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December 3, 1984

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Washington, D.C. 20555

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Washington, D.C. 20555

Dr. James H. Carpenter
Atomic Safety and Licensing Board
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

In the Matter of
Carolina Power & Light Company and North
Carolina Eastern Municipal Power Agency
(Shearon Harris Nuclear Power Plant)
Docket No. 50-400 OL

Administrative Judges Kelley, Bright and Carpenter:

During the most recent hearings in the above referenced proceeding Applicants made an oral motion regarding two deferred Eddleman contentions on diesel generators. Tr. 6842-50. The Board requested that Applicants supplement the motion by informing the Board "the extent to which the Commission or the Appeal Board or other Boards have signed on the safety aspects of other [Transamerica Delaval, Inc. ("TDI") DSRV-16 diesel generator engines], except Catawba." Tr. 6850. Off the record, the Board also requested the ratings and loads of other DSRV-16 diesel generators.


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Three nuclear plants with TDI DSRV-16 diesel generators are further along in the licensing process than Harris -- Mississippi Power and Light Company's Grand Gulf Nuclear Station Unit 1 ("Grand Gulf"), Duke Power Company's Catawba Nuclear Station, Unit 1 ("Catawba") and Texas Utilities Generating Company's Comanche Peak Steam Electric Station, Unit 1 ("Comanche Peak"). A contention with respect to the reliability of TDI diesel generators has not been litigated in any of the three proceedings.

The Commission voted to authorize the NRC Staff to issue a full power operating license for Grand Gulf on July 31, 1984. The Grand Gulf operating license was not contested. However, the Commission received a detailed briefing on the diesel generators prior to voting to authorize the full power license. A copy of the relevant pages from the transcript of the Commission meeting of July 31, 1984 is attached hereto as Attachment 1. In approving full power operations, Chairman Palladino noted that: "the NRC Staff has determined that the emergency on-site diesel generators are reliable to perform their intended function if needed." Tr. 108 (July 31, 1984 Meeting).

Certain admitted contentions in Comanche Peak are still before the Atomic Safety and Licensing Board in that proceeding. While there has not been a contention admitted on diesel generator reliability, the Comanche Peak Board did request certain information from the applicant regarding TDI diesel generators in reference to an admitted contention on quality assurance. Counsel for the applicant in Comanche Peak informs me that there has been no resolution of that issue. As this Board is aware, contentions relating to diesel generators in the Catawba proceeding were dismissed.

In all three of the above-mentioned proceedings, a Safety Evaluation Report ("SER") on the reliability of diesel generators has been issued by the NRC Staff. A copy of the three SER's is enclosed as Attachments 2, 3 and 4.

Finally, appended as Attachment 5 is a table providing comparative ratings and loads of the diesel generators at Grand Gulf, Comanche Peak, Catawba and Harris. Except for the Harris Plant, the information in the enclosed table was obtained from the Diesel Generator Owners' Group. While all four plants purchased virtually identical diesel engines (as indicated by the rating parameters), the Harris Plant required a somewhat lower design output from the manufacturer. The lower rating is not, however, due to a design difference in the engine but rather reflects the design specifications of Applicants and the KW output commitment from the manufacturer. In other words, TDI supplied for Harris engines actually capable of 7000 KW output with a slightly different generator to meet Applicants' 6500 KW design requirement.

Respectfully submitted,

John H. O'Neill, Jr., P.C.
Counsel for Applicants

cc: Attached Service List

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

| | | |
|---|---|---|
| In the Matter of | ) | |
| | ) | |
| CAROLINA POWER & LIGHT COMPANY and NORTH CAROLINA EASTERN MUNICIPAL POWER AGENCY | ) | Docket No. 50-400 OL |
| | ) | |
| (Shearon Harris Nuclear Power Plant) | ) | |

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Attachment 1

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

IN RESPONSE, PLEASE REFER TO: M840731B

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August 1, 1984

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MEMORANDUM FOR: William J. Dircks, Executive Director for Operations

FROM: Samuel J. Chilk, Secretary

SUBJECT: STAFF REQUIREMENTS - DISCUSSION/POSSIBLE VOTE ON FULL POWER OPERATING LICENSE FOR GRAND GULF, 11:00 A.M., TUESDAY, JULY 31, 1984, COMMISSIONERS' CONFERENCE ROOM, D.C. OFFICE (OPEN TO PUBLIC ATTENDANCE)

The Commission met to be briefed by staff and by representatives of Mississippi Power and Light Company on the readiness for a FPOL at Grand Gulf Unit 1.

The Commission voted 4-0 (Commissioner Asselstine abstaining) to authorize staff to issue the full power operating license amendment.

(NRR)

cc: Chairman Palladino
Commissioner Roberts
Commissioner Asselstine
Commissioner Bernthal
Commissioner Zech
Commission Staff Offices
PDR - Advance
DCS - 016 Phillips

ORIGINAL

UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

In the Matter of:

DISCUSSION AND VOTE ON FULL POWER OPERATING LICENSE

FOR GRAND GULF

OPEN MEETING

Location: Washington, D.C. Pages: 1 - 114

Date: Tuesday, July 31, 1984

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UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

DISCUSSION ON FULL POWER OPERATING LICENSE

FOR GRAND GULF

OPEN MEETING

Nuclear Regulatory Commission
1717 H Street, N.W.
Room 1130
Washington, D.C.

July 31, 1984

The Commission met, pursuant to notice, at 11:00 a.m.

COMMISSIONERS PRESENT:

NUNZIO PALLADINO, Chairman of the Commission
THOMAS ROBERTS, Commissioner
JAMES ASSELSTINE, Commissioner
FREDERICK BERNTHAL, Commissioner
LANDO ZECH, JR., Commissioner

STAFF AND PRESENTERS SEATED AT COMMISSION TABLE:

S. Chilk, Secretary
H. Plaine, General Counsel
D. Eisenhut
H. Denton
W. Dircks
J. O'Reilly
M. Malsch
W. Cavinaw
W. Johnston
T. Novac
D. Lewis
B. Wilson
J. O'Shinski
A. Wagner
G. Hollihan
H. Thompson
Dr. Dengy
Dr. Berlinger

DISCLAIMER

This is an unofficial transcript of a meeting of the United States Nuclear Regulatory Commission held on July 31, 1984 in the Commission office at 1717 H. Street, N.W., Washington, D.C. The meeting was open to public attendance and observation. This transcript has not been reviewed, corrected, or edited, and it may contain inaccuracies.

The transcript is intended solely for general informational purposes. As provided by 10 CFR 9.103, it is not part of the formal or informal record of decision of the matters discussed. Expressions of opinion in this transcript do not necessarily reflect the final determinations or beliefs. No pleading or other paper may be filed with the Commission in any proceeding as the result of or addressed to any statement or argument contained herein, except as the Commission may authorize.

of standardized tech specs plant design.

MR. EISENHUT: If I could go on to slide number nine, skip by the next two slides on tech specs, the next issue I'd like to address is Transamerica diesel valve, diesel generator.

It's really the diesel. In January of this year, we had a generic meeting with a number of owners, the owners of the TDI Diesels, and we reached the conclusion at that point, we really didn't have enough confidence to go forth in making licensing decisions with TDI diesels without some additional work.

Earlier this year, the owners group put together, they had even at that time started putting together a very concerted, major effort to get their hands around this problem.

The staff had developed and put together a project group. Let me give you the bottom line, and then I'd like to have the head of our staff project group on the staff here give you a short summary.

We believe the progress is developed to date with the programs and inspections and the reworks, we are now confidence that these diesels at Grand Gulf satisfy the requirements.

With that sort of an overview, I'd like to turn it over to Dr. Carl Burlinger of the staff, who is the

staff director of the project group we set up earlier this year to bring this review together in a concentrated effort.

DR. BERLINGER: Good morning. The TDI Project Group was formed, as Darrell said, in January. We have several staff members in-house, primary function is to coordinate the review effort, but the primary technical review work is being performed for the staff on the contract with Battelle, Pacific Northwest Laboratory.

Battelle has put together a program and a representative of Battelle is here. I'll give him an opportunity to describe his organization and some of the efforts that they have been performing on behalf of the staff.

What I'd like to take an opportunity to describe for you at the present time is the inspection which was ordered to be conducted in an order dated May 22nd.

The need for the inspection stems from a review conducted by our contractor at Battelle. Their review of information provided by the licensee which built upon what appeared in January and February to be a void of information with regard to reliability of these engines, was conducted in such a way that the owners group had provided some information at a point in time such as April of this year, '84.

That information was, in fact, either just recently submitted from the standpoint of eight out of a planned 16 technical reports had been received by the staff.

But the staff had not had an opportunity to get into the review of those reports to any great degree, and the particular inspections which had been conducted at the Grand Gulf nuclear plant in January and early February of '84 had, in fact, been visual examinations.

They had not been detailed, non-destructive examinations. They had not been the type of inspections which had been recommended in some of the reports that the owners group had submitted to the staff for review.

In fact, some of the owners group reports which had been submitted in March and early April had recommended inspections be performed which, in fact, were clearly not done on either particular components which we deemed critical or in fact, the methods of inspection that had been used on these inspections of parts had, in fact, been far less than what the owners group or the staff felt was adequate.

In addition, there were many parts within the engine which had been operated. They had been operated for a number of--several hundred hours, as a minimum, and to date, some of these components have amassed

1,100 to 1,300 hours of operation. Several critical components had never been non-destructively examined since they had been put into operation.

These included pistons, connecting rod bearings, connecting rods, wrist pin bushings, the engine block, turbocharger, thrust bearings.

These are components which have been identified by the owners group in the Phase I program as critical components for which the potential existed for a generic problem.

They are problems that actually have occurred in nuclear facilities, in some non-nuclear facilities, including marine applications and stationary electric power generating units.

In addition, there had been inspections which had been performed at both Shoreham and at Kataba. These inspections, if they hadn't been completed 100%, were near completed at the time which we were deliberating with regard to Grand Gulf and the need for further inspection.

The deficiencies which have been identified in December and January and specifically discussed with the owners group representatives in January, the deficiencies in the quality assurance and quality control at TDI had, in fact, made it difficult if not

impossible for us to say that the inspections performed at other facilities could, in fact, be applied to Grand Gulf.

There are just too many deficiencies for us to be able to show that they were equivalent on a design and construction basis to, say, a plant like Kataba, where they have the same V-16 type engines.

Okay. At this time, I would like to introduce Dave Dengy, who is with Battelle Northwest Laboratory, and he can give you a description of PNL's involvement since this spring.

Dr. Dengy is one of the managing personnel in charge of this contract at Battelle, and he has brought to the meeting today one of our diesel engine consultants, Adam Hendrix, who is employed by Battelle.

I'm sure if you have any specific questions during their presentation, they'd be glad to try and answer them for you.

COMMISSIONER ASSELSTINE: Just before you do that, I have more of a general question that maybe you can address and then maybe they can follow up on with specifics.

As I understood it, the staff response based upon our consultant's expert advice to the owners group report was intended to serve as the basis for interim

licensing for plants. I gather that there are still a number of open issues at least as far as our expert consultants are concerned regarding the owners group responses in various areas concerning the diesels.

I have a couple of them in particular that I'm interested in. The staff is in the position today of saying, "You can go ahead and license Grand Gulf without having reached a resolution on those open items."

And I guess what I'm trying to get a sense for is the basis for that judgment in light of the fact that in some areas, at least, the owners group information that's been submitted so far hasn't proved to fully resolve all the issues to the staff's satisfaction.

MR. DENTON: Commissioner, we're on the verge of approving the overall owners group program and the issues that are left, to the extent they apply to Grand Gulf, have been taken into account. But let me ask Carl to answer that.

DR. BERLINGER: Thank you, Harold. The owners group program plan has been under review since it was submitted early March.

The consultants at Pacific Northwest Laboratory have submitted their report, which addresses the program plan.

They have drawn certain conclusions and made specific recommendations. That report is in our hands and we are in the process of finalizing a staff safety evaluation report which will specifically address the adequacy of the overall owners group program plan to solve and address the entire issue in total.

But in addition, it also addresses the owners group proposal as a basis for interim licensing, interim meaning between now and when the entire owners group program plan has been completed and implemented, all the recommendations from both the owners group and the staff have been implemented by the utilities.

The conclusion that we have drawn at this point in our review, which is basically finished, with regard to program plan, is that although some of the technical reports, we have not completed our review, we feel confident at this stage that we can go forward on the basis of the technical analyses that have been submitted as part of their Phase I program.

However, that alone cannot stand by itself. The Phase I technical reports really must be supplemented with the tear-down and inspection of one of the engines at each of the installations, to verify the condition of those engines prior to allowing the plant to operate.

In addition, any other diesels at that site which would be depended upon by the utility in the event of off-site power or similar event, would have to be shown to be essentially equivalent in design construction and basically by reviewing the quality assurance records at TDI, the manufacturer and their own quality assurance and quality control records at the utilities, they are being asked to justify that engine B is representative by engine A at a particular site.

In addition, there is specific need for enhanced maintenance and surveillance programs. These programs are absolutely necessary to assure that the condition of the diesels is maintained at a level which we are assured of by the inspection throughout, say, the first refueling cycle, 18 months.

Basically, we're saying that we can go forward with the licensing of these plants because on the basis of our review and our inspections and maintenance and surveillance programs that have been, especially in the Grand Gulf case, been totally adopted by the utility, that we have an adequate basis that the engines do provide reliable service and satisfy GDC-17.

COMMISSIONER ASSELSTINE: So you're basically saying as far as the owners group proposal is concerned, at least you have reached a consensus and

our expert consultants have as well, on an interim approach that you believe is satisfactory for a period of time.

DR. BERLINGER: That is correct.

COMMISSIONER ASSELSTINE: In every area that the consultants have concerns about the owners group proposal.

DR. BERLINGER: That is correct.

COMMISSIONER ASSELSTINE: And involves not only the material that they've submitted, but also the kind of inspection that is required in this particular case.

DR. BERLINGER: Yes. And it's extremely important for us in the area of maintenance and surveillance requirements.

For instance, surveillance requirements that we have specified be adopted by all of the utilities is what is called a barring over or engine air roll, and this is conducted prior to planned operation of the engine, which is done periodically in accordance with tech specs, once a month or every 18 months.

The requirement for the air roll is to verify that there are no water jacket leaks into the engine, into the cylinders.

So that head cracks or cylinder liner cracks or gasket leaks could be detected and corrected prior to

running the engine and putting it in an undue stressful situation.

As a result of an air roll which was conducted within a last few days prior to some surveillance testing at Grand Gulf, there was water noted in one cylinder, and as a result of this procedure, that cylider head, which was discovered to have a crack in it, has been replaced so that this is the type of maintenance and surveillance which we're looking at, which is really a hard type maintenance and surveillance, where we monitor lube oil quality to look for problems like bearing wear or look for problems such as water leaks into the crankcase.

COMMISSIONER ASSELSTINE: There were two areas, in particular, when I read through the supporting material, that you all had supplied that I was interested in that seemed particularly relevant to Grand Gulf.

One of them was the crankshaft cracks, and the other was the cylinder head cracks that I guess you just talked about.

Was the cylinder head that you found the cracks in in the diesel that was inspected or in the diesel that was not inspected?

DR. BERLINGER: I think it was in the Division One

diesel.

COMMISSIONER ASSELSTINE: The one that was inspected.

DR. BERLINGER: That was inspected.

COMMISSIONER ASSELSTINE: Does that mean that that's a new crack that appeared after the inspection was done?

DR. BERLINGER: Not necessarily. The crack occurred in a place which has never been found to have failed in the past in any of the TDI engines in nuclear service.

And even the records for some of the non-nuclear service, there's no indication that a crack has occurred in a similar location.

The location is really not on the surface, the internal surface, within the cylinder cavity. It's back behind in the exhaust port area, behind the valve seat up into the area where the valve stem is located or passes.

It's possible, although we don't have any confirmatory information at this time, that that could have been a casting defect or problem which may have existed but which may not have been leaking in the past.

COMMISSIONER ASSELSTINE: Do we know enough about

why the inspection didn't identify this problem to still have confidence in the accuracy and adequacy of the inspection that was done on the Division One diesel?

DR. BERLINGER: For two reasons. The inspections which we requested were looking for specific problems, and most of the non-destructive examinations that were conducted not only at Grand Gulf but at other utility sites were in those areas where we knew that known problems had occurred before.

In addition, we are required to do a general inspection, which is more than just visual. The particular crack which occurred in the last few days or has been identified in the last few days, was in fact not in an obviously visible location.

In order to observe the crack, you had to use a boroscope techniques to see inside the head.

COMMISSIONER ASSELSTINE: Do we know enough about what causes these cracks in the cylinder heads and the crankshafts to be satisfied that just the inspection of Division One diesel is good enough, that having inspected the Division One diesel and not found these problems, and having been able to relate the manufacturing and QA records of Division Two to Division One, that there's not also a need to conduct

the same kind of inspection for the Division Two diesel, particularly now in light of the crack you found in the Division One head?

DR. BERLINGER: To respond to your comment and question, it would be appropriate for me to ask Dave Dengy to come up.

COMMISSIONER ASSELSTINE: Okay.

DR. BERLINGER: That was specifically one of the items in which Battelle provided the staff support.

COMMISSIONER ASSELSTINE: I have one other question. Let me ask it, and then maybe he can address both of those.

I know that another utility went ahead and took the step of replacing all of the cylinder heads on their V-16 diesel.

When I visited that plant, I was told, "Look, we're just not going to fool with it. We want to make sure that we don't have problems in this area. We're going to replace them all."

Why isn't that the preferred course? I gather it was a redesigned, modified, upgraded cylinder head.

DR. BERLINGER: TDI has developed over the years, I think, three cylinder head designs. I think they call them Model 1, 2, and 3.

COMMISSIONER ASSELSTINE: Yes. These are all ones.

DR. BERLINGER: Pardon?

COMMISSIONER ASSELSTINE: These are all ones, right? At Grand Gulf I think that's what...

DR. BERLINGER: I don't know for sure. I think they are. I think they're early models.

COMMISSIONER ASSELSTINE: Yes.

DR. BERLINGER: I think at this time, Dave, I could use some details from you.

MR. DENTON: I think it would be useful if you'd describe the composition of your review team and the expertise that you've been able to bring to bear on this issue.

DR. DENGY: I'm Dave Dengy from PNL. The PNL organization was called into this program in late February, early March. At that time we set up an organization consisting of the technical disciplines that we thought would be needed to support the program, namely, metallurgists, stress analysts, and non-destructive evaluation experts, as well as leading project engineers throughout the organization to take on various elements of the program.

The program was guided by the director's office and we have a senior review board, consisting of three members of the director's office, as well as our project manager.

I'm the deputy project manager. And our first task was to bring in the consultants or technical expertise in the diesel engines.

It's not something that PNL had, nor do I think any other laboratory has on hand.

So we went out very aggressively to find consultants both within the U.S. and as far abroad as we felt we should go to get an adequate number of diesel experts.

At this time, we have about ten individual consultants and, I believe, four organizations from England, from Norway, from Canada, and organizations here in the U.S., as well as the ten individual consultants, many of whom are retired and have the time available to devote and dedicate to this program on an extended basis.

The program was then organized to respond immediately to several tasks at once, one being the owners group plan that was given to us, and we had provided an evaluation of that plan to help NRC provide them a technical basis for establishing an interaction with the owners group regarding that plan.

That report was issued recently. It has a section that I think Carl has referred to, that deals with interim licensing.

That is, plants that we knew were coming onstream or would like to come onstream for licensing action before the owners group had completed its program, which program might take still many months for completion.

I think he's alluded to or referred to the areas where we felt we could take interim action and what sort of requirements we would need for that.

At the same time, we took on the job of looking at plants' specific requests, such as the Mississippi Power & Light request.

We entered that with the February 20th submittal from Mississippi Power & Light, where they identified their inspection program, their proposed testing program, and to some extent, a proposed maintenance program.

We responded immediately and interacted with NRC and our consultants at that time. We brought four consultants in from England, from Norway, two from the U.S. to review that program that Mississippi Power & Light had given us.

We felt is was inadequate on a number of bases. We told NRC of the inadequacies and that was subsequently communicated.

Over a period of several weeks on interactions, we

went to the meetings, attended the meetings between NRC and MP&L and participated as needed to form viewpoints on site at those meetings.

Subsequently, the order went out to tear the engine down. That was, of course, in accordance with our recommendations as well.

We attended the engine tear-down inspection, looked at the results, and formed our own view and provided NRC with our findings relevant to that tear-down inspection.

And so that's sort of the technical basis for the kind of organization we have and the technical basis for forming our judgments based on our own staff metallurgists, stress analysts, and consultants, with large emphasis on the consultants' views.

CHAIRMAN PALLADINO: Are you satisifed that the surveillance program would disclose any cracks in the head in time enough to prevent malfunctioning of the diesel?

DR. DENGY: Yes, I am, and the procedure is that after the engine is run, before the engine or just as the engine cools down until it reaches a steady state, any cracks that have been closed because of the thermal expansion would open up.

So after about four hours, the first time you can

reasonably get in there and look for cracks, we require the engine barring a roll over, to see if there's any water leaks that have developed.

We then ask that that be done within 24 hours, and then there is strong confidence beyond that time if no cracks develop, that it won't develop subsequently.

So then before every plant start, you would go through a normal barring over or roll over to make sure that that's true, so it can be--there are three time scales, four hour, 24 hour and then every time before the engine is started.

CHAIRMAN PALLADINO: Was the cracked head replaced with a Model 1, 2, or 3?

DR. DENGY: I don't know.

CHAIRMAN PALLADINO: Do you know?

DR. BERLINGER: We haven't been provided with enough information to identify specifically the model head that was put in.

CHAIRMAN PALLADINO: I understand that disassembly also disclosed some difficulties with cap screws and turbochargers.

Is that significant? I wasn't sure.

DR. DENGY: Yes, it was significant, and we had the turbochargers sent back to Elliot for a complete refurbishment.

We recommended that, and MP&L subsequently did that to return the turbochargers to essentially new condition.

MR. EISENHUT: Mr. Chairman, that wasn't something that was like this other issue which was found in the last couple of days.

CHAIRMAN PALLADINO: I understand that. That was during the disassembly.

DR. DENGY: We reviewed their report on that, and it was a stress corrosion or defect or cracking that occurred in the bolts, and we think there's adequate action taken to prevent that.

We've recommended to NRC that any licensing action for the first refueling cycle would be appropriate.

COMMISSIONER ASSELSTINE: Does the identification of this new crack in any way alter your confidence in the inspection?

DR. DENGY: No. The crack occurred in an area, as Carl said, that wasn't normally thought of as an area having any particular stress.

And it wasn't part of their original inspection, so not being part of the original inspection, it wouldn't have been found.

And it isn't one where we would have expected it. I have not seen a report on the causes or anything else

at this point in time.

It's relatively new to me.

COMMISSIONER ASSELSTINE: What's the basis for your confidence that the inspection from the Division One diesel is sufficient as far as the Division Two diesel?

I noted in particular, for example, you talked in your report about the crankshaft failures.

One of those you couldn't identify the cause of previous crankshaft failures. So to what extent can you draw confidence that having inspected Division One, that's good enough, as long as you can also trace the quality assurance records and the other records for Division two as well?

(Note: Commissioner Roberts leaves the meeting at this time.)

DR. DENGY: Well, the basis for accepting Division Two without tear-down inspection was basically it had fewer hours under comparable maintenance and surveillance procedures as engine one, so engine one would have had the most damage, if you will.

And there was nothing on engine one tear-down inspection that seemed to suggest that there was a problem, that engine two should be torn down or inspected.

So that provided we didn't get anything suspicious,

that is, something that looks like, gee, this is a problem peculiar to that particular engine or peculiar to MP&L's maintenance, surveillance procedures, and they could show the adequacy of the records to convince us that engine two and engine one were built to the same specs, had the same material, quality control, manufacturing, installation quality control, which they provide us with a report on that, we felt that that tear-down would not be necessary.

COMMISSIONER ASSELSTINE: Given the fact that most all the cracks in the heads have occurred in the group one heads, why isn't it just a prudent thing to do to replace all of the group one heads with the upgraded heads that haven't had the same kind of significant problems?

DR. DENGY: I feel that the group one heads have had a reasonable positive survival in other applications, so it's reasonable to expect that they might be acceptable in this application as well.

Other utilities have replaced them. It wasn't a requirement.

CHAIRMAN PALLADINO: Any more? Okay.

MR. EISENHUT: I'd like to go to the next slide. I put this slide in for consistency. You will recall that in May, there was a Shoreham order, and it turns

out a couple of days later than that, we informed Mississippi Power and Light of the need for an exemption in connection with the diesel inspection, that we had determined they did not meet GDC-17.

We sort of cast that upon them. We also told them at that time to address exigency and as-safe-as. They did file the exemption as we requested. They filed it on June 4, 1984.

The staff shortly after starting that review until up until last Wednesday was engaged in a very detailed review of as-safe-as, which, to give you an idea on the extreme, we had the utility back redoing those calculations.

We're to the point where we think, of course, depending on today's meeting, upon the issuance of the full power license, the need for that exemption is a moot point, and we would propose no further action be taken on that matter.

COMMISSIONER ASSELSTINE: You're conclusion, then, is the plant with these diesel generators meets GDC-17.

MR. DENTON: That's correct.

MR. EISENHUT: That is correct. If I can go to the next slide.

COMMISSIONER ASSELSTINE: I have one other related question on diesels. This came out of my visit to the

plant. That had to do with the extent of testing that we require these diesels.

One of the things I was told by the utility was that the actual load on the diesels at Grand Gulf was about 70%, but that our requirements force them to test these diesels at 110% of capacity.

I guess I wondered whether that's something that is being looked at in terms of the overall review of diesel testing requirements.

Their point to me was running a diesel engine at 110% of rated capacity puts a great deal of strain on the engine itself and may not be necessary, given the lower load for that particular plant.

Is that something that you all are looking at as a general matter?

MR. EISENHUT: Yes, it is, but as a general matter, though, we recognize that the emergency loads on a diesel may only be something on the order of 70%.

As time goes on, following an event where you need those, there are a number of house loads that normally get put on to this, or number of non-essential loads that normally get on, to bring it considerably above the 70%.

In fact, pre- the situation I'm told that in the Grand Gulf situation is actually up in the order of

90%. For this exercise, on these diesels, with the corrected situation, we are, I believe, by this tech spec amendment, dropping that testing limit to a lower level such that we don't overstress the diesel.

MR. DENTON: This has been the subject of a lot of discussion between the industry and ourselves, because obviously if you don't push it toward its nameplate's rating, the survival and the stresses are much lower than you'd get from running it high.

So I think that whole area is under examination, and in fact, we have recently concluded we should relax some of our requirements for fast start, full load test, because of that same sort of consideration that we were perhaps wearing them out rather than gaining the confidence of them.

MR. DIRCKS: I think generically we are taking a look at all of our testing requirements. We're beginning to take a look.

We do have a lot of testing requirements not only in diesels, but across the board. We do have tests required, that people are beginning to wonder whether we might not be reducing safety margins by this constant testing procedure we go through.

MR. DENTON: If you'd like, we could come back and talk further about that issue. We don't have a final

resolution of it, but it is an important issue.

We're looking at it across the board, and will probably be resolved in the course of our completing this overall diesel review.

COMMISSIONER ASSELSTINE: I think that would be useful at some point.

CHAIRMAN PALLADINO: All right. Maybe that's enough on that for the moment, unless you have more. Okay.

MR. EISENHUT: If I could go to the next slide. I'm sorry, this is on shift advisors. This flows from a previous Commission discussion and meetings on the lack of hot operating experience on shift at a number of plants.

Recall that on Diablo Canyon, we had a review there of the industry group going in, reviewing the shift advisor program, and the staff went in and also did a review.

The situation here is pretty much the same in the sense that the industry go in in April, 1984. I believe it was the same head of the team that was used at Diablo Canyon.

They reviewed all aspects of the shift areas, interfaces, between the shift and the advisors, the procedures.

comment that if, in fact, you weren't informed that you would be expected to present statements here today, at least you should get credit, then, for being prepared for an unanticipated event.

(Laughter.)

CHAIRMAN PALLADINO: Now is the Commission prepared to consider voting? All right. I propose to poll each commissioner so that each one of you has the opportunity to make whatever statement you'd like to make with regard to your vote.

I thought I'd start off. I cast my vote to authorize the issuance of full power operating license for Grand Gulf Unit 1 nuclear power plant because after a careful examination of the issues, I am convinced that the plant can operate safely and in accordance with NRC's regulations.

Although this plant first licensed to operate up to 5% in June 1982, it has experienced a number of problems.

I believe that these problems have been resolved. The NRC staff has advised the Commission that all remaining full power issues have been satisfactorily addressed by the utility, specifically operators have completed a recertification program and have passed NRC tests.

The technical specifications is corrected, have been determined by the NRC staff to provide assurance that the plant can be operated safely.

Additionally, the NRC staff has determined that the emergency on-site diesel generators are reliable to perform their intended function if needed.

Particularly relevant to MP&L's successful resolution of identified problems have been their efforts to upgrade management capability.

Since the discovery of the problems at Grand Gulf, the utility has made a number of significant management and personnel changes and these changes have been made at levels including the plant manager, the president of MP&L, the senior vice president, the nuclear operations supervisor of training, and special corporate consultants.

Lastly, I would note my firm belief that the regulatory licensing process has worked in this case.

Many of the plant's problems were identified during the shakedown period associated with low power testing.

Such problem identification is a fundamental reason for carrying out such testing.

Now, in my view, Grand Gulf's problems have been resolved by the utility and confirmed by the NRC staff review.

My vote today underscores my studied determination that the plant can operate safely at full power.

Now let me turn to Commissioner Roberts.

COMMISSIONER ROBERTS: I would accept the recommendation of the regional administrator of the director of licensing, the director of nuclear reactor regulation, that this plant is safe and I would let it begin power ascension leading to full power and commercial operation.

And good luck in your endeavor.

CHAIRMAN PALLADINO: Comissioner Asselstine?

COMMISSIONER ASSELSTINE: I think that, as Mr. Cavenaw said, this utility has had a rough time in its low power program.

I think there are lessons that all of us can learn from that. We didn't do as well as we should, they didn't do as well as they should during the low power program.

We ought to be more careful in the future to make sure that these kinds of problems don't reoccur.

I have to say that there has been, in my view, a strong response to those problems, key to the principle weakness that was involved, weakness in management of the company.

I have been impressed both in what I've heard today

and over the past week or so in my visit to the plant, that the progress and improvements have been made in restructuring the organization, changing the attitudes and commitments to safety on the part of the utility, and generally, I'm satisfied with what I heard today and with the staff's recommendation.

There is one problem I have, and that's a problem that was not created by the utility or the staff, but by my colleagues on the Commission.

Last week, the Commission decided that it was going to change the position that it had outlined in the Shoreham decision just about a month or so ago on what would be required in terms of issuing exemptions from our regulations for new license applicants.

I disagreed with that change by the Commission. I think that the standard that's set forth in Shoreham is the right standard.

I don't see any reason for differentiating between Shoreham and this or any other new plant that's applying for a license.

Unfortunately, the staff hasn't completed its review of those exemption requests, and therefore I'm going to abstain from the vote today on this license issuance.

I want to see what the staff has to say in terms of

whether the exemption requests for this plant meet the kind of rigorous safety test that I think ought to be applied in all of these cases.

So until that work is done, I'm going to abstain, although I have to say that in the other areas that we have discussed today, I'm generally satisfied with the changes that have been made and the improvements that have been taken by the utility and in their general readiness to operate the plant.

CHAIRMAN PALLADINO: Commissioner Bernthal?

COMMISSIONER BERNTHAL: I hesitate to use the term lessons learned from an experience here, because that has come to be a rather chilling phrase since it's so often been used in other contexts.

But I think that everybody in this case has learned some valuable lessons in the case of the Grand Gulf experience.

The NRC has learned some lessons of its own. Certainly the utility has evidenced in part by the significant and important management changes they've made over the recent past, learned a number of lessons the hard way, I might add.

I think the AE itself and the vendor probably learned some lessons from the advent of this new generation plant.

Whatever the difficulties of the past, we're required to deal today with what the current situation is and in my judgment, today, Mississippi Power & Light is the utility and this plant has the first of a next generation BWR prepared for operation, and I'm prepared to cast my vote in favor of that operation today.

CHAIRMAN PALLADINO: You do so?

COMMISSIONER BERNTHAL: I do so.

CHAIRMAN PALLADINO: Commissioner Zech?

COMMISSIONER ZECH: I had had a chance to review the history and the problems of Grand Gulf. I must admit I would have liked to have had more time to do that.

But I have given it, I believe, considerable attention. I have visited the plant, and talked to the senior management, talked to the operators, looked at the plant from many different angles.

I have given considerable thought to the possibility of voting for full power operations. In my view, Grand Gulf is ready for full power operations, and I so vote.

CHAIRMAN PALLADINO: This is the result that you've all heard is four in favor, authorizing the staff to permit full power ascension up to full power, and one abstention.

CERTIFICATE OF PROCEEDINGS

This is to certify that the attached proceedings before the NRC COMMISSION

In the matter of:

DISCUSSION AND VOTE ON FULL POWER OPERATING LICENSE FOR GRAND GULF

Date of Proceeding: July 31, 1984

Place of Proceeding: Washington, D.C.

were held as herein appears, and that this is the original transcript for the file of the Commission.

MELBA REEDER

Official Reporter

Melba Reeder

Official Reporter - Signature

July 24, 1984 - Attachment 2

SAFETY EVALUATION REPORT

GRAND GULF NUCLEAR STATION UNIT 1

RELIABILITY OF DIESEL GENERATORS

MANUFACTURED BY TRANSAMERICA DELAVAL, INC.

TDI PROJECT GROUP

DIVISION OF LICENSING

## 1.0 INTRODUCTION

In support of its request for a full power license for Grand Gulf Nuclear Station (GGNS) Unit 1 and in response to an NRC Order dated May 22, 1984, Mississippi Power and Light Company (the licensee) submitted by letter dated July 5, 1984, a description of the June 1984 disassembly and inspection of the Division I diesel generator; the post-inspection engine test program; and proposed enhancements to the licensee's maintenance and surveillance program. As required by the NRC Order, the licensee submittal also addresses the similarity of the "as-manufactured quality" of the Division I and II diesel generators as part of the licensee's justification for not inspecting the Division II engine.

## 2.0 BACKGROUND

Concerns regarding the reliability of large bore, medium speed diesel generators of the type supplied by TDI at GGNS Unit 1 and at fifteen (15) other domestic nuclear plants were first prompted by a crankshaft failure at Shoreham in August 1983. However, a broad pattern of deficiencies in critical engine components have since become evident at Shoreham, Grand Gulf Unit 1 and at other nuclear and non-nuclear facilities employing TDI diesel generators. These deficiencies stem from inadequacies in design, manufacture and QA/QC by TDI.

In response to these problems, thirteen U.S. nuclear utility owners, including the licensee, formed a TDI Diesel Generator Owners Group to address operational and regulatory issues relative to diesel generator sets used for standby emergency power. The Owners Group program, which was initiated in October 1983, embodies three major efforts.

1. Resolution of 16 known generic problem areas (Phase I program) intended by the Owners Group to serve as an interim basis for the licensing of plants.

2. Design review of important engine components and quality revalidation of important attributes for selected engine components (Phase II program).

3. Identification of any needed additional engine testing or inspections, based on findings stemming from the Phase I and II programs.

Pending completion of the Owners Group program, the licensee submitted a number of reports concerning its actions to ensure the reliability of the TDI diesels at GGNS Unit 1. Based on its review of these reports and the status of the Owners Group program, the staff stated in its Safety Evaluation Report issued in support of the May 22, 1984 Order that additional information was needed regarding the present condition of critical engine components to support operation of GGNS Unit 1 at power levels in excess of 5% of full power for the interim period pending completion of the Owners Group program and NRC staff review of recommendations stemming from this program as they apply to GGNS Unit 1. In addition to the engine inspections and subsequent post-inspection engine tests required by the Order, the staff's SER stated it would be necessary to review the licensee's proposed engine maintenance and surveillance program and any needed license conditions prior to issuance of a full power license.

3.0 EVALUATION

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

In addition to the July 5, 1984 submittal, PNL and its consultants also reviewed the licensee submittals dated February 20, April 17, and May 6, 1984, and performed an onsite inspection of key engine components in June 1984, while the Division I engine was disassembled. PNL and its consultants also considered the status of the generic Owners Group program relative to the actions taken by the licensee to establish the reliability of the diesels.

The staff has reviewed the enclosed TER, and adopts the TER as part of this Safety Evaluation by reference.

3.1 Division I Engine

The June 84 inspection of key engine components, including those identified by the Owners Group as known potential problem areas, indicates that these components are acceptable for nuclear service for the interim period extending to the first refueling of GGNS Unit 1. This finding is subject to (1) operating restrictions as identified in Section 3.4 of this SER, and (2) completion of licensee actions pertaining to confirmatory issues as identified in Section 3.5 of this SER.

Post-inspection testing, as required by the May 22, 1984 Order, was satisfactorily completed. The licensees letter dated July 2, 1984, provided the licensees clarifications/interpretations of the required testing. Although the fast start tests of the engine in accordance with the Order were performed subsequent to a manual prelubing of the turbocharger thrust bearings and thus did not simulate the worst challenge to the bearings, PNL does not recommend additional testing to simulate this challenge. The NRC staff concurs with this PNL finding and concludes that the tests performed by the licensee meets the intent of the NRC Order.

3.2 Division II Engine

In the Order dated May 22, 1984, the NRC staff stated that the need for Division II engine inspection would be contingent upon:

1. Results of the inspection of the Division I engine
2. The licensee's ability to demonstrate, through a review of the manufacturers QA records, that the two engines are of similar "as manufactured" quality.

The Division I engine inspection revealed only one component, the turbocharger, where failed elements, bolts and a vane, might be expected to occur in the Division II engine. The other components showed no rejectable indications or incipient problems that suggested adverse conditions might be present in the Division II engine.

Accordingly, PNL concluded that the turbochargers from the Division II engine should be inspected and any corrective actions taken and findings documented. No other Division II inspections were recommended on the basis of the Division I results.

In its submittal dated July 20, 1984, the licensee reported that the Division II turbochargers have been inspected for the type of damage found in the Division I turbochargers. The scope of the inspection included the stationary nozzle ring, vanes, bolts, and rotating turbine blades. The Division II turbochargers showed no signs of rotating disk damage, although one vane was found to be missing from each stationary nozzle ring (a similar condition was observed in the Division I turbochargers - see discussion in enclosed TER). The stationary nozzle ring bolts were found to be intact with no evidence of stress corrosion cracking. The licensee elected to replace the nozzle ring assembly and bolts although the old parts were judged to be acceptable. Turbine rotor float measurements were also performed and indicated no significant thrust bearing wear. Based upon its review of the licensee's July 20, 1984 submittal, the NRC staff concludes that the licensee has satisfactorily addressed PNL's concern with respect to the Division II turbocharger.

On the basis of the review conducted by the licensee on the manufacturer's QA records and the upgrades accomplished for both engines, PNL concludes that the Division I and II engine components are of comparable "as-manufactured" quality. On the basis of their operating history, PNL concludes that the

engines have been assembled and maintained comparably. Moreover, PNL has noted that the Division II engine has seen less service than the Division I engine. In addition, based upon the status of its review of the Owners Group proposed generic resolution of the connecting rod issue, PNL has concluded that visual inspections of the connecting rods and a preload check of the connecting rod bolts should be performed on the Division II engine prior to plant operation above 5% power. The license has committed to per-forming this inspection in its submittal dated July 20, 1984. Based on these factors and the absence of significant adverse findings from the recent inspection of Division I engine, the staff has concluded that no further inspections of the Division II engine beyond those identified above are necessary at this time.

3.3 Augmented Maintenance and Surveillance Program

PNL concluded in the enclosed TER that modifications to the Augmented Maintenance/Surveillance Program proposed by the licensee in their July 5, 1984 submittal are needed to provide adequate assurance of engine reliability/operability. These modifications are discussed in detail in Section 6 of the enclosed TER.

By letters dated July 20, and July 23, 1984, the licensee committed to a revised Augmented Maintenance and Surveillance Program. The NRC staff has reviewed these letters and concludes that the MP&L program incorporates all of the modifications recommended by PNL. Therefore, the staff finds the Augmented Maintenance and Surveillance Program, as identified in the licensee's July 20, and July 23, 1984 letters, to be acceptable.

3.4 Operating Restrictions

PNL recommendations and conclusions regarding TDI diesel engine reliability at GGNS Unit 1 are predicated on the following assumptions:

1. The emergency service requirements the licensee currently forsees for GGNS Unit 1 will not exceed the engine load corresponding to a break mean effective pressure (BMEP) of 185 psig. The need for this assumption is based on PNL concerns regarding the acceptability of crankshaft stresses at higher BMEP loadings.

2. All future engine testing (except the torsiograph test and the test to obtain preturbine exhaust temperature data as described in the next Section) including surveillance testing required by the plant Technical Specifications will be limited to within ± 5% of the nominal engine load where the upper limit of this load range corresponds to a BMEP of 185 psig.

3. In the absence of the Owners Group completing all elements of their program plan, PNL's conclusions are plant-specific, applying only to GGNS Unit 1 and are applicable only during its first reactor refueling cycle. It is understood by PNL that at the first refueling, the licensee will implement all applicable recommendations of the Owners Group.

With regard to item I above, the licensee reported by letter dated July 20, 1984, (AECM-84/0376) that 185 psig BMEP corresponds to a generator load of 5740KW, about 82% of full rated load. This exceeds the maximum ESF loads, 52% and 68% of full rated load for the Division I and II engines, respectively, required to shutdown the plant and maintain it in a safe condition for loss of offsite power and LOCA. Thus, there exists sufficient engine capacity at 185 psig BMEP to assure that the fuel design limits and design conditions of the reactor coolant system boundary are not exceeded, and that the core is cooled and containment integrity and other vital functions are maintained in the event of postulated accidents as required by GDC-17.

The licensee also states in a letter dated July 20, 1984, (AECM 08/0373) that a precautionary note will be added to the GGNS Off-Normal Event Procedure for Loss of Offsite Power to ensure that loads will not be added unnecessarily to the engines in excess of 185 psig BMEP (5740 KW). In addition, future training with respect to this procedure will explain both the basis for the note and the aspects to be taken into consideration in its application. The staff agrees in principle with these precautions; however, the staff is adding a condition to the license (See Appendix A "License Conditions") to require that these actions be completed prior to plant operation above 5% power[redacted]. The NRC will verify that these actions have been completed.

With regard to item 2 above, the licensee has submitted proposed Technical Specification changes incorporating this item. Specifically, the proposed changes would require that the monthly and 18 month surveillance tests be performed at a minimum of 5450 KW (70% of rated load), but not to exceed 5740 KW (82% of rated load, 185 psig BMEP). The lower limit is greater than the auto-connected loads required for the loss of offsite power and post-LOCA conditions as described above. Therefore, the staff finds these changes to be acceptable.

With regard to item 3, the full power license is being conditioned to require NRC review and approval of licensee actions pertaining to a final resolution of the TDI diesel generator issues at GGNS Unit 1 (See Appendix A).

### 3.5 Additional License Conditions

By letter dated July 17, 1984, the staff identified additional information requested by the staff. The specific information requested was identified under item D in the July 17, 1984 letter and includes those informational items (referred to as "additional MP&L submittals") identified in Section 6 of the enclosed TER.

By letter dated July 20, 1984, AECM-84/0373, the license provided satisfactory responses to all but 3 items. These items for which satisfactory responses were not received include the following:

1) crankshaft torsiograph data at 0%, 25% 50%, 75%, and 100% of engine nameplate loading were not submitted. This information is needed (1)

to confirm adequate crankshaft torsional responses over the spectrum of engine loads to be seen in service, and (2) to provide relevant data to assist the staff and PNL in completing its generic evaluation of the adequacy of the DSRV-16-4 crankshaft design.

2) Preturbine exhaust temperature data at 0%, 25%, 50%, 75%, and 100% of engine nameplate loading was not submitted. This data was requested as a result of a review of cylinder exhaust temperature data obtained from the engine operating logs when the PNL diesel engine expert consultants visited the site on June 4 and 5, 1984. This information is needed to confirm that the even hotter turbine inlet temperatures do not exceed the manufacturers recommendations.

3) Information provided regarding the corrective actions taken in response to numerous fuel oil line leaks during the period of September to November 1983 has not convinced the NRC staff these actions are sufficient to prevent further occurrences of this kind. Apart from the major leak which occurred on September 4, 1983, causing a fire and for which the staff agrees the licensee has taken sufficient action (See attached TER), the other several occurrences involved minor damage to tubes from external causes, particularly from damage caused by maintenance operations. Clearly, periodic inspection of the fuel lines is a major element to preventing reoccurrences.

Although the torsiograph test is a requirement of the May 22, 1984 Order, it is the staff's understanding that the test has not yet been completed. Under the Order, the licensee must complete this test prior to operating the plant above 5% power.

The staff concludes that the above torsiograph and preturbine exhaust temperature data is primarily of a confirmatory nature and is therefore not likely to change the conclusions of this SER. For this reason the staff concludes that plant operation in excess of 5% power should not be conditioned upon staff review and approval of this information. However, this data should be submitted to the NRC prior to plant operation above 5% power as a condition of the license (See Appendix A).

Regarding the fuel oil lines, the staff concludes that the licensee should perform, as a condition of the license (See Appendix A), an inspection of all fuel lines in the Division I and II engines for external damage, and replace or repair all defective lines. These inspections may include inspections already completed provided they were performed subsequent to relevant engine reassembly operations associated with the inspection of the Division I diesel generator and of the Division II turbochargers in June and July 1984. The NRC will verify that these actions have been completed. The licensee should also submit a proposed periodic surveillance program for the fuel oil lines. These actions shall be completed prior to plant operation above 5% power.

## 4.0 Conclusions

The NRC staff concludes that the TDI diesel engines at GGNS Unit 1 will provide a reliable standby source of onsite power in accordance with General Design Criterion 17. This finding is based upon the NRC staff/PNL review of (1) the current status of the TDI Owners Group Program in resolving the TDI diesel engine issue; (2) actions taken by the licensee to enhance and verify the reliability of the Division I and II engines, including those actions taken in response to the NRC order dated May 22, 1984; (3) the Augmented Engine Maintenance and Surveillance Program which the licensee committed to by letters dated July 20 and 22, 1984; and (4) changes to the Technical Specifications to limit future testing of the engines to 185 BMEP. In addition, this finding is subject to the license conditions identified in Appendix A, which assure that Grand Gulf Unit 1 will continue to meet GDC 17 beyond the first refueling outage.

## Appendix A

### License Conditions Pertaining to the Division I and II Diesel Generators at Grand Gulf Nuclear Station, Unit 1

1. The licensee shall submit the following information prior to operation of GGNS Unit 1 at a power level exceeding 5% of full power.

   a) Torsiograph data for the Division I diesel generator at 0%, 25%, 50%, 75%, and 100% of full engine rated load, and associated stresses.

   b) Preturbine exhaust temperature data for the Division I and II diesel generators at 0%, 25%, 50%, 75%, and 100% of full engine load. Maximum values for this data as recommended by the turbocharger manufacturer shall also be provided.

2. The licensee shall complete the following actions prior to GGNS Unit 1 operation above 5% of full power.

   a) A precautionary note shall be added to the GGNS Off-Normal Event Procedure for Loss of Offsite Power to ensure that loads will not be added unnecessarily to the Division I and II engines in excess of 5740 KW. Operators shall be trained with regard to the basis for the note and the factors to be taken into consideration regarding its application.

   b) All fuel-oil lines (including injector lines) shall be visually inspected in the Division I and II diesel generator for external damage, and defective lines repaired or replaced. The inspections may include inspections already completed provided they were performed subsequent to relevant engine reassembly operations associated with the inspections of the Division I diesel generator and of the Division II turbochargers in June and July, 1984. The licenses shall also submit a proposed periodic surveillance program for the fuel-oil lines.

3. Final evaluations and recommendations from the TDI Owners Group Program applicable to GGNS Unit 1, and the licensees actions in response to this program for the Division I and II diesel generators shall be submitted for NRC review and approval prior to plant restart from the first refueling outage.

# Review and Evaluation of Transamerica Delaval, Inc., Diesel Engine Reliability and Operability - Grand Gulf Nuclear Station Unit 1

July 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

Battelle

PNL-5201

# REVIEW AND EVALUATION OF TRANSAMERICA DELAVAL, INC., DIESEL ENGINE RELIABILITY AND OPERABILITY - GRAND GULF NUCLEAR STATION UNIT 1

July 1984

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

Project Title: Assessment of Diesel Engine Reliability/Operability

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

## 1.0 INTRODUCTION

In support of its request for a full power license of Grand Gulf Nuclear Station (GGNS) Unit 1 and in response to an NRC Order dated May 22, 1984, Mississippi Power & Light Company (MP&L) submitted a report on July 5, 1984, addressing three areas:

- a description of the June 1984 disassembly and inspection of the Division I diesel generator
- the post-inspection engine test program
- proposed enhancements to the MP&L maintenance and surveillance program.

As also required by the NRC Order, the MP&L submittal addresses the similarity of the "as-manufactured quality" of the Division I and II diesel generators as part of MP&L's justification for not inspecting the Division II engine. These diesel generators are Model DSRV-16-4 manufactured by Transamerica Delaval, Inc. (TDI).

This Technical Evaluation Report (TER) documents Pacific Northwest Laboratory's (PNL) evaluation of the reliability and operability of the Division I and II diesel generators at GGNS Unit 1. In addition to the July 5, 1984 submittal, PNL has reviewed MP&L submittals dated February 20, April 17, and May 6, 1984. Other information, identified herein, was also considered as needed to support conclusions.

The TER organization is as follows: Section 2 provides background on the TDI problem resolution by both the group of nuclear utility TDI owners and MP&L. Section 3 provides a detailed review and evaluation of the Division I engine disassembly and inspection. Section 4 reviews the MP&L report on the comparability of the Division I and Division II engines. Sections 5 and 6 document PNL's review/evaluation of MP&L's post-inspection engine tests and the

utility's proposed augmented maintenance/surveillance program, respectively. Finally, Section 7 presents PNL's overall conclusions and recommendations regarding the two engines' suitability to serve as standby power sources at the GGNS.

This TER was prepared by the following PNL staff and consultants:

- D. A. Dingee, PNL project staff
- A. J. Henriksen, diesel consultant to PNL
- J. E. Horner, representing Seaworthy Systems, Inc., diesel consultants to PNL
- P. J. Louzecky, Engineered Applications Corporation, diesel consultant to PNL.

Others whose contributions were considered in formulating the conclusions include PNL Assesment 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, B. J. Kirkwood (Covenant Engineering), and J. A. Webber (representing Ricardo Engineering).

## 2.0 BACKGROUND

### 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 (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 (NRC) outlining a comprehensive program including 1) an in-depth assessment of 16 known engine problems (Phase I), 2) a design review and quality revalidation program that addresses other key engine components (Phase II), and 3) engine tests and inspections. A review of that submittal was conducted by PNL and reported to NRC in PNL-5161 dated June 1984.

Section 4 of PNL-5161 deals with considerations for interim licensing of nuclear stations prior to completion of the implementation of the Owner's Group Program Plan. Recommendations relevant to MP&L licensing of the GGNS at this time are:

- The engine should have AE pistons or complete "lead-engine" tests as described in Section 2.3.2 of PNL-5161.
- The diesel generator should not be required to carry a load in excess of that corresponding to engine Brake Mean Effective Pressure (BMEP) of 185 psig.
- The engine should be inspected per Section 2.3.2.1 of PNL-5161 to confirm that the components are sound.
- Pre-operational testing should be performed as discussed in Section 2.3.2 of PNL-5161.
- The engines should receive enhanced surveillance and maintenance.

## 2.2 GRAND GULF NUCLEAR STATION

An MP&L submittal to NRC, dated February 20, 1984, provided a review of the results of their program of inspection, upgrading, testing and maintenance. The PNL review of this document was provided to NRC in a letter dated March 30, 1984. A number of concerns were identified by PNL, namely:

- The MP&L report did not provide sufficient information to convince the reviewers that the AE pistons were suitable for GGNS licensing.
- The evidence was insufficient to conclude that the cylinder heads would perform reliably.
- The connecting rod bearings were not demonstrated to be suitable for operation at GGNS.
- The push rods were not adequately tested.
- Data concerning crankshaft deflections and main bearing wear were needed to confirm the adequacy of the crankshaft.
- The high-pressure fuel line needed to be examined to assure the reviewers that the new lines installed at GGNS are not defective.
- MP&L did not adequately consider the possibility of cracks in the cylinder block.
- Additional information was needed to confirm that the engine base would not crack.
- MP&L did not address head stud problems noted by the Owners' Group.
- The issues on rocker arm capscrews were not closed out per the Owners' Group recommendations.
- The PNL reviewers needed more information from MP&L on turbocharger mounting.
- The evidence provided by MP&L on the connecting rods was insufficient to conclude that they would be adequate.

- MP&L did not address the potential for wrist pin bushing failures; PNL noted that cracks had been observed in wrist pin bushings at the Shoreham Nuclear Power Station.

- The test program was deemed to be inadequate.

- The description of the surveillance and maintenance program was insufficient for the PNL reviewers to draw conclusions.

This detailed PNL review of the February 20 MP&L submittal was followed by a letter dated April 16, 1984, in which PNL recommended a number of actions to support licensing of the GGNS. These included 1) inspection of one engine at GGNS, 2) post-inspection testing, and 3) maintenance and surveillance items. In a letter dated April 17, 1984, PNL provided additional clarification on these actions.

On April 25, 1984, NRC issued a letter to MP&L identifying these actions as an acceptable basis to support full power operation at GGNS for one fuel cycle pending completion of the Owners' Group Program Plan.

After considering additional, updated information provided by MP&L by letter dated May 6, 1984, NRC issued an Order dated May 22, 1984, requiring disassembly and inspection of one engine before the power ascension program could be authorized. Comments pertaining to the need for these inspections were provided in a PNL letter dated May 21, 1984.

On June 4 and 5, 1984, PNL staff and consultants visited MP&L to review the Division I engine components. A PNL letter dated July 9, 1984, summarized the results of this inspection. In general, the inspection did not reveal any problems that should seriously impact the reliability and operability of the engine for the first reactor fuel cycle.

On July 5, 1984, MP&L provided NRC with a report on the Division I disassembly and inspection, in response to the May 22, 1984, Order. This report also compared the Division II diesel generator (DG) to the Division I DG, and addressed post-inspection testing and a proposed augmented maintenance and surveillance program aimed at assuring the future satisfactory performance of both engines. This submittal was the topic of discussion at a meeting held July 13, 1984, among representatives of MP&L, NRC, and PNL.

## 3.0 EVALUATION OF MP&L DIVISION I ENGINE DISASSEMBLY AND INSPECTION

In compliance with the NRC Order of May 22, 1984, MP&L disassembled the Division I TDI engine and inspected all critical components. These components included those that are being addressed as part of the Owners' Group Phase I Program regarding known generic problem areas: cylinder heads, engine block and base, connecting rods, pistons, studs, cap screws, push rods, etc. The specific inspection methods used were identified in the NRC Order. Actions taken by MP&L in conducting the disassembly and inspection are consistent with Section 2.3.2.1 of PNL-5161 dealing with pretest inspections.

This section documents PNL's technical evaluation of MP&L's resolution of each of the 16 known generic problems (components) as well as 8 problems specific to GGNS. It consists of worksheets providing 1) component identification, 2) a brief history of failures, 3) the status of the Owners' Group Program aimed at resolving the problem, 4) the status of MP&L in resolving the problem, and 5) PNL comments/conclusions. PNL's conclusions and comments are based not only on the MP&L submittal of July 5, 1984, and the related discussions on July 13, 1984, but also on an onsite inspection of the engine components. It must be emphasized that, pending completion of the implementation of the Owners' Group Program Plan, PNL's conclusions are plant-specific, applying only to MP&L's Grand Gulf Nuclear Station Unit 1 and to operations only during its first reactor refueling cycle. It is understood that, at the first refueling, MP&L will implement all applicable recommendations of the Owners' Group.

The order of worksheet presentation is as follows. The 16 known problems are reviewed in the order listed in PNL-5161, Table 1. Next, the GGNS-specific problems are reviewed in the following order: low-presure fuel lines, crankcase cover capscrews, fuel oil leaks, air start valve failures, air start solenoid valve failure, fuel oil injection pump, cracks in air box, and failures to start Division I engine.

## 3.1 GENERIC PROBLEMS

Component: Piston Skirt
Part No. 03-341-04-AE
Owners' Group Report: FaAA-84-2-14

### Brief History of Failures

Based on a number of cracks found in AF piston skirts at GGNS, Shoreham, and at non-nuclear installations, the skirt design was strengthened in the boss area where the cracks had been found. No failures have been reported to date on the redesigned piston skirt, labeled AE, in either nuclear or non-nuclear installations. Kodiak has operated in excess of 6000 hours at approximately 185 BMEP (1200 psi maximum pressure); the TDI R-5 test engine in excess of 600 hours with maximum pressures of 2000 psi.

### Owners' Group Status

The Owners' Group consultant, Failure Analysis Associates (FaAA), has analyzed the AE piston skirt design and has concluded that the AE skirts may crack at 10% overload, but that cracks will not propagate to the point of failure.

### MP&L Status

After observing cracks in several skirts, all AF skirts on both Division I and II engines were replaced with AE skirts in January/February 1984. Subsequently, after 270 hours of operation, all Division I skirts were inspected by liquid penetrant and no rejectable indications were observed. However, the piston skirt-to-crown surface on all skirts and crowns showed slight signs of fretting due to relative movement.

### PNL Conclusions

PNL has reviewed both the Owners' Group report and the relevant inspection data. Based on this review, as well as on the aforementioned operating

experience with the Kodiak and R-5 engines, PNL concludes that the piston skirts are acceptable for operation up to and including 185 BMEP at 450 rpm (the 185 BMEP criterion is discussed in PNL-5161, Section 4, "Considerations for Interim Licensing").

Component: Connecting Rod Bearing Shell

Part No. 02-340-04-AG

Owners' Group Report: FaAA-84-31

## Brief History of Failures

No failures of the V-engine connecting rod (conrod) bearing shells have been reported in nuclear applications. However, a number of bearings have been replaced due to nonconformity with Owners' Group recommendations.

## Owners' Group Status

Failure Analysis Associates has conducted both stress and orbital analyses of the conrod bearing shells. Provided the shells are dimensionally correct and otherwise conform to specifications as recommended by the FaAA report, FaAA has concluded that the bearings are suitable for the service intended.

## MP&L Status

In January/February 1984 all conrod bearings in both engines were replaced as a matter of policy. In June 1984, after 270 hours of operation, the Division I engine shells were inspected visually and by liquid penetrant. All bearings (except No. 7) were x-rayed. Bearing No. 7 was sent to FaAA to aid in the ongoing generic analysis. All other bearings were found acceptable in accordance with Owners' Group acceptance criteria. However, bearing No. 4 was replaced nonetheless, due to a 1/2-inch wide wipe caused by dirt. Bearing No. 7 was also replaced; all other bearings were reinstalled.

## PNL Conclusions

PNL has reviewed the Owners' Group report and the relevant inspection data, and has visually inspected the bearings. PNL concludes that the bearings are acceptable for the first refueling cycle.

Component: Rocker Arm Capscrew

Part No. 02-390-01-0G

Owners' Group Report: Stone & Webster, March 1984

## Brief History of Failures

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

## Owners' Group Submittal

Stone & Webster Engineering Corporation, a consultant to the Owners' Group, has performed stress analyses of both the original capscrew design (the type that failed at Shoreham) and a newer design. Stone & Webster has concluded that both designs are adequate for the service intended. Stone & Webster has attributed the failure at Shoreham to undertorquing.

## MP&L Status

The rocker arm capscrews at GGNS are of the original design. These capscrews have experienced in excess of $10^7$ loading cycles without reported failures. Breakaway torques measured during the June 1984 inspection were within acceptable limits. Torque was checked on all capscrews after reassembly in June 1984.

## PNL Conclusions

Based on the analytical results and operating experience to date, PNL concludes that adequate torquing ensures that the capscrews will provide acceptable service.

Component: Air Start Valve Capscrews

Part No. Gb-032-114

Owners' Group Report: Stone & Webster, March 1984

Brief History of Failures

No actual failures of capscrews have been reported. However, on May 13, 1984, 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.

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.

MP&L Status

Capscrews on both Division I and II DGs have been modified by shortening the 3-inch capscrews by 1/4 inch. Proper torque values were confirmed after reassembly.

PNL Conclusions

After reviewing available reports and inspection data, PNL concludes that proper corrective measures were taken and that capscrews are acceptable for the first refueling cycle.

Component: Push Rods

Part No. 02-390-06-AB

Owners' Group Report: FaAA 84-3-17

Brief History of Failures

The push rods originally had tubular steel bodies fitted with hardened steel end pieces attached with plug welds. Reportedly, an estimated 2% developed cracks in or around the plug welds. A push rod design introduced later consisted of a tubular steel body with a carbon steel ball fillet welded to each end. This design proved to be very prone to cracking at the weld. In all, 15 of 16 rods on the GGNS Division I engine and 13 of 16 rods on the Division II engine were found to be cracked. All push rods on both Division I and Division II DGs have been replaced by a new design consisting of a tubular steel body with a steel cylinder friction-welded to each end. No failures are reported on this design.

Owners' Group Status

Failure Analysis Associates has a performed stress analysis as well as cycle wear test to $10^7$ cycles on a sample of the friction-welded push rod at conditions simulating full engine nameplate loading. No sign of abnormal wear or deterioration of the welded joints was observed.

MP&L Status

All push rods on both Division I and II engines were replaced in January/February 1984 by a new design consisting of a tubular steel body with a steel cylinder friction-welded to each end. During the June 1984 inspection, all push rods were inspected by liquid penetrant and no relevant indications were observed.

PNL Conclusions

After reviewing the FaAA report and inspection data and noting the GGNS replacements, PNL concludes that the push rods incorporating the friction weld design are acceptable for the first refueling cycle.

Component: Cylinder Head Stud

Part No. 03-315-01-0A (Old Design)

Owners' Group Report: Stone & Webster, March 1984

## Brief History of Failure

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 reported.

## Owners' Group Status

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

## MP&L Status

The MP&L visual inspection revealed many instances of flat crests on the top threads of the studs and one instance of minor thread damage to the bottom threads. On the engine left bank cylinder No. 3, studs No. 4 and 5 had a 360° discernable surface indication on the stud shank. None of the thread damage was considered service-related and it was concluded that the damage to stud No. 4 and 5 shanks was done during machining of the studs. These two studs were replaced by new studs. It is believed the replacement studs are of the new necked down design. This will be confirmed by MP&L. The damaged stud threads were chased with a die, re-examined, accepted, and reinstalled. Preload was checked on all studs after installation.

## PNL Conclusions

Based on a review of the Owners' Group report and the inspection data supplied in the July 5 submittal of MP&L, PNL concludes that the cylinder head studs are acceptable for the first refueling cycle.

Component: High-Pressure Fuel Tubing

Part No.: 03-365C

Owners' Group Report: Stone & Webster, April 1984

Brief History of Failures

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

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 specified conditions, the HP tubing is considered suitable for the service intended.

MP&L Status

Fifteen HP fuel lines on both Division I and II engines are original equipment and have experienced over 10 million operating cycles. Operating stresses are therefore believed to be smaller than the high-cycle fatigue endurance limit, and thus these tubes are believed to be free of detrimental defects to the inner surface. Both replacement tubes, one on each Division engine, have been subjected to the prescribed surveillance and were found to be sound.

PNL Conclusions

PNL has determined that the original high-pressure lines are acceptable, based on their completing $10^7$ operating cycles. PNL has also determined that the replacement tubes have been adequately inspected. Thus, PNL concludes that the HP fuel tubing is acceptable for the first refueling cycle.

Component: Crankshaft

Part No. 02-310A

Owners' Group Report: FaAA-84-4-16, (dated May 22, 1984)

Brief History of Failures

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.

Owners' Group Status

Failure Analysis Associates has performed torsional and bending stress analyses of the subject crankshaft and has concluded that the shaft will meet Diesel Engine Manufacturers Association (DEMA) standards at the nameplate rated load and speed. The radius of the fillets in main journal oil holes was identified as an area of potential stress concentration and careful inspection of this area was prescribed.

MP&L Status

At MP&L's request, Bechtel Corporation reviewed the FaAA analysis and conducted an independent dynamic analysis of the crankshaft. Bechtel concluded that the shaft will meet DEMA standards. Torsiograph tests will be conducted to compare operating values with analytical values. During inspections in June 1984, crank fillets were inspected by liquid penetrant and found to be sound. Further, oil hole fillets on main journals No. 4, 6, and 8 were inspected by liquid penetrant with no indications noted. Minor scratches were noted on several crank journals. Also, on crank journal No. 4 a slight metal buildup (rodbearing replaced) was noted; it was removed and the journal polished. Hot and cold crankshaft deflections have been measured and documented and reported to be within TDI and Owners' Group specifications.

PNL Conclusions

Based upon the status of PNL's review of the Owners' Group report prepared by FaAA regarding the crankshaft, PNL is not prepared to agree with the FaAA analysis at this time, and has requested further analytical data from the Owners' Group. PNL has also requested that torsiograph tests be conducted at 0%, 25%, 50%, 75%, and 100% rated nameplate loads and rpm. PNL views the torsiograph data as confirmatory to the analysis. PNL concurs that documented hot and cold crankshaft deflections are within TDI and Owners' Group specifications. On this basis, PNL agrees that the crankshaft will be adequate for operation at loads up to and including 185 BMEP and 450 rpm (as described in PNL-5161 Section 4, "Considerations for Interim Licensing").

Component: Turbochargers

Part No.: Elliott 90G

Owners' Group Report: FaAA-84-5-7

## Brief History of Failures

Reports of turbocharger thrust bearing problems are limited to the nuclear industry. To date, thrust bearing problems have been reported for San Onofre, Catawba, and Comanche Peak. Nozzle vane and capscrew problems have also been reported; such problems have occurred at GGNS. Misalignment problems resulting in sheared foundation bolts, as well as broken lube oil return lines and mounting welds, have also been experienced at various nuclear power stations.

## Owners' Group Status

In Report No. FaAA-84-5-7, dated May 1984, Failure Analysis Associates has analyzed the turbocharger thrust bearing problems for the model 90G turbocharger and has concluded that the problems are due to insufficient lubrication of the thrust bearings during "fast" starts (i.e., automatic starts for which no prelubrication is provided to the thrust bearing). Several types of startup lubrication systems have been implemented at nuclear power plants to avoid these problems. One type is a drip system that provides lubrication from the before-and-after (B&A) recirculation system. An alternate type (in use at GGNS) is an auxiliary B&A lube oil pump. This pump is activated prior to any planned start and provides the turbocharger bearings with sufficient lube oil to complete fast starts as required for nuclear standby tests.

FaAA states in the above-mentioned report that findings related to nozzle-vane life and nozzle-ring capscrew design will be presented in a following report. Misalignment problems are not addressed in the FaAA report, and are not mentioned as a topic for a following report.

## MP&L Status

During the June 1984 inspection of the Division I engine, it was discovered that two nozzle ring capscrew heads and one nozzle ring blade were missing on the right-bank turbocharger. It was assumed that the capscrew heads

had passed through the turbine. On the left-bank turbocharger, one nozzle ring capscrew head had broken off, but was still attached to the locking wire. One nozzle ring blade was also found to be missing. Subsequent inspection of the Division II turbocharger revealed one nozzle ring blade missing on each turbocharger. No broken capscrews were found on Division II turbochargers.

MP&L concluded that missing nozzle ring blades had been removed on purpose. The broken capscrews were metallurgically examined and the failure mechanism determined to be intergranular stress corrosion cracking, believed to have been initiated by sulfurous compounds in the exhaust gases during shop tests at TDI. An engineering study by MP&L to determine the need for a different capscrew material is underway.

Division I turbochargers were sent to Elliot for refurbishment, where the thrust bearings, although still serviceable, were replaced. Nozzle ring blades to replace those missing were also installed on both Division I turbochargers.

MP&L has taken extensive actions to correct vibration problems and is confident that earlier misalignment problems resulting in sheared foundation bolts, as well as broken lube oil return lines and mounting welds, are solved through proper alignment.

PNL Conclusions

On the basis of information presented in the FaAA report referenced above, the transcript of the meeting among representatives of FaAA, the Owners' Group, NRC, and PNL on June 22, 1984, and the inspection data presented by MP&L, PNL concludes that the action taken at GGNS to provide lubrication to turbocharger bearings is adequate for the first refueling cycle. Key considerations in support of this conclusion are as follows:

- According to Failure Analysis Associates, as confirmed in a telephone conversation between PNL (W. Laity) and FaAA (T. Thomas) on July 20, 1984, the shortest known time-to-failure of a turbocharger thrust bearing subjected to "dry" starts (for which no bearing prelubrication was provided) occurred at the Shoreham Nuclear Power Station. That bearing experienced at least 62 "dry" starts before failure.

- On the basis of operating experience at GGNS over a 2-year period, MP&L estimates that the diesels may experience two "dry" starts per diesel per year. Turbocharger thrust bearings examined from the Division I engine after two "dry" starts showed no evidence of distress. Float measurements of thrust bearings in the Division II engine are well within manufacturer's specifications, also indicating no thrust bearing distress.

PNL has also reviewed the MP&L actions regarding turbocharger realignment and notes that in excess of 100 hours of operation have occurred without incidents attributable to misalignment or vibration. PNL concludes that MP&L has taken appropriate actions to correct misalignment problems.

In addition, PNL has reviewed the MP&L conclusion that service-related conditions are not responsible for the missing nozzle ring blades. The fact that one blade is missing from each of four nozzle rings (both engines) and that there is a high probability of damage to the turbocharger if the vane breaks in service (not seen on inspection) supports the MP&L conclusion.

On the basis of the above-mentioned analyses, inspections and reviews, PNL concludes that the turbochargers are acceptable for the first refueling cycle.

Component: Connecting Rod

Part No.: 03-340A

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

Brief History of Failures

Connecting rod failures have been reported from the non-nuclear field. Two failure modes have been observed. The first mode was link rod bolt failure due to loss of bolt preload. The second mode of failure was fatigue cracking of connecting rod bolts and/or the link rod box in the mating threads. No connecting rod failures have occurred in nuclear service.

Owners' Group Status

The first failure mechanism is fatigue failure of the link rod bolts resulting from loss of bolt preload. The problem and its solution were addressed by TDI in Service Information Memo No. 349, dated September 18, 1980 (pp. 1-3). According to this SIM, engines manufactured between 1972 and February 1980 may have been shipped with an insufficient locating dowel counterbore depth in the link rod or link pin, resulting in clearance between the link rod and link pin as assembled. Under firing load, this locating dowel will yield, allowing the above clearance to disappear and resulting in loose link rod bolts. The Owners' Group (through the above-mentioned FaAA report) has determined that there must be zero clearance under the specified bolt torque of 1050 ft-lb, and they recommend that the utilities check the clearance with a 0.0015-in feeler gage.

The second failure mechanism is fatigue cracking of the connecting rod bolts and/or the link rod box in the mating threads. TDI attributed these rod cracks to "thread fretting". This "thread fretting" was concluded by TDI to result from distortion of the rod bolt under operating loads in the area of the mating threads; the distortion could occur if the bolts had been installed with the originally specified bolt preloads. The Owners' Group addresses 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 are equipped with a 1-1/2-inch bolts. Stress analysis, including finite element,

has been completed by FaAA. Failure Analysis Associates has concluded that both designs are adequate for the service intended, provided conrod bolt preload is checked within time limits specified as related to engine load requirement in terms of percentage of nameplate rating. However, the rod with the 1-1/2-inch bolts has an 8% to 9% higher margin of safety than the rod with 1-7/8-inch bolts because the rod box structure is more massive with the smaller bolt configuration.

MP&L Status

With regard to the link rod/link pin clearance, MP&L has performed the Owners' Group recommended measurements described above.

The status of the fatigue cracking in the rod boxes is as follows. Both Division I and II conrods are equipped with 1-7/8-inch conrod bolts. During the June 1984 inspection, all connecting rods and accessory equipment were inspected; the findings and dispositions are as follows:

- Serrated joint teeth surfaces were found to have minor fretting on all conrod boxes. At NRC's request, the serrated teeth were dressed via stoning and the contact surface verified by "blueing" as per TDI specifications.
- Conrod external machined surfaces were inspected by MP&L and revealed no indications.
- Magnified borescopic inspection of female threads indicated pitting in one hole of No. 1, galling in one hole of No. 6, and heavy galling in one hole of No. 5. All conditions were judged to be maintenance- rather than service-induced. Rod No. 5 was replaced and threads in the other rods were tapped and reinspected.
- Conrod bolt inspection revealed that approximately 50% of the bolts had minor galling, which was judged to be maintenance-related. All bolts were replaced with fully inspected new bolts. When bolts were installed, they were properly lubricated as per instructions. Proper preload was ascertained by ultrasonic methods.

- All conrod dimensions were checked and found to be within specified tolerances. All wrist pin bushings were inspected by liquid penetrant and found to be in good condition. MP&L has proposed to check conrod bolt preload after 270 hours operation or at first refueling, whichever comes first.

PNL Conclusions

PNL concurs with the MP&L resolution of the connecting rod problem resulting from link rod/link pin clearance, namely feeler-gage confirmation that no clearance exists.

Relative to the fatigue cracking in the rod bolts and/or the link rod box, PNL has reviewed all available information on the subject, and concludes that, provided the check on conrod bolt preload is carried out after 200 hours of operation or after 9 months, whichever comes first, the conrods are acceptable for the first refueling cycle.

Component: Engine Base and Bearing Cap

Part No.: 03-305C, CSG Class A

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

## Brief History of Failures

The only failure reported by the Owners' Group for DSRV-16 engines occurred in a non-nuclear application: a nut pocket failed on a DSRV-16 engine at the ANAMAX mine near Tucson, Arizona. According to FaAA, the engine manufacturer (TDI) reported that this failure was due to impurities in the casting material that reduced the engine base strength.

## Owners' Group Status

Failure Analysis Associates 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 their specifications, that they have not been damaged, and that proper preloads are maintained.

## MP&L Status

During the June 1984 inspection liquid penetrant techniques were used on the main bearing cap-to-engine base saddle surfaces on main bearings No. 4, 6, and 8. No relevant indications were observed.

## PNL Conclusions

Based upon PNL's review of the Owners' Group report and the engine inspection findings reported by MP&L, PNL concludes that the engine base assembly is acceptable for the first refueling cycle.

Component: Cylinder Head

Part No.: 03-360A

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

## Brief History of Failures

Numerous reports on cylinder head failures are available from both the nuclear and non-nuclear industry. For identification purposes, TDI cylinder heads are classified as I, II, and III, all under the same part number. Group I are heads cast prior to October 1978; Group II are heads cast between October 1978 and September 1980; and Group III are heads cast after September 1980. 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. Many of the cracks initiated at the stellite valve seats.

## Owners' Group Status

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 inspected by liquid penetrant and magnetic particle as well as ultrasonic testing to determine firedeck thickness. For Group III heads, sample inspection as described above is recommended. For all three groups of heads, barring over before startup is recommended.

## MP&L Status

During the June 1984 inspection, all heads (all of which are believed to be Group I) on Division I engines were inspected in accordance with Owners' Group recommendations. Eleven heads met all Owners' Group acceptance criteria. Five heads needed further engineering evaluation before being accepted. MP&L proposed to bar the engine over 4 hours after engine shutdown, and once weekly thereafter. Routinely, the engine will be rolled over prior to a planned start.

PNL Conclusions

PNL has reviewed all the pertinent material and also notes that MP&L will limit the engine load during the first refueling cycle to that corresponding to 185 BMEP. On these bases, PNL concludes that the cylinder heads are acceptable for the first refueling cycle, provided that the engine is rolled over 4 hours after shutdown, 24 hours after shutdown, and thereafter prior to each planned start, to check for water leakage into the cylinders.

Component: Jacket Water Pump

Part No.: 03-425

Owners' Group Report: Stone & Webster, June 1984

Brief History of Failures

Shoreham has experienced a jacket water pump shaft failure on the TDI R-4 engine. There is no history of failures on jacket water pumps designed for the V-16 engines.

Owners' Group Status

Stone & Webster has investigated this design jacket water pump and has concluded that, provided proper care is taken to ensure minimum and maximum torque when installing the nut holding the external spine in the taper, the jacket water pump is adequate for the service intended.

MP&L Status

No problems have been experienced.

PNL Conclusions

Based upon the absence of adverse experience with water pumps designed for the V-16 engines, as well as on the review of the Stone & Webster report, PNL concludes that the jacket water pump is acceptable for the first refueling cycle.

Component: Engine Mounted Electrical Cable

Part No.: 03-688B

Owners' Group Report: Stone & Webster, June 1984

Brief History of Failures

No failure of this part has been reported. However, in TDI Service Information Memo No. 361, TDI reported that three engine mounted cables associated with 1) the Woodward governor/actuator, 2) the Air-Pax magnetic pick-up, and 3) the Air-Pax tachometer relay, represent potential fire hazards.

Owners' Group Status

Stone & Webster carried out a field survey. Based on the survey results, Stone & Webster concluded that Class 1E IEEE 383-1974 qualified cable, as now installed in both the Division I and II engines, meets the intended function and is acceptable for the required operation.

MP&L Status

The original commercial grade cable has been replaced by Class 1E IEEE 383-1974 qualified cable in both Division I and II engines.

PNL Conclusions

PNL concludes that the Class 1E IEEE 383-1974 qualified cable as installed is acceptable for the first refueling cycle.

Component: Cylinder Block

Part No.: 03-315A

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

## Brief History of Failures

Numerous incidents of cylinder block failures have been reported in the non-nuclear field. In the nuclear field, all three engines at Shoreham have cracks in their cylinder blocks. At Comanche Peak, cracks were observed after 90 hours of operation.

## Owners' Group Status

Failure Analysis Associates performed strain gauge testing combined with two-dimensional analytical modeling of the block top and liner. Based on these efforts, FaAA concluded:

- Eventually, depending upon load and operating hours, cracks will initiate between stud hole and line counterbore. Cracks are predicted to be benign.
- Cracks between stud hole and liner counterbore will increase likelihood of cracks developing between stud holes of adjacent cylinders. The deepest crack measured in this region (5-1/2 inches in depth at Shoreham) did not degrade engine operation or loosen studs.
- Provided there are no cracks between stud holes between adjacent cylinders, the block is predicted to have sufficient margin to withstand a LOOP/LOCA event.

The FaAA report recommends inspections of cylinder blocks at intervals related to load and operating hours.

## MP&L Status

At the June 1984 inspection, the Division I cylinder block was inspected in all critical areas by liquid penetrant as recommended by the Owners' Group. No critical indications were observed.

PNL Conclusions

After reviewing the FaAA report, and noting that MP&L found no significant indications on the cylinder block and, further, that MP&L will limit the engine load to that correspondiong to 185 BMEP, PNL concludes that the cylinder block is acceptable for the first refueling cycle, subject to the periodic surveillance proposed by MP&L in Section 6.2 of their July 5 submittal.

Component: Cylinder Liner

Part No.: 02-315-02-0G

Owners' Group Report: FaAA 84-5-4

Brief History of Failures

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

Owners' Group Status

The Owners' Group has identified incorrect cylinder liner dimensions as being a contributing factor in liner stresses.

MP&L Status

During the June 1984 inspection all liners were inspected, deglazed, and reinstalled. Dimensional inspections of the liners were performed by MP&L to ensure that the clamping force of the cylinder head on the liner would not induce excessive stress on the cylinder block.

PNL Conclusions

Based upon the MP&L inspection and determination of correct dimensions, as well as upon PNL's onsite inspection during the June 1984 plant visit, PNL concludes that the liners are acceptable for the first refueling cycle.

## 3.2 PLANT-SPECIFIC PROBLEMS

Component: Low-Pressure Fuel Lines

### Brief History of Failures

On September 4, 1984, the Division I engine was stopped due to a fire that broke out at the engine. The fire was caused by a break in a 1-inch fuel oil supply header. MP&L investigated the failure and concluded that it was due to the absence of a clamp, resulting in excessive vibration.

### MP&L Status

MP&L designed and installed a tubing support for this section of tubing on both Division I and II engines. Vibration tests indicated vibration levels to be well within normal levels for this type of machinery.

### PNL Conclusions

PNL has reviewed the pertinent MP&L report and determined that the cause of the failure is well understood and that MP&L has taken appropriate corrective action. Therefore, PNL concludes that the low-pressure fuel lines are properly supported and are acceptable for the first refueling cycle.

Component: Crankcase Capscrews

## Brief History of Failures

During a 24-hour run of the Division II engine on March 15, 1982, the generator was damaged by the head of a 15/16-inch crankshaft capscrew that broke off, found its way into the generator, and became embedded in the stator.

MP&L analysis of the capscrew concluded that the failure was due to a low-cycle stress fatigue front expanding from an initial small crack. The failed capscrew also had a decarburized skin, which may have contributed to the failure. Vibratory tests indicate that vibrations during startup and shutdown may be contributory to capscrew failure.

## MP&L Status

MP&L has installed protective screens at the generators of both Division I and II engines. MP&L has also provided for proper preload of crankcase capscrews to be measured periodically.

## PNL Conclusions

PNL concludes that, although capscrews may continue to fail from time to time, this no longer represents a problem for the generators because the protective screen has been installed to prevent broken capscrews from entering the generator. Therefore, PNL recommends that the crankcase capscrews be accepted for the first refueling cycle.

Component: Fuel Oil Leaks; Air Start Valve Failures; Air Start Valve Solenoid Failures; Fuel Oil Injection Pump; and Division I Engine Failures to Start

Brief History of Failures

Failures of all the above five items were recorded in GGNS Division I and II engine logs.

Cause of Failure and Utility Status

All the above items were discussed at the July 13, 1984, meeting among NRC, MP&L, and PNL. For each issue MP&L orally explained the cause of the problem and corrective action taken. MP&L agreed to furnish NRC with documentation on the cause of the failures and the corrective action taken.

PNL Conclusions

PNL considers the information provided orally on July 13, 1984, to be reasonable. That is, MP&L has adequately determined the causes of the problems and has taken appropriate actions to correct them. PNL considers the forthcoming MP&L documentation of resolution of the five items to be confirmatory to the July 13 discussions and concludes that these items should not prevent the Division I engine from being accepted for the first refueling cycle.

## 4.0 ANALYSIS OF THE REQUIREMENT FOR DIVISION II ENGINE INSPECTION

In the Safety Evaluation Report accompanying the NRC Order of May 22, 1984, requiring diesel generator inspection, the NRC staff stated that the need for Division II engine inspection would be contingent upon:

1. results of the inspection of the Division I engine
2. MP&L's ability to demonstrate, through a review of the manufacturer's QA records, that the two engines have similar "as-manufactured" quality.

### 4.1 DIVISION I ENGINE INSPECTION RESULTS

Conclusions reached by PNL regarding the Division I engine inspection are provided in Section 3 of this TER. In summary, the Division I engine can reliably serve as a standby power source for the first refueling cycle, subject to load limitations and supported by an enhanced surveillance and maintenance program.

#### 4.1.1 PNL Evaluation

The PNL onsite inspection and the MP&L report of July 5, 1984, revealed only one component, the turbocharger, in which failed elements, bolts and a vane, might be expected to occur in the Division II engine. The other components showed no rejectable indications or incipient problems that suggested adverse conditions might be present in the Division II engine.

#### 4.1.2 PNL Conclusion

The turbochargers from the Division II engine should be inspected, any corrective actions taken, and findings documented. No other Division II inspections are recommended on the basis of the Division I results.

### 4.2 ENGINE SIMILARITY DEMONSTRATION

MP&L performed a review and assessment that included the following considerations:

- the similarity of the design and as-manufactured quality of the two diesel engines
- the similarity of the post-manufactured upgrades accomplished for each of the two engines
- a comparison of the operating history and operational performance of the two engines
- a comparison of the results of the previous inspections of the two engines.

#### 4.2.1 PNL Evaluation

The "comparability" review was thorough and did not reveal any engine components where differences between Division I and II would significantly affect the Division II engine performance. It was reported that the crankshafts were manufactured by different vendors. Both vendors are judged adequate by the PNL consultants. The difference noted in the oil hole fillets (7/16 inch in Division I versus 3/16 inch in Division II) was noted. MP&L stated in the July 5, 1984, submittal that FaAA analysis concluded that oil hole radius contributes little to the stress concentration. The PNL consultants believe this conclusion is reasonable.

The engine upgrades (installation of AE piston skirts and friction-welded push rods) on Division I were also implemented on Division II. Thus, the two engines are comparably equipped.

The engine operating records supplied by MP&L in the July 5, 1984, submittal indicate that the Division II engine has about 66% fewer starts and 36% less run time than Division I. Further, there is no pattern to valid failures to start that would suggest the Division II engine is significantly less reliable than Division I. PNL notes, however, that the connecting rods have been subjected to approximately 200 hours of operation since the bolt preloading was last checked.

#### 4.2.2 PNL Conclusions

On the basis of the review conducted by MP&L on the manufacturer's QA records and the upgrade accomplished for both engines, PNL concludes that the

Division I and II engine components are of comparable "as-manufactured" quality. On the basis of the operating history, PNL concludes that the engines have been assembled and maintained comparably and the Division II engine has seen less service. Based on these factors and the absence of adverse findings from the recent inspection of the Division I engine, the Division II inspections can be limited to verifying the Division II connecting rod bolt preloading and inspecting the Division II turbocharger, as identified in Section 4.1.2 above.

PNL assumes that MP&L will implement the same enhanced surveillance and maintenance program on the Division I and II engines to maintain their equivalence.

## 5.0 REVIEW OF THE POST-INSPECTION TESTING

The NRC Order of May 22, 1984, required post-inspection testing to confirm the engines' operability. The testing requirements included the engine manufacturer's recommended preoperational test and additional tests as follows:

- 10 modified starts[(a)] to 40% load (i.e., 40% of nameplate rating)
- 2 fast starts[(b)] to 70% of nameplate rating
- one 24-hour run at 70% of nameplate rating.

MP&L's letter (AECM-84/0325) to NRC of July 2, 1984, provided NRC with MP&L clarifications/interpretations of the required testing. The tests accomplished are:

- 10 modified starts to 50% load
- 2 fast starts, started manually from the control room with demonstrated load sequencing and shedding, to 70% load
- one 24-hour run at 70% load.

### 5.1 PNL EVALUATION

MP&L reported successfully accomplishing all engine manufacturer-recommended post-maintenance testing and all NRC required testing. PNL had understood the fast starts would be done without manual prelubing of the turbochargers. However, the MP&L clarification/interpretation letter (AECM-84/0325) dated July 2, 1984, stated that "all engine starts required by the Order will be preceded by a prelube period...". Such starts are not recognized as simulating starts accompanying loss of offsite power.

### 5.2 PNL CONCLUSIONS

PNL concludes that post-inspection testing was satisfactorily accomplished with the exception that the fast starts did not simulate the worst challenge to the turbocharger bearings. PNL does not recommend additional testing to

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(a) 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 one hour.
(b) A fast start simulates ESF signal with the engine in ready-standby status.

simulate this challenge. The information cited earlier in this report for turbocharger thrust bearings provides assurance that the number of "dry" starts anticipated by MP&L is small (two per year per engine), and that the thrust bearings may reasonably be expected to operate satisfactorily for many more than the anticipated number of "dry" starts through the first refueling cycle.

## 6.0 REVIEW OF THE PROPOSED AUGMENTED MAINTENANCE/SURVEILLANCE PROGRAM

In a letter dated April 16, 1984, to C. Berlinger, PNL identified elements of a maintenance/surveillance (M/S) program that would provide added assurance that the performance of key components of the GGNS TDI engines would be regularly reviewed and that early data would be available to detect potential component failures. It was felt that, in the absence of the completed Owners' Group Program Plan, enhanced M/S is needed to ensure engine reliability. Clarification of some elements of the M/S program was provided to NRC in a letter to C. Berlinger dated April 17, 1984. Subsequently, the features of the enhanced M/S program suggested by PNL were incorporated by the NRC staff in a letter to MP&L dated April 25, 1984.

The MP&L submittal of July 5, 1984, proposed an augmented M/S program for the GGNS Unit 1 diesel engines. MP&L proposed that this revised program remain in effect "...until such time that the reliability of the TDI engines has been demonstrated as adequate by MP&L and the TDI D/G Owners' Group to the satisfaction of the NRC." The MP&L proposed program differs somewhat from the NRC staff recommendations. The differences are aimed at reducing the time that the engines would not be available while the GGNS is at power. Table 1 provides a comparison of the NRC and MP&L M/S program elements.

### 6.1 PNL EVALUATION

PNL has recommended that utilities seeking licensing prior to the Owners' Group completing all elements of their plan should provide for enhanced surveillance and maintenance (see Section 4 of PNL-5161). Generally, MP&L has provided this. However, as evidenced in Table 1, there are significant differences between the NRC guidance of April 25 and the July 5 proposal by MP&L.

TABLE 1. Comparison of NRC and MP&L Proposed Maintenance/Surveillance for Key Components of the GGNS TDI Engines

| Component | NRC Guidance (April 25) | MP&L Proposal (July 5) |
|---|---|---|
| Cylinder heads | Air roll 4 hours after engine runs and each day thereafter | Air roll 4 hours after engine runs and each week thereafter |
| Engine block and base | Visually inspect after 24 hours operation or monthly | Same as NRC |
| Connecting rods | Visually inspect and retorque after 24 starts, 50 hours operation, or 6 months, whichever is first | Visually inspect and retorque after 50 starts, 270 hours operation, or at the first refueling outage, whichever is first |
| Lube oil check | Check for water following preoperational tests, then weekly or after 24 hours operation, whichever is first. Check monthly for contaminants and water in sump; check filters | Monthly checks |
| Studs/fixtures | Check 25% monthly for torque | Check 25% after 270 hours or at the first refueling outage, whichever is first |
| Push rods, cams, tappets, etc. | Visually inspect after 24 hours operation | Visually inspect after 270 hours operation or at the first refueling outage, whichever is first |
| Other M/S items | Standby: Lube oil filter differential pressure - daily | Standby: Lube oil filter differential pressure - hourly |
| | Crankshaft deflections - 6 months | Crankshaft deflection - after 270 hours or at refueling |
| | Operations: Exhaust temp. - continuous (record hourly) | Operations: Generally per NRC guidance |
| | Lube oil, jacket water, interlock temp., air pressure, accelerometers - continuous (record hourly) | |

6.1.1 Cylinder Heads

The engine air-roll is to detect water in the cylinder, indicating cracked cylinder heads. Water in the cylinder would seriously impact engine operability. The MP&L proposal is to air roll weekly rather than daily to reduce engine unavailability. PNL does not consider this proposal to be adequate for assuring timely detection of water in the cylinders. A revised schedule of air rolls, including one each at 4 and 24 hours after engine shutdown and, thereafter, prior to planned engine starts, is recommended. The basis for the change from the earlier PNL recommendation (which called for rolling the engine every 24 hours) is the recognition that, if a leak has not occurred before 24 hours downtime, it is unlikely that one will be generated before the next time the engine is operated.

6.1.2 Connecting Rods

The visual inspection and retorquing are to provide assurance that the serrated rod joint has not loosened, which could lead to engine failure. The relevant Owners' Group report (FaAA-84-3-14) recommends that the bolt retorquing interval not exceed 200 hours at full load, 248 hours at 85% load, and 286 hours at 75% load. The Owners' Group does not differentiate between conrods having 1-1/2-inch bolts and those having 1-7/8-inch bolts (the latter having higher stresses). However, the GGNS conrods have the 1-7/8-inch bolts; theirs is the only V-16 engine in nuclear service with bolts of this size. Add to these factors the observation of some minor fretting in the serrated joints, noted in connection with the latest engine inspection, and a retorquing approach more conservative than that proposed by MP&L is recommended. A retorquing schedule of 200 hours of operation or 9 months, whichever occurs first, is considered adequate. The 200-hour retorquing interval (rather than the earlier proposed 50-hour interval) is based on PNL's review of the Owners' Group report and the MP&L analysis of the adverse impact of more frequent inspections on engine availability.

6.1.3 Lube Oil Checks

Lube oil checks serve two main functions: they indicate water in the oil that can lead to early engine failures (as well as indicating cracks in engine

components), and they may be useful for detecting abnormal wear of engine parts. In this last regard it is important to collect the lube oil sample while the engine is running; MP&L did not specifically provide for this. Otherwise, the proposed monthly rather than weekly lube oil check is considered sufficient, in light of reevaluation based on the experience of the PNL diesel engine consultants.

6.1.4 Studs/Fixtures

Loss of preload on studs can affect engine operability if it goes unnoticed. The air start valve capscrews are more susceptible to loss of preload than are the other threaded fasteners because the gasket material used with these capscrews is softer. One consequence of loss of preload may be loss of cylinder compression.

The MP&L proposed schedule of retorquing on a 25% sampling basis at 270 hours or at the first refueling outage is considered acceptable, based on the judgment of the PNL diesel engine consultants, with the exception of the air start valve capscrews. All (100%) of these capscrews should be retorqued on the MP&L frequency.

6.1.5 Push Rods, Cams, Etc.

Engine operability is affected by defects in push rods, cams, and other similar components. Periodic visual inspection is therefore needed. The difference between the NRC guidance (after 24 hours operation) and MP&L proposal (after 270 hours operation or at the first refueling, whichever is first), is not considered significant in light of the low wear rates of these components, because all parts have been inspected and because, in the opinion of the PNL consultants, there is very little chance of changes in the condition of these parts taking place in the 270-hour (versus the 24-hour) time period. Therefore, the MP&L proposal is considered acceptable.

Additional Surveillance

Surveillance of a number of key engine parameters is essential to assuring reliable engine performance. The NRC guidance and MP&L proposed surveillance are generally quite similar. The differences noted in frequency of measuring

lube oil pressure difference and hot and cold crankshaft deflection are not of major significance; thus, the MP&L proposals in these areas are acceptable.

Some clarification of the terms used in the MP&L July 5, 1984, submittal is recommended. Also, one item of surveillance, engine load, was not addressed. The following changes in Section 6.7 of the MP&L submittal are therefore recommended:

p. 57, Discussion - add the word "hourly" after "recorded" in line 2.

p. 58 - replace as noted:

- "lube oil pressure" to "engine inlet lube oil pressure"
- "combustion air L.B. pressure" and "combustion air R.B. pressure" to "air manifold pressure L.B. and R.B."
- "jacket water pressure" to "jacket water pressure in and out"
- "cylinder temperatures" to "all cylinder exhaust temperatures"
- "stack temperatures" to "preturbine exhaust temperatures"
- add "engine load" as a new item.

p. 59, MP&L Proposed Action - add "or each refueling cycle, whichever occurs first," after "operation" in line 3.

p. 59 - Add a new item of surveillance, namely "check the rotor float of at least one turbocharger and inspect stationary nozzle ring bolts, after 270 hours of operation or at the first refueling outage, whichever comes first."

p. 64, Table 6-2 - add "clear water system (flush out)" with frequency of 3 to 4 years.

## 6.2 PNL CONCLUSIONS

PNL concludes that the MP&L proposed M/S activities need some modifications to provide adequate assurance of engine reliability/operability. The modifications are discussed in detail above in Section 6.1. In summary they are:

- cylinder heads - Revise air roll to 4 and 24 hours after each engine shutdown and prior to planned engine starts.

- connecting rods - Revise retorquing frequency to 200 hours or 9 months, whichever occurs first. A retorquing check should be performed on the Division II engine prior to plant operation.
- lube oil checks - Add that a lube oil sample will be obtained while engine is running.
- studs/fixtures - Modify to assure that 100% of the air start valve capscrews will be retorqued on the schedule indicated.
- additional surveillance - Provide changes as detailed above in Section 6.1.6.

With these modifications, the MP&L proposed M/S activities are considered acceptable for the first refueling cycle.

## 7.0 OVERALL CONCLUSIONS

PNL and its consultants conclude that the TDI diesel engines at the GGNS have the needed operability and reliability to fulfill their intended (auxiliary) emergency power function for the first refueling cycle. This conclusion is reached with a number of understandings regarding 1) limits to the engine requirements, 2) NRC concurrence with MP&L findings/conclusions regarding items to be supplied to NRC, 3) limitations on the engine Brake Mean Effective Pressure (BMEP), and 4) MP&L's implementation of the modifications to their proposed surveillance and maintenance program identified in Section 6. Further details on these items follow.

### 7.1 LIMITED ENGINE REQUIREMENTS

PNL understands that the emergency service requirements MP&L now foresees for the GGNS will not exceed the engine load corresponding to a BMEP of 185 psig.

### 7.2 NRC CONCURRENCE WITH ADDITIONAL MP&L SUBMITTALS

The PNL conclusion that the TDI engines will provide adequate standby power for the GGNS is predicated on an understanding that a technical review of the following MP&L submittals to NRC will not raise unanticipated problems:

- an inspection report confirming that the turbocharger turbine nozzle bolt failure was due to intergranular stress corrosion
- a submittal describing in detail the method used and the results to confirm the surface area contact of the serrated surfaces of each connecting rod is at least 75%
- documented results of measurements of the cylinder head firedeck surface flatness
- the inspection and engineering evaluation reports confirming the acceptability for continued service of the two cylinder heads that contain cracks in the stellite seats
- a submittal identifying the design of cylinder head replacement studs

- MP&L documentation of the indications noted and the engineering disposition concerning the relative motion between the piston crown and skirt
- documented crankshaft deflections relative to TDI specifications
- crankshaft torsiographs at 0%, 25%, 50%, 75% and 100% of engine nameplate loading and associated stresses as identified in a PNL letter to NRC dated July 17, 1984
- documented preturbine exhaust temperatures relative to the manufacturer's recommended maximum.

## 7.3 ENGINE BMEP LIMITATIONS

PNL understands that all subsequent engine testing (except the above-mentioned torsiograph at 100% loading and the test to obtain preturbine exhaust temperature data) will be limited to the load corresponding to 185 BMEP.

## 7.4 REVISED SURVEILLANCE/MAINTENANCE PROGRAM

PNL understands that MP&L will resubmit to NRC a revised surveillance and maintenance plan incorporating the recommended changes identified in Section 6 of this report.

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SAFETY EVALUATION REPORT

CATAWBA NUCLEAR STATION UNIT 1

RELIABILITY OF DIESEL GENERATORS

MANUFACTURED BY TRANSAMERICA DELAVAL, INC.

TDI PROJECT GROUP

DIVISION OF LICENSING

## 1.0 INTRODUCTION

In support of its request for a full power license for Catawba Nuclear Station (Catawba), Unit 1, Duke Power Company (the licensee) submitted by letter dated June 29, 1984, a description of the inspection results of the 1A diesel generator. Further, on July 6, 1984, the licensee submitted its inspection plans for the 1B engine along with its proposed return-to-service testing of the 1A engine. The licensee submitted its enhanced maintenance and surveillance program for the diesels on July 16, 1984.

Both diesel generators at Catawba Unit 1 (designated 1A and 1B) have 16 cylinders in the vee configuration with a full load engine rating of 7000KW. The engine manufacturer is Transamerica Delaval, Inc. (TDI).

## 2.0 BACKGROUND

Concerns regarding the reliability of large bore, medium speed diesel generators of the type supplied by TDI at Catawba Unit 1 and at fifteen (15) other domestic nuclear plants were first prompted by a crankshaft failure at Shoreham in August 1983. However, a broad pattern of deficiencies in critical engine components have since become evident at other nuclear and non-nuclear facilities employing TDI diesel generators. These deficiencies stem from inadequacies in design, manufacture and QA/QC by TDI.

In response to these problems, thirteen (13) U.S. nuclear utility owners, including the licensee, formed a TDI Diesel Generator Owners Group to address operational and regulatory issues relative to diesel generator sets used for standby emergency power. The Owners Group program, which was initiated in October 1983, embodies three major efforts.

1. Resolution of 16 known generic problem areas (Phase I program) intended by the Owners Group to serve as an interim basis for the licensing of plants.

2. Design review of important engine components and quality revalidation of important attributes for selected engine components (Phase II program).

3. Identification of any needed additional engine testing or inspections, based on findings stemming from the Phase I and II programs.

## 3.0 EVALUATION

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

In addition to the submittals listed in Section 1.0 above, PNL and its consultants also reviewed other licensee submittals (identified in Section 2.0 of the enclosed TER) and performed onsite inspections of key engine components in April and July, 1984, while the 1A and 1B engines were disassembled, respectively. PNL and its consultants also considered the status of the generic Owners Group program relative to the actions taken by the licensee to establish the reliability of the diesels.

The staff has reviewed the enclosed TER, and adopts the TER as part of this Safety Evaluation by reference. The remainder of the SER provides clarification of the TER and indicates items required of the licensee.

### 3.1 Extended Operational Tests

In an April 5, 1984 letter to the NRC, Duke Power Company described their extended operational tests on the 1A engine. The 1A engine had been operated to over 810 hours with about 76% of those hours at operating levels greater than required for emergency power. The licensee's intent in operating the 1A engine (and subsequently the 1B engine) for this amount of time was to establish the reliability and operability of the engine. The 1B engine has also been tested to greater than 750 hours with more than 75% of the tests conducted at full load or above and approximately 80% of the tests conducted at operating levels greater than required for emergency power.

### 3.2 Inspections Following Extended Operational Tests

#### 3.2.1 1A Engine

Following the extended operational tests, the licensee conducted an extensive teardown and inspection of the 1A engine which presently is almost complete. The inspection of key engine components, including those identified by the Owners Group as known potential problem areas, indicates that these components are acceptable for nuclear service for the interim period extending to the first refueling of Catawba Unit 1. This finding is subject to (1) operating restrictions as identified in Section 3.5 of this SER, and (2) completion of licensee actions pertaining to confirmatory issues as identified in Section 4.0 below.

The most significant findings as a result of this inspection include cracks in four of the AN type piston skirts (all pistons in both engines have been replaced with the later model AE skirts), wear on the turbocharger thrust bearings, cracks in two intake rocker arm pedestals, small jacket water leaks in two cylinders, and three minor indications on the crankshaft which were polished out.

In a June 29, 1984 submittal, Duke Power discussed their inspections and their evaluation and final disposition of findings. For the most part, the staff has concurred with Duke Power's assessment and resolution of inspection results. However, the staff has no basis to find that Duke Power's solution to preventing weld cracking on the right bank at the turbocharger adapter to the intercooler interface, i.e., providing stiffeners to span the weld area, is adequate considering the amount of surging and vibration that this interface is likely to experience. The staff believes a solution which would alleviate this problem involves installation of a flexible joint at this juncture. Because of the potential impact to operation that failure at the adapter could have, the staff requires Duke Power to install a flexible joint arrangement at the turbocharger right bank of both engines prior to operation above 5% power.

Additionally, Duke Power must install an improved turbocharger prelubrication system by first refueling, or in lieu of installation, must fully inspect the turbocharger thrust bearings of one engine at the first refueling. Duke Power has committed to install an improved system by September 1984. In addition, prior to operation above 5% power, Duke Power must commit to perform such an inspection if an improved prelubrication system is not installed.

Duke Power has indicated in their June 29, 1984 inspection report that #6L cylinder head will be replaced. The staff requires that this head be replaced prior to operation above 5% power with either a new cylinder head or one obtained from another engine such as those at Catawba Unit 2.

There remains several plant-specific and generic problem areas where Duke Power has not yet completed the inspection or where investigation is continuing. Satisfactory completion and resolution of these areas must be confirmed to the staff prior to full power licensing of Catawba. Confirmation is required of the following:

- Satisfactory reassembly and walkdown results for the fuel line fittings,
- Satisfactory inspection results, including necessary replacement of fuel injection pump valve holders,
- Replacement of turbocharger gas inlet bolts,
- Satisfactory results of eddy-current testing of high pressure tubing, and
- Installation of the jacket water pump impeller nut within the recommended torque range.

### 3.2.2 1B Engine

The inspections performed on the 1B engine are identified in a July 6, 1984 letter to the NRC and are also quite thorough and extensive. They are very similar in scope to those performed on the 1A engine. The justification for reduced inspection of some components is based on satisfactory results on the

The most significant findings as a result of this inspection include cracks in four of the AN type piston skirts (all pistons in both engines have been replaced with the later model AE skirts), wear on the turbocharger thrust bearings, cracks in two intake rocker arm pedestals, small jacket water leaks in two cylinders, and three minor indications on the crankshaft which were polished out.

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- Replacement of turbocharger gas inlet bolts,
- Satisfactory results of eddy-current testing of high pressure tubing, and
- Installation of the jacket water pump impeller nut within the recommended torque range.

### 3.2.2 1B Engine

The inspections performed on the 1B engine are identified in a July 6, 1984 letter to the NRC and are also quite thorough and extensive. They are very similar in scope to those performed on the 1A engine. The justification for reduced inspection of some components is based on satisfactory results on the

1A engine. By letter dated August 1, 1984, Duke Power has committed to perform examinations of the 1B engine's link rod bushings for any damage.

As resolution to the problem of chrome peeling on the intake and exhaust valves, Duke Power has replaced the affected valve stems where found, on both engines. The staff and its consultants agree with the licensee's approach. It is not the consultant's intent in the enclosed TER to suggest that all valves need to be replaced.

The staff concludes that the licensee's proposed 1B inspection plan, as contained in the July 6 and August 1, 1984 submittals, is adequate with one modification. Prior to operation above 5% power, the staff requires that Duke Power commit to check the torque of the jacket water pump impeller nut at the time of the first refueling outage.

The staff concludes that the 1B diesel can reliably meet its intended design function based on the proposed inspection plan. The staff anticipates receipt of the 1B inspection results by October 31, 1984.

3.3 Return-to-Service Testing

The licensee proposed certain return-to-service tests for the engine in its July 6, 1984 submittal to the staff. The purpose of the tests is to demonstrate the engine's operability following reassembly. By letter dated August 1, 1984, Duke Power committed to install temporary thermocouples on the 1B engine to measure pre-turbine exhaust temperatures at 25%, 50%, 75% and 82% of full engine load during that engine's return-to-service testing program. In addition, Duke Power has committed to install permanent thermocouples on both engines by the first refueling outage. The staff and its consultants have reviewed the licensee's proposed testing and find it acceptable with the following modification:

° Duke Power must perform the tests within the operating restrictions outlined in Section 3.5 of this SER.

The staff concludes that the licensee's proposed testing plan, with the above modification is sufficient to establish the 1A engine's operability for return-to-service. If a test failure occurs during return-to-service testing, the problem must be corrected and that particular test sequence (e.g. endurance test or modified start tests) must be reperformed.

The staff understands that the testing program for the 1B engine will duplicate that of the 1A engine with the addition of the monitoring of the pre-turbine exhaust temperatures. As with the 1A engine, the staff concludes that successful completion of the 1B testing program will establish the 1B engine's operability for return to service.

### 3.4 Enhanced Maintenance and Surveillance Program

PNL concluded in the enclosed TER that modifications to the Enhanced Maintenance/Surveillance (M/S) Program proposed by the licensee in their July 16, 1984 submittal are needed to provide adequate assurance of engine reliability/operability. These modifications are discussed in detail in Section 7 of the enclosed TER.

The staff will require that the licensee commit to a modified M/S program as discussed in this section of the SER and in Section 7 of the enclosed TER as a prerequisite to a operation above 5% power. The connecting rod bearing shell inspection called for on page 50 of the enclosed TER should include a complete inspection (dimensional, visual and radiographic) of all bearing shells after 500 hours of operation. The bearing shell inspection discussed on page 92 should be a sample inspection of four bearing shells to evaluate their condition in relation to the 500 hour inspection interval.

Duke Power indicated in its inspection report dated June 29, 1984, that until the cause of the rocker box subassembly cracking was determined, the subassemblies would be inspected regularly. Duke Power must supply to the staff the planned surveillance activities and frequencies of inspections of the subassemblies prior to operation above 5% power. Increased surveillance activities should continue until identification and resolution of the cause of the failure is accomplished to the staff's satisfaction.

The TER specifies an inspection interval for the connecting rod bolting* of 200 hours or nine months, whichever comes first. Since issuance of the final TER, PNL has reevaluated the inspection interval in terms of the operating time expected in nine months which is on the order of 50 hours. Their reevaluation is contained in an August 10, 1984 letter to the staff provided as an enclosure to this SER. Because the operating time in nine months is not expected to approach 200 hours, inspection of the connecting rod bolts at the first refueling outage, rather than nine months, is deemed acceptable. The staff agrees with this assessment since the inspection time interval will now correspond more closely with the operating time inspection interval. Therefore, the connecting rod bolting should be inspected at 200 hours or first refueling, whichever comes first.

The licensee is required to check the lubricating oil of the engine for chemical and particulate contamination on a monthly basis for the first three months of operation at which time the results will be reviewed by the staff to determine a subsequent surveillance schedule.

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* The diesel engines at Catawba have 1½" connecting rod bolting rather than 1-7/8" bolting as identified in the TER.

3.5 Operating Restrictions

The staff recommendations and conclusions regarding TDI diesel engine reliability at Catawba Unit 1 are predicated on the following:

1. Engine operation and testing, including surveillance testing required by the plant Technical Specifications, will be limited to within ± 5% of the nominal engine load where the upper limit of this load range corresponds to a BMEP of 185 psig. The need for this is based on PNL and staff concerns regarding the acceptability of crankshaft stresses, and the lack of substantial AE piston operational data at higher BMEP loadings.

2. The emergency service requirements of Catawba Unit 1 do not exceed the engine load corresponding to a brake mean effective pressure (BMEP) of 185 psig.

3. At the first refueling, the licensee is required to implement all applicable recommendations of the Owners Group, as reviewed and accepted by the staff. This implementation will be a condition of the license.

With regard to item 1 above, the licensee must submit proposed Technical Specification changes incorporating this item prior to operation above 5% power. Specifically, the proposed changes would require that the monthly and 18 month surveillance tests be performed at a load greater than or equal to the maximum emergency service load, but not to exceed 5750KW (82% of rated load, 185 psig BMEP). This limit is greater than the auto-connected loads required for the loss of offsite power and post-LOCA conditions as described below in reference to item 2. Therefore, the staff finds these changes acceptable.

With regard to item 2 above, the 185 psig BMEP corresponds to a generator load of approximately 5750KW, slightly more than 82% of full rated load. This exceeds the maximum emergency service loads of 5714KW and 5256KW required to shut down the plant and maintain it in a safe condition for loss of offsite power and LOCA, respectively. Thus, there exists sufficient engine capacity at 185 psig BMEP to assure that the fuel design limits and design conditions of the reactor coolant system boundary are not exceeded, and that the core is cooled and containment integrity and other vital functions are maintained in the event of postulated accidents as required by GDC-17.

The licensee must add, prior to full power licensing, a precautionary note to the Catawba Abnormal Procedure for Loss of Normal Power, and to any other applicable plant procedures, to ensure that loads will not be added unnecessarily to the engines in excess of 185 psig BMEP (5750KW). In addition, future training with respect to this procedure will explain both the basis for the note and the aspects to be taken into consideration in its application. The NRC will verify that these actions have been completed.

With regard to item 3, the full power license is being conditioned to require NRC review and approval of licensee actions pertaining to a final resolution of the TDI diesel generator issues at Catawba Unit 1.

## 4.0 CONCLUSIONS

The staff and its consultants have reviewed the licensee's extended operational test program, its post-operational inspection program, its return-to-service test plan and its maintenance/surveillance schedule. The staff believes that the licensee has adequately tested the engines prior to disassembly and inspection. The inspections performed by the licensee were sufficiently broad in scope to encompass both Catawba-specific occurrences as well as the significant generic problems identified by the Owners Group. Further, the staff concludes that upon satisfactory completion of return-to-service testing and implementation of the modified maintenance/surveillance program, the Unit 1 engines should be reliable to perform their design functions through the first reactor refueling outage.

Therefore, the NRC staff concludes that the TDI diesel engines at Catawba Unit 1 will provide a reliable standby source of onsite power in accordance with General Design Criterion 17. This finding is based upon the NRC staff/PNL review of (1) the current status of the TDI Owners Group Program in resolving the TDI diesel engine issue; (2) actions taken by the licensee to enhance and verify the reliability of the 1A and 1B engines (contingent upon satisfactory completion of the 1B engine inspections and the 1A and 1B engines' return-to-service testing); (3) the enhanced maintenance and surveillance program as described in Section 3.4 of this SER and in Section 7 of the TER which the licensee must commit to; and (4) changes to the Technical Specifications to limit future testing and operation of the engines to a BMEP of 185 psig. Furthermore, the Catawba license will be conditioned to require Duke Power to implement the Owners Group recommendations applicable to Catawba Unit 1, as reviewed and accepted by the staff, by the plant's first refueling outage.

As discussed in the SER, the following items are required of the licensee prior to operation above 5% power to support the staff's conclusions.

- Installation of a flexible joint arrangement at the turbocharger right bank of both engines.
- A commitment to inspect the turbocharger bearings of one engine if an improved prelubrication system is not installed.
- Replacement of the 6L cylinder head on the 1A engine.
- A commitment to inspect the 1B engine's jacket water pump impeller nut at the first refueling.
- A commitment to incorporate the modified maintenance and surveillance program as discussed in the SER and TER, including identification of the rocker box subassembly inspection frequency and cause of failure.
- Revised Technical Specifications limiting operation and testing to 185 psig BMEP (5750KW).

- Revised plant procedures incorporating a precautionary note to ensure that loads will not be unnecessarily added in excess of 185 psig BMEP (5750KW).

Confirmation of the following is required on the 1A inspection prior to operation above 5% power:

- Satisfactory reassembly and walkdown results for the fuel line fittings.
- Satisfactory inspection results, including necessary replacement of fuel injection pump valve holders.
- Replacement of turbocharger gas inlet bolts.
- Satisfactory results of eddy-current testing of high pressure tubing.
- Installation of the jacket water pump impeller nut within the recommended torque range.

Enclosure 1

PNL-5211

# Review and Evaluation of Transamerica Delaval, Inc., Diesel Engine Reliability and Operability - Catawba Nuclear Station Unit 1

August 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

Battelle

PNL-5211

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PNL-5211

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

August 1984

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

Project Title: Assessment of Diesel Engine Reliability/Operability

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PACIFIC NORTHWEST LABORATORY

PROJECT APPROVALS

for [signature] Date 8/2/84

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Pacific Northwest Laboratory

## CONTENTS

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

## 1.0 INTRODUCTION

Duke Power Company (Duke) has requested an operating license for its Catawba Nuclear Station Unit 1 (Catawba). One key 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, Duke has undertaken a number of industry-wide and plant-specific investigative, corrective, and administrative efforts. These have been addressed by Duke and its consultants in numerous 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 Duke's underlying efforts and to prepare this technical evaluation report (TER) expressing its conclusions and recommendations.

Catawba Nuclear Station Unit 1 is served by two emergency standby engines to meet its ESF loads. Each engine is a TDI DSRV-16-4 engine, nameplate rated by TDI at 7000 kW, operating at 450 rpm with a brake mean effective pressure (a computed measure of the average cylinder pressure in the firing stroke) of 225 psig. These engine-generators are designated by Duke as 1A and 1B. The latest information in the Final Safety Analysis Report (FSAR) specifies the emergency loads for these engines as a maximum of 5256 kW for a loss of coolant accident (LOCA) and a maximum of 5714 kW for a blackout or loss of offsite power (LOOP).

## 1.1 SCOPE OF REPORT

This TER is organized as follows:

- Section 2.0 provides relevant background information on the known problems and efforts toward their resolution by both Duke and an ad hoc group of similar TDI engine owners (the TDI Owners' Group) who have united their efforts in regard to these mutual concerns.
- Section 3.0 presents a review and evaluation of specific problems experienced on the Catawba engines as well as of activities pertaining to the TDI Owners' Group generic components.
- Section 4.0 reviews Duke Power Company test and inspection activities on the 1A engine.
- Section 5.0 reviews the activities Duke has conducted or plans to perform on the 1B engine.
- Section 6.0 documents PNL's evaluation of Duke's post-inspection engine tests.
- Section 7.0 presents PNL's review of the utility's proposed maintenance and surveillance (M/S) program.
- Finally, Section 8.0 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 Catawba Nuclear Station 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 Duke and NRC, and has observed components of both engines as disassembled in Duke'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). Because none of the various phases of the OGPP (as described in Section 2.1) has yet been finalized, PNL is not in a position to draw final conclusions on the overall extended operability and

reliability of these TDI engines in general, nor extensions thereof to plant-specific engines such as those installed at Catawba.

This TER on the Catawba 1A and 1B engines' operability and reliability precedes completion of the OGPP and its appropriate implementation by Duke. This document also precedes full plant-specific DR/QR analyses of both the 1A and 1B engines. Therefore, PNL is constrained from reaching unlimited conclusions relative to the Catawba 1A and 1B engines' operability and reliability to perform indefinitely their expected design function. Any such conclusions, if supportive toward licensing, must necessarily be somewhat tentative, subject to full completion of all OGPP and Duke DR/QR programs and implementation of their findings (these actions should be a part of Duke's licensing authorization).

Hence, PNL has been constrained to evaluate all components in light of expected operating conditions and patterns at Catawba over a relatively short term. The term chosen, thought by PNL's diesel consultants to be reliably conservative, was until 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 Catawba DR/QR program should be complete or ready to implement. In PNL's judgment, it would be more appropriate to decide long-term O/R at that time (near the first reactor refueling outage), rather than now.

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 infer (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

This TER was prepared by the following PNL staff and consultants:

- J. F. Nesbitt, PNL project staff
- B. J. Kirkwood, Covenant Engineering, diesel consultant to PNL
- J. E. Horner, Seaworthy Systems, Inc., diesel consultants to PNL

- P. J. Louzecky, Engineered Applications Corporation, 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, D. A. Dingee, R. E. Dodge, W. W. Laity, J. C. Spanner, and F. R. Zaloudek; and consultants S. H. Bush, A. J. Henriksen, and J. A. Webber (representing Ricardo Consulting Engineers plc).

## 2.0 BACKGROUND

This section presents background information on efforts undertaken by the TDI Diesel Generator Owners' Group and by Duke Power 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 that included 1) an in-depth assessment of 16 known engine problems (Phase I), 2) a design review and quality revalidation (DR/QR) program that addresses other key engine components (Phase II), and 3) engine tests and inspections. A review of that submittal was conducted by PNL and reported to NRC in PNL-5161 dated 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 Duke Power Company's license for the Catawba Nuclear Station at this time are:

- The engines should have AE pistons; if they do not, then "lead-engine" tests should be completed prior to licensing.
- The diesel generators should not be required to carry a sustained emergency load in excess of that corresponding to engine brake mean effective pressure (BMEP) of 185 psig, because, at that recommended limit, the maximum cylinder pressure is also approximately 1200 psig. The 6000-hour operating experience at Kodiak establishes a reasonable basis for confidence that AE piston skirts will operate satisfactorily at this load level. Also, pending evaluation and approval of Owners' Group reports addressing crankshaft stress levels at higher loads, the load corresponding to 185 psig BMEP is

considered reasonably conservative for the crankshaft. In addition, because of certain 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. Key engine components of particular concern in this regard include the piston skirts and the crankshaft, because their condition cannot be monitored without significant engine disassembly.

- The engines should be inspected to confirm that the components are sound (see Sections 4 and 5).
- Preoperational testing should be performed (see Section 6).
- The engines should receive enhanced surveillance and maintenance thereafter (see Section 7).

## 2.2 CATAWBA NUCLEAR STATION

In their efforts to establish the reliability and operability of Catawba's TDI diesel engines, Duke Power Company has produced numerous letters and reports, as well as holding meetings and conducting tests, inspections, and examinations. Items pertinent to this Technical Evaluation Report are listed below.

- A letter dated February 17, 1984, to the Atomic Safety and Licensing Board Panel (ASLB), "Duke Power Company et al. (Catawba Nuclear Station, Units 1 and 2), Docket Nos. 50-413 and 50-414", noted problems with some components on the 1A engine at Catawba.
- In a letter dated February 22, 1984, "Catawba Nuclear Station Docket Nos. 50-413 and 50-414", Duke Power Company transmitted their responses to 17 NRC questions regarding the TDI diesel generators installed at Catawba.
- A letter dated March 29, 1984, to the ASLB, "Duke Power Company et al. (Catawba Nuclear Station, Units 1 and 2), Docket Nos. 50-413 and

50-414", noted problems that had occurred with the 1A and 1B diesel engines during the extended operational tests and the ESF test currently being conducted.

- In an April 5, 1984, letter to NRC, Duke provided a written description of the extended operational tests and inspection plans for the 1A diesel generator (engine) in addition to a discussion of Catawba-specific problems.
- On April 26 and 27, 1984, PNL staff and consultants visited Catawba to view the disassembly and inspection of the 1A diesel engine and its components. A PNL letter dated May 7, 1984, summarized comments and suggestions made to NRC pertaining to this visit. A report on the trip was submitted to NRC by PNL in a letter dated May 11, 1984. During the April 26 and 27 visit, the PNL observers recommended 100% (instead of 25%) inspection of AN pistons in 1A. Upon completing the full inspection, Duke personnel reported four AN piston skirts had indications. Subsequently, Duke decided to replace all AN piston skirts with the latest AE design.
- On June 1, 1984, Duke provided a submittal to NRC addressing 76% of the 1A diesel engine inspection results.
- On June 21, 1984, a meeting was held in Washington, D.C., at which Duke Power Company presented results of the 1A diesel engine inspections to NRC and PNL.
- On June 22, 1984, PNL staff and consultants met with representatives of NRC at Failure Analysis Associates in Palo Alto, California, to discuss Owners' Group reports prepared by FaAA.
- A letter dated June 25, 1984, to the ASLB, "Duke Power Company et al. (Catawba Nuclear Station, Units 1 and 2) Docket Nos. 50-413 and 50-414", summarized the findings of the substantially completed 1A diesel engine inspection effort.
- Via a letter to NRC dated June 29, 1984, Duke Power Company transmitted the report, Catawba Nuclear Station Diesel Engine 1A Component Revalidation Inspection Final Report. This report

described the results of the inspections and evaluations performed and addressed over 99% of the inspection plan. Duke also indicated that all remaining inspections would be documented in the Owners' Group Phase II Program report.

- NRC Generic Letter 84-15, dated July 2, 1984, "Proposed Staff Actions to Improve and Maintain Diesel Generator Reliability", was issued to all licensees of operating reactors, applicants for an operating license, and holders of construction permits.
- A letter to NRC dated July 6, 1984, outlined Duke Power Company plans for the inspection of the Catawba 1B diesel engine and the return-to-service testing of the 1A diesel engine.
- On July 10, 1984, two PNL consultants visited the Catawba Nuclear Station to view the status of the 1A diesel engine reassembly.
- In a letter dated July 16, 1984, Duke Power Company submitted its plans to NRC for the periodic maintenance, inspection, and surveillance of the Catawba 1A and 1B diesel engines.
- A July 17, 1984, letter from Duke to C. Ray, Jr., of the TDI Owners' Group detailed the operating history of the 1A and 1B diesels.
- On July 25 and 26, 1984, PNL staff and consultants visited the Catawba Nuclear Station to view the disassembly and inspections being performed on the 1B engine. The PNL team also observed the status of the reassembly of the 1A engine, and reviewed and discussed the findings noted and actions taken on specific engine components with Duke and NRC representatives. During the July 25 and 26 visit, the PNL observers queried various items, including the need to fully inspect the link-pin bushings, and to take pre-turbine exhaust gas temperatures.
- In an August 1, 1984, letter to NRC, Duke responded to concerns and queries raised by NRC and PNL in the July 25 and 26 meeting.

## 3.0 EVALUATION OF COMPONENT PROBLEM RESOLUTION

During the tests and inspections conducted by Duke Power Company on the Catawba Nuclear Station Unit 1 diesel engines, problems were noted or experienced with certain engine components. The affected components included:

- piston skirts[a]
- push rods[a]
- cylinder head[a]
- fuel line fittings
- fuel oil injection pump valve holders
- turbocharger[a] bearings
- turbocharger adapter
- turbocharger lube oil drain line
- turbocharger prelube oil lines
- turbocharger exhaust gas inlet bolts
- crankcase and camshaft cover capscrews
- triple-clamp bolts
- lube oil and jacket water thermocouples
- rocker box (subcover) assembly
- intermediate rocker arm sockets
- exhaust valve tappets (rocker arm adjusting screw swivel pad)
- intake and exhaust valves
- spring retaining nut and roll pin on air start valves.

Section 3.1 documents PNL's evaluation of the actions taken by Duke Power Company to resolve known problems with these diesel engine components. The information on these components is presented in a worksheet format. Each worksheet identifies the component, briefly reviews its history, and describes the status of, or the actions taken by the Owners' Group and Duke to evaluate or resolve, the problem. The last item on each worksheet presents PNL's evaluative comments and/or conclusions.

(a) TDI engine generic problem components.

Section 3.2 documents the actions taken by Duke regarding the engine components classified in the generic problem category by the TDI Owners' Group. These components include:

- crankshaft
- connecting rod bearing shells
- cylinder blocks
- cylinder liner
- cylinder head studs
- engine base and bearing caps
- rocker arm capscrews
- connecting rods
- engine mounted electrical cable
- high-pressure fuel tubing
- jacket water pumps
- air start valve capscrews.

Although Duke has not experienced any specific failures with these components at Catawba, they are nevertheless documented here for completeness, also in a worksheet format. Each worksheet for these items includes a brief history of the component, a review of actions taken by the Owners' Group to evaluate the problem, a description of the tests, inspections, or evaluations performed on these components at Catawba, and PNL's evaluative comments and/or conclusions.

PNL's conclusions and comments are based on the available Duke Power Company documents, on onsite inspections of the Catawba engine components and examinations of identical or at least similar components of TDI diesels in other nuclear facilities, reviews of the specific known-problem issue reports prepared by (or under the auspices of) the TDI Owners' Group, and the experienced judgment and appropriate evaluations of PNL's diesel engine consultants. However, pending completion of the implementation of the Owners' Group Program Plan, PNL's conclusions as stated in this report are plant-specific, applying only to Duke Power Company's Catawba Nuclear Station Unit 1.

### 3.1 PLANT-SPECIFIC PROBLEMS

Component: Piston Skirts

Part No.: 02-341

Owners' Group Report: FaAA-84-2-14

#### Brief History of Component

Based on a number of cracks found in the AF piston skirts at the Grand Gulf Nuclear Station, the Shoreham Nuclear Power Station, and at non-nuclear installations, the skirt design was strengthened in the boss area where the cracks had been found. No operational failures have been reported to date on the redesigned piston skirt, labeled AE, in either nuclear or non-nuclear installations. Kodiak (an electrical generation station) has operated in excess of 6000 hours at approximately 185 psig BMEP (1200 psig maximum firing pressure) with the AE skirts; the TDI R-5 test engine has 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.

Another type of piston skirt labeled AN is in wide use according to TDI. Only Catawba, of all of the nuclear plants, had AN piston skirts. TDI has indicated that the AN piston skirts, if properly heat-treated, have performed satisfactorily.

#### 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), has analyzed the AE piston skirt design and has concluded that the AE skirts may crack at 10% overload of nameplate rating, but that cracks will not propagate to the point of actual functional failure. Cracks have been found to occur in the vicinity of a structural rib and bolting boss inside the skirt.

The issue of AE piston skirts was addressed by PNL in its June 1984 Review and Evaluation of TDI Diesel Generator Owners' Group Program Plan (PNL-5161), Section 4.0, relative to nuclear plants seeking interim licensing (prior to finalization and full implementation of the OGPP). Therein it was concluded

that plants with AE piston skirts having sustained emergency load requirements not exceeding 185 psig BMEP could logically and safely be licensed without prior lead-plant testing to 10 million cycles (750 hours) at or above this load.

Duke Power Company Status

During the extended operational test, the 1A diesel was operated with AN piston skirts that had been heat-treated at the TDI factory. During the subsequent disassembly and inspection, cracks were found in 4 of the 16 piston skirts.

The inspections of AN piston skirts conducted by Duke Power Company were directed at assessing these components' structural integrity. All 16 piston skirts on the 1A engine were subjected to the following inspections:

- visual inspection
- liquid penetrant examination of stud bosses
- liquid penetrant examination of piston pin bosses
- liquid penetrant or magnetic particle examination of areas adjacent to the piston pin bosses (i.e., the areas where several cracks were noted)
- ultrasonic and radiographic examinations if liquid penetrant or magnetic particle examinations revealed indications.

The most significant condition noted during the inspections conducted at Catawba was the presence of cracks adjacent to piston pin bosses in four piston skirts. As reported by Duke, the largest crack was 3 or 4 inches long and penetrated through the wall. The cracks appeared to originate at the skirt ID, on the fillets where a reinforcing rib intersects the piston pin bosses, and to run in an approximately axial direction. The cause of the cracking is undetermined at this time but is believed to be high-frequency cyclic fatigue. One small (1/2-inch long) linear indication was also noted in the bore of a piston pin boss. No indications were found at stud bosses.

The AN piston skirts from the 1A diesel at Catawba have been sent to FaAA for a detailed failure analysis as a part of the TDI Owners' Group Program.

Duke Power Company has reported its intention to replace the AN piston skirts with type AE skirts. This has been done on the 1A diesel engine and is in progress on the 1B engine. PNL understands that Duke either has performed or will perform surface nondestructive examination (primarily magnetic particle tests) and hardness tests on the AE piston skirts prior to their installation in an engine to verify their acceptability.

PNL Conclusions

Upon completion of reassembly of engine 1B, both Catawba diesels will be fully fitted with AE piston skirts. The Catawba emergency load requirements, listed in Section 1.0, do not exceed interim-licensing recommendations of PNL-5161 (referred to above). Based on this knowledge, on all available analytical information (principally the OG generic issue report, FaAA-84-2-14), the operational history of AE skirts, the test results on AE skirts elsewhere, and the judgment of its diesel consultants, PNL concludes that the AE piston skirts are suitable for the intended use in the Catawba 1A and 1B engines, at least until the time of the first reactor refueling outage.[a]

(a) This conclusion, and similar conclusions regarding other components, is based upon the assumption that NRC and the Owners' Group will satisfactorily resolve concerns regarding the component and implement all requirements (see Section 1.2).

Component: Push Rods

Part No.: 02-390-C

Owners' Group Report: FaAA 84-3-17

## Brief History of Component

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

## 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 cycle wear tests to 10 million 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 was observed.

## Duke Power Company Status

The push rods supplied as the original components of the Catawba 1A and 1B diesels experienced cracking in the plug welds joining the center to the end sections. However, these failures did not prevent the push rods from performing their intended functions, nor did they result in any abnormal or adverse engine performance. During the week of February 5, 1984, all of the push rods in engine 1A were replaced with those of the friction-welded design. In the subsequent extended operational tests, about 400 hours of operation were accumulated on this set of friction-welded push rods prior to the disassembly and inspection of the 1A engine. This set of friction-welded push rods was then removed from the 1A engine and installed in the 1B diesel

engine at Catawba. According to Duke Power Company personnel, this set of push rods has now been in operation for over 900 hours, with at least one-half of that time being at engine loads above 185 psig BMEP.

The Duke Power Company inspections of the friction-welded design push rods in the 1A engine included:

- visual inspection of the shaft end-welds to verify that the desired new type of friction welds were used
- liquid penetrant examination of all welds.

Duke Power Company reported their confirmation that all the push rods in the 1A engine had the correct type of end-welds and were free of defects.

Duke is performing visual and surface nondestructive examinations on this same set of push rods after its extended service in the 1B diesel engine. This examination is still underway, but Duke personnel indicated to PNL representatives during the Catawba site visit on July 25 and 26, 1984, that no defects had yet been found.

PNL Conclusions

After reviewing the FaAA report, the Catawba inspection data, and examining some of the friction-welded push rods at Catawba on July 25, 1984, PNL concludes that the push rods incorporating the friction-welded design are satisfactory for their intended purpose, until at least the time of the first reactor refueling outage.

Component: Cylinder Heads

Part No.: 02-360A

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

Brief History of Component

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 are classified 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. 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 stellite valve seats.

The most recent, known head failure was reported by Mississippi Power & Light relevant to their Division I TDI diesel engine (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 (head 7L). It 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 an original that 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 no similar failure has occurred to MP&L's knowledge, it concludes this was a unique, isolated failure.

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 inspected by liquid

penetrant and magnetic particle, as well as 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 barring the engine over before manual startup, to assure no water has leaked into the cylinders.

Cylinder heads are also included in the TDI Owners' Group design review/ quality revalidation (DR/QR) program. The first such program report, pertaining to the Shoreham Nuclear Power Station, has just been released. In that report, the Owners' Group has concluded that the cylinder heads are acceptable for their intended design function at Shoreham, provided that engine barring-over is conducted.

Duke Power Company Status

Two small jacket water leaks have been experienced in heads at Catawba, one each in engines 1A and 1B. As a result, water leaked into the fuel injector nozzle cavity (i.e., external to the head and cylinder). Failure Analysis Associates performed a metallurgical analysis of the leak that occurred on the 1A engine. FaAA reported that the leak was due to cracks propagating from a corner where a repair plug was welded into the fuel injector nozzle seating area. This welded plug had been installed by TDI during manufacture to repair the injector bore.

As stated by Duke Power Company in their inspection report dated June 29, 1984, the inspections of the 1A engine cylinder heads included:

- liquid penetrant examination of valve seats in cylinder heads
- ultrasonic examination of firedeck thickness at selected locations.

Duke has stated that no other cracks were detected and that all firedeck thicknesses of cylinder heads on the 1A engine were found to be acceptable.

Duke Power Company performed an engineering evaluation to determine if any of the heads now installed on the 1A diesel engine had been repaired during manufacturing. A borescope was used to show whether there was a parting line at the bottom of the fuel injector cavity, indicating the presence of a plug. In addition, visual inspection of the firedeck area of the head was used to check for the presence of weld metal, indicating a plug was installed.

According to Duke, the results of this engineering evaluation indicate that the head installed on the no. 6 cylinder in the left bank was repaired with a welded plug. This head (6L) had been factory-installed on the engine and has seen over 800 hours' operation at varying loads, with at least one-half of that time being at loads in excess of 185 psig BMEP.

Duke has reported that, in its opinion, the cylinder heads currently installed in the 1A diesel engine are satisfactory because they were not leaking when last used, and because they exhibit no cracks in inspectable areas. Further, the leaks caused by cracks due to plug-welding are only to areas external to the head and cylinder, do not affect diesel operation, and are not significant. However, the repaired head (6L) is to be replaced as soon as Duke can obtain a replacement that does not contain similar weld plugs.

The same examinations are to be performed on the 1B engine cylinder heads.

PNL Conclusions

PNL has reviewed all the pertinent documentation noted above: the FaAA report, TDI Owners' Group DR/QR report on the Shoreham plant, and the Duke inspection report. In addition, PNL has reviewed the engine inspection results onsite with Duke Power Company. On these bases, PNL concludes that the cylinder heads on the Catawba 1A diesel engine are acceptable for the first refueling cycle, provided that the engine is barred-over 4 hours after shutdown, then again 24 hours after shutdown, and thereafter prior to each planned start, to check for water leakage into the cylinders.

PNL also concludes that Duke should replace the 6L head on the 1A engine, as well as any of the cylinder heads on the 1B engine that have repair plugs installed.

Based on the assumption that the results of tests and inspections on the 1B cylinder heads will be positive, that Duke has reported only satisfactory operation during the extended tests, and that the 1B engine will be barred-over as was the 1A engine, PNL concludes that the heads on the 1B engine will be acceptable for their intended purpose through at least the first refueling cycle.

Until the generic-issue analysis on heads has been finalized and a technical evaluation report has been released indicating satisfactory conclusion of the issue, PNL cannot grant unreserved approval of the heads, regardless of their manufacturing group classification (I, II, or III).

Component: Fuel Line Fittings

Part No.: 02-450B

## Brief History of Component

A low-pressure fuel line between two fittings failed at the Grand Gulf Nuclear Station. Mississippi Power & Light, the owner utility, concluded that this isolated failure was due to fatigue caused by vibration due to insufficient clamping. One low-pressure fuel line was replaced on the Catawba 1A diesel engine because of leakage. Inspection of this line indicated its fittings were not swaged properly. Duke Power Company reported that the leakage resulted after a flat spot in the cone section of the tube eroded away. No similar failure has been noted on the 1B engine.

## Owners' Group Status

The TDI Owners' Group has included fuel line fittings in the ongoing DR/QR program. The just-released DR/QR report on the Shoreham Nuclear Power Station concluded that, with stipulated modifications to meet design requirements, the equivalent fuel oil headers-piping and tubing will meet the stress and support design criteria and will perform their intended design function under all normal and earthquake loadings.

## Duke Power Company Status

Most of the fuel lines and fittings were disconnected during the recent disassembly and inspection. They will be reinstalled during the reassembly of the 1A diesel engine. Duke Power Company has announced its intention to follow specific fitting installation instructions during the reassembly process to guard against improper swaging. In addition, after the 1A engine is reassembled, Duke personnel will inspect the subject lines and fittings. This will include a walkdown inspection to verify that the piping has been installed according to the applicable design drawings.

## PNL Conclusions

The Duke Power Company fitting installation instructions and inspection procedure were discussed during PNL's visit to the Catawba Nuclear Station on July 26, 1984. PNL concurs with Duke's analysis of, and actions taken to

correct, the problem. PNL also concurs that reinstallation of the fuel lines and fittings on the Catawba 1A diesel engine, if conducted according to the planned procedure, should be sufficient to assure that they will perform their intended functions. This problem and its resolution appear to be specific to the 1A engine only.

Component: Fuel Oil Injection Pump Valve Holder
Part No.: 02-365-A

## Brief History of Component

Minor failures of fuel oil injection pump components have been recorded at the Grand Gulf Nuclear Station.

## Owners' Group Status

This component is included in the TDI Owners' Group DR/QR Program. In the recent DR/QR report for the Shoreham Nuclear Power Station, it was concluded that the pump is acceptable for its intended design function at Shoreham. The report also stated that "A review of the operating history of the Bendix fuel injection pumps at Shoreham and other nuclear power plants indicates that any leaks that occurred were attributed to loose connections, fittings and bleed screws, etc., and not to the primary pressure boundary."

## Duke Power Company Status

A fuel injection pump valve holder, which is exposed to full discharge pressure, fractured on the Catawba 1A engine. Duke Power Company submitted the part to Babcock & Wilcox Alliance Research Center for examination. Babcock & Wilcox concluded that the fracture initiated at a casting defect in the part, and that it was not the result of a design deficiency.

Transamerica Delaval, Inc., reported to NRC on July 13, 1984, that Bendix Corporation (the fuel injection pump manufacturer) had reviewed the component failure at Catawba and indicated the cause to be a material defect in the valve holder. Further, in Bendix's opinion, this defect was an isolated case. TDI stated that Bendix high-pressure fuel injection pumps have been installed on all DSR and DSRV engines manufactured by TDI in the past 15 years and that the Catawba holder failure is the first and only one of this type of which they are aware.

In addition to Babcock & Wilcox's detailed examination of the one failed valve holder, related inspections performed on the 1A engine to date by Duke Power Company include:

- measuring the hardness of each valve holder
- ultrasonic testing of each fuel pump valve holder.

Duke has reported that, based on the inspections conducted, all fuel pump valve holders on the 1A engine were found to be acceptable.

Duke also performed a failure analysis on the fractured fuel injection pump nozzle valve holder. The results of this analysis indicated that an axially-oriented linear indication in the high-pressure fuel oil passage of the valve holder led to the reported failure. Further analysis revealed that axial linear indications that would lead to cracking of the valve holder could cause cracking to occur within 10 million cycles of fuel pump operation. Because the remaining valve holders on the Catawba 1A diesel engine have withstood 10 million cycles of operation, the valve holder failure experience is considered the result of an isolated material defect.

In addition to this analysis, a borescope evaluation of the high-pressure fuel oil passage was made. Results of this evaluation indicate that several of the valve holder bores were rough-machined, as evidenced by observed protrusions, counterbore type steps, and tool marks. One valve holder, cylinder 6R, appeared to have a linear indication. Three valve holders (5R, 1L, and 8L) had recesses. Duke has stated that these four valve holders will be removed from the engine, cleaned, rechecked by borescope, and reamed if indications are still present after cleaning. Valve holders that have indications after reaming will be replaced.

PNL Conclusions

A failure of this specific pump component will tend to reduce engine capacity by 7% and imbalance the load on the crankshaft, but will not lead to immediate shutdown. Based on the results of examinations and analyses performed by Duke Power Company, as well as an examination by PNL during the Catawba site visit on July 25 and 26, 1984, PNL concurs with Duke's analyses of, and actions taken to correct, the problem. PNL concludes that the fuel injection pumps as now installed on Catawba's 1A engine will perform their intended design functions. This problem and its resolution appear to be a one-time occurrence, limited to the 1A engine only.

Component: Turbocharger Bearings

Part No.: MP-022/23, 02-CFR

Owners' Group Report: FaAA-84-5-7

Brief History of Component

Turbocharger thrust bearing problems reportedly are limited to the nuclear industry. To date, thrust bearing problems have been reported for the Grand Gulf Nuclear Station, Shoreham Nuclear Power Station, San Onofre Nuclear Generating Station, Comanche Peak Steam Electric Station, and Catawba Nuclear Station.

Owners' Group Status

The TDI Owners' Group has included turbochargers in general in the generic problem category.

Failure Analysis Associates analyzed the turbocharger thrust bearing problems for the Elliott 90G turbocharger. In Report FaAA-84-5-7 dated May 1984, FaAA concluded that the problems are due to insufficient lubrication of the thrust bearings during "fast" starts (i.e., automatic starts for which no prelubrication is provided to the thrust bearing). Various types of startup lubrication systems have been implemented at nuclear power plants to avoid these problems. One type is a drip system that provides lubrication from the before-and-after (B&A) recirculation system. Another type (in use at the Grand Gulf Nuclear Station) is an auxiliary B&A lube oil pump. This pump is activated prior to any planned start and provides the turbocharger bearings with sufficient lube oil to complete fast starts as required for nuclear standby tests.

Duke Power Company Status

On February 17, 1984, Duke Power Company reported finding excessive wear on a bearing in one turbocharger of engine 1A. As Duke reported later, on March 29, 1984, the thrust faces of bearings were found to be severely worn in turbochargers in both 1A and 1B engines.

Duke personnel performed visual and dimensional inspections of the 1A engine turbocharger bearings. The thrust faces were found to be severely worn.

However, Duke noted that this wear had not affected turbocharger operation during the extended (>800 hours) operational tests on the 1A engine. Similar inspections of turbocharger bearings on the 1B engine are in progress.

The turbocharger bearings on the 1A engine were replaced. In Duke's opinion, these will operate as well as the original bearings, which caused no operational problems for several hundred hours. In addition, in a June 29, 1984, letter to NRC, Duke has stated its intention to install the new increased flow lube oil system by September 1984. Until that time, Duke plans to inspect the new bearings periodically to assure their continuing operability.

PNL Conclusions

PNL and its consultants have not had an opportunity to review the specific prelube system design planned by Duke for the Catawba engines. However, 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 Duke Power Company. During the Catawba site visit on July 25 and 26, 1984, PNL examined the 1B engine turbocharger bearings, which, like those from engine 1A, were scarred 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 planned for installation on the diesels at Catawba probably will provide sufficient additional lubrication to augment the protection of the turbocharger bearings during planned fast starts. Further, in PNL's view, the number of unplanned fast starts, without prelube, likely will be sufficiently few as to not lead to bearing failure prior to the first refueling outage, at which time the bearings on at least one turbocharger per engine should be reinspected (unless, by that time, the revised turbocharger prelube system has been installed and accepted by the Owners' Group and NRC).

Component: Turbocharger Adapters

Part No.: 00-495A

## Duke Power Company Status

At Catawba, one turbocharger adapter on the 1A diesel cracked at a flange weld. This adapter provides the interface between the turbocharger air discharge and the intercooler airbox. Duke Power Company has attributed the crack to poor flange alignment with mismatched bolt holes. Duke reports it now uses updated alignment practices when installing the adapters and torquing turbocharger flange bolts. Duke has reported that the weld joints on the 1A diesel engine turbocharger adapters were examined visually and with magnetic particle detection techniques. These examinations revealed no defects.

During PNL's Catawba site visit in July 1984, Duke personnel reported having obtained TDI's concurrence to overbore the mounting holes and use an alternative gasketing arrangement. It is PNL's understanding that this was done on the right bank of the 1B diesel engine, which was found to be cracked in a manner comparable to that of the 1A right bank. No problems have been noted on the left bank of either engine, which is of a configuration different from that of the right bank.

According to Duke personnel, they and TDI are considering improved configurations for the right bank interface that will assure the elimination of this problem. These may require making a number of changes on the engines.

## PNL Conclusions

PNL concludes that Duke has adequately identified the problem and its cause. However, in reviewing the Duke Power Company information available on the turbocharger adapter flange and the noting of the subsequent crack on the 1B diesel engine, PNL has found no evidence to support a conclusion that an adequate corrective method has been implemented. In the opinion of PNL's consultants, the Catawba diesels could be relied on for satisfactory operation for a period of time, possibly up to several days, even with cracks in the welds at this adapter, although some power reduction and imbalance between left and right cylinder banks could result. Thus, these adapters and the entire

turbocharger/intercooler interface are considered to be marginally suitable for their intended use in the Catawba 1A and 1B engines even until the first reactor refueling outage. Therefore, PNL recommends that Duke/TDI continue with the development of an alternative design for the right bank connections between the turbocharger and the intercooler and, further, that adapters of a new design be installed.

It is believed by PNL and its consultants that the alternative connection design being considered or developed by Duke/TDI should be one incorporating a flexible joint. Such a design is deemed to be one that could eliminate the problem and have an adequate operating life.

Component: Turbocharger Lube Oil Drain Line

Part No.: 02-467A

## Brief History of Component

Duke Power Company reported that a temporary drain line on the 1A diesel engine leaked during the recent extended operational test. The leak was attributed to vibration in the drain line. This drain line was of rubber hose, installed in place of the original compression-coupling fitting furnished by TDI, which, for some unexplained reason, would not fit properly at installation. The installation on the 1B engine reportedly was as per the TDI design.

## Owners' Group Status

The TDI Owners' Group Program Plan indicates that the turbocharger lube oil drain line is included in the ongoing DR/QR program. In the DR/QR report on the Shoreham Nuclear Power Station on the equivalent component, it was concluded that, when installed and supported in accordance with TDI design, the small-bore piping and tubing included in the review meets the stress design criteria and will perform its intended design function at Shoreham under all normal and earthquake loadings.

## Duke Power Company Status

The leaking 1A engine drain line was replaced with the proper line and fittings during reassembly of the 1A diesel engine. During the July 25 and 26 Catawba site visit, Duke personnel stated that the line now installed on the 1A engine meets the TDI design requirements.

## PNL Conclusions

PNL concludes that Duke has appropriately identified the problem and its cause. PNL representatiaves examined the lube oil drain line during the Catawba site visit on July 25 and 26, 1984. They noted that the subject line on the 1A diesel engine now contains only welded or clamped joints. Based on these observations, PNL concludes that the new drain lines as now installed on the Catawba diesels will satisfactorily perform the intended design function. This problem and its resolution appear to be specific to the 1A engine only.

Component: Turbocharger Prelube Oil Lines

Part No.: 02-307B

Brief History of Component:

Two failures of prelube oil lines were reported by Duke Power Company. Both failures occurred on the 1A engine during the extended operational test.

Owners' Group Status

The turbocharger prelube oil lines are included as part of the Owners' Group DR/QR Program. In the DR/QR report on the Shoreham Nuclear Power Station, the conclusion on the equivalent components was as follows:

> The tubing components, as defined by this component design review have been evaluated to the referenced stress design criteria and found acceptable. It is concluded that the system will perform its intended design function at Shoreham under all normal and earthquake loadings.

Duke Power Company Status

Duke personnel performed visual, chemical, and metallographic tests on the failed components. Based on the test results, they reported the probable failure mechanism of the tubes was high-cycle fatigue that originated at stress concentrations produced in the area of the compression fittings.

Duke subsequently replaced the failed lines with heavier wall stainless steel tubings and improved compression fittings. These were installed using an improved procedure, additional clamps, and vibrational dampening devices. No failures have since occurred.

Duke has stated its plans to reassemble and install the piping on the 1A diesel engine in accordance with the latest approval drawings and procedures. In addition, the system will be inspected after reassembly to verify proper installation.

PNL Conclusions

PNL concludes that Duke has adequately identified the problem and its cause, and has responded appropriately. During PNL's onsite visit in July 1984, it was noted that the turbocharger prelube oil lines will be replaced

with ones of a different design when the new turbocharger lubrication system is installed on the Catawba engines. In PNL's opinion, lines and fittings installed in a manner similar to those installed after the original failures will adequately fulfill their intended purposes. No comment, evaluations, or conclusions on the redesigned system can be made at this time.

PNL assumes that Duke will follow the improved procedures and use the same additional and improved material on the subject lines of the 1B engine as they did on the 1A engine. If so, PNL concludes that the subject items on the 1B engine would also fulfill their intended purposes.

Component: Turbocharger Exhaust Gas Inlet Bolts

Part No.: 02-380B

## Brief History of Component

Duke Power Company has reported the failure of four 1/2-inch diameter turbocharger exhaust gas inlet bolts on the 1A engine.

## Owners' Group Status

These components are also included in the TDI Diesel Generator Owners' Group DR/QR Program. The Shoreham Nuclear Power Station DR/QR report concludes that, based on new bolting materials and revised installation procedures, the exhaust manifold components are acceptable for the intended service and design function at Shoreham.

## Duke Power Company Status

The failed bolts were examined by Duke Power Company's Physical Sciences Laboratory. They concluded that the bolt failures were caused by

- bonding of the bolt threads to the adapter flange during service at high temperature, necessitating the application of excessive force to remove the bolts
- creep rupture due to a combination of a) use of lubricant plus applied torques leading to high axial stresses (easily over 25,000 psi and possibly as high as 75,000 psi); b) high temperature; and c) use of an alloy not resistant to creep.

The original 36 bolts, which had been exposed to over 800 hours of operation, and the four replacement bolts were inspected visually at 5X magnification. Duke reported that no defects or indications were found on any of these bolts.

Duke has announced their intention to replace all of the subject bolts on the 1A diesel with others of the same material, using installation procedures to assure the application of proper preloads. In addition, new bolts made of a creep-resistant material are being considered as replacements for those currently installed.

## PNL Conclusions

During the PNL onsite visit on July 25 and 26, 1984, Duke personnel reiterated their application and use of torque criteria on essentially all fasteners of the Catawba diesel engines. PNL concludes that Duke has adequately identified the problem and its cause and has proceeded with an acceptable resolution. In PNL's opinion, the turbocharger exhaust gas inlet bolts will satisfactorily perform their intended function over their expected service life, provided that procedures which Duke has agreed to use are employed to prevent both under- and overtorquing.

It is PNL's understanding that Duke plans to replace the subject bolts on the 1B engine. If so, and if this is done following the procedures used on the 1A engine, PNL concludes that the subject components will adequately perform their intended function.

Component: Crankcase and Camshaft Cover Capscrews
Part No.: 02-386B

## Brief History of Component

Duke Power Company reported occasional failure of crankcase and camshaft cover capscrews at Catawba during the extended operational tests and as found during inspections of the 1A diesel engine. These failures were random and usually occurred as the bolts were being tightened to seal minor oil leaks or as the bolts were being removed. In a few instances, the bolt heads separated while the diesel was operating.

## Duke Power Company Status

Based on their examinations of the failed components, Duke has concluded that the capscrews failed due to fatigue caused by over- or undertorquing during installation on the 1A engine. Duke has also reported confidence that the problem has been resolved by replacing the failed components with capscrews of more appropriate quality and by revising installation procedures to control torque.

## PNL Conclusions

PNL reviewed the capscrew problem with Duke during the Catawba site visit in July 1984. PNL concludes that Duke has adequately identified the problem and its cause, and that the use of higher strength and higher fatigue endurance limit items (e.g., Grade 5) installed within torque values established by TDI/Duke for that installation and that size item should eliminate any future failures. Thus, the capscrews as now installed on the 1A diesel at Catawba should satisfy the intended design requirements.

Provided that Duke replaces the subject components on the 1B engine with higher strength items under controlled torquing procedures, these capscrews too should satisfy the intended design requirements.

Component: Triple-Clamp Bolts

Part No.: 02-450D

Brief History of Component

The triple clamps support various types of piping lines along the top side of the engine. During the extended operational tests and the subsequent disassembly of the 1A diesel engine at Catawba, Duke Power Company found that several of the triple-clamp bolts had failed in service. These failures occurred in the threaded portion of the bolt inline where the first threads engaged the subcover assembly.

Duke Power Company Status

Duke subjected the failed bolts to a failure analysis. The results indicated that the bolts failed because of fatigue and being under- or overtorqued. Duke indicated that all triple-clamp bolts were replaced with new bolts having higher strength and higher fatigue endurance limits (e.g., Grade 8). In addition, reinstallation procedures now include provisions to assure that under- and overtorquing do not occur.

PNL Conclusions

During the Catawba site visit on July 25 and 26, 1984, PNL personnel and consultants discussed Duke's review of the triple-clamp bolts, their replacements, and torque limitations. PNL concludes that Duke has adequately identified the problem and its cause and that the actions implemented should eliminate the recurrence of similar failures of the subject components. Thus, the bolts as eventually installed in the diesels at Catawba should satisfy the intended design requirements.

Component: Lube Oil and Jacket Water Thermocouples
Part No.: 02-630D

## Brief History of Component

Inconsistent or improper indications of operating conditions have been experienced with some thermocouples (T/Cs) at Catawba. According to Duke personnel, when these T/Cs were replaced, the indications of the operating conditions returned to the normal or expected operating range. Duke personnel have stated that these inconsistencies (or failures to indicate properly) were believed to be the result of intermittent shorts.

## Owners' Group Status

The Owners' Group DR/QR Program report for the Shoreham Nuclear Power Station concluded that the pyrometer conduit assembly thermocouples are acceptable for their intended design function at Shoreham, provided 1) each T/C indicated temperature is consistent with the engine ambient temperature when the engine is cold and 2) the T/C is removed, cleaned, and inspected for fatigue indications every 36 months.

## Duke Power Company Status

Duke Power Company stated that occasional T/C failures can be expected and do occur. Duke further stated that failure of the lube oil and water thermocouples would not affect diesel engine operability under emergency-run conditions. Duke has reported that the failed T/Cs were repaired or replaced and that inspection of the failed T/Cs was not considered useful.

## PNL Conclusions

PNL discussed the failed T/C problem and operating history with Duke personnel during the Catawba site visit in July 1984. PNL concurs with Duke's analysis, i.e., T/C failures are an expectable occurrence, particularly during the early stages of equipment or system startup and operation. In PNL's opinion, occasional operating inconsistencies or failures of the subject T/Cs can be expected to occur during the life of the diesel engine. However, if such a failure does occur, it will not likely compromise the continued safe and

reliable operation of the diesel engine. Therefore, PNL believes the corrective actions taken by Duke to be logical and supportable, and should be continued as required by subsequent failures in the subject components.

Component: Rocker Box (Subcover) Assemblies
Part No.: 02-362A

## Brief History of Component

Two different problems have been experienced with the rocker box (subcover) assembly on the 1A diesel engine at Catawba. The first reported by Duke involves the fracturing off of a piece of a boss located on the inside of the unit (also identified as rocker arm pedestal). The second problem, found in the post-operational test inspections of the 1A diesel, consists of hairline fractures running down the boss in the web between the machined bolt hole and the boss surface.

## Owners' Group Status

The subject component is included in the DR/QR program. The DR/QR review for the Shoreham Nuclear Power Station concluded that the subcover is acceptable for its intended design function at Shoreham.

## Duke Power Company Status

Duke Power Company reported finding one subcover with a piece of a boss fractured off when the push rods were replaced. However, Duke noted that this situation had not adversely affected the engine's operation.

After the extended operational tests, Duke performed liquid penetrant examinations on all of the bosses in all of the 1A engine subcover assemblies. They found two subcovers with cracked bosses. All others were found to be free of defects.

Although none of these failure had caused a loss of operability of the engine, Duke has replaced all of the affected covers.

Duke reported that the fractured boss was apparently due to installation with a misaligned dowel pin. A failure analysis of the cracked bosses in the other subcovers is being conducted by FaAA.

Duke has reported that, until the cause of failure and the frequency of cracking are better established, they will periodically inspect the subcover assemblies at Catawba to verify that additional cracking has not occurred.

PNL Conclusions

Subcover assemblies and their failures were observed during PNL's Catawba site visits in April and July 1984. PNL concurs with Duke's identification of the problem and its cause, and concludes that Duke's actions, namely replacing the subject components containing failures and providing for future inspection, are adequate to address this problem. However, Duke should provide confirmatory information on the scheduling and extent of future inspections. This should be incorporated into the periodic maintenance, inspections, and surveillance of these items on the Catawba 1A and 1B diesel engines.

Component: Intermediate Rocker Arm Sockets
Part No.: 02-390A

Brief History of Component

Duke Power Company reported that two of the intermediate rocker arm sockets were found to be chipped and/or to have cracks on their peripheral lips. However, these chips and cracks did not adversely affect functioning of the socket or interfere with engine operation because the push rods normally seat into the socket well inside the area where the chips or cracks were found.

Owners' Group Status

The intermediate rocker arm socket is included in the Owners' Group DR/QR Program. The report for Shoreham concluded that similar assemblies were acceptable for their intended design function at Shoreham.

Duke Power Company Status

Duke examined the failed components and reported finding no evidence of the chips or cracks propagating into the functioning part of the socket. Duke believes the problem is due to improper installation of the rocker arms prior to valve adjustment such that excessive clearance existed, allowing the push rod to move and contact the lips of the socket.

All other sockets in the 1A diesel engine at Catawba were visually inspected by Duke Power Company. No other problems were found or noted during these inspections.

Duke considers the chipped and cracked sockets to be only a cosmetic problem. In their opinion, there has been no detrimental effect on diesel engine operability. Duke has instigated procedural changes to assure that excessive clearance does not exist in the rocker arm assembly; this action is expected to prevent recurrence of the problem.

PNL Conclusions

The intermediate rocker arm sockets were visually examined by PNL personnel and consultants during their visits to Catawba in April and July 1984. PNL reviewed the problem with Duke personnel during the July 1984

visit. PNL concurs with Duke's analysis of the cause of the failures experienced to date in the subject components. PNL also concludes that, if Duke follows their newly instigated procedures, the intermediate rocker arm sockets can be expected to meet their intended operational requirements.

Component: Exhaust Valve Tappet (Rocker Arm Adjusting Screw Swivel Pad)
Part No.: 02-390B

## Brief History of Component

Duke Power Company has reported that one of the swivel pads on the 1B diesel at Catawba was found to be cracked.

## Owners' Group Status

This component is included in the Owners' Group DR/QR program. In the DR/QR report for Shoreham Nuclear Power Station on a similar assembly, it was concluded that the entire intake/intermediate and exhaust rocker shaft assemblies are acceptable for their intended design function at Shoreham.

## Duke Power Company Status

Duke conducted a failure analysis of the one failed swivel pad and reported that it was swaged or rolled more excessively than were the other screw swivel pads. They concluded that this apparent one-time manufacturing defect caused an overload on the pad, resulting in its failure.

Using visual and liquid penetrant examination techniques, Duke has inspected all 64 swivel pads on the 1A engine at Catawba. They have reported finding no defects; all of the inspected sockets appear to be consistently and properly swaged.

## PNL Conclusions

The subject components were examined by PNL personnel and consultants during the Catawba site visits in April and July 1984. PNL concurs that the results of Duke's analysis appear to be logical and supportable. PNL concurs with Duke that the swivel pads now installed in the 1A engine at Catawba are satisfactory and should be capable of meeting their functional requirements for the life of the diesel engine as dependent on the manufacturer's recommended maintenance and/or replacement programs. It is also assumed that the pads on the 1B engine are also capable of meeting their functional requirements.

Component: Intake and Exhaust Valves
Part No.: 02-360B

## Brief History of Component

During the disassembly and inspection of the 1A engine at Catawba after the extended operational tests, Duke found nine exhaust valve stems with areas of flaked or peeling chrome plate. The separation of chrome occurred from about 6 to 8 inches above the seat of the valve and at a location corresponding to where the stem enters the valve guide. Duke has reported that separation of the chrome had no effect on the diesel engine operability and did not cause any observable damage in the valve guides. The valves themselves have undergone over 800 hours of engine operation, with at least half of that at engine loads over 185 psig BMEP.

## Owners' Group Status

Intake and exhaust valves are included in the DR/QR Program. The Shoreham DR/QR report on intake and exhaust valves concluded that flaking and loss of chrome plating from the valve stem is an isolated event that has a minor effect on engine performance. It was reported that fuel used at Shoreham does not contain significant quantities of sulfur, and corrosion of the alloy steel stem will be minor if chrome is lost. There may be some increase in oil leakage past the stem seal, but this will not affect engine operation. Thus, an isolated occurrence of chrome loss will not significantly affect engine reliability. The report concludes that the valves are acceptable for their intended design function at Shoreham.

## Duke Power Company Status

Duke Power Company observed no structural damage in the valve stems where chrome plate flaking or peeling occurred. During the Catawba site visit in July, Duke reported that the affected valves were replaced during the reassembly of the 1A engine.

## PNL Conclusions

The chrome peeling on the valve stem was noted during the April and July 1984 visits to the Catawba plant by PNL personnel and consultants. PNL agrees

with Duke that the chrome peeling found on the valve stems is of only minor importance. However, because this peeling could possibly allow corrosion and an accumulation of corrosion products that could eventually affect the operation of the valve and/or the valve guide, valve replacement is considered necessary. This has been completed on the 1A engine; PNL concludes it should be done also on the 1B engine.

Component: Spring Retaining Nut and Roll Pin on Air Start Valves
Part No: 02-359

## Brief History of Component

During the extended operational testing of the 1A diesel engine at Catawba, Duke Power Company found the spring retaining nut on one air start valve was jammed due to galled threads. In addition, a spring retaining nut roll pin was missing from another valve. Duke reported that neither the galled threads nor the missing roll pin had any adverse effects on the diesel's operability.

## Owners' Group Status

The subject air start valve is an assembly included in the DR/QR program. The DR/QR report for the Shoreham Nuclear Power Station documents the design and quality revalidation reviews conducted on the assembly and its equivalent components. The final conclusion of this report is that the air start valve, as an assembly including these components, is acceptable for its intended design function.

## Duke Power Company Status

All of the air start valves on the Catawba 1A engine were disassembled and visually inspected by Duke personnel. The one jammed nut and the one missing roll pin were the only deficiencies found on the 16 subject valves of engine 1A.

Duke has expressed the opinion that the jammed nut and missing roll pin were the result of installation errors. These items have been replaced. Duke has also implemented installation procedures to assure that similar omissions or problems will not recur.

## PNL Conclusions

The subject deficiencies were reviewed with Duke by PNL personnel and consultants during the Catawba site visit in July 1984. PNL concurs with

Duke's assessment of the problem, its cause, and its correction, and concludes that similar errors are not likely to occur in any subsequent engine reassembly, provided that appropriate procedures are followed.

## 3.2 GENERIC PROBLEMS

Component: Crankshaft

Part No: 02-310A

Owners' Group Report: FaAA-84-4-16 (dated May 22, 1984)

### Brief History of Component

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. However, because of the individual nature of shaft stresses, such are not necessarily germane to V-16 engines in general nor to the Catawba engines specifically.

### Owners' Group Status

Failure Analysis Associates has performed torsional and bending stress analyses of the subject crankshaft and has concluded that the shaft will meet the Diesel Engine Manufacturers Association (DEMA) standards at the engines' nameplate rated load and speed. The radius of the fillets in main journal oil holes was identified as an area of potential stress concentration, and careful inspection of this area was prescribed. PNL's review of the FaAA report on these shafts has not yet been concluded. Various considerations remain pending, in the view of PNL's diesel consultants, and must be adequately addressed and favorably resolved before PNL could be confident that the shafts can be shown analytically to be able to function properly over their expected functional life at their design ratings, and also accept such excursions in load, load balance, and speed as sometimes occur with engines.

### Duke Power Company Status

Both Catawba engines have undergone extensive operation, with over 750 hours on each; more than half of the loads were above 185 psig BMEP. These crankshafts in the Catawba diesels have 13-inch diameter crankpins and 13-inch diameter main bearing journals, as opposed to the failed R-48 shafts at Shoreham with 13-inch main journals and 11-inch crankpins.

The completed in situ inspection of the 1A diesel crankshaft included:

- web deflection measurements
- torsiograph tests (with the AN piston skirts)
- visual inspection of all crankpin journals and the fillets at either end
- eddy-current testing of all crankpin-to-web fillets except for those of crankpin #2
- visual inspection of main bearing journals and journal-to-web fillets for 50% of the main bearings (#4, #5, #6, and #8)
- fluorescent dye penetrant testing of the lube oil holes in main journals #4, #6, and #8.

No visually discernible indications were found on the crankpin fillets. Minor indications were detected on the crankpin-to-web fillets on crankpin #7 and on the #8 main journal oil hole. The indications found as a result of the eddy-current testing and the fluorescent dye penetrant test were polished out in less than 0.020 inch.

The 1B diesel crankshaft inspection will include web deflection measurements and visual inspections of the crankpin journals and fillets.

Duke has concluded that the 1A crankshaft evidences no meaningful, deleterious problems, present or potential, and that it is serviceable for its designed function.

PNL Evaluation and Conclusions

PNL consultants have reviewed report FaAA-84-5-23 entitled Torsiograph Test of Emergency Diesel Generator 1A at Catawba Nuclear Power Station. They concluded that this test, conducted on the 1A engine while it contained AN piston skirts, is representative of what would be expected of similar tests of the same engine with AE piston skirts installed. Therefore, PNL does not see the need to conduct additional torsiograph tests on the 1A engine at this time. As discussed in this TER, Duke has completed extended operational tests on the 1B diesel engine at Catawba that consisted of

sufficient operating time to indicate the crankshaft is capable of the intended service. Further, in the July 6, 1984, letter to NRC, Duke has identified the tests and inspections they plan to perform on the crankshaft of the 1B engine. In PNL's viewpoint, this proposed test and inspection program are adequate to verify the physical condition of the 1B crankshaft. Assuming that the results of Duke's test and inspection program are satisfactory, then PNL would not have any reservations about the crankshaft of the 1B engine being capable of performing its intended functions, at least until the next reactor refueling outage.

Because the relevant Owners' Group analyses of RV-16 crankshafts are not yet finalized to acceptable conclusions, in PNL's view, PNL cannot conclude in an unqualified manner that the Catawba shafts are unreservedly reliable. However, PNL does conclude that sufficient operating time has been accumulated on the 1A engine, and that adequate inspection tests have been performed on the crankshaft in the 1A engine, to verify its adequacy to perform its intended functions at least until the next reactor refueling outage, provided the engine operating BMEP is kept below 185 psig. It is PNL's understanding that Duke's emergency load profile meets this condition. By the next reactor fueling outage, it should be possible to draw definitive conclusions on these shafts.

Component: Connecting Rod Bearing Shells

Part No: 03-340-B1

Owners' Group Report: FaAA-84-31

## Brief History of Component

No total failures of the TDI DSRV type diesel engine connecting rod (conrod) 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.

## Owners' Group Status

Failure Analysis Associates has conducted both stress and orbital analyses on the conrod bearing shells. They concluded that the bearings are suitable for the intended service, provided 1) they conform to the manufacturer's specification and 2) they meet a criterion for subsurface voids developed by FaAA for the Owners' Group.

## Duke Power Company Status

The engines at Catawba, with original bearing shells in place, have each operated for over 750 hours, more than one-half that time at loads above 185 psig BMEP. That is approximately the maximum emergency load (LOOP and LOCA) for which these engines were selected.

All (100%) of the conrod bearing shells for the 1A diesel engines at Catawba were examined using the following techniques:

- thickness measurement
- visual inspection of bearing and back surfaces
- liquid penetrant examination
- radiograph examination.

These inspections are now underway on the 1B conrod bearing shells.

The thicknesses of the bearing shells from the 1A engine were found to be within specification. Visual and liquid penetrant examinations showed deterioration of the babbit layer in the areas where maximum pressure is

exerted on the bearing. Duke has concluded that this deterioration is the result of normal wear; it had not progressed to the point at which engine operation would be affected. Therefore, Duke determined that the bearing shells are acceptable for reuse.

Radiography detected five conrod bearing shell halves that contained voids larger than specified by the Owners' Group criterion. During the July 1984 site visit, Duke personnel indicated that the upper and lower bearing shell halves of no. 5, 6, and 7 conrods were replaced in the 1A engine at Catawba.

PNL Evaluation and Conclusions

The subject bearing shells from the 1A engine were not available for PNL inspection during the Catawba visit in April 1984. However, photographs of the bearing surface of each were reviewed. During PNL's visit to Catawba in July 1984, the bearing shells from the 1B engine were viewed by PNL staff and consultants. The deterioration noted in both sets of bearing shells has been reviewed and discussed. PNL's consultants conclude that this deterioration could be the result of insufficient oil pressure, and PNL recommends that Duke investigate this possibility. PNL concurs with Duke that the subject components retain sufficient service life for reinstallation and use. However, subsequent inspections should be made on the bearing shells within the next 500 hours operation to verify their continued integrity. This is approximately the operating time expected over the next 10 years and agrees roughly with Duke's inspection plan. Duke's planned regular monitoring of the lube oil for contaminants, such as bearing babbit metal, will help assure reliability of these components.

Component: Cylinder Blocks

Part No: 02-315A

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

## Brief History of Component

Numerous incidents of cylinder block cracking have been reported in the non-nuclear field. In the nuclear field, all three engines at Shoreham have cracks in their cylinder blocks. At Comanche Peak, cracks were observed after 90 hours of operation. None has resulted in catastrophic engine failure or emergency shutdown. A number of engines have continued to operate many hours with known cracks.

Affected areas are primarily the cylinder liner landing area, between the cylinder opening and adjacent head stud holes, and between adjacent cylinder head stud holes.

## Owners' Group Status

Failure Analysis Associates performed strain gauge testing combined with two-dimensional analytical modeling of the block top and liner. In their report only recently published, FaAA concluded:

- Eventually, depending upon sufficiently high load and operating hours, cracks will initiate between stud hole and liner counterbore. Cracks are predicted to be benign (e.g., non-propagative) if the block materials are free of deleterious materials and properly cast, and if engine loads remain below 225 psig BMEP. [That some (such as those at Catawba) have operated many hours at loads at and exceeding these levels without even initial crack indications is, in FaAA's opinion, indicative of the conservative nature of their evaluation.]

- Cracks between stud hole and liner counterbore will increase the likelihood of cracks developing between stud holes of adjacent cylinders. The deepest crack measured in this region (5-1/2 inches in depth at Shoreham) did not degrade engine operation or loosen studs.

- Provided there are no cracks between stud holes between adjacent cylinders, the block is predicted to have sufficient margin to withstand a LOOP/LOCA event.

The FaAA report recommends visual and eddy-current inspections of cylinder blocks at intervals related to load and operating hours.

Duke Power Company Status

Both Catawba engines have operated over 750 hours each, over half of that time at loads exceeding 185 psig BMEP.

The block inspection for the 1A diesel, which revealed no cracks, included:

- liquid penetrant examination of all cylinders around the studs, and between the cylinder studs and liner
- dimensional and liquid penetrant examination of the cylinder liner landing area of seven cylinders
- eddy-current testing of stud holes of these seven cylinders.

The proposed inspection plan for the 1B engine will include only 25% of the block (four cylinder areas), covering only dimensional and liquid penetrant examination.

PNL Evaluation and Conclusions

After reviewing the FaAA report and noting that Duke's inspections of the 1A engine blocks revealed no indication of cracks, PNL concurs that the blocks are acceptable for their intended purpose, at least until the next reactor refueling outage. PNL's conclusions regarding the scope and frequency of inspections are expressed in Section 7.0.

If the results of Duke's inspections on the cylinder blocks of the 1B engine are satisfactory, PNL would have no reservation about the continued use of these components and their ability to fulfill their intended purpose.

Component: Cylinder Liners

Part No: 02-315C

Owners' Group Report: FaAA 84-5-4

Brief History of Component

Only one incident of cylinder liner "f''ure" in nuclea- service is available. 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.

Owners' Group Status

The Owners' Group analysis has identified some cylinder liner dimensions as not being compatible with those of interfacing components. This incompatibility could be a contributing factor in liner stresses.

Duke Power Company Status

The original liners on both the 1A and 1B engines at Catawba have served for over 750 hours of operation, with over one-half that period at loads exceeding 185 psig BMEP.

Cylinder liner inspection on the 1A diesel included those listed below. The 1B diesel inspection percentages are shown in parentheses.

- visual inspection of 100% of the cylinder liners (100%)
- bore measurements of 100% of the cylinder liners (100%)
- material comparitor and hardness tests on 20[illegible] [illegible] the liners (0%)
- dimensional check of cylinder protrusi[illegible] [illegible] the block on 100% of the liners (100%)
- dimensional check of the cylinder liner landing area for 40% of the cylinders (25%).

All cylinders showed minor scuffing. Duke has concluded that the scuffs are a result o[illegible] ormal wear and are acceptable. Twenty-three percent of the bore measurements and 33% of the cylinder protrusion measurements did not meet TDI specifications. Duke has concluded that the out-of-specification

measurements are acceptable for used cylinders. Although the material comparitor tests showed differences from the Owners' Group standard, Duke considers the liners to be satisfactory based on their performance record. The hardness test results were found by Duke to be acceptable.

PNL Observations and Conclusions

PNL concurs with Duke that the inspections made and the results are acceptable. The Duke conclusions regarding scuffing, bore measurement, and materials composition are judged to be reasonable and supportable. In view of these considerations, the already acceptable service for over 750 hours in the 1A engine, and the general history of reliability of TDI liners, PNL concludes that the liners in the 1A engine are suitable for their intended purpose. If the results of the inspections on the 1B engine cylinder liners are acceptable, PNL concludes that these liners also will suit their intended purpose.

Component: Cylinder Head Studs

Part No: 03-315-01-0A (Old Design)

Owners' Group Report: Stone & Webster, March 1984

## Brief History of Component

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 reported.

## Owners' Group Status

Stone & Webster Engineering Corporation 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.

## Duke Power Company Status

The original studs in both Catawba engines have experienced over 750 hours of operation, over half of which has been at loads exceeding 185 psig BMEP.

Duke has not replaced any of the cylinder head studs with the new necked-down design. In the 1A diesel inspection, head studs of four cylinders were measured for as-found torque and then visually inspected. Also, material comparitor and hardness tests were performed on a single stud from each of four cylinders.

The as-found torque was above 1100 ft-lb (1500 ft-lb specified) for all measured studs. Duke believes this to be acceptable. No significant indications or material problems were detected. The 1B diesel inspection will include a visual inspection of 25% of the cylinder head studs as in the 1A diesel inspection.

## PNL Observations and Conclusions

From the analysis and inspections performed on the subject studs, PNL concludes that the old design as being used at Catawba remains adequate for its intended purpose, assuming all stud preloads are as specified.

Component: Engine Base and Bearing Caps

Part No: 02-305C

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

## Brief History of Component

The only failure reported by the Owners' Group for DSRV-16 engines occurred in a non-nuclear application: a nut pocket failed on a DSRV-16 engine at the ANAMAX mine near Tucson, Arizona. According to FaAA, TDI determined that this failure was due to impurities in the casting material that reduced the engine base strength.

## Owners' Group Status

Failure Analysis Associates, 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, and that proper preloads are maintained.

## Duke Power Company Status

On engine 1A, 50% of the main bearing saddle area (around four bearings) was checked by liquid penetrant and visually examined around and between the stud holes. In addition, stud tension for removal of the nuts was measured. No abnormalities were detected. This component will not be inspected as part of the 1B diesel inspection, per Duke's current inspection plans.

## PNL Evaluations and Conclusions

The one reported failure of these components appears to be traceable to a manufacturing defect in a particular casting. There has been no indication of a similar failure occurring in the 1A engine that has been operated for over 800 hours, with at least one-half of this time at BMEPs of over 185 psig.

PNL concludes that Duke has conducted adequate inspections and, further, that there is no apparent reason why these components cannot continue to perform their intended functions in both of the TDI diesel engines at Catawba.

Component: Rocker Arm Capscrew

Part No: 02-390-01-0G

Owners' Group Report: Stone & Webster, March 1984

## Brief History of Component

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

## Owners' Group Status

Stone & Webster Engineering Corporation, a consultant to the Owners' Group, has performed stress analyses of both the original capscrew design (the type that failed at Shoreham) and a newer design. Stone & Webster has concluded that both designs are adequate for the service intended. Stone & Webster has attributed the failure at Shoreham to undertorquing.

## Duke Power Company Status

The rocker arm capscrews at Catawba are of the original design. These capscrews have experienced in excess of 10 million loading cycles in both Catawba diesel engines without reported failures.

Inspections of all rocker arm capscrews on the 1A diesel included:

- measuring breakaway torques
- visual examination
- magnetic particle testing
- material comparitor and hardness tests.

The range of breakaway torques for the intake/intermediate and exhaust capscrews was 278 to 376 ft-lb and 324 to 498 ft-lb, respectively. Comparing these values to the specified torque of 365 ft-lb, Duke concluded that these ranges were acceptable. Further, no indications or material problems were identified. Due to the satisfactory inspection results on the 1A diesel, Duke proposes to examine the 1B diesel rocker arm capscrews visually and by magnetic particle detection only.

PNL's Conclusions

Based on the satisfactory performance of the subject capscrews at Catawba for over 10 million cycles, PNL concludes that the currently available components are adequate for the intended service in both the 1A and 1B diesel engines. Also, in view of the satisfactory service performance, PNL concurs with the reduced scope of inspections as Duke has proposed on the 1B engine.

Component: Connecting Rods

Part No: 02-340A

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

## Brief History of Component

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. Another 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.

## Owners' Group Status

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

The second failure mechanism is fatigue cracking of the connecting rod bolts and/or the link rod box at the mating threads. TDI attributed these rod cracks to "thread fretting." This "thread fretting" was concluded by TDI to result from distortion of the rod bolt under operating loads in the area of the mating threads; the distortion could occur if the bolts had been installed with the originally specified bolt preloads. The 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 are equipped with a 1-1/2-inch bolts. Stress analysis, including finite element studies, has been completed by FaAA. Failure Analysis Associates has concluded that both designs are adequate for the service intended, provided conrod bolt

preload is checked within time limits specified as related to engine load requirement in terms of percentage of nameplate rating. However, the rod with the 1-1/2-inch bolts has an 8% to 9% higher margin of safety than the rod with 1-7/8-inch bolts because the related rod box structure is more massive with the smaller bolt configuration.

<u>Duke Power Company Status</u>

The Catawba engines were furnished with connecting rods employing the 1-7/8-inch bolt. The 1A engine has undergone over 800 hours of operation (over 10 million load cycles), with over half of that at engine loads exceeding 185 psig BMEP. The 1B engine has been operated for over 750 hours, with over 80% of this time at engine loads exceeding 185 psig BMEP.

The connecting rod bolt inspections on engine 1A were as follows:

- visual inspection of 100% of areas subject to wear (rack teeth, washers, seating surfaces)
- measurement of 100% of link pin and link bushing dimensions (25% for piston pin bushing)
- material comparitor and hardness tests on 25% (4) connecting rod assemblies (master rod, rod box, and link rod)
- liquid penetrant test of rod box areas subject to cracking
- eddy-current inspection of 100% of the rod box threaded holes
- measurement of breakaway torque on 100% of connecting rod assemblies
- inspections of connecting rod oil passages
- magnetic particle testing of 100% of connecting rod bolts
- visual inspection of the connecting rod contact surfaces
- measurement of the contact of the connecting rod rack-teeth (serrations) with the mating part by "bluing", for 100% of the rods
- measurement of connecting rod bolt elongation by ultrasonic testing.

Results of the material comparitor and hardness tests, the magnetic particle and eddy-current examinations, and the oil passage inspections showed

no abnormalities. Some scratches and pitting were detected through the visual inspection of possible wear areas, which Duke concluded have no adverse effects. The TDI-allowed clearance tolerance for new piston pin bushings is 10 to 15 mils; for used piston pin bushings, it is 20 mils. The four bushings measured 11 to 13 mils, which is within the specification for new bushings. The dimensions of the link pin and the link pin bushing were satisfactory in all cases.

The liquid penetrant test showed a 1-1/2-inch long scratch on link rod bushing 1L, which was replaced. Breakaway torque values for the master rods and the link rods ranged from 1260 to 2150 ft-lb (specified torque of 1700 ft-lb) and 880 to 1410 ft-lb (specified torque of 1050 ft-lb), respectively. Galling under bolt heads was observed in the visual inspection of the contact surfaces. Duke has concluded that the galling was due to bolt torquing and is acceptable. The degree of contact from bluing showed a range of 80 to 100%. The manufacturer requires at least 75% contact. Inspection results are not yet available for the elongation tests.

PNL Evaluations and Conclusions

TDI and the Owners' Group have each 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.

Duke has appropriately addressed the generic issue of potential connecting rod problems through extended operations, disassembly, and inspection. PNL concludes from the available evidence that the connection rods on the Catawba engines can be expected to perform their intended function reliably. This is stated, however, with the proviso that Duke fully check (and correct as needed) the locating-dowel problem and the rack-teeth contact ratio, and establish a comprehensive surveillance and maintenance program (see Section 7.0).

Component: Engine Mounted Electrical Cable

Part No: 02-688B

Owners' Group Report: Stone & Webster, June 1984

## Brief History of Component

No failure of this part has been reported. However, in TDI Service Information Memo (SIM) No. 361, Rev. 1, TDI reported that two engine-mounted cables, those associated with the Woodward governor/actuator and the Air-Pax magnetic pick-up, represent potential fire hazards.

## Owners' Group Status

Based on the survey results for Catawba, Stone & Webster has recommended to Duke that they implement TDI SIM 361 and that they replace some of their installed 14 AWG wire with wire that is qualified to the IEEE-383-1974 standard. Stone & Webster has also recommended that Duke verify the time period during which their type N7 sliding link terminal blocks were manufactured.

## Duke Power Company Status

In their report issued to NRC on June 29, 1984, Duke stated their intentions to replace wiring and implement TDI SIM 361 by September 1984. This report also referenced Duke's program for inspecting sliding link terminal blocks rather than verifying the manufacturing date of the TDI-provided items.

## PNL Evaluation and Conclusions

When the electrical cable is replaced with IEEE-38-1974 qualified cable capable of withstanding the ambient temperature that might occur adjacent to the diesel engine proper, PNL concludes that there should be no more concern about the integrity of the cable and its ability to function at the normally expected temperatures.

During the Catawba site visit in July, PNL obtained information from Duke on sliding link terminal blocks. According to these data (Reference 19 to the report issued on June 29, 1984, to NRC), they have found a small percentage of

defective links at Catawba. However, Duke reported no incidents of a defective link causing degradation or failure of an electrical circuit.

PNL and its consultants have not completed their review of either the Stone & Webster reports on the subject components at the TDI Owners' Group plants (including Catawba) or Duke's inspection approach on the sliding link terminal blocks. However, PNL concludes that the terminal blocks as installed at Catawba will be capable of fulfilling their intended functions, at least until the first refueling outage at the reactor.

Component: High-Pressure Fuel Tubing

Part No.: 02-365C

Owners' Group Report: Stone & Webster, April 1984

## Brief History of Component

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.

## 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 manufacturer specification, Stone & Webster has concluded the HP tubing is suitable for the service intended.

## Duke Power Company Status

The tubing for both diesels at Catawba has operated satisfactorily for greater than 10 million cycles. Duke proposes to perform eddy-current tests along with visual inspections of the HP tubing of both the 1A and 1B diesel engines. The inspection results have not yet been made available.

## PNL's Evaluation

The isolated failures that have occurred on the high-pressure fuel tubing appear to have been a result of internal flaws. The subject components have neither been a source of problems nor failed on either of the diesel engines at Catawba during their extended operational tests.

PNL concurs that, if the eddy-current tests show all new or replaced tubing does not contain unacceptable inner surface flaws, then these components should be capable of fulfilling their intended design function.

Component: Jacket Water Pumps

Part No.: 02-425

Owners' Group Report: Stone & Webster, June 1984

Brief History of Component

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.

Owners' Group Status

Stone & Webster has investigated the jacket water pumps as installed on the TDI in-line and V 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 Catawba 1A and 1B engines to be acceptable, with a recommendation that a limiting torque be established for one of the pump shaft nuts.

Duke Power Company Status

The 1A diesel jacket water pump inspections included:

- visual inspection of the driving gear, coupling, and clearance ring
- material comparitor and hardness tests of the shaft
- liquid penetrant examination of the coupling, shaft, and impeller
- radiography examination of the impeller.

Porosity was noted in the impeller casting. Based on radiography results, Duke concluded that the porosity was acceptable. The jacket water pump will not be inspected as part of the 1B diesel inspection.

PNL's Evaluation

The analysis conducted on the subject pump has been quite extensive. PNL concurs with the investigat.ons' conclusions and concludes that the pumps as installed should be adequate to meet their design purposes. However, Duke must check the subject component on the 1B engine to assure that the nut holding the

external spline in the shaft taper is neither under- nor overtorqued. Duke should also confirm that the 1A engine jacket water pumps were reinstalled within the recommended torque ranges.

Component: Air Start Valve Capscrews

Part No.: Gg-032-114

Owners' Group Report: Stone & Webster, March 1984

## Brief History of Component

No actual failures of these capscrews have been reported. However, on May 13, 1984, 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.

## 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.

## Duke Power Company Status

Capscrews on both the 1A and 1B diesels were modified prior to the extended operational tests. All of the 1A air start valve capscrews were measured for torque with values varying from 45 to 134 ft-lb. Duke concluded that this range represents an acceptable variation from the specified torque of 100 ft-lb. Twenty-five percent of the 1A capscrews were measured for length; all those measured were within tolerance. For the 1B diesel inspection, Duke will measure and retorque 25% of the capscrews.

## PNL's Evaluation

PNL agrees with Duke's assessment of the problems. The actions taken by Duke to eliminate the potential interference would appear to be adequate to prevent any subsequent failures. PNL concludes that, with the continued use of Duke's installation procedures to control torque of bolts, studs, and screws to specified ranges, these components will not present future problems on the Catawba engines.

## 3.3 RESPONSES TO NRC QUERIES ON COMPONENT PROBLEMS

In their August 1, 1984, letter to NRC, Duke Power Company has indicated its reponses to, or the actions to be taken on, specific items or issues raised during the Catawba site visit in July. PNL has reviewed this letter and concludes that the response to each item or issue is acceptable.

## 4.0 EVALUATION OF CATAWBA 1A DIESEL ENGINE INSPECTION

This section documents PNL's technical evaluation of the disassembly, inspection, and reassembly of the 1A diesel engine at Catawba. These efforts were performed by Duke Power Company following successful completion of the planned extended operational tests.

### 4.1 STATUS AT CATAWBA

When the extended operational tests were finished in March 1984, the 1A diesel engine had accumulated more than 800 hours total operating time. For 50% of this time, the 1A engine was operated with loads at or greater than 5800 kW (186 psig BMEP). A load of 5714 kW (184 psig BMEP) is the maximum required in any emergency postulated for Catawba. Duke subsequently initiated extensive disassembly and inspection of the engine to confirm the condition of various parts and to identify any parts requiring repair, replacement, and/or redesign to ensure highly reliable standby electric generator service. Duke's inspection program involved 100% inspection of parts for which there was a history of problems or other reasons for special concern. Substantial sampling inspections were performed on other important parts for which there was no history of problems.

The inspections of the 1A diesel engine were performed during April through June 1984. As reported by Duke, the diesel disassembly, inspections, and reassembly were performed in accordance with Duke Power Company's Quality Assurance Program. The work was performed primarily by Duke personnel; however, selected inspections were performed by Failure Analysis Associates (FaAA), Stone & Webster Engineering Corporation, and others in conjunction with the TDI Owners' Group Program. Duke has stated that the inspections of the 1A diesel are now complete, except for a few that must be performed during or following engine reassembly. "Walkdown" inspections of the various piping, tubing, and electrical conduit runs on the engine are planned following completion of the 1A engine reassembly. Results of these inspections will be factored into the Owners' Group Phase II DR/QR program for Catawba.

Duke Power Company's report, entitled Catawba Nuclear Station Diesel Engine 1A Component Revalidation Inspection, dated June 29, 1984, describes the methodology and results of the inspections and examinations performed.

## 4.2 TEST AND INSPECTION RESULTS

The post-extended operational test inspections on the 1A engine are now nearly complete. Engineering and quality assurance evaluations of the inspection results have been performed by Duke. They consider this work to have identified all significant conditions.

As reported by Duke, the most significant results of the Catawba 1A diesel engine post-test inspections are as follows:

- Many of the major problems experienced with other TDI diesel engines did not occur in the Catawba 1A diesel engine.
- One major problem was noted on the 1A diesel. Four of the type AN piston skirts used in the 1A diesel were found to have one or more cracks in the region where an internal circumferential reinforcing rib intersects the piston pin boss.
- The turbocharger thrust bearings were found to be severely worn, although they had continued to function satisfactorily during the test. This condition was anticipated because similar problems have been experienced at other stations. As a result of this history, a redesigned lube oil system is being developed to minimize possible recurrence of the problem. It will be installed by September 1, 1984. In the meantime, the bearings have been replaced as necessary to ensure operability.
- Several other problems of potential significance to engine 1A operability were detected and are being investigated further as part of the TDI Owners' Group Program:
    - Two subcover castings were found to have cracks in an intake rocker arm pedestal.

- Two Catawba cylinder heads (one on diesel 1A and one on 1B) experienced small jacket water leaks into the exterior fuel injector cavity. Metallographic examinations of the head removed from the 1A diesel indicates that the leak was due to a fatigue crack of the spray nozzle hole repair at a weld performed at the TDI factory.

- A small eddy-current test (ECT) indication was detected in crankpin-to-web fillet #7 (generator end) on the crankshaft. Metallurgical examination suggests that the indication was due to 0.027-inch and 0.021-inch long linear defects located about 0.105 inches apart. The 0.021-inch defect was polished out at a depth of less than 0.005 inch. The 0.027-inch indication was polished out in about 0.020 inch of depth. Another indication was detected by fluorescent dye penetrant in the #8 main journal oil hole. This indication was approximately 0.25-inch long and made up of a series of extremely small pores. This indication was polished out in less than 0.005 inch. Evaluation of these indications shows that they were due to initial fabrication.

- A variety of routine minor conditions was noted; these are discussed in Section 3.0 of this TER. None of these conditions impacts the operability or structural integrity of the diesel. Typical conditions included:
  - chipped and cracked edges of rocker arm sockets and cracked tappet
  - flaked and peeled valve stem chrome plate
  - jammed air start valve adjusting nut
  - heads of small bolts broken off, due to under- or overtorquing
  - fuel oil injection pump valve holder cracked at a casting defect
  - repeated cracking of the right-bank turbocharger/intercooler adapter
  - turbocharger prelube oil line fractures at connection fittings.

## 4.3 EVALUATION

As stated in PNL-5161, Review and Evaluation of TDI Diesel Generator Owners' Group Program Plan, engine testing and inspections are the key elements

of the TDI Owners' Group Program for tying corrective actions together and for verifying adequate results.

PNL believes that the extended operational tests conducted by Duke on the 1A engine at Catawba, lasting over 800 hours (over half of which were at loads of over 185 psig BMEP), were of sufficient length and magnitude and adequate to verify the operability and reliability of components. Further, in PNL's opinion, the tests were adequate to demonstrate whether or not the components will meet load and service requirements without evidence of distress under conditions that could induce high-cycle fatigue.

## 4.4 CONCLUSIONS

Based on its evaluation of the activities associated with or reported on the inspection and reassembly of the 1A diesel engine, PNL concludes that

- Except for the AN piston skirts, the significant engine components were found to be in operable and reliable condition after the extended operational tests, or were appropriately serviced or replaced.
- No major problems were found at the end of the extended operational tests that would have prevented the 1A engine from continuing to operate at that point in time.
- The miscellaneous problems found have been addressed, and corrective actions have been taken or proposed that should be adequate to prevent a recurrence.

PNL concludes overall that, upon Duke's satisfactory completion of the return-to-service testing, the 1A diesel engine at Catawba should be adequately operable and reliable to fulfill its intended purpose, at least until the first reactor refueling outage.[a]

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[a] The phrase "until the first reactor refueling outage" is defined in Section 1.2 on p. 3 of this report.

## 5.0 EVALUATION OF CATAWBA 1B DIESEL ENGINE OPERATION TEST AND INSPECTION

The Duke Power Company report, Catawba Nuclear Station Extended Operation Tests and Inspections of Diesel Generator, transmitted to NRC on April 5, 1984, outlined the inspections that had been performed on the 1B diesel engine prior to operation tests. The report also expressed Duke's intent to extend the 1B engine high load operating time to at least 750 hours and to perform additional inspections on the engine and its components following the extended operation tests. Duke noted that the extent of the inspections to be conducted on the 1B engine would be based on the results of the Catawba 1A and other TDI emergency diesel engine inspections.

Duke Power Company has now completed its planned extended operation tests on the 1B diesel engine at Catawba. During the NRC-PNL/Duke Power Company meetings on July 25 and 26, 1984, Duke personnel indicated that the 1B engine had been operated more than 750 hours, and that 80% of those hours were at ≥ 5800 kW. A July 17, 1984, Duke Power Company letter from G. W. Hallman to C. L. Ray, Jr., summarized the operating history of Catawba Unit 1 diesels (1A and 1B). In an earlier letter, dated July 6, 1984, from H. B. Tucker to NRC, Duke presented a proposed inspection plan for the 1B engine at Catawba.

### 5.1 CATAWBA 1B DIESEL ENGINE OPERATION

Duke established the extended operation tests to demonstrate the fatigue resistance of the diesel engine components and to demonstrate the ability of the Catawba engines to operate in a reliable fashion. Duke has concluded that the 810 hours of operation on the 1A engine (50% at ≥ 5800 kW) has served to demonstrate the fatigue life capability of the engine parts; that the 1A engine is capable of sustained operation at high loads; and that the 1A engine has the ability to operate continuously for periods of time that may be required in an emergency situation.

According to Duke Power Company personnel, the 1B engine at Catawba recently sucessfuly completed its extended operation test, which consisted of

over 750 hours of operation. Duke has concluded that the 1B engine has demonstrated its ability to operate in reliable fashion.

5.1.1 PNL Evaluation

As covered in PNL-5161, Review and Evaluation of TDI Diesel Generator Owners' Group Program Plan, engine testing and inspections are the key elements of the TDI Owners' Group Program for tying corrective actions together and for verifying adequate results. Engine tests are required to demonstrate whether or not a component or unit will meet load and service requirements without evidence of unacceptable stress. This is particularly important in plants seeking licensing prior to the full implementation of the Owners' Group Program Plan.

5.1.2 PNL Conclusions

As reported in Section 4.3, PNL believes that the extended operation tests conducted by Duke on the 1A engine at Catawba were of sufficient length and magnitude and adequate to verify the acceptable function of components, as well as to demonstrate the ability of components to meet load and service requirments under conditions that could induce high-cycle fatigue.

Likewise, in PNL's opinion, tests of a sufficient duration and intensity have been performed on the 1B diesel engine at Catawba to demonstrate its state of component adequacy, subject to satisfactory inspection results. Over 750 hours of operation were involved, with nearly 80% at or over 185 psig BMEP.

5.2 CATAWBA 1B DIESEL ENGINE INSPECTIONS

Duke Power Company has developed and published in the July 6th letter noted above their proposed inspection plan matrix for the Catawba 1B diesel engine. The sample size of components they plan to inspect on the 1B engine, except for a few components, is the same as that performed on the 1A engine.

5.2.1 PNL Evaluation

The plans for the 1B diesel engine inspection were reviewed by NRC/PNL and Duke Power Company personnel at the Catawba meeting on July 25, 1984. PNL

considered Duke's plans in light of published results of inspections on the 1A engine, as well as the results to date of the Owners' Group analyses on known issues and DR/QR.

### 5.2.2 PNL Conclusions

In PNL's opinion, the inspection plan is adequate to determine if the key and critical components of the 1B diesel engine have met load and service conditions without undue evidence of stress.

PNL recommends that Duke Power Company perform the following inspection in addition to those listed in their referenced inspection plan:

- 100% disassembly of link and master rods and in situ inspection (visual and surface nondestructive evaluation) of the link rod bushings. In their August 1, 1984, letter to NRC, Duke has concurred with this activity.

The inspections of the 1B diesel engine have only recently begun and the results are, of course, not complete at this time. Hence, the unavailability of the 1B engine inspection report precludes PNL from evaluating the inspection findings and dispositions. After Duke Power Company has completed the 1B engine inspections, they should document the methodology, the findings, and the actions taken. Pending successful completion of the 1B engine inspection, reassembly, and return-to-service testing, it is assumed that the Catawba 1B diesel engine will have compiled a record that will demonstrate its operability and reliability.

## 6.0 REVIEW OF POST-INSPECTION TEST PLAN

This section documents PNL's review of the post-inspection tests to be performed by Duke Power Company on the Catawba diesel engines. Elements of Duke's proposed return-to-service tests are presented first. Next, factors and data considered in PNL's evaluation of Duke's test plan are described. Last, the overall conclusion reached by PNL regarding Duke's post-inspection test plan is presented.

### 6.1 DUKE POWER COMPANY POST-INSPECTION TEST PLAN

Duke Power Company outlined its plans for the return-to-service testing of the 1A diesel engine in a July 6, 1984, letter to NRC (H. B. Tucker to H. R. Denton, "Catawba Nuclear Station Docket Nos. 50-413 and 50-414"). The planned tests included:

- run-in operations in accordance with the TDI Instruction Manual
- ten modified-start[a] load tests of at least 3500 kW (i.e., 50% of nameplate rating)
- a 24-hour run consisting of 22 hours at 7000 kW and 2 hours at 7700 kW (i.e., 100% and 110% of nameplate rating, respectively)
- two fast starts[a] to a peak load of 4100 kW (59% of nameplate rating): one start with manual turbocharger prelube, and one without
- trip device verification
- load rejection test.

During PNL's visit to the Catawba site on July 25 and 26, 1984, Duke personnel indicated that these tests could not be performed on the 1A engine before August 1, 1984. Similar tests cannot be performed on the 1B engine until the current inspection program is completed and the engine is reassembled.

(a) A modified start is a start including turbochargers prelube; a fast start simulates ESF signal with the engine in ready-standby status.

## 6.2 EVALUATION

PNL evaluated the elements of Duke Power Company's post-inspection test plan within the context of two principal items:

- PNL recommendations made earlier to NRC regarding diesel engine preoperational testing
- NRC-proposed staff actions to improve and maintain diesel generator reliability.

These items are described in detail in the next two paragraphs.

In June 1984, PNL recommended to NRC that preoperational testing be performed on all diesel engines following their assembly, to confirm that the engine is operable (PNL-5161). For engines such as at the Catawba Nuclear Station Unit 1 (viz, a candidate for an operating license prior to completion of the implementation of the Owners' Group Program Plan) PNL recommended that this testing include the manufacturer's preoperational test recommendations as well as the following elements, if they are not already contained in the manufacturer's recommendations:

- ten modified starts to at least 40% of "qualified" load (as defined in PNL-5161)
- two fast starts to "qualified" load
- one 24-hour run at "qualified" load.

PNL had also recommended to NRC (PNL-5161) that, because of the plant-specific nature of engine installations, the owners should prepare detailed plans for engine tests and inspections.

During the July 1984 Catawba site visit, PNL learned of NRC Generic Letter 84-15 dated July 2, 1984, that addressed proposed staff actions to improve and maintain diesel generator reliability. Enclosure 1 of this generic letter states:

> It is the staff's technical judgment that an overall improvement in diesel engine reliability and availability can be gained by performing diesel generator starts for surveillance testing using engine prelube and other manufacturer recommended procedures to reduce engine stress and wear. The staff has also determined that the demonstration

of a fast start test capability for emergency diesel generators from ambient conditions cannot be totally eliminated because the design basis for the plant, i.e., large LOCA coincident with loss of offsite power, requires such a capability.

In view of the above, the staff has concluded that the frequency of fast start tests from ambient conditions of diesel generators should be reduced.

PNL reviewers noted that Duke's return-to-service test plan states that all 10 modified start load tests will be performed with a prelube of the engine and that one of the fast start tests will be conducted under prelube conditions. The other of these tests will be performed with the engine in ready-standby status without prelube.

PNL also notes that Duke's post-inspection return-to-service test plan calls for a 24-hour run to nameplate rating (22 hours) and overload rating (2 hours), as detailed in Section 6.1 above. In light of the need for conservative operation relative to crankshaft and cylinder block conditions (as previously discussed in Section 3 of this TER and in Section 4 of PNL-5161), PNL concludes it would be inappropriate for Duke to further operate the Catawba engines above 185 psig BMEP, as long as emergency loads do not necessitate such operation. (Refer also to Section 1 and 2.1 herein.)

PNL also recommends that, as part of the return-to-service tests, Duke observe, record, and report pre-turbine exhaust gas inlet temperatures at levels of 25%, 50%, 75%, and 82% of nameplate rating (i.e., at BMEPs of 56, 113, 169, and 185 psig).

## 6.3 CONCLUSIONS

Based on its review, PNL concludes that Duke's post-inspection test plan is compatible with NRC requirements described in Section 6.2. It is the opinion of PNL's consultants that TDI engines such as those at Catawba should not be operated above a BMEP of 185 psig except for brief periods, at least until all concerns pertaining to the current crankshaft are fully resolved. Therefore, PNL recommends that Duke conduct the post-inspection 24-hour runs on the 1A and 1B engines at a qualified maximum load of 5800 kW. Finally, PNL

concludes that the successful completion of Duke's return-to-service tests will be adequate to confirm that the 1A engine and its associated systems are operable.

PNL also concludes that similar return-to-service tests on the 1B engine will be adequate in scope and objective. However, any failure to meet the objectives of the tests will require reconsideration of this conclusion.

## 7.0 REVIEW OF THE PROPOSED MAINTENANCE, INSPECTION, AND SURVEILLANCE PROGRAM

While reviewing the Owners' Group Program Plan (OGPP), 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 eventually in its formal review of the OGPP as published in June 1984 (PNL-5161). 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.

Elements of such a 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.

A letter from H. B. Tucker of Duke Power Company to H. R. Denton, Office of Nuclear Reactor Regulation, NRC, dated July 16, 1984, addressed "Periodic Maintenance, Inspection and Surveillance of the Catawba 1A and 1B Diesel Engines (Catawba Nuclear Station, Docket Nos. 50-413 and 50-414)." Therein, Mr. Tucker references the NRC staff letter of April 25, cited above, as one basis of the Duke Power Company M/S program plan. (Other bases cited by Tucker include an engineering evaluation of the results of the Catawba 1A diesel engine post-extended operating test inspection and the TDI Owners' Group recommendations.)

Duke's July 16th letter discussed NRC's comments, and indicated how Duke plans to resolve those comments. Table 1 of the letter provided a schedule for periodic inspection, maintenance and surveillance.

This section presents PNL's review of Duke Power Company's planned M/S program. Significant features of the program are discussed, followed by summary observations and comments.

## 7.1 PNL EVALUATION

In Section 4 of PNL-5161, Review and Evaluation of TDI Diesel Generator Owners' Group Program Plan, PNL recommended that utilities seeking licensing prior to completion of the Owners' Group Plan for M/S and its full implementation by the individual utilities, should provide for enhanced surveillance and maintenance. In general, Duke's July 16th proposal has provided for this, although their program differs somewhat from the NRC staff's April 25th recommendations. Table 1 provides a comparison of the two approaches (NRC and Duke), and presents a parallel listing of PNL's recommendations. Comments on individual component plans follow.

### 7.1.1 Cylinder Heads

Barring the engine over 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 and/or piston on engine startup and could seriously impact engine operability. The Duke proposal is to bar-over weekly, rather than daily, to reduce engine unavailability. PNL does not consider this proposal to be adequate for assuring timely detection of water in the cylinders.

PNL Recommendation

PNL recommends a revised schedule for barring-over, as follows:

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

The basis for the change from the earlier PNL recommendation (which called for barring-over 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

TABLE 1. PNL's Recommendations Concerning Duke's Proposed Maintenance/Surveillance Plans for Key Components of the Catawba TDI Engines

| Component | NRC Guidance (April 25) | Duke Proposal (July 16) | PNL Recommendation |
|---|---|---|---|
| Cylinder Heads | Bar-over 4 hours after engine runs and each day thereafter. | Bar-over within 4 hours after engine runs and weekly thereafter, and prior to routine starts. | Bar-over 4 to 8 hours after engine runs, and again after 24 hours and prior to routine starts. |
| Engine Block and Base | Visually inspect after 24 hours operation or monthly | Visually inspect monthly "or more often". | Visually inspect daily during operation, with intensely lighted inspection monthly, while operating. |
| Connecting Rods | Visually inspect and retorque after 24 starts, 50 hours of operation, or 6 months, whichever is first. | Check bolt preloads at first refueling outage (estimated equivalent to 25 to 50 starts and 50 to 200 hours of operation). | Visual surface inspection and bolt preload check at 200 hours or 9 months, whichever is first. |
| Lube Oil Check | Check for water following preoperational tests, then weekly or after 24 hours of operation, whichever is first. Check monthly for contaminants and water in sump; check filters. | Check following preoperational tests, then monthly or after 24 hours of operation, whichever is first. Check monthly for water in sump; semiannually for contaminants. Check filter pressure drop during diesel operation. | Check for water following preoperational tests, then monthly or after 24 hours of operation, whichever is first. Check for chemical and particulate contamination on same schedule. Check filter pressure drop hourly during operation. |

TABLE 1. (contd)

| Component | NRC Guidance (April 25) | Duke Proposal (July 16) | PNL Recommendation |
|---|---|---|---|
| Studs/ Fixtures | Spot-check 25% monthly for torque. | Spot-check 25% at each refueling outage. | Check 100% of air-start valve capscrews and 25% of all other items at each refueling outage. |
| Push Rods, Cams, Tappets, Etc. | 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. |
| Other M/S Items | Standby: Lube oil filter differential pressure - daily | Standby: Weekly | Standby: Weekly |
| | Crankshaft deflections - hot and cold every 6 months; hot within 15 minutes of shutdown. | Once each refueling cycle; hot within 4 hours of shutdown. | Once each refueling cycle; hot to start in 15 minutes, complete within 30 minutes. |
| | Operations: Exhaust temperature - continuous (record hourly) including pre-turbine inlet temperature. | Operations: Continuously monitored and recorded (no comment re: pre-turbine exhaust inlet) | Operations: Continuously monitored and recorded, including pre-turbine exhaust inlet. |
| | Lube oil, jacket water, inter-cooler temperatures, air pressure accelerometers - monitor continuously, record hourly. | Generally per NRC guidance (excepting accelerometers, which give no readings) | As per Duke proposal. |

small leak to weep 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.

Duke contends that the absence of a history of cracked heads at Catawba precludes the necessity of such precautions. Nevertheless, Duke has offered to bar-over the engine weekly as a precaution. Because Catawba has neither identified the "group" affiliation of its heads, nor replaced all with heads clearly of Group III (when TDI manufacturing QA/QC reportedly was better), it is important that these reasonable precautions be taken so as to assure engine reliability. The desirability of doing so is further substantiated by the recent occurrence of just such a leak, detected by barring-over, at Grand Gulf Nuclear Station (see Section 3 re: cylinder heads).

7.1.2 Engine Block and Base

There are three primary structural components to a Vee engine: the base; the crankcase; and the cylinder block. The history of problems in the population of TDI engines, and relevant analyses by TDI and the Owners' Group, lead PNL to conclude that there is insignificant 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 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 at unspecified intervals. By their criteria, however, this would not be necessary on the Catawba engines on a regular basis (until a substantial number of additional operating hours at high load levels have accumulated).

Duke's proposal is to conduct "visual inspections of the block and base" (and, presumably, the crankcase) "routinely during engine operation, i.e, every month or more often. These inspections will be directed at... verifying that dangerous cracks are not propagating from stud holes in the block... and will be limited to those inspections which can be performed without disassembly of any parts." (Emphases added).

In light of the history of block cracks and the FaAA analysis, PNL and its diesel consultants remain concerned that even at Catawba 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 Duke. Nevertheless, because of the favorable Catawba history, and in light of FaAA's evaluation thereof, PNL concurs with Duke's plan for regular, thorough visual monitoring, which must be done under conditions of strong lighting.

PNL Recommendation

PNL recommends routine daily inspection during operating periods, with a more thorough inspection under strong lighting at least monthly. These should be conducted while the engine is operating.

### 7.1.3 Connecting Rods

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 known-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 286 hours at 75% load. In making that recommendation there was 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, it is deemed prudent to establish an enhanced surveillance plan.

Duke contends that it has experienced no relevant problems or indications thereof, such as fretting of the connecting rod serration teeth. However, some surface "roughing" has been observed, the interpretation and importance of which is viewed differently by Duke and PNL observers. Furthermore, the

equivalent rods (with 1-1/2-inch bolting) at Comanche Peak evidenced apparent fretting somewhat more pronounced, to PNL's observers, than that observed at Catawba.

There is some uncertainty, also, on the required amount of 'tooth' contact area to be expected in a proper fit, and just how the lapping and 'bluing' is to be properly achieved. ('Bluing' is a process of using a thin surface coating of a chemical which, when pressed or rubbed against a mating surface, will be removed where contact is achieved.)

In light of these points, PNL recommends a degree of surveillance somewhat more conservative than that proposed by Duke (viz, at the first refueling outage, generally expected to be at 18 months of operation and, by Duke's own estimate, involving up to 50 starts and 200 hours of operation).

PNL Recommendation

PNL recommends visual surface inspection and bolt preload check at 200 hours of operation or 9 months, whichever occurs first.

This should conservatively address the Final Safety Analysis Report load levels (for LOOP or LOCA events) for Catawba's units, as well as all pre-operational 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.

### 7.1.4 Lube Oil Checks

These 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). Upon further consideration of likely operating patterns at Catawba, PNL and its consultants

agree that weekly sampling is not warranted. However, PNL does not believe that Duke's proposed 6-month intervals between contaminant analyses is frequent enough to avoid possible problems.

PNL Recommendation

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 bar-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 while the engine is running, immediately prior to shutdown.
- Check differential pressure across all filters and strainers hourly during engine operation.

### 7.1.5 Studs and Fixtures

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 Catawba in this regard warrants a less rigorous schedule of checking, which, as proposed by Duke, will reduce engine downtime while head covers are off.

PNL Recommendation

PNL concurs with Duke's proposal for 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 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.)

### 7.1.6 Push Rods, Cams, Etc.

Engine operability is affected by defects in push rods, cams, tappets, and other similar components and their supporting structures. Some of these components at Catawba have suffered damage. 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 Duke proposal (at the first refueling outage, estimated by Duke to involve 50 to 200 hours of operation) is not considered significant in light of the low wear rate or limited likelihood of structural failure for these components, because all parts will have been inspected recently, and because, 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 Duke proposal.

PNL Recommendation

PNL considers the Duke proposal acceptable.

### 7.1.7 Lube Oil Pressure Drop

The NRC guidance called for the pressure drop across the filters to be checked daily, during engine standby, and hourly during operation. Duke contends that during standby there is little opportunity for contaminants to develop so as to plug the filters, and that only low, keep-warm flow is involved so that a significant pressure drop is not likely. Although this view is relatively valid, it does not reflect two factors:

- 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 (as proposed by Duke) is not deemed significant; the latter is considered acceptable.

PNL Recommendation

PNL recommends a weekly check of oil filter pressure drop during standby. The hourly check during sustained engine operation remains important, for comparable reasons.

7.1.8 Crankshaft Deflection Checks

Three purposes are accomplished in crankshaft deflection checks:

- detection of changes in shaft configuration, such as a developing crack in a web or journal
- 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 indeed change shape with prolonged engine operation, tending to hump toward the middle due to thermal growth, which must be reflected in appropriately shimming the engine. It may also undergo long-term permanent change as chemical processes continue within the concrete.)

The NRC guidance was for checks each 6 months, the hot-deflection check being completed within 15 minutes of engine shutdown. Duke has counterproposed a check at each refueling outage, to be completed within 4 hours of engine shutdown. Such an interval would increase total engine availability, of course.

PNL Recommendations

Reflecting all considerations, PNL recommends the following pattern:

- Take hot and cold deflection readings at every refueling outage (as proposed by Duke). PNL's consultants deem it unlikely that the expected hours and character of operation in the longer period will raise the risks significantly.

- 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, and starting with the last throw of the engine (generator end). Such a schedule, although strenuous, is deemed achievable.

### 7.1.9 Monitoring Exhaust Temperatures

NRC's guidance was for continuous monitoring and hourly recording of engine exhaust temperatures, including pre-turbine temperatures. Duke has proposed continuous recording, but with no mention of pre-turbine (inlet) temperatures. [However, in an August 1, 1984, letter to NRC following onsite discussions on July 26, 1984, Duke has agreed to make provision for pre-turbine temperature checks in addition to cylinder exhaust temperature and turbine outlet (stack) temperature, as is already being done.]

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" temperature thereat 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 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 such engines as at Catawba 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).

- While vanes have not been found missing on the Catawba turbochargers, they have been noted elsewhere on similar nuclear engines. Because the mechanism of the vanes' disappearances has not been identified with certainty, it is important to avoid influences toward thermally-induced failures.

PNL Recommendation

PNL recommends continuous monitoring and hourly recording of turbine inlet exhaust gas temperatures.

#### 7.1.10 Surveillance of Operating Parameters

Surveillance of a number of key engine operating parameters is essential to assuring reliable engine performance. The initial NRC guidance and the Duke proposed surveillance generally are quite similar.

PNL Recommendation

The Duke proposals are deemed acceptable, with the clarification that engine lube oil and jacket water temperatures continuously recorded should be discharge temperatures, and that the inlet temperatures should also be monitored, with hourly recording.

#### 7.1.11 Other Inspection and Surveillance

In its letter of July 16, 1984, Duke includes Table 1, which lists its proposed "Periodic Inspection, Maintenance and Surveillance Schedule". In general, it reflects sound and acceptable patterns. However, to incorporate the recommendations herein above, some will need to be modified in the final Duke plan. This includes several components that are categorized as needing surveillance or maintenance only every 10 years. PNL does not deem this to be

an acceptable frequency for these, considering the nature of the component, the overall TDI-owner history of problems and indications, and the analyses (to date) of known issues.

PNL Recommendation

Until DR/QR resolution is achieved on all these items and/or until further field experience justifies a longer interval such as Duke proposes, PNL comments and recommends sampling inspections as follows:

| Part No. | Part Name | Remarks/PNL Recommendations |
|---|---|---|
| 02-305D | Main bearing caps | Disassemble two caps and visually inspect at first refueling |
| 02-310B | Crankshaft bearing shells | Visual and RT of two highly loaded bearing sets at first refueling |
| 02-340B | Connecting rod bearing shells | Dimensional, visual, and RT of bearing shells at first refueling |
| 02-341A | Pistons | Disassemble four pistons and inspect visually and with magnetic particle detection at first refueling |
| 02-360A | Cylinder heads | Remove four heads and inspect visually and with liquid penetrant at first refueling |
| 02-390A,B<br>02-362A | Rocker arms<br>Rocker box assemblies | Visually inspect rockers and supports monthly and check capscrew preloads on four heads at first refueling. |
| 02-315A | Cylinder block | Inspect top surface visually monthly in accessible areas. Remove four heads and inspect areas at liner landings and head studs visually and with liquid penetrant at first refueling. |
| 02-315C | Cylinder liner | Inspect liner surfaces, four cylinders, for surface scuffing or scratching and other signs of lubrication problems at first refueling. |

Assuming the turbocharger prelube system as finally developed is deemed adequate by NRC, the 5-year inspection plan proposed by Duke is acceptable. Otherwise, at least one turbocharger per engine should be inspected at the first refueling outage.

## 7.2 PNL CONCLUSIONS

PNL concludes that the Duke proposed M/S activities need some modification to provide adequate assurance of engine reliability/operability. Those recommendations, with supporting rationale, are fully delineated above. With those modifications, the Duke proposed M/S program is considered acceptable through the first refueling cycle. As the OGPP and related M/S activities become fully developed and accepted by NRC, it may be appropriate for Duke to modify their plan still further.

# 8.0 OVERALL CONCLUSIONS

## 8.1 GENERAL CONCLUSION

In general, PNL and its consultants conclude that the two TDI DSRV-16-4 diesel engines in Catawba Nuclear 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 on the 1A engine, and upon the premise that test and inspection results on the 1B engine will prove that it is comparable to the 1A engine. It also reflects PNL's current knowledge and evaluation of the ongoing Owners' Group investigation on specific, generic component issues. Further, it is necessarily contingent upon satisfactory completion of all actions recommended in this TER and upon final reassembly of both engines with satisfactory return-to-service test results, as well as on the assumption that the Catawba-specific DR/QR investigations will further confirm operability and reliability of key components.

## 8.2 LONG-TERM APPLICABILITY

In Section 1.2 of this TER, PNL expressed its opinion and rationale that it cannot responsibly reach unconstrained conclusions on the operability and reliability of the Catawba 1A and 1B standby engines. Hence, throughout this report, PNL has expressed its conclusions in such terms as "until the first reactor refueling outage". These conclusions have been predicated upon all evidence available to PNL, including preliminary elements of the OGPP and the Duke DR/QR analyses as applicable to these specific engines. As these analyses are completed and appropriately implemented, and as 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. Until that time, however, the suggested time constraint is deemed essential.

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

## 8.3 KEY CONSIDERATIONS

The conclusion stated in Section 8.1 reflects PNL's careful evaluation of all known considerations. Specific considerations have been addressed in Sections 3 through 7 of this TER and reference should be made thereto for PNL's component-specific conclusions and recommendations.

Certain key considerations warrant emphasis, however.

- Should remaining inspections, return-to-service testing, or DR/QR analyses at Catawba or functional occurrences in other plants, reveal adverse conditions or results not currently expected, modification of this general conclusion may be warranted.
- The conclusion presumes that relevant emergency loads will not require the Catawba engines to operate under other than momentary loads exceeding 185 psig BMEP.
- Duke must implement and rigorously control a plan of regularly barring-over the engines to check for cylinder head water leaks.
- An improved, successful turbocharger prelubrication system must be devised and installed.
- An improved right-bank turbocharger-to-intercooler connection must be devised and installed.
- Duke must appropriately revise its surveillance and maintenance program to achieve the objectives set out in Section 7 of this TER.

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Enclosure 2

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August 10, 1984

Mr. Carl Berlinger
Division of Licensing
Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

Dear Mr. Berlinger:

SUBJECT: "REVIEW AND EVALUATION OF TRANSAMERICA DELAVAL, INC., DIESEL ENGINE RELIABILITY AND OPERABILITY - CATAWBA NUCLEAR STATION UNIT 1", PNL Report No. 5211, prepared for U.S. Nuclear Regulatory Commission by Pacific Northwest Laboratory, August 1984

In Section 7.1.3 of the subject document, PNL recommended a visual surface inspection and bolt preload check of the connecting rods at 200 hours of operation or 9 months, whichever occurs first. This is consistent with an earlier recommendation made by PNL for the diesel engines at Grand Gulf. However, the engines at Catawba are equipped with connecting rods of a later design than those at Grand Gulf. In a report on connecting rods prepared for the TDI Diesel Generator Owners' Group, Failure Analysis Associates concluded that the later design has an 8% to 9% higher margin of safety than the earlier design, because the rod box structure is more massive.

Accordingly, PNL has reconsidered its recommendation for surveillance of connecting rods in the engines at Catawba. PNL now recommends a visual surface inspection and bolt preload check of these connecting rods at 200 hours of operation or 18 months, whichever comes first. Per discussions with M. Miller of the NRC staff, we understand that this new recommendation has been incorporated into the Catawba SER.

PNL consultants B. J. Kirkwood, P. J. Louzecky, J. E. Horner, and A. J. Henriksen, who participated in the preparation of the subject report, concur with this new recommendation. If further clarification is needed, please give me a call at (509) 375-2332.

Sincerely,

J F Nesbitt

J. F. Nesbitt
PNL Diesel Engine O/R Project

Concurrence: W. W. Laity
W. W. Laity
PNL Project Manager

JFN:ri
cc: M. Miller, NRC
A. J. Henriksen
J. E. Horner
B. J. Kirkwood
P. J. Louzecky

Attachment 4

# SAFETY EVALUATION REPORT

# RELIABILITY OF DIESEL GENERATORS

# MANUFACTURED BY TRANSAMERICA DELAVAL, INC.

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## 1.0 INTRODUCTION

In support of its request for an operating license for Comanche Peak Steam Electric Station (CPSES) Unit 1, Texas Utilities Generating Company (TUGCo; the applicant) has provided submittals listed below which describe actions taken by TUGCo and proposed future actions to ensure the reliability of the diesel generators at CPSES Unit 1.

1) Letter dated April 30, 1984, from George to Denton, SUBJECT: Comanche Peak Steam Electric Station Diesel Generator Requalification Program Plan.

2) Letter dated June 7, 1984, from George to Ippolito, SUBJECT: Inspection Results of the CPSES Unit 1 Train A Diesel Generator (1A).

3) Letter dated June 29, 1984, from George to Ippolito, SUBJECT: Inspection Results of the CPSES Unit 1 Train B Diesel Generator (1B).

4) Letter dated August 1, 1984, from George to Youngblood, SUBJECT: CPSES Diesel Generator Preventive Maintenance/Surveillance Schedules and Texas Utilities Responses to the Phase I Recommendations of the TDI Diesel Generator Owners Group.

5) Letter dated August 15, 1984, from George to Youngblood, SUBJECT: CPSES Unit 1, Comprehensive Report on the CPSES Diesel Generator Requalification Program.

6) Letter dated August 17, 1984, from George to Youngblood, SUBJECT: Errata Sheet for Comprehensive Report on the CPSES Diesel Generator Requalification Program for Unit 1.

The staff has issued a generic Safety Evaluation Report (SER), dated August 13, 1984, on the Owners Group Program Plan. The generic SER addresses the resolution of known problems, the design review/quality revalidation program, engine testing and inspections, maintenance and surveillance and administrative controls that are necessary to assure diesel engine reliability. The generic SER also sets forth diesel engine requirements for owners seeking to operate their plants prior to completion of the Owners Group Program Plan.

## 2.0 BACKGROUND

Concerns regarding the reliability of large bore, medium speed diesel generators of the type supplied by TDI at CPSES Unit 1 and at fifteen (15) other domestic nuclear plants were first prompted by a crankshaft failure at Shoreham in August 1983. However, a broad pattern of deficiencies in critical engine

components have since become evident at Shoreham, Grand Gulf Unit 1 and at other nuclear and non-nuclear facilities employing TDI diesel generators. These deficiencies stem from inadequancies in design, manufacture and QA/QC by TDI.

In response to these problems, thirteen U.S. nuclear utility owners, including the applicant, formed a TDI Diesel Generator Owners Group to address operational and regulatory issues relative to diesel generator sets used for standby emergency power. The Owners Group program, which was initiated in October 1983, embodies three major efforts.

1. Resolution of 16 known generic problem areas (Phase I program) intended by the Owners Group to serve as an interim basis for the licensing of plants.

2. Design review of important engine components and quality revalidation of important attributes for selected engine components (Phase II program).

3. Identification of any needed additional engine testing or inspections, based on findings stemming from the Phase I and II programs.

Although the total program has not yet been completed, most of the work leading to completion of Phase I has been performed.

This SER and PNL's TER precede completion of the Owners Group Program (OGP) and staff review of the Owners Group findings. The staff intends to issue an SER on each of the 16 generic components that have been reviewed in Phase 1 of the OGP. Phase 2 of the OGP, a plant-specific design review/quality revalidation of all engine components recessary for engine operability, has not been submitted for Comanche Peak, Unit 1. The staff, with PNL assistance, will evaluate the Phase 2 reports and issue a plant-specific SER documenting its findings. The staff's conclusions regarding interim licensing of CPSES, Unit 1 pending completion of the items just described are given in this SER. The staff's position relating to interim licensing has been previously delineated in the staff's generic SER, dated August 13, 1984, on the OGP. Conclusions reached in this report are based on actions taken thus far by Texas Utilities Generating Company (TUGCo) to enhance the reliability of the diesels, the results of recent diesel inspections, an enhanced maintenance and surveillance program, operating restrictions and staff/PNL review of the current status of the TDI Owners Group Program in resolving the TDI engine issue.

The 1A and 1B engines at CPSES Unit 1 were disassembled during February and March of 1984 for the purpose of replacing type AH pistons with new type AE pistons. In anticipation of the Owners Group recommendations regarding engine inspections, the applicant decided to fully disassemble both engines and perform detailed examinations. During the course of the inspection, many components were replaced either because unacceptable flaws were found, newer component designs existed, or because minor, non-critical flaws were noted.

The diesel generators at CPSES Unit 1 have a continuous rating of 7000 kw and a two hour overload rating of 7700 kw. The engines are DSRV-16-4 models with 16 cylinders arranged in a "vee" along the crankshaft.

## 3.0 EVALUATION

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

The staff, PNL, and its consultants reviewed the applicant's submittals listed in Section 1.0 and have performed an onsite inspection of key engine components in May 1984, while the Train B engine was disassembled.

The staff has reviewed the enclosed TER, and adopts the TER as part of this Safety Evaluation by reference.

The February and March 1984 inspection results of engine components and resultant actions taken by TUGCo, indicates that the components in the reassembled engines are acceptable for nuclear service for the interim period to the first refueling of CPSES Unit 1. This finding is subject to a) operating restrictions as identified in Section 3.4 of this SER, b) successful completion of commitments made by the applicant described in Section 4.0, and c) successful completion of additional actions required by the staff, also described in Section 4.0.

### 3.1 Inspections and Results

Detailed inspections were performed on all Phase 1 components except for the high pressure fuel oil tubing, which will be replaced with shrouded tubing and inspected per Owners Group Criteria prior to installation before fuel load, and the engine mounted electrical cable which has been previously replaced with qualified cable. The inspections varied depending on the component but included visual, dimensional verification, material comparator testing, liquid penetrant, magnetic particle, ultrasonic, radiography and eddy-current. The inspections utilized acceptance criteria established by the Owners Group where available or criteria thought to be conservative by TUGCo where Owners Group criteria did not exist or was not fully detailed. Inspections performed on Phase ' components of the Train A engine were duplicated on the Train B engine whereas the Phase 2 components inspected varied between engines. In general, inspections performed on disassembled components were also performed on any replacement parts.

3.1.1 Phase 1 Components

The most significant results of these inspections are an indication on the Train A main bearing saddle, block cracking in the liner landing area of both Trains A and B, and excessively worn turbochargers, most notably the thrust bearings in both Trains A and B. All cylinder heads, push rods and piston skirts were replaced with improved versions of the same component.

Linear indications were found on the Train A main bearing saddles of journals 1, 3 and 9 during visual and liquid penetrant inspection. The Owners Group has concluded that the indications on journals 1 and 9 are acceptable, minor casting flaws. Final disposition of the indication found on journal number 3 has not yet been completed by the Owners Group; however, preliminary results are that the indication is acceptable since a large factor of safety exists against crack propagation. The indication is approximately 1/8" long by 1/32" wide and is located in a corner away from the crankshaft on the horizontal surface of the main bearing saddle. The staff will require that the final evaluation of the number 3 saddle indication and the bases for the conclusions reached on saddles 1 and 9 be submitted prior to exceeding 5% power.

Linear indications were found on the liner landing areas of cylinders 4R, 5R and 6L on Train A and on the liner landing areas of cylinders 1R, 4R and 5R of Train B. The Train A indication on 6L is located on the vertical face of the liner landing "lip." It was examined using eddy-current techniques and found to be non-relevant since no depth could be determined. The Train A indications on 4R and 5R extended along the vertical and top horizontal surfaces of the liner landing "lip" and the vertical surface of the block above the "lip." These indications did not, however, extend to the block top nor did they extend between the cylinder stud hole and the cylinder counterbore. Since they did not extend between the cylinder stud hole and cylinder counterbore, they are not ligament cracks as defined by the Owners Group; however, in order to define future block inspections, they are considered by TUGCo as though they are ligament cracks. Indications on Train B cylinders 1R, 4R and 5R were evaluated by eddy-current techniques. All were located on the vertical face of the liner landing "lip" and concluded to be rounded and non-propagating with the exception of two indications on cylinders 1R and 4R. Both indications were examined with 10x magnification and it was concluded that they are a result of the casting process. The above indications (i.e., 1R, 4R on Train B and 4R, 5R on Train A) are formally under evaluation by the Owners Group pending release of the Phase 2 report; however, block cracking has been analyzed by the Owners Group generically a part of Phase 1. Conclusions reached in that generic evaluation are that the block is satisfactory provided no cracks exist between stud holes of adjacent cylinders and that periodic examinations of the block be performed. No cracks between studs of adjacent cylinders have been found at CPSES Unit 1. Based on its review and the enclosed TER, the staff concludes that the blocks at CPSES Unit 1 will perform satisfactorily through the first refueling cycle. This finding is subject to (1) an engine load limit of 185 BMEP as discussed in Section 3.4 below, (2) TUGCo submittal

of an acceptable maintenance and surveillance program as identiifed in Section 3.3 below and (3) final disposition of indications that are under review by the Owners Group. The staff also understands that TUGCo will submit supplemental report(s) by the Owners Group concerning cylinder block strain gage and metallurgical tests as discussed in Section 10.0 of TUGCo's August 15, 1984 submittal.

All four turbochargers (2 per engine) were inspected and found to have numerous nicks and gouges on turbine and fan blades. Most notably, all four thrust bearings were found to be scratched, scored and excessively worn. On Train A, the rotor assemblies, including thrust collars and bearings were replaced on both turbochargers. On Train B, the entire right bank turbocharger was replaced with a spare and appropriate repairs and replacements were made to the left bank turbocharger. Preliminary conclusions reached by the Owners Group are that worn thrust bearings are a result of quick starts without adequate prelubrication and recommends that auxiliary full-flow lube pumps be installed and operated prior to planned starts and that a drip lube system be installed to minimize wear on unplanned starts. CPSES Unit 1 has had the auxiliary full-flow pump installed prior to performance of any preoperational testing, however, the pump was not used prior to planned starts. Sites that have used the auxiliary full-flow pump prior to planned starts (i.e., Grand Gulf, San Onofre) have not experienced any unusual wear. The starts that have occurred at CPSES Unit 1 after the recent engine inspection and reassembly have included thrust bearing pre-lube via the auxiliary full-flow pump prior to the start. TUGCo has committed to follow the Owners Group recommendations to provide adequate lubrication via the auxiliary pump prior to planned starts and to modify their drip lube system prior to fuel load to minimize wear during unplanned starts. Additionally, TUGCo has committed to follow Owners Group recommendations regarding turbocharger inspection intervals based on number of engine starts and will inspect the thrust bearing of one turbocharger at the first refueling shutdown even if the number of starts accumulated on a diesel is less than that recommended by the Owners Group. Based on these commitments and commitments to other Owners Group recommendations regarding the turbocharger, the staff concludes that the turbochargers will perform adequately through the first cycle of operation.

During the recent disassembly, TUGCo replaced Type AH piston skirts which were originally installed in the engine with Type AE skirts. Although none of the type AH skirts had failed at CPSES, TUGCo felt that the AH skirts were similar to Type AF skirts which have developed cracks at other installations. By analysis, the AE skirts are superior to the AF skirts. Additionally, no reported failures have occurred on similar type AE skirts in the R-5 engine test which included approximately 600 hours of operation at higher loads than th se postulated to occur at CPSES Unit 1.

During the inspection, three rejectable indications were found on "ball-end" pushrods, and as a result, TUGCo replaced all pushrods with "friction-welded" rods. The "friction-welded" rods have been analyzed and tested by the Owners Group with acceptable results.

TUGCo also elected to replace all 32 originally installed cylinder heads (non-Group III) with heads designated as Group III. Group III heads incorporate design changes to improve casting control and other quality control improvements. Most instances of cracked heads in TDI engines have involved Group I. Inspections performed on heads removed from Train A resulted in three heads having firedeck thicknesses below the minimum specified by the Owners Group.

3.1.2 Phase 2 Components

Of the Phase 2 components inspected that were found to be unsatisfactory on at least one engine, the staff judged camshaft bolting, turbocharger support bolting, main bearing shells, rocker arms and subcovers, intake and exhaust valves, intake manifold flanges and starting air distributors to be components whose failure could significantly affect engine operability/reliability. Through a combination of information provided in the licensee's August 15, 1984 submittal, discussions with the licensee, and the judgment of PNL diesel consultants, the staff concludes that appropriate actions have been taken, where necessary, to insure the reliability of the above components. However, the staff will require that the starting air distributor on the Train B engine be inspected in light of the wear found on the Train A starting air distributor coupled with the relatively short service life experienced. The action must be performed and the results reported to the staff before exceeding 5% power.

3.2 <u>Preoperational Testing</u>

Prior to disassembly and inspection, each diesel had been run for approximately 92 hours (including factory run times of 6 hours and 50 minutes for Train A and 6 hours and 35 minutes for Train B) at varying loads that averaged between 62 and 63 percent of continuous rated output. During this preoperational testing, the Train A and B engines had been started 67 and 83 times onsite, respectively. Included in the starting and run times was the successful completion of testing required by Regulatory Guide 1.108, Revision 1. The only instances of unsatisfactory engine response during these preoperational tests occurred during the first and third test of the Train A engine. These instances involved (1) blown fuses from a defective light bulb in the standby voltage regulator and (2) a foot valve installed incorrectly by the manufacturer which resulted in low oil pressure.

Following engine disassembly, inspection, and subsequent reassembly, preoperational tests specified in NRC Regulatory Guide 1.108, Revision 1, as modified in the staff's letter of August 2, 1984, were again performed. These tests included additional tests specified by the staff in that same letter, namely:

1) Ten modified starts to 40% load.

2) Two fast starts to a load greater than or equal to the maximum emergency loads the engines are predicted to experience but not greater than a load corresponding to 185 psig brake mean effective pressure (BMEP).

3) One 24 hour run at a load greater than or equal to the maximum emergency loads the engines are predicted to experience but not greater than a load corresponding to 185 psig BMEP.

The licensee reports that 45 starts were performed on Train A and 54 on Train B during the post inspection testing. During these tests, one of the fuel injection pumps on the Train A engine failed and was replaced. The cause of failure is under investigation by TUGCo, however, preliminary indications are that the bolts on the top of the pump were improperly torqued by the vendor after refurbishment. Also, the phase metering potential for the Train A engine was lost due to failed solder joints on screw-in type fuse holders. All screw-in fuse holders were subsequently replaced by cartridge-type fuse holders. The staff found no unusual failures in the post inspection testing and believes that the failures reported are routine and that the actions taken by TUGCo are appropriate. The staff will require that final evaluation of the failed fuel injection pump as well as the supplemental report describing preoperational test results be submitted to the staff prior to exceeding 5% power. The supplemental report should verify that the fuel injection pumps on both engines were checked for proper torque and document any failures to start along with the diagnosed cause, and the corrective action taken.

### 3.3 Augmented Maintenance and Surveillance Program

PNL concluded in the enclosed TER that modifications to the Augmented Maintenance/Surveillance Program proposed by the applicant in their August 15, 1984 submittal are needed to provide adequate assurance of continued engine reliability/operability. In the applicant's submittal, maintenance and inspections of certain components that the staff believes should be inspected periodically was not addressed. Additionally, the proposed maintenance or maintenance intervals of certain components was not acceptable to the staff and should be revised by TUGCo. These modifications are discussed in detail in Section 5 of the enclosed TER.

Accordingly, the staff is requiring that TUGCo submit a revised Augmented Maintenance/Surveillance Program incorporating the modifications identified in Section 5 of the enclosed TER. (PNL recommended modifications in Table 5.2 of the enclosed TER are excepted from this requirement; however, the staff suggests that the recommendations in that Table should be carefully considered by TUGCo, consistent with good engineering judgment, in establishing their program.) The revised program must be submitted for NRC review prior to plant operation in excess of 5% power.

Items requiring maintenance and inspection that were not included in the licensee's August 15, 1984 submittal or require revision are:

1. Engine base/engine block
2. Connecting rods
3. Pistons
4. Cylinder heads
5. Studs and fixtures

6. Crankshaft deflection checks
7. Main bearing shells
8. Connecting rod bearing shells
9. Cylinder liners
10. Jacket water pumps
11. Lube oil check

Engine surveillance data to be monitored during operation that was not included in the applicant's proposal and deemed necessary by the staff are:

| Item | Staff Guidance |
|---|---|
| 1. Exhaust Temperature Inlet to Turbo (RB, LB) | Log every 60 minutes |
| 2. Intake manifold Air Pressure (RB, LB) | Log every 60 minutes |
| 3. Intake manifold Air Temperature (RB, LB) | Log every 60 minutes |
| 4. Visual Inspection for Leaks | Check hourly |

Revisions to the standby surveillance data proposed by the licensee that are required by the staff are: 1) the differential pressure of the keepwarm oil filter be monitored weekly and 2) testing of the jacket water for pH, conductivity and corrosion inhibitor be performed after adding make-up water or monthly

The applicant has informed the staff that the Owners Group will soon issue a comprehensive maintenance/surveillance plan and that TUGCo plans to adopt it, as appropriate, to supersede their current proposal. In light of this, the above staff requirements regarding maintenance/surveillance may be revised after staff review of the Owners Group maintenance/surveillance plan.

### 3.4 Operating Restrictions

PNL recommendations and conclusions regarding TDI diesel engine reliability at CPSES Unit 1 are predicated on the following assumptions:

1. The emergency service requirements the applicant currently forsees for CPSES Unit 1 will not exceed engine load corresponding to a brake mean effective pressure (BMEP) of 185 psig. The need for this assumption is based on PNL concerns regarding the acceptability of crankshaft stresses and AE piston skirt stresses at higher BMEP loadings, and because of open items in the implementation of the Owners Group Program Plan.

2. All future engine testing, including surveillance testing required by the plant Technical Specifications, will be limited to within ±5% of the nominal engine load where the upper limit of this load range corresponds to a BMEP of 185 psig.

3. In the absence of the Owners Group completing all elements of their program plan, PNL's conclusions are plant-specific, applying only to CPSES Unit 1 and are applicable only during its first reactor refueling cycle. It is understood by PNL that at the first refueling, the applicant will implement all applicable recommendations of the Owners Group and staff.

Regarding item (1), the applicant has calculated that 185 psig BMEP corresponds to a generator load of 5980kw at CPSES Unit 1. As noted in Section 6.1.1 of the enclosed TER, PNL finds that this evaluation did not consider the generator efficiency. Using an estimated efficiency of 0.96, PNL calculated that the 185 psig BMEP limit corresponds to 5740 kw. The staff, therefore, concludes that the appropriate load limitation is 5740 kw. The applicant has reported that the maximum emergency service load requirements are 4200kw for the Train A diesel and 4350kw for the Train B diesel, both of which occur for the design basis accident conditions (LOCA) coincident with loss of offsite power (LOOP).

The loads were obtained from actual readings taken in the control room as sequencing of actual emergency service loads onto the diesels was performed for LOOP and LOOP/LOCA conditions during the recently completed post inspection testing. Thus, there exists sufficient engine capacity at 185 psig BMEP to assure that the fuel design limits and design conditions of the reactor coolant pressure boundary are not exceeded and that the core is cooled and containment integrity and other vital functions are maintained in the event of postulated accidents as required by GDC-17. However, the applicant should submit a revision to the CPSES FSAR, as appropriate, to demonstrate that the maximum emergency load requirements are within the 5740 kw load limitations being placed on the engines.

With regard to item (2), the applicant has committed to change the Technical Specifications to limit monthly and 18 month diesel generator surveillance testing to a load corresponding to 185 psig BMEP, which the staff concludes is 5740Kw. The testing shall also be performed at a load which envelopes the maximum emergency service load requirements of 4200kw and 4350kw. The staff will require that the applicant modify the loss of offsite power procedures to assure that the engines are not unnecessarily loaded above a load corresponding to 185 psig BMEP. Future operator training with respect to this procedure should explain the basis for the restriction and aspects to be taken into consideration in its application.

With regard to item (3) above, the staff will include the following license condition in the operating licensee:

> Final evaluations and recommendations from the TDI Owners Group Program applicable to Comanche Peak, Unit 1 and the licensee's actions in response to this program for the Train A and B diesel generators, shall be submitted for the NRC review and approval before plant restart from the first refueling outage.

## 4.0 CONCLUSION

The NRC staff concludes that the TDI diesel engines at CPSES Unit 1 will provide a reliable standby source of onsite power in accordance with General Design Criterion 17. This finding is based upon the NRC staff/PNL review of (a) the current status of the TDI Owners Group Program in resolving the TDI diesel engine issue; (b) actions taken by the applicant to enhance and verify the reliability of the Train A and B engines, (c) an acceptable Augmented Engine Maintenance and Surveillance Program as identified in Section 3.3 of this SER, and (d) operating restrictions to limit future operation and testing of the engines to 185 psig BMEP. The finding is contingent upon successful completion of actions listed below and is subject to the license condition given in Section 3.4 which assures that Comanche Peak Unit 1 will continue to meet GDC 17 beyond the first refueling outage. Items required to be submitted prior to exceeding 5% power are viewed by the staff to be confirmatory in nature since the results, when submitted, are not expected to alter present staff conclusions. In many instances, preliminary results at CPSES Unit 1 or information obtained from other sites indicate that these results will prove to be satisfactory when completed.

In the August 15, 1984 submittal, the applicant has identified items to be completed prior to fuel load. The applicant has subsequently modified its commitment such that the following items now will be completed prior to fuel load:

1. Crankshaft main journal hole inspection for both engines.
2. Torsiograph test for one engine.
3. Evaluation by the Owners Group of the TDI recommendation for running of crankshafts for 15 min. at 150 rpm following each major overhaul, in light of Owners Group recommendation to run at 450 rpm at all times.
4. Review by TUGCo of an additional Phase 1 supplementary report by the Owners Group on cylinder block strain gage testing on Train A at CPSES.
5. Review by TUGCo of an additional Phase 1 supplementary report by the Owners Group cylinder block metallurgical testing at all sites.
6. Establishment of CPSES Unit 1 cylinder block top eddy-current inspection intervals based on (5).
7. Installation of shrouded SAE-1010 high pressure fuel oil injection tubing for both CPSES engines.
8. Eddy-current testing of this tubing.
9. High pressure fuel oil tubing support modification.

10. Review by TUGCo of an additional Phase 1 supplementary report by the Owners Group on connecting rod strain gage testing at another site.

11. Evaluation of CPSES connecting rod inspection requirements based on (1).

12. Modification of turbocharger lube oil drip systems to TDI recommendations.

13. Replacement of 16 remaining original exhaust manifold bolts on Train B with new TDI socket head type bolts.

14. Replacement of pneumatic tubing for engine protective functions w/ stainless steel tubing.

15. Re-evaluation by the Owners Group of the recommendation for destructive testing of pushrods on a sample basis.

16. Detailed evaluation of CPSES preoperational testing (to be documented in a supplemental report that includes items described in Section 3.2).

17. Material verification of rocker arm and airstart valve capscrews

The applicant has also committed to complete the following prior to exceeding 5% power:

18. Recording of exhaust temperature at turbocharger inlet relative to manufacturer's recommended maxiumum.

19. Visual inspection of newly installed fuel oil injection tubing for leaks during engine operation of both engines.

20. Review by Texas Utilities of an additional Phase 1 supplementary report by the Owners Group on design review of turbocharger vanes and capscrews.

The staff concurs with this commitment by the applicant. The results of items 1, 2, 3, 4, 5, 6, 10, 11, 15, 16, 18, and 20 should be reported to the staff and receive staff approval prior to exceeding 5% power.
The applicant should confirm to the staff that items 7, 8, 9, 12, 13, 14, 17, and 19 have been performed as committed to.

Additionally, the staff will require that the following information be provided:

1. Final disposition of #3 bearing saddle indication; bases for conclusions reached on saddles 1 and 9.

2. Hot and cold crankshaft deflection relative to TDI specifications.

3. Cylinder liner material verification.

4. Final evaluation of TUGCo investigation of the fuel injection pump failure on Train A.

5. Revised maintenance/surveillance program to satisfactorily address the following items:

   a. Engine base/engine block
   b. Connecting rods
   c. Pistons
   d. Cylinder heads
   e. Studs and fixtures
   f. Crankshaft deflection checks
   g. Main bearing shells
   h. Connecting rod bearing shells
   i. Cylinder liners
   j. Jacket water pump
   k. lube oil checks
   l. Exhaust temperature, inlet to turbo
   m. Intake manifold air pressure
   n. Intake manifold air temperature
   o. Visual inspection for leaks
   p. Keepwarm oil filter p during standby
   q. Jacket water test for pH, conductivity, corrosion inhibitor

6. Inspect starting air distributor on Train B engine for excessive wear.

7. Final disposition of block indications that are formally under review by the Owners Group.

Prior to exceeding 5% power, items 1, 4, 5, and 7 must be submitted to the staff and receive staff approval and items 2, 3 and 6 should be confirmed as having been completed with satisfactory results.

The staff will require that the following items be provided and approved by the staff prior to fuel load:

1. Operating procedures to include a precautionary note to the operator to ensure that loads will not be added unnecessarily to the engines which cause the 18[illegible] psig BMEP to be exceeded.

2. Plant Technical Specifications to limit engine surveillance tests to within ±5% of the nominal engine load where the upper limit of this load range corresponds to a BMEP of 185 psig (5740 kw).

3. Revisions to the FSAR, as appropriate, to demonstrate that the maximum emergency service load requirements for the diesel generators are within the 5740 kw load limitation.

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
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Battelle

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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
Division of Licensing
Office of Nuclear Reactor Regulation
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NRC FIN B2963

Project Title: Assessment of Diesel Engine Reliability/Operability

NRC Lead Engineer: C. H. Berlinger

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PACIFIC NORTHWEST LABORATORY

PROJECT APPROVALS

W. W. Laity   Date Sept. 10, 1984

W. W. Laity, Project Manager
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.

CONTENTS

## TABLES

## 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 (Pacif 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 G...erator 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 bedded in half-circle bearings set within "saddles" in the base. The bearing caps are structural members that hold the upper bearing shells in place over the shaft main journals while also absorbing the upward, reciprocating piston inertial loads. The studs and nuts hold the cap (and shaft) in place. A failure of base, cap, or bolting would allow shaft motion or misalignment, 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 (~600 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]].<br><br>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 (02-362A). 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).<br><br>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)]].<br><br>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)]].<br><br>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 unconsequential), 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 (02-3506) 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)<br><br>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)<br><br>Measure/record (every disassembly/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) | Visual (every outage) |
| | | 2) dimensional verification of backlash and thrust (every 2nd refueling 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) | Concur with TUGCO |
| | | 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) | |
| 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 Linka_e | | 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 or 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 Parameterr 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 | --- | ↓ | ↓ |
| 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 C .ES 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 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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ATTACHMENT 5

# TDI DSRV-16 DIESEL GENERATOR ENGINE RATINGS*

| RATING | GRAND GULF (MP&L) | CATAWBA (DUKE) | COMANCHE PEAK (TUGC) | HARRIS (CP&L) |
|---|---|---|---|---|
| Displacement | 76266 $in^3$ | 76266 $in^3$ | 76266 $in^3$ | 76266 $in^3$ |
| KW(design) | 7000 | 7000 | 7000 | 6500 |
| BMEP** | 225 psi | 225 psi | 225 psi | 209 psi |
| BHP*** | 9770 @450 RPM | 9770 @450 RPM | 9783 @450 RPM | 9074 @450 RPM |
| 2 HOUR RATING (KW) | 7700 (110%) | 7700 (110%) | 7700 (110%) | 7150 (110%) |
| MAX.LOAD (safe shutdown) (KW) | 3495(Div.1)<br>3703(Div.2) | 5714 | A - 7019<br>B - 6686 | ****<br>A - 5524<br>B - 5571 |
| (LOCA) KW | 4654(Div.1)<br>3712(Div.2) | 5256 | (safety injection)<br>A - 6355<br>B - 6355<br>(Recirc.)<br>A - 6370<br>B - 6370 | ****<br>A - 5592<br>B - 5598 |

*Information provided by Diesel Generator Owners' Group

**Brake mean effective pressure at maximum load

***Brake horsepower

****These are automatic and manual IE loads from a recent calculation that are not yet reflected in FSAR. These numbers are subject to revision, particularly in taking into account the cancellation of Unit 2.