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PNL-5234

Technical Evaluation Report

Review and Evaluation of Transamerica Delaval, Inc., Diesel Engine Reliability and Operability - Comanche Peak Steam Electric Station Unit 1

September 1984

Prepared for
the U.S. Nuclear Regulatory Commission
under Contract DE-AC06-76RLO 1830
NRC FIN B2963

Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
by Battelle Memorial Institute

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Project Title: Assessment of Diesel Engine Reliability/Operability

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PROJECT APPROVALS

W. W. Laity Date Sept. 10, 1984

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Pacific Northwest Laboratory

[signature] Date 9/12/84

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 20-19-40-42-1 FIN No. B2963.

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ABBREVIATIONS AND INITIALISMS

BMEP	brake mean effective pressure
CPSES	Comanche Peak Steam Electric Station
DR/QR	design review/quality revalidation
EDG, EDGs	emergency diesel generator(s)
ESF	engineered safety feature
FaAA	Failure Analysis Associates
LOCA	loss-of-coolant accident
LOOP	loss of offsite power
M/S	maintenance/surveillance
NDE	nondestructive examination
NRC	U.S. Nuclear Regulatory Commission
OG	Owners' Group; the TDI Diesel Generator Owners' Group
OGPP	Owners' Group Program Plan
O/R	operability and reliability
PNL	Pacific Northwest Laboratory
SWECo	Stone & Webster Engineering Corporation
TDI	Transamerica Delaval, Inc.
TER	technical evaluation report
TUGCO	Texas Utilities Generating Company

REVIEW AND EVALUATION OF
TRANSAMERICA DELAVAL, INC., DIESEL ENGINE
RELIABILITY AND OPERABILITY -
COMANCHE PEAK STEAM ELECTRIC STATION UNIT 1

1.0 INTRODUCTION

Texas Utilities Generating Company (TUGCO) has requested an operating license for its Comanche Peak Steam Electric Station (CPSES) Unit 1. One matter before the U.S. Nuclear Regulatory Commission (NRC) in considering this request is the operability and reliability (O/R) of the station's standby emergency diesel-engine generators, which have been brought into question by a number of circumstances (as described in Section 2.0). The subject engines were manufactured by Transamerica Delaval, Inc. (TDI).

To identify, evaluate, and correct these concerns, TUGCO has undertaken a number of investigative and corrective efforts. These have been addressed by TUGCO in several documents and related meetings with NRC staff and NRC's consultant, Pacific Northwest Laboratory (PNL). PNL has been requested by NRC to review and evaluate these documents and TUGCO's underlying efforts. This technical evaluation report (TER) expresses PNL's conclusions and recommendations regarding the operability/reliability of TUGCO's TDI standby emergency generators to serve their intended function.

Comanche Peak Steam Electric Station Unit 1 is served by two standby engines to meet its emergency service loads. Each is a TDI DSRV-16-4 engine, nameplate rated by TDI at 7000 kW, operating at 450 rpm with a brake mean effective pressure or BMEP (a computed measure of the average cylinder pressure in the firing stroke) of 225 psig. TUGCO has designated these engine-generators as Train A and Train B. The latest information provided by TUGCO specifies the emergency loads for these engines as a maximum of 4200 kW for Train A and 4350 kW For Train B under design basis accident conditions coincident with a simulated loss of offsite power.

1.1 ORGANIZATION OF REPORT

This technical evaluation report is organized as follows:

- Section 2.0 provides relevant background information on the known problems and efforts toward their resolution by both TUGCO and an ad hoc group of similar TDI engine owners (the TDI Owners' Group) who have united their efforts in regard to these mutual considerations.
- Section 3.0 presents a review and evaluation of TUGCO's resolution of component problems that have been designated by the Owners' Group (OG) as generic (termed Phase 1 component problems).
- Section 4.0 presents a review and evaluation of TUGCO's identification and resolution of other component problems (termed Phase 2 component problems) pertinent to the engines at CPSES.
- Section 5.0 documents PNL's evaluation of TUGCO's preoperational testing plan and results.
- Section 6.0 presents PNL's review of the utility's proposed maintenance and surveillance (M/S) program.
- Finally, Section 7.0 presents PNL's overall conclusions and recommendations regarding the suitability of the two diesel engines to perform their intended function as emergency standby power sources for the CPSES Unit 1.

1.2 LIMITED APPLICABILITY OF CONCLUSIONS

PNL has reviewed the basic documents referred to in Section 2.0, has participated in various meetings with TUGCO and NRC, and has observed components of the Train B engine as disassembled in TUGCO's inspection program. Concurrently, PNL also has reviewed various relevant Owners' Group documents and participated in their meetings with NRC, and has completed TERs on some elements of the Owners' Group Program Plan (OGPP).

This TER on the CPSES Train A and Train B engines' operability and reliability precedes completion of the OGPP and its appropriate implementation by TUGCO. This document also precedes the OG planned full plant-specific design

review/quality revalidation (DR/QR) analyses of both the Train A and Train B engines. Therefore, PNL is constrained from reaching unlimited conclusions relative to the CPSES Train A and Train B engines' operability and reliability to perform indefinitely their expected design function. PNL conclusions are subject to full completion of all OGPP and TUGCO DR/QR programs and implementation of their findings (PNL feels these actions should be a part of TUGCO's licensing authorization).

Hence, PNL has evaluated all components in light of expected operating conditions and patterns at CPSES over a period of time corresponding to the first reactor refueling outage, which PNL understands to be approximately 18 months from initial plant startup. By that time, all phases of both the general OGPP evaluation and implementation and the plant-specific CPSES DR/QR program should be complete and ready to implement. Because these actions will represent proposed resolution of the TDI engine issues at CPSES, PNL will make its final conclusions regarding the long-term operability/reliability of the CPSES engines at that time.

The considerations and recommendations presented in this TER are sometimes expressed in terms of "until the first reactor refueling outage." However, in using this phrase, PNL does not intend to imply (unless specifically stated otherwise) that the engines or their components are therefore unreliable or inoperable for their intended use over their normally expected life.

1.3 REPORT PREPARATION

As stated, this report is based in part on a review of documents cited in Section 2.0. The PNL team also visited the CPSES on May 24 and 25, 1984, while the Train B engine was disassembled for inspection. At that time many of the "generic" components of that engine (identified by the Owners' Group as Phase I issues) were visually examined, and the TUGCO disassembly, inspection, and replacement parts records were reviewed for both Train A and Train B. At that time the PNL team, together with NRC, also met with appropriate TUGCO staff and management concerned with diesel engine operability/reliability.

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

- D. A. Dingee, PNL project staff
- B. J. Kirkwood, Covenant Engineering, diesel consultant to PNL
- J. E. Horner, Seaworthy Systems, Inc., diesel consultants to PNL
- H. M. Hardy, diesel consultant to PNL.

Others whose contributions were considered in formulating the conclusions include PNL Assessment of Diesel Engine Reliability/Operability Project team members J. M. Alzheimer, M. Clement, S. D. Dahlgren, R. E. Dodge, W. W. Laity, J. F. Nesbitt, J. C. Spanner, and F. R. Zaloudek; and consultants S. H. Bush, A. J. Henriksen, P. J. Louzecky, A. Sarsten, and J. A. Webber (representing Ricardo Consulting Engineers plc). 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 Texas Utilities Generating Company to resolve the problems identified in the TDI diesel engines.

2.1 OWNERS' GROUP PROGRAM PLAN

Thirteen nuclear utilities that own diesel generators manufactured by Transamerica Delaval, Inc. (TDI), have established an Owners' Group to address questions raised by a 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 for standby emergency power.

The Owners' Group Program Plan specifies a three-stage approach to resolving the known and potential problems:

- Phase 1 is an in-depth analysis of the core group of 16 known "generic problem" components identified by a review of the operating history of TDI engines in nuclear and non-nuclear service. The Phase 1 analysis provides a determination of the operating history within the general population of these engines, the apparent cause (or causes) of problems, and methods for achieving their satisfactory resolution. Phase 1 of the OG Program Plan is pertinent to all nuclear utility TDI diesel engine owners.
- Phase 2 is a comprehensive design review/quality revalidation (DR/QR) process to address all other significant components of the engine system, to ensure that they, too, are reliably operable for the intended safety function of these engines. In cooperation with the utility members, the Owners' Group is identifying a number of components for each engine that should be inspected, and is providing an

inspection plan and acceptance criteria. PNL understands that CPSES has been supplied this Phase 2 information for their Train A and B engines.

- The third stage is a program of further testing and surveillance and maintenance. Testing and inspection are intended to help identify and evaluate the problems, both initially and at appropriate future intervals. The surveillance and maintenance procedures, enhanced beyond that which is "customary", are meant to prevent or to identify future problems before they appear.

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

Section 4 of PNL-5161 deals with considerations for interim licensing of nuclear stations prior to completion of the implementation of the Owners' Group Program Plan. Recommendations in that report relevant to TUGCO's license for the Comanche Peak Steam Electric Station at this time are:

1. The engine should have AE pistons or complete "lead-engine" tests as described in Section 2.3.2 of PNL-5161. (Confirmed in Section 3.7.4 herein.)
2. The diesel generator should not be required to carry a load in excess of that corresponding to an engine brake mean effective pressure (BMEP) of 185 psig. (Confirmed in Sections 6.1.1.)
3. The engine should be inspected per Section 2.3.2.1 of PNL-5161 to assure that the components are sound. (Confirmed in Sections 3.0 and 4.0.)
4. Preoperational testing should be performed as discussed in Section 2.3.2 of PNL-5161. (Confirmed in Section 6.1.)
5. The engines should receive enhanced surveillance and maintenance. (Discussed in Section 5.0.)

The significance of Recommendation 1, the AE piston skirts, is that relevant service experience (10^7 cycles) exists to provide empirical support of satisfactory analytical results. Recommendation 2 derives from the fact that this experience is at a level corresponding to the BMEP limit of 185 psig. Also, pending evaluation and approval of Owners' Group reports addressing crankshaft stress levels at higher loads, PNL considers the load corresponding to 185 psig BMEP to be reasonably conservative for the crankshaft. In addition, because of open items in the implementation of the Owners' Group Program Plan, an adequate basis does not yet exist to provide reasonable assurance that TDI diesel engines would operate reliably in nuclear service at power levels higher than those corresponding to a BMEP of 185 psig.

The other three recommendations are self-evident, namely that the engine has sound parts, that appropriate preoperational tests have been satisfactorily completed, and that a suitable program of surveillance and maintenance is established to assure future performance.

2.2 COMANCHE PEAK STEAM ELECTRIC STATION

In their efforts to establish the operability and reliability of CPSES TDI diesel engines, TUGCO has conducted a number of tests and inspections and has provided NRC with relevant letters and reports. Items considered in this Technical Evaluation Report are listed below.

- A letter dated April 30, 1984, from J. B. George (TUGCO) to H. R. Denton (NRC), "Comanche Peak Steam Electric Station Diesel Generator Requalification Program Plan." This document and attachment discuss diesel generator performance experience at CPSES and actions taken to enhance reliability. The testing and inspection program underway at CPSES is also outlined.
- A letter dated June 7, 1984, from J. B. George (TUGCO) to T. A. Ippolito (NRC), "CPSES Unit 1 Train A Diesel Generator Inspection Results." This document provides NRC with the Train A inspection results following engine disassembly in February and March 1984.

- A letter dated June 19, 1984, from B. J. Youngblood (NRC) to M. D. Spence (TUGCO), "TDI Diesel Generator Reliability Verification Required for the Licensing of the Comanche Peak Steam Electric Station, Unit 1." This document identifies plant-specific actions that must be taken by TUGCO prior to NRC licensing of CPSES.
- A letter dated June 29, 1984, from J. B. George (TUGCO) to T. A. Ippolito (NRC), "CPSES Unit 1 Train B Diesel Generator Inspection Results." This document provides NRC with the Train B inspection results following engine disassembly in February and March 1984.
- A letter dated August 1, 1984, from J. B. George (TUGCO) to B. J. Youngblood (NRC), "CPSES Diesel Generator Preventive Maintenance/Surveillance Schedules and TUGCO Responses to the Phase 1 Recommendations of the TDI Diesel Generator Owners' Group."
- A letter dated August 2, 1984, from B. J. Youngblood (NRC) to M. D. Spence (TUGCO), "TDI Diesel Generator Reliability Verification Required for the Licensing of the CPSES Unit 1." This document provides details of items to be included in TUGCO's future submittals. It also supplied TUGCO with a TDI maintenance/surveillance program approved by the NRC staff for the Grand Gulf Nuclear Station.
- A letter dated August 15, 1984, from J. B. George (TUGCO) to B. J. Youngblood (NRC), "Comprehensive Report on the CPSES Diesel Generator Requalification Program for Unit 1." This report provides details on the DR/QR done to date. It summarizes the results of the engine inspections, proposes a surveillance and maintenance program, describes CPSES diesel generator quality assurance activities, and sets out verification procedures to assure that the maximum emergency service loads are in compliance with a 185-psig BMEP limit.
- A letter dated August 17, 1984, from J. B. George (TUGCO) to B. J. Youngblood (NRC), "Errata Sheet for Comprehensive Report on the CPSES Diesel Generator Requalification Program for Unit 1." This errata sheet provided 14 changes to the August 15, 1984, submittal.

3.0 PHASE 1 COMPONENT PROBLEM RESOLUTION

This section documents PNL's evaluation of TUGCO's efforts to identify and resolve site-specific problems noted with the 16 generic components. These components had been identified by the Owners' Group in Phase 1 of the OGPP implementation.

The overall TUGCO inspection process is reviewed first. Then PNL's review, evaluation, and conclusions regarding TUGCO's component problem resolution efforts are described. It is very important to note that PNL's conclusions incorporate, generally without stating, TUGCO's commitment to the surveillance and maintenance program described in Section 5.0 of this TER, as well as the utility's commitment to implement, as appropriate, the applicable recommendations of the OG as soon as practicable.

3.1 TUGCO PHASE 1 INSPECTION

TUGCO began the Phase 1 inspections after each emergency diesel generator (EDG) had been operated for only approximately 92 hours. This total included the TDI shop runs of about 7 hours on each engine plus the required preoperational testing at CPSES.

3.1.1 Inspection Procedures

TUGCO disassembled each EDG, removing all parts normally disassembled for overhaul. This left intact the engine base, crankcase, cylinder blocks, crankshaft, and gearing (plus miscellaneous other components attached thereto, some of which were themselves inspected in place). Detailed inspections were performed on all but two Phase 1 components, on each engine. (Those are discussed below.) Additionally, some 45 Phase 2 components were inspected (some from only one of the two engines). Visual inspection, dimensional checking, and testing by material comparator, liquid penetrant, magnetic particle, ultrasonic, radiography, and eddy-current techniques were utilized, all to criteria established by the OG (where available) or to criteria thought by TUGCO to be conservative where Owners' Group criteria did not exist or were not fully detailed. Records were maintained for each part (or group); these records were

then subjected to a process of review, evaluation, and disposition, which was designed to maintain quality control.

The same procedures used for inspection and evaluation of the disassembled components were, in general, applied to all replacement parts (e.g., AE skirts, push rods, cylinder heads). Furthermore, TUGCO reports they have established enhanced onsite QA/QC oversight procedures at TDI's plant so that all future parts of significance will be adequately surveyed and the documentation checked before the parts leave that plant.

The decision to thoroughly disassemble and inspect both engines was made by TUGCO in early 1984, to be done in conjunction with the process of replacing the original AH piston skirts. (This was decided after an evaluation of them showed they were quite similar to the AF skirts about which serious questions on O/R had been raised within the industry.) This meant that some component inspection and quality control criteria were necessarily established locally, ahead of determinations on such items by the OG. However, TUGCO staff communicated with the OG staff on such items so as to both make and receive input constructive to the process.

3.1.2 Results/TUGCO Conclusions

A detailed description of TUGCO's Phase 1 inspection results is presented in Comprehensive Report on CPSES Diesel Generator Requalification Program for Unit 1 (George August 15, 1984). Based on those results, TUGCO concluded (p. 69) that:

1. The CPSES Unit 1 TDI diesel generators are adequate to perform their intended function.
2. Licensing of CPSES Unit 1 for first cycle operation is permissible while the remaining diesel generator open items in [their] report are being accomplished prior to fuel load.

The TUGCO report also noted that these two EDGs were purchased, manufactured, shipped, and installed at virtually the same time. Startup was roughly concurrent and, when disassembled, both had operated about the same number of hours. Inspection of Train B lagged that of Train A by a matter of only a few weeks. As noted previously, virtually the same inspections were made on each,

the exception relating mostly to the Phase 2 components. Identical changeouts were made to the as-received "generic component" items of piston skirts, cylinder heads, head studs, electrical cable, and push rods, all of which were inspected to the same sets of standards. All other components (such as turbocharger parts, bearings, and valves) replaced on an as-needed basis were checked against applicable TDI and OG standards.

3.2 PNL EVALUATION

PNL's review of TUGCO's Phase 1 component requalification efforts is documented in this section. Each generic problem component is discussed individually. The components are presented in a sequence reflective of their 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).

The components are described in terms of their function, operating history, and status as determined by the Owners' Group and TUGCO. Then, PNL's evaluation and conclusion(s) are presented for each component.

3.2.1 Engine Base and Bearing Caps

Part No. 02-0305A-D
Owners' Group Report FaAA-84-6-53

3.2.1.1 Component Function

The base itself supports the crankshaft and upper structures and carries the thrust of the cylinder combustion loads. The shaft is bended in half-circle bearings set within "saddles" in the base. The bear[illegible]ps are structural members that hold the upper bearing shells in place ov[illegible] shaft main journals while also absorbing the upward, reciprocating pis[illegible]rtial loads. The studs and nuts hold the cap (and shaft) in pl[illegible] failure of base, cap, or bolting would allow shaft motion or misalig[illegible]t, potentially leading to shaft fracture and seizure, sudden engine stoppage, and possible ignition of crankcase vapors (termed crankcase explosion).

3.2.1.2 Component Problem History

Two basic problems have occurred that warranted OG evaluation of this component as a generic Phase I issue:

- Saddle structures were found to be cracked in one engine base (an inline DSR4-8 engine) at Long Island Lighting Company's Shoreham Nuclear Power Station.
- On a non-nuclear application of a DSRV-16-4 engine a nut pocket failed on the through-bolting from the crankcase.

3.2.1.3 Owners' Group Status

Failure Analysis Associates (FaAA), as discussed in the Owners' Group report, has analyzed the base, bearing saddles, bearing caps, nut pockets, and bolting/nuts. FaAA has 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. They concluded that the failed nut pocket was due to impurities in the casting material. The pattern of saddle fractures at Shoreham was determined to be related to improper procedures in disassembly. The OG/FaAA report has not been finally evaluated by PNL to this date, pending resolution of several matters.

3.2.1.4 TUGCO Status

There have been no instances of failure or evident deficiency on CPSES Train A or B. Saddle and cap surfaces of both Train A and B were inspected visually and with liquid penetrant. There were no indications at all on Train B, nor on Train A caps. On Train A, however, there were linear indications on the journal Nos. 1, 3 and 9 bearing saddles. All were reported to the Owners' Group. Nos. 1 and 9 were evaluated as minor, acceptable casting flaws. The indication at No. 3 remains under TUGCO and OG evaluation. No cause was set forth by TUGCO; they report, however, that the preliminary conclusion drawn by the OG from fracture mechanics analysis is that there is a large factor of safety against propagation. Further, the OG gave conditional release to permit reassembly and preoperational testing.

According to TUGCO, material and dimensional characteristics will be documented in the Phase 2 report on CPSES engines.

The engines were reassembled in accordance with requirements on cleanliness and bolt torque. TUGCO contends the components are adequate and ready for their intended nuclear standby service.

3.2.1.5 PNL Evaluation and Conclusion

There is no indication of widespread, generic failure in bases or caps of TDI V-16 engines, either in general or at CPSES. Hence, there is no basis for fundamental concern at CPSES at this point. However, TUGCO should fully document its engineering disposition and technical justification of the indications found on the No. 3 bearing saddle for Train A. This should include the bases for its finding that there exists a large factor of safety against crack propagation. If the engineering disposition includes provisions for enhanced surveillance, this should also be documented. This documentation should be provided before final conclusions can be reached be PNL regarding acceptability of Train A for one refueling cycle operation.

With regard to Train B, PNL concludes that TUGCO has provided satisfactory evidence that the Train B engine base and associated components are free of deleterious indications. Thus, PNL believes they are acceptable for their intended EDG service.

3.2.2 Cylinder Block

Part No. 02-315A
Owners' Group Report FaAA-84-5-4

3.2.2.1 Component Function

Cylinder blocks (with their associated cylinder liners) contain the pistons. They are bolted to the vee-engine crankcase. The cylinder heads are bolted to the blocks; hence, the blocks are subject to the power forces from the cylinders. They also support the camshaft and other miscellaneous components and serve as the outer containments for the jacket water system. Depending upon its nature and location, a structural failure can lead to inadequate

support of the primary combustion and mechanical forces, with concomitant sudden engine shutdown.

3.2.2.2 Component Problem History

Several incidents of cylinder block cracking have been reported in non-nuclear TDI engine applications. In nuclear service, indications have been reported to date on engines at Shoreham and Comanche Peak. None has resulted in emergency shutdown or catastrophic failure. A number of engines have continued to operate many hours with known cracks.

Two basic problems have occurred that warranted OG evaluation of blocks as a generic Phase I issue:

- Supports for the camshaft were found cracked in Shoreham's inline engines.
- Cracks have been found in the upper reaches of various blocks. Most have been on the top surface, between the cylinder liner opening and adjacent head stud openings (ligament cracks); some, however, have been between stud openings in adjacent cylinders. At Comanche Peak "vertical" cracks have occurred in the area of the liner landings, but have not extended to the top surface. At least one instance of a circumferentially oriented crack along the liner landing (support ledge) itself has been reported, in the V-16 engine at St. Cloud, Florida.

3.2.2.3 Owners' Group Status

Failure Analysis Associates performed strain gauge testing combined with two-dimensional analytical modeling of block tops and liners. In their report, FaAA concluded, in part:

- Eventually, depending upon a combination of sufficiently high load and operating hours, and/or engine starts to high load, cracks can be expected to initiate between stud hole and liner openings. However, such cracks are predicted to be benign (e.g., nonpropagating) if the block materials are free of deleterious materials and properly cast, and if engine loads therein remain below the nominal 225 psig BMEP

rating. FaAA notes that some engines (such as those at Duke Power Company's Catawba Nuclear Station) have operated many hours at loads at and exceeding these levels without even initial crack indications. This is, in FaAA's opinion, indicative of the conservative nature of their evaluation.

- The initial development of ligament cracks between the stud hole and liner opening will increase the likelihood of more serious cracks developing between stud holes of adjacent cylinders. Therefore, the Owners' Group has recommended that engine blocks with ligament cracks be inspected by the eddy-current technique prior to the engine's return to standby service after any period of operation above no load.
- The FaAA report implies that, if block material is equal to or better than typical Class 40 grey iron, is properly cast, and has no initial cracks between stud holes of adjacent cylinders, the block of any engine can be expected to survive the service requirements of any LOOP/LOCA event (even to 225 psig BMEP).

The OG/FaAA report has not received full PNL evaluation to this date. However, PNL views FaAA's conclusions as reasonable and useful in evaluating the CPSES block for interim licensing actions. PNL has, however, expressed some concern over the effectiveness of eddy-current testing if cracks do not penetrate to the surface.

3.2.2.4 TUGCO Status

Up to the time of disassembly and inspection, each CPSES engine had operated approximately 92 hours. This operating history is too short to provide an adequate basis for evaluating fatigue experience of these engines. However, other V-16 engines with over 750 hours' service at loads exceeding 185 psig BMEP have developed no cracks.

All liner landing areas were inspected by liquid penetrant. The entire top faces of all four blocks (each bank, each engine) were examined by magnetic particle methods. Eddy-current examination was conducted in the region between studs of adjacent cylinders where experience with other engines indicates the

potential for cracks. Certain indications also were examined under 10X magnification, and all liner landing areas were checked dimensionally.

On Trains A and B, all dimensions were satisfactory. In addition, all block faces were satisfactory, with no indications between stud holes nor to liner openings.

On Train A, three liner landings showed indications (not extending to the block surface). One was evaluated as "nonrelevant". The other two remain under formal evaluation by the OG; TUGCO concludes from the OG generic report that, given ongoing monitoring, the block is serviceable.

On Train B, three landings showed indications similar to those of Train A, plus various other minor marks (determined to be machining marks). Most were evaluated as rounded, nonpropagating, and acceptable. The others were evaluated as acceptable casting shrinkages, but remain under OG investigation.

As noted, some aspects of these indications at CPSES remain under OG investigation and evaluation, including strain gauge monitoring of one Train A block. [Results will be reported in a supplement to the Phase 1 report and in the CPSES Phase 2 reports (in progress).]

TUGCO has committed to perform the block-top surveillance inspections (visual and eddy current) recommended by the OG report when ligament cracks exist, even though TUGCO contends the indications found are not ligament cracks. TUGCO concludes that these blocks are adequate for nuclear standby service.

3.2.2.5 PNL Evaluation and Conclusion

There is indication of cracking of cylinder blocks, in both nuclear and non-nuclear service. Therefore, the nontypical indications at CPSES warrant some attention.

In addition to the investigations and analyses already completed, TUGCO has committed to a program of monitoring its blocks, including eddy-current monitoring as recommended by the Owners' Group when ligament cracks exist. Furthermore, TUGCO has committed to limit its EDG operations to loads no higher

than 185 psig BMEP (i.e., 82% of nameplate rating) until final conclusions regarding the OGPP are reached by PNL and NRC; its evaluated LOOP and LOCA loads are well below 185 psig BMEP (the highest of which is 62% of engine rating, or 140 BMEP).

In light of the data provided, the commitments made to monitor, and the site-specific load expectations, PNL concludes that the blocks--both Train A and Train B--can be expected to operate reliably for their intended duty and can be placed in service at least through the first refueling cycle. The PNL concern regarding the inability of eddy-current to detect subsurface cracks is also mitigated by the TUGCO commitments and engine load limits. This conclusion is subject to confirmatory information regarding the strain gauge measurements of the Train A block.

3.2.3 Crankshaft

Part No. 02-310A

Owners' Group Report FaAA-84-4-16

3.2.3.1 Component Function

The crankshaft receives the reciprocating power strokes from the cylinders (via the connecting rods), converts them to rotary motion, and transfers the shaft power to the generator. It also drives the gear trains for operating cylinder head valves, etc. The crankshaft is supported in journal bearings in the engine base. The shaft is of machined steel and forged to the appropriate configuration. In TDI vee engines, opposite pistons are connected to the same throw by an articulated master/slave connecting rod arrangement. By means of holes drilled throughout the shaft and shaft journals, oil is picked up from main journal bearing supply points and transmitted to connecting rod bearings, link pins, wrist pins and undersides of the pistons, and other parts.

The shaft is subject to a variety of complex stress fields resulting from the piston thrusts, inertial effects of rotating and reciprocating masses, torsional vibrations, bending forces due to variations in support alignments, and stress fields reflective of oil holes, crankweb-to-journal interfaces, etc., as well as shaft material and fabrication influences, and operating conditions and accidents. The machined journal bearing surfaces are subject to

damage from oil impurities, bearing deterioration, and excessive heat. Failure, therefore, can come in various ways. At its worst, a shaft may actually break, leading to immediate shutdown and possible significant damage to numerous components. Other failures may evidence themselves less destructively and more gradually, and can sometimes be detected via monitoring, surveillance, and maintenance activities. However, generally speaking, significant occurrences are rare in engines of this general class (rating, speed, service).

Some of these incipient problems can be detected and avoided through periodic crankshaft deflection checks. These checks accomplish two basic purposes:

- detection of gradual shifts in shaft support internal to the engine (e.g., significant bearing deterioration)
- detection of changes in external engine support, as in the concrete foundation, loose foundation bolts, or a shift of shims between the foundation rails and the engine base plate.

3.2.3.2 Component Problem History

Three V-16 crankshaft failures have been reported, all in the non-nuclear industry. Two failures were attributed to torsional stress due to operation too close to the critical speed. No cause has been suggested for the third failure. There also have been failures of shafts of other TDI R-4 engine models, most notably one broken and two cracked shafts at Shoreham. Because of the engine-specific nature of shaft stresses, the Shoreham failure is not necessarily germane to V-16 engines in general nor to the Comanche Peak engines specifically. However, it did signal a justifiable cause of concern on TDI engines.

3.2.3.3 Owners' Group Status

The Owners' Group undertook in-depth Phase 1 analyses of the inline-8 shafts of Shoreham and the V-16 shafts at Mississippi Power & Light's Grand Gulf Nuclear Station. Only the latter are of similar design parameters and comparable operating conditions to the shafts at Comanche Peak. However, because of differences in generator and flywheel characteristics, the torsional

stresses would be somewhat different at each plant. Hence, as part of the OG Phase 2 efforts, the CPSES shafts are being evaluated separately.

The OG analysis on Grand Gulf drew generally favorable conclusions on adequacy for their intended service, with certain provisos or cautions:

- 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 (which, at Grand Gulf, was established as a 440 rpm lower limit).

PNL's review of the OG/FaAA report has yet to be finalized.

3.2.3.4 TUGCO Status

Upon disassembly to the point of crankshaft accessibility, TUGCO performed visual inspections of all crankpin journals on both engines. One journal on Train A and one on Train B had minor scoring marks; the former was honed out, while the latter was deemed too minor to need attention.

Because initial indications from the Shoreham problem emphasized crankpin fillet areas as most critical, TUGCO ran eddy-current examinations on seven crankpin journals of Train A and six on Train B, with no relevant indications.

No examinations were conducted on main journals, nor at oil holes anywhere. (The latter OG requirement was published after the CPSES inspections were underway.)

Hot and cold crankshaft deflection measurements were conducted on both engines following reassembly; they were completed within 40 minutes of shutdown. Results were reported in George (August 15, 1984). No evaluations were presented, but TUGCO has stated (and will confirm) they meet TDI standards. TUGCO has committed to the following actions:

- One engine will be torsiographed, at 25, 50, 75 and 100% loads (based on 225-psig BMEP ratings). No definite schedule was stated, but TUGCO has advised NRC it will be run the week of September 2, 1984.
- Oil holes on the three main journals recommended by the OG will be inspected on each engine, prior to fuel loading at CPSES, and reported to NRC and others.
- The engines will not be run below 450 rpm except at startup and shutdown.

Additionally, the Phase 2 DR/QR report will directly assess the design adequacy and quality of the shafts at CPSES (with, presumably, any appropriate adjustments to the above commitments).

On the basis of the OG analyses and conclusions on the Grand Gulf shafts, and with subject provisos outlined above, TUGCO concludes the Train A and B shafts are satisfactory for nuclear standby service.

3.2.3.5 PNL Evaluation and Conclusions

Based on its review of the information provided on the crankshaft, and subject to the following conditions, PNL concludes that the crankshafts for both the Train A and B engines are acceptable for service through the first refueling cycle.

- Customary engine operations will be limited to loads at or below 185 psig BMEP. Because the anticipated LOOP/LOCA loads are evaluated by TUGCO at 140 psig BMEP, this load limitation should not create safety concerns at CPSES Unit 1.
- The oil holes will be inspected prior to fuel loading per TUGCO commitment, with satisfactory results.
- The torsiograph will be completed by the same time, prior to fuel loading per TUGCO commitment, with satisfactory results.
- TUGCO or OG evaluation of hot and cold shaft deflections, determined to be within TDI specifications, will be submitted.

3.2.4 Connecting Rods

Part No. 02-340A

Owners' Group Report FaAA-84-3-14

3.2.4.1 Component Function

Connecting rods transmit the power thrusts between the pistons and the crankshaft. They are of forged steel, either round or H-shaped cross section. In TDI vee engines there are two types of rods. One is a master rod serving one bank, which is directly connected to the crankthrow (or crankpin) of the crankshaft. The other is the articulated link or slave rod, and is connected to the master rod via a link pin. The master rod lower end is split diagonally across the crankpin annulus. The mating surfaces, generally known as serrated joints, are machined as racks (i.e., with gear-like teeth) and bolted together.

Rods can fail in various ways. Of greatest concern in these engines is the possibility of breakage in the "rod box" in the vicinity of the link pin and/or failure of the bolts across the mating faces. Major failure will lead to instant damage to major parts of the engine. Lesser failures, as in the bearing support areas or link pin assembly, may lead to damage to bearings and journals, link or wrist pins, or even to piston seizure or a loose connecting rod (with possible major damage to the engine).

3.2.4.2 Component Problem History

Various connecting rod failures have been reported from the non-nuclear field. One failure mode was in the link-rod blade-to-pin bolting, due to loss of bolt preload. The other principal mode of failure was fatigue cracking of connecting rod bolts and/or the link rod box in the area of the mating threads. No connecting rod failures have occurred in nuclear service.

3.2.4.3 Owners' Group Status

In light of the problems in a few specific installations (nonnuclear), the OG undertook an in-depth evaluation of all known potentialities. The OG determined that the loss of preload on bolting between the link rod and link pin stemmed from an incorrectly sized locating dowel. The dowel's excessive length prevented proper bolting contact between pin and rod. Under firing-load

conditions the dowel would yield sufficiently in compression that the bolt preload would relax, with resultant fatigue problems. Replacement with dowels of proper length, followed by proper bolt preload, corrects the incipient problem.

The second failure mechanism was fatigue cracking of the cross-joint connecting rod bolts and/or the link rod box at the mating threads. TDI attributed these rod cracks to "thread fretting," which they concluded resulted from distortion of the rod bolt under operating loads in the area of the mating threads. The distortion could occur even if the bolts had been installed with the originally specified bolt preloads. The Owners' Group addressed this concern for the two versions of the connecting rod, namely the original design equipped with 1-7/8-inch bolts and a later design in which the rod boxes were equipped with 1-1/2-inch bolts. Stress analysis, including finite element studies, was done by FaAA. They concluded that both designs are adequate for the service intended, provided connecting rod bolt preload is regularly checked within specified time limits that are related to engine load requirement. However, the rod with the 1-1/2-inch bolts was found to have an 8% to 9% greater 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 Owners' Group recommends inspection by eddy current of the rod box threaded hole. Implementation of this recommendation has so far proven to be impractical.

Another area of concern was that of possible sideways bowing of the connecting rod, sometimes coming as a consequence of the forging process. FaAA computed the consequences and established a functional tolerance limit against which connecting rods should be checked.

The last area of possible failure was in the wrist pin (or piston pin) bushings, considered by TDI as a component of the connecting rod assembly. Several original and replacement bushings at Shoreham, in particular, were found to have indications on both inner and outer surfaces. FaAA evaluated these as interdendritic anomalies (casting defects), having little functional significance but best replaced where encountered.

3.2.4.4 TUGCO Status

TUGCO performed comprehensive inspections and examinations of the connecting rods and related parts on both Train A and B engines during their complete disassembly. The results were reported in George (August 15, 1984). A brief summary of those results follows.

For Train A:

- Visual inspection revealed many areas of galling on bolts, studs, washers, nuts, and bolt holes.
- Liquid penetrant inspection of certain surface areas on the link rod box, inner diameter of box bushings, and rack surface areas were deemed satisfactory, except for linear indications found on all connecting rod-box external surfaces.
- Magnetic particle testing was done on all bolts and studs, with satisfactory results reported.
- Eddy-current examination was conducted on "mating threads" (apparently meaning the female threads) of connecting rod boxes, with satisfactory results. (PNL subsequently reviewed this result in a telephone conversation with TUGCO and NRC in view of the difficulty encountered at other engines in conducting eddy-current tests. TUGCO agreed that the results were uncertain.)
- Material comparator and hardness tests were performed on all rods, rod-box areas, pins, and bushings, including spares, with satisfactory results.
- Dimensional checks of link pin locating dowels were all found to be satisfactory.
- Bolts were torqued to standards, using a calibrated hydraulic wrench.

The results for Train B were:

- Visual inspection revealed galling similar to that on Train A.
- Liquid penetrant inspection (on bushings only) revealed several areas of scoring.

- Magnetic particle examinations of rack areas and rod-box external surfaces revealed no indications.
- No eddy-current, material comparator, or hardness tests were conducted.
- Dimensional checks of link pin locating dowels all were satisfactory.
- Bolts were torqued to standards, using a calibrated hydraulic wrench.

The items with unsatisfactory indications were dispositioned as follows:

- Galled threads, etc., were honed; galled washers were replaced with hardened components.
- Linear indications on Train A rod-box external surfaces were determined to be babbitt smears to the rod-thrust face areas from the adjacent journal bearings, and were deemed nonrelevant.
- Except for one that was replaced, bushings with score marks were deemed acceptable.
- One link pin was replaced due to galling found while replacing bushings.

TUGCO did not check for connecting rod bowing because its inspection preceded the applicable OG report. Instead, TUGCO relied on inspection for bearing and bushing wear patterns as evidence of rod distortion. The results were deemed acceptable. TUGCO did not conduct nondestructive examination (NDE) inspections of the bolts and mating threads at the rod-box joint on Train B, relying instead on acceptable results from the Train A inspections as sufficient.

TUGCO reports that no unfavorable indications were found on relevant areas of the wrist-pin bushings on either engine as examined by liquid penetrant (LP) methods.

As a consequence of their inspections and analyses, and the dispositions made on unsatisfactory components, TUGCO believes that connecting rods of both engines now are fully adequate for their intended standby nuclear service.

3.2.4.5 PNL Evaluations and Conclusions

TDI and the Owners' Group each have conducted extensive investigations and analyses of the connecting rod failures. PNL has not been able to reach final closure on the sufficiency of their results, but generally concurs with their conclusions as to the failure mechanisms, subsequent corrective actions, and overall operability and reliability of the components if given sufficient surveillance and maintenance.

TUGCO has appropriately addressed the generic issue of potential connecting rod problems through comprehensive disassembly and inspection (with certain exceptions) and appropriate analysis, replacement and refurbishment. PNL remains concerned, however, about the following aspects:

- TUGCO's inspection by visual and LP examination of the rod-rack tooth surfaces did not reveal indications of concern. Yet PNL's representatives, in viewing these surfaces, saw numerous surface abnormalities--long, linear striations--on many teeth, often with matching indications on the mating surfaces. These indications were not considered to seriously affect the engine operability or reliability. PNL's consultants believed these evidenced the start of fretting that might result from inadequate bolt and joint preload.
- TUGCO did not lap the mating surfaces or check contact by "blueing" techniques in the reassembly of the engines. ("Blueing" is a process confirming mating surface contact area by using a thin surface coating of a chemical that, when pressed or rubbed against a mating surface, will indicate where contact is achieved.)
- PNL does not agree with TUGCO's contention that bearing and bushing wear patterns will, of themselves, establish clear proof of rod straightness. If indeed such bowing were to occur in forging, the process of boring for wrist, link and crank pins should provide end-connection alignment. Then only rod flexure, over a prolonged period, would show up in noticeable bearing wear patterns. Meanwhile, potential fatigue stresses would accumulate. However, this

area remains one of concern subject to findings of the OG strain-gauge testing on connecting rods.

- PNL representatives observed burrs and sharp edges at bolt hole openings in various rods at the master-slave joint, which represent potential stress risers.

Since publication of George (August 15, 1984), TUGCO has reported the following: 1) burrs and sharp edges were removed on bolt holes of Train B rods before reassembly; 2) the rod racks were "blued-in" at the TDI factory before original engine assembly; 3) upon being advised of PNL observers' concerns on the apparent fretting, TUGCO had those surfaces inspected by TDI personnel; TUGCO was informed the observed amount was typical of vee engines (even with so few hours of operation), but was encouraged to hone or stone any "raised" areas and then reassemble, which was done on Train B. PNL understands this information will be confirmed in writing to NRC. PNL believes this confirming document will alleviate concerns with respect to rod-rack tooth fretting and the potential for stress risers at bolt hole openings.

PNL concludes from all available and confirmatory information that the connecting rods on the Comanche Peak engines--both Train A and Train B--can safely and reliably perform their intended function through the first refueling cycle. This is stated with the following rationale and provisos:

- The CPSES engine connecting rod boxes have 1 1/2-inch bolts (rather than 1 7/8-inch bolts); this provides a rod-box structure with a higher factor of safety in the area of concern.
- The CPSES engines have very few service hours logged relative to service of engines when rod-box failures occurred (many thousands of hours).
- Engine operations will be limited to loads no higher than 185 psig BMEP. This will limit firing load effects on rack surfaces and bolting, and on any rod bowing.

- TUGCO conducts an adequate reinspection of the rod-box bolt tension at acceptable time intervals; and examines the condition of bolt-hole entrances and teeth, and rod straightness, at the first refueling outage.

3.2.5 Connecting Rod Bearing Shells

Part No. 02-340B
Owners' Group Report FaAA-84-31

3.2.5.1 Component Function

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

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

In light of the several 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.

3.2.5.2 Component Problem History

No significant failures of the TDI DSRV-type diesel engine connecting rod bearing shells have been reported in nuclear applications. However, some have been replaced because of deterioration due to inservice conditions or because they were found to be in nonconformance with Owners' Group recommendations regarding voids in the base material.

3.2.5.3 Owners' Group Status

Various problems were encountered in the inline TDI DSR engines at Shoreham. Edge cracking occurred, allegedly due to inappropriate bearing shell overhang beyond the support structure. In checking the cause, the OG also concluded that bearing serviceability was influenced by the number and size of subsurface voids in the aluminum castings, and subsequently established criteria for their detection and evaluation.

The OG has investigated both the Shoreham (inline) and Grand Gulf (vee) bearing shells. On their behalf, Failure Analysis Associates conducted various analyses. They concluded that the bearings are suitable for the intended service, provided 1) they conform to the manufacturer's specification and 2) they meet the criterion for subsurface voids developed by FaAA for the Owners' Group. Indeed, on the basis of their analyses of the Shoreham bearing conditions (reflecting their brief service operating hours and loads, etc.), FaAA concluded that the different, but generally similar, bearings in the vee engines can expect a 38,000-hour life at full load, if void criteria are met.

3.2.5.4 TUGCO Status

Both Train A and B EDGs were inspected by the following means:

- full dimensional measurement
- visual inspection for scoring, galling, cracks or excessive wear
- liquid penetrant inspection for linear indications
- radiographic inspection for internal defects.

On Train A, eddy-current testing was done on those linear indications requiring further evaluation.

In summary, the results for Train A were:

- All showed some visible markings; they were deemed reusable, except as noted below. (Wear was not referenced.)
- All showed some linear indications via LP test.
- Following radiographic and/or eddy-current inspection, one upper and four lower shells were rejected, and one upper shell was relegated to only lower service. All others were deemed reusable.

For Train B, TUGCO found:

- Ten shells had markings; they were deemed reusable except as noted below. (Wear was not referenced.)
- Four showed linear indications via LP test.
- Following radiographic inspection, three upper and one lower shells were rejected, which included three that had detectable visual or LP indications. All others were deemed reusable.

TUGCO concludes that, with the evaluations and replacements made, the connecting rod bearing shells in the reassembled engines are "adequate for service through the first cycle of operation."

3.2.5.5 PNL Evaluation and Conclusions

PNL representatives viewed bearing shells during the period of inspection of Train B, and noted numerous surface blemishes. No meaningful cavitation or erosion was seen. PNL also has reviewed both TUGCO and OG reports and certain documentation. The OG/FaAA conclusion extrapolating the brief Shoreham experience to 38,000 hours' expectable life on the larger-diameter vee bearings has not been accepted by PNL and its consultants.

PNL does conclude that, on the basis of engine loading limitations and monitoring of oil pressure and condition, the connecting rod bearings for both Train A and Train B will be adequate to operate reliably through the first refueling outage.

3.2.6 Piston Skirts

Part No. 02-341A

Owners' Group Reports FaAA-84-2-14 and FaAA-84-5-18

3.2.6.1 Component Function

The piston (as an assembly of piston crown and piston skirt, along with rings, piston pin, et al.) receives the thrust of combustion in the cylinder and transfers it to the connecting rod. The cast steel crown carries the immediate pressure load and thermal conditions; the skirt, of ductile iron, actually transfers the load to the piston pin/connecting rod and guides the reciprocating motion 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 reflect excessive pressure and thermal stresses, of both high-cycle and low-cycle character. Durability is affected by material selection and fabrication quality, as well as design characteristics. A crown separation will require immediate shutdown; it is likely to lead quickly to serious cylinder, head, and rod damage and piston seizure, with adverse impact on the crankshaft and possible crankcase explosion. Hence, adequate attachment of crown to skirt is a serious concern.

3.2.6.2 Component Problem History

TDI has utilized several skirt designs in R-4 engines, variously designated models AF, AH, AN, and AE. Most early nuclear service engines were furnished with AF and AH skirts, although one plant received AN skirts. The EDGs at CPSES were outfitted with AH skirts, which are reportedly quite similar to AF skirts.

Cracks have been found in a number of AF skirts, including earlier configurations of the TDI engines at Grand Gulf and Shoreham. The area of sensitivity was at a "boss" where the bolts join the crown and skirt together. Some skirts also have had problems at the interface of an internal, circumferential rib and the piston-pin boss. A redesign of the stud/boss area and attachment system (washers) constitutes the principal change from an AF to an AE model. No operational failures have been reported to date on the redesigned piston skirt in either nuclear or non-nuclear installations. Kodiak (a

baseload electrical generation station) has operated in excess of 6000 hours at approximately 185 psig BMEP (1200 psig maximum firing pressure) with AE skirts in a V-16 engine. A TDI R-5 test engine was operated in excess of 600 hours, with a maximum firing pressure of 2000 psig and BMEP of 275 psig, with a slightly modified AE skirt design, without known cracks.

3.2.6.3 Owners' Group Status

Piston skirts have been identified by the TDI Owners' Group as one of the generic problem components. The Owners' Group consultant, Failure Analysis Associates (FaAA), analyzed the AE piston skirt design and concluded that the AE skirts still may crack at 10% overload of nameplate rating (i.e., 248 BMEP), but that cracks will not propagate to the point of actual functional failure. Cracks have been analyzed to occur in the vicinity of the structural rib and bolting boss inside the skirt. The failure will occur primarily as a function of high-cycle fatigue (i.e., a large number of stress cycles, reflective of the piston's duty in absorbing and transmitting the power thrust). If materials of this nature can survive, under load, for 10^7 cycles, then they are generally capable of much longer (than 10^7 cycle) lives at that load. In four-cycle engines like these, operating at 450 rpm, 10^7 cycles will occur in 741 hours.

The issue of AE piston skirts was addressed by PNL in Section 4.0 of Review and Evaluation of TDI Diesel Generator Owners' Group Program Plan, PNL-5161 (June 1984), relative to nuclear plants seeking interim licensing (prior to finalization and full implementation of the OGPP). PNL concluded that plants with AE piston skirts expecting sustained emergency load requirements not exceeding 185 psig BMEP could logically and safely be licensed, because AE piston skirt testing to 10^7 cycles (740 hours) at or above this load has been confirmed.

3.2.6.4 TUGCO Status

None of the original AH skirts failed in their brief history at CPSES. Nevertheless, TUGCO elected to replace them with AE piston skirts. The AH skirts were not inspected upon removal (but reportedly some or all will be inspected at TDI). The new, replacement AE skirts were inspected, including LP examination in skirt boss areas. Three showed linear indications. Two of

these were eddy-current tested to determine depth of cracks; the depth of the third visibly extended through a "lip" of metal (the region that develops as a result of machining the washer landing into the skirt). All were determined by TUGCO (with advice of TDI and the OG) to be in supposedly noncritical areas of the skirt structure, so all were ground out to sound metal and satisfactorily LP-tested again. All were reinstalled.

Wrist pins of both engines were examined. Of the 32 total, six were found to have rejectable scoring, galling, pitting, chipping, or heat-checking. In a telephone conversation among TUGCO, NRC, and PNL, TUGCO reported that none was found to have linear indications. All were replaced. A sampling of wrist pins also was checked dimensionally and for materials and hardness, with satisfactory results.

The new skirts have no operational history at CPSES. However, predicated on the OG/FaAA analyses, the generally favorable history in service elsewhere, and the imposed operating limit of 185 psig BMEP, TUGCO concludes the skirts now in the engines will be adequate for service through the first operating cycle.

3.2.6.5 PNL Evaluation and Conclusions

PNL has reviewed the two applicable OG/FaAA generic reports on piston skirts and notes the successful operation reported for the TDI R-5 test engine equipped with AE piston skirts. On these bases, PNL concludes that the AE piston skirts can be expected to operate reliably through the first refueling cycle under conditions no higher than 185 psig BMEP. PNL notes that three new skirts were received from TDI with indications. These indications were ground out by TUGCO and satisfactorily reexamined to OG specifications. PNL concurs with TUGCO that, following successful preoperational testing, these skirts--of both Train A and Train B--can be expected to operate reliably at least through the first operating cycle.

3.2.7 Cylinder Liners

Part No. 02-315C
Owners' Group Report FaAA-84-5-4

3.2.7.1 Component Function

Engines of this size and character are designed with individual, removable cylinder liners, which fit inside the cylinder block. The liners contain the pistons and are capped at the upper end by the cylinder head. Thus, they act as containment for the firing forces, subject to the stress and heat thereof, and the reciprocating travel of the pistons. Their outer surfaces are cooled by jacket water circulating within the block. The lower end is sealed against an opening in the block floor 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 scraping 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. 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.

3.2.7.2 Component Problem History

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

3.2.7.3 Owners' Group Status

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

- The TDI design calls for the liner to protrude slightly above the top deck of the block, to ensure a tight, compressive fit against the head and gasket. However, this produces bending moments in the head

and substantial shear stresses on the cast iron liner landing of the block. Both aspects are suspect in some of the real or incipient failures in those components. TDI has approved remachining to reduce the protrusion.

- The design also calls for a tight fit between the outer ring of the liner ledge and the matching counterbore of the block. There is some concern by the Owners' Group that this could increase hoop stresses in the block, which might lead to block cracks.

3.2.7.4 TUGCO Status

In its inspection process, TUGCO verified that all cylinder dimensions were satisfactory. All liners also were inspected for signs of interior wear, scoring, or scuffing (although each engine had operated only 92 hours), and for marring at the liner/block interface.

One liner from Train A was replaced due to a casting flaw. Two liners on Train B were replaced due to undefined exterior surface indications. All others were deemed reusable as was, or with insignificant indications and spurious metallic surface coatings. All were honed to ensure that the new skirts and rings would seat properly.

TUGCO also machined all upper ledges so that the protrusion of the liner tops would be within TDI's revised standards.

One of the rejected liners is at FaAA for destructive examination; results will be reported in the CPSES Phase 2 report.

TUGCO concludes that the liners in these two EDGs at CPSES are adequate for nuclear standby service.

3.2.7.5 PNL Evaluation and Conclusions

PNL representatives viewed the liners removed from Train B, finding no surface indications of significance. In PNL's view , TUGCO has appropriately inspected the liners and taken proper action regarding findings. Regarding the possibility of hoop stress induced cracks, PNL notes that 1) there were no relevant findings at Comanche Peak, 2) TUGCO has agreed to frequent inspections for critical block cracks (see Section 3.2.2.4), and 3) TUGCO plans to imple-

ment any Owners' Group recommendations in this regard. PNL therefore concludes the liners are suitable for nuclear service pending receipt of confirmatory information regarding satisfactory results of the destructive examination of the liner sent to FaAA.

3.2.8 Cylinder Heads

Part No. 02-360A
Owners' Group Report FaAA-84-15-12

3.2.8.1 Component Function

The cylinder head caps the cylinder, providing (along with the liners) the enclosure needed to direct the combustion forces against the piston. Its lowest surface, facing the cylinder, is known as the firedeck. In the TDI design there are two intake and two exhaust valves in the flat surface of the firedeck, plus the fuel injector and an air starting valve. All these openings and their associated passageways have to be cast into the structure of the head, which, in itself, must also contain substantial internal jacket water (JW) passages for cooling. In addition to the firedeck there is a top deck or enclosure and an intermediate deck providing structural rigidity and control over JW flow.

The head is bolted to the cylinder block via a number of studs extending through the head from the block. On top of the cylinder head are two more components: the subcover or rocker box, which supports the valve actuating mechanisms, and a light top cover.

The TDI R-4 heads are cast of steel alloy. Casting a head of this complexity is difficult, particularly in steel. The internal passages are achieved via casting cores, which are challenging to hold in place during casting. Consequently, such heads have had a tendency to have uneven and/or incomplete sections. These can lead to a variety of flaws or indications, some of which can be repaired in the manufacturing and machining process.

Failures have tended to be mostly rather superficial linear indications with no consequential results. However, some deficiencies lead to warpages or cracks. The latter, if through to the JW passages, will result in leaks of water into the cylinder when the engine is down, and of combustion gases into

the JW during operation. The former can result in a "block" of water in the cylinder, which could severely damage head, piston, rod bearings, and shaft on startup.

3.2.8.2 Component Problem History

Numerous reports on TDI cast steel cylinder head failures are available from both the nuclear and non-nuclear industry. For identification purposes, TDI cylinder heads have been classified by FaAA as I, II and III, all under the same part number. Group I heads include those cast prior to October 1978; Group II heads are those cast between October 1978 and September 1980; and Group III comprises heads cast after September 1980. The distinctions involve both design changes to facilitate casting control and general quality control improvements. Most instances of cracked heads have involved Group I. Only five instances of water leaks in Group II and III heads have been reported, all in marine applications. Most of the reported cracks initiated at the stellited valve seats.

The most recent known head failure was reported by Mississippi Power & Light relevant to their Division I TDI diesel engine at Grand Gulf (letter to NRC dated July 30, 1984, AECM 84/0401). It reported a 2-inch through-wall crack in the right exhaust port casting surface between the valve seat area and the exhaust valve guide. This allowed jacket water to penetrate from the head cooling passages into the cylinder cavity, and was detected by barring-over the engine with 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. Of this total, approximately 335 operating hours were at 100% load (7000 kW, 225 psig BMEP) and 31 hours were at 110% load. This failure is still undergoing investigation; however, because MP&L knows of no occurrence of other similar failure, it concludes this was a unique, isolated event.

3.2.8.3 Owners' Group Status

The cylinder heads are included in the TDI Owners' Group generic problem category. Failure Analysis Associates' mechanical and thermal stress calculations, which did not include finite element calculations, concluded that Group I, II, and III heads, as designed, are adequate for the service intended.

The report recommends that Group I and II heads be 100% inspected by liquid penetrant, magnetic particle, and ultrasonic testing to determine firedeck thickness. For Group III heads, sample inspection as described above is recommended. For all three groups of heads, FaAA recommended rolling the engine over before manual startup, with cylinder cocks open, to assure no water has leaked into the cylinders.

3.2.8.4 TUGCO Status

In response to concern over heads of Group I and II--as originally furnished on the CPSES engines--TUGCO replaced all 32 heads on Unit 1, Trains A and B, with Group III heads. All new heads were inspected visually and by magnetic particle, liquid penetrant, and ultrasonic techniques. All were dispositioned as acceptable by TUGCO.

Predicated on 1) improved manufacturing practices at TDI reflected in the Group III heads, 2) TUGCO's satisfactory results in inspecting them, and 3) the favorable conclusions claimed in the OG review of the latest head grouping, TUGCO concludes that the new heads now installed in Trains A and B are adequate for standby nuclear service.

3.2.8.5 PNL Evaluation and Conclusions

In general, PNL concurs that, with the following provisos, the Group III TDI R-4 heads should serve satisfactorily for both Train A and Train B engines through the first refueling cycle:

- Engines should be air-rolled over with cylinder cocks open 4 to 8 hours, and again at 24 hours, after any operation, and thereafter prior to any planned start, to detect any water leakage into the cylinders.
- The engines should be limited to loads of 185 psig BMEP or less (as already committed to by TUGCO).

3.2.9 Cylinder Head Studs

Part No. 02-315E

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

3.2.9.1 Component Function

Eight studs per cylinder are used to bolt the heads to the cylinder block. Together they transmit the power load from the head to the block.

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

3.2.9.2 Component Problem History

TDI has employed two basic stud designs recently. One is of straight shank diameter. 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 also reduces the preload needed to maintain positive stresses during the firing cycle.

To date, no failure of cylinder head studs 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.

3.2.9.3 Owners' Group Status

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

3.2.9.4 TUGCO Status

The CPSES engines were furnished originally with the straight-shank stud design. In light of evolving concern over these, TUGCO decided to replace all

(128 per engine) with 256 studs of the newest design; replacement was done in the recent reassembly.

Of the original studs, 32 were given material tests (with satisfactory conclusions). The new studs have documented material properties, so were not rechecked by TUGCO.

Of the original 256 studs, four were given careful visual inspection. Galling (at the bottom washer interface) and other marks were evidenced on all. Additionally, three showed areas of heavy rusting; no further comment has been made on causes, but TUGCO has recently advised NRC that rusting was prevalent on many studs. They characterized the rust as typical of atmospheric-induced rust during storage.

TUGCO concludes, from the OG/SWECo evaluation, that these replacement studs are satisfactory for their intended service.

3.2.9.5 PNL Evaluation and Conclusions

PNL finds that TUGCO's actions to replace all studs with those of the necked-down design and documented material properties are acceptable. PNL believes TUGCO's explanations of the bolt rust is reasonable.

PNL has learned that TUGCOO has confirmed to NRC that these bolts were installed with proper preloading. PNL therefore concludes that the studs now installed will be reliable for normal nuclear standby service, for Train A and Train B.

3.2.10 Push Rods

Part No. 02-390C & D
Owners' Group Report FaAA-84-3-17

3.2.10.1 Component Function

Push rods transmit the cam action from the camshaft on the engine side to the intake and exhaust valves in the head. One main rod extends from the camshaft to the subcover where it acts directly on the intake valve rocker arms. The second main rod transfers cam action to an intermediate rocker in the subcover and on through an intermediate push rod to the exhaust valve rocker arms. They are subject to high-acceleration compressive forces 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.

3.2.10.2 Component Problem History

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

3.2.10.3 Owners' Group Status

Because industry (both nuclear and non-nuclear) had expressed substantial 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 has performed stress analyses as well as stress tests to 10^7 cycles on a sample of 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, with no adverse results, beyond 10^7 cycles.

FaAA, in their analyses, concludes this design is serviceable as required, but does provide stipulations for inspection and action, including destructive examination of a random sample from each plant.

3.2.10.4 TUGCO Status

Following 92 hours of operation, TUGCO inspected four of its original push rods of the ball-end type. Three had rejectable indications in the fillet welds, though none had actually failed. TUGCO decided to replace all push rods, an action which, in conjunction with a decision to also substitute AE for AH piston skirts, triggered the whole process of engine inspection at CPSES at this early date.

All ball-end push rods were replaced with friction-welded rods. Satisfactory LP tests were run on the welds. However, TUGCO has appealed to the OG its requirement for destructive testing of a sample rod, believing that the tests run, coupled with the OG generic report conclusions, obviate the need. In a telephone discussion among TUGCO, NRC, and PNL, TUGCO reported that the OG has informed them that destructive tests are not currently needed. They recommend instead that a random check be made of new purchases, to confirm manufacturing quality.

TUGCO concludes that the new rods, as installed, are reliably serviceable for their standby nuclear service.

3.2.10.5 PNL Evaluation and Conclusions

After reviewing the FaAA report, the TUGCO actions and reports, and examining push rods in extended service elsewhere, PNL concludes that such rods of the friction-welded design are satisfactory for their intended purpose in both Train A and Train B. Based on successful operating history, PNL concurs with the revised Owners' Group recommendations regarding destructive testing.

3.2.11 Rocker Arm Capscrews

Part No. 02-390G

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

3.2.11.1 Component Function

The rocker arm capscrews bolt in place the rocker arm shaft bearing caps in the subcover assemblies. They are 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.

3.2.11.2 Component Problem History

Rocker arm capscrew failures at Shoreham have been reported. There have been no reports of similar failures elsewhere.

3.2.11.3 Owners' Group Status

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

3.2.11.4 TUGCO Status

The capscrews at CPSES are of the necked-down model. Pursuant to OG/SWECo analyses and recommendations, TUGCO examined the capscrews from the disassembled heads by magnetic particle inspection, with favorable results. However, no material verification was performed, as had been recommended; TUGCO now proposes to do this before fuel loading, while crankshaft oil holes are being inspected.

The capscrews were reinstalled at recommended torques. TUGCO concludes--subject to favorable material verification--that they are properly serviceable for their intended function at CPSES.

3.2.11.5 PNL Evaluation and Conclusions

PNL concludes, from the OG analyses and the inspection results at CPSES, and from observation of high-cycle operating results on identical components elsewhere, that TUGCO's conclusion is acceptable. PNL concurs that the capscrews are serviceable as intended, subject to the TUGCO planned material confirmation prior to fuel loading.

3.2.12 Turbochargers

Part No. MP022/3

Owners' Group Report FaAA-84-5-7

3.2.12.1 Component Function

The turbochargers (two per engine) provide 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. The associated housing ducts the air and exhaust to and from the two rotors, and holds the inlet vanes of the turbine, which 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--over 10,000 rpm.

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

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

The turbochargers on the CPSES TDI DSR V-16 engines are model 90G units manufactured by the Elliott Company.

3.2.12.2 Component Problem History

Various problems have occurred in the turbochargers on TDI DSR-4 engines in nuclear service. The principal one has been the rapid deterioration of the combination turbine thrust/radial bearings. There also have been concerns over missing exhaust inlet vanes, missing or broken bolts joining the exhaust manifold to the turbocharger at the inlet, and broken bolts and welds in support mounts. To date, thrust bearing problems have evidenced themselves at the Comanche Peak, Shoreham, Catawba, and San Onofre nuclear plants.

Because nuclear EDGs have 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 did not provide adequate lubrication on the bearing thrust pads and rotor thrust collars under fast startup conditions to high loads. TDI instituted 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.

3.2.12.3 Owners' Group Status

In 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.)
- 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 whatever nature. Inspection should also be done following 40 starts without manual prelube.

An OG supplementary report dealing with turbocharger vanes and inlet capscrews has yet to be released.

3.2.12.4 TUGCO Status

TUGCO instituted the drip system on the Unit 1 EDGs in 1980, prior to EDG operation. When the engines were disassembled early in 1984, all four turbochargers were thoroughly inspected.

Train A inspections, conducted after 67 local starts and 92 hours total operation, revealed that:

- Bearings were scratched, scored, pitted, and had lost babbitt. They were replaced.
- Several turbine blades, fan blades, and nozzle vanes were nicked, pitted, or bent. Shafts, thrust collars, and oil seals were unsatisfactory. Rotors were replaced, but stator components were deemed acceptable and returned to service.

Results for Train B, inspected after 83 local starts and 92 hours total operation, were:

- Bearings were worn, scratched, and scored. On one bank they were replaced; on the other, the entire turbocharger was replaced.
- Turbine and fan blades and nozzle vanes were variously nicked and gouged. One vane was missing from the right bank nozzle ring. Welds in the centerplug of both were broken. The right bank turbocharger assembly was totally replaced; appropriate replacements and repairs were made on the left bank unit.

In addition to these maintenance efforts, TUGCO has committed to the basics of the OG plan for turbocharger modifications, operations and maintenance, including inspection of the turbocharger thrust bearings of any engine experiencing 40 fast starts (starts without manual prelubrication of the bearings).

After making the cited changes, and in light of the OG/FaAA analyses that claim satisfactory O/R if their recommendations are followed (which TUGCO has agreed to), TUGCO concludes these turbochargers now installed will adequately perform their intended function through the first operating cycle, unless they experience an abnormally high number of starts. (TUGCO's August 15, 1984,

submittal provides information that Train A has had another 45 starts, Train B another 54, since these maintenance activities, as of mid-August 1984. TUGCO has informed PNL and NRC that all of these utilized manual prelube prior to the start.)

3.2.12.5 PNL Evaluation and Conclusions

PNL has reviewed the FaAA report referenced above, the results of the June 22, 1984, meeting among representatives of FaAA, the Owners' Group, NRC, and PNL, and the inspection data presented by TUGCO. During the Comanche Peak site visit on May 24 and 25, 1984, PNL examined the Train B engine turbocharger bearings, which were scored and substantially worn. PNL also has examined the prelube system at other, similar plants. On these bases, PNL concludes that a similar new prelube system now installed on the diesels at CPSES 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 will not lead to bearing failure prior to the first refueling outage. PNL notes that TUGCO has agreed to modify the drip lubrication system in accordance with the latest TDI recommendations. PNL also notes that TUGCO has established a planned program of relevant surveillance and maintenance and, at the first refueling outage, has agreed to implement the OG recommendations for inspections. It is expected that TUGCO will also appropriately comply with OG recommendations regarding capscrews, vanes, and mounting and supports that may result from the Phase 2 DR/QR.

On the bases of the above, PNL concludes that the turbochargers at CPSES Unit 1--Train A and Train B--are adequately operable and reliable until the first refueling outage.

3.2.13 Jacket Water Pump

Part No. 02-425A

Owners' Group Report Emergency Diesel Generator Engine Driven Jacket Water Pump Design Review (SWECo April 1984)

3.2.13.1 Component Function

The engine driven jacket water pump furnishes water to the engine jackets (i.e., the cylinder block surrounding the liners) and thence to the heads.

Water is also sent to the turbocharger jackets. They are customary centrifugal pumps, driven by a power takeoff from the front-end gear case.

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

3.2.13.2 Component Problem History

A TDI engine at Shoreham has experienced a jacket water pump shaft failure. There is no history of failures on jacket water pumps designed for the V-16 engines.

3.2.13.3 Owners' Group Status

Stone & Webster has investigated the jacket water pumps as installed on the TDI in-line and vee engines. They reviewed these jacket water pumps from the standpoints of mechanical design, material suitability, and hydraulic performance. Stone & Webster found the pumps such as those installed on the Comanche Peak Train A and B engines to be acceptable, with a recommendation that a limiting torque be established for the pump shaft nut holding the "external spline" in the shaft taper.

3.2.13.4 TUGCO Status

During inspection, both Train A and B pumps were examined. Material comparator and hardness tests on Train A were satisfactory. Excessive wear was noted on the Train A wear ring, which exhibited galling, and the impeller was loose on the shaft. The Train B impeller back plate was found deformed (possibly due to disassembly efforts). The Train A pump was replaced totally; the Train B pump impeller was replaced.

TUGCO concludes that, with these steps taken and the spline nuts properly torqued, the pumps are now ready for their intended service.

3.2.13.5 PNL Evaluation and Conclusions

PNL concurs with TUGCO and concludes that these pumps--for Train A and Train B--are serviceable for their intended use in the Comanche Peak EDGs.

3.2.14 High-Pressure Fuel Oil Tubing

Part No. 02-365C

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

3.2.14.1 Component Function

The high-pressure fuel oil tubing carries the fuel oil from the cam-driven injection pumps on the engine sides to the injector nozzles 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, etc., will release oil in high-pressure bursts, with consequential fire risks.

3.2.14.2 Component Problem History

High-pressure (HP) fuel tubing leaks have developed during preoperational engine testing on Shoreham and Grand Gulf engines. There are no other reported failures in nuclear application.

3.2.14.3 Owners' Group Status

Stone & Webster has analyzed the failed HP fuel tubing and has concluded that the failures originated in inner surface flaws that were initiated during fabrication. If, through eddy-current inspection, the inner surface condition of new tubing is found to be within the manufacturer's specification, Stone & Webster has concluded the HP 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" to protect against open oil sprays in the event of future leakages.

3.2.14.4 TUGCO Status

TUGCO has decided to proceed with full replacement. Hence, no inspections were made on the original lines, which, having given no previous difficulty at CPSES, were returned to temporary service. When the replacement lines, with shrouds, are received, they will receive the OG recommended inspections and subsequent monitoring. This is due to take place before fuel loading.

Upon the satisfactory installation and inspection of the replacement lines, TUGCO concludes this component will be satisfactory for future EDG service.

3.2.14.5 PNL Evaluation and Conclusions

PNL concurs with TUGCO, relative to both Train A and Train B.

3.2.15 Air Starting Valve Capscrews

Part No. Gg-032-114

Owners' Group Report Emergency Diesel Generator Air Start Valve Capscrew Dimension and Stress Analysis (SWECo April 1984)

3.2.15.1 Component Function

These capscrews bolt in place on the head of the air start valves, which admit starting air to the cylinder. A failure, or an inappropriately long capscrew, will not keep the starting valve assembly in correct contact with its seat, with consequential risk of damage as high-pressure combustion gases escape.

3.2.15.2 Component Problem History

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

3.2.15.3 Owners' Group Status

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

3.2.15.4 TUGCO Status

Upon receiving a 10 CFR 21 report from TDI in 1982, TUGCO checked all capscrews and shortened them as necessary. During the recent engine inspections, lengths were reverified, and torque checks were run after 8 hours of operation.

The OG recommended, in the supplemental report, that a sampling of capscrews be checked for material selection. TUGCO will do so prior to fuel loading.

TUGCO maintains that, subject to the material verification, these capscrews and their reinstallation meet TDI and OG requirements and are adequate for standby nuclear service.

3.2.15.5 PNL Evaluation and Conclusions

The actions taken by TUGCO to eliminate the potential interference would appear to be adequate to prevent any subsequent failures. PNL concludes that, with the continued use of TUGCO's installation procedures to control torque of bolts, studs, and screws to specified ranges, these components will not present future problems on the CPSES engines, and concludes these components--on Train A and Train B--are operable and reliable for their intended service.

3.2.16 Engine-Mounted Electrical Cable

Part No. 02-688B

Owners' Group Report SWECo No. DR4-210-013

3.2.16.1 Component Function

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

3.2.16.2 Component Problem History

No failure of these cables has been reported. However, a TDI service information memo warned of potentially defective engine-mounted cables.

3.2.16.3 Owners' Group Status

Analyses of the subject wiring, and of the recommended replacements, were conducted by Stone & Webster Engineering Corporation, both generically and specifically for TUGCO. The replacement cable and terminations were deemed serviceable for this duty.

3.2.16.4 TUGCO Status

In response to the original service information, TUGCO performed a complete review of all engine-mounted cable. All unsuitable cable was replaced

appropriately. Based on this action, TUGCO did not reinspect the cable during the recent inspection process.

TUGCO concludes that the engine-mounted electrical cable at CPSES is suitable for its intended nuclear standby service.

3.2.16.5 PNL Evaluation and Conclusions

Predicated on the evidence furnished, PNL concurs and concludes that the subject cables--on Train A and Train B--are serviceable for their intended use at CPSES.

4.0 PHASE 2 COMPONENT REQUALIFICATION

Toward the goal of requalifying the Train A and Train B engines, TUGCO inspected other significant engine components identified by the Owners' Group technical staff in Phase 2 of the OGPP implementation. This section describes the DR/QR inspection program conducted at CPSES and the results reported. PNL's evaluation of TUGCO's Phase 2 efforts is then presented, along with conclusions drawn from that evaluation.

4.1 TUGCO PHASE 2 PROGRAM INSPECTION

Train A and B engine inspections were performed in accordance with component selection and inspection plans developed by the Owners' Group specifically for CPSES.

4.1.1 Inspection Procedures

Procedures used in Phase 2 inspections were largely the same as those used in Phase 1. The inspection plans were carried out by TUGCO maintenance personnel following CPSES QA/QC procedures. These procedures included the preparation of Maintenance Action Requests delineating the requalification action required. Components found to have indications were documented on TUGCO Nonconformance Reports. These were subsequently dispositioned by TUGCO engineering and QA as to 1) use as is, 2) repair/rework, or 3) replace. Each replaced component was subjected to the same inspection protocol.

Results for Train A Phase 2 inspections are reported in George (June 7, 1984); Train B results are presented in George (June 29, 1984). These two documents are supplemented by a summary section in George (August 15, 1984).

4.1.2 Results/TUGCO Conclusions

The complete list of Phase 2 component inspection results is given in Table 4.1. The Train A and Train B components included in the inspection are provided, along with an indication of whether the results were satisfactory or unsatisfactory; a blank indicates the component was not inspected.

TABLE 4.1. Phase 2 Component Inspection Results

Item	Part Number	Train A	Train B
Lube oil fittings, internal header piping	02-307A	S[a]	
Lube oil fittings, internal header tubing and fittings	02-307B	S	
Lube oil fittings, internal header piping and tubing supports	02-307D	S	
Crankshaft main bearing shells	02-310B	U[b]	U
Crankcase assembly	02-311A	S	S
Cylinder block, liner, and manifold nuts	02-315F	U	U
Jacket water inlet manifold coupling	02-316B		S
Water discharge manifold, coupling, and seals	02-317B		S
Flywheel bolting	02-330B	S	
Front gearcase gaskets and bolting	02-335B	S	
Piston rings	02-341B	S	
Tappets and guides, intake and exhaust tappet assembly rollers	02-345A	S	S
Tappets and guides, fuel tappet assembly rollers	02-345B	S	S
Camshaft	02-350A	S	S
Camshaft supports, bolting and gear	02-350C	U	S
Idler gear assembly, crank to pump gear set	02-355A	S	S
Idler gear assembly, idler gears	02-355B	S	S
Idler gear assembly, bolting and gaskets	02-355C		U
Air start valve	02-359	S	U
Cylinder head valves, intake and exhaust	02-360B	U	U
Cylinder head valve cover gaskets	02-360C		S
Valve springs	02-360D	S	S
Cylinder head subcovers, subcover assembly	02-362A	U	U
Fuel pump, linkage/control shaft	02-371A	S	

(a) S = Satisfactory
(b) U = Unsatisfactory

TABLE 4.1. (contd)

Item	Part Number	Train A	Train B
Fuel pump linkage/bearings	02-371B	S[a]	S
Intake manifolds	02-375	U[b]	U
Exhaust manifold bolting and gaskets	02-380B	U	U
Cylinder block covers, gaskets and bolts	02-385B	S	
Cylinder block covers, gaskets and mounting hardware	02-386B	S	S
Rocker arms and push rods, intermediate/intake rocker shaft assembly	02-390A	U	S
Rocker arms and push rods, exhaust rocker shaft assembly	02-390B	S	S
Rocker arms and push rods, lifters	02-390F	U	U
Overspeed trip, governor and accessory drive assembly	02-410B	U	S
Overspeed trip couplings, flexible and spider	02-410C	U	S
Governor drive gear shaft coupling	02-411A	S	S
Governor drive coupling	02-411B	S	S
Governor linkage	02-413	U	S
Governor assembly heat exchangers	02-415C	S	S
Intercooler piping coupling	02-436B	S	S
Starting air distributor assembly	02-442A	U	
Turbocharger bracket-air butterfly valve assembly, with actuator	02-475B	U	S
Turbocharger bracket, bolting and gaskets	02-475D	U	U
Control panel assembly terminal boards, switches, and wiring	02-500N	U	U
Lube oil sump tank, miscellaneous fittings, gasket, pipe and valve bolting materials	02-540B	S	

(a) S = Satisfactory
(b) U = Unsatisfactory

All items listed in Table 4.1 that have at least one S and no U are considered satisfactory by TUGCO. An S means that the component passed all the inspections without exceeding allowable criteria and that no repair or replacement was needed. A U denotes failure to comply with criteria in effect at the time of the inspection. In discussions with NRC and PNL, TUGCO noted that some components (viz., air start distributor) could now be considered satisfactory because the acceptance criteria applied by TUGCO at the time led to some components being rejected that would be accepted under the OG criteria. When more than one unit of a component was tested and one of those units did not pass the inspection, the result was a U in Table 4.1.

In George (August 15, 1984) TUGCO provides summary details of the findings and disposition of the unsatisfactory findings for Train A and B components. In evaluating the TUGCO Phase 2 U components, PNL has elected to consider them in two categories: those U components with any conditions found that could influence the engines' function, and those U components considered to be less consequential. This subdivision is useful in reviewing the evaluation and conclusions provided in Section 4.2.2 of this TER. Tables 4.2 and 4.3 provide the TUGCO inspection results in these two categories, respectively.

4.2 PNL EVALUATION

4.2.1 Methodology

The PNL evaluation is based largely on a review of the three documents describing the inspection plans and results (George June 7, June 29, and August 15, 1984). This review is supplemented by a visit to TUGCO on May 23 and 24, 1984, during which PNL and its consultants briefly reviewed the Phase 2 revalidation process. This included a sampling review of inspection plans and Nonconformance Reports and their disposition. Backup photographs and files were viewed also.

4.2.2 Findings and Conclusions

On the basis of information provided to date, the TUGCO inspection procedures and acceptance criteria are considered adequate. The PNL sampling inspection of records suggests that adequate records are kept and that any

TABLE 4.2. Defective Components That Could Significantly Affect Engine Operability/Reliability

Component/(TDI Part No.)	TUGCO Findings/Actions
Crankshaft main bearing shells (02-310B). This component supports and aligns the crankshaft, its failure will lead to engine shutdown.	Train A - No. 10 upper and lower shells were replaced because of indications that extended through the babbitt overlay into the base metal [LP,[a] VI,[b] DI[c]].
	Train B - No. 1 upper shell showed rejectable linear indications and No. 10 lower shell was galled. Both were replaced with spares (LP, VI, DI).
Camshaft support bolting (02-350C). These bolts support the camshaft. The engine can operate with some bolts loosened but sufficient loss of bolt support can lead to engine shutdown.	Train A - 16 bolt holes would not permit 1-1/4-inch bolts without bottoming out. New 1-inch bolts were installed at all 16 locations. Sufficient thread engagement is provided with the 1-inch bolts for proper torqueing [TO[d] for bolts, MA[e] and VI for gears].
Cylinder head valves, intake and exhaust (02-360B). These valves control air into the cylinders and exhaust out of the cylinders; minor leakage is tolerable.	Nearly all valves showed evidence of inadequate seating, scuffing or erosion of stems and/or scuffing or pitting of valve stem contact areas. Three valves required replacement and the rest are being machined to fit the new cylinder heads (VI, DI, LP of stem/head blended radius).
Cylinder head subcovers (02 [illegible]2A). These elements support the rocker shafts and their structural integrity is essential to engine performance.	Train A - three subcovers were replaced with satisfactory spares because of rejectable linear indications (VI, LP).
	Train B - an unsatisfactory weld repair area was noted on the web area of subcover 7L. Linear indications were also found by inspection on subcovers 7L, 6L and 8R in the boss areas. These were replaced with satisfactory spares (VI, LP).

(a) LP = liquid penetrant inspection
(b) VI = visual inspection
(c) DI = dimensional inspection
(d) TO = torque verification
(e) MA = material verification

TABLE 4.2. (contd)

Component/(TDI Part No.)	TUGCO Findings/Actions
Intake Manifolds (02-375). The elbow flange helps support manifold and seals gasket. Leakage will degrade engine output.	Train A - intake manifold elbow no. 8L had a corner broken off of the head flange and was replaced with a satisfactory spare [VI[(a)]]. Train B - intake elbow 8R was replaced with a satisfactory spare because of two broken-off corners and elongated bolt holes (VI).
Rocker arms, intermediate rocker shaft assembly (02-390A). This assembly transmits cam motion to valves and its operation is essential to engine operation.	Train A - chips or linear indications in three intermediate rocker arms resulted in replacement with satisfactory spares for two rocker arms and refurbishment of the other [VI, DI,[(b)] MA[(c)]].
Starting air distributor assembly (02-442A). This assembly sends starting air to cylinders. It is essential for startup.	Train A - both assemblies were replaced because of "excessive wear" (VI).
Turbocharger bracket, bolting and gaskets (02-475D). This bracket supports the turbocharger. Some missing bolts can be tolerated; however, loss of turbocharger seriously reduces engine power.	Train A - 24 bolts on the right bank were found to have insufficient thread engagement, and were properly retorqued. One bolt was replaced with a modified bolt because of stripped bolt hole threads. Missing lockwashers were also replaced where necessary [VI, VID[(d)]]. Train B - five bolts without grade 5 markings were replaced with grade 5 bolts.

(a) VI = visual inspection
(b) DI = dimensional inspection
(c) MA = material verification
(d) VID = visual inspection of identification markings

TABLE 4.3. Defective Components That Will Not Significantly Affect Engine Operability/Reliability

Component/(TDI Part No.)	TUGCO Findings/Actions
Cylinder Block, Liner and Manifold Nuts (02-315F)	Train A - 48 of 128 nuts had no identifying marks. LP was satisfactory and all nuts were reinstalled in the engine [VI,[a] TO,[b] LP[c]].
	Train B - four nuts on cylinder head No. 8R had forging laps extending across the flat onto the machined face, and were replaced with satisfactory spares.
Idler Gear Assembly (02-355C)	Train B - because of a number of different markings and lengths on camshaft cover and idler gear cover bolting, all bolts have been replaced with 1-1/4-inch grade 5 bolts to ensure uniformity (except for four camshaft cover bolts which require 1-inch bolts because of shorter hole depths) [VI, DI, VID[d]].
Air Start Valve (02-359)	Train B - a layer of carbon deposition was cleaned from the valves (VI, DI, TO).
Exhaust Manifold Bolting and Gaskets (02-380B)	Train A - one bolt was too long, one bolt was of the incorrect material, and two bolts were damaged. All four of these bolts were replaced with satisfactory bolts of the new socket head type (TO, DI, VI).
	Train B - nine bolts were found to be of incorrect length. All of the bolts on Train B are being replaced with the latest TDI socket head type. Only 48 were available for reassembly; however, the remaining 16, which are satisfactory, will be replaced later (DI, VID).

(a) VI = visual inspection
(b) TO = torque verification
(c) LP = liquid penetrant inspection
(d) VID = visual inspection of identification markings

TABLE 4.3. (contd)

Component/(TDI Part No.)	TUGCO Findings/Actions
Valve Lifters (02-390F)	Train A - four lifters did not pass the leak down rate test and were replaced with satisfactory spares [VI,[a] LP[b]].
	Train B - 32 of 64 lifters did not pass the leak down rate test. 57 satisfactory spares were available and were installed with 7 of the original satisfactory lifters (VI, LP).
Overspeed Trip, Governor, and Accessory Drive (02-410B)	Train A - a missing locking clip on one bolt and a missing lockwire on one coupling capscrew were replaced [DI,[c] MA[d] on shaft].
Overspeed Trip Coupling (02-410C)	Train A - coupling spider showed some peeling and couplings had some nicks. Spider was replaced with a satisfactory spare and the couplings were refurbished. Neoprene peeling on the spider was caused by burrs or discontinuities on the coupling, which were removed. A missing setscrew was also replaced (VI).
Governor Linkage (02-413)	Train A - some rust, but no pitting, was noticed on the linkage. Rust was removed prior to reinstallation (VI).
Turbocharger Bracket - Air Butterfly Valve Assembly (02-475B)	Train A - right bank shaft showed some pitting at 3 locations and was refurbished [VI, VID[e]].
Control Panel Assembly (02-500N)	Train A and Train B - cleaning of assembly was required (VI).

(a) VI = visual inspection
(b) LP = liquid penetrant inspection
(c) DI = dimensional inspection
(d) MA = material verification
(e) VID = visual inspection of identification markings.

component's history can be reconstructed. It is noted that the TUGCO DR/QR reports have not been issued as of this date, so the PNL evaluation does not provide conclusions relative to the Phase 2 revalidation program for the CPSES. Consequently, the adequacy or completeness of the components selected by the Owners' Group for the CPSES Phase 2 revalidation program is not evaluated here. PNL has concluded that interim licensing action is not contingent upon the OG Phase 2 completion (Pacific Northwest Laboratory June 1984, p. 10). In reviewing the Phase 2 component revalidation, PNL noted that TUGCO states that they have addressed 45 components (George August 15, 1984, p. 5), whereas only 44 component findings are reported. In a telephone conversation with NRC, TUGCO reported that 44 is the correct number due to the method TUGCO later used to account for the wrist pin (as part of the connecting rod).

4.2.2.1 Satisfactory Components

PNL notes that there are components found satisfactory by TUGCO for one engine but not inspected for the other engine. In those cases it is PNL's judgment that that same component in the other engine need not be inspected. The probability for significant findings is considered small. PNL considers all components found satisfactory are adequate to perform their intended function both for Train A and Train B.

4.2.2.2 Defective Components That Could Affect Engine Operability/Reliability

In general, the TUGCO Component Revalidation Checklist and accompanying QA Inspection Plans do not provide any indication of the underlying cause for the rejectable indications reported. Presumably this will be supplied in the DR/QR submittal to NRC. In the absence of TUGCO's presenting a definite cause (PNL acknowledges that in many instances the cause may be indeterminable and inconsequential), PNL consultants have applied judgment, based on experience with other engines, to evaluate the adequacy of the TUGCO actions to remedy the problem.

Two items, camshaft bolting (02-350B) and turbocharger support bolting (02-475D), appear to be assembly errors. No further problem is anticipated following the TUGCO repair/replacement actions. PNL notes that the camshaft

bolting problem is not the same problem encountered at the Shoreham Nuclear Power Station where cracks occurred in a region of the block that supports the camshaft. This region is different in the straight and vee engine designs. However, failure of any bolts or threads can have serious consequences.

The main bearing shells (02-310B), rocker arms (02-390A), and subcovers (02-362A) all had generally minor indications. No cause was supplied by TUGCO. In view of the low number of operating hours, and based on previous experience, PNL consultants believe manufacturing defects (especially the faulty weld repair in the subcover) or minor abrasives in the lubricant could cause the indications noted. All replacement parts were inspected to the Owners' Group specification. PNL judges the possibility of recurrence to be small, and considers TUGCO's actions adequate for these components to serve their intended functions.

Intake and exhaust valves (02-360B) showed more than normal surface distress but no fundamental weakness. The pattern of poor seating could indicate poor QA/QC procedures in manufacturing. The scuffing or scoring of the chrome is common and of little concern. PNL considers TUGCO's actions appropriate and adequate for these components to serve their intended functions.

The intake manifold flanges (02-375) on both Train A and Train B engines were found to have broken corners and, on Train B, the bolt holes were found to be elongated. No explanation was presented in TUGCO's comprehensive report (George August 15, 1984), but in a subsequent telephone communication to NRC and PNL, TUGCO noted that the corner breaks were minor and of no significance to the serviceability of the flanged connection. On the basis of this explanation, PNL concludes these components are serviceable.

Both standby air distributors (02-442A) on the Train A engine exhibited "excessive wear" and were replaced. This raised the concern of PNL, in that a similar inspection of Train B was not conducted. In a later telephone communication to NRC and PNL, TUGCO advised that the condition of the components was subsequently checked with the Owners' Group due to uncertainty on inspection standards. TUGCO was advised that the wear encountered was normal; hence, Train B was not inspected.

PNL noted that failure of a starting air distributor would compromise engine reliability. Because the wear was deemed excessive at the time by TUGCO inspection personnel, after only 67 starts onsite, PNL remains concerned and recommends that distributors on Train B be inspected before the Train B engine can be considered qualified for nuclear service.

4.2.2.3 Defective Components That Will Not Significantly Affect Engine Operability/Reliability

PNL has reviewed the significant indications reported by TUGCO (see Table 4.3) and believes that the actions taken by TUGCO are adequate. PNL concludes that the repaired and replacement parts will serve their intended function in the Train A and Train B engines.

5.0 PROPOSED MAINTENANCE, INSPECTION AND SURVEILLANCE PROGRAM

While evaluating the Owners' Group Program Plan, PNL recognized that a comprehensive maintenance and surveillance (M/S) program would be a key aspect of the overall effort to assure future TDI diesel engine operability and reliability, and so stated in its formal review of the OGPP (Pacific Northwest Laboratory June 1984). Recognizing that the Owners' Group Program Plan had not yet specifically addressed M/S activities, PNL recommended that the Owners' Group develop a definitive M/S program (in consultation with TDI), and that detailed plans based on those Owners' Group recommendations be developed for each engine installation by the individual owners.

The need for an enhanced M/S plan was further identified for nuclear stations seeking licensing actions prior to the completion of all elements of the OGPP (Pacific Northwest Laboratory June 1984, Sec. 4.0). Some elements of such an enhanced M/S plan were initially identified by PNL in letters of April 16 and 17, 1984, to C. Berlinger at NRC (dealing specifically with Mississippi Power & Light's Grand Gulf Nuclear Station). The features of the enhanced M/S program suggested by PNL were subsequently incorporated by the NRC staff in a letter to MP&L dated April 25, 1984, re: "Evaluation of the TDI Diesel Generator Reliability for Power Operations at GGNS."

In a letter (Youngblood August 2, 1984), NRC requested that TUGCO describe their enhanced M/S program. This section reviews TUGCO's response. This review responds to the information supplied to date by TUGCO. The review is not intended to address the broader issue of adequate surveillance and maintenance that is being addressed by the Owners' Group. It is considered likely that additions/modifications to the M/S program will be required following the OG recommendations.

5.1 MAINTENANCE AND INSPECTION PLAN

TUGCO has reviewed the OGPP Phase I M/S recommendations and revised their CPSES Unit 1 M/S schedules as documented in George (August 15, 1984).

Section 8, "CPSES Unit 1 Diesel Generator Preventative Maintenance and Surveillance Program" is the specific reference in George (August 15, 1984).

5.1.1 Elements and Rationale

Tables 5.1 and 5.2 present a comparison of TUGCO's proposed maintenance schedule, the earlier NRC guidance, and current PNL recommendations. Items are arranged in the same sequence philosophy as used in Section 3.0 of this TER (viz., structural components; power train components; ancillary and auxiliary components and systems; and generally from the bottom of the engine to the top).

5.1.2 PNL Evaluation and Recommendations

The TUGCO M/S proposals do provide coverage of a number of items and systems considered key to maintaining engine operability and reliability. They should be deemed applicable to each engine. However, in reviewing TUGCO's proposals, PNL noted several important components and systems that were not incorporated in the list, as well as areas where TUGCO's proposal should be revised. The items listed in both Tables 5.1 and 5.2 are deemed by PNL to deserve periodic observation, evaluation, and maintenance, as appropriate. PNL's recommendations presented in Tables 5.1 and 5.2 related to maintenance actions beyond the first refueling cycle (i.e., PNL concurrence with TUGCO's long-range maintenance plans) are necessarily tentative.

PNL feels that NRC should require that the items listed in Table 5.1 be incorporated into TUGCO's surveillance and maintenance program. These are:

- foundation and foundation bolting
- engine block and base
- crankshaft
- main bearing shells
- connecting rods
- connecting rod bearing shells
- pistons
- cylinder liner
- cylinder head
- cylinder valve springs and hydraulic lifters
- rocker arms, push rods, tappets, cams, and camshaft
- gear train
- turbocharger
- air start valves
- air start distributor filter
- studs and fixtures
- jacket water pump
- lube oil duplex filter
- lube oil check.

TABLE 5.1. Comparison of TUGCO's Proposed Maintenance Plan: Items That Should Be Incorporated into TUGCO's Plan

Component	NRC Guidance (April 25)	TUGCO Proposal (August 1)	PNL Recommendations
Foundation & Foundation Bolting		Check for bolt preload NOTE: Sole plate and grout to be inspected at this time (every refueling outage)	Concur with TUGCO
Engine Block and Base	Visually inspect after 24 hours operation or monthly	(not listed by TUGCO, but committed to OG plan)	Visually inspect daily during operation; with intensely lighted inspection monthly, while operating. Eddy current tests as specified by OG. Inspection of the camshaft support in the galleries at times of maintenance.
Crankshaft	Hot and cold every 6 months; hot within 15 minutes of shutdown	Hot and cold deflection measurement (every refueling outage)	Once each refueling cycle; hot to start in 15 minutes, complete within 30 minutes
Main Bearing Shells		Visual exam and dimensional verification of thickness. NOTE: The procedure for this inspection includes cleanliness and bolt preload requirements (every 2nd refueling outage)	Sampling and inspection procedure to be developed from from Owners Group and/or two highly loaded bearings at every 2nd refueling outage.
Connecting Rods	Visually inspect and retorque after 24 starts, 50 hours of operation, or 6 months, whichever is first	(Not listed by TUGCO)	Visual surface inspection of external surface and bolt preload check each 200 hours or 9 months, whichever is first

TABLE 5.1. (contd)

Component	NRC Guidance (April 25)	TUGCO Proposal (August 1)	PNL Recommendations
Connecting Rod Bearing Shells		Measure bearing clearance, bump method. NOTE: Inside of engine will be examined for abnormal conditions during this time (every refueling outage)	Pull 2 sets of pistons-examine conrod bearings (at first refueling outage) Measure bearing clearance (every refueling outage)
Pistons		(not listed by TUGCO)	Pull 2 sets of pistons for examination; all others visual bottom side exam (boroscope) (first refueling outage)
Cylinder Liner		Boroscope inspection (every refueling outage)	Visual (every refueling outage) Measure/record (every dis-assembly/overhaul)
Cylinder Heads	Air-roll 4 hours after engine runs and each day thereafter	(not listed by TUGCO)	Air-roll 4 to 8 hours after engine runs, and again after 24 hours and prior to planned starts. Inspect four heads at first refueling.
Cylinder Valve Springs and Hydraulic Lifters		Visual exam for proper operation and adjustment (every refueling outage)	Concur with TUGCO
Rocker Arms, Push Rods, Tappets, Cams, Camshaft	Visually check after pre-operational testing and after each 24 hours of operation	Visually check at each refueling outage	Visually check (at each refueling outage)

TABLE 5.1. (contd)

Component	NRC Guidance (April 25)	TUGCO Proposal (August 1)	PNL Recommendations
Gear Train		1) Visual check of lube oil spray jets and visual exam of gears (every refueling outage) 2) dimensional verification of backlash and thrust (every 2nd refueling outage)	Visual (every outage) Backlash and thrust (every 2nd refueling outage)
Turbocharger		1) Teardown, check rotor float and stationary nozzle ring bolts (after 40 auto starts or 100 starts or first refueling outage, whichever comes first) 2) Teardown, includes visual exam of all major components verification of bearing running clearances, blue check of thrust bearing and replacement of nozzle ring bolts (every 3rd refueling outage)	Concur with TUGCO
Air Start Valves		Teardown, with visual examination; verify valve seat contacting, refurbish as required. Each refueling cycle	Concur with TUGCO
Air Start Distribution Filter		Inspect; clean. Replace as required each month.	Concur with TUGCO

TABLE 5.1. (contd)

Component	NRC Guidance (April 25)	TUGCO Proposal (August 1)	PNL Recommendations
Studs and Fixtures	Spot check 25% monthly for torque	Air start valve capscrews 100%, re-torque after a minimum of 8 hours of running whenever bolts are disturbed	Check 100% of air starts valve capscrews and 25% of all other items at each refueling outage
Jacket Water Pump			Train A and B - disassemble/ examine for shaft galling, worn wear rings, warped backing plate (first refueling outage)
Lube Oil Duplex Filter		Drain sludge or water each 3 months. Inspect, clean; replace as required at pressure drop of 20 psig, or each refueling cycle, whichever is first	Concur with TUGCO
Lube Oil Check	Check for water following pre-operational tests, then weekly or after 24 hours of operation whichever is first. Check monthly for contaminants and water in sump; check filters	Sample. This sample is taken during the monthly surveillance test at the inlet to the lube oil filter. NOTE: Sample sent off-site for full spectro-chemical analysis (monthly)	Check for water following pre-operational tests, then monthly or after 24 hours of operation, whichever is first. Check for chemical and particulate contamination on same schedule. The sample should be collected while the engine is running. Check filter pressure drop hourly during operation

The maintenance items noted in Table 5.2 are considered to be good practice. PNL feels they should be carefully considered by TUGCO in establishing its maintenance plan; however, PNL is not recommending that NRC require TUGCO to incorporate them into its maintenance program. These items are:

- fuel injection pump
- fuel injection nozzle
- fuel pump and governor linkage
- governor
- air start valve admission valve strainer
- intake air filter
- fuel oil drip tank
- fuel oil filter; fuel oil duplex strainer (02-455B)
- fuel oil duplex strainer (02-825E)
- lube oil sump tank
- lube oil heat exchanger
- lube oil keep warm filter
- lube oil strainer
- jacket water system
- jacket water heat exchanger
- engine performance.

Since issuing their Comprehensive Report (George August 15, 1984), TUGCO has informed NRC and PNL that a comprehensive M/S plan will be published shortly by the Owners' Group. TUGCO will adopt it, as appropriate, in lieu of their current proposal. PNL believes that this should be reviewed with the idea, as a minimum, of incorporating the PNL recommendations outlined in Tables 5.1 and 5.2 if they are not included in the OG plan.

The following sections provide PNL recommendations and the supporting discussion relative to the M/S plans presented in Table 5.1 *where PNL recommendations differ from TUGCO plans.*

5.1.2.1 Engine Block and Base

TUGCO provides no maintenance plan for the engine block and base.

A vee engine has three primary structural components: the base, the crankcase, and the cylinder block. The history of problems in the population of TDI engines as reported by the Owners' Group, and relevant analyses by TDI and the Owners' Group, lead PNL to conclude that there is no significant likelihood of failures to occur in the base and crankcase in external locations where they are visibly discernible. However, there has been a substantial history of cracks on the top of the cylinder block, some of which are visibly

TABLE 5.2. Comparison of TUGCO's Proposed Maintenance Plan: Items to be Considered in Establishing TUGCO's Plan

Component	NRC Guidance (April 25)	TUGCO Proposal (August 1)	PNL Recommendations
Fuel Injection Pump		Teardown, includes visual exam, verification of dimensions and refurbishment as required (every 2nd refueling outage)	Verify calibration/operation (every 3rd refueling outage)
Fuel Injection Nozzles		Teardown, includes visual exam of contact surfaces, setpoint verification and refurbishment as required	Check popping pressure and spray pattern characteristics (every refueling outage)
Fuel Pump and Governor Linkage		Inspect and lubricate (yearly)	Inspect and lubricate (monthly)
Governor		Change oil (every refueling outage)	Concur with TUGCO
Air Start Admission Valve Strainer		Inspect; clean as required each 3 months	Concur with TUGCO
Intake Air Filter		Inspect, clean; replace as required; each 6 months	Concur with TUGCO
Fuel Oil Drip Tank		Drain and clean; each refueling outage	Check monthly; drain and clean as required
Fuel Oil Filter; Fuel Oil Duplex Strainer (02-455B)		Inspect, clean. Replace as required. At pressure drop of 20 psig or each refueling, whichever comes first	Concur with TUGCO

TABLE 5.2. (contd)

Component	NRC Guidance (April 25)	TUGCO Proposal (August 1)	PNL Recommendations
Fuel Oil Duplex Strainer (02-825E)		Inspect, clean as required (each refueling cycle)	Concur with TUGCO
Fuel Oil Transfer Pump Strainer		Inspect, clean as required. At pressure drop of 7 psig or each refueling cycle, whichever comes first	Concur with TUGCO
Lube Oil Sump Tank		Clean and inspect each refueling cycle	Concur with TUGCO
Lube Oil Heat Exchanger		Inspect, clean as required. Every 2nd refueling cycle	Concur with TUGCO
Lube Oil Keep Warm Filter		Inspect, clean or replace as required. At pressure drop of 20 psig or each refueling outage, whichever is first	Concur with TUGCO
Lube Oil Strainer		Drain sludge or water each 3 months. Inspect, clean; replace as required at pressure drop of 20 psig, or each refueling cycle, whichever is first	Concur with TUGCO

TABLE 5.2. (contd)

Component	NRC Guidance (April 25)	TUGCO Proposal (August 1)	PNL Recommendations
Jacket Water System		Check pH, conductivity and corrosion inhibitor each month	Concur with TUGCO
Jacket Water Heat Exchanger		Inspect, clean as required each 2nd refueling	Concur with TUGCO
Engine Performance		Cold compression check; maximum firing pressure check. Each refueling.	Concur with TUGCO

discernible and/or detectable by NDE methods without head removal. The Owners' Group generic issue report (FaAA-84-15-12) calls for careful surveillance of this surface on certain engines, but at unspecified intervals.

TUGCO did not address the routine inspection/maintenane of the engine block and base.

In light of the history of block cracks at CPSES, the FaAA analysis, and the unresolved status of indications at 4R and 5R (Train A) and 1R and 4R (Train B), PNL agrees with TUGCO that there remains legitimate reason to maintain enhanced surveillance of the blocks, at least through the first opportunity for heads-off reinspection and until a more definitive resolution of the problem is established by the Owners' Group and TUGCO. Furthermore, because of the problems encountered in the inline engines, PNL feels it would be prudent to inspect the cylinder block camshaft gallery in the vicinity of the camshaft support at each maintenance interval.

PNL Recommendation

In addition to the inspections recommended by the OG and committed to by TUGCO, PNL recommends routine daily visual inspection of the block and box external surfaces during operating periods, with a more thorough inspection under strong lighting at least monthly. These should be conducted while the engine is operating.

PNL also recommends that, at the first refueling outage, the respective indications noted in Trains A and B should be reinspected for propagation, and that OG recommendations for heads-on eddy-current testing (or approved substitute) be followed (to which TUGCO has committed).

5.1.2.2 Crankshaft Deflection Checks

TUGCO proposes hot and cold crankshaft deflection checks each refueling outage, but does not commit to a time after engine shutdown to initiate and complete these checks.

Two purposes are accomplished in crankshaft deflection checks:

- detection of gradual shifts in shaft support internal to the engine (most likely being significant bearing deterioration)

- detection of changes in external engine support, as in the concrete foundation, or a shift of shims between the foundation rails and the engine base plate. (The foundation will change shape with prolonged engine operation, tending to hump toward the middle due to thermal growth, which must be corrected by appropriately shimming the engine. It may also undergo long-term permanent change as chemical processes continue within the concrete.)

PNL Recommendations

PNL recommends that TUGCO take hot and cold deflection readings at every refueling outage. The hot deflection checks 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.

5.1.2.3 Main Bearing Shells

TUGCO proposes to inspect all shells at every second refueling outage. PNL recommends a sampling inspection following disassembly/overhaul.

In general, the main bearing shells on the CPSES engines have not been a problem area. Four bearing halves were replaced due to linear and galling indications; the remainder were deemed acceptable for use. TUGCO proposed a visual exam and dimensional verification of all bearing thicknesses every second outage. This is not consistent with the amount of disassembly being proposed on other components of the engine that have to be removed for access to the main bearings.

PNL therefore feels that, although the TUGCO proposed maintenance is acceptable, this frequency and magnitude of inspection may engender unwarranted engine unavailability. PNL feels the maintenance plan should be developed as a function of experience in this application. Factors taken into account should recognize the greater than normal function of wear due to minimal lubrication that occurs during the starting and stopping cycles of the engine.

PNL Recommendations

A sampling and inspection program should be developed from the Owners' Group information. For the interim, two highly-loaded bearings (identified in FaAA reports as Bearings 5 and 6) should be inspected at each second refueling outage. Associated caps and saddles should be checked also.

5.1.2.4 Connecting Rods

TUGCO provides no maintenance plan for the connecting rods. PNL recommends visual inspection of connecting rod boxes and checks of bolt preload every 200 hours of operation or 9 months, whichever is first.

In light of the history in the TDI engine population (however limited) of connecting rod link-rod box cracking, bolting problems (viz., some galling, some preload relaxation, some failures), and fretting along contact areas of the serrated teeth, some regular visual inspection and bolt retorquing (or equivalent checking) is deemed warranted. The relevant Owners' Group generic issue report (FaAA-84-3-14) recommends that the interval on bolt retorquing not exceed 200 hours of operation at full load (i.e., manufacturer's rated load), 248 hours at 85% load, or 285 hours at 75% load. In making that recommendation, FaAA provided no differentiation between connecting rods having 1-1/2-inch bolts and those with 1-7/8-inch bolts. Although the history of 1-1/2-inch bolting is reportedly better, it apparently is not totally devoid of problems (either experientially or analytically). Thus, even by the Owners' Group's own analysis, the establishment of an enhanced surveillance plan is deemed prudent.

TUGCO does not propose any surveillance for the connecting rods or bolting systems. Recognizing that TUGCO reassembled the connecting rods before verification of tooth contact could be made, it is recommended that a definite surveillance plan (e.g., external inspection and checking bolt torque) should be in effect.

PNL Recommendation

PNL recommends visual inspection of all rod box external surface areas and bolt preload check each 200 hours of operation after post-inspection reassembly or 9 months, whichever occurs first.

As compared to NRC's original proposal and the Owners' Group recommendations, this approach should conservatively address the load levels for LOOP and LOCA events for CPSES's units, as well as all preoperational testing following engine reassembly, and the possible impacts of low-cycle fatigue associated with a multitude of starts. At the same time, this revised pattern will reduce the cumulative downtime required, thereby enhancing engine availability.

5.1.2.5 Connecting Rod Bearing Shells

TUGCO proposes to measure bearing clearance at every refueling outage. PNL recommends a sampling inspection of bearings themselves, as well as bearing clearance, at each refueling outage.

The Owners' Group Phase I design review report (FaAA-84-3-1) concluded that the bearings were adequate at site loads for up to 38,000 hours, or ten times the lifetime expected usage. TUGCO, in turn, has based its inspection criteria on these findings. PNL is not in complete agreement with this philosophy due to the duty cycle of the engines and the high number of starts they will experience.

Each engine start effectively influences the rate of wear (increased) between 10 to 100 times the normal rate of wear on the bearings. In addition, putting the engines on high loads soon after starting also increases bearing wear rate more than does a more relaxed load application. Thus, the bearing wear may easily exceed the predicted rate. TUGCO's approach, therefore, requires modification to allow for visual inspection of bearing sets that may be suffering from galling, wiping, cavitation or load-induced damage. This can be a sensitive area with aluminum bearings.

PNL Recommendations

PNL recommends inspecting these bearings (two sets of pistons) by visual and radiography methods at the first refueling outage; obtaining product oil contamination analyses; and monitoring bearing clearance at every refueling outage.

5.1.2.6 Pistons

TUGCO provides no maintenance plan for the piston skirts. PNL recommends a sampling inspection at the first refueling outage.

The family of piston skirts (AN, AH, AF, AE) in the R-4 series of engines has experienced various types of failures. The Owners' Group discovered this history when the structural integrity of the AF and AE piston skirts was investigated by Failure Analysis Associates (FaAA-84-2-14). TUGCO's EDG units were originally furnished with type AH piston skirts, which have subsequently been replaced with AE skirts. Several of the new retrofitted and installed AE pistons required relief grinding due to crack/linear indications. The AE piston experience is limited to one location in Alaska, which has not been subjected to a full inspection with documented results.

TUGCO did not address maintenance level or interval.

PNL Recommendations

PNL recommends that two sets of pistons (four pistons) be disassembled at the first refueling outage and inspected for crack indications per procedures recommended by the Owners' Group.

5.1.2.7 Cylinder Liners

TUGCO proposes boroscope inspection at every refueling outage. PNL concurs and recommends dimensional check for wear at every disassembly.

Cylinder liners now installed in CPSES Unit 1 were machined and honed prior to installation of the type AE piston skirts. In addition, dimensional verification was satisfactory. Pending the Phase II report by Failure Analysis Associates on the liners, they are considered acceptable.

However, TUGCO did not indicate any measurement of wear on the liners. Because liner wear provides an important indication of engine operability and reliability, it should be monitored whenever possible.

PNL Recommendations

All liners should be visually inspected at each refueling outage, to check for any scuffing or metal deposition. In addition, the liners should be measured for wear at every disassembly, and the dimensions recorded for trend analysis.

5.1.2.8 Cylinder Heads

TUGCO provides no maintenance plan for the cylinder heads. PNL recommends a schedule of engine air-rolls to detect water leakage.

Air-rolling the engine is done to detect water in the cylinder, which would indicate a cracked cylinder head (or liner), with water not drained to crankcase. Any substantial water accumulation in a cylinder could lead to severe damage to head, piston, crankshaft, and/or bearings on engine startup, and could seriously impact engine operability. TUGCO has not addressed this in their proposal.

PNL Recommendations

PNL 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.

The basis for the change from the earlier NRC guidance, based on PNL recommendations (which called for air-rolling the engine every 24 hours), is the recognition that, if a leak of substantial, detectable proportions has not occurred within the first 24 hours of cooldown, it is unlikely that one will develop before the next engine operation. However, because it is still possible, although not likely, for a small leak to seep and accumulate (i.e., the water be retained by the piston rings), it remains prudent to check for the presence of water before any planned start.

The desirability of air-rolling the engine was further substantiated recently by the occurrence of just such a leak, detected by barring-over the engine, at Grand Gulf Nuclear Station.

PNL also recommends removal of four heads and visual and LP inspection of the firedeck at first refueling.

5.1.2.9 Rocker Arms, Push Rods, Cams, Camshaft

TUGCO proposes visual checks at each refueling outage. PNL concurs, differing slightly from NRC guidance.

Engine operability is affected by defects in push rods, cams, tappets, and other similar components and their supporting structures. Some of these components at CPSES have shown indications. Hence, regular visual inspection is needed, although few operating hours are anticipated. The difference between the NRC guidance (after 24 hours of operation) and the TUGCO proposal is not considered significant, in light of the low wear rate or limited likelihood of structural failure for these components, for two reasons: 1) all parts will have been inspected recently and 2) in the opinion of the PNL consultants, very little change in the condition of these parts is expected during the 50- to 200-hour operating time involved in the CPSES operation.

PNL Recommendations

PNL considers the TUGCO proposal acceptable.

5.1.2.10 Fuel Injection Pumps

TUGCO proposes refurbishment at every second refueling outage. PNL recommends in addition a calibration/operation check at each third refueling outage.

Fuel injection pumps on the CPSES Train A and B engines have not been a source of problems. TUGCO proposes to completely disassemble all pumps at every second refueling outage. Due to the precision and close-tolerance nature of the fuel injection pumps, they can easily be damaged during a disassembly, thus requiring replacement of parts when otherwise unnecessary. Fuel injection pumps can be checked for proper operation and calibration at any reliable diesel service center; faulty or questionable pumps can then be put aside for

disassembly. It is important to note that the same test should be performed on all pumps after reassembly, should they be disassembled.

PNL Recommendations

PNL does not otherwise object to pump inspection every second refueling cycle, but suggests TUGCO verify calibration and operation of all fuel injection pumps at every third refueling outage. Should other tests or operating surveillance (i.e., cylinder firing pressure or exhaust temperature) indicate a potential fuel pump problem, verification of the suspect pump should be performed at that indication.

5.1.2.11 Fuel Injection Nozzles

TUGCO proposes refurbishment as required. PNL recommends that "popping" pressure and spray pattern checks be performed at each refueling outage.

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

PNL Recommendations

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

5.1.2.12 Fuel Pump and Governor Linkage

TUGCO proposes yearly inspection/lubrication. PNL recommends weekly inspection and monthly lubrication.

Rusted/pitted fuel pump and governor linkage can result in unstable engine load and speed response. Considering the potential for high humidity

associated with plant siting and the relatively long-term standby periods, it would be prudent to perform a walk-around inspection utilizing a high intensity light to examine linkages.

PNL Recommendations

Perform weekly visual inspections and apply lubricant as required, typically during the monthly testing period.

5.1.2.13 Studs and Fixtures

The TUGCO maintenance plan addresses only air start valve capscrews. PNL recommends also that other studs and fixtures be maintained on a sampling basis at each refueling outage.

Loss of preload on cylinder head studs, rocker arm capscrews, and air start valve capscrews can adversely affect engine operability if it goes unnoticed. The generally positive experience at CPSES in this regard warrants a less rigorous schedule of checking.

PNL Recommendations

PNL recommends a 25%-sample check of head stud and rocker arm capscrew preload 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 these be checked 100% at the same frequency. (One consequence of the loss of air start valve capscrew preload may be loss of cylinder compression; another will be "torching" of the passage permitted by a "loose" valve, with consequential irreparable damage to the head, and with potential risk to operating personnel from high velocity, unnoticeable hot gases.)

5.1.2.14 Jacket Water Pump

TUGCO provides no maintenance plan for the jacket water pumps. PNL recommends disassembly/examination at the first refueling outage.

The jacket water pumps on both Train A and B engines exhibited damage of various forms. Shaft galling, worn wearing rings, or a warped backing plate can cause reduction in pump capacity and pump life, both of which are detrimental to engine reliability and operability.

TUGCO was not able to identify the cause of these damages but did replace all damaged parts. Based on the coincident damage experienced on the pumps on each engine, this event is being considered specific to the CPSES Unit 1 engines. The damage could have been sustained at the factory during testing and/or during startup due to incorrect system commissioning.

PNL Recommendations

Because of the critical nature of this pump and the history of the above problems, PNL recommends that the pumps be disassembled and inspected and repaired as necessary at the first refueling outage.

5.1.2.15 Lube Oil Checks

TUGCO proposes a monthly surveillance check at the inlet to the filter. PNL recommends more definitive checks for water and other contaminants after 24 hours' operation or monthly, whichever is first.

Lube oil checks serve two main functions:

- They reveal any water in the oil, indicative of cracks in water-bounded components or leakage past lower liner seals. Such water can lead to lubrication failures, with potential major damage.
- They reveal abnormal wear of bearings and related engine parts.

It is important to collect and analyze samples with sufficient frequency that adverse conditions are detected early enough to avoid either engine damage or engine outage (and possibly consequential reactor shutdown). PNL basically agrees with TUGCO's proposal with the following modification.

PNL Recommendations

PNL recommends the following pattern:

- Check for water contamination after preoperational testing, and then monthly or after 24 hours of operation, whichever comes first; collect the sample from the bottom of the sump tank, preferably about 4 hours after engine shutdown, at the time of the engine roll-over.
- Check for chemical and particulate contamination and imbalance near the close of preoperational testing, and then monthly or after

24 hours of operation, whichever comes first; collect the sample (before the filter) while the engine is running, immediately prior to shutdown.

- Check differential pressure across all filters and strainers hourly during engine operation.

5.2 OPERATIONAL SURVEILLANCE PLAN

5.2.1 Elements and Rationale

Operational surveillance is necessary to ensure safe and efficient operation of the diesel engine. By monitoring and recording various engine parameters, trends in degradation may be noted, thus allowing preventive maintenance. In addition, trend monitoring permits engine shutdown prior to major engine failure. A listing of recommended parameters and frequency of surveillance is presented in Table 5.3.

5.2.2 PNL Evaluation

NRC's guidance was for continuous monitoring and hourly recording of exhaust temperature, including the pre-turbine temperatures. TUGCO has proposed recording of exhaust temperatures on the half hour, without mention of pre-turbine temperatures.

PNL's consultants deem it very desirable to monitor the turbine inlet temperature for these reasons:

- Monitoring would avoid the possibility of such temperatures exceeding the limits set by the turbocharger manufacturer.
- It is possible for the "average" inlet pre-turbine temperature to exceed the "average" temperature measured at the individual cylinder outlet (the latter reflects a time-averaged combination of true exhaust temperature and a much lesser quantity of cooler "scavenging air" that occurs during valve overlap in the exhaust/intake strokes). This higher actual turbine inlet temperature results from three possible conditions: 1) The pulse of hot exhaust and the subsequent, lesser pulse of cool air may not mix, even though two

TABLE 5.3. Diesel Engine Operating Surveillance Parameters and Frequency

Component	NRC Guidance	TUGCO Proposal	PNL Recommendations
Lube Oil Inlet Pressure to Engine	Monitor continuously, record hourly	Log every 30 minutes	Log every 60 minutes
Turbocharger Oil Pressure	↓	↓	↓
Pump	↓	↓	↓
Fuel Oil Filter/Strainer ΔP	↓	↓	↓
Lube Oil Filter/Strainer ΔP	↓	↓	↓
Jacket Water Pressure	↓	↓	↓
Crankcase Vacuum	↓	↓	↓
Engine Speed	↓	↓	↓
Stack Temperature (RB, LB)	↓	↓	↓
Lube Oil Temperature	↓	↓	↓
Jacket Water Temperature (In, Out)	↓	↓	↓
Lube Oil Sump Level	↓	↓	↓
Room Temperature	↓	↓	↓
Engine Cylinder Temperature (all)	↓	↓	↓
Kilowatt Load	↓	↓	↓
Engine Hourmeter	↓	↓	↓
Exhaust Temperature Inlet to Turbo (RB, LB)	Monitor continuously, record hourly	Not Proposed	↓
Fuel Oil Transfer Pump Strainer ΔP	---	Log every 30 minutes	Log every 60 minutes unless pump is auto/duplexed and alarmed
Starting Air Pressure (RB, LB)	---	Log every 30 minutes	Check hourly
Fuel Oil Day Tank Level	---	Log every 30 minutes	Check hourly
Manifold Air Pressure (RB, LB)	Monitor continuously record hourly	Not Proposed	Log every 60 minutes
Manifold Air Temperature (RB, LB)	---	Not Proposed	Log every 60 minutes
Visual Inspection for Leaks, etc.		Not Proposed	Check hourly

cylinders are involved with each manifold; 2) exothermic chemical reactions tend to continue after the cylinder exhausts, even with proper firing timing; and 3) any inappropriate timing of fuel injection can lead to continuing flame propagation during exhaust.

- Plots of pre-turbine temperatures for TDI DSRV-16 engines show that, at full load and overload (i.e., the TDI rating of 7000 and 7700 kW, respectively), the temperatures of even properly-timed engines can approach 1200°F (the reported upper limit allowed by the turbocharger manufacturer).
- Vanes have been found damaged and missing on the CPSES turbochargers; the same finding has been noted elsewhere on similar engines in nuclear service. Because the mechanism of the vanes' damage and disappearances has not been identified with certainty, it is important to avoid influences toward thermally induced failures.

PNL Recommendations

Table 5.3 lists those parameters that TUGCO plans to use to monitor engine performance. PNL and NRC recommend the continuous monitoring and/or hourly recording of turbocharger inlet exhaust temperatures, manifold air pressure, and manifold air temperature. The TUGCO program to log the various parameters at 30-minute intervals is acceptable but considered in excess of normal 1-hour intervals.

5.3 STANDBY SURVEILLANCE PLAN

5.3.1 Elements and Rationale

Standby surveillance is important to ensure the reliability of the diesel engines. The parameters monitored on a "secured" engine show that it is prepared for rapid startup and load acceptance. The two factors that contribute most to this are engine temperature and lubrication. Thus, by keeping the engine warm and all oil passages pressurized, the time lag associated with load acceptance is minimized. In addition, a ready supply of quality compressed air is required for starting the engine. Patterns of standby surveillance of the engine are shown in Table 5.4.

TABLE 5.4. Diesel Engine Standby Surveillance Parameters and Frequency

Component	NRC Guidance	TUGCO Proposal	PNL Recommendations
Starting Air Pressure	---	Every 4 hours	Visual check every 8 hours; log every 24 hours
Lube Oil Temperature (In, Out)	---	↓	↓
Jacket Water Temperature (In, Out)	---	↓	↓
Lube Oil Sump Level	---	↓	↓
Fuel Oil Day Tank Level	---	↓	↓
Room Temperature	---	↓	↓
Test Annunciators	---	↓	Every 8 hours; log every 24 hours
Check Alarm Clear	---	Daily	Daily
Check Operation of Comp. Air Traps	---	↓	↓
Operation of Fuel Rack	---	↓	↓
Governor Oil Level	---	↓	↓
Inspect for Leaks	---	↓	↓
Air Butterfly Valve and Cylinder	---	Weekly	Weekly
Check Internals of Block and Base for Leaks	---	Monthly	At each refueling outage
Keepwarm Oil Filter ΔP	Daily	---	Weekly
Test Jacket Water for pH, Conductivity, Corrosion Inhibitor	---	At each refueling outage	After adding make up water, or monthly
Cylinder Compression/Peak Pressure	---	At each refueling outage	At each fefueling outage
Air Start Distributor Filter	---	Monthly	Monthly
Air Start Admission Valve Strainer	---	Every 3 months	Every 3 months

5.3.2 PNL Evaluation

NRC's guidelines for standby surveillance recommend a daily check of lube oil filter differential pressure. The TUGCO proposal covers several parameters to be monitored every 4 hours, but does not mention the lube oil filter. It is felt that the 4-hour monitoring cycle is more than necessary for a standby engine; the parameters may be checked visually every 8 hours and recorded daily. Two points regarding the lube oil filter are important:

- Entrained water will tend to plug some filter media (or weaken others), and so would gradually change pressure drops.
- The continuous keep-warm flow through the filters will (purposefully) continually "polish" the oil, with gradual buildup of contaminants in the media; the material scavenged out thereby itself helps filter even finer particles as time continues.

Thus, it remains valid to monitor oil filter pressure drops during standby. However, the difference between a daily check (per NRC guidance) and a weekly check is not deemed significant; the latter is considered acceptable.

PNL Recommendations

PNL recommends a weekly check of all oil filter pressure drops during standby. The hourly check during sustained engine operation remains important. Otherwise, the TUGCO proposal is acceptable, with certain additions and clarifications recommended above and shown on Table 5.4.

5.4 PNL CONCLUSIONS

PNL concludes that the TUGCO-proposed M/S activities require modification to provide adequate assurance of engine reliability/operability. The recommended modifications, with supporting rationale, are delineated in the preceding subsections (5.1, 5.2, 5.3). With those modifications, the TUGCO-proposed M/S program is considered acceptable through the first refueling cycle. As the Owners' Group Program Plan and related M/S activities become fully developed and accepted by NRC, it may be appropriate for TUGCO to modify their plan still further.

6.0 ENGINE TESTING

This section reviews and evaluates the engine testing program identified by TUGCO. Included are post-inspection tests prescribed by the information provided in an NRC letter (Youngblood August 2, 1984), and routine/periodic testing in accordance with NRC Regulatory Guide 1.108, Revision 1. This section also provides an evaluation of data concerning onsite starts of the CPSES Unit 1 engines prior to the disassembly and inspections.

6.1 TUGCO REPORTED POST-INSPECTION TESTING

TUGCO reports they have conducted engine break-in runs, calibration runs, and preoperational tests following reassembly of the Train A and Train B engines. The detailed preoperational tests were done in conformance with NRC Regulatory Guide 1.108, Revision 1, and as specified in the applicable sections of the NRC letter (Youngblood August 2, 1984). Detailed results of the post-inspection tests are not yet available; however, TUGCO did report certain failures/observations and actions taken to resolve them. These are listed in Table 6.1.

TABLE 6.1. Preoperational Test Results

Reported Failures/Observations	Planned TUGCO Resolution
Fuel injection pump failure on Train A led to manual engine shutdown.	Effort initiated to determine cause; initial findings are that top bolts were improperly torqued; all pumps were checked for proper torque.
The phase metering potential for the Train A engine was lost for about 1 minute.	Determined to be caused by failed solder joints on two of four screw-in type fuse holders; all such screw-in holders were replaced with new cartridge-type holders on both engines.
Pneumatic tubing associated with Train A engine protective trip function was was found to have corrosion.	All pneumatic tubing on both Train A and B engines will be replaced with stainless steel tubing prior to fuel loading.

TUGCO also reports that, since engine assembly in Spring 1984, the Train A engine has undergone 45 starts and has accumulated 100 hours of operation (load not stated). The Train B engine has undergone 54 starts and 84 additional hours of operation (load not stated).

TUGCO reported that all testing on the diesel generators was done at or below 5.8 MW, except for approximately one-half hour of load rejection testing at 7 MW. TUGCO reports that testing below 5.98 MW provides assurance that the cylinder BMEP will be below 185 psig.

6.1.1 PNL Evaluation

PNL believes TUGCO's plans regarding post-inspection testing should include two elements:

1. The engine manufacturer's recommended post-reassembly tests.
2. The testing specified in NRC Regulatory Guide 1.108, Revision 1, as modified by NRC post-inspection testing requirements specified in Youngblood (August 5, 1984).

   The modifications mentioned in Item 2 above include the following tests:

- Ten modified starts to 40% load. (A modified start is a start including turbocharger prelube and a 3- to 5-minute loading to the specified load and run for a minimum of 1 hour.)
- Two fast starts to a load greater than or equal to the maximum emergency loads the engine will experience but not greater than a load corresponding to 185 psig BMEP. (A fast start simulates an ESF signal with the engine in ready-standby status.)
- One 24-hour run at a load greater than or equal to the maximum emergency loads the engine will experience but not greater than a load corresponding to 185 psig BMEP.

TUGCO did not report on tests to the manufacturer's recommendations (Item 1 above). However, PNL assumes that appropriate engine manufacturer's required testing was accomplished and that the TUGCO post-reassembly test report will provide these results.

With respect to the reported failures or observations (corrosion) by TUGCO, PNL believes these are routine and that the reported actions are appropriate. PNL assumes that the fuel injection pumps for both engines (not just Train A) were checked for proper torque. This should be verified by TUGCO.

TUGCO did not report whether all post-assembly starts for both engines were successful. This will be confirmed by TUGCO in a detailed supplement to their earlier submittal (George August 15, 1984).

PNL has learned that half-hour load rejection tests requiring engine operation at 7 MW will not be repeated. These tests required cylinder pressures well in excess of the 185 psig BMEP currently evaluated as acceptable for these engines, pending completion of the Owners' Group Program. On this same topic, PNL finds that the TUGCO analysis showing that the 185-psig BMEP limitation corresponds to 5.98 kW did not consider the generator efficiency. Using an estimated efficiency of 0.96, PNL calculates that the 185-psig BMEP limit corresponds to 5.74 MW. Engine testing should be limited to this value.

6.1.2 PNL Conclusions

Based on its review, PNL concludes that TUGCO's post-inspection testing on the Train A and B engines is compatible with NRC requirements. In addition, PNL has learned that TUGCO has informed NRC that the manufacturer's recommended testing has also been performed.

PNL concludes that TUGCO has taken appropriate action regarding the reported failure and observations (corrosion) occurring during post-reassembly testing. PNL also concludes that the final disposition of these items should be supplied in the TUGCO submittal to NRC describing post-inspection test results. PNL concludes that no future testing above cylinder pressures of 185 psig BMEP (corresponding to a load limit of 5.74 MW) should be performed without prior NRC approval.

In summary, PNL concludes that post-inspection testing of both Unit 1 engines has been satisfactorily completed. This conclusion is conditional upon the receipt and satisfactory review of the TUGCO post-inspection report, confirmation regarding testing per TDI specifications, and limits on future test loads as stated above.

6.2 REVIEW AND EVALUATION OF ENGINE STARTS

PNL has reviewed the data sheets documenting the onsite starts of CPSES Unit 1 diesel engines that were run prior to engine disassembly and inspection. The Train A engine was started 67 times between September 29, 1982, and March 29, 1983. The Train B engine was started 83 times between September 16, 1982, and May 31, 1983.

During these tests the Train A engine experienced eight abnormal engine shutdowns. Two of these shutdowns were attributed to operator error, two were attributed to errors in the procedures, two were a result of miscalibration of the high vibration trip, and two were caused by a field ground relay trip (the field ground relay trip would be overridden in an emergency).

The Train B engine experienced nine abnormal shutdowns during these tests. Two that TUGCO has classified as "unsatisfactory engine response" include 1) a low oil pressure trip caused by an incorrectly installed foot valve in the auxiliary lube oil pump and 2) a short in the DC power supply caused by a blown-out indicator light. Of the remaining seven, two were a result of an incorrectly calibrated high vibration trip, and five shutdowns were attributed to operator error.

These data fully corroborate Section 3.1 of TUGCO's August 15, 1984, submittal, which identifies only two instances of unsatisfactory engine response. In both instances, PNL feels the cause of the unsatisfactory performance has been identified and appropriate corrective action has been taken.

7.0 OVERALL CONCLUSIONS

7.1 GENERAL CONCLUSION

In general, PNL and its consultants conclude that the two TDI DSRV-16-4 diesel engines at the Comanche Peak Steam Electric Station Unit 1 will have the needed operability and reliability to fulfill their intended emergency power function, at least to the time of the first reactor refueling outage.

This conclusion is predicated upon the known results of the completed extended operational tests and subsequent inspections. It also reflects PNL's current knowledge and evaluation of the ongoing Owners' Group investigation on specific, generic component issues. It is also contingent upon satisfactory completion and documentation of all actions recommended in this TER and identified in the August 15, 1984, submittal from TUGCO to NRC. These actions are summarized in Section 7.3. The PNL conclusions pertaining to the operability of the Train A and B engines are contingent upon TUGCO's timely implementation of all OG recommendations and plant-specific items that may result from the CPSES-specific DR/QR investigations.

7.2 LONG-TERM APPLICABILITY

In Section 1.2 of this TER, PNL expressed its opinion and rationale that it cannot responsibly reach conclusions on the operability and reliability of the Comanche Peak Train A and Train B standby engines beyond the first refueling outage. Hence, throughout this report, PNL has expressed its conclusions in such terms as "until the first reactor refueling outage." This constraint has been predicated upon all evidence available to PNL, including preliminary elements of the OGPP and the TUGCO evaluations as applicable to these specific engines. When these analyses are completed and appropriately implemented, and when operational results on these engines (under enhanced surveillance and maintenance) and on others in the general population of equivalent TDI engines are accumulated, it may then be possible to draw unconstrained, long-term conclusions.

It is not PNL's intent, however, in expressing this constraint to imply any inherent unreliability or inoperability of these engines, either specifically at CPSES or in general nuclear standby service.

7.3 LICENSING CONSIDERATIONS

The conclusion stated in Section 7.1 reflects PNL's careful evaluation of all TUGCO and Owners' Group submittals. Specific considerations have been addressed in Sections 3.0 through 6.0 of this TER and reference should be made thereto for PNL's component-specific conclusions and recommendations. PNL assumes that TUGCO will agree to modifications or additions to their August 15 submittal that appear in these sections.

Certain considerations warrant emphasis. They relate to TUGCO commitments and to recommendations made by PNL. The conclusion by PNL regarding the Train A and Train B operability and reliability to serve as nuclear standby emergency power supplies throughout the first refueling cycle is predicated on an understanding that a technical review of all TUGCO submittals concerning open items described below will not raise unanticipated problems. The open items are presented in four categories: 1) general; 2) open items specifically identified by TUGCO in Section 10.0 of the August 15, 1984, submittal; 3) open items mentioned by TUGCO in the August 15, 1984, submittal but not addressed in Section 10.0 of that submittal; and 4) concerns raised by PNL to be addressed by TUGCO prior to PNL concluding that the engines are ready for nuclear service.

7.3.1 General Considerations

The following items relate to TUGCO's conformance with the ongoing Owners' Group Program and certain significant NRC and PNL requirements and recommendations. They are:

- PNL understands that TUGCO will implement all relevant Owners' Group recommendations in a timely manner.

- Should any remaining inspections, further testing, DR/QR findings at CPSES, or functional occurrences at other plants reveal adverse conditions or results not currently expected, modifications of the PNL conclusions may be warranted.
- PNL assumes that TUGCO will resubmit to NRC a revised surveillance and maintenance plan incorporating changes and additions such as those identified in Section 5.0 of this report.
- PNL understands that engine testing and emergency service requirements TUGCO now foresees for the CPSES will not exceed the engine load corresponding to a BMEP of 185 psig (5740 kW).

7.3.2 TUGCO Open Items Identified and Addressed

The items identified below are listed in George (August 15, 1984, Section 10.0) as Open Items for CPSES Unit 1. TUGCO has agreed to close out and document these items prior to fuel loading.

7.3.2.1 Crankshaft Open Items

- crankshaft main journal oil hole inspection for both CPSES Unit 1 engines
- crankshaft torsiograph test for one engine
- evaluation by the Owners' Group of the TDI recommendation for running of crankshafts for 15 minutes at 150 rpm following each major overhaul, in light of the Owners' Group recommendation to run at 450 rpm at all times.

7.3.2.2 Cylinder Block Open Items

- TUGCO review of an additional Phase I supplementary report by the Owners' Group on cylinder block strain gauge testing on the Train A engine at CPSES Unit 1
- TUGCO review of an additional Phase I supplementary report by the Owners' Group on cylinder block metallurgical testing at all sites
- establishment of CPSES Unit 1 cylinder block top eddy-current inspection intervals based on the above.

7.3.2.3 Fuel Oil Injection Tubing Open Items

- Installation of shrouded SAE-1010 high pressure fuel oil injection tubing for both CPSES Unit 1 engines
- eddy-current inspection of newly installed tubing for flaws
- visual inspection of newly installed tubing for leaks during engine operation
- modification of tubing affected by the 10 CFR Part 21 report of September 21, 1983.

7.3.2.4 Connecting Rod Open Items

- TUGCO review of an additional Phase I supplementary report by the Owners' Group on connecting rod strain gauge testing at another site
- evaluation of CPSES Unit 1 connecting rod inspection requirements based on the above.

7.3.2.5 Turbocharger Open Items

- Modification of the CPSES Unit 1 turbocharger lube oil drip systems to the recommendations specified by TDI following the 10 CFR Part 21 report by the Owners' Group on design review of turbocharger vanes and capscrews.

7.3.2.6 Additional Open Items

- Replacement of 16 remaining original exhaust manifold bolts on Train B with new TDI socket head types
- replacement of pneumatic tubing for engine protective functions with stainless steel tubing
- TUGCO review of the CPSES Unit 1 Phase 2 report by the Owners' Group
- re-evaluation by the Owners' Group of the recommendation for destructive testing of push rods on a sample basis
- detailed evaluation of CPSES Unit 1 diesel generator preoperational testing

- recording of CPSES Unit 1 diesel generator pre-turbine exhaust temperature relative to the TDI recommended maximum as specified by NRC
- submittal of proposed technical specifications to limit monthly and 18-month CPSES Unit 1 diesel generator surveillance testing to 185 psig BMEP.

7.3.3 Other TUGCO Identified Open Items

PNL has identified additional open items mentioned by TUGCO in the August 15, 1984, submittal but not addressed in Section 10.0 of that submittal. PNL believes that these items need to be addressed prior to qualifying the Unit 1 TDI diesel engines for nuclear service:

- results of material check on air start valve capscrews (p. 16) and rocker arm capscrews (p. 15 of the TUGCO August 15, 1984, document)
- results of formal evaluation of the indication on No. 3 main bearing saddle, Train A. This should include the determination of the "large factor of safety against propagation" and, as appropriate, the basis for the OG's "conditional release to permit reassembly and preoperational testing" (p. 34)
- results of the TUGCO investigation of the fuel injection pump failure on Train A engine (p. 53).

7.3.4 Open Items Raised by the PNL Review

In Section 3.0 of this Technical Evaluation Report, PNL has raised a number of issues to be addressed and documented by TUGCO. In PNL's view, these concerns should be resolved prior to concluding that the TDI engines are suitable for nuclear service:

- engine base and bearing cap (Section 3.2.1 of this TER), Train A - satisfactory resolution of the indication on bearing saddle No. 3, still under formal evaluation (as referenced previously above), with either a disposition as being shown to be of no further concern, or a rationale for operation with enhanced monitoring (with details)

- cylinder block (Section 3.2.2), both Trains A and B - completion of acceptable OG analyses and reports on indications that are formally under OG review, and submission of details on an acceptable plan of monitoring and evaluation based on these results
- crankshaft (Section 3.2.3), both Trains A and B - submission of evaluation of hot and cold shaft deflection tests
- connecting rods (Section 3.2.4 and Section 5.1.2.4), both Trains A and B - submission of a satisfactory plan for enhanced monitoring and inspection of cross-joint bolting and/or rod box surfaces and/or rack teeth
- connecting rods (Section 3.2.4), both Trains A and B - submission of a letter to NRC confirming information provided by telephone regarding removal of burrs and sharp edges on bolt holes, TDI factory "blueing in" of rod racks, and final preparation of rod rack surfaces
- cylinder liners (Section 3.2.7), both Trains A and B - confirmation of satisfactory material per analyses being conducted by FaAA
- starting air distributor (Section 4.2.2.2), Train B - completion of a satisfactory inspection
- surveillance and maintenance program (Section 5.0) - submission of a revised program with appropriate modifications to accommodate PNL comments.

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