP engines and the lead-engine component reviews previously performed for Comanche Peak, provide a basis for confidence that the overall design review and quality revalidation of the PNPP engines has been performed adequately.

PNL has the following additional comments and recommendations:

- PNL notes CEI's commitment to implement the maintenance and surveillance recommendations of the Owners' Group and SwRI for the components discussed in Section 4. PNL's recommendations documented in Section 4 should also be implemented.
- Recognizing that this report precedes the final review by PNL and by NRC of the Owners' Group Program findings, any additional recommendations and requirements from that review that may be relevant to PNPP should also be implemented by CEI.
- PNL considers CEI's plans for post-reassembly tests of the PNPP engines sufficient to detect any abnormal engine behavior following the recent inspections. These plans include the tests required by NRC Regulatory Guides 1.108 and 1.9, plus the 100-hour component inspections recommended by the Owners' Group. However, PNL recommends that fast starts be limited to the number consistent with current NRC requirements. Test results should be provided to NRC.
- The following PNL recommendations discussed in Section 4 warrant reemphasis here:
    - Any cylinder head with a through-wall weld repair of the firedeck, performed from one side only, should not be placed in nuclear service because of the potential stress concentration associated with

such a repair. CEI should verify, through appropriate inspection records, that no such heads are installed on the PNPP engines.

- CEI should confirm that the friction-welded push rods installed in the PNPP engines are from a lot that has been subjected to destructive examination of a random sample, in accordance with an Owners' Group recommendation.
- CEI should confirm, through inspection records and/or field verifications as appropriate, that air-start valve capscrews used in the engines will not bottom out. Owners' Group recommendations for avoiding this problem should be followed.
- CEI should verify that the torque on the nut of the jacket water pump shaft is as recommended by the Owners' Group.

4.0 COMPONENTS WITH KNOWN PROBLEMS ADDRESSED BY OWNERS' GROUP

Each of the 16 components addressed in Phase I of the Owners' Group Program Plan is discussed in this section in terms of three topics: 1) Owners' Group status, 2) CEI/PNPP status, and 3) PNL evaluation and conclusions. PNL has the following general comments on this aspect of the review:

- Based on an examination of a sample of CEI's procedures for disposition of component inspection findings, the PNL reviewers found that these procedures are adequate.
- Recommendations applicable to these components that are summarized in Section 3 of this report and discussed in more detail in this section should be implemented by CEI.

4.1 ENGINE BASE AND BEARING CAPS

Part No. 02-305A, D

Owners' Group Report: FaAA-84-6-53

4.1.1 Owners' Group Status

The base and bearing caps of all TDI model DSRV-16 engines were reviewed by Failure Analysis Associates (FaAA) on behalf of the Owners' Group because of failures of these components in other TDI engines at the Shoreham Nuclear Power Station (SNPS), two marine installations, and in an industrial engine. The FaAA review included stress and fatigue analyses of the bearing saddles, bearing caps, bolting, nuts, and nut pockets. It was determined that the failures experienced were due to specific assembly problems and not to inherent deficiencies of the parts.

The Owners' Group concluded that the DSRV-16-4 engine base assembly components have sufficient strength to operate for indefinite periods at full load, provided that the base casting and bolting components meet their nominal material and dimensional specifications, that components have not been damaged, and that bolt torque specifications are held. Because the factor of safety was low for friction forces resisting the lateral motion of the bearing caps, the Owners' Group recommended cleaning the mating surfaces with a solvent to remove lubricant prior to assembly or reassembly.

4.1.2 CEI/PNPP Status

At the request of CEI, SwRI reviewed the OG report, generally verifying the applicability and accuracy of the FaAA analyses and conclusions. However, the SwRI analysis yielded more assurance of reliability, as they concluded the cap-to-saddle interface would prove to be stronger than determined by FaAA. Hence, SwRI concluded that the saddle-cap assembly has infinite life against fatigue failure (Wood January 31, 1985, p. 19). The SwRI analysis also supported the OG recommendations regarding cleaning the mating surfaces upon any reassembly. They also recommended checking preload torque of both bearing cap studs and through-bolts prior to engine operation.

PNPP conducted inspections and found minor indications on the No. 5 bearing cap of the Division 1 engine [actually reported as Division 2 in Edelman (January 17, 1985, p. 11)]. These indications were documented and referred to the OG for evaluation. The OG results are to be reported later, and PNPP "will implement any recommendations which result..." (Edelman op. cit.).

4.1.3 PNL Evaluation and Conclusions

Based on the review of the subject FaAA report, PNL concurs with the Owners' Group conclusions that the DSRV-16 engine base, bearing caps, and associated bolting are adequate for their intended service.

PNL notes that the service history of the engine base components in the TDI DSRV-16 engines and other TDI engine types in nuclear service indicates that a principal cause of component failure has been insufficient preload on associated bolting. TDI has recommended that the torque on all main bearing saddle bolts be checked against TDI specifications at alternate refueling cycles. PNL concurs with this recommendation. Due to the low factor of safety for the friction force resisting lateral motion of the bearing caps, the Owners' Group recommended that all lubricant be removed from the mating surfaces of the bearing cap and engine base during installations. PNL concurs that this should be done any time a cap is removed. Furthermore, PNL recommends that these mating surfaces be inspected to ensure the absence of surface imperfections that may prevent the tight bolt-up of the component. Imperfections should be removed by stoning, machining, or replacing parts, as needed.

In light of CEI's inspection results, available analytical evidence, and favorable operating experience, PNL concludes that the engine bases and bearing caps are suitable for the intended service at PNPP.

4.2 CYLINDER BLOCK

Part No. 02-315A

Owners' Group Report: FaAA-84-5-4

4.2.1 Owners' Group Status

Cracks in cylinder block tops have been reported in TDI engines in both nuclear and non-nuclear service. Four types of cracks have been observed: 1) vertical cracks in the ligament between the cylinder liner counterbore landing and a cylinder stud hole, 2) stud-to-stud cracks between studs of adjacent cylinders, 3) circumferential cracks from the corner formed by the cylinder landing and counterbore extending downward into the block, and 4) horizontal cracks in the cam gallery at the upper radius of the camshaft bearing supports.

On behalf of the OG, FaAA conducted 1) an analysis of loads on the block that influence fatigue and fracture, 2) a stress analysis to estimate the levels of stresses caused by these loads, and 3) a 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 the original Shoreham block (an inline DSR-48 engine) at various loads and types of starts, as well as two- and three-dimensional finite element analyses of the top of the block. With the exception of the crankshaft gallery region, the DSR-48 and DSRV-16 engine blocks are identical. The finite element analyses were used to 1) analyze the stresses in the ligament region (between the head stud hole and cylinder liner counterbore) 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 cracked and uncracked ligaments, 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 strain gauge locations to those at the crack initiation sites.

In addition, sections of the original Shoreham EDG 103 block were removed and subjected to metallurgical tests (including fractography and metallography) and visual inspection of cracks in counterbore-to-stud hole, stud hole-to-stud hole, and counterbore radii.

The FaAA findings are summarized as follows:

- Initiation of cracks in the ligament between stud hole and liner counterbore was predicted to occur after accumulated operating hours at high load and/or engine starts to high load. These cracks were considered to be 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.
- 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, and stud-to-stud cracks are predicted to initiate after additional operating hours at high load and/or engine starts to high load.
- Blocks with ligament cracks are predicted to withstand a LOOP/LOCA event with sufficient margin, provided that 1) inspection shows no stud-to-stud cracks prior to the event, and 2) the block material has the appearance and ultimate tensile strength of typical gray cast iron, class 40, or better.
- 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 substantially lower load levels than their nameplate rating 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 (proudness) above the block will reduce stresses, and site-specific analyses of such modifications could also permit relaxation of inspection requirements.
- Circumferential cracks originating in counterbore radii will not propagate to a point were they will impair the intended function of the block.

4.2.2 CEI/PNPP Status

As a consultant to CEI/PNPP, SwRI has made a complete study of the FaAA analysis of the cylinder block. SwRI agrees with the assumptions, methods, procedures, and results as presented in the analysis. Further, SwRI concurs with the OG recommendations, and concludes:

- Periodic inspections are necessary to demonstrate that each cylinder block is capable of meeting its intended function.

- All blocks should be metallurgically evaluated to verify that the microstructure is characteristic of typical gray cast iron.
- Cylinder blocks that are inspected and found to be free of ligament cracks can operate without additional inspections for combinations of load and time that produce less than the excess cumulative damage index that has been demonstrated by its operation at the time of the latest block top inspection. Blocks of engines that have operated without block top inspection or for a time beyond the last inspection in excess of the allowable fatigue damage index should conservatively be assumed to have cracked ligaments.
- For blocks with known or assumed ligament cracks, absence of detectable stud-to-stud or stud-to-end cracks between the heads should be established before returning the engine to emergency standby after any operation in excess of 50% nameplate load. Any stud-to-stud or stud-to-end crack indications must be inspected to ensure that they extend less than 1.5 inches from the block top before the engine is returned to emergency standby after any operation in excess of 50% nameplate load. It is also necessary to evaluate the microstructure to ensure typical cast iron.
- Available documentation indicates that the cylinder blocks for both the Division 1 and 2 engines have been inspected by CEI in accordance with OG DR/QR recommendations. The inspection reports have been reviewed by the OG design group, who determined that both blocks were dimensionally within drawing specifications. No cracks were detected in either cylinder block top. The material in both blocks has been confirmed to meet the specification for gray cast iron, class 40.

4.2.3 PNL Evaluation and Conclusion

PNL's review of the PNPP cylinder blocks included consideration of 1) the FaAA design review of the cylinder blocks, 2) the inspection reports for both Division 1 and Division 2 cylinder blocks, and 3) the results of the materials confirmation. The implications of observed ligament, circumferential, and stud-to-stud cracks experienced in both nuclear and non-nuclear applications

were considered. Because there is no evidence of ligament cracks in either of the PNPP EDG cylinder blocks, inspection for stud-to-stud cracks may not be necessary. PNL believes it is essential that the cylinder blocks from both engines be reinspected for ligament cracks at intervals based on the formula described in the OG report FaAA-84-5-4.

In consideration of the above, PNL concludes that the blocks installed in the Division 1 and 2 engines are acceptable for their intended service, subject to the inspections discussed above.

4.3 CRANKSHAFT

Part No. 02-310A

Owners' Group Report: FaAA-84-4-16

4.3.1 Owners' Group Status

The Owners' Group analyzed the V-16 shafts at Mississippi Power & Light's Grand Gulf Nuclear Station. These engines are of similar design parameters and comparable operating conditions to those at PNPP; however, because of differences in generator and flywheel characteristics, the torsional stresses would be somewhat different at each plant. Therefore, as part of the OG Phase 2 efforts, the PNPP shafts are being evaluated separately.

The OG analysis on Grand Gulf included 1) audits of TDI's calculations of crankshaft stresses for single orders of torsional vibrations and torsiograph tests and 2) calculations of stresses associated with combined orders. It was concluded that the DSRV-16-4 engine crankshafts were designed in accordance with Diesel Engine Manufacturers Association (DEMA) recommendations and were adequate for their intended function. The OG recommended the following:

- Oil holes in certain main journals present the most critical torsional stress concentrations and should be inspected for machining discontinuities and fatigue cracks.
- Torsiograph testing should be done to establish or confirm torsional stresses.
- Engines should not be run close to speeds considered harmonically critical. (At Grand Gulf, a lower limit of 440 rpm was established.)

4.3.2 CEI/PNPP Status

The crankshaft for the Division 1 engine was made by Ellwood City Forge Company and the crankshaft for Division 2 by National Forge Company. (Based on previous experience, these shafts are made from slab forgings.) The material certification reports for these shafts show that they meet the TDI material specifications. Also, the crankshaft torsional system was designed to meet the DEMA requirements.

As part of the OG DR/QR the crankshafts of both Division 1 and 2 engines were examined by OG representatives. The crankpin and main bearing journal surfaces were found to comply with OG requirements. Eddy-current (ET) examinations of the oil holes, including all crankpin oil holes and the No. 2 and 8 main bearing journal holes, was also performed. The oil holes had a number of surface machine marks that required polishing or grinding prior to ET measurements. Furthermore, the ET inspection down to a depth of 3 inches in the oil holes revealed a number of indications that were subsequently polished or ground out.

CEI plans to conduct torsional vibration tests on one of the PNPP engines to verify FaAA vibration calculations. These tests are currently planned for late February or early March 1985.

4.3.3 PNL Evaluation and Conclusion

PNL consultants reviewed the OG DR/QR results and the referenced inspection reports. Based on this information, PNL concludes that the indications noted on the shafts have been properly dispositioned.

Until the torsional analysis and confirming torsiograph information have been reviewed, PNL cannot formulate final conclusions on the adequacy of these crankshafts. In this regard PNL notes:

1. The calculated fourth-order critical is 438 rpm. This appears to be closer to the 450-rpm operating speed than other DSRV-16-4 TDI engines that have been studied. Accordingly, PNL recommends that any steady operation below 450 rpm be minimized (the OG allows operation to 440 rpm) and that the torsiograph testing include not only variable load tests but also variable speed tests. The variable speed tests should consider speeds extending throughout the engine operating range from startup to load rejection.
2. Also, in view of Note 1, PNL considers it important that the load developed in each cylinder be balanced and that the engine does not misfire.
3. Calculations are needed to determine if higher stresses occur at the oil holes or at the crankshaft fillets. If higher stresses occur at

the fillets, inspections of the fillet regions should be performed in addition to the inspections already planned for the oil holes.

4. If the fourth-order critical frequency is determined through the torsiograph test to occur at a speed near (or within) the allowable range recommended by the Owners' Group for steady operation, it may be necessary to establish special surveillance requirements to control engine timing, balance, and speed to alleviate the effects of the critical frequency. For example, such special requirements would be necessary if the fourth-order critical is confirmed to occur at 438 rpm, which is within 2 rpm of the minimum speed of 440 rpm recommended by the Owners' Group.

The results of the torsiograph test should be compared with test results for other 16-cylinder engines in nuclear service, to ascertain whether the torsional systems are sufficiently similar that extended testing performed on another engine (e.g., at Catawba) might be applicable to the engines at PNPP. Crankshaft stresses calculated on the basis of the torsiograph data should also be evaluated against applicable criteria. NRC should be informed of the results and conclusions of the torsiograph test and analysis, and the basis for the conclusions.

Depending on the outcome of the torsiograph test and analysis, further testing may be called for to qualify the crankshaft. The approach recommended in PNL's review[a] of the Owners' Group Program Plan is to operate an engine at the load chosen by the utility as the "qualified" load for enough time (approximately 750 hours at 450 rpm) to accumulate 10^7 stress cycles on the crankshaft. Such a test should be followed by appropriate nondestructive examinations to detect any abnormalities that might indicate crankshaft deficiencies.

(a) Pacific Northwest Laboratory. June 1984. Review and Evaluation of TDI Diesel Generator Owners' Group Program Plan. PNL-5161, Richland, Washington.

4.4 CONNECTING RODS

Part No. 02-340A

Owners' Group Report: FaAA-84-3-14

4.4.1 Owners' Group Status

The Owners' Group addressed two connecting rod failure mechanisms identified through surveys of reported failures in non-nuclear applications.

The first failure mechanism considered was the fatigue of the link rod bolts resulting from loss of bolt preload. The problem and its solution were addressed by TDI in Service Information Memo (SIM) No. 349, dated September 18, 1980. According to this SIM, engines manufactured between 1972 and February 1980 may have been shipped with an insufficient locating-dowel counterbore depth in the link rod or link pin, resulting in unintended clearance between the link rod and link pin as assembled. Under firing load, this locating dowel will yield, allowing the unintended clearance to disappear and resulting in loose link rod bolts. The OG (through the above-mentioned FaAA report) has determined that there must be zero clearance under the specified bolt torque of 1050 ft-lb.

The second failure mechanism is fatigue cracking of the connecting rod bolts and/or the link rod box at the mating threads. TDI attributed those rod cracks to "thread fretting." This "thread fretting" was concluded by TDI to result from distortion of the rod bolt under operating loads in the area of the mating threads; the distortion could occur if the bolts had been installed with the originally specified bolt preloads. The OG addressed this concern for the two versions of the connecting rod--the original design equipped with 1-7/8-inch bolts and a later design in which the rod boxes are equipped with 1-1/2-inch bolts. Stress analyses of both designs, including finite element studies, were completed by FaAA, and it was concluded that both designs are adequate for the service intended, provided that connecting rod bolt preload is checked within time limits specified as related to engine load requirement in terms of percentage of nameplate rating. However, the rod with the 1-1/2-inch

bolts has an 8% to 9% higher margin of safety than the rod with 1-7/8-inch bolts because the related rod box structure is more massive with the smaller bolt configuration.

The OG reviewed the rod design for buckling and concluded that it is adequate. The OG also reviewed the bronze wrist pin bushings at the upper end of the rod and concluded that the bushings are satisfactory, provided that any indications or porosity meet the specifications and that there are no indications within ±15° of the bottom center.

4.4.2 CEI/PNPP Status

PNPP connecting rods are fitted with the 1-1/2-inch diameter bolts. To comply with OG recommendations, CEI performed the required tests on the connecting rods and bolts as follows:

- Eddy-current tests were performed on the female threads in the rod box. Two minor indications were found and were removed by retapping the threads.
- A magnetic particle inspection was performed on all the connecting rod bolts. No linear indications were found.
- A visual inspection of the connecting rod bolts was also made. The bolt washers and undersides of the bolt heads were galled. The washers were replaced and the bolt heads cleaned.
- A visual inspection of the rack teeth (serrations) was made. The teeth showed apparent fretting that was judged to be minor, and the rods were used as is.
- The 1-1/2-inch diameter connecting rod bolts installed in the rods were torqued to 1700 ft-lb per TDI recommendations.
- The connecting rod wrist pin bushings were inspected with liquid penetrant. All the bushings were found to be acceptable according to the OG acceptance standards.
- The clearance of the link rod to the link rod pin was measured. The clearance was zero when the bolts were tightened.

- A material check of the connecting parts was made for the Division 1 and Division 2 engines by Stone & Webster Engineering Corporation.
- A material hardness check was also made of the master rod, link rod, link rod pin, link rod box, master rod, master rod bushings, link rod bushing, and connecting rod box bushing.

4.4.3 PNL Evaluation and Conclusion

PNL reviewed the inspections conducted by CEI on the connecting rods. PNL notes that the fretting at the joint between the master and link rod at PNPP was slight; thus, PNL does not believe this is of concern. Based on this review, PNL concludes that the connecting rods are adequate for their intended service, provided that the OG-recommended maintenance/surveillance is performed and any additional recommendations identified in the ongoing NRC/PNL review of the OG Phase 1 report on the connecting rods are implemented.

4.5 CONNECTING ROD BEARING SHELLS

Part No. 02-340B

Owners' Group Report: FaAA-84-31

4.5.1 Owners' Group Status

FaAA, on behalf of the Owners' Group, performed stress analyses of the 12-inch and 13-inch connecting rod bearing shells and found them to be adequate for the intended service. A criterion was developed that allowed acceptance of bearing shells with voids up to 0.050 inch, because voids of this size were shown not to degrade their fatigue performance. FaAA recommended that radiographic inspection be used to ensure compliance with this criterion.

4.5.2 CEI/PNPP Status

The bearing shells from both engines were inspected visually and by radiograph, eddy current, and liquid penetrant (LP). The visual and LP inspection showed some slight galling and scoring considered typical for new engine bearings; shells with these indications were reinstalled in the engines if they were not found unacceptable for other reasons. The radiographic examination and eddy-current tests showed that some shells were not acceptable for use as top bearings because of voids but could be used as bottom shells. CEI used the OG acceptance criterion to make these determinations. If the questionable shells could not be used as bottom shells, they were discarded.

4.5.3 PNL Evaluation and Conclusion

PNL reviewed the inspections performed on the connecting rod bearing shells. The eddy-current, radiograph, liquid penetrant, and visual inspections were found to have been performed as required by the OG. PNL concluded that the bearing shells as installed are satisfactory for the intended service.

4.6 PISTON SKIRTS

Part No. 02-341A

Owners' Group Reports: FaAA-84-2-14, FaAA-84-5-18, and FaAA-84-10-30

4.6.1 Owners' Group Status

FaAA evaluated four basic types of TDI piston skirts for the Owners' Group. Type AE and modified type AF skirts were analyzed and reported in some depth; types AN and AH were analyzed together with appropriate consideration of the previous AE/AF study. Variations in bolt bosses, rib ends, and heat treatments among these designs led to differing conclusions:

- Types AE and AH skirts were found satisfactory for EDG service to full TDI nameplate rating (i.e., to 225 psig BMEP). The OG concluded that, although cracks might initiate at high loads, they would not grow.
- Cracks were likely to initiate in the modified AF skirts at nameplate loads, but would not propagate out of the immediate high-stress region. Therefore, the AF skirts were deemed usable.
- Although crack initiation and propagation in type AN skirts could not be determined analytically with certainty, actual experience in nuclear and non-nuclear installations resulted in numerous cracks. Hence, the OG concluded that AN skirts should not be used for EDG service.

AE skirts have recently completed substantial operating experience at high load levels. At SNPS, eight AE skirts experienced over 10^7 cycles at 212 psig BMEP or higher; subsequent 100% inspections showed no cracks. In addition, a TDI research engine with slightly modified AE skirts successfully underwent 9.6×10^7 cycles at firing pressures of 2000 psig, considerably higher than the 1750-psi firing pressure encountered at 225 psig BMEP.

4.6.2 CEI/PNPP Status

The PNPP TDI EDGs were furnished originally with AH skirts; CEI chose to replace all with new AE skirts. The replacement skirts were fully inspected and found acceptable to OG criteria.

At the request of CEI, SwRI reviewed the OG/FaAA reports; no additional analyses were performed. However, SwRI found the OG report on AE skirts was appropriate and applicable to the skirts at PNPP and made no recommendations (Wood January 31, 1985, p. 55).

4.6.3 PNL Evaluation and Conclusion

In its evaluation of the OG report on piston skirts (FaAA-84-2-14), PNL concluded that type AE skirts are suitable for use to normal TDI ratings (225 psig BMEP).

Based on reviews of CEI's inspection results, the available analytical evidence, and favorable industry-wide operating history, PNL concludes that the type AE skirts installed at PNPP are suitable for their intended service.

4.7 CYLINDER LINERS

Part No. 03-315C

Owners' Group Report: FaAA-84-5-4

4.7.1 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 protrusion (termed "proudness") 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 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 block.

4.7.2 CEI/PNPP Status

In preparation for putting the engines into service, CEI/PNPP dismantled all cylinder liners from the cylinder block of both the Division 1 and 2 engines. All liners were inspected per OG recommendations. The inspection documentations have been reviewed by the OG design group who determined that all liners were dimensionally within acceptable tolerances. While the liners were out for inspection, all were machined to reduce liner-to-block proudness, block counterbore-to-liner interference fit, and block-to-liner fit just below the counterbore. All dimensional changes were in accordance with OG recommendations.

4.7.3 PNL Evaluation and Conclusion

In evaluating the cylinder liners, PNL noted that 1) cylinder liners have not been reported as a problem, 2) all liners at PNPP were found to be

dimensionally correct, and 3) all liners were modified per OG recommendations to reduce stresses in the cylinder blocks. In consideration of the above, PNL concludes that the cylinder liners installed in the Division 1 and 2 engines are acceptable for the intended service.

4.8 CYLINDER HEADS

Part No. 02-360A

Owners' Group Report: FaAA-84-15-12

4.8.1 Owners' Group Status

FaAA calculated mechanical and thermal stresses in the cylinder heads and concluded that Group I, II and III heads as designed were adequate for the service intended. FaAA recommended that the Group I and II heads be LP and MP inspected and that the firedeck thickness be measured for acceptability.

4.8.2 CEI/PNPP Status

The cylinder heads for the PNPP engines were cast prior to October 1978 and are, therefore, Group I heads. To upgrade their heads in accordance with OG recommendations, CEI returned them to TDI for inspection and measurement of the firedeck thickness, LP examination of the valve seats, MP examination of the firedeck area (excluding the valve seat area), and heat treatment of the cylinder heads. This work was done in the presence of a PNPP inspector. Of the 32 PNPP heads sent to TDI, three were scrapped and one was weld-repaired in the firedeck area. This repaired head was installed on cylinder No. 4R of the Division 2 engine.

The deck thickness on the acceptable Division 1 heads ranged from 0.453 to 0.968 inch. On the acceptable Division 2 heads, the deck thickness ranged from 0.409 to 0.967 inch.

In addition to inspecting the heads, CEI also examined the valve guides. The chrome-plated valve stems showed no scuffing, so it was assumed that the guides did not show any wear after the 10 to 12 hours of engine operation.

4.8.3 PNL Evaluation and Conclusion

The engine cylinder head inspection and DR/QR reports submitted by CEI were reviewed. PNL concludes that the Group I cylinder heads as inspected and heat-treated by TDI are acceptable for use in Division 1 and 2 engines. However, any cylinder head with a through-wall weld repair of the firedeck, performed on one side only, should not be placed in nuclear service because of the stress concentration associated with such a repair. CEI should verify,

through appropriate inspection records, that no such heads, and particularly the repaired head referenced above, have such through-wall weld repairs.

PNL considers it important that the maintenance/surveillance plan specify that, after engine operation, the engine must be air-rolled with stopcocks open 4 to 8 hours after shutdown and then again after 24 hours. In this way, any water that leaks into the cylinder will be recognized and corrective action taken. Also, the engine should be rolled again before a planned start to detect possible water leaks into the cylinder. Each cylinder compression and firing pressure should be checked at each power plant refueling for possible cylinder problems.

4.9 CYLINDER HEAD STUDS

Part No. 02-315E

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

4.9.1 Owners' Group Status

On behalf of the Owners' Group, Stone & Webster Engineering Corporation (SWEC) investigated both the necked-down and straight shank cylinder head stud designs. Although neither had experienced failure in nuclear EDG service, the generic issue was raised by the OG due to the occurrence of isolated failures in non-nuclear service, determined by SWEC to have resulted from insufficient preload. SWEC concluded that both designs were adequate for the intended service, given proper preload torque. However, head studs of the necked-down shank design were considered preferable because 1) they have greater fatigue resistance, 2) they are less likely to lose preload, and 3) the design avoids possible interference with the cylinder head stud hole, which could produce side-thrust upon the cylinder block and induce block damage. The SWEC analysis reflected applied stress from operation at rated engine load (225 psig BMEP), and considered endurance limits, fatigue, thread distortion, and thermal stresses.

4.9.2 CEI/PNPP Status

At the request of CEI, SwRI conducted an analysis on both stud designs. The results did not differ significantly from those obtained earlier by the OG. SwRI concluded that either stud design is satisfactory for use at PNPP (Wood January 31, 1985, p. 32). However, CEI chose to replace all straight shank studs with the alternative necked-down design because the latter design is more fatigue-resistant (Edelman January 17, 1985, p. 10).

The replacement studs were checked upon receipt against applicable OG and TDI standards. SwRI recommended that the head studs be retorqued periodically during initial engine operation until no movement is detected and thereafter at each refueling outage (Wood January 31, 1985, p. 33).

4.9.3 PNL Evaluation and Conclusion

PNL evaluated the OG/SWEC generic analysis and report on the cylinder head studs and concurred with the OG conclusion that both designs are suitable for the intended service. In addition to reviewing the referenced SWEC report, PNL reviewed the Wood affidavit (January 31, 1985), the Edelman/CEI letter (January 17, 1985), the OG DR/QR report for PNPP, and the PNPP inspection reports.

Based on reviews of CEI's inspection results, available analytical evidence, and favorable operating history, PNL concludes that the replacement necked-down cylinder head studs used by CEI are suitable for their intended service at PNPP.

4.10 PUSH RODS

Part No. 02-390C and D

Owners' Group Report: FaAA-84-3-17

4.10.1 Owners' Group Status

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.

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

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

4.10.2 CEI/PNPP Status

The push rods used in the Division 1 and 2 engines at PNPP are of the friction-welded design. Two sets of push rods, both main and connector, were examined with LP in accordance with the OG recommendations; no cracks were found.

4.10.3 PNL Evaluation and Conclusion

The absence of reported failures of any friction-welded push rods in bench tests and in engines that have operated more than 10^7 cycles, coupled with the satisfactory results obtained in the PNPP push rod examinations, led PNL to conclude that they are suitable for their intended service. However, CEI should confirm that the friction-welded push rods installed in the PNPP engines are from a lot that has been subjected to destructive examination of a random sample, in accordance with an Owners' Group recommendation.

4.11 ROCKER ARM CAPSCREWS

Part No. 02-390G

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

4.11.1 Owners' Group Status

On behalf of the OG, SWEC investigated the rocker arm capscrews. This component had experienced some failures in nuclear standby service (at the Shoreham Nuclear Power Station). There have been no reported failures elsewhere.

Two capscrew designs are used in TDI engines; SWEC evaluated both and found them to be adequate for the service intended. SWEC attributed the SNPS failures to insufficient preload. Satisfactory fatigue life reportedly has been demonstrated by several engines with more than 10^7 cycles of operation (Wood January 31, 1985, p. 6).

4.11.2 CEI/PNPP Status

At the request of CEI, SwRI reviewed the OG reports on rocker arm capscrews. SwRI conducted its own analyses of both capscrew designs; no significant differences between the OG and SwRI analysis results were found as to stress, fatigue, temperature effects, or creep, when properly torqued (Wood January 31, 1985, pp. 8, 10). SwRI recommended that the capscrews be retorqued periodically during initial engine operation until no further movement is detected, and then be checked at every refueling outage thereafter. (These recommendations are consistent with those of the Owners' Group.)

CEI personnel conducted the requisite OG inspections on the capscrews. Visual examinations revealed scoring and other surface damage on the thread surfaces of numerous capscrews; however, this was considered normal. Subsequent MP examination cleared all but one for reuse. The rejected capscrew was damaged in ET examinations and replaced. Requisite hardness and material comparator tests were also conducted, with acceptable results (Edelman January 17, 1985, p. 10). Retorque was verified by the onsite inspectors.

4.11.3 PNL Evaluation and Conclusion

In its evaluation of the OG/SWEC generic analysis and report on the rocker arm capscrews, PNL predicted stresses three times higher than those determined by SWEC. Nevertheless, PNL concluded that margins remain adequate for both designs. The conclusion also reflected service history within the population of TDI engines.

Based on CEI's inspection results, the available analytical evidence, and favorable operating history, PNL concludes that the rocker arm capscrews are suitable for their intended service at PNPP.

4.1.2 TURBOCHARGERS

Part No. MP-022/23

Owners' Group Reports: FaAA-84-6-56 and FaAA-8a-5-7.1

4.12.1 Owners' Group Status

On behalf of the Owners' Group, FaAA undertook an extensive study into the causes of reported failures of Elliott Model 90G turbochargers in nuclear service. The net result was an affirmation of basic qualification and capability of these turbochargers for their intended service. However, the OG has noted inadequate startup thrust bearing lubrication. Consequently, they recommended improvements to the turbocharger lubrication system, operating procedures, and maintenance and surveillance program to enhance and ensure turbocharger operability and reliability.

In a separate study, FaAA considered various exhaust gas nozzle ring component failures (including missing and cracked vanes, broken capscrews, and a cracked hub) that have been observed in 90G turbochargers. With regard to the missing vanes, FaAA concluded that these f· ˜ed principally from fatigue due to environmental vibrations and/or from effects of corrosion, and that disappearance of the vanes apparently caused neither structural nor functional damage to the turbochargers or their performance. Likewise, failures of other nozzle ring components did not, nor would they, lead to adverse performance. FaAA did, however, recommend enhanced surveillance of exhaust temperatures.

4.12.2 CEI/PNPP Status

The two turbochargers for each PNPP EDG were removed, disassembled, inspected, and reassembled or replaced, with appropriate actions taken. In addition, CEI requested SwRI to independently review the OG analyses performed by FaAA.

SwRI was in agreement with the OG results and conclusions in regard to turbocharger operability/reliability, bearings and lubrication, and nozzle ring components. SwRI did, however, add recommendations on surveillance of lubricating system operation and oil condition, as documented in Wood (January 31,

1985, pp. 67-68). SwRI concluded that the turbochargers will perform satisfactorily on the PNPP engines.

CEI inspected the two turbochargers for each EDG. Despite the low number of operating hours, the inspections revealed scored and excessively worn bearings, vanes with slightly bent ends, and some wear marks on shafts and thrust collars. In this regard, CEI has stated that at least eight fast starts were performed at TDI with no prelube or drip lube system utilized on the thrust bearing. There were no dents or knicks in vanes, and no report of missing vanes (as has occurred elsewhere); CEI has confirmed orally (on February 11, 1985, at a meeting with NRC) that none was missing.

As a consequence of the inspections, the following actions were taken:

- Division 1 - Replaced left bank turbocharger with spare; sent rotating elements to Elliott for inspection and refurbishment; replaced worn and scored bearings; hand-dressed and polished shafts, thrust collars, etc. (The refurbished original left bank turbocharger became the spare.)
- Division 2 - Sent rotating elements to Elliott for inspection and refurbishment; replaced bearing of left bank turbocharger; hand-dressed and polished shafts, thrust collars, etc.

CEI has agreed to implement all relevant OG and SwRI recommendations for modifications, maintenance, and surveillance (Christiansen February 1, 1985, p. 24). CEI has implemented OG-recommended prelubrication systems (Edelman January 17, 1985, p. 12).

4.12.3 PNL Evaluation and Conclusion

The PNPP EDGs are nameplate rated to 7000 kW, or 224 psig BMEP, and the turbochargers reportedly are sized accordingly. However, PNL notes that CEI states that the engines will be operated at a nominal maximum of 5634 kW (Edelman January 17, 1985, p. 20), or approximately 180 psig BMEP. This rating is well below the nameplate rating and should result in exhaust gas temperatures well under the manufacturer's recommended maximum. The fast starts at TDI without the prelube or drip system on the thrust bearing would account for the excessive thrust bearing wear that was found.

PNL's review of the Owners' Group reports on turbochargers and nozzle rings has not yet been completed. On the basis of the information and observations referenced above, however, the 90G turbochargers are considered to be suitable for service, provided that:

- the FaAA recommendations on installation and use of drip and full-flow prelube systems are followed (affirmed, as above)
- the OG recommendations on maintenance/surveillance are followed
- CEI implements the SwRI recommendations (contained in Wood January 31, 1985, pp. 67-68)
- CEI inspects nozzle rings at each refueling (and replaces missing or cracked components)
- CEI monitors the exhaust temperatures at the turbocharger inlet on an hourly basis.

4.13 JACKET WATER PUMP

Part No. 02-425A

Owners' Group Report: Emergency Diesel Generator Engine Driven Jacket Water Pump Design Review (SWEC June 1984)

4.13.1 Owners' Group Status

Failures of water pumps at Shoreham and in similar non-nuclear installations have resulted in two redesigns of pumps installed in the DSR-48 engines and caused the OG to include this component in the list of generic parts to be investigated. However, the engines at PNPP and other DSRV-12 and DSRV-16 engines installed at other nuclear installations have larger, more robust, pumps than those at Shoreham, and no failures have been reported for pumps of this kind. The OG reviewed the design of the DSRV-16 engine water pump and concluded that the pump is adequate for the intended service. However, the OG recommended that the installation procedure be revised to ensure that the nut holding the external spline on the individual pump shaft would not be over- or under-torqued (i.e., it would be torqued from 120 ft-lb minimum to 660 ft-lb maximum).

4.13.2 CEI/PNPP Status

The water pumps used on the Division 1 and 2 engines were examined according to the OG recommendation. The pumps were disassembled and visually inspected. The shaft material and hardness were checked, and the pump drive gear teeth were checked with LP for root cracks and indications.

This inspection revealed no defects with the pumps, gears, shaft, or keyways in the shafting.

4.13.3 PNL Evaluation and Conclusion

The analysis performed by SWEC on the water pumps for the various engines was comprehensive. PNL concurs with the results of this study. This concurrence, coupled with results of CEI's inspection, led PNL to conclude that the pumps are suitable for service. However, a torque should be specified by CEI for holding the pump impeller and gear onto the shafting as recommended in the SWEC pump study.

4.14 HIGH-PRESSURE FUEL OIL TUBING

Part No. 02-365-C

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

4.14.1 Owners' Group Status

On behalf of the OG, SWEC investigated causes of leaks in the high-pressure fuel oil tubing and fittings. It was determined that leaks were due to isolated manufacturing defects on interior surfaces of the tubing and improper installation of compression fittings. The OG concluded, however, that the tubing and fittings, if properly manufactured and installed, are suitable for the service intended.

They recommended eddy-current inspection of the interior of existing lines, and that all future replacement lines be of a superior material and "shrouded" to protect against open oil sprays in the event of leakages. The OG also recommended that inspections for fuel oil leaks near compression fittings be performed while an engine is running.

4.14.2 CEI/PNPP Status

At the request of CEI, SwRI reviewed the OG report on fuel oil tubing to verify its applicability to the PNPP. SwRI concluded that the SWEC assumptions and methods of analysis were acceptable; additional analyses were not deemed necessary. SwRI agreed with the OG recommendations.

FaAA inspected the tubing per OG instructions (excepting certain sections of tubing where openings were restricted). No reportable indications were found. Nevertheless, CEI has decided to install shrouds on the fuel oil lines as an added precaution (Edelman January 17, 1985, p. 11).

CEI has not yet performed the fitting checks. Consistent with the OG recommendations, these checks are to be done with the engine running, which has yet to occur at PNPP.

4.14.3 PNL Evaluation and Conclusion

PNL has reviewed the OG/SWEC generic analysis and report on high-pressure fuel oil tubing, the Wood/SwRI affidavit (January 31, 1985), the Edelman/CEI letter (January 17, 1985), the PNPP DR/QR report, and the PNPP inspection reports.

Based on the available analytical evidence and favorable industry-wide operating history, PNL concludes that the high-pressure fuel oil tubing and fittings, as used at PNPP, are suitable for their intended service. However, PNL recommends that the periodic checks for leaks at fittings be done using the manual pump jacks, rather than when the engine is operating, to minimize risk to operating personnel.

4.15 AIR-START VALVE CAPSCREWS

Part No. 02-359

Owners' Group Report: Emergency Diesel Generator Air Start Valve Capscrew Dimension and Stress Analysis (SWEC March 1984)

4.15.1 Owners' Group Status

No actual failures of the air-start valve capscrews have been reported. However, in 1982, TDI issued a Service Information Memo warning of a potential defect due to the possibility of the 3/4-10 x 3-inch capscrews "bottoming out" in their holes in the cylinder heads, resulting in insufficient clamping of the air-start valves. SWEC analyzed the capscrews from the standpoint of stress and fatigue and concluded that they are suitable for their intended service, provided that they have the appropriate length. SWEC recommended that the length of these capscrews be checked and that any 3-inch capscrews found be shortened by 1/4 inch or replaced by 2-3/4-inch long capscrews.

4.15.2 CEI/PNPP Status

At CEI's request, SwRI reviewed the OG report on air-start valve capscrews. SwRI conducted independent computations paralleling those of SWEC. No significant difference between the OG analysis results and those of SwRI was observed (Wood January 31, 1985, p. 35). Factors of safety of 1.6 in stresses during tightening and operation were deemed satisfactory. SwRI recommended retorquing of all capscrews at 8-hour intervals during initial engine operation (per TDI and OG specifications) until no further yield of the soft metal gasket material is evidenced. SwRI further recommended that care be taken in cleaning and lubricating threads of both capscrews and heads.

PNPP personnel conducted the inspections recommended by the OG. Capscrew lengths were verified to be 3 inches, not the 2-3/4 inches recommended in the SWEC report. (The DR/QR and Component Revalidation Checklist prepared by the OG, against which inspections were conducted, do not give a specific length criterion). Material comparitor tests were also conducted, with satisfactory results. Hence, no changes were made in the capscrews. Initial cold torques were verified; hot retorquing cannot be done until the EDGs are operated.

4.15.3 PNL Evaluation and Conclusion

In its evaluation of the OG/SWEC analysis and report on the air-start valve capscrews, PNL concurred that the capscrew design is adequate, provided that field verifications comply with the OG requirements.

From both analytical evidence and successful operating experience elsewhere, PNL concludes that the air-start valve capscrews are suitable for their intended service at PNPP. This conclusion is subject to clarification of the discrepancy between the 2-3/4-inch capscrew length specified in the SWEC report and the 3-inch length utilized by CEI at PNPP. This may require additional inspection, verification, and/or replacements.

4.16 ENGINE-MOUNTED ELECTRICAL CABLE

Part No. 02-688B

Owners' Group Report: Emergency Diesel Generator Engine and Auxiliary Module Wiring and Termination Qualification to IEEE-383-1974 (SWEC April 1984)

4.16.1 Owners' Group Status

SWEC investigated, both generically and specifically for PNPP, the engine-mounted cables that had been the subject of a TDI Service Information Memo warning of potential defects. This analysis included a review of circuit requirements and the wire insulation ratings, termination types and ratings, voltage class, maximum temperatures, flame retardancy and routing in actual use. The OG found that the components in actual service at PNPP met the applicable requirements.

4.16.2 CEI/PNPP Status

At CEI's request, SwRI reviewed the OG report on engine-mounted electrical cable and wiring terminations. SwRI agreed with the OG/SWEC analyses and conclusions; they did not find it necessary to conduct additional analyses. SwRI also cited a favorable history of these components in service in both nuclear and non-nuclear TDI engines.

Actual verification of PNPP wiring and termination qualification was conducted onsite by SWEC for the OG, as part of the Phase 2 DR/QR process. No unsatisfactory materials or installation were reported.

4.16.3 PNL Evaluation and Conclusion

Based on CEI's inspection results and available evidence, PNL concludes that the wiring and terminations, as installed at PNPP, are suitable for their intended service at PNPP.

5.0 DESIGN REVIEW AND QUALITY REVALIDATION OF ENGINE COMPONENTS

The second phase of the Owners' Group Program entails a comprehensive design review (DR) and quality revalidation (QR) of engine components. Components selected for review, and the type of review performed for each, are determined by the Owners' Group on the basis of the impact of the components on engine performance. Of the 171 components evaluated in the PNPP DR/QR, over 150 had been subjected to both a DR and a QR.

PNL reviewed the PNPP DR/QR of the 16 components discussed in Section 4 of this report, together with supporting inspection reports and documentation of the disposition of inspection findings. The design reviews rely on applicable lead-engine component reviews previously performed for Comanche Peak. For the 16 components discussed in Section 4, the design reviews are also supported by reports prepared by the Owners' Group (the "Phase I" reports) on resolution of problems with potential generic applicability. The PNL reviewers found the design review aspects of the PNPP DR/QR to be acceptable for the 16 components.

The quality revalidations of engine components involve documentation reviews, inspections, and tests as appropriate to verify important attributes identified by the Component Quality Revalidation Group established by the Owners' Group. The PNL reviewers were able to trace all of the supporting records for the PNPP QR of the 16 components referred to above, and found them in order for documenting the as-built and as-inspected quality of the components. For example, the reviewers found nothing contrary to accepted practice in the documentation of nondestructive examinations performed by CEI or Owners' Group examiners. The documentation indicated that the examiners held Level II certification or above in NDE procedures, consistent with accepted practice, and that the examinations were performed in accordance with procedures and acceptance criteria approved by the Owners' Group.

Of the 171 components addressed in the PNPP DR/QR report, 11 were reported by CEI to differ from similar components in the Comanche Peak engines. PNL reviewers consider EDG differences that affect only one of these components--the crankshaft--to warrant further attention. Because of differences in generator and flywheel characteristics, the torsional crankshaft stresses will

differ from plant to plant. PNL recommendations concerning the crankshaft are summarized in Section 3 of this report and discussed in more detail in Section 4.3.

As noted in Section 3 of this report, PNL's review of the DR/QR for Comanche Peak has not yet been completed. However, sufficient progress has been made for PNL to conclude that the overall approach is adequate for the intended purpose. The results of PNL's limited review of the PNPP DR/QR as discussed above, together with the similarity of the components in the Comanche Peak and PNPP engines and the lead-engine component reviews previously performed for Comanche Peak, provide a basis for confidence that the overall design review and quality revalidation of the PNPP engines has been performed adequately.

6.0 MAINTENANCE AND SURVEILLANCE PLANS

Appendix 2 of the PNPP DR/QR report deals with only maintenance; no mention is made of planned surveillance during engine operation or while the engine is in standby status. In this regard, therefore, the PNPP DR/QR report is incomplete. However, CEI has committed to incorporate the OG recommendations on maintenance and surveillance into their M/S plan.

On February 11, 1985, NRC requested that the OG prepare M/S plans specific to each TDI engine model. The plan for the DSRV-16 engines was thus unavailable for this PNL review. Assuming that 1) the OG responds to this NRC request in a timely manner, and 2) the plan is reviewed and approved by NRC, PNL concludes that PNPP will have an adequate M/S plan in place prior to plant startup.

7.0 ENGINE TESTING AND INSPECTION

The PNPP Unit 1 Division 1 and 2 EDGs were installed in 1981 and have not yet been operated onsite. The only operational time on these engines was accumulated during testing at the TDI factory in 1978 prior to shipment. Test-bed logs reveal the operational data summarized in Table 7.1.

TABLE 7.1. Perry Nuclear Power Plant Engine Loads and Operating Time

	Division 1			Division 2		
	rpm	hr	hp	rpm	hr	hp
	200	2	1,092	210	1.17	1,165
	275	2	1,512	270	1	1,498
	380	1	2,185	380	1	2,109
	400	1	4,730	400	1	4,369
	450	1	2,488	450	1	2,497
	450	1	4,915	450	0.83	4,915
	450	1	7,311	450	1	7,296
	450	2	9,717	450	2.25	9,687
	450	1	10,689	450	1	10,656
TOTAL		12.0			10.25	
At 450 rpm		6.0			6.08	

Because the engines have not been operated at the site, CEI has performed the inspections and relevant component replacement and refurbishment without any prior operational experience, relying solely on the guidance of the Owners' Group. However, CEI is planning to proceed according to NRC regulatory guides to perform the required preoperational testing of these engines. This testing will consist of 35 starts on one unit and 34 starts on the other to satisfy the requirement of NRC Regulatory Guide 1.108 for 69 starts. Additionally, CEI proposes 10 more starts for each engine according to Regulatory Guide 1.9 and IEEE-387-1977, Section 6.3.2. Load imposition will not, however, be in steps,

but as rapid as possible. Following the stipulated 100 hours of preoperational testing, CEI will conduct additional component inspections (Edelman January 17, 1985). These inspections will encompass 19 components or assemblies identified in the DR/QR report for PNPP, plus four other components added due to changes in the OG's stipulation since the preoperational inspections were conducted.

PNL reviewed these preoperational testing plans and believes that specified testing will be adequate to detect any abnormal engine behavior. However, PNL believes that the number of fast starts currently planned by CEI could be deleterious to the engines, based on the operational history of other TDI engines in nuclear service. This concern was addressed in the NRC Generic Letter 84-15-Draft. Therefore, PNL recommends that the CEI testing plans be revised to minimize the number of fast starts consistent with current NRC requirements. Further, plans for component inspections should reflect the PNL recommendations discussed in Section 4 of this report.

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