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UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

ATOMIC SAFETY AND LICENSING BOARD

Before Administrative Judges:

Lawrence Brenner, Chairman
Dr. George A. Ferguson
Dr. Peter A. Morris

In the Matter of	Docket No. 50-322-OL
LONG ISLAND LIGHTING COMPANY	LBP-85-18
(Shoreham Nuclear Power Station, Unit 1)	June 14, 1985

PARTIAL INITIAL DECISION

ON EMERGENCY DIESEL GENERATORS

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APPEARANCES

T. S. Ellis, III, E. Milton Farley, III, Odes L. Stroupe, Jr., Anthony F. Earley, Jr., David Dreifus and John Jay Range, Esquires, of Hunton & Williams, Richmond, Virginia, Washington, DC, and Raleigh, North Carolina, for the Long Island Lighting Company.

Edwin J. Reis, Assistant Chief Hearing Counsel, Richard J. Goddard, Robert G. Perlis and Bernard M. Bordenick, Esquires, Office of the Executive Legal Director, U. S. Nuclear Regulatory Commission, Washington, DC, for the NRC Staff.

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I. INTRODUCTION

A. Background

When this Licensing Board issued the Partial Initial Decision (P.I.D.) in September 1983, we found that all issues in controversy, except one, had been resolved in favor of permitting the Applicant, Long Island Lighting Company (LILCO), to operate the Shoreham Nuclear Power Station, a one unit boiling water reactor located in Suffolk County, New York, at low power levels up to five percent of rated power. 18 NRC 445, 468 (1983). That issue related to certain alleged defects in the three emergency diesel generators (EDGs) manufactured by Transamerica Delaval, Inc. (TDI), and proposed for use on the Shoreham site. These EDGs are required to supply backup emergency electrical power to safely shut down the Shoreham plant in the event of a loss of offsite power (LOOP) in compliance with General Design Criterion 17. 10 C.F.R. Part 50, Appendix A.

Diesel issues were pending at the time of the P.I.D. because of a prior ruling by us, which was followed by a major diesel failure during testing. On June 22, 1983, we had granted, in part, the motion of Intervenor, Suffolk County, New York, to reopen the record and admit a new contention concerning the emergency diesel generators. LBP-83-30, 17 NRC 1132 (1983). A hearing on the low power aspects of the new contention was thereafter scheduled to begin on August 29, 1983. However, on August 12, 1983, the original crankshaft on EDG 102 severed during testing. Inspections revealed cracks in the crankshafts of the other two EDGs, 101 and 103. As a result, the pending hearing was cancelled at the unanimous request of LILCO, the NRC Staff and Suffolk County.

The background history thereafter is lengthy and unnecessary to recount in detail for present purposes. In short, the nuclear power plant owners and the NRC Staff launched into a comprehensive review of TDI diesels. Parts of the review were continuing at the end of the hearing. During the time of those reviews, numerous defects with respect to different components in TDI diesel engines came to light. Prominent among these was a defective cylinder block on the Shoreham EDG 103, which was replaced by LILCO. The Staff and LILCO believed the technical reviews were finally sufficiently complete for the hearing to begin on September 10, 1984, on the four diesel issues then in controversy before us, which involved the crankshaft, cylinder block, cylinder heads and pistons. The diesel hearing began on that date.

As it later turned out, LILCO had not been ready for the hearing to begin when it did. Rather, LILCO apparently wished to change and justify its proposed operation of the diesels to a so-called "qualified load" of 3300 kw, rather than the original 3500 kw continuous rating and 3900 kw two-hour short time rating. LILCO also wished to conduct a 10E7 cycle 740 hour "endurance run" test (taking some credit for previous test hours) along with inspections which had been advocated by the NRC

Staff and Suffolk County. As a result, as the originally contemplated evidentiary hearing drew to a close in November 1984, the Board granted LILCO's motion to reopen and supplement the record, as confirmed in our unpublished Order, dated December 4, 1984. Pursuant to the schedule agreed upon by the parties, the reopened hearing began on February 12, 1985. The record was closed on March 12, 1985. Proposed findings were filed by all parties pursuant to an agreed-upon accelerated schedule, culminating in LILCO's reply findings being filed on May 2, 1985.

B. Summary of Decision

The diesel issues remaining in controversy before us relate to three matters: blocks, crankshafts, and the qualified load proposal. Our decision is divided into these three parts, with the numbered findings beginning with B, C, or L, respectively. With respect to these issues, we find there is reasonable assurance that for the first fuel cycle the TDI EDGs can perform their required safety function, if necessary, at a qualified load level up to 3300 kw, and that operation at such a level will not lead to failure of the crankshaft. We also find that routine required surveillance testing can be conducted at 3300 kw plus or minus 100 kw without leading to failure of the crankshaft, and that an additional cumulative operation time of two hours between 3300 kw and 3400 kw during the first fuel cycle, if necessary, would not cause failure of the crankshaft. Operation above 3400 kw is not permitted because of our findings regarding the crankshafts. With respect to the blocks, we find there is reasonable assurance that the EDGs will not be prevented from performing their safety function of supplying standby electrical power, if needed, due to block top cracks, of which three types were in controversy: so-called ligament, stud-to-stud and circumferential cracks. Insofar as the diesel issues before us are concerned, this decision authorizes the issuance of a full power operating license for the first fuel cycle. However, as noted below, there are still offsite emergency planning issues pending before another Licensing Board. Accordingly, this decision, effective immediately, authorizes the NRC Staff to issue only a low power (up to five percent of rated power) operating license, providing the Staff has made findings supporting such a license on all issues not in controversy.

During the litigation, the parties reached agreements, approved by us, on three issues: cylinder heads (October 30, 1984, Board Diesel Ex. 1 for Ident., ff. Tr. 25,204); pistons (November 14, 1984, Tr. 26,450-58, 26,620-22), and camshaft gallery cracks in the cylinder block (March 7, 1985, ff. Tr. 28,766). We reiterate our commendation of the parties and counsel for their energetic efforts to reach acceptable settlements on the issues in controversy. We think the parties and the public interest have been well served by these settlements. Some of these settlements require conditions, generally related to future monitoring and inspections. The NRC Staff and other responsible parties shall assure that those requirements are properly reflected in the operating license conditions or technical specifications.

The contentions in issue were jointly sponsored by Suffolk County and New York State. Suffolk County (SC or the County) was the lead intervenor at the hearing. As we had required for efficiency, the County and the State coordinated closely their participation and filed joint proposed findings. For brevity, we will refer only to the County in our decision on the joint contentions. The other parties participating were LILCO and the NRC Staff.

There are offsite emergency planning issues in controversy before another Licensing Board which must be resolved in LILCO's favor before a full power operating license could be authorized. At this point, that Board has effectively found against LILCO, but that proceeding is continuing. "Partial Initial Decision on Emergency Planning," LBP-85-12, 21 NRC ____, slip op. at 426 (April 17, 1985). For this reason the effect of our decision is to authorize only a low power license. The Commission has previously rejected the recommendation of this Licensing Board (then consisting of Judges Brenner, Carpenter and Morris), that so long as Suffolk County refused to participate in emergency planning, and that the willingness of New York State to participate was then unclear, a low power license should not be issued unless and until a factual inquiry could support a finding of reasonable assurance that offsite emergency planning, required for a full power license could be developed. LBP-83-21, 17 NRC 593 (1983); CLI-83-17, 17 NRC 1032 (1983). See also Partial Initial Decision, LBP-83-57, 18 NRC 445, 623-33 (1983); CLI-84-9, 19 NRC 1323, 1325-29 (1984).

C. Investigations

We have been informed that the NRC Office of Investigations (OI) has before it a pending investigation of Transamerica Delaval, Inc. We have inquired of OI, through the NRC Staff, on three occasions over the past year, whether anything in their investigation would materially affect the record on the TDI EDGs at Shoreham. We received no helpful information in OI's vague response over a year ago (Memo to G. Cunningham, ELD, from B. Hayes, OI, March 12, 1984), and we received no response from OI to our more recent inquiries on the record of the proceeding. Tr. 28,245-53 (February 21, 1985). Ltr to Board from B. Bordenick, NRC Staff Counsel, February 28, 1985; Tr. 28,408-11 (March 6, 1985); Ltr to Board from B. Bordenick, March 22, 1985. The NRC Staff did assure us that it presented our inquiries to OI as we had requested. Id.

We assume that OI's recent failures to respond are benign and due to some miscommunication of the import of our inquiry and expectation of a response. At the time, we considered taking further action, but decided this could lead to a collateral digression from the complex issues in controversy before us. A Licensing Board fully occupied at trial expects its bench requests to OI, through the only NRC entity present before it, the NRC Staff, to be given the same attention as direct written inquiries and orders. Indeed, Boards sometime use a bench order to permit prompt and fuller explanation of its wishes to avoid an unnecessarily digressive confrontational situation. We expect OI and the NRC Staff to examine the cause of the apparent communication breakdown and to see that it does not recur.

Since we are ignorant of the nature of the information before OI, our decision does not encompass it. OI was, of course, under an obligation to inform us if it had developed information material to the issues in controversy before us.[1/] We therefore deem its silence to

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1/ Mr. Hayes' memo of March 12, 1984, states:

> The Office of Investigations (OI) has opened an investigation concerning Transamerica Delaval Incorporated and the Commissioners have been apprised of this investigation being initiated. However, due to limited resources and other priority commitments, actual field work has not commenced and a realistic estimated completion date cannot be ascertained at this juncture.
>
> In accordance with OI policy, we are unable to reveal the particulars of the various allegations, however, they appear to be generic rather than site specific. If safety significant information is developed which impacts on Shoreham or any other facility, OI will make appropriate notifications to cognizant NRC staff members.

(Footnote Continued)

mean that it had no such information. If this is incorrect, OI shall immediately notify the Appeal Board and the Commission. We also note that OI stated that the Commission was informed about the pending investigation by OI. This gives us confidence that the Commission, by not stepping in while knowing we were approaching a decision on the diesel issues, believes there is no information before OI which forms a basis to prohibit reliance on the TDI diesels at Shoreham.

During the course of the prehearing and hearing stages of this case, information has been publicly filed, or testified to by parties, which we believe provides a basis for the Commission to investigate whether TDI has violated its legal obligations to report potential defects in its diesels being proposed or used for backup emergency electrical power at nuclear power plants. E.g., Section 206, Energy Reorganization Act of 1974, 42 USC § 5846; 10 C.F.R. Part 21. Some of this information related to an apparent failure by TDI to disclose potential defects as recently as the August-September 1984 time-frame of the filing of testimony and the beginning of this hearing. We emphasize that none of the information we have in mind undercuts the findings in our decision, or provides a basis to believe that there are existing

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(Footnote Continued)
Staff Counsel's letter to the Board of February 28, 1985, states that as of that time, a year later, OI verbally informed the Staff that there was no change in the status of this investigation; i.e., the investigation is "opened" but no work has been done on it.

defects in the TDI diesels at Shoreham. However, given the Commission's extensive reliance on self-reporting and inspections by vendors and licensees, we believe that possible violation of reporting requirements by TDI is a serious matter with respect to the integrity of the Commission's overall regulatory responsibilities. We recommend that the Commission direct OI or another appropriate NRC Staff or Commission entity to investigate whether TDI has violated reporting requirements, and, if so, what enforcement or other action is required.

The parties in the proceeding before us, particularly LILCO and its consultants, are knowledgeable sources of the information regarding apparent nonreporting by TDI which we are mindful of through the public filings before us, and perhaps of additional instances of apparent nonreporting. We choose not to catalogue the apparent instances in this decision. If the Commission accepts our recommendation, we are willing, after our jurisdiction terminates, to point the investigating body to the public information filed with us which contains examples of apparent nonreporting. We do note that the apparent nonreporting of defects by TDI has been a concern pursued by the NRC Staff several times, but each time there were subsequent assurances by TDI that all matters had then been reported. See, e.g., Region I Report No. 50-322/83-17, at 10 (July 8, 1983); Region IV (vendor) Report No. 99900334/83-01, Notice of Violation by TDI (Oct. 3, 1983); 1984 Region I Systematic Appraisal of Licensee Performance (SALP) Report, at 14 (May 8, 1984); Region I Report

No. 50-322/84-37, at 2 (November 28, 1984). Thereafter, additional instances of apparent nonreporting by TDI came to light. Three prominent, but by no means complete, examples are: (1) The inadequate degenerate metallurgical structure of the original EDG 103 block, which was discovered by LILCO only after the block cracked in April 1984; (2) the existence of cracks in the camshaft gallery of the blocks, not discovered by LILCO until 1984. Moreover, these cracks had been repaired by welding and painted over by TDI after fabrication (in the 1970's), but this was not discovered by LILCO until September 1984. (Indeed, written testimony filed before us by TDI witnesses on August 14, 1984, but fortuitously for TDI, withdrawn by LILCO before presentation as evidence, discussed the camshaft gallery cracks but failed to disclose that they had been welded over); and (3) the fact that TDI's torsional stress calculations for the original 13 X 11 crankshafts were grossly in error. (As we understand it, TDI used this size crankshaft only in the three diesels of that model sold to LILCO, and not in others made after the mid-1970's time-frame when the three Shoreham diesels were fabricated).

We reiterate that we believe the situation regarding apparent nonreporting by TDI deserves the Commission's attention. To the extent Commission entities have looked into this matter, it appears to us that the inquiries may not have been comprehensive nor inclusive, and may not have received the proper priority and resources.

II. CYLINDER BLOCKS

A. Introduction

B-1. Suffolk County and the State of New York jointly contend that the Emergency Diesel Generators (EDGs) at Shoreham are inadequate because:

- Cracks have occurred in the cylinder blocks of all EDGs and a large crack propagated through the front of EDG 103.
- Cracks have also been observed in the camshaft gallery area of the blocks.[2/]
- The replacement cylinder block for EDG 103 is a new design which is unproven in DSR-48 diesels and has been inadequately tested.

B-2. The three Shoreham EDGs are Transamerica Delaval, Inc. ("TDI"), model DSR-48 diesel engines with eight cylinders in line,

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[2/] By stipulation dated January 14, 1985, the parties advised that the County no longer sought to disqualify the blocks on the basis of the camshaft gallery cracks. LILCO Ex. B-67. Accordingly, our decision does not deal with these cracks.

having a 17-inch base and 21-inch stroke. These EDGs constitute the onsite electrical power system for the Shoreham plant. Hubbard and Bridenbaugh, ff. Tr. 23,826, at 12, 14. The safety function of this system (assuming the offsite system is not functioning) is to provide sufficient capacity and capability to assure that (1) specified acceptable fuel design limits and design conditions of the reactor coolant pressure boundary are not exceeded as a result of anticipated operational occurrences and (2) the core is cooled and containment integrity and other vital functions are maintained in the event of postulated accidents. The onsite electrical power supplies, including the batteries, and the onsite electric distribution system, shall have sufficient independence, redundancy, and testability to perform their safety functions assuming a single failure. 10 C.F.R. Part 50, Appendix A, General Design Criterion (GDC) 17. A single failure means an occurrence which results in the loss of capability of a component to perform its intended safety functions. Multiple failures resulting from a single occurrence are considered to be a single failure. Id. at Definitions and Explanations.

B-3. The function of the cylinder blocks is to form the framework of the liquid-cooled engine, provide passage for coolant and support for the cylinder liners and cylinder heads and to restrain the forces generated by gas loads. McCarthy et al., ff. Tr. 24,372, at 8. The configuration for one cylinder liner and head is illustrated in LILCO Exhibit B-7 (Figure 1, attached), and plan views of block tops, showing crack locations and depths for DG 101, DG 102 and DG 103, are given in LILCO Exhibits B-16, B-17 and B-25 (Figures 2, 3 and 4), respectively. The block material was specified as ASTM A-48-64 Class 40 gray cast iron. Id. at 9.

B-4. As part of the engine qualification testing program, each engine was operated for 100 hours at or above full load (3500 kw) and then disassembled and inspected. This inspection, in February 1984, identified ligament cracks in the blocks of all three EDGs, and stud-to-stud cracks and one stud-to-end crack in the original EDG 103 block. Id. at 13-15, Tr. 24,603-04 (Schuster). A ligament crack extends from the cylinder head stud counterbore to the cylinder liner counterbore and lies in a vertical plane, extending downward from the block top surface. A stud-to-stud crack extends from one stud counterbore to an adjacent stud counterbore of an adjacent cylinder. The locations of ligament and stud-to-stud cracks are illustrated in LILCO Exhibit B-20 (Figure 5). A stud-to-end crack extends from a stud counterbore of an end cylinder (either no. 1 or no. 8) to the end of the block. See McCarthy et al., ff. Tr. 24,372, at 14-15.

B-5. The location and depth of the ligament cracks were measured using a series of liquid penetrant, eddy current and visual inspections of the block tops, stud holes and cylinder liner landings. Id. at 13. EDG 101 had 13 ligament cracks, EDG 102 had 18 ligament cracks and EDG 103 had 21 ligament cracks at the time of these inspections. LILCO Exs.

B-16, B-17 and B-18. These cracks varied in depth, with the ones in EDG 103 being the most severe. Id. No ligament crack in EDGs 101 and 102 extended below a depth of 1.5 inches nor on to the liner landing. As of March 11, 1984, the original EDG 103 block had no measured ligament cracks deeper than 1.5 inches. The deepest stud-to-stud crack in the original EDG 103, between cylinders No. 4 and 5, was measured by eddy current to have a depth of 1.4 to 1.6 inches. LILCO Exs. B-16, B-17, B-18; McCarthy et al., ff. Tr. 24,372, at 14, 15; Tr. 28,823-24 (Johnson); Tr. 28,825-27 (Rau). The original EDG 103 also had seven surface "indications" (cracks which were not deep enough to be measurable), five of which occurred in stud-to-stud locations and two of which were located between a stud hole and the outer perimeter of the block top. Id.

B-6. Following inspection, EDG 102 was operated through 100 starts to loads greater than 50 percent (i.e., greater than 1750 kw). McCarthy et al., ff. Tr. 24,372, at 15; LILCO Ex. B-21. Based on subsequent eddy current examination, LILCO concluded that there had been no discernible extension of cracks on the 102 block. Id. It appears, however, that this general conclusion was based on eddy current measurements only at cylinder No. 7. See Tr. 24,411 (Johnson); LILCO Ex. B-21. While this may be reassuring, since based on the EDG 102 crack map cylinder No. 7 has the worst cracks, we do not find it conclusive that no crack extension at all took place.

B-7. Between March 11 and April 14, 1984, EDG 103 underwent additional operational testing for a longer time at higher loads than the EDG 102 testing. LILCO Ex. B-15. On April 14, the EDG block experienced an abnormal load excursion in which the power demand exceeded the EDG capacity for approximately 25 seconds, causing the engine to slow from the normal 450 rpm to 390 rpm. The engine was operating with the fuel rack set at 3500 kw when the power demand from the site load was accidentally picked up. The engine speed slowed until the output breaker tripped due to low engine rpm; the diesel continued to run at no load for an additional ten minutes before it was shut down. McCarthy et al., ff. Tr. 24,372, at 17-18; Tr. 24,655-61 (Youngling, Seaman). The engine was later restarted and the qualification testing continued at 3900 kw for about 1.75 hours, when an operator noticed oil seeping from a crack running down the front of the block at cylinder No. 1, and the engine was shut down. The engine was operating satisfactorily and producing power prior to shutdown. McCarthy et al., at 17-18; Tr. 24,434 (McCarthy); Tr. 24,661-62 (Youngling). The area of this crack had not been inspected after the load excursion and before restarting the engine. Tr. 24,663 (Youngling). The crack was later measured to be 4.4 inches long at the front surface of the block. No one recalled its depth at the stud hole, but it would not be more than 4.4 inches because that was the largest measurement observed. Tr. 24,668 (Wells), Tr. 24,669 (Schuster, Johnson).

B-8. After shutdown of the EDG 103 engine on April 14, 1984, inspection of the block revealed that the deepest stud-to-stud crack, located between cylinders No. 4 and 5, had extended from a depth of 1.4 to 1.6 inches to a maximum depth of three inches.[3/] McCarthy et al., ff. Tr. 24,372, at 18; Tr. 28,823-24 (Johnson); Tr. 28,905-06 (Rau); LILCO Exs. B-18, B-25. Between March 11 and April 14, 1984, additional ligament and stud-to-stud cracks had initiated and propagated at other block top locations; however, none of the ligament cracks extended on to the liner landing. McCarthy et al., ff. Tr. 24,372, at 18-19; Tr. 25,538 (Johnson); LILCO Exs. B-16, B-18, B-25.

B-9. Based on the lack of confidence that the EDG 103 block could be repaired satisfactorily, LILCO decided to replace it. Tr. 24,665-66 (Youngling). A new block was installed in the EDG 103 in June 1984. Johnson et al., ff. Tr. 28,799, at 5.

B-10. In September 1984, destructive sectioning, magnetic particle, and ultrasonic examinations revealed the presence of shallow circumferential cracks in the original EDG 103 block. McCarthy et al., (Supp.) ff. Tr. 24,372, at 2, 11; Anderson et al., (Supp.) ff. Tr. 25,565, at 10-11; SC Ex. S-10. These cracks were located in the sharp

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3/ All measurements referred to are the revised measurements (for EDG 103) taking into account the presence of Widmanstaetten graphite. Tr. 24,442 (Rau).

corner formed by the cylinder liner counterbore and the cylinder liner landing. They extended at about a 45° angle from the corner to a maximum depth of 3/8 inch. McCarthy et al. (Supp.), ff. Tr. 24,372, at 2, 11. See also Anderson et al., ff. Tr. 25,565, at 10-11; SC Ex. S-10.

B-11. As of September 22, 1984, the EDG 101 and 102 blocks had each accumulated more than 1200 hours of operation. On the EDG 101 block, about 440 hours were at or above full load (3500 kw), including 25 hours at or above 110 percent of full load. Tr. 28,887 (Rau); LILCO Ex. B-13. On the EDG 102 block, about 475 hours were at or above full load (3500 kw), including 30 hours at or above 110 percent of full load. Tr. 28,887-88 (Rau); LILCO Ex. B-14. The original EDG 103 block also accumulated more than 1200 hours of operation, of which about 428 hours were at or above full load (3500 kw), including 30 hours at or above 110 percent of full load. LILCO Ex. B-15.

B. Methods of Evaluation

B-12. It is abundantly clear from this proceeding that the evaluation of the adequacy of the Shoreham diesels has presented a novel situation. Complete failure of the EDG 102 crankshaft, the presence of ligament cracks, stud-to-stud cracks, circumferential cracks, camshaft gallery cracks and replacement of the EDG 103 block, perforce have led to new bases for evaluation, as developed by the Staff and LILCO (and the TDI Owners Group), to show compliance with GDC 17. Traditionally, and in all cases prior to the appreciation of the difficulties with the TDI diesels, especially at Shoreham, evaluation was guided by the concepts described in Institute for Electrical and Electronics Engineers, Inc. (IEEE) standards and NRC Regulatory Guides. This approach made reference to "continuous duty" and "short-time" ratings compared to the actual loads anticipated over the life of the plant. LILCO, in fact, used this approach originally in its Final Safety Analysis Report (FSAR), using 3500 kw as the continuous duty rating and 3900 kw as the short-time rating.

B-13. Neither LILCO nor the Staff now use the IEEE approach for Shoreham. Rather, a new concept of "qualified load" (3300 kw) has been introduced and extensive investigations of crack initiation and propagation have been carried out to attempt to demonstrate that the diesels will perform their intended safety function during the course of a coincident loss of offsite power and a loss of coolant accident (LOOP/LOCA). Further, this demonstration applies only to the first refueling cycle. Tr. 23,105-06 (Ellis). LILCO testified that based on its analysis, "EDG 101 and EDG 102 should perform their intended function, plus surveillance and periodic operational testing, <u>until the first refueling outage</u> without developing significant stud-to-stud cracking. McCarthy <u>et</u> <u>al</u>., ff. Tr. 24,372, at 74. (Emphasis added). We do agree with LILCO and the Staff that the record supports the approval of continued operation of the Shoreham TDI EDGs for multiple fuel cycles--with appropriate inspections--but consider it prudent for the NRC to defer a decision on operation past the first fuel cycle until industry experience with TDI diesels up to that time can be reviewed. Similarly, the results of inspections during and after the first fuel cycle at Shoreham should be evaluated before the second fuel cycle. LILCO and the Staff aver that their evaluations do demonstrate compliance with GDC 17; the County contends they do not. We proceed to examine the parties' positions in detail.

B-14. First, we observe that GDC 17 is the applicable regulation, whereas Regulatory Guide 1.9, Selection, Design, and Qualification of Diesel-Generator Units Used as Standby (Onsite) Electrical Power Systems at Nuclear Power Plants, (which references IEEE standards) is not a substitute for the regulation, and compliance with it is not required. "Methods and solutions different from those set out in the guide will be acceptable if they provide a basis for the findings requisite to the issuance ... of a ... license by the Commission." Regulatory Guide 1.9, Rev. 2, December 1979, at explanatory footnote, at 1. GDC 17 does not provide specific standards for evaluating the capacity and capability of the EDGs. It does specifically require that the onsite electrical power system provide sufficient capacity and capability to assure that (1) specified acceptable fuel design limits and design conditions of the reactor coolant pressure boundary are not exceeded as a result of anticipated operational occurrences and (2) the core is cooled and containment integrity and other vital functions are maintained in the event of postulated accidents. LILCO has interpreted this to mean that the EDGs will be capable of supplying (sufficient) power for a seven-day (168 hour) period in response to a LOOP/LOCA event. Tr. 24,823 (Youngling).

B-15. While normally an application for an operating license would contemplate an analysis and evaluation of the design and performance of structures, systems and components during the life of the facility (10 C.F.R. Part 50.34(a)(4); Part 50.34(b)(4)), we understand and determine that LILCO is requesting approval of its analysis and evaluation of the EDGs for only the first refueling cycle and for only one LOOP/LOCA should that occur during this cycle. See B-13, supra. The Staff has not taken this position. In fact, the Staff took the position that the adequacy of the diesels must be evaluated on the basis of whether the EDGs can withstand repeated LOOP/LOCA events throughout the life of the plant. Tr. 28,139; 28,141-42; 28,148 (Berlinger). The Staff later explained, however, that its evaluation, in accordance with GDC 17, does not consider whether there will be one LOOP/LOCA or one hundred LOOP/LOCAs. Tr. 28,184 (Berlinger). The Staff would assume that maintenance and surveillance programs would be incorporated at the plant which would assure that in the future the engines would be maintained in order to respond to a LOOP/LOCA or any other LOOP event, if there were repeated LOOP events. Tr. 28,285 (Berlinger). The Staff, however, did not provide any testimony that the EDGs could perform their function for more than one LOOP/LOCA. We repeat, that with respect to the acceptability of the EDG blocks, we consider their capability to perform their function for one LOOP/LOCA occurring before the end of the first refueling cycle.

B-16. The County would have us reject the LOOP/LOCA "standard" proposed by LILCO and the Staff. SC PF, Cylinder Blocks, at 11, ¶ 17. We do not view the LOOP/LOCA test as a standard, per se, but as a proposed basis for evaluating the capability of the EDGs to perform their function in compliance with GDC 17 for one LOOP/LOCA event occurring during the first refueling cycle. Tr. 26,234-37 (Berlinger). We accept this approach and shall examine the expected response of the blocks to the duty cycle imposed on the EDGs as a result of a LOOP/LOCA during the first refueling cycle. As a preliminary matter, we first examine the material properties of the blocks.

C. Material Properties of the EDG 101, 102 and Replacement 103 Blocks

B-17. There is no disagreement among the parties that the original EDG 103 block contained widespread, degenerate, Widmanstaetten graphite structure[4/] and that it therefore lacked the tensile strength of normal Class 40 gray cast iron. McCarthy et al., ff Tr. 24,372, at 29-35;

4/ Widmanstaetten graphite is a degenerate form of graphite that occurs infrequently in heavy-section gray cast iron. A combination of very (Footnote Continued)

Berlinger et al., ff. Tr. 23,126, at 25; Tr. 25,781 (Bush); Tr. 25,552-53, 25,674 (Anderson); Tr. 24,746 (Wachob).

B-18. As a result, the original 103 block was more susceptible to fatigue crack initiation and propagation because the block strength was as low as 14.9 ksi which is approximately 40 percent below the anticipated minimum value of 25 ksi for typical Class 40 gray cast iron of this thickness. McCarthy et al. ff. Tr. 24,372 at 35-36, Tr. 25,284-86 (Wachob). See also LILCO Ex. B-40. LILCO's consultant, Failure Analysis Associates (FaAA), calculated that the fatigue life of the original EDG 103 was reduced by a factor of 10 to 100 times as a result of the presence of degenerate graphite. McCarthy et al. ff. Tr. 24,372 at 40.

B-19. In contrast, the FaAA inspection of the microstructure of 101 and 102 confirms that they are typical Class 40 gray cast iron. Tr. 24,771 (Rau). The UTS strengths for 101 and 102 were in the range of 45 to 47 ksi. Tr. 24,766 (Wachob).

B-20. LILCO and the Staff contend that the EDG 101 and 102 blocks consist of normal Class 40 gray cast iron and that they are, therefore,

(Footnote Continued)
slow cooling rate and tramp elements can combine to form Widmanstaetten graphite. McCarthy et al., ff. Tr. 24,372, at 30-31; Tr. 24,745, 25,010 (Wachob); Tr. 25,059-60 (Rau, Wachob); Tr. 25,064 (Rau).

superior to the original EDG 103 block. McCarthy et al., ff. Tr. 24,372, at 41-42; Berlinger et al., ff. Tr. 23,126, at 26-27; Tr. 24,752-55 (Rau); LILCO Exs. B-33, B-38. Metallurgical analyses using two different techniques were used by LILCO (FaAA) to analyze the cast iron material of the blocks. First, metal samples were removed from the EDG 101, 102, and original 103, and replacement 103 block tops. These samples were then metallographically polished and examined under a microscope to evaluate their microstructure. Second, plastic replicas were taken of polished surfaces of the EDG 101, 102, and original 103 blocks. Both of these techniques revealed extensive quantities of Widmanstaetten graphite throughout the original EDG 103 block and typical gray cast iron microstructure throughout the 101, 102, and replacement 103 blocks. McCarthy et al., ff. Tr. 24,372, at 29-31, 41-42; Tr. 24,741, 24,746, 24,752-55 (Rau); Tr. 24,748-54, 24,756-57, 24,769-71 (Wachob); LILCO Exs. B-33 - B-38.

B-21. The County contends that there is insufficient evidence of the properties of EDG 101 and 102 blocks to conclude that they are superior to the original EDG 103 block. In essence, the County asserts that to reach conclusions about the material strength of the blocks of EDGs 101 and 102 compared to that of the original EDG 103, the material of all three blocks must be properly evaluated. Anderson, ff. Tr. 25,564, at 172. The County does not tell us what a proper evaluation would be, but alleges that there is insufficient evidence of any actual block material properties of EDGs 101 and 102, because:

- FaAA examined only a small area of each block top,
- within the same block the cast iron properties may vary widely due to the presence of trace elements in certain areas,
- a meaningful analysis of the material properties of a cylinder block would require metallurgical examination of numerous sample areas of the block,
- FaAA assumed the block to be homogeneous,
- FaAA assumes the materials of the EDG 101 and 102 blocks are at least as strong as "typical" material.

Id. at 171-172.

B-22. The metal samples tested were cut from identical sites on each of the EDG 101, 102, and original 103 block tops: the block top corners adjacent to cylinders no. 4 and 5 on the exhaust side and the crotch between cylinders no. 4 and 5 on the exhaust side. Tr. 24,738-39, 24,941-44, 26,651-52 (Wachob, Rau); Tr. 24,951 (Wachob). On the replacement 103 block, one metal sample was taken from the exhaust manifold adjacent to cylinders no. 4 and 5. Tr. 24,951 (Wachob). Various metallographic preparation procedures were employed to examine the samples, and the results were evaluated and compared to assure that the observed microstructure had not been affected by artifacts produced by the polishing procedures. Tr. 24,947-48 (Wachob); Tr. 24,948-49 (Rau). The samples, and all of the approximately 10 replicas evaluated from the EDG-101 and 102 blocks, showed typical gray cast iron microstructure.[5/] McCarthy et al., ff. Tr. 24,372, at 41; Tr. 24,749, 28,830 (Wachob); Tr. 24,771 (Rau); Tr. 24,945-48 (Wachob, Rau).

B-23. LILCO and the Staff agree that the samples and replicas taken from the EDG 101 and 102 blocks provide a representative sample for determining that extensive Widmanstaetten graphite is not present.[6/] Tr. 25,063-65 (Rau); Tr. 26,651-53 (Wachob, Rau); Tr. 26,287-88 (Bush). At least two factors support this conclusion. First, the formation of Widmanstaetten graphite is influenced by the rate of cooling which is virtually uniform throughout the heavy-section portions of a large casting such as the blocks. Thus, the microstructure in one block top location would be representative of the microstructure throughout the block top. Second, the extensive additional metallography and

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5/ Although small, isolated locations in the EDG 102 block contain some unconfirmed Widmanstaetten microstructural features, the areas represent such a small fraction of the cell wall in that location and a negligible fraction of the cell walls in the structure that they have no significant impact on mechanical properties. Tr. 24,755, 26,657 (Rau).

6/ Although Dr. Bush would have preferred to see additional metallurgical site evaluation, he agreed that there is a very definite difference in the microstructure of EDGs 101 and 102 and the original EDG 103 microstructure. Tr. 26,287-88 (Bush).

mechanical testing performed on the original EDG 103 block confirmed that, at a range of depths beneath the block top, extensive Widmanstaetten graphite was present. Thus, each location sampled, including the identical locations sampled in the EDG 101 and 102 blocks, confirmed that the sample locations were representative of the microstructure of the entire block. McCarthy et al., ff. Tr. 24,372, at 32; Tr. 25,063-65 (Rau); Tr. 24,743-45, 26,651-53 (Wachob, Rau); Tr. 24,745-47, 24,949-50 (Rau, Wachob); see LILCO Ex. B-39; see also Tr. 24,612-15 (Wachob).

B-24. SC witness Anderson asserted that FaAA's sampling technique did not provide sufficient evidence that all portions of the EDG 101 and 102 block tops have typical gray cast iron microstructure. Anderson et al., ff. Tr. 25,564, at 171; Anderson et al. (Rebut), ff. Tr. 26,326, at 1; Tr. 25,552-53 (Anderson). He based that opinion, in part, on his belief that the material of each block is not homogeneous. However, Dr. Anderson's opinion is entitled to little weight since he offered no independent metallographic evaluation of the Shoreham EDGs to refute either (1) the principle that these large blocks would have a virtually uniform cooling rate and therefore be homogeneous, or (2) FaAA's testing of several samples of each, which indicated that the blocks have a virtually uniform microstructure. Also unpersuasive is Dr. Anderson's testimony that the samples are not reliable because they are not a significant portion by weight of the entire block. As LILCO and Staff witnesses agreed, reliability is assured by sample location, not sample weight. Tr. 24,756-57 (Rau); Tr. 24,745-46 (Rau, Wachob); Tr. 26,651-53 (Rau, Wachob). Compare Anderson et al. (Rebut), ff. Tr. 26,326, at 1 with Tr. 26,032-33, 26,287-88 (Bush); Tr. 26,651-53 (Wachob, Rau). In fact, Dr. Anderson subsequently agreed that sample location is a more important factor than the sample weight. Tr. 26,649-51 (Anderson).

B-25. The County also argues that the results of tensile strength measurements of test B-bars cast with the blocks of EDGs 101 and 102 cannot be used to infer the tensile strengths of the EDG 101 and 102 blocks, because there is no independent proof that the blocks of EDGs 101 and 102 do not contain Widmanstaetten graphite, because the sampling was inadequate. SC PF Cylinder Blocks, at 31, 33. The County says it is particularly uncomfortable with the lack of thoroughness of FaAA's examination in view of the fact that Dr. Wachob (FaAA's witness) could not affirm that FaAA found no evidence of Widmanstaetten graphite in the EDG 102 block. Id. at 33. LILCO, however, asserts that metallographic testing of the EDG 101 and 102 blocks demonstrates that they have a normal microstructure for Class 40 gray cast iron, and the B-bar tests exceed the minimum strength requirements for Class 40 gray cast iron, therefore the strength of the blocks also exceeds the minimum requirements for Class 40 gray cast iron. Tr. 24,642, 24,770-72 (Rau). We recognize the importance and the difficulties of extrapolating from B-bar results to the large castings (e.g., because of differences in cooling rates), but despite the County's uncomfortableness, find that there is reasonable assurance that the EDG 101 and 102 block materials at least meet the minimum strength requirements for Class 40 gray cast iron and clearly are superior to the material of the original EDG 103 block.

B-26. The County also argues that the cracking in the EDG 101 and 102 blocks is sufficiently similar to the cracking in the EDG 103 block prior to its replacement to rebut LILCO's claims that EDG 101 and 102 blocks possess superior metallurgical properties. SC PF Cylinder Blocks, at 34. We do not agree that whatever similarity exists overrides the persuasive evidence from metallurgical and metallographic analyses that are consistent in showing the superiority of the EDG 101 and 102 block material; e.g., the difference in microstructure, LILCO Exs. B-35, B-36 and B-37, and the fatigue crack growth rate measured for a sample of material taken from the original EDG 103 block. LILCO Ex. B-44.

B-27. The B-bar test for the EDG 103 replacement block indicated a UTS of 54 ksi, which is well in excess of the specified Class 45 requirement, and, indeed, in excess of requirements for Class 50 gray cast iron. Tr. 24,764-69 (Rau, Wachob). Since FaAA's metallographic testing confirmed that the replacement block has a normal microstructure, similar to that of the B-bar, the B-bar test results may be relied upon to indicate that the strength of the replacement block exceeds the requirements for Class 45 gray cast iron. McCarthy et al., ff. Tr. 24,372, at 36-38, 41-42, 69-70; Tr. 24,767-69, 28,849 (Rau); Tr. 24,951-52 (Wachob); <u>see</u> LILCO Ex. B-42.

B-28. Based on the foregoing, we believe that indeed the Widmanstaetten graphite severely degraded the original EDG 103 block and was a large contributor to the extensive cracking found after the endurance testing. Further, we accept the analysis of FaAA concurred in by Dr. Bush that there is sufficient evidence to support a finding that EDG 101 and 102 blocks are free from the extensive Widmanstaetten graphite that degraded original EDG 103 block.

D. Block Stress Analyses

B-29. The primary loadings that influence block cracking result from the stud preload, thermal stresses, and pressure stresses associated with cylinder firing during operation. To quantify these stresses, strain gauge measurements were made on the original EDG 103 block to evaluate the total stresses developed in the block top region. McCarthy <u>et al</u>., ff. Tr. 24,372, at 15-16, 22-23, 27; Tr. 24,511 (Youngling); <u>see also</u> LILCO Exs. B-22, B-23.

B-30. The recorded strain gauge data were used to compute the stresses at the locations on the blocks where the gauges were placed and, in conjunction with finite element analyses, to compute the stresses present elsewhere in the block top. McCarthy et al., ff. Tr. 24,372, at 27-28; see LILCO Exs. B-22, B-26 - B-31; Tr. 24,518 (Wells).

B-31. FaAA conducted two-dimensional and three-dimensional finite element stress analyses of the block top. The results of these analyses were used to determine scale factors that conservatively relate the stress at the location of strain gauge no. 13, located between the cylinder heads nos. 5 and 6 in the stud-to-stud region, to the stresses at the edge of the stud holes where ligament and stud-to-stud cracks have been observed to initiate. McCarthy et al., ff. Tr. 24,372, at 42-44; Tr. 24,650, 24,724 (Rau); see LILCO Exs. B-22, B-27, B-30, B-45 - B-48.

B-32. Three mechanisms of crack initiation were identified that can act separately, or in combination, in the block top. They are (1) low cycle fatigue, associated with the stress range developed during start-up to high load levels, (2) high frequency fatigue, associated with stress variations resulting from cylinder firing during operation, and (3) overload rupture associated with the highest tensile stress resulting from a combination of pressure, thermal, and preload stresses. McCarthy et al., ff. Tr. 24,372, at 44-44; Tr. 24,690-95 (Wells, Rau).

B-33. To ascertain whether fatigue crack initiation was possible in blocks with minimum typical materials properties for Class 40 cast iron, the stresses calculated from FaAA's conservative finite element analyses were plotted on two modified Goodman (Smith) diagrams. See LILCO Exs. B-49, B-50. The Goodman diagrams predicted the possibility that stresses in the block top were sufficiently high for fatigue crack initiation (either ligament or stud-to-stud) to occur in the EDG 101 and 102 blocks. McCarthy et al., ff. Tr. 24,372, at 45-56; Tr 24,648-51 (Rau).

B-34. The finite element analyses and materials properties used in the Goodman diagram analysis of fatigue crack initiation have been demonstrated by actual operating experience at Shoreham and other nuclear plants to be extremely conservative. McCarthy et al., ff. Tr. 24,372, at 46-47; Tr. 24,654 (McCarthy); Tr. 26,291-92 (Bush). In addition, the scale factors based upon the results of the conservative finite element analyses introduce further conservatism into the Goodman diagram analysis of possible crack initiation. Tr. 24,640-41, 24,649-50 (Rau); Tr. 29,112-13 (Bush).

B-35. The Goodman diagrams are far too conservative and were not intended to be used to predict the specific load levels at which cracks would initiate. Tr. 24,649-50 (Rau); Tr. 24,707-08 (McCarthy). The conservatism is confirmed by the fact that ligament cracks have not occurred at all locations even in the original EDG 103 block with degraded properties. Tr. 24,654 (McCarthy); Tr. 24,649-50 (Rau); see LILCO Exs. B-16, B-17, B-25. Further conservatism is shown by the fact that the Goodman diagrams indicate the possibility of stud-to-stud cracking in only a few loading cycles, yet stud-to-stud cracks have not initiated in the EDG 101 or 102 blocks despite extensive high load service. Tr. 24,648-51 (Rau); Tr. 26,062, 26,065-66, 26,291-92 (Bush); Tr. 24,654 (McCarthy); see LILCO Exs. B-16, B-17.

E. Ligament Cracks

B-36. Ligament cracks in the EDG blocks appear to be caused by operation of the EDGs, i.e., the loads to which the engines are subjected and the time at these loads. McCarthy et al., ff. Tr. 24,372, at 22-23; Anderson et al., ff. Tr. 25,564, at 181. FaAA's analysis concluded that the cracks result from the interaction of stresses imposed on the cylinder blocks by a number of forces including (i) the preload forces derived from clamping of the cylinder heads to the block tops by the cylinder head stud nuts; (ii) the thermal loads derived from temperature differences in the cylinder liner, cylinder block, cylinder head and cylinder head studs; and (iii) the firing pressure loads derived from gas pressure in the combustion chamber. The interaction of all these loads is very complex. McCarthy et al. ff. Tr. 24,372 at 22-26. LILCO and the Staff assert that ligament cracks are benign because they are unlikely to propagate deeper than 1½ inches and, even if they propagated deeper, they would at most cause minor cooling water leakage that would not affect continued operation of the engine. Tr. 25,271-74 (McCarthy); Tr. 25,930-32 (Berlinger). The County is not persuaded that the risk of ligament cracks propagating to the point of EDG failure during a LOOP/LOCA is so small that it is acceptable.

B-37. LILCO bases its conclusion on considerations of material properties, operating experience, finite element stress analysis, strain gauge measurements, detailed knowledge of dimensions and geometry of the blocks and expert opinion. As discussed in Section III, above, we have found that the material properties of the blocks are sufficiently well known to conclude that the ultimate tensile strengths of the EDG 101, 102 and replacement 103 blocks meet or exceed those for Class 40 gray cast iron.

B-38. Testing of the EDG 102 resulted in no discernible crack propagation following 100 consecutive fast starts, including three fast starts to full load in less than 60 seconds in accordance with FSAR requirements. McCarthy et al., ff. Tr. 24,372, at 15. After more than 1000 hours of operation, including more than 350 hours at or above 3500 kw, none of the ligament cracks on the EDG 101 or 102 blocks propagated onto the cylinder liner landing or extended deeper than 1.5 inches in the stud hole counterbore. Id.; Tr. 24,404 (Johnson); Tr. 24,507-08 (Schuster, Wells); Tr. 28,821 (Rau); see LILCO Exs. B-13, B-14, B-16, B-19; see also Tr. 24,399-400 (Schuster, Johnson); Tr. 24,505-06 (Youngling). No ligament cracks on the original EDG block extended onto the cylinder liner landing, but one crack adjacent to the three inch deep stud-to-stud crack between cylinders no. 4 and 5 extended to a depth of 2½ inches on the stud hole side of the ligament. Tr. 25,538 (Johnson); LILCO Ex. B-25.

B-39. The County would have us find that the experience with the original EDG 103 block contradicts LILCO's assertion that ligament cracks are benign, because "the crack growth demonstrated in that engine could not happen." SC PF Cylinder Blocks, at 15-16. The "crack growth demonstrated" to which the County refers, however, is not that which LILCO has determined to be present for ligament cracks. That is, the one ligament crack that propagated to 2½ inches did not do so at the liner landing[7/]; the stud-to-stud crack and the stud-to-front surface crack are not ligament cracks. In any event, the experience with ligament cracks in the original EDG 103 block is not directly applicable to a conclusion as to the likelihood of propagation of such cracks in the EDG 101, 102 and replacement 103 blocks. The County also would have us find that LILCO's reliance on "field experience" (presumably experience with other plant EDGs) is misplaced. In fact, LILCO, in its proposed findings, does not reference any such experience. In any event, what evidence there is in the record on such experience we find too insubstantial to rely upon. See, e.g., McCarthy et al., ff. Tr. 24,372, at 20-22; 47; Tr. 24,685-86 (Wells); Tr. 24,708-09 (Wells).

7/ Stresses are highest at the top of the block and they are highest adjacent to the stud hole. Tr. 24,689 (Rau).

B-40. As discussed in Section IV, the finite element stress analyses, combined with the strain gauge measurements on the original EDG 103 block and using modified Goodman (Smith) diagrams, conservatively predict crack initiation in the EDG 101, 102 and replacement 103 blocks. The stress analysis, however, does not predict precisely where ligament crack propagation will arrest. LILCO and the Staff agree that stresses decrease with distance beneath the surface of the block top and become fully compressive. Tr. 24,465-66, 28,820, 24,689 (Rau); Tr. 25,845, 25,854, 25,880 (Bush); see also Tr. 25,853-54 (Berlinger); but see Tr. 26,059 (Bush). Although Dr. Bush expressed some reservation that secondary thermal stresses were not completely taken into account in the analysis, his reservation was limited to the exact point at which stresses became compressive and did not affect his conclusion that the ligament cracks move into a compressive stress field and arrest. Tr. 25,845-49 (Bush). Not entirely consistent with LILCO's assertion that ligament cracks are not likely to propagate more than 1½ inches below the block top was testimony that the stress at the first thread of the stud hole in the block (located about an inch and a half below the block top) would be in the range of three to five ksi. Tr. 25,499-500 (Rau). Thus, in the stud hole region, the stress would still be positive at a depth of about an inch and a half. LILCO's position is that there have not been any ligament cracks that extended below the liner ledge. Tr. 25,501 (Johnson).

B-41. There are additional observations that bear on the conclusions that can be drawn from the results of stress analysis. For example, there were only three strain gauge locations, all on the surface of the original block, from which stresses throughout the block were deduced from the finite element stress analysis. McCarthy et al., ff. Tr. 24,372, at 15-16, 27; LILCO Exs. B-22, B-23. The Staff would normally expect the highest stresses to occur during a fast startup of the EDGs and believed that stresses are normally greater in emergency diesels because of the quick start feature, but FaAA's strain gauge data and stress determinations indicate that such stresses are not higher than at steady state operation. Tr. 26,294-95 (Berlinger); Tr. 25,804 (Bush). The Staff also had reservations about the way in which FaAA had accounted for the thermal gradient occurring during a "cold" startup and for the pulsating thermal gradient resulting from firing in the cylinders. Tr. 25,843-50 (Bush); Tr. 25,874-80 (Bush). Also, it appears that there was conflicting strain gauge data obtained by TDI. Testimony by TDI personnel originally filed by LILCO was withdrawn, however, so that these data could not be examined.

B-42. In summary, the available operating experience data tend to support the conclusion that ligament cracks in the EDG 101, 102 and replacement 103 blocks will not propagate on to the liner landing. It is less certain that they will not propagate below 1½ inches in the stud hole. The finite element stress analysis supports the conclusion that the ligament cracks will arrest, but where this will occur is uncertain.

The County raised the possibility that a leakage path may be established to the cooling water jacket. Both LILCO and the Staff appear to conclude that ligament cracks would arrest before such leakage could occur. Neither the Staff nor the County had performed independent finite element stress analyses or fracture mechanics analyses of crack progression. Tr. 25,844 (Bush); Tr. 25,619 (Anderson); Tr. 25,631-40 (Christensen, Bridenbaugh, Hubbard, Eley, Anderson); Tr. 26,377-78 (Eley, Bridenbaugh); Tr. 25,630-31 (Stipulation re Christensen, Eley).

B-43. In the absence of dispositive hard facts, we must consider what facts there are and the credibility of the analyses and expert opinion before us. We are favorably impressed with the technical competence of LILCO's consultant, FaAA, and are generally inclined to accept its technical conclusions. We cannot ignore the expert opinions of the Staff's technical experts (particularly Dr. Bush), but must also acknowledge that those opinions were largely reservations with respect to FaAA's analyses and conclusions stemming from a lack of an independent analysis and a lack of complete knowledge as to how FaAA's analyses were done. Neither can we totally ignore the questions raised by the County, although many of these were speculative and raised by non-experts who also had performed no independent analysis.

B-44. Based on the above, we conclude that it is not likely that coolant leakage paths would result from ligament cracks in the blocks of EDGs 101, 102 and replacement 103. We cannot rule it out completely, however, and therefore must consider the consequences of such a circumstance.

B-45. Both LILCO and the Staff agreed that a ligament crack could lead to seepage of water from the coolant jacket to the stud hole if it propagated at least 2½ inches deep on the liner side and traversed to the stud hole. Tr. 26,055-56 (Henriksen); Tr. 24,459 (Wells). See Staff Ex. D-9. No party provided any definitive analysis of how much leakage could be expected. It is obvious that this would depend on the number of cracks and their width and extension. The County asserts that coolant could leak rapidly because the coolant water is under pressure. Christensen and Eley, ff. Tr. 25,564, at 153. The normal pressure is 25 psi. Tr. 25,490 (Johnson). LILCO and the Staff agree that any coolant water leakage would be minor and would not cause an operational problem. Tr. 24,459, 25,210-11, 25,231-32 (Wells); Tr. 25,238 (McCarthy); Tr. 25,232 (Youngling); Tr. 26,055, 26,187 (Henriksen), Staff Exs. 9 and 10. If coolant leakage did occur, a loss of 20 gallons would cause a low level water alarm. Tr. 25,232 (Youngling). Virtually unlimited makeup coolant water could be added to an engine during operation through a 1.5 inch water pipe capable of delivering 70 gpm from storage tanks having capacities of 100,000 and 600,000 gallons. Tr. 25,272 (McCarthy); Tr. 25,492 (Youngling); Tr. 26,188 (Henriksen). Even at 70 gpm (which is far greater than seepage) the tank storage would last for a week and could easily be augmented. Thus, we conclude that for any credible leak, even though unlikely, the cooling water system would not be depleted and that continued EDG operation would not be affected. Tr. 26,189 (Henriksen).

B-46. We conclude that there is reasonable assurance that ligament cracks will not initiate and propagate sufficiently to impair the performance of the EDGs.

F. Stud-to-Stud Cracks

B-47. Although no stud-to-stud cracks have been observed on the EDG 101 and 102 blocks, the initiation and propagation of such cracks must be considered for at least two reasons. Such cracks did occur in the original EDG 103 block (although its material properties were admittedly markedly inferior) and at least the possibility of such cracks is predicted by use of finite element stress analysis and Goodman diagrams for low cycle and high frequency fatigue at load levels of 3150 kw and above and possibly below. LILCO Exs. B-49 and B-50. Tr. 24,705 (Rau); Tr. 24,707-08 (McCarthy). LILCO, therefore, assumed the presence of such cracks in the EDG 101 and 102 blocks and did an analysis to determine the effect on the performance of the EDGs during a LOOP/LOCA.

B-48. Since the Goodman diagrams do not predict the rates of crack propagation, FaAA performed a cumulative fatigue damage analysis to bound the rate of crack propagation in the EDG 101 and 102 blocks. McCarthy et al., ff. Tr. 24,372, at 48. The starting point of the analysis is a calculation, based on FaAA's strain gauge measurements, of the different stress ranges imposed on the original EDG 103 block by the various power levels of the engine during the qualification testing between March 11 and April 14, 1984. Tr. 24,694 (Rau). The analysis relates that operating profile to the cumulative damage (crack growth) actually experienced during that testing. Id. The block experienced a maximum crack extension of one and one-half inches, with the deepest stud-to-stud crack extending to a maximum depth of three inches on the exhaust side between cylinders nos. 4 and 5). McCarthy et al., ff. Tr. 24,372, at 53. The reason that this crack was considered in the cumulative damage analysis, rather than the 4.4 inch stud-to-end crack at cylinder no.1, was because there was even more margin (for the 4.4 inch crack) between the required LOOP/LOCA cumulative damage and that which had been demonstrated by the performance of the original 103 block during the test period, due to the different stresses present. Tr. 24,811-13 (Rau). The analysis then calculates the cumulative damage predicted to result from a LOOP/LOCA load profile. Tr. 24,694-95 (Rau); McCarthy et al., ff. Tr. 24,372, at 49-52. These calculations take into account the crack growth rate dependence on the material properties. Tr. 24,693 (Rau).

B-49. FaAA's calculations showed that the cumulative damage to which the original EDG 103 block would have been exposed during a postulated LOOP/LOCA event would have been about two thirds of the cumulative damage actually sustained during the qualification testing. McCarthy et al., ff. Tr. 24,372, at 52-53. Its cumulative damage analysis of the EDG 101 and 102 blocks indicated that the cumulative damage predicted for these blocks during a postulated LOOP/LOCA load profile[8/] is less than two percent of the damage sustained by the original EDG 103 block during the qualification testing. Id. at 53-54. From this result, FaAA inferred that the EDG 101 and 102 blocks can withstand 50 consecutive "3900/3500 kw" LOOP/LOCAs before accumulating the same amount of fatigue crack growth experienced by the original EDG 103 block that did not affect its operation during the test period. Tr. 25,313-14. Further, FaAA found that the crack propagation rate is 3.5 times slower at 3300 kw than it is at 3900 kw and a crack would require 20 percent more time at 3300 kw than at 3500 kw to propagate an equal amount. Tr. 28,904-05 (Rau).

B-50. Suffolk County finds the FaAA cumulative damage analysis to be unreliable. LILCO finds the analysis to be conservative. We proceed to examine their bases.

B-51. The County would have us find that the evidence does not establish that the physical properties of the blocks in EDGs 101 and 102

8/ The load profile assumed was 0.2 hours at 3,881 kw, 0.8 hours at 3,409 kw and 167 hours at 2,617 kw.

are superior to EDG 103. SC PF Cylinder Blocks, at 30. In Section III we have already concluded that this is not the case. The superiority is dramatically portrayed in LILCO Ex. B-40, which lists the differences in ultimate tensile strength; Ex. B-42, which portrays the differences in cyclic strain amplitude; Ex. B-44 which portrays the differences in fatigue crack growth rate; and in the differences in microstructure illustrated in Exs. B-33, B-34, B-35, B-36, B-37 and B-38, not to mention the differences in crack frequency and character actually observed for similar operating experience. LILCO Exs. B-16, B-17, B-18. See also Tr. 29,079 (Bush).

B-52. The County would have us find that the evidence is insufficient to establish that the load excursion (during qualification testing of the original EDG 103) caused additional damage to the EDG 103 block, or that that damage would not have been disabling. SC PF Cylinder Blocks, at 35. As support, the County implies that the FaAA analysis incorrectly assumes rapid crack growth rate during the excursion. Although he couldn't quantify it, Dr. Bush was convinced that the load excursion was a major contributor to such crack growth. Tr. 29,039-40 (Bush). In fact, the analysis attributes all crack growth during the qualification test period to fatigue and does not take credit for any rapid crack propagation that might have occurred during the unusual load excursion. Tr. 29,076-78 (Bush). See also, McCarthy et al., ff. Tr. 24,372, at 19-20, 57-58; Tr. 25,324-25, 28,831-33, 28,896-99 (Rau).

B-53. The County challenges the LILCO position that the original EDG 103 was likely to continue to function with the three-inch stud-to-stud crack. SC PF Cylinder Blocks, at 36. We agree with the County that we do not have an evidentiary basis for predicting how long the engine would have continued to function under this circumstance. We find it irrelevant, however, because the evidence is strong that the EDG 101, 102 and replacement 103 blocks will not encounter this situation. We also note that during the 30 to 45 minute test operation of the original EDG 103 at 3830 kw, a strain gauge placed to detect changes in the stud-to-stud crack opening, before the load excursion, indicated no increase, implying no increase in the depth of the crack. McCarthy et al., ff. Tr. 24,372, at 19; Tr. 24,626 (Wells, Youngling); Tr. 24,515 (Youngling).

B-54. The County does not address the nine specific conservatisms that LILCO lists in its proposed findings; it simply states that it does not agree that all of them are valid bases for describing the analyses as conservative for reasons discussed elsewhere. SC PF Cylinder Blocks, at 39.

B-55. The County asserts that the Staff witness (Dr. Bush) appears to have no confidence in the analysis because he testified that he would stop engine operation if any stud-to-stud crack existed in EDGs 101 or 102. This seriously distorts Dr. Bush's complete position on the analysis (although we agree that should stud-to-stud cracks occur in EDG

101, 102 or replacement 103 blocks, operation should not continue without thorough reassessment). Although Dr. Bush would have performed the analysis differently, he agreed that FaAA's methodology was conservative. Tr. 26,228, 26,313, 29,077-78, 29,094-95 (Bush).

B-56. The County attacks the validity of the analysis because LILCO asserts that the analysis purports to analyze the worst crack extension in the original EDG 103 during the qualification testing, but it ignores the 4½ inch crack running down the block front at cylinder no. 1. SC PF Cylinder Blocks, at 40. In fact, FaAA did consider the stud-to-end crack from cylinder no. 1 and demonstrated by cumulative damage analysis that propagation of this crack during a postulated LOOP-LOCA would be less than that for a stud-to-stud crack. Tr. 24,808, 24,811-13 (Johnson, Rau).

B-57. The County asserts that crack dynamics are affected by the sequence of loads as well as load duration and the analysis fails to account for that fact. SC PF Cylinder Blocks, at 41. It is correct that the analysis model did not take into account the relative sequence of the different power levels. The uncontroverted testimony, however, is that unless there are enormous differences in the magnitude of the stresses (such as on an airplane wing bouncing up and down in wind gusts) there would be no significant difference (in the results of the analysis resulting from a difference in the order of the sequence of loads). Tr. 24,818 (Rau).

B-58. The County asserts, "most importantly," that FaAA lacked significant information about the behavior of the original EDG 103 that is vital to valid predictions of behavior of the other blocks. SC PF Cylinder Blocks, at 41. The County then lists a series of questions it asked in its prefiled testimony. Anderson and Bridenbaugh, ff. Tr. 25,564, at 169-70. It claims that FaAA failed to provide any satisfactory answer to the concerns raised by the County. SC PF Cylinder Blocks, at 41. The questions the County asked relate to when cracks initiated in each of the three blocks and, of course, cannot be answered _post facto_.

B-59. The County's "greatest concern" is "that no one knows when the cracks started and how fast they grew." _Id._ at 43. The County therefore concludes that no one can reliably predict how they will behave in the future. The whole point of the cumulative damage benchmark analysis was to relate the observed damage between two known times to the known load profile and resulting stress history. _See_ discussion below. The analysis was a non-linear one. The County's overly simplistic exercise of adding up total depth of cracks serves to emphasize that SC's witnesses performed no independent cumulative damage analysis on the blocks and have no experience in performing such analyses. Tr. 25,637-39 (Anderson); Tr. 25,639-42 (Bridenbaugh, Christensen, Eley, Hubbard). SC's principal witness on cumulative damage did not review FaAA's cumulation damage calculations. Tr. 25,637-38 (Anderson). By not limiting its analysis and not taking credit for variations in crack growth rates at various points in time due to load sequencing, FaAA actually increased conservatism in its cumulative damage analysis. McCarthy et al., ff. Tr. 24,372 at 57-58; Tr. 25,324-25, 28,831-33, 28,897-99 (Rau).

B-60. The cumulative damage model was not based on inadequate crack propagation data. FaAA used accurate data obtained by direct testing on the original EDG 103 block and on Class 40 gray cast iron with a normal thick-section microstructure like that present in the EDG 101 and 102 blocks. Tr. 28,828-30 (Rau, Wachob); Tr. 29,071-73, 29,118 (Bush); see LILCO Ex. B-44. FaAA did not rely upon imprecise crack measurements. The deepest crack at the beginning of the benchmark period was measured by eddy current to be between 1.4 and 1.6 inches. Tr. 28,823 (Johnson). The deepest crack after the load excursion was accurately determined to be 2.8 to 3 inches by destructive sectioning and four independent NDE techniques. Tr. 28,825-27 (Rau); McCarthy et al., (Supp.), ff. Tr. 24,372, at 10. In any event, assuming a final crack size of three inches, whether it started at 1.6, 1.4 or 1.0 inches, the conclusions won't change and the numbers will not change significantly. Tr. 25,316 (Rau).

B-61. It is not necessary to identify when ligament or stud-to-stud cracks initiated, because the cumulative damage analysis (for prediction of crack growth) does not take credit for the time required for crack initiation. Rather, the analysis begins with the conservative assumption that ligament and stud-to-stud cracks having a depth of 1.5 inches are already present. Tr. 28,894-98, 28,908-10 (Rau); Tr. 29,074-77 (Bush).

B-62. The County asserts that FaAA should have performed a fracture mechanics analysis to predict growth of the ligament and stud-to-stud cracks. Anderson et al., ff. Tr. 25,564, at 170. In fact, FaAA's cumulative damage analysis is a fracture mechanics analysis that conservatively bounds the rate of crack growth. Since this analysis has demonstrated a significant margin, 50 consecutive 3900/3500 LOOP/LOCAs, it is not necessary to perform a more detailed fracture mechanics analysis, merely to verify that the blocks will perform their intended function. Tr. 24,803 (Rau). Moreover, FaAA directly measured the fatigue crack propagation rates in both conventional Class 40 gray cast iron which contains the same microstructure as EDG blocks 101 and 102, and in the material cut from the original EDG 103 block. Tr. 28,828-30 (Rau, Wachob).

B-63. The EDG 101 and 102 blocks have operated at or above 3500 kw for more than 400 hours (more than 5×10^6 loading cycles) without developing stud-to-stud cracks. This operation, combined with the superior fracture and fatigue properties of these blocks compared to the original EDG 103 block, tends to support the conclusion that stud-to-stud cracks are unlikely to initiate in the EDG 101 and 102 blocks. McCarthy et al., ff. Tr. 24,372, at 60, 74; Johnson et al., ff. Tr. 28,799, at 12; Tr. 28,810-11, 28,884-88, 28,853-54 (Rau); Tr. 29,052-53 (Bush); LILCO Exs. B-13, B-14, B-42; see also Tr. 29,129 (Bush).

B-64. Following any operation of EDGs 101 or 102 at loads greater than 1800 kw, the block tops will be inspected visually and by eddy current to detect any stud-to-stud cracks, Attachment 1, Block Top Inspections; Staff Ex. 14, at 25;[9/] Tr. 29,098 (Bush); Tr. 25,897-98 (Berlinger). If a crack is detected the engine will be removed from service and the crack evaluated. If the crack is not more than 1.5 inches deep, LILCO believes that the EDG remains acceptable for emergency standby service, because the cumulative damage analysis has demonstrated a margin of at least 50 consecutive LOOP/LOCAs even assuming the existence of a 1.5 inch deep crack. McCarthy et al., ff. Tr. 24,372, at 71. The Staff acknowledges that FaAA's cumulative damage analysis provides a conservative bound on crack growth rates, but nevertheless Staff believes that if a stud-to-stud crack initiates, further analysis should be conducted before the EDG is returned to service. In its view, continued operation without repair of such a crack in normal quality cast iron would not be justified. The presence of such a crack would indicate that the current analytic techniques

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9/ Staff Ex. 14 is the marked up version of Dr. Bush's testimony, which was initially bound into the record following Tr. 28,503. See Tr. 29,020.

do not accurately model crack initiation and growth. Bush and Henriksen, ff. Tr. 25,775, at 29a - 30; Tr. 29,076-78. The Board agrees with the Staff and orders that any license authorizing operation of the TDI EDGs 101 and 102 be conditioned to require the additional analysis upon discovery of a stud-to-stud crack, prior to continued operation.

B-65. The County contends that a deep stud-to-stud crack could cause loosening of the cylinder head studs, causing loss of power and overloading of the remaining cylinders, causing engine failure. Bridenbaugh et al., ff. Tr. 25,564, at 165. LILCO asserts that a stud-to-stud crack would not be disabling to the EDG even if it propagated more deeply than LILCO predicts. The worst consequence LILCO could envision from a stud-to-stud crack would be loosening of one cylinder head stud, which would not be a problem because there are seven other studs to hold the cylinder head down. Tr. 25,234-37 (Wells). The County was also concerned about coolant leakage. According to LILCO, a stud-to-stud crack cannot realistically get to the water coolant area. Tr. 25,236 (Wells); 25,238 (McCarthy). Such a crack would have to be six or seven inches deep to sever the structural material. Tr. 25,234 (Wells). In that case, there would be some loss in the ability of the block top to withstand the bending moment caused by the support of the cylinder heads on the block top. Two mitigating factors limit the consequences of such a crack: the presence of cylinder compartment webs and the strength of the heads themselves. Tr. 25,235-37 (Wells).

B-66. The County thinks it is pertinent that LILCO had not undertaken an analysis of the effects of extensive stud-to-stud cracking. SC PF Cylinder Blocks, at 50. We find, however, that based on the expert testimony of both LILCO and the Staff such an analysis is not necessary. Extensive stud-to-stud cracking is very unlikely. Tr. 25,234-37 (Wells); Tr. 26,189-90 (Henriksen, Bush, Berlinger). We also note that LILCO will perform eddy current testing between adjacent cylinder heads after any operation of EDG 101 or 102 at greater than 1800 kw. Attachment 1. See Section I, below.

B-67. We conclude that there is reasonable assurance that stud-to-stud cracks will not initiate and propagate sufficiently to impair the performance of the EDGs.

G. Circumferential Cracks

B-68. The County would have us find that the possibility of circumferential cracks renders the EDGs 101 and 102 unfit for nuclear service. SC PF Cylinder Blocks, at 52. LILCO would have us find that circumferential cracks are not present and will not impair EDG operation if they initiate. LILCO PF, Cylinder Blocks, at 20. Such cracks, at the juncture of the cylinder counterbore and the cylinder liner landing (see Figure 1), were found in the original EDG 103 block sometime after August 14, 1984. Rau and Wachob (Supp.), ff. Tr. 24,372, at 11. According to LILCO, the cracks were "very shallow," extending a maximum of 3/8 inch into the block top. Id. A magnetic particle examination report, dated September 19, 1984, indicated that linear indications extended entirely around the circumference of all eight cylinders of EDG 103. Hubbard and Anderson (Supp.), ff. Tr. 25,565, at 11; SC Ex. S-10.

B-69. All three of the EDGs had been inspected for circumferential cracks using liquid penetrant in February and March 1984. Tr. 24,866-67 (Schuster). A liquid penetrant inspection of EDG 103 was repeated in April 1984. Id. There were no reported indications of cracks prior to the sectioning of EDG 103. Tr. 24,444 (Johnson). It is difficult to inspect for these cracks (using penetrant), because the cracks, if present, form in the corner between the cylinder liner counterbore and the cylinder liner landing. It is hard to clean this area entirely for testing, making interpretation of the results more difficult. McCarthy et al. (Supp.), ff. Tr. 24,372, at 12.

B-70. Liquid penetrant and ultrasonic inspections performed on the EDG 101 and 102 blocks indicate that these blocks have no circumferential cracks. Tr. 28,815-16, 28,870-72 (Schuster); Tr. 28,816-17 (Johnson); Tr. 20,813 (Rau); Tr. 24,447-50 (Schuster); Tr. 26,692-93, 26,871-72 (Rau). Although liquid penetrant inspections on the 101 block revealed some background indications, these indications occurred as a result of liquid penetrant collecting in a carbon deposit that had not been completely removed. Tr. 24,444-50 (Schuster, Wells); Tr. 28,815 (Schuster). Ultrasonic inspections are highly reliable for circumferential crack detection because they are not affected by deposits collecting in the corner or on the cylinder liner counterbore. Tr. 24,449-50 (Schuster); Tr. 26,692-93, 26,871-72 (Rau); Tr. 28,816 (Johnson); Tr. 28,872-73 (Schuster).

B-71. The Staff originally testified that it had no confidence that the EDG 101 and 102 blocks did not have circumferential cracks. Bush and Henriksen, ff. Tr. 25,775, at 709; Tr. 26,020, 26,155 (Bush). Dr. Bush originally misunderstood the procedure used by LILCO in its ultrasonic testing. Tr. 26,874-75 (Bush). He later agreed that the UT procedure used by LILCO was technically feasible for detecting circumferential cracks. Id.

B-72. SC does not believe LILCO's non-destructive examinations of EDG 101 and 102 blocks, for circumferential cracks should be considered reliable, and therefore the Board should conclude that EDGs 101 and 102 should be assumed to have circumferential cracks. SC PF, at 53-54. Regardless of any difficulty with dye penetrant testing, the results of the most recent penetrant testing (after careful cleaning) and of the reliable ultrasonic testing indicate that no circumferential cracks are present in the EDG 101 and 102 blocks. SC offers no evidence to the contrary.

B-73. Even if circumferential cracks were to develop in the EDG 101 and 102 blocks, they would not affect the suitability of these EDGs for nuclear standby service. Tr. 28,813 (Rau); Tr. 26,020 (Bush, Berlinger); Tr. 26,023 (Bush); Staff Ex. 14, at 25-26. FaAA conservatively assumed the presence of circumferential cracks 360° around each cylinder, and analyzed these cracks using the results of its finite element stress analysis. These analyses indicated that such circumferential cracks would slow in propagation rate, arrest, and therefore not impair EDG operation. McCarthy et al. (Supp.), ff. Tr. 24,372, at 12-14; Tr. 28,812-13 (Rau). Specifically, the analyses show that if a crack initiated, it would propagate from the corner at an angle of 45° and would arrest within 0.4 inch when the stresses become fully compressive. Tr. 25,100, 25,343-45, 28,819 (Rau); McCarthy et al. (Supp.), ff. Tr. 24,372, at 13. This conclusion is strongly supported by the experience with the inferior EDG 103 block, which operated more than 1200 hours, including more than 400 hours at or above 3500 kw, wherein the circumferential cracks did not propagate to a depth beyond 3/8 inch and did not impair engine operation. Id. at 13.

B-74. Although Dr. Bush testified that he would not be surprised if circumferential cracks initiated in the EDGs, he concluded, based on his engineering judgment, that the stresses decrease rapidly with distance into the block top and move into a compressive stress field. Tr. 26,021, 26,149-52, 26,225, 26,279 (Bush). He also concluded that this compressive stress field is strong enough so that circumferential cracks, if they initiate, will not propagate to the point that they impair engine operation. Bush et al., ff. Tr. 25,775, at 8; Tr. 26,019-21 (Bush).

B-75. SC witness Anderson testified that he observed multiple, small, disconnected cracks branching out below the tip of the 3/8 inch circumferential crack on the original 103 block, and that he did not see extensive amounts of Widmanstaetten graphite in the sample he examined from the original EDG 103 block. Anderson et al., ff. Tr. 25,565, at 11-12. Neither Dr. Rau nor Dr. Wachob, LILCO consultants from FaAA, observed any branching cracks. Tr. 25,096 (Rau, Wachob). Dr. Anderson's observations many have been unreliable because they were made on a rough cut surface that had not been metallographically polished. See Tr. 26,354 (Anderson); Tr. 25,097-98 (Rau, Wachob); Tr. 26,666 (Rau). Complete, accurate and detailed examination of gray cast iron requires careful metallographic polishing because flakes of graphite are broken out of the iron when it is cut, leaving artifacts which appear as shallow holes or trenches in the surface of the iron. Tr. 26,663-64 (Anderson); Tr. 26,666-68 (Rau). These artifacts make it impossible to draw reliable conclusions about the presence or size of cracks or the amount of Widmanstaetten graphite present. Tr. 25,097-98, 25,138-40, 26,666 (Rau). Liquid penetrant, magnetic particle and eddy current testing of the sample examined by Dr. Anderson established that there were no cracks deeper then 3/8 inch. Tr. 25,139-40, 26,667 (Rau). Because Dr. Anderson's only basis for concluding the circumferential crack in the original EDG 103 block was propagating was his unreliable visual observation of branching cracks, Tr. 26,409 (Anderson), there is no sound basis for his conclusion that circumferential cracks propagate.

B-76. SC's witnesses also testified that the development of a large circumferential crack could permit some up and down movement of the cylinder liner against the gasket that seals the liner to the cylinder head. They postulated that this could cause leakage of combustion gases into the jacket water, and that crack propagation through the liner landing would cause the cylinder liner to fall into the crankcase. Anderson et al., ff. Tr. 25,565, at 13; Anderson et al., ff. Tr. 26,326, at 3. This testimony, based on Dr. Anderson's incorrect and unsupported conclusion that circumferential cracks propagate, is not probative.

B-77. Even if crack propagation beyond 3/8 inch were assumed to occur, SC's claim that combustion gases could escape into the cooling water system is far-fetched. Tr. 26,216-17 (Henriksen). SC witnesses have performed no calculations or analyses of stresses in the block top to support their claim. Tr. 26,355, 26,370-71, 26,373-75 (Eley, Anderson). Since at least one-third of the circumference of the liners is supported by eight gusset-reinforced stud bosses, Tr. 25,100, 25,246-47 (Wells); see also LILCO Ex. B-9 and Staff Ex. 9, a circumferential crack would have to propagate vertically four to five inches to cause appreciable motion between the cylinder liner and the block. The chances of this occurring are remote. It contradicts both the physical observations and FaAA's finite element analyses, which demonstrate cracks propagate at about a 45° angle, move into a compressive stress field, and arrest. Tr. 25,095-96, 25,100-01, 25,246-47 (Wells); Tr. 28,812-13, 28,819 (Rau); LILCO Ex. B-64.

B-78. Even if combustion gases did leak, they would not necessarily enter the water jacket because there is virtually no driving force to push the gases into the cooling system. Tr. 26,217-19 (Henriksen). Moreover, if combustion gases did enter the cooling system, they would cause no operational problem because the gases would be released into the expansion tank. Tr. 26,218-19 (Henriksen).

B-79. SC's claim that the cylinder liner landing could separate from the block, causing the cylinder liner to fall into the crankcase, is improbable because, as noted previously, a crack would have to propagate vertically four to five inches through the gusset-reinforced stud bosses to cause the liner landing to separate from the block. If a circumferential crack propagated at a 45° angle from the liner landing through all the ligament material to the stud hole, it would still not affect the ability of the block material to support the cylinder liner. Tr. 25,100-02, 25,104-06 (Wells, Rau); see LILCO Ex. B-9.

B-80. The evidence supports the conclusion that the EDGs are qualified for nuclear service, even if circumferential cracks should initiate. McCarthy et al. (Supp.), ff. Tr. 24,372, at 12-14; Tr. 28,812-13, 28,818-19 (Rau); Bush and Henriksen, ff. Tr. 25,775, at 7;

Bush, Staff Ex. 14 at 25-26; Tr. 26,020, 26,023 (Bush); Tr. 26,020 (Berlinger). LILCO and the Staff have agreed that a scheduled program of monitoring the blocks for circumferential cracks is not required but that LILCO will inspect the block and liner landing area for circumferential cracks in the event a cylinder liner is removed. Bush, Staff Ex. 14, at 26; see Attachment 1. We agree that this is reasonable and adequate.

B-81. We conclude that there is reasonable assurance that the circumferential cracks will not initiate and propagate sufficiently to impair the performance of the EDGs.

H. EDG 103 Replacement Block

B-82. The County would have us find that the evidence is not sufficient to establish that the EDG 103 replacement block is reliable. SC PF, Cylinder Blocks, at 61. LILCO believes the block is capable of performing its intended function. LILCO PF, Cylinder Blocks, at 26. The County and the State "do not challenge the adequacy of the replacement block for EDG 103, if loads do not exceed 3230 kilowatts, which assumes a maximum instrument error of plus or minus 70 kilowatts." Tr. 28,800 (Dynner).

B-83. In spite of this statement of lack of challenge, the County proceeds to challenge, regardless of power level, the adequacy of testing of the replacement EDG 103 block. The County accepts that the design changes in the replacement block enhance its strength over EDGs 101 and 102. It complains, however, that LILCO has provided no quantitative analysis upon which it can measure that enhancement. SC PF, at 2. We need no such quantitative analysis, however, since we find both that the EDG 101 and 102 blocks are acceptable and that the EDG 103 replacement block is superior; SC has provided no analysis or other basis for concluding otherwise.

B-84. SC's stipulation that the replacement block is adequate at 3230 kw is, for all intents and purposes, a recognition that the replacement block is acceptable for nuclear service at the qualified load of 3300 kw. LILCO Exhibit B-30, which plots the principal stresses vs. load recorded by strain gauges nos. 11-13, demonstrates that the difference in stresses in the block between 3230 kw and 3300 kw is almost imperceptible. See LILCO Ex. B-30. Given that the difference in stresses between 3230 kw and 3300 kw is insignificant even if a 70 kw meter error is assumed and, further, given the evidence that the meter actually provides a reliable mean load, and SC's stipulation, we conclude that the replacement block is adequate for nuclear service at the 3300 kw qualified load.

B-85. Apart from SC's stipulation, the evidence demonstrates the replacement block is a proven design that has been adequately tested. FaAA's review of the replacement block shows that this block is a current production model, not a new design as alleged by SC. The product enhancements incorporated in the replacement block -- lengthening the stud bosses, thickening the block top, and increasing the clearance gap -- are relatively minor, yet they reduce the stresses in the block top and make the block more resistant to fatigue crack initiation. Johnson et al., ff. Tr. 28,799, at 8; see McCarthy et al., ff. Tr.24,372, at 68-71. In addition, the use of Class 45 gray cast iron in the replacement block further reduces the possibility of fatigue cracking. McCarthy et al., ff. Tr. 24,372, at 69-70.[10/]

B-86. The improved fatigue resistance provided by the product enhancements incorporated in the replacement block has been tested and proven in the TDI R-5 test engine. The R-5 test engine has been operated for more than 5000 hours at loads exceeding the full rated load (3500 kw) of the Shoreham engines. McCarthy et al., ff. Tr. 24,372, at 70-71; Johnson et al., ff. Tr. 28,799, at 8; Tr. 24,879-84 (Wells). Inspections after this operation revealed only one ligament crack, and this crack occurred in a cylinder where an improper cylinder liner had been installed. Tr. 24,885 (Wells); Tr. 25,373-81 (Wachob).

10/ Tensile tests on the B-bar for the replacement block demonstrated that the cast iron actually meets or exceeds the requirements for Class 50 material. Tr. 24,764-65 (Wachob); Tr. 24,766 (Pau); see also Tr. 24,874-75 (Wells).

B-87. The adequacy of the design enhancements incorporated into the replacement block has also been demonstrated by operation of the EDG 103 replacement block at Shoreham for more than 849 hours. The block has been operated for more than 577 hours at or above 3300 kw, including more than 70 hours at or above 3500 kw, without developing ligament or stud-to-stud cracks. Johnson et al., ff. Tr. 28,799, at 5-6. This operation confirms that the design enhancements have reduced the possibility of fatigue crack initiation. It is also a direct demonstration that the replacement block has been adequately tested. Id. at 8-9.

B-88. FaAA's cumulative damage analysis also demonstrates that the replacement block is capable of performing its intended function. FaAA's conservative analysis of the EDG 101 and 102 blocks at the 3900/3500 kw LOOP/LOCA loads has demonstrated that these blocks, which have known ligament cracks, can withstand 50 consecutive 3900/3500 LOOP/LOCAs. Since the replacement block has superior mechanical properties and has not developed ligament cracks after operating at an approximately equivalent number of hours as the EDG 101 and 102 blocks, it has demonstrated even greater margin against fatigue cracking. Id. at 8-9; McCarthy et al., ff. Tr. 24,372, at 70-71. Thus, the replacement block will perform its intended function at 3300 kw, as well as at loads up to its overload rating (3900 kw) for brief periods of time. Johnson et al., ff. Tr. 28,799, at 11-12; McCarthy et al., ff. Tr. 24,372, at 75; Bush, Staff Ex. 14, at 24-25.

B-89. We conclude that the replacement block for EDG 103 is a proven design, that it has been adequately tested and is acceptable.

I. TDI EDG Block Top Inspections[11/]

B-90. LILCO's commitments and Staff concurrence and recommendations contemplate inspection criteria that would be effective over many fuel cycles. We are approving Shoreham operation for only one fuel cycle, but nevertheless agree that certain inspections are required. The presence of ligament cracks between the cylinder counterbore and the stud holes increases the stresses present in the block top between the stud holes (thereby increasing the possibility of stud-to-stud cracking). McCarthy et al., ff. Tr. 24,372, at 59. Since EDGs 101 and 102 already have ligament cracks, close surveillance is necessary. Since EDG 103 has now had extensive operating experience at the qualified load or higher, and no ligament cracks are present, eddy current testing between adjacent cylinder heads of the EDG 103 block is not required during the first fuel cycle. At the first refueling outage, we are requiring the same block top inspection of EDG 103, including removal of two cylinder heads, as for EDGs 101 and 102, to

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11/ See Attachment 1, which describes the agreement reached by LILCO and the NRC Staff.

provide further assurance that any ligament cracks will be detected and evaluated.

B-91. We summarize our conclusions on the minimum block top inspections required as follows:

A. During the first fuel cycle:

1. EDGs 101, 102 and 103

a. During any period of continuous operation following automatic diesel generator initiation, LILCO will perform daily visual inspections of the area between adjacent cylinder heads and the general block top. LILCO will also perform visual inspections of the same areas under intense light during the monthly surveillance testing.

b. LILCO will perform a liquid penetrant and, as appropriate, UT inspection of the cylinder liner landing at any time a cylinder liner is removed for any other reason.

2. EDGs 101 and 102

LILCO will perform eddy current testing between adjacent cylinder heads after any operation of EDG 101 or 102 at greater than 1800 kw.

B. Following any LOOP event during the first fuel cycle, and during the first refueling outage, LILCO will inspect the top surface of the block exposed by the removal of two appropriate cylinder heads from each of the three EDG engines. Inspections will be by liquid penetrant, with eddy current for any identified cracks, to determine the presence of new cracks and the depth of any new or old cracks.

C. Following the first fuel cycle, the Staff should re-evaluate the TDI EDG block top inspection requirements.

BLOCK TOP INSPECTIONS

I. LILCO COMMITMENTS

1. During any period of continuous operation following automatic diesel generator initiation, Lilco will perform daily visual inspections of the area between adjacent cylinder heads and the general block top. Lilco will also perform visual inspections of the same areas under intense light during the monthly surveillance testing.

2. Lilco will inspect the top surface of the block exposed by removal of two cylinder heads each from the EDG 101 and 102 engines at each of the first four consecutive refueling outages. Inspection will be by liquid penetrant with eddy current as appropriate. Based on the results of these inspections, Lilco may request such inspections be terminated after the fourth outage.

3. Lilco will perform eddy current testing between adjacent cylinder heads after any operation of EDG 101 or 102 at greater than 1800 KW.

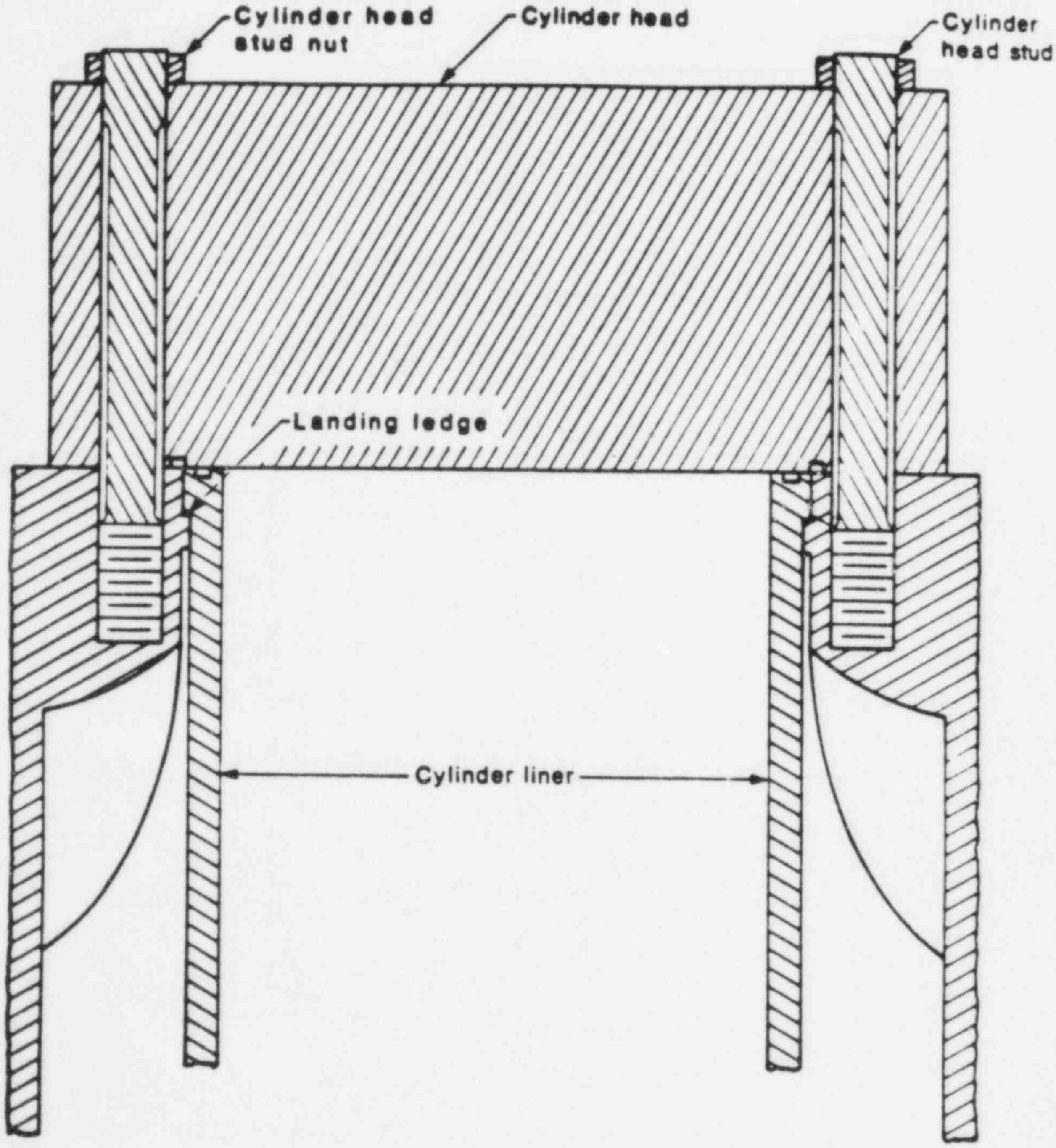
4. Lilco will perform a liquid penetrant and, as appropriate, UT inspection of the cylinder liner landing at any time a cylinder liner is removed for any other reason.

II. NRC STAFF RECOMMENDATIONS

1. The foregoing Lilco commitments satisfy NRC Staff recommendations with respect to block top inspections. Thus, there are no NRC Staff recommendations not accepted by Lilco. In addition to the inspections set forth in paragraphs I.2 and I.3 above, the current SER also recommends that two cylinder heads be removed from EDG 103 at each of four consecutive refueling outages for purposes of inspecting the block top areas. The NRC Staff no longer considers this necessary and intends to issue a revised SER to reflect that removal of two cylinder heads each from EDG 101 and 102 at each of four consecutive refueling outages for purposes of inspecting the block top is sufficient.

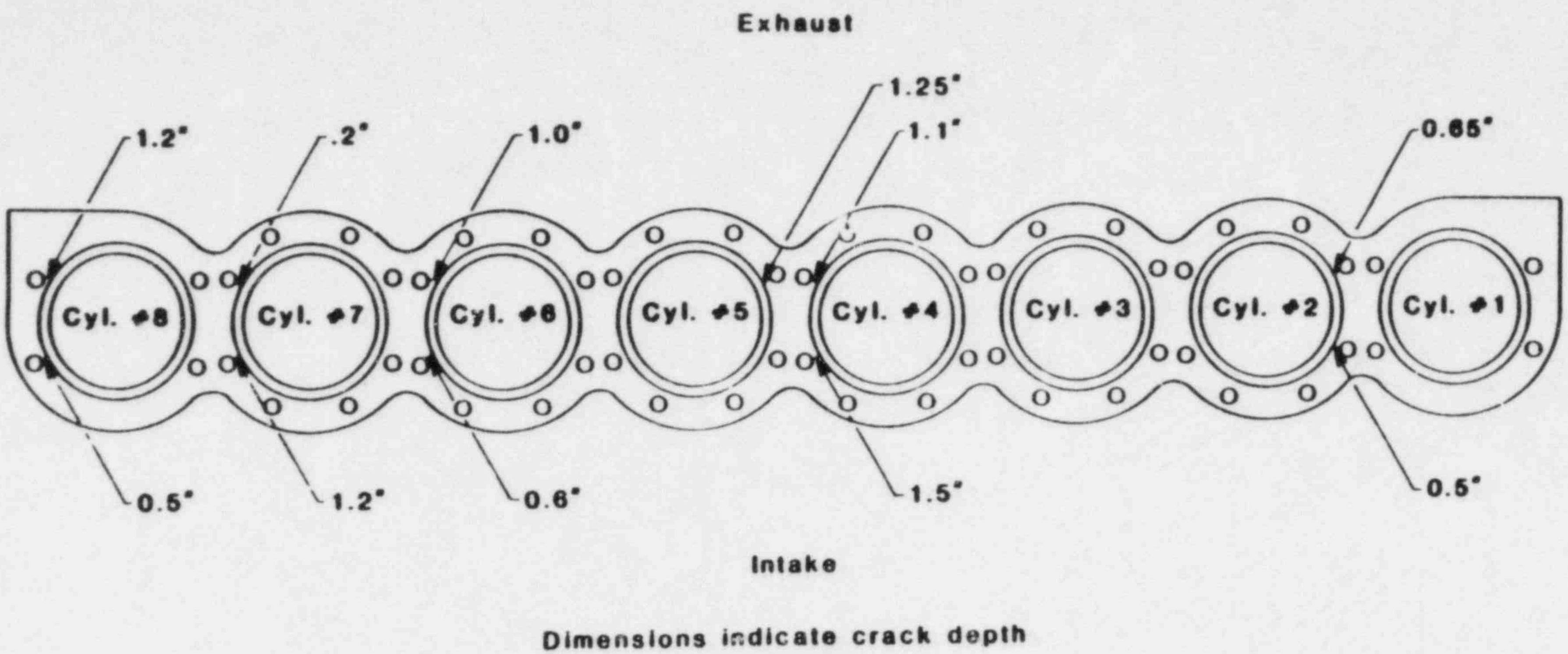
2. It is also agreed by and between the NRC Staff and Lilco that at the conclusion of the fourth refueling outage, the necessity for further inspections in accordance with paragraph I.2 above, if any, will be re-evaluated.

3. It is agreed by and between the NRC Staff and Lilco that because there are no ligament cracks in the EDG 103 replacement block, eddy current testing between adjacent cylinder heads of the EDG 103 block (paragraph I.3 above) is not required.


Cylinder head stud nut
Cylinder head
Cylinder head stud
Landing ledge
Cylinder liner

LILCO Ex. B-7

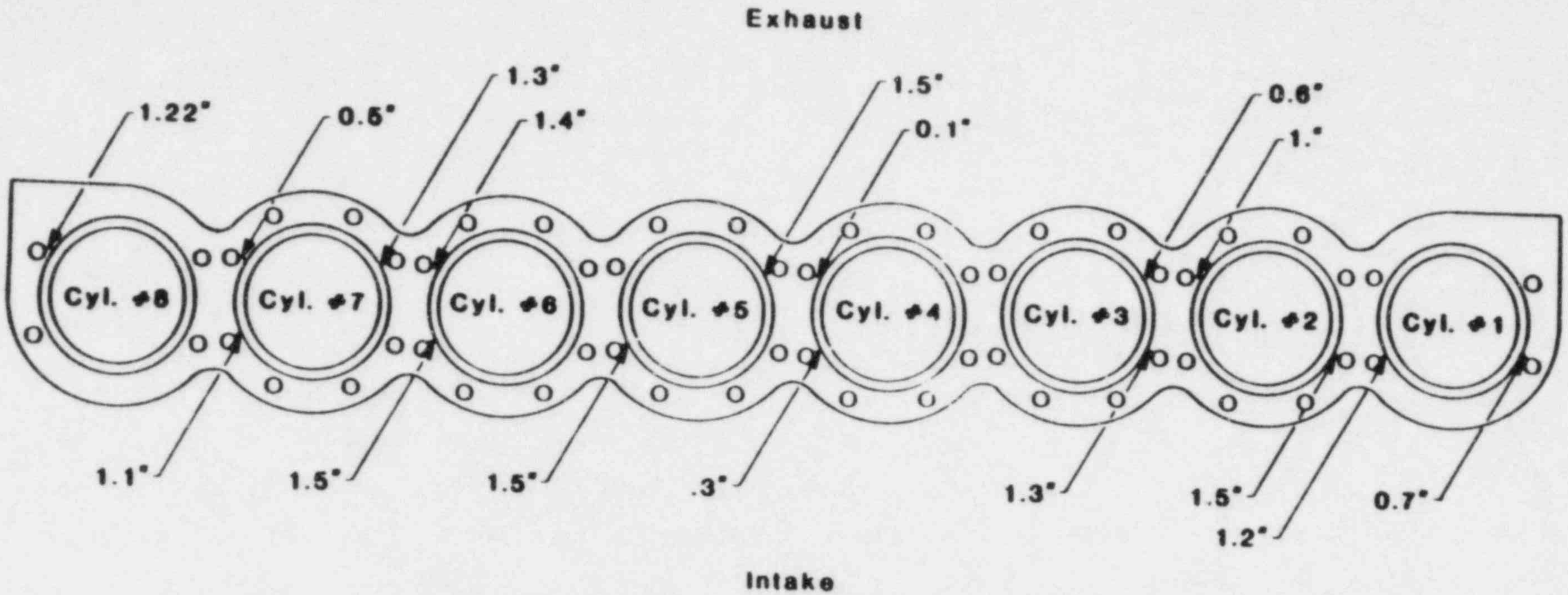
Figure 2.



SNPS DG101 crack map.

LILCO Ex. B-16

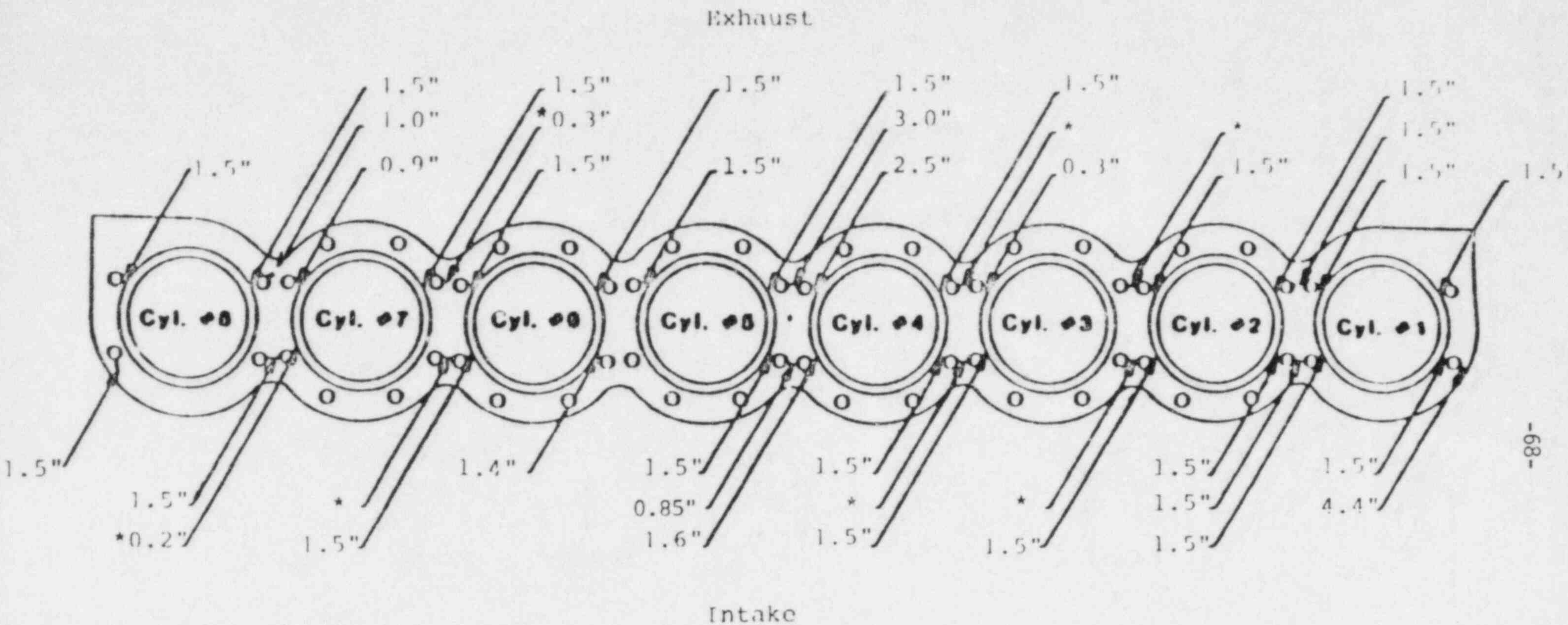
Figure 3.



Dimensions indicate crack depth

SNPS DG102 crack map.

LILCO Ex. B-17



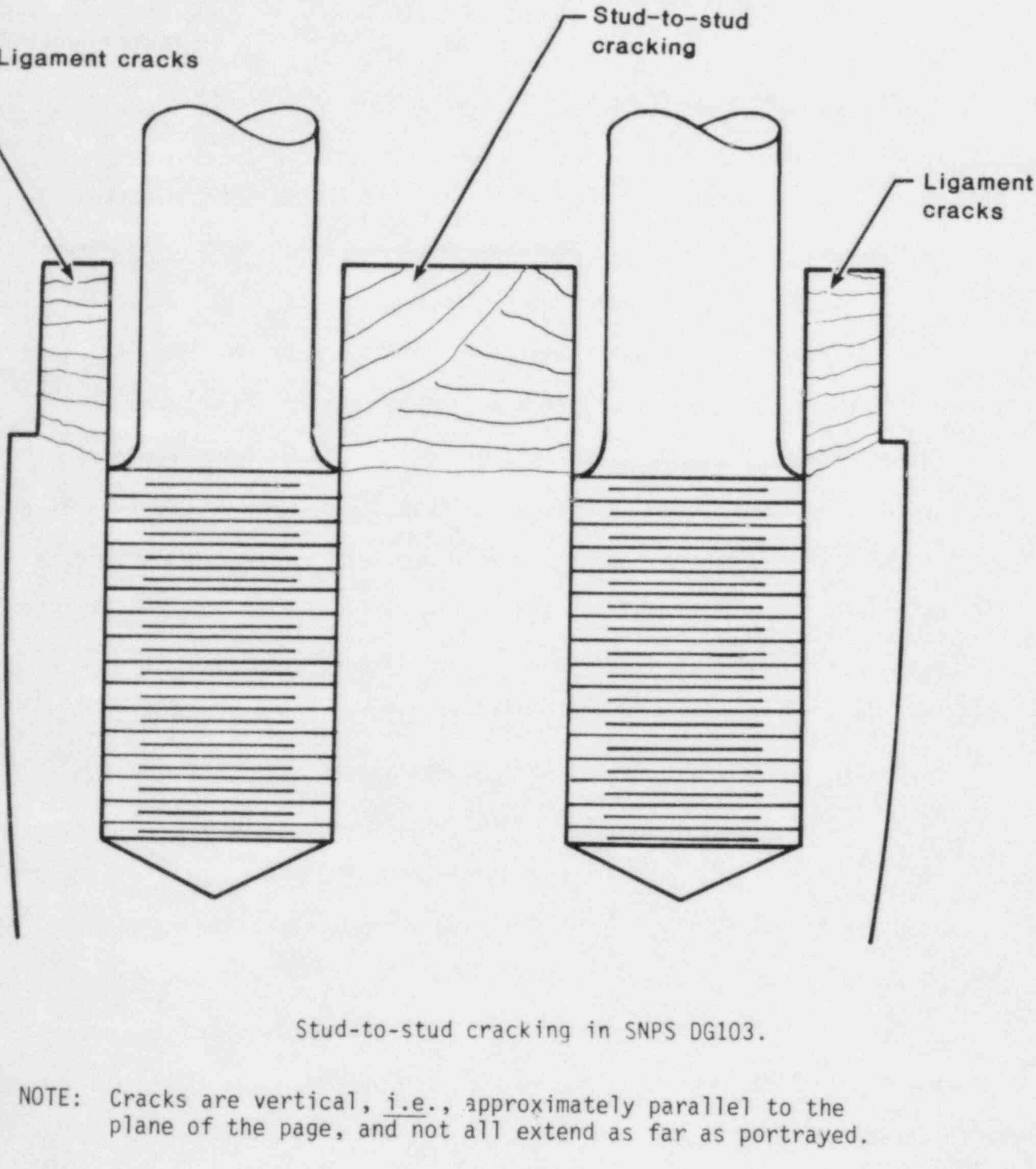
Dimensions indicate crack depth

*Top surface indication. No depth to crack measurable down stud hole.

SNPS DG103 crack map as of 9/22/84.

LILCO Exhibit B-25

Figure 4.



Stud-to-stud cracking in SNPS DG103.

NOTE: Cracks are vertical, i.e., approximately parallel to the plane of the page, and not all extend as far as portrayed.

III. CRANKSHAFTS

A. Summary and Introduction

C-1. As a result of changes in circumstances since the initial litigation (in September and October 1984) of the contention challenging the adequacy of the replacement crankshafts in each of the three TDI EDGs at Shoreham, this once complex issue can now be resolved in a relatively simple and straightforward manner for the first fuel cycle. Rather than seeking approval for a design load of 3500 kw, LILCO now proposes to operate the EDGs at a qualified load of only 3300 kw. Based on the 10E7 cycle (745 hour) endurance run test of the EDG 103 replacement crankshaft at and above 3300 kw, and the stipulation of the County that it does not challenge the adequacy of the crankshafts for continuous operation up to 3300 kw (Tr. 28,417-18 (Dynner) and Joint Report of Parties, dated February 8, 1985), there is no dispute that so long as LILCO operates within the limitations of the 3300 kw qualified load, there is reasonable assurance that the crankshafts will not fail so as to prevent the EDGs from performing their required safety function.

C-2. As set forth in the portion of this decision on the qualified load contention, there is reasonable assurance that the EDGs will not be operated at load levels in excess of 3300 kw in the event they are needed during plant operation due to a loss of offsite power (LOOP), even in the presence of the design basis loss of coolant accident

(LOCA). As also set forth in our qualified load findings, the permissible surveillance testing (1 hour per month) load range of 3300 ± 100 kw, will not result in a load which departs by either a significant amount or for a significant time from the 3300 kw load. Moreover, even if we make the highly unrealistic assumption that the operators do not control the load, so that it is actually at 3400 kw throughout all of the tests, this would still result in only approximately 18 hours (about 0.25 X 10E6 cycles) of operation before the crankshaft inspection during the first refueling outage.[12/] For the reasons discussed in this section, although we do not find the crankshafts acceptable for unlimited continuous operation at 3400 kw, we do find that such additional time of operation at loads between 3300 and 3400 kw that might occur during testing is not likely to lead to failure of the crankshaft in the absence of any prior damage indications.

C-3. In the face of disagreements between LILCO's experts and those for the NRC Staff and the County about whether the crankshafts were acceptable for the originally proposed continuous diesel rating of 3500 kw, we granted LILCO's motion to reopen the record in order to permit LILCO, inter alia, to conduct an "endurance run" test of the EDG 103 replacement crankshaft at 10E7 cycles (740 hours). LILCO chose to

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12/ Due to the flexibility of ± 100 kw which we permit for the surveillance tests, we include EDG 103 in the first refueling outage crankshaft inspections, as set forth at the end of this section.

conduct this test at a "qualified load" of 3300 kw, as described in our findings on the qualified load, taking credit for about 220 hours previously run at 3500 kw or higher, and an additional 525 hours run (between October 8 and November 2, 1984) at approximately 3300 kw. Dawe et al., ff. Tr. 27,153, at 38-39; Pischinger et al., ff. Tr. 28,416, at 5. Inspections of the crankshaft after this endurance run disclosed no indications of damage. Pischinger et al., ff. Tr. 28,416, at 8. This conscious choice by LILCO to conduct the test at 3300 kw limits the qualified load to this value, regardless of any analyses by LILCO which purport to support higher values. LILCO cannot seriously expect the Board, in the face of the conflicting analyses, to be less prudent than LILCO itself and permit a higher qualified load. LILCO PF Crankshafts (April 4, 1985), 6-7. We do not intend criticism of LILCO's selection of 3300 kw for the qualified load, since it is appropriate for LILCO to have been prudently conservative in selecting a qualified load which we find is as high as is needed for operational purposes through the first fuel cycle, rather than risk crack initiation and cumulative fatigue damage now or in the future due to extensive testing at an unnecessarily high load. We do find, however, that the other analyses provide reasonable assurance that operation for short periods of time, if necessary, up to 3400 kw, will not result in fatigue failure of the crankshafts.

C-4. The replacement crankshafts which are the subject of this decision have a 13 inch diameter main journal and a 12 inch diameter crankpin, with 3/4 inch crankpin fillet radii. The original crankshafts were 13 X 11 inches, with 1/2 inch crankpin fillet radii. The original EDG 102 crankshaft severed during testing on August 12, 1983, through the crankpin and rear web under cylinder No. 7. Inspections showed that the original EDG 101 crankshaft was cracked at the No. 5 and 7 crankpins, and that the original EDG 103 crankshaft was cracked at the No. 6 crankpin. McCarthy et al., ff. Tr. 22,610, at 7-8; Anderson et al., ff. Tr. 23,826, at 106-107. The cause of the crankshafts' failure and cracks was determined by LILCO's consultant, Failure Analysis Associates (FaAA), to be high cycle vibratory fatigue. The torsional (twisting) stresses imposed on the crankshafts during operation exceeded their fatigue endurance limit. Id. Contrary to TDI's erroneous certification, LILCO and its consultants determined that the original crankshafts did not meet the LILCO procurement specification that they comply with the Diesel Engine Manufacturers Association (DEMA) standards for allowable crankshaft vibratory stress under even less conservative calculations of such stresses than are now generally performed. LILCO Ex. C-2; Tr. 22,840 (Johnston); Tr. 22,841 (Chen).

B. Adequacy of the Crankshafts for Loads Over 3300 kw Under DEMA Standards

C-5. The parties had disputed the proper standards against which to judge the adequacy of the replacement crankshaft for loads over 3300 kw. However, all the parties, in effect, take the position that if the crankshafts do not comply with the DEMA recommendations for torsional vibratory stress, they are not acceptable. DEMA is a trade association of American diesel engine manufacturers. Berlinger et al., ff. Tr. 23,126, at 10. Albeit in an obscure way, the DEMA recommendations are the only ones referred to by an NRC regulatory document. NRC Staff Regulatory Guide 1.9, Revision 2 (1979) (LILCO Ex. C-3), which addresses the design of standby diesel generators, states in general that conformance with the requirement of the Institute of Electrical and Electronics Engineers (IEEE) Standard 387-1977, which addresses the same subject as the Regulatory Guide, is acceptable for meeting NRC Staff requirements. In turn, IEEE Std. 387-1977 (LILCO Ex. C-4), Section 4 "Reference Standards," lists, as item [5], the DEMA Standard Practices as one of the standards to which diesel generators "shall conform to the applicable portions of". McCarthy et al., ff. Tr. 22,610, at 11-12. Although not in evidence, the Board notes that the updated IEEE Std. 387-1984 softens the required adherence to DEMA (and the other section 4 references) by merely listing them under the label "4. References" with no exhortation of conformance.

C-6. The DEMA recommendations for allowable crankshaft vibratory stress (LILCO Ex. C-14, at 54-55) state:

* * *

> In the case of constant speed units, such as generator sets, the [design] objective is to insure that no harmful torsional vibratory stresses occur within five percent above and below rated speed.

> For crankshafts, connecting shafts, flange or coupling components, etc., made of conventional materials, torsional vibratory conditions shall generally be considered safe when they induce a superimposed stress of less than 5000 psi, created by a single order of vibration, or a superimposed stress of less than 7000 psi, created by the summation of the major orders of vibration which might come into phase periodically.

McCarthy et al., ff. Tr. 22,610, at 20. DEMA last revised its Standard Practices in 1972. Tr. 22,689 (Chen); Tr. 23,238 (Sarsten). However, LILCO's consultant, Dr. Chen of Power & Energy International (PEI), testified that these limits were established in 1959 and the "conventional material" referenced (in the standards) would be SAE 1045 steel with an ultimate tensile strength (UTS) of 70,000 psi (Tr. 22,710-11 (Chen)), which is less than the UTS of at least 100,000 psi in the replacement crankshafts. McCarthy et al., ff. Tr. 22,610, at 9. We have no basis to vary the DEMA standards, even if, arguendo, "conventional" material has improved in modern times. Obviously, however, stronger material is less prone to failure for the same loading.

C-7. The main dispute over how to apply DEMA standards centers on the phrase "major orders of vibration." The turning moment on the crankshaft is broken into a series of sine waves (harmonics) which vary over the complete engine cycle, called orders, which describe the shape of the torque input (vs. time) to the vibratory motion of the crankshaft. Tr. 23,496-97 (Sarsten). See also Tr. 23,301 and 23,304 (Sarsten). As just noted, the DEMA standards limit of 7000 psi for the summation of the major orders is about 25 years old. Modern methods of summation of the complex dynamic actions of the orders utilize the vector summation of the first 24 orders, with each order measured at 1/2 amplitude, i.e., one-half peak to peak amplitude, from the one-half order to the twelfth order (i.e., the sine wave which varies twelve times for each engine cycle of two crankshaft revolutions). This modern approach is the one generally used to assess the crankshaft stress values under other calculational methods. E.g., Tr. 23,326-27, 23,498, 23,250-53, 23,283-86 (Sarsten); Tr. 22,798 (Pischinger).

C-8. LILCO's witnesses maintain that the proper approach is to use the methods in existence when the DEMA value of 7,000 psi was established, which, among other differences with more modern methods, would sum only the most significant four or six orders. Tr. 22,729-30, 22,832, 23,018-19 (Chen); Tr. 22,851-53 (Johnston). Dr. Chen, using six orders, calculated that the stress was well below 7,000 psi at 3500 kw for the synchronous engine speed of 450 rpm, as well as for the 5 percent underspeed (427.5 rpm) and 5 percent overspeed (472.5 rpm) values, as follows:

Engine Speed (RPM)	Nominal Stress (PSI)
427.5	6232
450	5101
472.5	5673

McCarthy et al., ff. Tr. 22,610, at 29-30. Dr. Chen also summed twelve orders at 3500 kw as a further conservatism, in his view, with the calculated stress result of 6020 psi at 450 rpm. LILCO Ex. C-18, at 10.

C-9. We are willing to accept the fact that Dr. Chen is knowledgeable about how compliance with DEMA standards was calculated in the past. However, the DEMA standards use of "major orders" is vague, the standards are old, the reference to it in the 1977 IEEE Std. 387 was general and not prominent to begin with, and any exhortation of compliance with DEMA standards has been removed in the 1984 IEEE Std. 387. LILCO produced no direct interpretation from DEMA of how it should be applied today, apparently because the nature of the collegial DEMA organization provides no mechanism for giving one. Tr. 22,692-93, 22,701-04 (Chen).

C-10. In the circumstances of this uncertainty, it is reasonably prudent to accept Professor Sarsten's approach at least where, as in the case before us, use of all of the first 24 orders, as opposed to only the first six or twelve orders, would make a significant difference in the result of whether the crankshaft complies with the DEMA limit. Tr. 23,297-99 (Sarsten); see also 23,309-10 (Sarsten). Indeed, although emphasizing that his purpose was not to judge compliance with DEMA, FaAA's expert Dr. Johnston thought it "prudent to follow up . . . with a more complete analysis" using a summation of the 24 orders. Tr. 22,737 (Johnston).

C-11. The Board observes, in passing, that when the DEMA standards were first issued, computer technology was not yet sufficiently developed to permit easy calculations involving more than a few orders. Tr. 23,018-19 (Chen); Tr. 23,282 (Sarsten); Tr. 22,989-90 (Pischinger). Where the results of calculations exist for 24 orders, there is no reason not to acknowledge those results.

C-12. The experts agree that shaft number 6, the portion of the crankshaft between the crankpins for cylinder numbers 5 and 6, turns out to be the most critical for torsional stress. Staff Ex. 2; LILCO Ex. C-17, at 3-15. The Staff's values for shaft 6 at 3500 kw are:

Engine Speed (RPM)	Nominal Stress (PSI)
427.5	7,051
450	7,096
472.5	7,851

Tr. 23,358-59, 23,380-81 (Sarsten). This represents close agreement with FaAA's calculation, using 24 orders, of 7,006 psi at the synchronous speed of 450 rpm for 3500 kw (LILCO Ex. C-17, at 3-15; Tr. 22,735, 22,888 (Johnston)), with a similar result of 7,000 psi plus or minus 3 percent between the 5 percent underspeed and overspeed values. Tr. 22,834-35 (Johnston); LILCO Ex. C-17, at 2-5. Dr. Pischinger's preliminary calculations for 3500 kw, which he would have preferred to have more opportunity to check, resulted in 6240 psi at 5 percent underspeed, 6890 psi at rated speed of 450 rpm, and 7470 psi at 5 percent overspeed. Tr. 22,800-805 (Pischinger, Johnston).

Accordingly, the 7,000 psi DEMA limit is not met within the five percent below and above rated speed at a load level of 3500 kw based on any of these calculations. Moreover, we note that Professor Sarsten's values were properly adjusted to account for appropriate damping values and to agree with the measured value of free-end amplitude for the TDI EDGs. Tr. 23,307-08, 23,380, 23,442-44 (Sarsten). Professor Sarsten's method of calculation resulted in a free-end amplitude value of 0.690 degrees, which was in closer agreement with LILCO's actual measured free-end amplitude value of 0.693 than those calculated by FaAA (0.662), Dr. Pischinger (0.665) and Dr. Chen (0.59). Tr. 23,443-44 (Sarsten); Tr. 22,815-16 (Pischinger); Tr. 22,858 (Chen). This gives us confidence that it is reasonable and prudent to rely on Professor Sarsten's higher values. Tr. 23,443-44 (Sarsten).

C-13. The remaining purpose in discussing the torsional stress calculations, given our view at the outset (Finding C-3, above) that LILCO's action in selecting the 3300 kw load for its endurance test speaks louder than words as to the prudent permissible load rating for continuous operation, is to ascertain what light Professor Sarsten's conservative approach would shed on possible short term operation of the diesels at loads between 3300 and 3500 kw. Stress levels at lower loads were testified to by Professor Sarsten before the reopened hearing.[13/] No further testimony was offered by any party on compliance with DEMA standards at load levels between 3300 and 3500 kw, at the reopened hearing. Professor Sarsten testified that based on preliminary calculations, the corrected value for 3300 kw at the synchronous speed of 450 rpm is 6,456 psi. Tr. 23,378 (Sarsten). By interpolation (which is an appropriate method, Tr. 23,377 (Sarsten)) between this value for 3300 kw and the value noted above for 3500 kw, we can conclude on the basis of Professor Sarsten's preliminary calculations at least, that for 3400 kw the torsional stress value at the rated speed of 450 rpm would be approximately 6776 psi. However, within the range of the 5 percent overspeed of 472.5 rpm, at around 466 rpm, the 7,000 psi is exceeded for even the 3300 kw load level (Tr. 23,382-83 (Sarsten), with an approximate value of 7,356 psi, based on the Board's interpolation between the overspeed value of 7,108 psi for 3200 kw (Tr. 23,377 (Sarsten)) and the overspeed value for 3500 kw of 7,851 psi as noted above. The 5 percent overspeed stress at 3400 kw, based on the above interpolation, would be approximately 7603 psi.

C-14. The DEMA requirement for the torsional stress calculations in the speed range from 5 percent below synchronous speed to 5 percent over

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13/ The untimely death of Professor Sarsten in February 1985 prevented testimony by him at the reopened hearing.

rated synchronous speed was not well focused on in the hearing, other than the obvious fact that the DEMA recommendation itself (as quoted in Finding C-6 above) and the IEEE Std. 387-1977 contain this requirement. LILCO Ex. C-4, at 11, § 5.6.1.2. (This requirement remains in IEEE Std. 387-1984, at § 5.5.1.2). Given this requirement, we cannot conclude that the replacement crankshafts meet the DEMA standards for operation above 3300 kw. Indeed, if in the future LILCO would seek to justify a continuous load level higher than the level of 3300 kw which was removed from controversy by stipulation, the appropriate regulators should assess what assurance exists for acceptability over the full range of 5 percent under to 5 percent over rated speed; for example, it may be that an endurance test run by itself would not be informative with respect to underspeed and overspeed conditions.

C. Other Calculational Methods

C-15. We have given serious consideration to FaAA's fatigue analysis which utilized the actual experience of the failed original crankshafts as well as measured data from the original and replacement crankshafts, in a dynamic finite element calculational model of the torsional stress. See, for a summary, McCarthy et al., ff. Tr. 22,610, at 32-41. In general, we were favorably impressed with the reasonableness of the approach and the bases for the inputs used to determine the maximum stress which the crankshafts will experience and the endurance limit of the replacement crankshafts. Id. at 32. This comparison resulted in a factor of safety of 1.48 at 3500 kw. Id. at 38. Prior to the endurance run, the Staff and the County pointed out that FaAA's reliance on the evidence of the failed crankshafts provides only one limited data point, and also that FaAA relied on limited inputs which nonconservatively determined the endurance limits of the replacement crankshafts, although the County agreed the analysis had some significance. County PF (Nov. 15, 1984), at 66-72; Staff PF (Nov. 27, 1984), at 21-23; see e.g., Tr. 23,402-06, 23,528-29 (Sarsten).

C-16. Notwithstanding this criticism by those who were then advocating the 10E7 cycles endurance test, we now have the evidence of no fatigue damage after the 10E7 cycles endurance run (Pischinger et al., ff. Tr. 28,416, at 8). This and the fact that the mechanism of concern is high cycle torsional vibration fatigue, which can cause initiation of cracks and subsequent failure over time, but not instantaneously, FaAA's fatigue analysis does contribute to the reasonable assurance that: (1) surveillance testing at 3300 kw ± 100 kw would not lead to failure of the crankshafts prior to detection of cracks during refueling outage inspections; and (2) allowance of a very small number of hours of operation over 3300 kw but below 3400 kw, in addition to the required surveillance testing, without requiring an earlier inspection than that which will occur during the next refueling outage, is acceptable. For the first fuel cycle, we conservatively set a two-hour limit for cumulative operation of each TDI diesel at loads between 3300 and 3400 kw, in addition to the monthly surveillance tests. If this limit is exceeded, crankshaft inspections required during the first refueling outage must be performed as soon as the plant operating configuration permits the affected diesel to be removed from service. Operation over 3400 kw is not permitted. Any operation over 3400 kw, which is unlikely, based on LILCO's qualified load evidence, triggers the inspection requirement as soon as the affected diesel may safely be removed from service.

C-17. The Staff's metallurgical expert, Dr. Bush, believes that the almost 3 X 10E6 cycles (220 hours) that the replacement EDG 103 crankshaft has been run at loads at or above 3500 kw, followed by 7 X 10E6 cycles at or above 3300 kw (with a small amount of hours slightly below 3300 kw), without any indication of cracks, provide assurance of a probable high cycle fatigue limit at or above 3430 kw. (Dr. Bush uses this value to conservatively account for his assumed plus or minus 70 kw instrument error). Bush and Henriksen, ff. Tr. 28,503, at 4, 16-17. This may be true, but an essential element in Dr. Bush's conclusion is that any cracks caused by exceeding the lifetime torsional fatigue endurance limit of the crankshaft would initiate within 3 X 10E6 cycles, and would propagate (at least to detection, if not failure) within the following 7 X 10E6 cycles at the 3300 kw load. Id. We have no problem with the latter part of this proposition. Indeed, other evidence is that there would be a relatively short time (less than 168 hours of operation) from the time of initiation of a crack to failure of the crankshaft. Tr. 23,064 (McCarthy). And Dr. Bush could be correct about the first part of his assumption. However, it is not well supported in the record before us, and therefore not accepted by us.

C-18. Dr. Bush compiled a table showing examples of actual failures of various objects (some of which were aircraft and automobile engine crankshafts) made of various types of ferrite steels. Id. at 18. His point was that there was a relatively narrow band of cycles for the "beginning of fatigue limit" reported, many at or below 1 X 10E6 cycles, and only one reported as high as around 3 X 10E6 cycles. Id. at 17; Tr. 28,534-35, 28,649 (Bush). However, we agree with the County that the incomplete, almost casual method of compilation of the examples by Dr. Bush (Tr. 28,741-42 (Bush)), and the lack of basis to assure that the examples would be representative of the Shoreham replacement crankshafts (Tr. 28,650-57, 28,739-42 (Bush)), render Dr. Bush's table inadequate for the purpose it was presented. Indeed, this testimony appears to be inconsistent with the Staff's insistence that a test to 10E7 cycles was necessary to assure that the crankshaft had been tested past the "knee" of the S-N curve for all steels to show that there would be no significant damage due to high cycle fatigue for unlimited life of the crankshaft. Berlinger et al., ff. Tr. 23,126, at 17; Tr. 23,526, 23,533-35 (Sarsten); Staff PF (November 27, 1984), at 21. If there was a strong basis for Dr. Bush's conclusion, the Staff could have accepted the already existing 220 hours at a nominal load of 3500 kw, with perhaps a relatively small number of additional hours at the qualified load (about 2 X 10E6 cycles or 148 hours) to assure coverage of the relatively short time from initiation to propagation of any crack to at least a readily detectable level (if not failure).

C-19. In fairness to the Staff, notwithstanding our disagreement that Dr. Bush's table can support the Staff's subsidiary conclusion in its proposed findings that the high cycle fatigue limit for the crankshafts is at or above 3430 kw, the Staff's ultimate conclusion in its proposed findings advocates only permission for LILCO to operate up to 3300 kw, with a plus or minus 100 kw band for the surveillance tests. Staff [crankshafts] PF (April 25, 1985), at 60-61. Both Drs. Bush and Pischinger performed cumulative damage calculations based on the endurance test of EDG 103. Without exploring the details of the calculations, Dr. Pischinger concluded that the replacement crankshafts would have unlimited life at 3505 kw. Similarly, Dr. Bush concluded that the high cycle fatigue endurance limit would be at least 3430 kw, allowing for a 70 kw instrument error. See [crankshafts] LILCO PF (April 4, 1985), at 3-4; LILCO Reply PF (May 2, 1985), at 26-27; County PF (April 15, 1985), at 8-9; and Staff PF (April 25, 1985), at 57-58. The actual experience during the 10E7 cycles endurance run at a nominal 3300 kw and higher loads certainly provides reasonable assurance that operation between 3300 kw and 3400 kw for the number of hours required by the surveillance tests, and a small number of additional hours, would not lead to torsional fatigue failure of the crankshafts before the next refueling outage inspection for possible indication of cracks in the regions of and between the highest stressed crankpin numbers 5, 6 and 7.

D. License Conditions and Technical Specifications

C-20. License conditions and technical specifications for limitations on the load level during operation and for surveillance test runs, and for the first refueling outage inspection of the crankshaft shall be established which are consistent with the minimum requirements as found in this decision. They shall include items 1 and 2 of LILCO's commitments as set forth in the attachment provided by LILCO and appended hereto (with the addition, to item 2, of EDG 103 and inclusion of the main bearing journals between crankpins 5, 6 and 7). Any necessary detailed conditions or implementing technical specifications for the appropriate conditions, along the lines of those attached to the Staff's proposed findings, shall be included in the license. The commitment that there will be a control room alarm to alert operators in the event an EDG exceeds 3300 kw during times other than the surveillance test runs shall also be a requirement of the license.

CRANKSHAFT INSPECTIONS

I. LILCO Commitments

1. At each refueling outage, LILCO will measure and record hot and cold web deflection readings on each of the diesels.

2. At the first refueling outage, LILCO will inspect the crankpin journals numbers 5, 6 and 7 and associated oil holes in these journals, using LP and ET as appropriate. These inspections will only be performed on EDG 101 and EDG 102.

3. During the second and subsequent refueling outages, LILCO will inspect two of the three crankpin journals subject to the highest stresses (Numbers 5, 6 and 7) and associated oil holes in these journals, using LP and ET as appropriate. These inspections will be performed on EDG 101, 102 and 103.

4. At intervals of every 3 refueling outages, LILCO will inspect the main bearing journals and associated oil holes, between crankpin journals numbers 5, 6 and 7, using LP and ET as appropriate. These inspections will be performed on EDG 101, 102 and 103. Based on the results of this first inspection, LILCO may request that such inspections be terminated.

II. NRC Staff Recommendations

1. The foregoing LILCO commitments satisfy NRC Staff recommendations with respect to crankshaft inspections. Thus, there are no NRC Staff recommendations not accepted by LILCO. As opposed to the intervals discussed in paragraph I.4 above, the current SER recommends that inspection intervals for the main bearing journals on EDG 101 and 102 be at the first and all subsequent refueling outages, and for EDG 103, the second and all subsequent refueling outages. The Staff no longer considers this necessary and intends to issue a revised SER to reflect the changes in inspection intervals to those shown in paragraph I.4 above.

2. It is also agreed by and between the NRC staff and LILCO that at the conclusion of the first, 3 refueling outage interval, the necessity for further inspections in accordance with paragraph I.4 above, if any, will be re-evaluated.

IV. QUALIFIED LOAD

A. Introduction

L-1. Intervenors Suffolk County and New York State have contended that:

> Contrary to the requirements of 10 CFR, Part 50, Appendix A, General Design Criterion 17 --- Electric Power Systems, the emergency diesel generators (EDGs) at Shoreham with a maximum "qualified load" of 3300 kw do not provide sufficient capacity and capability to assure that the requirements of clauses (1) and (2) of the first paragraph of GDC 17 will be met, in that:
>
> a. LILCO's proposed "qualified load" of 3300 kw is the maximum load at which the EDG may be operated, but is inadequate to handle the maximum load that may be imposed on the EDGs because:
>
> (i) intermittent and cyclic loads are excluded;
>
> (ii) diesel load instrument error was not considered;
>
> (iii) operators are permitted to maintain diesel load at 3300 ± 100 kw;
>
> (iv) operators may erroneously start additional equipment.
>
> c. The EDG qualification test run performed by LILCO was inadequate to assure that the EDGs are capable of reliable operation at 3300 kw because:
>
> (iii) operators were permitted to control the diesel generators at 3300 kw ± 100 kw during the test;
>
> (iv) instrument accuracy was not considered;

L-2. GDC 17 requires *inter alia* that electric power systems shall have sufficient capacity and capability to assure that:

> "...(1) specified acceptable fuel design limits and design conditions of the reactor coolant pressure boundary are not exceeded as a result of anticipated operational occurrences and (2) the core is cooled and containment integrity and other vital functions are maintained in the event of postulated accidents."

Suffolk County contends that a maximum "qualified load" of 3300 kw for the Shoreham EDGs does not provide this assurance.

L-3. The Staff introduced[14/] the concept of a "qualified load" as an interim licensing basis for TDI diesel engines. The qualified load is that load which bounds the maximum emergency service load (MESL) for the diesel generator at which certain key components of the engine have been successfully operated for at least 10E7 loading cycles. The proposed qualified load at Shoreham is 3300 kw. Dawe *et al*., ff. Tr. 27,153, at 10. The Staff has reached licensing decisions on other nuclear plants with such engines using this approach, but no other engine has been tested this way. Tr. 27,990 (Berlinger).

14/ *See* NRC Staff's Safety Evaluation Report on the Transamerica Delaval, Inc. Diesel Generators Owners Group Plan, August 1984. Dawe *et al*., ff. Tr. 27,153, at 9-10.

L-4. The MESL at Shoreham, defined in Amendment 52 to the License Application (FSAR, Revision 34), is the maximum load existing on any EDG during a loss of offsite power (LOOP) in conjunction with a loss of coolant accident (LOCA). The MESL is determined for the EDG by summing individual loads from all equipment which will be connected for more than short periods of time following initiation of a LOOP/LOCA event. These loads are engineered safety features (ESF) or ESF support equipment which are automatically powered following the start of the EDG in response to LOOP/LOCA initiation signals. Dawe et al., ff. Tr. 27,153, at 8-9. The Staff concluded that the FSAR gives an accurate representation of loads expected to occur in a LOOP/LOCA event. Tr. 27,756 (Berlinger).

L-5. The MESL values at Shoreham were obtained by a combination of actual load measurements and nameplate ratings on components which will be connected to the EDG for more than a short time period following the LOOP/LOCA event. Dawe et al., ff. Tr. 27,153, at 9. LILCO measured 27 loads accounting for 60% of the electrical load calculated for the MESL. It was pointed out that the loads which were not measured were a number of small items of approximately the same value. Tr. 27,515-16 (Youngling).

L-6. LILCO found the nameplate rating to be a reasonable indicator of the loads drawn by the equipment when operating. Of all the loads measured, only one case was found which disagreed with this finding.

This case was the emergency switch gear room air-conditioning units whose measured load was 36.4 kw whereas the rated value was 33.9 kw. Tr. 27,202-204 (Youngling). Although the nameplate ratings were higher in all but one case, the MESL was calculated conservatively using measured loads accounting for only 30% of the MESL load and nameplate ratings for all others. Tr. 27,207-208 (Youngling); Tr. 27,212-213 (Dawe).

L-7. The calculated MESL was based on the assumption that all items of equipment would be required to operate simultaneously at their design values. This is a situation not likely to be realized during a LOOP/LOCA event. Tr. 27,201-202 (Dawe). For example, the MESLs for EDG 101 and EDG 102 each include 235 kw for one RBSVS chiller at nameplate rating while the MESL for EDG 103 includes 470 kw for two chillers at full load. Tr. 27,643 (Dawe). These chillers are oversized for the LOCA condition. In addition to being redundant equipment, they were sized for the greater heat load from a pipe break outside of the containment. There will be insufficient heat load in a LOOP/LOCA event to cause the chillers to operate at full load. Tr. 27,668-71 (Dawe). Thus, the 235 kw included for each chiller in the MESL calculations of peak load will be significantly reduced on an EDG following a LOOP/LOCA. Tr. 27,642-44, 27,649-51 (Dawe).

L-8. The MESLs for the Shoreham diesels are set forth in Table 8.3.1-1A of Revision 34 of the FSAR. Their values are 3253.3 kw for EDG

101, 3208.7 kw for EDG 102 and 3225.5 kw for EDG 103. Dawe et al., ff. Tr. 27,153, at 29. These values were obtained by a combination of actual load measurements and nameplate ratings on components which will be connected to the EDG for more than a short time period following the LOOP/LOCA event. Dawe et al., ff. Tr 27,153, at 9. The Staff concluded that the loads in the FSAR give an accurate representation of loads expected to occur in a LOOP or LOOP/LOCA. Tr. 27,756 (Berlinger).

B. Load Contention (a) (i): The MESL Does Not Include Intermittent and Cyclic Loads

L-9. Suffolk County contends that the qualified load is inadequate because the MESL excludes intermittent and cyclic loads. LILCO reviewed the Staff SER for the TDI Diesel Generator Owners Group Program Plan and concluded that intermittent or cyclic loads should be excluded when determining the qualified load for the EDGs. The Staff agreed. Tr. 27,742 (Berlinger). The County states that such an exclusion is unprecedented. SC PF (April 15, 1985), at L-16.

L-10. Three load groups were excluded by LILCO as intermittent or cyclic loads. They were (a) automatically activated motor operated valves, (b) diesel generator fuel oil transfer pumps and, (c) diesel generator air compressors. Dawe et al., ff. Tr. 27,153, at 12; Knox, ff. Tr. 27,735, at 5. The Staff agreed with LILCO's identification of intermittent loads. Knox, ff. Tr. 27,735, at 5; Tr. 27,764-65, 27,794 (Knox).

Motor Operated Valves

L-11. Automatically actuated motor operated valves are those which receive power from an EDG and operate automatically in the event of a LOOP/LOCA. Dawe et al., ff. Tr. 27,153, at 12-14. Examples of such valves are containment isolation valves, emergency core cooling system injection valves and various system valves used to isolate redundant trains, unnecessary system loads or unwanted flow paths. Id. at 13. Not all of these valves would be expected to reposition following a LOOP/LOCA and represent a load on the EDG. Although each receives actuation signals to ensure proper positioning, many will be in their designed post-accident position during normal operation, and thus will not operate even upon receipt of a signal. Id. Those that do operate generally do so only once and in such cases operation occurs during the first several minutes after the EDG starts. Not all valves that do operate will do so simultaneously. Id.; see also Knox, ff. Tr. 27,2735, at 5-6; Tr. 28,195 (Knox). The intermittent loads associated with unrealistically assumed simultaneous operation of these valves are calculated to be 65.7 kw for EDG 101, 64.3 kw for EDG 102, or 46.7 kw for EDG 103. Dawe et al., ff. Tr. 27,153, at 15.

EDG Fuel Oil Transfer Pumps

L-12. The diesel generator fuel oil transfer pumps transfer oil for the generators from the storage tanks to the day tanks in the diesel generator rooms. Each diesel generator has two associated fuel oil transfer pumps. Only one pump per diesel will operate at a time; the second operates only if the first fails. The preferred pump only operates after the fuel oil level in the day tank has been lowered to a predetermined level by operation of the diesel. The pump will operate for approximately 22 minutes in every 48-minute period during the operation of the diesel in order to maintain the fuel oil level. Dawe et al., ff. Tr. 27,153, at 16. The diesel generator fuel oil transfer pump load is a negligible 0.2 kw per pump. Id.

Diesel Generator Air Compressors

L-13. The diesel generator air compressors are used to recharge the air start receivers. Each generator has two independent, redundant air starting systems. Each compressor will automatically operate after the EDG has energized its associated emergency bus. Following one successful start attempt, each compressor will operate for approximately 15 minutes. Each compressor can recharge its associated air system in 30 minutes following the design capability of five starts. The air compressor load is 12 kw per generator.

L-14. If all intermittent loads, assumed to occur simultaneously, were summed and added to the MESL for each EDG, the predicted loads would be 3331.4 kw for EDG 101, 3285.4 kw for EDG 102 and 3284.6 kw for EDG 103. Dawe et al., ff. Tr. 27,153, at 18.

L-15. LILCO performed an integrated electrical test (IET) with the TDI diesel generators. The IET starts with the introduction of LOOP/LOCA signals and proceeds through the time sequencing and operation of the required loads on the EDGs. Tr. 27,412 (Dawe). The peak loads measured during the IET were 2833.6 kw for EDG 101, 2806.9 kw for EDG 102 and 3072.0 kw for EDG 103. Dawe et al., ff. Tr. 27,153, at 20. These loads are estimated to be within a few percent of the actual loads that would be observed following a LOOP/LOCA (Dawe et al., ff. Tr. 27,153, at 19-20; Tr. 27,219-21 (Dawe)), except that the IET value for EDG 103 is high by a large portion of 358 kw as it included a second reactor building service water pump which is not needed for a LOCA and is no longer automatically connected to the EDGs. Dawe et al., ff. Tr. 27,153, at 20-21. The significant difference between peak loads observed during the IET and the predicted MESLs is due, in large part, to conservatism introduced into the calculation of the MESL by the use of nameplate loads and the assumption of coincident demand. Tr. 27,461-62 (Dawe).

L-16. The Staff witness testified that the IET was not an accurate model of true plant response to an accident but conceded that the IET would give a better estimate of the loads that the plant would have to support in response to an accident than the MESL. E.g., Tr. 28,273 (Berlinger). However, the Staff noted that it did not consider the IET results in its review. Tr. 28,151 (Knox, Berlinger, Clifford, Buzy, Eckenrode). The County's witnesses questioned whether the IET was representative of actual LOOP/LOCA loads but did not present specific information to support their position. Tr. 27,552-54 (Bridenbaugh).

L-17. Based on the testimony presented during the hearing, the Board is persuaded that the MESL is a conservative estimate of the expected EDG loads following a LOOP/LOCA. The results obtained during the integrated electrical test provide an estimate of this conservatism. We believe that intermittent and cyclic loads have been accounted for. In this accounting, the expected loads on any EDG following a LOOP/LOCA are bounded by the MESL in all cases except for short term (less than three minutes) operation of EDG 101 at 31 kw over the 3300 kw MESL. When the conservatism in the MESL is considered, we believe that the EDGs will perform their intended function when called upon to do so, either because 3300 kw will not be exceeded, or if it is, it would only be by a small amount on one EDG for a negligibly short time. See also our crankshaft findings in Section III, supra.

C. Load Contention (a) (ii): Diesel Load Meter Instrument Error Was Not Considered (in the Determination of the MESL), and (c) (iv) Was Not Considered in the (Endurance) Qualification Test at 3300 kw

L-18. Suffolk County contends that LILCO failed to consider instrument error in establishing the qualified load and in running the 3300 kw qualification testing of EDG 103 at 10E7 cycles (745 hours). Bridenbaugh and Minor, ff. Tr. 27,500, at 21-23.

L-19. Each EDG at Shoreham has a Weston wattmeter, located in the control room, which has a full scale reading of 5600 kw. Dawe et al., ff. Tr. 27,153, at 27-28. The specified accuracy of this meter is 2% of full scale and the overall instrument accuracy is 2½% of full scale when combined with the instrument loop. Id.

L-20. As part of the Shoreham instrument calibration program, each wattmeter is calibrated annually, along with its associated instrument loop. Calibration is performed with a reference standard traceable to the National Bureau of Standards. Dawe et al., ff. Tr. 27,153, at 28-29; Tr. 27,266-68, 27,384 (Youngling); Tr. 27,309-10 (Dawe). Calibration checks performed prior to, and following, the EDG 103 qualification run showed that the wattmeter accuracy ranged from ± 60 to 70 kw. Dawe et al., ff. Tr. 27,153, at 28-29; Tr. 27,265 (Dawe).

L-21. During the confirmatory test performed by LILCO on EDG 103 for 10E7 cycles at 3300 kw, load readings were taken both from the

Weston wattmeter and a digital test loop used with a process computer. The accuracy of the test loop is approximately 0.6%. Tr. 27,311-14, 27,423 (Youngling).

L-22. In response to a LOOP/LOCA incident the initial EDG loading is automatic and below the qualified load of 3300 kw. Dawe et al., ff. Tr. 27,153, at 29. The actual load profile following a LOOP/LOCA is bounded by 3200 kw after 12 minutes into the event and by a little over 2600 kw after one hour. This profile includes manual loading of the EDG. Id. at 30. Subsequent operator actions will result in load reduction and it is unlikely that additional loads added by an operator would exceed the qualified load. Id. See subsection IV.D., below.

L-23. During surveillance testing of the EDGs (one hour per month during the first fuel cycle) at 3300 kw, the actual load on the diesel could differ from that indicated by the amount of instrument error. This does not invalidate the surveillance testing since the testing is representative of actual operation. To the extent the test load may be slightly below 3300 kw due to instrument error, the necessary load carrying capability of the EDG is adequately demonstrated. To the extent the qualified load is slightly exceeded during testing as a result of instrument error, the time duration of such loading is not long. Dawe et al., ff. Tr. 27,153, at 31.

L-24. The Board finds that diesel load meter instrument error has been considered and accounted for in the qualification test. Such errors are small and will have no adverse impact on the EDGs in performing their intended function.

D. <u>Contention (a) (iii) and (c) (iii): Operators Were Permitted to Operate With a Test Band of ± 100 kw During the Qualification Test and Will Be Permitted to Do So During Future Surveillance Testing</u>

L-25. Suffolk County contends that a test band of ± 100 kw used in the 10E7 cycle (total of 745 hours) endurance run and intended for use during future surveillance testing at 3300 kw renders the qualified load and the endurance run test results inadequate. It is also contended that the actual endurance run could only be accurate to 3230 kw which accounts for a ± 70 kw error band.

L-26. During the approximately 220 hour segment of the approximately 745 hour endurance run, EDG 103 was operated at loads of 3500 kw and above. Bush <u>et</u> <u>al</u>., ff. Tr. 28,503, at 16; Tr. 28,635 (Bush); <u>see</u> <u>also</u> LILCO Ex. B-15. Review of the operating logs during the approximately 525 hour portion of the endurance run showed 81 hours recorded at loads between 3300 and 3400 kw and 20 hours at loads between 3250 and 3300 kw, with the other approximately 424 hours recorded at 3300 kw. Bush <u>et</u> <u>al</u>., ff. Tr. 28,503, at 11. Dawe <u>et</u> <u>al</u>., ff. Tr. 27,153, at 38. Hence, many more hours of operation were accumulated above 3300 kw than the 20 hours which were at most 50 kw below 3300 kw.

Moreover, the fact of a test band of ± 100 kw in the endurance run did not result in the endurance test being run lower than the qualified load of 3300 kw.

L-27. LILCO witnesses testified that testing of the diesel generator at 3300 kw requires it to be connected to the grid. When the diesel generator is connected to the grid it is difficult to maintain a constant load value due to engine response to fluctuations on the grid and an independent pulsation effect on the meter due to the mode of governor operation. Thus, ± 100 kw is necessary to accommodate these phenomena, which have an actual value between 60 and 100 kw. This is only true when the engine is connected to the grid, however, and not when it is operating in a LOOP situation. Tr. 27,316-21 (Dawe, Youngling).

L-28. As a practical matter, a tolerance band is required. If there were no band, whenever the meter read slightly above 3300 kw, the operator would be in violation of the Technical Specifications. Tr. 27,318 (Dawe); Tr. 27,321-22 (Youngling). The Board finds that utilization of a tolerance band of ± 100 kw in future surveillance testing is appropriate. Moreover, as evidenced by the endurance run, through most of the test the operators should be able to control the load close to 3300 kw. Finding L-26, above. Future routine surveillance testing transiently as low as 3200 kw poses little concern for validity of the test; no such concern was raised by any party or discerned by us. Routine monthly surveillance testing as high as 3400 kw will not result in failure of a crankshaft. See Section III, above.

E. Load Contention (a) (iv): Qualified Load Does Not Encompass Operator Error Load

L-29. Suffolk County asserts in Contention (a) (iv) that the diesels do not comply with GDC 17 because the qualified load of 3300 kw does not possess sufficient margin to accommodate operator errors. Bridenbaugh and Minor, ff. Tr. 27,500, at 28. Essentially, the County's position appears to be that GDC 17 mandates, as a matter of law, the inclusion of a margin within the design load to accommodate potential operator errors. In addition to exploring the relationship of operator actions to GDC 17, the litigation of this contention at the hearing included a lengthy examination of the procedures and training LILCO has developed to protect against operators erroneously attaching loads to the diesels that might result in exceedance of the qualified load of 3300 kw.

L-30. At the outset, one has to assess how compliance with GDC 17 is determined. The Staff testified that such compliance is demonstrated, *inter alia*, by ensuring the plant's design loads do not exceed the capacity and capability of the diesel generators. Knox, ff. Tr. 27,735, at 4. The design load is defined in IEEE-387-1977; this load consists of that combination of electric loads having the most severe power demand from a diesel generator for the operation of engineered safety features and other systems required during and following shutdown of the reactor. Id. The design load, as defined in IEEE-387-1977, does not include loads attributable to operator error. Tr. 27,796-97, 28,174 (Knox); Tr. 28,277-81 (Berlinger, Hodges). Thus such error need not be considered in setting the design load for the diesels.

L-31. In addition to possessing sufficient capacity and capability to power the design loads, the onsite AC power system must also be designed to safely withstand a single failure in order to comply with GDC 17. As a general matter, operator errors are not applicable to the single failure criterion. The purpose of the single failure analysis is to gain greater assurance of system reliability through redundancy; operator reliability can not be assured by such an analysis. Hodges, ff. Tr. 27,735, at 4-6; see also Tr. 27,884-87 (Berlinger). Procedures generally are not relied upon in determining whether the requirements of GDC 17 are met. Tr. 28,274-75 (Berlinger); Tr. 27,882 (Clifford).

L-32. Operator error is included in the single failure analysis to the extent that the cause of any single error can be attributable to operator action as well as to a passive or a mechanical failure. Tr. 27,891 (Hodges); 27,954, 28,149 (Berlinger); Tr. 28,350 (Clifford). For GDC 17 purposes, it thus becomes important to know whether any single operator action can result in the failure of more than one diesel because of overloading. The single worst case load that could be manually added erroneously to each of the three diesels as a result of three separate operator errors following a LOOP/LOCA would result in loads of 3459.4 kw on EDG 101; 3414.8 kw on EDG 102; and 3583.5 kw on EDG 103. Dawe et al., ff. Tr. 27,153, at 32-33. The single worst case load that could be added erroneously following a LOOP would result in loads of 3839.2 kw on EDG 101; 3627.6 kw on EDG 102; and 3867.3 kw on EDG 103. Id. at 33-35.[15/] These loads all exceed the qualified load of 3300 kw. However, there is no single operator action that would result in exceedance of the qualified load on more than one diesel. Id. at 37. Even if such an overload is conservatively assumed to result in a failure of the diesel involved, the onsite system is designed to accommodate the failure of one diesel. Id. Thus only two out of the three diesels are required to safely shut down and maintain the plant. There are three diesels required to be available to meet GDC 17 precisely because of the need for redundancy to meet the single failure criterion. Thus the design of the plant is sufficient to accommodate any single failure attributable to operator error. See also Tr. 27,947-49 (Berlinger); Tr. 28,350 (Clifford).

[15/] It must be kept in mind that the equipment that is needed in the immediate event of a LOOP or LOOP/LOCA will all actuate automatically; it is this equipment that makes up the design load. The equipment that makes up the worst case load that can be erroneously added by operators is not needed for mitigation purposes. Dawe et al., ff. Tr. 27,153, at 34.

L-33. Operator errors need not be accounted for in the design load and, insofar as they are applicable to the single failure criterion, are adequately accounted for at Shoreham. Operator errors are accounted for in the design of the plant in a number of other ways. Hodges, ff. Tr. 27,735, at 4. First, for actions that must be accomplished on a relatively short time scale and are necessary to mitigate transients and accidents, the Staff policy has been to eliminate the need for operator action by automating the action. Id. at 5.[16/] By not challenging the operator with an action in a relatively short time frame, the potential for operator error is greatly reduced, so that it need not be considered in the context of the design. Id. For situations in which operator actions are relied upon for event mitigation, the Staff will ensure that procedures and guidelines provide the necessary guidance to the operator to take the correct actions, and that the operators have been properly trained in the action. Id.

L-34. Much of the hearing was spent on the adequacy of LILCO's procedures and training to minimize the potential for operator overload of the diesels. The question of procedures and training must be kept in context. The question of the design adequacy of the diesels is separate from issues relating to the adequacy of procedures and training. The

16/ The equipment needed to respond in the event of either a LOOP or a LOOP/LOCA is so automatically activated. See n.15, supra.

procedures and training are reviewed to evaluate the capability of plant operators to operate within the design. Procedures thus provide additional assurance, beyond that provided by design, that diesels can be operated safely. Tr. 27,882, 28,343, 28,347, 28,354-55, 27,882-83 (Clifford); Tr. 27,885-57 (Berlinger). However, for the Shoreham diesels, procedures are not necessary to demonstrate compliance with GDC 17. Tr. 28,275 (Berlinger).

L-35. Procedures and training can provide this additional assurance through three mechanisms: procedures should not be written in a manner that will result in operators overloading the diesel, they should enable the operators to take corrective actions if an overload should occur, and the training should adequately address the technical concerns associated with the design load limit. Clifford et al., ff. Tr. 27,732, at 5. Substantial written and oral testimony at the hearing examined in detail the adequacy of the procedures and training insofar as they relate to potential overload of the diesels. The Staff was unable at the outset of the hearing to conclude that the procedures and training at Shoreham were adequate. Id. at 9-10. Many of the Staff's concerns were, subsequent to a site visit, resolved during the hearing. Tr. 28,829-91 (Clifford and Eckenrode). However, the Staff took the position that the performance of a task analysis would be necessary in order to validate and affirm the adequacy of the procedures. Tr. 28,292

(Clifford).[17/] The task analysis was set to be completed in early May; the Staff was to review the analysis in a Supplemental Safety Evaluation Report which was expected to be issued in June 1985. Tr. 28,369-372 (Clifford).

L-36. LILCO's witnesses testified concerning the adequacy of the procedures and training as they relate to maintaining diesel generator loading below the qualified load. LILCO's testimony in this area was provided by witnesses with significant experience related to Shoreham. Dawe et al., Tr. 27,153, at 2-5. These witnesses had participated in the preparation of both the procedures and training. See, e.g., Tr. 27,353 (Dawe); 27,372 (Notaro). They identified a number of emergency operating procedures and system procedures that had been reviewed and, in some cases, revised as a result of establishing the qualified load. Tr. 27,156-61, 27,252 (Notaro). The changes which have been made are mainly added cautions to highlight the diesel generator load. Tr. 27,263 (Dawe); Tr. 27,367 (Youngling); Tr. 27,372, 27,395,

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17/ A task analysis is essentially a specification of all tasks necessary to accomplish actions for a scenario. The task analysis identifies the equipment to be run, the function to be maintained, the systems to be run to maintain those functions, the tasks necessary to operate the equipment and subtasks necessary for the operator to operate switches, monitor instrumentation or parameters that are necessary. The analysis evaluates whether the plant can be operated within the 3300 kw qualified load or whether the operators are capable of operating within that load by going through various combinations of scenarios. Tr. 28,360 (Clifford).

27,454-55 (Notaro). Also the diesel generator load meters in the control room will be banded at 3300 kw. The operators are trained and knowledgeable in the diesel generator qualified load. Dawe et al., ff. Tr. 27,153, at 33, 35; Tr. 27,297-98 (Youngling). In addition, LILCO has committed to provide a distinctive visual and audible alarm for each diesel generator in the main control room that will be set no higher than 3300 kw for operation, other than possibly during the routine surveillance tests. Tr. 27,298-302, 27,333-35 (Youngling).

L-37. In response to a LOOP/LOCA, four procedures (loss of offsite power, level control, emergency shutdown and containment control) may be entered simultaneously. Tr. 27,277-78, 27,368 (Notaro). LILCO testified that there is no manageability concern with the simultaneous use of these procedures by the operators. The NRC has tested the operators in their ability to use and manage the procedures, and they have been licensed. The operators are not confused or misled by the multiple procedures. Tr. 27,434-35, 27,404-05 (Notaro); see also Tr. 27,277 (Notaro). They are typical of the procedures for all BWR plants. Tr. 27,885-87 (Berlinger). The procedures have been verified at the Limerick simulator. LILCO personnel have trained at this simulator for four years. See Tr. 27,401-02 (Notaro).

L-38. LILCO witnesses discussed two types of procedures, emergency operating procedures and system procedures, used to guide the operators in the conduct of plant operations. The pertinent emergency operating procedures have been revised to include cautions as a reminder of diesel generator loading conditions when equipment operation is called for. The system procedures direct the "how to" of system operation once the decision to operate has been made. This decision-making is guided by the emergency operating procedures which have cautions designed to ensure diesel generator loads are considered before actions that can increase load are taken. E.g., Tr. 27,165, 27,171, 27,473-74 (Notaro); 27,170-72 (Dawe).

L-39. LILCO has incorporated the qualified load into its training program. Classroom and simulator training for the licensed operators is part of a requalification training program. A specific lesson plan related to the qualified load has been developed for classroom training. At the simulator, the operators will use the revised procedures, thus operating with the (equivalent of the) 3300 kw qualified load. Classroom training related to the qualified load began in mid-February 1985 and was to take six weeks to complete for all six operating crews. The simulator training follows the classroom training in the next six-week cycle. Tr. 27,177-79, 27,262, 27,353, 27,361, 27,373, 27,398 (Notaro); Dawe et al., ff. Tr. 27,153, at 27.

L-40. The LILCO training organization is responsible for certifying that training has been conducted properly and completed satisfactorily. The training is certified by independent reviewers. The NRC reviews and evaluates the requalification training program on an annual basis.

General Physics Corporation, which operates the simulator used by LILCO, evaluates the examination process, examination questions, responses and grading as an independent consultant. In addition, the LILCO QA program and the LILCO Nuclear Review Board evaluate the training program. The Nuclear Review Board also includes an independent consultant with extensive training experience. Tr. 27,381-83 (Notaro, Youngling).

L-41. The Staff agreed with the process LILCO used to verify the manageability of the procedures but stated that further information was needed to verify that the operators and supervisors could manage the procedures. Tr. 28,081 (Eckenrode).

L-42. In early January 1985, the Staff commenced a review of procedures and training relating to the qualified load, which included a brief site visit. In the time available prior to the hearings in February 1985, Staff witnesses were unable to obtain all the information necessary to understand the details of plant performance and plant response and the role of procedures and training. Clifford et al., ff. Tr. 27,732, at 7-8; Tr. 27,710-12, 27,895 (Buzy, Clifford, Eckenrode); Tr. 28,219 (Clifford). Given the time available and subsequent revisions by LILCO, the Staff reviewed some procedures only preliminarily and others not at all. See Tr. 27,841-42, 28,062-69 (Clifford).

L-43. As a result of the need for more information, the Staff sent LILCO a request for additional information on a number of matters which were of concern to the Staff. Clifford _et al_., ff. Tr. 27,732, at 9. A number of these concerns were reviewed in the hearings. _See_, _e.g._, Tr. 27,822-23 (Buzy); Tr. 27,877-80, 27,917-18 (Clifford, Hodges); Tr. 28,082-83, 28,095-99 (Clifford); Tr. 27,914-15 (Hodges); Tr. 28,040-41, 28,052-53 (Clifford); Tr. 28,107-08 (Clifford); Tr. 27,901, 27,905-06 (Clifford, Eckenrode).

L-44. In connection with the need for further information, the Staff visited the site a second time during the period February 27 to March 1, 1985. The results of the second site visit are reflected in the Staff's testimony of March 5, 1985. This testimony reflects that many Staff concerns had been resolved. _See_, _e.g._, Tr. 28,288-92 (Clifford, Eckenrode). For example, most of the Staff's specific concerns regarding "caution" notes in the procedures were generally resolved with only a small number remaining to be resolved by the job task analysis. Tr. 28,307-08 (Clifford). Further, while the Staff had found in the past that LILCO's overall training program was adequate and appropriate, Tr. 27,822-23, 28,108 (Buzy), the Staff had not had an adequate opportunity to review LILCO's revised lesson plans that addressed the qualified load until the second site visit during the week of February 27. As a result of this further review, the Staff expressed satisfaction with LILCO's approach to training with respect to the qualified load and noted that the classroom exercises implemented by

LILCO were well structured. Tr. 28,298-99 (Buzy). Based on the results of this subsequent review, the Staff concurred with LILCO that the training program adequately addressed the 3300 kw qualified load. Tr. 28,299, 28,388 (Buzy). Similarly, the Staff originally expressed a concern regarding restriction of the operators' flexibility to utilize loads in accordance with procedures, but following the second site visit, Staff witness Clifford agreed operators were able to take the actions they were expected to take to operate the plant within its design and avoid loading the EDGs above the qualified load. Tr. 28,290-96 (Clifford). Thus, the Staff also concluded that operators' flexibility to utilize loads in accordance with procedures was not as restricted as thought. Tr. 28,311, 28,356-62 (Clifford).

L-45. During the Staff's second site visit, LILCO presented a program for a job task analysis pertaining to the qualified load to be performed by an outside consultant. The Staff has reviewed the proposed job task analysis program and believes it is appropriate to resolve any remaining concerns. The Staff also believes that LILCO and the contractor are qualified to perform the job task analysis. Tr. 28,290-92, 28,297 (Clifford, Eckenrode). Staff witnesses Clifford and Buzy support LILCO's conclusion that the operators can operate the plant and maintain all safety functions within the design of the plant and the qualified load, but believe that the results of the job task analysis are needed to confirm this conclusion. Tr. 28,295-96 (Clifford, Buzy). Staff witness Clifford believes the job task analysis is appropriately considered as confirmatory. Tr. 28,315 (Clifford). The Staff witnesses do not believe resolution of procedures and training to the Staff's satisfaction is in any way precluded. See Tr. 28,295-97 (Clifford, Buzy, Eckenrode).

L-46. Suffolk County provided no specific evidence addressing procedures or training. Their witnesses testified that they had examined the procedures governing operation of the EDG equipment in the emergency situation and found the operations to be relatively complex, offering many opportunities for error. The testimony consisted of a summary description of four procedures. Bridenbaugh and Minor, ff. Tr. 27,500, at 25-28. These witnesses had limited experience with emergency procedures. Tr. 27,504-11 (Bridenbaugh, Minor). Their examination consisted of some review, but not a detailed analysis of the procedures. Tr. 27,562-64 (Bridenbaugh, Minor). Neither has ever been a licensed reactor operator. Tr. 27,513 (Bridenbaugh, Minor). We give their testimony little weight.

L-47. The County believes that to assure that the EDGs have sufficient capacity and capability to perform their function, the qualified load must envelope the operator error load since human error cannot be precluded in the operation of equipment. See, e.g. SC PF [Load], at 16. Furthermore, no procedures and training can ensure that an operator will not erroneously add loads. Id. While the County's concern is conservative, the contention fails in that it infers that such assurance is required at Shoreham by 10 CFR Part 50, Appendix A, General Design Criterion 17. Procedures and training can not guarantee that human error will be prevented. They are intended to minimize the likelihood of such occurrence. Based on the testimony presented, we believe that the current programs of the Staff and LILCO will result in acceptable procedures and training exercises that will minimize the likelihood of operator errors that could result in EDG overload. The Staff will continue to review LILCO's procedures and the task analysis to assure that this result is achieved. The Board finds that it can delegate this responsibility to the Staff, not because the act of reviewing procedures is ministerial in nature, but rather because the review of procedures is not necessary to resolve the matter in controversy between the parties (whether the design load needs to accommodate a margin to account for operator error). Additionally, we believe that litigation is not well suited nor necessary for the remaining detailed review and refinement of the procedures and training programs, given the findings we have been able to make regarding the scope and content of the programs.

F. Conclusion on the Qualified Load

L-48. We conclude that the qualified load presents an adequate interim licensing basis for the Shoreham TDI emergency diesel generators. We agree with LILCO and the Staff that there is reasonable assurance that cyclic and intermittent loads would not result in the qualified load of 3300 kw being exceeded, and in any event, any exceedance would be insignificant with respect to amount and duration. We also agree that the operation of the engines during surveillance testing with a ± 100 kw test band is appropriate. We further agree that compliance with GDC 17 does not mandate consideration of operator error loads in the circumstances of this case; there is no single operator error which can overload (over 3300 kw) more than one TDI diesel.

V. CONCLUSIONS OF LAW

In reaching this decision, the Board has considered all the evidence submitted by the parties and the entire record of this proceeding. That record consists of the Commission's Notice of Hearing, the pleadings filed by the parties, the transcripts of the hearing, and the exhibits received into evidence. All issues, arguments, or proposed findings presented by the parties, but not addressed in this decision, have been found to be without merit or unnecessary to this decision. Based upon the foregoing Findings which are supported by reliable, probative, and substantial evidence as required by the Administrative Procedure Act and the Commission's Rules of Practice, and upon consideration of the entire evidentiary record in this proceeding, the Board, with respect to the issues in controversy before us;

CONCLUDES that the Applicant, Long Island Lighting Company, has met its burden of proof on each of the contentions decided in this P.I.D. As to these issues, there is reasonable assurance that the Shoreham Nuclear Power Station, Unit 1, can be operated without endangering the health and safety of the public.

VI. ORDER

WHEREFORE, in accordance with the Atomic Energy Act of 1954, as amended, and the rules of the Commission, and based on the foregoing Findings of Fact and Conclusions of Law, IT IS ORDERED THAT:

The Director of Nuclear Reactor Regulation is authorized, upon making the findings on all applicable matters specified in 10 C.F.R. § 50.57(a), to issue to the Applicant, Long Island Lighting Company, a license to authorize low power testing (up to 5 percent of rated power) of the Shoreham Nuclear Power Station, Unit 1.

Pursuant to 10 C.F.R. § 2.760 of the Commission's Rules of Practice, this Partial Initial Decision shall become effective immediately. It will constitute the final decision of the Commission forty-five (45) days from the date of issuance, unless an appeal is taken in accordance with 10 C.F.R. § 2.762 or the Commission directs otherwise. See also 10 C.F.R. §§ 2.764, 2.785 and 2.786.

Any party may take an appeal from this decision by filing a Notice of Appeal within ten (10) days after service of this Partial Initial Decision. Each appellant must file a brief supporting its position on appeal within thirty (30) days after filing its Notice of Appeal (forty (40) days if the Staff is the appellant). Within thirty (30) days after the period has expired for the filing and service of the briefs of all appellants (forty (40) days in the case of the Staff), a party who is not an appellant may file a brief in support of or in opposition to the appeal of any other party. A responding party shall file a single, responsive brief only regardless of the number of appellants' briefs filed. (See 10 C.F.R. § 2.762).

IT IS SO ORDERED.

THE ATOMIC SAFETY AND
LICENSING BOARD

Lawrence Brenner
Lawrence Brenner, Chairman
ADMINISTRATIVE JUDGE

George A. Ferguson
Dr. George A. Ferguson
ADMINISTRATIVE JUDGE

Peter A. Morris
Dr. Peter A. Morris
ADMINISTRATIVE JUDGE

Bethesda, Maryland
June 14, 1985

Attachments (unpublished):
Appendix A - List of Exhibits
Appendix B - Sequence of Testimony
Appendix C - Witnesses in Alphabetical Order

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

ATOMIC SAFETY AND LICENSING BOARD

Before Administrative Judges:

Lawrence Brenner, Chairman
Dr. George A. Ferguson
Dr. Peter A. Morris

In the Matter of	)	Docket No. 50-322-OL
LONG ISLAND LIGHTING COMPANY	)	LBP-85-18
(Shoreham Nuclear Power Station, Unit 1)	)	

PARTIAL INITIAL DECISION

ON EMERGENCY DIESEL GENERATORS

APPENDICES

EXHIBITS BY PARTY AND NUMBER

Exhibit Number	Description	Identified at Transcript Page	Admitted at Transcript Page
LILCO Ex. B-7	Typical configuration of the cylinder block, cylinder head, cylinder liner and cylinder head studs	24,372	24,372
LILCO Ex. B-8	Plan view of block top, cylinder bore, cylinder head studs and cylinder head	24,372	24,372
LILCO Ex. B-9	Section view of a cylinder head stud	24,372	24,372
LILCO Ex. B-10	Section view of a non-stud region	24,372	24,372
LILCO Ex. B-11	Section view of a cylinder liner	24,372	24,372
LILCO Ex. B-12	Graph depicting the effect of section thickness on tensile strength of gray cast iron	24,372	24,372
LILCO Ex. B-13	Table depicting load history of EDG 101	24,372	24,372

Exhibit Number	Description	Identified at Transcript Page	Admitted at Transcript Page
LILCO Ex. B-14	Table depicting load history of EDG 102	24,372	24,372
LILCO Ex. B-15	Table depicting load history of original EDG 103	24,372	24,372
LILCO Ex. B-16	EDG 101 crack map	24,372	24,372
LILCO Ex. B-17	EDG 102 crack map	24,372	24,372
LILCO Ex. B-18	Original EDG 103 crack map	24,372	24,372
LILCO Ex. B-19	Diagram: typical example of a ligament crack	24,372	24,372
LILCO Ex. B-20	Figure depicting stud-to-stud cracking in original EDG 103	24,372	24,372
LILCO Ex. B-21	Component task evaluation report Q-410	24,372	24,372
LILCO Ex. B-22	Figure depicting strain gauge placement on original EDG 103	24,372	24,372
LILCO Ex. B-23	Figure depicting strain gauge placement on original EDG 103	24,372	24,372

Exhibit Number	Description	Identified at Transcript Page	Admitted at Transcript Page
LILCO Ex. B-24	Drawing showing crack-mouth opening displacement	24,372	24,372
LILCO Ex. B-25	Original EDG 103 crack map as of 4/23/84	24,372	24,372
LILCO Ex. B-26	Graph showing strain v. load for gauges 8, 9, 10	24,372	24,372
LILCO Ex. B-27	Graph showing strain v. load for gauges 11, 12, 13	24,372	24,372
LILCO Ex. B-28	Graph showing strain v. load for gauge no. 3	24,372	24,372
LILCO Ex. B-29	Graph showing principal stresses v. load for gauges 8, 9, 10	24,372	24,372
LILCO Ex. B-30	Graph showing principal stresses v. load for gauges 11, 12, 13	24,372	24,372
LILCO Ex. B-31	Graph showing principal stresses v. load for gauge no. 3	24,372	24,372
LILCO Ex. B-33	Photograph of the Widmanstaetten microstructure in original EDG 103	24,372	24,372

Exhibit Number	Description	Identified at Transcript Page	Admitted at Transcript Page
LILCO Ex. B-34	Microscopy comparison of original EDG 103 sample	24,372	24,372
LILCO Ex. B-35	Details of Widmanstaetten graphite in original EDG 103	24,372	24,372
LILCO Ex. B-36	Photomicrographs of microstructure of EDG 101	24,372	24,372
LILCO Ex. B-37	Photomicrographs of microstructure of EDG 102	24,372	24,372
LILCO Ex. B-38	Photomicrographs showing comparison of eutectic cell boundaries in EDG 101, EDG 102 and original EDG 103	24,372	24,372
LILCO Ex. B-39	Schematic drawing of specimen location from original EDG 103 segment removed from between cylinders 6 and 7	24,372	24,372
LILCO Ex. B-40	Table summarizing tensile tests on original and new EDG 103 block material	24,372	24,372
LILCO Ex. B-42	Graph of strain-life data for TDI gray cast iron	24,372	24,372

Exhibit Number	Description	Identified at Transcript Page	Admitted at Transcript Page
LILCO Ex. B-43	Graph of strain life data from literature sources	24,372	24,372
LILCO Ex. B-44	Graph of fatigue crack growth rates of original EDG 103 gray cast iron	24,372	24,372
LILCO Ex. B-45	Planar two-dimensional model	24,372	24,372
LILCO Ex. B-46	Perspective view of three-dimensional block top model	24,372	24,372
LILCO Ex. B-47	Two-dimensional block top model depicting loads	24,372	24,372
LILCO Ex. B-48	Table showing stress measured at strain gauge 13 to block top crack sites	24,372	24,372
LILCO Ex. B-49	Goodman-Smith curve for low cycle fatigue at 100% load for Shoreham EDG 101 and EDG 102	24,372	24,372
LILCO Ex. B-50	Goodman-Smith curve for high cycle fatigue at 100% load for Shoreham engines EDG 101 and EDG 102	24,372	24,372

Exhibit Number	Description	Identified at Transcript Page	Admitted at Transcript Page
LILCO Ex. B-51	FSAR 8.3.1-1 and letter from Stone and Webster depicting load levels for Shoreham	24,372	24,372
LILCO Ex. B-59	"Supplemental Testimony of Roger L. McCarthy, Charles A. Rau, Clifford H. Wells, Harry F. Wachob, Duane P. Johnson, Craig K. Seaman, Edward J. Youngling and Milford H. Schuster On Behalf of Long Island Lighting Company on Suffolk County Contention Regarding Cylinder Blocks," with attached exhibit	25,082	
LILCO Ex. B-60	Preliminary cam gallery strain gauge data	26,336	
LILCO Ex. B-61	Drawings depicting the cam gallery region of the original EDG 103 block, after casting, after grinding and after weld repairs	26,464	26,757
LILCO Ex. B-62	Drawings depicting the cam gallery regions of EDG 101 and 102 blocks, after casting, after grinding and after weld repairs	26,464	26,757

Exhibit Number	Description	Identified at Transcript Page	Admitted at Transcript Page
LILCO Ex. B-63	Photographs [at 100X and 500X] showing the tip of casting shrinkage crack	26,519	26,741
LILCO Ex. B-64	Photograph showing the liquid penetrant test for circumferential crack of cross-section through cylinder no. 5 on original EDG 103 block	26,686	26,741
LILCO Ex. B-65	550x magnification photomicrographs of the weld shrinkage crack at face 1 of cam saddle no. 7 of the original EDG 103 block	28,794 (withdrawn)	
LILCO Ex. B-66	Mark-up 100x magnification photomicrograph of the weld shrinkage crack at face 1 of cam saddle no. 7 of the original EDG 103 block	28,794 (withdrawn)	
LILCO Ex. B-67	Stipulation of the parties regarding cam gallery crack contention	28,793	28,799
LILCO Ex. B-68	Strain gauge measurements on cam gallery of replacement EDG 103 block	28,794 (withdrawn)	

Exhibit Number	Description	Identified at Transcript Page	Admitted at Transcript Page
LILCO Ex. C-1	Evaluation of Emergency Diesel Generator Crankshafts at Shoreham and Grand Gulf Nuclear Power Stations prepared for TDI Diesel Generator Owners Group dated May 22, 1984 (hereinafter "Owners Group Crankshaft Report"), Figure 3-4	22,610	22,610
LILCO Ex. C-2	Specification for Diesel Generator Sets, Shoreham Nuclear Power Station - Unit 1, Spec. No. SH1-89, Revision 2, January 26, 1983, pages 1-20	22,610	22,610
LILCO Ex. C-3	U.S. Nuclear Regulatory Commission Regulatory Guide 1.9, Revision 2, December 1979.	22,610	22,610
LILCO Ex. C-4	IEEE Standard Criteria for Diesel Generator Units Applied as Standby Power Supplies for Nuclear Power Generating Stations, Std. 387-1977	22,610	22,610

Exhibit Number	Description	Identified at Transcript Page	Admitted at Transcript Page
LILCO Ex. C-5	Transcript of July 11, 1984 meeting of the TDI Diesel Generator Owners Group, pages 124-25	22,610	22,610
LILCO Ex. C-6	Available Logged Hours of Operation of DSR-48, Rated 3500 KW at 450 RPM	22,610	
LILCO Ex. C-7	TDI Diesel Generator Run History - Shoreham Nuclear Power Station - Unit 1 - August 6, 1984	22,610	22,610
LILCO Ex. C-8	Results of non-destructive examinations of replacement crankshafts at Shoreham after 100 hours of operation at full load or greater	22,610	22,610
LILCO Ex. C-9	American Bureau of Shipping, Rules for Building and Classing Steel Vessels (1983) § 37.17.1	22,610	22,610
LILCO Ex. C-10	American Bureau of Shipping, Rules for Building and Classing Steel Vessels (1983), Table 34.3	22,610	22,610

Exhibit Number	Description	Identified at Transcript Page	Admitted at Transcript Page
LILCO Ex. C-12	American Bureau of Shipping Reports on Castings or Forgings of Replacement Crankshafts	22,610	22,610
LILCO Ex. C-13	American Bureau of Shipping letter to TDI dated May 3, 1984	22,610	22,610
LILCO Ex. C-14	Diesel Engine Manufacturers Association Standard Practices for Low and Medium Speed Stationary Diesel and Gas Engines (1972 ed.), pages 53-56	22,610	22,610
LILCO Ex. C-15	TDI Proposed Torsional and Lateral Critical Speed Analysis, August 22, 1983	22,610	22,610
LILCO Ex. C-16	Field Test of Emergency Diesel Generator 103 with 13 x 12 Crankshaft, April, 1984	22,610	22,610
LILCO Ex. C-17	Owners Group Crankshaft Report	22,610	22,610
LILCO Ex. C-18	Crankshaft Torsional Stress Calculations for 8L 17 x 21 Engine-Generator Set, July 19, 1984	22,610	22,610

Exhibit Number	Description	Identified at Transcript Page	Admitted at Transcript Page
LILCO Ex. C-19	Table 2.2 from Owners Group Crankshaft Report showing natural frequencies from TDI analysis	22,610	22,610
LILCO Ex. C-20	Table 2.4 from Owners Group Crankshaft Report showing single order nominal stresses from TDI analysis	22,610	22,610
LILCO Ex. C-21	Table 2.5 from Owners Group Crankshaft Report showing nominal stresses calculated from torsiograph	22,610	22,610
LILCO Ex. C-22	Crankshaft Torsional Stress Calculations for 8L 17 x 21 Engine-Generator Set, July 19, 1984, page 11	22,610	22,610
LILCO Ex. C-23	Figure 3-3 from Owners Group Report showing comparison of measured and calculated torque	22,610	22,610
LILCO Ex. C-24	Tables 3.6 and 3.7 from Owners Group Crankshaft Report showing comparison between analytical and test results	22,610	22,610

Exhibit Number	Description	Identified at Transcript Page	Admitted at Transcript Page
LILCO Ex. C-25	Figure 3-13 from Owners Group Crankshaft Report showing fatigue endurance limit of replacement crankshafts on Goodman diagram	22,610	22,610
LILCO Ex. C-26	Oberg and Jones, Machinery's Handbook (18th Ed.) pages 352-53; Shigley, Mechanical Engineering Design (Mcgraw-Hill) pages 212-13; Rothbart (editor), Mechanical Design and Systems Handbook (McGraw-Hill) page 18-4	22,610	22,610
LILCO Ex. C-27	Engineering and Design Coordination Report No. F-46109G	23,121	23,122
LILCO Ex. C-28	Military Specification No. 13165B, Amendment 2, June 25, 1979	23,121	23,122
LILCO Ex. C-29	LILCO Operational Quality Assurance Reports (EDG 102 and 103 Crankshafts)	23,121	23,122
LILCO Ex. C-30	Metal Improvement Company Certificate of Shot Peening (EDG 102 and 103 Crankshafts)	23,121	23,122

Exhibit Number	Description	Identified at Transcript Page	Admitted at Transcript Page
LILCO Ex. C-31	Certificate of Non-Destructive Testing Issued by Krupp Stahl AG (EDG 102 and 103 Crankshafts)	23,121	23,122
LILCO Ex. C-32	LILCO Magnetic Particle Testing and Liquid Penetrant Testing Records (EDG 102 and 103 Crankshafts)	23,121	23,122
LILCO Ex. C-33	LILCO Ultra Sonic Testing Records (EDG 102 and 103 Crankshafts)	23,121	23,122
LILCO Ex. C-34	H. Fuchs and R. Stevens, Metal Fatigue in Engineering (1980) at pages 226-227; H. Uhlig, Corrosion and Corrosion Control at pages 132-133	23,121	23,122
LILCO Ex. C-35	Metal Improvement Company Certificate of Shot Peening (EDG 101 Crankshaft)	23,121	23,122
LILCO Ex. C-36	LILCO Operational Quality Assurance Reports (EDG 101 Crankshaft)	23,121	23,122

Exhibit Number	Description	Identified at Transcript Page	Admitted at Transcript Page
LILCO Ex. C-37	Certificates of Non-Destructive Testing Issued by Krupp Stahl AG (EDG 101 Crankshaft)	23,121	23,122
LILCO Ex. C-38	LILCO Magnetic Particle Testing, Liquid Penetrant Testing and Ultra Sonic Testing Records (EDG 101 Crankshaft)	23,121	23,122
LILCO Ex. C-39	Kirk, Behavior of Peen-Formed Steel Strip on Isochronal Annealing, Proceedings of the Second International Conference on Shot Peening at page 231, (May, 1984)	23,121	23,122
LILCO Ex. C-40	Deposition testimony of Dr. Robert N. Anderson, dated May 10, 1984, pages 70-71	23,881	24,333
LILCO Ex. C-41	Rules and Regulations for the Classification of Ships, Lloyd's Register of Shipping, Part 5, Chapter 2 (July, 1982) and Part 5, Chapter 1 (January, 1983)	24,010	24,333

Exhibit Number	Description	Identified at Transcript Page	Admitted at Transcript Page
LILCO Ex. C-42	Deposition testimony of Woytowich Blanding and Guiffra (ABS), dated July 18, 1984, pages 129-130	24,143	24,333
LILCO Ex. C-43	"Proffered Testimony of Paul R. Johnston," dated March 8, 1985	28,844	
LILCO Ex. P-1	Photograph of piston skirt with mounted crown and rings	21,949	21,949
LILCO Ex. P-2	Photograph of a piston from a Shoreham EDG showing skirt and crown	21,949	21,949
LILCO Ex. P-3	Cross section of crown and skirt indicating the two areas of load transfer from the crown to the skirt	21,949	21,949
LILCO Ex. P-4	Piston reassembly guidelines showing measurements of cold gap	21,949	21,949
LILCO Ex. P-5	Gas pressure versus crank angle diagram	21,949	21,949
LILCO Ex. P-6	Comparison of all AE and AF piston skirts in the region of the stud attachment bosses	21,949	21,949

Exhibit Number	Description	Identified at Transcript Page	Admitted at Transcript Page
LILCO Ex. P-7	Representative dimension checks on Task Evaluation Reports Q-338, 310, 194, 203 and 182	21,949	21,949
LILCO Ex. P-8	Trip report on non-destructive examination of AE piston skirt and a copy of AE piston skirt inspection, requirements, certificates of compliance and receipt inspection documentation	21,949	21,949
LILCO Ex. P-9	A sample preoperational test procedure and Appendix F showing peak firing pressures taken before the crankshaft failure and after the crankshaft replacement	21,949	21,949
LILCO Ex. P-10	Strains and sigma III stress from strain gauge rosette measurements	21,949	21,949
LILCO Ex. P-11	Results of templug measurements of peak temperature as a function of position on crown	21,949	21,949

Exhibit Number	Description	Identified at Transcript Page	Admitted at Transcript Page
LILCO Ex. P-12	Location of strain gauge rosettes on instrumented AE skirt	21,949	21,949
LILCO Ex. P-13	Summary of experimental observations related to crown/skirt interaction	21,949	21,949
LILCO Ex. P-14	Strain readings and calculated stresses for AE piston skirt for the complete stud boss rosettes at 1600 psig with a conventional crown	21,949	21,949
LILCO Ex. P-15	Comparison of experimental and numerical values of cyclic stresses for the AE piston skirt	21,949	21,949
LILCO Ex. P-16	Comparison of experimental observations of peak stress at 1627 psig for AE piston skirt with corresponding finite element results using extremes of wrist pin behavior	21,949	21,949
LILCO Ex. P-17	Cyclic stresses in AE piston skirts under isothermal and steady-state conditions	21,949	21,949

Exhibit Number	Description	Identified at Transcript Page	Admitted at Transcript Page
LILCO Ex. P-18	Comparison of peak stress in stud boss region of AE piston skirt for loads applied on inner and outer contact rings	21,949	21,949
LILCO Ex. P-19	Comparison of experimental and numerical gap closure and load split	21,949	21,949
LILCO Ex. P-20	Comparison of skirt stiffnesses as evaluated from experimental observation and crown/skirt interaction model with corresponding finite element values	21,949	21,949
LILCO Ex. P-21	Mean and cyclic stresses for infinite fatigue life	21,949	21,949
LILCO Ex. P-22	Stress states for isothermal AE piston skirt for various gap sizes plotted on graph of allowable stress amplitude as a function of mean stress	21,949	21,949

Exhibit Number	Description	Identified at Transcript Page	Admitted at Transcript Page
LILCO Ex. P-23	Stress states for AE piston skirt for various conditions plotted on a graph of allowable stress amplitude as a function of mean stress for various gap sizes and for isothermal and steady state temperature conditions	21,949	21,949
LILCO Ex. P-24	Summary of fracture toughness data from the literature for nodular cast iron with strength levels similar to 100-70-03	21,949	21,949
LILCO Ex. P-25	Applied values of Delta K and R as a function of crack depth and corresponding values of Delta K-th	21,949	21,949
LILCO Ex. P-26	Liquid dye penetrant inspection results after 100 hours of operation for EDGs 101, 102 and 103	21,949	21,949
LILCO Ex. P-27	Eddy current test results after 100 hours operation for EDGs 101, 102, 103; FaAA Procedure NDE 11.5, Rev. 0 and Rev. 1	21,949	21,949

Exhibit Number	Description	Identified at Transcript Page	Admitted at Transcript Page
LILCO Ex. P-28	Iron Castings Handbook, page 34	21,949	21,949
LILCO Ex. P-29	Results of inspection of AE pistons on the Kodiak Electric Association engine and the TDI R-5 prototype engine	21,949	21,949
LILCO Ex. P-30	Volume I, TDI Owners Manual (sections discussing engine lubrication)	21,949	21,949
LILCO Ex. P-31	Excerpts from Diesel Engine Design by T.D. Walshaw and Internal Combustion Engines by V.L. Maleev	21,949	21,949
LILCO Ex. P-32	Task evaluation reports and LILCO deficiency reports which discuss the DRQR's visual inspections of AE piston skirts	21,949	21,949
LILCO Ex. P-33	Liquid dye penetrant test results for AF piston skirts	21,949	21,949

Exhibit Number	Description	Identified at Transcript Page	Admitted at Transcript Page
LILCO Ex. P-34	Minimum and maximum stresses in AE piston skirt for various peak firing pressures for isothermal and steady state operating conditions; applied values of Delta K and R as a function of crack depth and corresponding values of Delta K-th (2,200 psig)	21,949	21,949
LILCO Ex. P-35	LILCO EDG 103 cylinder 7 pressure data	22,532	22,535
LILCO Ex. P-36	Influence of Thermal Distortion on Fatigue Performance of AF and AE Piston Skirts, June 1984	23,713	
County Ex. 7	Design Review of TDI R-4 and RV-4 Series Emergency Diesel Generator Cylinder Blocks and Liners, June 1984	23,827	

Exhibit Number	Description	Identified at Transcript Page	Admitted at Transcript Page
County Ex. 7 (Revised)	"Design Review of TDI R-4 and RV-4 Series Emergency Diesel Generator Cylinder Blocks and Liners, June 1984," pages i, ii, iii, 1-1, 1-2, 1-3, 3-5, 3-6, 3-9, 4-1, 4-5, 4-6, 4-8, 5-1, 5-2; Figures 1-1, 1-2, 1-3, 1-4, 1-5, 1-6, 1-7, 1-8, 3-1, 3-6, 3-7, 3-13, 3-14, 4-2, A-1, A-2, A-3	25,550	25,566
County Ex. 9	Page 8-3, TDI Instruction Manual for DSR 48 engine	26,556	26,557
County Ex. 10	Deposition of Gerald E. Trussell, dated May 7, 1984, pages 62, 45-48, 74-87, 107, 111-113, 128-129	23,827	23,827
	Pages 128-129	26,556	26,557
County Ex. 24	Deposition of Maurice H. Lowrey, dated May 10, 1984, pages 1, 15-16, 62, 85	23,827	23,827
County Ex. 24 (Revised)	Deposition of Maurice H. Lowrey, dated May 10, 1984, pages 1, 14-16	25,550	25,566

Exhibit Number	Description	Identified at Transcript Page	Admitted at Transcript Page
County Ex. 32	Deposition of Clinton S. Mathews, dated May 8, 1984, pages 106, 107	25,550	25,566
County Ex. 35	Board Notification 84-101; Evaluation of Diesel Generator Failure at Shoreham Unit 1, Franklin Research Center, pages 1-6, 33-34, 59-62, 63-68	23,827	23,827
County Ex. 36	Calculations for 12" x 13" Crankshafts under Lloyd's Register Rules by Professor Christensen	23,827	23,827
County Ex. 37	Calculations for 12" x 13" Crankshafts under Lloyd's Register Rules by Mr. Eley	23,827	23,827
County Ex. 38	IACS-CIMAC Rules for the Calculation of Crankshafts for Diesel Engines	23,827	23,827
County Ex. 39	TDI Calculations under IACS-CIMAC Rules on R-48 Crankshaft	23,827	23,827
County Ex. 40	Calculations under ABS Rules for Crankshafts with Solid Webs, by Profesor Christensen	23,827	23,827

Exhibit Number	Description	Identified at Transcript Page	Admitted at Transcript Page
County Ex. 41	Deposition testimony of Franz F. Pischinger, dated June 21, 1984, pages 1, 94, 97-98, 100-101, 108, 110, 185-187	23,827	23,827
County Ex. 43	Deposition testimony of Messrs. Woytowich, Blanding and Giuffra (ABS), dated July 18, 1984, pages 1, 80-81, 93, 98-99, 112, 163-165, 167-168 and exhibit 3 to the deposition	23,827	23,827
County Ex. 44	May 3, 1984 letter from ABS to TDI	23,827	23,827
County Ex. 45	TDI submission to ABS entitled "Report on Crankshaft Torsional Stresses, Transamerica Delaval Model DRS-48, Serial No. 74010/12 for Long Island Lighting Company, by Roland Yang, April 4, 1984	23,827	23,827

Exhibit Number	Description	Identified at Transcript Page	Admitted at Transcript Page
County Ex. 46	July 25, 1984 letter to Howard C. Blanding (ABS) from Alan Roy Dynner, and documents 1-12 attached	23,827	23,827
	Attachments 5 through 9 to July 25, 1984 Dynner letter to Blanding, American Bureau of Shipping	26,556	26,557
County Ex. 47	ABS Check Calculations (Exhibit 3 to ABS deposition) dated July 18, 1984	23,827	23,827
County Ex. 48	Letter dated February 17, 1984 to Gregory M. Beshouri (TDI) from Shinpei Denoh, (Kobe Steel Ltd.)	23,827	23,827
County Ex. 49	Field Test of Emergency Diesel Generator 103 With 13 x 12 Crankshaft, April 1984, pages 1 and 7-3	23,827	23,827
County Ex. 50	Field Test of Emergency Diesel Generator 101, October 1984, pages 1 and 7-2	23,827	23,827

Exhibit Number	Description	Identified at Transcript Page	Admitted at Transcript Page
County Ex. 51	Stone & Webster Engineering Corporation Engineering and Design Coordination Report No. F-46109G	23,827	23,827
County Ex. 52	Deposition testimony of Paul R. Johnston, May 9, 1984, pages 1, 39-40	23,827	23,827
County Ex. 53	Stone & Webster Engineering Corporation Interoffice Memorandum dated September 20, 1983	23,827	23,827
County Ex. 54	April 17, 1984 letter from Reis to the Administrative Judges Concerning Morning Report of April 16, 1984	25,550	25,566
County Ex. 55	March 20, 1984 Morning Report Concerning Con Rod Bearing Cracks and Eddy Current Examinations of the Cylinder Block Cracks	25,550	25,566
County Ex. 56	TDI Owners Group DRQR review of SNPS cylinder blocks	25,550	25,566
County Ex. 57	Deposition of William J. Museler, dated May 22, 1984, pages 1, 7-8, 14-17, 43-46, 98-99	25,550	25,566

Exhibit Number	Description	Identified at Transcript Page	Admitted at Transcript Page
County Ex. 58	Deposition of Robert K. Taylor, dated May 10, 1984, page 1 and exhibit no. 1	25,550	25,566
County Ex. 59	Deposition of Robert K. Taylor, dated May 10, 1984, pages 1, 39-41, 67, 69-70	25,550	25,566
County Ex. 66	Deposition of Simon K. Chen, dated May 15, 1984, pages 1, 29	25,550	25,566
County Ex. 67	Handwritten memo to Pratt from Lowrey on cylinder block castings	25,550	25,566
County Ex. 69	Article from <u>Motor Ship Technical Magazine</u>, February 1978, entitled "Sulzer's Four-stroke High and Medium Speed Engine Range"	22,365	
County Ex. 70	Article from <u>The Institute of Marine Engineers Transactions</u>, January 1966, entitled "The Development of a Highly Rated Medium Speed Diesel Engine of 7,000 to 9,000 Horsepower for Marine Propulsion"	22,384	

Exhibit Number	Description	Identified at Transcript Page	Admitted at Transcript Page
County Ex. 71	Photograph of piston removed from EDG 103 taken by Aneesh Bakshi at SNPS of scuffing, June 1984	22,421	
County Ex. 72	Deposition testimony of Woytowich, Blanding and Guiffra (ABS) dated July 18, 1984, pages 114-130	24,274	24,333
County Ex. 73	Liquid Penetrant Examination Report, Cylinder Liner Landing, Cylinder No. 7 EDG 102, February 10, 1984	24,398	
County Ex. 74	TER Q-329 Liquid Penetrant Examination Report, Cylinder Block Liner Landing. Cylinders 2, 3, 4, 5	24,445	
County Ex. 75	FaAA Eddy Current Examination Report, pages 11, 12, 21, 23, 27, 39	24,598	24,600
County Ex. 76	EDX analysis of EDG 103 Cam Gallery crack sample	25,387	25,479
County Ex. 77	Schematic of upper cam saddle area	25,455	25,479

Exhibit Number	Description	Identified at Transcript Page	Admitted at Transcript Page
County Ex. 78	Circilli trip report re: EDGs at Kansas and Delaval, April 13, 1983	25,463	25,479
County Ex. 79	Eddy Current Examination Report with attachments, dated September 12, 1984	25,503	25,539
County Ex. 80	SNPS-1 FSAR, page 8.3-5 (Rev. 26, April 1982)	26,157	26,164
County Ex. 81	Photographs HFW-4, dated September 13, 1984 and CB-1, dated September 11, 1984	26,808	26,875
County Ex. 82	FaAA photographs DP-1, DP-2, DP-3, dated September 12, 1984	26,817	26,875
County Ex. 83	Deposition of John Knox, pp. 1 and 22, December 13, 1984	27,499	27,500 (Bound In)
County Ex. 84	Deposition of Jack D. Notaro, Edward J. Youngling, George F. Dawe, and William Schiffmacher, pp. 1, 61-63, December 12, 1984	27,499	27,500 (Bound In)

Exhibit Number	Description	Identified at Transcript Page	Admitted at Transcript Page
County Ex. 85	Table entitled "Comparative BWR EDG Rating and LOOP/LOCA Loads," undated	27,499	27,500 (Rejected) (Bound In)
County Ex. 86	Deposition of Carl H. Berlinger, pp. 1, 5 and 21, December 13, 1984	27,499	27,500 (Received in part) (Bound In)
County Ex. 87	Interoffice Memorandum from J. Carney to R. M. Kascsak, "EDG 103 Load Reduction Removal of One Orange Service Water Pump from Auto Start, Shoreham Nuclear Power Station - Unit 1, LILCO," June 7, 1984	27,499	27,500 (Bound In)
County Ex. 88	EDG Load Data Tables, dated from 10/12/84 through 10/15/84	27,499	27,500 (Bound In)
County Ex. S-1	FaAA Liquid Penetrant Examination Report, dated August 24, 1984	25,550	25,566
County Ex. S-2	FaAA Crack Depth Measurements, dated September 21, 1984	25,550	25,566

Exhibit Number	Description	Identified at Transcript Page	Admitted at Transcript Page
County Ex. S-3	Photographs of Cam Gallery Bearing Saddles Nos. 5, 7 and 8, Original Block, EDG 103	25,550	25,566
County Ex. S-4	Photographs at 50 and 100X, of section of cam saddle No. 7, Original Block, EDG 103	25,550	25,566
County Ex. S-5	LILCO Magnetic Particle Examination Report, EDG 101, dated September 20, 1984	25,550	25,566
County Ex. S-6	LILCO Liquid Penetrant Examination Report, EDG 101, dated September 21, 1984	25,550	25,566
County Ex. S-7	LILCO Deficiency Report 2507 and attachments, dated October 1, 1984	25,550	25,566
County Ex. S-8	Inspection Report of C.R. Islieb, dated May 17, 1984	25,550	25,566
County Ex. S-9	Drawings of location of cracks	25,550	25,566
County Ex. S-10	LILCO Magnetic Particle Examination Report, dated September 19, 1984	25,550	25,566

Exhibit Number	Description	Identified at Transcript Page	Admitted at Transcript Page
Staff Ex. 1	PNL Evaluation of Crankshaft Dimensions	23,236	24,236
Staff Ex. 2	PNL Analysis of Torsional Stresses for Sum of 24 Orders of Vibration	23,236	23,236
Staff Ex. 3	PNL Analysis of Stress Levels for Single Orders	23,236	23,236
Staff Ex. 4	American Bureau of Shipping letter to TDI dated May 3, 1984	23,236	23,236
Staff Ex. 5	Kohls, et al., Effects of Multiple Shot-Peening/Cadmium-Plating Cycles on High-Strength Steel	23,124	23,128
Staff Ex. 7	Pages 6 and 7 of Ricardo Report with tabulation of seven piston skirts, August 10, 1984	23,579	23,579
Staff Ex. 8	Eisenhut letter to George, dated August 13, 1984, with attachments	23,704	
Staff Ex. 9	Dr. Wells drawing to illustrate potential leak path between block and liner	25,208	25,213

Exhibit Number	Description	Identified at Transcript Page	Admitted at Transcript Page
Staff Ex. 10	Drawing of "Section Through Cylinder Head Stud" (originally Ex. B-9) with additional markings	26,186	26,187
Staff Ex. 11	Memorandum from Dennis Crutchfield to Thomas Novak, re: Safety Evaluation Report, December 3, 1984	27,727	
Staff Ex. 12	Memorandum from Dennis Crutchfield to Thomas Novak, re: Safety Evaluation Report, December 18, 1984	27,727	
Staff Ex. 13	Letter from A. Schwencer, to John Leonard, on EDG Loading, with an attached RAI, February 5, 1985	27,727	
Staff Ex. 14	Joint Testimony of Spencer H. Bush and Adam J. Henriksen on Load Contentions of TDI Diesel Generators	29,020	29,020
Board Ex. 1	Resolution of Suffolk County Diesel Generator Contention re: Cylinder Heads, dated September 21, 1984	25,204	

SEQUENCE OF CRANKSHAFT TESTIMONY

Witness (Party)	Date	Transcript Page1/
Chen (LILCO)	9/17/84	22,664
Johnston (LILCO)	9/17/84	22,605
Montgomery (LILCO)	9/17/84	22,605
McCarthy (LILCO)	9/17/84	22,605
Pischinger (LILCO)	9/17/84 3/06/85	22,605 28,414
Youngling (LILCO)	9/17/84	22,605
Burrell (LILCO)	9/20/84	23,118
Cimino (LILCO)	9/20/84	23,118
Johnson (LILCO)	9/20/84 3/06/85	23,118 28,414
Seaman (LILCO)	9/20/84	23,118
Wachob (LILCO)	9/20/84	23,118
Wells (LILCO	9/20/84	23,118
Schuster (LILCO)	3/06/85	28,414
Bush (NRC)	9/20/84 3/06/85	23,118 28,492
Henriksen (NRC)	9/24/84 3/06/85	23,234 28,492
Sarsten (NRC)	9/24/84	23,234
Anderson (SC)	10/01/84	23,812
Bridenbaugh (SC)	10/01/84	23,812
Christensen (SC)	10/01/84	23,812
Eley (SC)	10/01/84	23,812
Hubbard (SC)	10/01/84	23,812

1/ The first page and date indicates where a witness first appears on a particular component. In some cases, this indicates where a witness was sworn in. A second page and date, if shown, indicates the appearance of a witness in the reopened February-March hearings.

SEQUENCE OF CYLINDER BLOCK TESTIMONY

Witness (Party)	Date	Transcript Page2/
Johnson (LILCO)	10/22/84 3/08/85	24,368 28,790
McCarthy (LILCO)	10/22/84	24,368
Rau (LILCO)	10/22/84 3/08/85	24,368 28,790
Schuster (LILCO)	10/22/84 3/08/85	24,368 28,790
Seaman (LILCO)	10/22/84	24,368
Wachob (LILCO)	10/22/84 3/08/85	24,368 28,790
Wells (LILCO)	10/22/84	24,368
Youngling (LILCO)	10/22/84 3/08/85	24,368 28,790
Anderson (SC)	11/01/84	25,541
Bridenbaugh (SC)	11/01/84 3/11/85	25,541 28,917
Christensen (SC)	11/01/84	25,541
Eley (SC)	11/01/84	25,541
Hubbard (SC)	11/01/84	25,541
Berlinger (NRC)	11/07/84	25,771
Bush (NRC)	11/07/84 3/12/85	25,771 29,022
Henriksen (NRC)	11/07/84	25,771

2/ See note 1.

SEQUENCE OF QUALIFIED LOAD TESTIMONY

Witness (Party)	Date	Transcript Page3/
Dawe (LILCO)	2/12/85	27,150
Notaro (LILCO)	2/12/85	27,151
Youngling (LILCO)	2/12/85	27,150
Bridenbaugh (SC)	2/14/85	27,497
Minor (SC)	2/14/85	27,498
Berlinger (NRC)	2/19/85	27,728
Buzy (NRC)	2/19/85	27,728
Clifford (NRC)	2/19/85	27,728
Eckenrode (NRC)	2/19/85	27,728
Hodges (NRC)	2/19/85	27,728
Knox (NRC)	2/19/85	27,728

3/ See Note 1.

WITNESSES IN ALPHABETICAL ORDER

Witness	Following Transcript Page
Anderson, Robert N.	
"Joint Direct Testimony of Dr. Robert N. Anderson, Professor Stanley G. Christensen, G. Dennis Eley, Dale G. Bridenbaugh and Richard B. Hubbard regarding Suffolk County's Emergency Diesel Generator Contentions" (section pertaining to crankshafts)	23,826
"Supplemental Testimony of Dr. Robert N. Anderson, Professor Stanley G. Christensen, G. Dennis Eley, and Richard B. Hubbard Regarding Suffolk County's Emergency Diesel Generator Contention Concerning Cylinder Blocks"	25,565
"Revised Joint Direct-Testimony of Dr. Robert N. Anderson, Professor Stanley G. Christensen, G. Dennis Eley, Dale G. Bridenbaugh and Richard B. Hubbard Regarding Suffolk County Emergency Diesel Generator Contentions Concerning Cylinder Blocks"	25,564
"Rebuttal Testimony of Dr. Robert N. Anderson, Professor Stanley G. Christensen, and G. Dennis Eley"	26,326
Berlinger, Carl H.	
"Joint Testimony of Carl H. Berlinger, Spencer H. Bush, Adam J. Henriksen, Walter W. Laity and Professor Arthur Sarsten on Contentions Concerning TDI Emergency Diesel Generators at the Shoreham Nuclear Power Station, Volume 1. Henriksen was deleted	23,126

Witness	Following Transcript Page
from the portion of this testimony pertaining to cylinder blocks (see page 25,775)	
Bridenbaugh, Dale G.	
"Joint Direct Testimony of Dr. Robert N. Anderson, Professor Stanley G. Christensen, G. Dennis Eley, Dale G. Bridenbaugh and Richard B. Hubbard regarding Suffolk County's Emergency Diesel Generator Contentions" (section pertaining to crankshafts)	23,826
"Revised Joint Direct Testimony of Dr. Robert N. Anderson, Professor Stanley G. Christensen, G. Dennis Eley, Dale G. Bridenbaugh and Richard B. Hubbard Regarding Suffolk County Emergency Diesel Generator Contentions Concerning Cylinder Blocks"	25,565
"Testimony of Dale G. Bridenbaugh and Gregory C. Minor Regarding Suffolk County's Emergency Diesel Generator Load Contention," with attachment	27,500
"Testimony of Dale G. Bridenbaugh regarding Suffolk County's Position Concerning LILCO's Additional Cylinder Block Testimony"	28,918
Burrell, N. Ken	
"Testimony of Clifford H. Wells, Duane P. Johnson, Harry F. Wachob, Craig K. Seaman, Dominic Cimino and N. Ken Burrell on behalf of Long Island Lighting Company Concerning Shotpeening of the Replacement Crankshafts"	23,122

Witness	Following Transcript Page
Bush, Spencer H.	
"Joint Testimony of Carl H. Berlinger, Spencer H. Bush, Adam J. Henriksen, Walter W. Laity and Professor Arthur Sarsten on Contentions Concerning TDI Emergency Diesel Generators at the Shoreham Nuclear Power Station." Henriksen was deleted from the portion of this testimony pertaining to cylinder blocks (see page 25,775)	23,126
"Supplemental Testimony of Spencer H. Bush and Adam J. Henriksen Concerning Cylinder Blocks of the TDI Emergency Diesel Generators at the Shoreham Nuclear Power Station"	25,775
"Joint Testimony of Spencer H. Bush, Adam J. Henriksen and Professor Arthur Sarsten on Load Contentions Concerning TDI Emergency Diesel Generators at the Shoreham Nuclear Power Station" (Professor Sarsten was deleted from the testimony on 3/7/85 at page 28,595.)	28,503 (also Staff Ex. 14, in revised form concerning cylinder blocks)
Buzy, Joseph J.	
"NRC Staff Testimony of James W. Clifford, Joseph J. Buzy, and Richard J. Eckenrode," with attachments	27,732
Chen, Simon K.	
"Testimony of Roger L. McCarthy, Paul R. Johnston, Eugene F. Montgomery and Simon K. Chen on behalf of Long Island Lighting Company on Suffolk County's Contention Regarding Replacement	22,610

Witness	Following Transcript Page
Clifford, James W.	
"NRC Staff Testimony of James W. Clifford, Joseph J. Buzy, and Richard J. Eckenrode," with attachments	27,732
Dawe, George F.	
"Diesel Generator Qualified Load Testimony of George F. Dawe, Jack A. Notaro and Edward J. Youngling on Behalf of Long Island Lighting Company," with attachments	27,153
Eckenrode, Richard J.	
"NRC Staff Testimony of James W. Clifford, Joseph J. Buzy, and Richard J. Eckenrode," with attachments	27,732
Eley, G. Dennis	
"Joint Direct Testimony of Dr. Robert N. Anderson, Professor Stanley G. Christensen, G. Dennis Eley, Dale G. Bridenbaugh and Richard B. Hubbard regarding Suffolk County's Emergency Diesel Generator Contentions" (section pertaining to crankshafts)	23,826
"Revised Joint Direct Testimony of Dr. Robert N. Anderson, Professor Stanley G. Christensen, C. Dennis Eley, Dale G. Bridenbaugh and Richard B. Hubbard Regarding Suffolk County Emergency Diesel Generator Contentions Concerning Cylinder Blocks"	25,564
"Supplemental Testimony of Dr. Robert N. Anderson, Professor Stanley G. Christensen, G. Dennis Eley, and Richard B. Hubbard	25,565

Witness	Following Transcript Page
Regarding Suffolk County's Emergency Diesel Generator Contention Concerning Cylinder Blocks"	
"Rebuttal Testimony of Dr. Robert N. Anderson, Professor Stanley G. Christensen, and G. Dennis Eley"	26,326
Henriksen, Adam J.	
"Joint Testimony of Carl H. Berlinger, Spencer H. Bush, Adam J. Henriksen, Walter W. Laity and Professor Arthur Sarsten on Contentions Concerning TDI Emergency Diesel Generators at the Shoreham Nuclear Power Station." Henriksen was deleted from the portion of this testimony pertaining to cylinder heads (see page 25,775)	23,126
"Supplemental Testimony of Spencer H. Bush and Adam J. Henriksen Concerning Cylinder Blocks of the TDI Emergency Diesel Generators at the Shoreham Nuclear Power Station"	25,775
"Joint Testimony of Spencer H. Bush, Adam J. Henriksen, and Professor Arthur Sarsten on Load Contentions Concerning TDI Emergency Diesel Generators at the Shoreham Nuclear Power Station" (Professor Sarsten was deleted from the testimony on 3/7/85 at page 28,595.)	28,503
Hodges, M. Wayne	
"Testimony of Wayne Hodges"	27,729

Witness	Following Transcript Page
Minor, Gregory C.	
"Testimony of Dale G. Bridenbaugh and Gregory C. Minor Regarding Suffolk County's Emergency Diesel Generator Load Contention," with attachment	27,500
Montgomery, Eugene F.	
"Testimony of Roger L. McCarthy, Paul R. Johnston, Eugene F. Montgomery and Simon K. Chen on behalf of Long Island Lighting Company on Suffolk County's Contention Regarding Replacement Crankshafts on Diesel Generators at Shoreham"	22,610
Notaro, Jack A.	
"Diesel Generator Qualified Load Testimony of George F. Dawe, Jack A. Notaro and Edward J. Youngling on Behalf of Long Island Lighting Company," with attachments	27,153
Pischinger, Franz F.	
"Testimony of Edward J. Youngling and Franz F. Pischinger on behalf of Long Island Lighting Company on Suffolk County's Contention Regarding Replacement Crankshafts on Diesel Generators at Shoreham"	22,610
"Additional Crankshaft Testimony of Franz F. Pischinger, Duane P. Johnson and Milford H. Schuster on Behalf of Long Island Lighting Company"	28,416

Witness	Following Transcript Page
"Supplemental Testimony of Roger L. McCarthy, Charles A. Rau, Clifford H. Wells, Harry F. Wachob, Duane P. Johnson, Craig K. Seaman, Edward J. Youngling and Milford H. Schuster On Behalf of Long Island Lighting Company On Suffold County Contention Regarding Cylinder Blocks"	24,372
Wachob, Harry F.	
"Testimony of Clifford H. Wells, Duane P. Johnson, Harry F. Wachob, Craig Seaman, Dominic Cimino and N. Ken Burrell on behalf of Long Island Lighting Company Concerning Shotpeening of the Replacement Crankshafts"	23,122
"Testimony of Roger L. McCarthy, Charles A. Rau, Clifford H. Wells, Harry F. Wachob, Duane Johnson, Craig K. Seaman, Edward J. Youngling and Milford H. Schuster On Behalf of Long Island Lighting Company on Suffolk County Contention Regarding Cylinder Blocks"	24,372
"Supplemental Testimony of Roger L. McCarthy, Charles A. Rau, Clifford H. Wells, Harry F. Wachob, Duane P. Johnson, Craig K. Seaman, Edward J. Youngling and Milford H. Schuster On Behalf of Long Island Lighting Company On Suffolk County Contention Regarding Cylinder Blocks"	24,372
"Additional Cylinder Block Testimony of Dr. Duane P. Johnson, Dr. Charles A. Rau, Jr., Milford H. Schuster, Dr. Harry H. Wachob and Edward J. Youngling on Behalf of Long Island Lighting Company"	28,799

<u>Witness</u>	Following <u>Transcript Page</u>
"Supplemental Testimony of Roger L. McCarthy, Charles A. Rau, Clifford H. Wells, Harry F. Wachob, Duane P. Johnson, Craig K. Seaman, Edward J. Youngling and Milford H. Schuster On Behalf of Long Island Lighting Company On Suffolk County Contention Regarding Cylinder Blocks"	24,372
"Diesel Generator Qualified Load Testimony of George F. Dawe, Jack A. Notaro and Edward J. Youngling on Behalf of Long Island Lighting Company," with attachments	27,153
"Additional Cylinder Block Testimony of Dr. Duane P. Johnson, Dr. Charles A. Rau, Jr., Milford H. Schuster, Dr. Harry F. Wachob and Edward J. Youngling on Behalf of Long Island Lighting Company"	28,799