ORIGINAL

UNITED STATES
NUCLEAR REGULATORY COMMISSION

IN THE MATTER OF: **DOCKET NO:**

LONG ISLAND LIGHTING COMPANY 50-322-1 (OL)

(Shoreham Nuclear Power Station)

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UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

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In the matter of: :

LONG ISLAND LIGHTING COMPANY : Docket No. 50-322-1 (OL)

(Shoreham Nuclear Power Station:

- - - - - - - - - - - - - - - - - - x

State Office Building,

Veterans Memorial Highway,

Hauppauge, New York

Monday, 22 October 1984

The hearing in the above-entitled matter was convened, pursuant to adjournment, at 10:30 a.m.

BEFORE:

JUDGE LAWRENCE BRENNER, Chairman,
Atomic Safety and Licensing Board.

JUDGE PETER A. MORRIS, Member,
Atomic Safety and Licensing Board.

JUDGE GEORGE A. FERGUSON, Member,
Atomic Safety and Licensing Board.

APPEARANCES:

On behalf of the Applicant:

E. MILTON FARLEY, III, ESQ.,
Hunton and Williams,
700 East Main Street,
Richmond, Virginia 23219

On behalf of the Nuclear Regulatory Commission Staff:

RICHARD J. GODDARD, Esq.,
Office of the Executive Legal Director

On behalf of the Intervenor, Suffolk County:

ALAN ROY DYNNER, Esq.,
JOSEPH J. BRIGATI, Esq.,
Kirkpatrick, Lockhart, Hill, Christopher
and Phillips,
1900 M Street, N.W.,
Washington, D.C. 20036

C O N T E N T S

WITNESSES:	DIRECT	CROSS
LILCO Panel on Cylinder Blocks		
Roger Lee McCarthy)		
Harry Frank Wachob)		
Charles A. Rau)		
Clifford H. Wells)		
Edward J. Youngling)		
Craig K. Seaman)		
Duane P. Johnson)		
Milford H. Schuster)		
By Mr. Farley	24369	
By Mr. Dynner		24373

DOCUMENTS INSERTED:

Prefiled testimony of LILCO Panel on Cylinder Blocks (see above) with attachments, and supplemental testimony, and errata (Fls Page 24372)

Luncheon Recess 24422

Afternoon recess 24469

wbl

EXHIBITS	For Id.
Applicant's Cylinder Block Exhibits B-1 through B-50:	24372

B-1 through B-6 (Not used)

B-7 - Diagram (not otherwise identified)

B-8 - Diagram: Block top dimensions, Reference Block

B-9 - Section through cylinder head stud

B-10 - Section through non-stud region

B-11 - Cylinder liner

B-12 - Effect of section thickness on tensile strength of gray cast iron

B-13 - Engine 101 load history, SNPS

B-14 - Engine 102 load history, SNPS

B-15 - Engine 103 load history, SNPS

B-16 - SNPS DG101 crack map

B-17 - SNPS DG102 crack map

B-18 - SNPS DG103 crack map

B-19 - Diagram: typical example of a ligament crack

B-20 - Diagram: stud-to-stud cracking in SNPS DG103

B-21 - Component task evaluation rpt Q-410, 12 pgs

B-22 - Strain gage placement, Rosette and Compliance

B-23 - Strain gage placement: uniaxial

B-24 - Typical cross-section of V-shape crack

B-25 - DNPS DG103 crack map, 9/22/84

B-26 - Strain vs load, Gages 8, 9, 10

B-27 - Strain vs load, Gages 11, 12, 13

wb2

B-28 - Strain/stress vs. load (Gage 3)

B-29 - Principal stresses vs. load for Gages 8, 9, 10

B-30 - Principal stresses vs. load for Gages 11, 12, 13

B-31 - Strain/stress vs. load (Gage 3)

B-32 - (Deleted)

B-33 - Widmänstatten microstructure in DG103

B-34 - Microscopy comparison

B-35 - Details of Widmanstatten graphite

B-36 - Microstructure of DG101

B-37 - Microstructure of DG102

B-38 - Comparison of eutectic cell boundaries

B-39 - Schematic drawing of specimen location from DG103 segment removed from between Cyls 6 and 7

B-40 - Summary of tensile tests

B-41 - (Deleted)

B-42 - Strain-life data for TDI gray cast iron

B-43 - Reversals to failure

B-44 - Alternating stress intensity range

B-45 - Diagram (not otherwise identified)

B-46 - Perspective view of 3-dimensional block top model

B-47 - 2-dimensional block top model with internal pressure equal

B-48 - Factors relating stress measured at Shoreham Gage 13 to block top crack sites

B-49 - Goodman-Smith diagram for low cycle fatigue at 100 % load for Shoreham DG-101 and DG-102 wb3

B-50 - Goodman-Smith diagram for high cycle fatigue at 100% load for Shoreham engines DG101 and DG102

B-51 - Ltr to Proj Engr, LILCO, SNPS, re: Two-year operating cycle, EDGs, SNPS, 12/15/83, with attachments (13 pgs)

B-52 - (Deleted)

B-53 - (Deleted)

B-54 - (Deleted)

B-55 - (Deleted)

B-56 - (Deleted)

B-57 - (Deleted)

B-58 - (Deleted)

Suffolk County Exhibits:		For Id
Diesel Exhibit D-73 -	Liquid Penetrant Exam Rpt, Cyl liner landing, Cyl #7, DG102, 2/10/84	24398
D-74 -	TER Q-329: Liquid Penetrant Exam Rpts, Cyl block liner landing, Cyl #2, #3, #4, #5	24445

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PROCEEDINGS

JUDGE BRENNER: Good morning. We are back on the record.

Let's get the appearances of the parties, starting with the Staff.

MR. GODDARD: Richard A. Goodard for NRC Staff.

MR. FARLEY: E. Milton Farley, III, for LILCO.

MR. DYNNER: Alan Dynner for Suffolk County.

JUDGE BRENNER: We have no preliminary matters.

As we established in our order, the sequence will be to take the testimony of witnesses on behalf of LILCO on the subject of the cylinder blocks.

Mr. Farley.

MR. FARLEY: Thank you, sir.

Judge Brenner, LILCO has called to the stand Dr. Roger L. McCarthy, Dr. Charles A. Rau, Dr. Clifford H. Wells, Dr. Harry F. Wachob, Dr. Duane Johnson, Mr. Edward J. Youngling, Mr. Craig K. Seaman, Mr. Milford H. Schuster.

I would ask each to identify himself for the Board, to state his business address, and to state his occupation, beginning with Dr. McCarthy.

MR. MC CARTHY: My name is Roger Lee McCarthy. My business address is Failure Analysis Associates, 2225 East Bayshore Road, Palo Alto, California. I am the president of FAA.

MR. WACHOB: Harry Frank Wachob, Fair Analysis Associates, 2225 East Bayshore Road, Palo Alto, California, manager of the Materials Testing Laboratory.

MR. RAU: Charles Alfred Rau, Jr., Failure Analysis Associates. My business address is 2225 East Bayshore Road, Palo Alto, California. I am vice president and principal engineer of Failure Analysis Associates.

MR. WELLS: I am Clifford Wells, also with Failure Analysis Associates, 2225 East Bayshore Road, Palo Alto. And I am also vice president and principal engineer.

MR. YOUNGLING: My name is Edward J. Youngling. I am employed by the Long Island Lighting Company as the manager of Nuclear Engineering. My business address is Shoreham Nuclear Power Station, Wading River, New York.

MR. SEAMAN: My name is Craig K. Seaman. I am a project engineer with the Long Island Lighting Company. My business address is Shoreham Nuclear Power Station, North Country Road, Wading River, New York.

MR. JOHNSON: My name is Duane P. Johnson. I am employed by Failure Analysis Associates. The business address is 2225 East Bayshore Road, Palo Alto, California. I am a managing engineer at Failure Analysis.

MR. SCHUSTER: My name is Milford H. Schuster. I am employed with the Long Island Lighting Company. My job title is chief welding supervisor for the Long Island

Lighting Company, and my business address is North Country Road, Wading River, New York.

MR. FARLEY: Gentlemen, please stand and be sworn.

Whereupon,

ROGER LEE MC CARTHY,

HARRY FRANK WACHOB,

CLIFFORD WELLS,

EDWARD J. YOUNGLING,

CRAIG K. SEAMAN,

and

DUANE P. JOHNSON,

resumed the stand and, having been previously duly sworn, were examined and testified further as follows;

And whereupon,

CHARLES A. RAU

and

MILFORD H. SCHUSTER

were called as witnesses and, having been first duly sworn, were examined and testified as follows:

JUDGE BRENNER: We should say welcome back to most of these witnesses, and welcome to Mr. Rau and Mr. Schuster.

Mr. Farley.

MR. FARLEY: Thank you, your Honor.

WRBeb

DIRECT EXAMINATION

BY MR. FARLEY:

Q Mr. Youngling, as chairman of the panel, do you have before you the 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 Contentions Regarding Cylinder Blocks, Volume 1, with Attachments as corrected by the earlier errata and Status Report previously filed with the Board?

A (Witness Youngling) Yes, I do.

Q Do you also have Volume 2, Cylinder Block Exhibits, including Exhibits 7 through 31, 33 through 41, and 42 through 51 as similarly corrected?

A Yes, I do.

Q Do you have the 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 as corrected by the Status Report previously filed with the Board?

A Yes, I do.

Q Gentlemen, beginning with Dr. McCarthy, is this testimony, with the attachments and the exhibits and the

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supplemental testimony true and accurate to the best of your knowledge and belief?

A (Witness McCarthy) It is.

A (Witness Wachob) Yes, sir.

A (Witness Rau) Yes.

A (Witness Wells) It is.

A (Witness Youngling) Yes, it is. However, there is one correction which I was supposed to go over when you asked.

Q Exhibit 44?

A Exhibit 44. There is a graphical error made by the graphical artist, and we have provided new graphs in your exhibits.

Basically what it does, there were squares and circles associated with the graphical line on the left side, which should have been darkened in and were left light. We have darkened those in.

In addition, there were circles associated with the middle graphical line which should have been darkened in. We have darkened those in also.

MR. FARLEY: Your Honor, I am advised that you may not have seen these, and I will be glad at a break to paste them over the old one in your book so there won't be any--

JUDGE BRENNER: We can take care of it. Thank

WRBeb

you.

(Documents distributed.)

BY MR. FARLEY:

Q Does that?

A (Witness Youngling) With that correction, it is true and accurate, yes.

Q Mr. Seaman?

A (Witness Seaman) Yes, it is.

A (Witness Johnson) Yes, it is.

A (Witness Schuster) Yes, it is.

Q Gentlemen, beginning with Dr. McCarthy, do you adopt this testimony with attachments, the exhibits and the supplemental testimony in this proceeding?

A (Witness McCarthy) I do.

A (Witness Wachob) I do.

A (Witness Rau) I do.

A (Witness Wells) I do.

A (Witness Youngling) I do.

A (Witness Seamans) I do.

A (Witness Johnson) I do.

A (Witness Schuster) I do.

MR. FARLEY: If the Board please, Long Island Lighting Company offers this testimony with attachments, the exhibits and the supplemental testimony as evidence in this proceeding.

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JUDGE BRENNER: All right.

I take it it would be acceptable to all the parties if we did grant the motion to admit the identified testimony and attachments and exhibits into evidence. And mechanically we can bind in the testimony and the attachments to the testimony, and follow that by binding in the supplemental testimony into the transcript as if read.

And the exhibits, which are the B series of exhibits, will accompany the official exhibit file, and the exhibit list should indicate which exhibits have in fact been just identified and moved into evidence.

MR. FARLEY: Yes, sir.

(Whereupon, the documents referred to were marked as Applicants' Exhibits B-7 - B-32, B-34 - B-41 and B-42 - B-52 for identification.)

(The documents follow:)

LILCO, August 14, 1984

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

Before the Atomic Safety and Licensing Board

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

TESTIMONY OF ROGER L. MCCARTHY,
CHARLES A. RAU, CLIFFORD H. WELLS,
HARRY F. WACHOB, DUANE JOHNSON,
~~ROBERT K. TAYLOR~~, CRAIG K. SEAMAN,
EDWARD J. YOUNGLING AND MILFORD H.
SCHUSTER ON BEHALF OF LONG ISLAND
LIGHTING COMPANY ON SUFFOLK COUNTY
CONTENTION REGARDING CYLINDER BLOCKS

Testimony and Attachments

Volume 1 ~~of 3~~

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UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

Before the Atomic Safety and Licensing Board

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

TESTIMONY OF ROGER L. MCCARTHY, CHARLES A. RAU, CLIFFORD H. WELLS, HARRY F. WACHOB, DUANE P. JOHNSON, ~~ROBERT K. TAYLOR,~~ CRAIG K. SEAMAN, EDWARD J. YOUNGLING AND MILFORD H. SCHUSTER ON BEHALF OF LONG ISLAND LIGHTING COMPANY ON SUFFOLK COUNTY CONTENTION REGARDING CYLINDER BLOCKS

I. Introduction

1. Please state your name and business address.

A. My name is Dr. Roger L. McCarthy. My business address is 2225 East Bayshore Road, Palo Alto, California.

My name is Dr. Charles A. Rau. My business address is 2225 East Bayshore Road, Palo Alto, California.

My name is Dr. Clifford H. Wells. My business address is 2225 East Bayshore Road, Palo Alto, California.

My name is Dr. Harry F. Wachob. My business address is 2225 East Bayshore Road, Palo Alto, California.

My name is Dr. Duane P. Johnson. My business address is 2225 East Bayshore Road, Palo Alto, California.

My name is Robert K. Taylor. My business address is 2225 East Bayshore Road, Palo Alto, California.

My name is Craig K. Seaman. My business address is North Country Road, Wading River, New York.

My name is Edward J. Youngling. My business address is North Country Road, Wading River, New York.

My name is Milford H. Schuster. My business address is North Country Road, Wading River, New York.

2. Please summarize your professional qualifications and your role in the investigation of the structural adequacy of the Shoreham TDI R-4 Cylinder Blocks.

A. (McCarthy) I am a registered professional engineer specializing in mechanical design. I am the principal design engineer at Failure Analysis Associates (FaAA). I have five degrees, culminating in a Ph.D. in Mechanical Engineering from Massachusetts Institute of Technology. My specialization and Ph.D. thesis was in mechanical and thermal design. A copy of my resume setting forth my professional qualifications is attached to this testimony as Attachment 1.

My role in the investigation of the Shoreham TDI R-4 cylinder blocks has been executive oversight of the task performance and final technical review of all the reports. I have ultimate management responsibility for the quality and caliber of FaAA's technical product.

(Rau) I am a principal engineer at FaAA specializing in fracture mechanics, fatigue, and mechanical reliability. I hold a Ph.D. and M.S. in Materials Science from Stanford University. I am a registered professional engineer in the State of California and the Province of Saskatchewan, Canada. A copy of my resume setting forth my professional qualifications is attached to this text as Attachment 2.

My role in the investigation of the Shoreham TDI R-4 cylinder blocks has been to plan and supervise the metallurgical evaluation, materials testing and cumulative fatigue damage analyses.

(Wells) I am a principal engineer at FaAA, specializing in mechanical engineering, materials, and nondestructive inspection. I hold a D. Eng. in Mechanical Engineering from Yale University. A copy of my resume setting forth my professional qualifications is attached to this testimony as Attachment 3.

My role in the investigation of the Shoreham TDI R-4 cylinder blocks has been technical program manager, with overall responsibility for the assignment of technical responsibilities and review and approval of results, conclusions, and reports.

(Wachob) I am the manager of the materials and testing laboratory and a metallurgical engineer specializing in the influence of metallurgical microstructure and environment on the mechanical behavior of materials. A copy of my resume setting forth my professional qualifications is attached to this testimony as Attachment 4.

My role in the investigation of the Shoreham TDI R-4 cylinder blocks has been to evaluate the metallurgical microstructure of the three LILCO emergency diesel generators (EDGs), determine the mechanical behavior of the EDG 103 cast iron, and to correlate these two observations.

(Johnson) I am a qualified Level III inspector in eddy current and ultrasonic testing. I hold a Ph.D. from the University of Washington in Physics. A copy of my resume setting forth my professional qualifications is attached to this testimony as Attachment 5.

My role in the investigation of the Shoreham TDI R-4 cylinder blocks has been to supervise the eddy current inspections on the Shoreham EDGs.

~~(Taylor) I am a registered professional engineer~~ specializing in mechanical engineering. A copy of my resume setting forth my professional qualifications is attached to this testimony as Attachment 6.

My role in the investigation of the Shoreham TDI R-4 cylinder blocks has been to act as task leader. As such, I have directed the assignment of technical analyses, and I have reviewed their content and results. I have also directed cylinder block strain gage testing at Shoreham and Comanche Peak. In this regard, I have been the main interface in the ~~block analysis for the preparation of FaAA's report~~.

(Youngling) I am the Manager of the Nuclear Engineering Department at LILCO. In this capacity, I am responsible for engineering support at Shoreham, including the three TDI diesel generators. From 1981 through 1984, I was the Start-up Manager for the Shoreham plant. In this position, I was responsible for implementing the preoperational test program for Shoreham, including implementing initial operation, check out and subsequent preoperational testing of the TDI diesel generators. After the failure of the EDG 102 crankshaft, I was designated as the Recovery Manager for the repair and requalification of the diesel engines. In my various capacities, I have supervised the operation of Shoreham's diesels for over 3,350 hours. A copy of my resume setting forth my professional qualifications is attached to this testimony as Attachment 7.

(Seaman) I am employed by LILCO as a Project Engineer. While serving as Program Manager for the TDI Owners Group Program, my responsibilities included: review and approval of the design review and quality revalidation task descriptions and Phase I and Phase II reports; chairing the Component Selection Committee charged with responsibility for selecting the cylinder blocks for inclusion in the DRQR Program; and establishing minimum review requirements and managing the overall program, which included the design review and inspection on the cylinder blocks. My professional qualifications are detailed in my resume, which is attached to this testimony as Attachment 8.

(Schuster) I am the senior LILCO representative in the quality revalidation group of the Design Review Quality Revalidation Program. My duties include reviewing and approving quality task descriptions and component reports. I also supervised inspections on the Shoreham diesels, including all cylinder block inspections. A copy of my resume setting forth my professional qualifications is attached to this testimony as Attachment 9.

3. Are you familiar with the Report prepared by Failure Analysis Associates dated June 1984 entitled "Design Review of TDI R-4 and RV-4 Series Emergency Diesel Generator Cylinder Blocks and Liners?"

A. (McCarthy, Rau, Wells, Wachob, Johnson, ~~Taylor,~~ Seaman, Youngling, Schuster) Yes. This report sets forth FaAA's initial analysis of the cylinder blocks. As indicated in the report, FaAA's analysis was not finally completed at the time the report was issued. This testimony updates the analysis and conclusions reached in the report.

4. Have you had an opportunity to review the Shoreham Emergency Diesel Generator Contention as admitted as an issue in controversy by this Board's Memorandum and Order dated July 17, 1984?

A. (McCarthy, Rau, Wells, Wachob, Johnson, ~~Taylor,~~ Seaman, Youngling, Schuster) Yes. The specific contentions admitted by the Board's Order regarding cylinder blocks are that the 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. The replacement cylinder block for EDG 103 is a new design which is unproven in DSR-48 diesels and has been inadequately tested.

5. Please briefly summarize the conclusions of your testimony with respect to the issues raised by the County's testimony.

A. (McCarthy, Rau, Wells, Wachob, Johnson, ~~Taylor,~~ Seaman, Youngling, Schuster) Our conclusions with respect to the issues raised by the County's contentions may be summarized as follows:

1. The ligament cracks present in EDG 101 and EDG 102 are benign. Observations of various engines indicate that the cracks will not propagate beyond a depth of 1 1/2 inches. Accordingly, the ligament cracks in EDG 101 and EDG 102 do not and will not impair the ability of the EDGs to perform their intended function.

2. The crack that propagated down the front of the old EDG 103 block and the cracks that developed between the stud holes of adjacent cylinders on the old EDG 103 do not threaten the integrity of EDG 101 or EDG 102. Metallurgical analysis of the existing blocks has established that EDG 101 and EDG 102 do not have the extensive degenerate graphite microstructure that produced markedly inferior fracture fatigue properties in the old EDG 103 block. Further, EDG 103 was subjected to an abnormal load excursion that contributed to further crack extension. A cumulative damage analysis predicts that the EDG 101 and EDG 102 blocks are substantially less likely to develop stud-to-stud cracking and that they will withstand a LOOP/LOCA with sufficient margins even if they were to initiate stud-to-stud cracking during a LOOP/LOCA.

3. The cam gallery cracks in the Shoreham EDGs, which were discovered more than 1 1/2 years ago, are not predicted to propagate significantly even after hundreds of hours of engine operation. In addition, there is no reported incident in which cam gallery cracks have caused a sudden engine failure. The cam gallery cracks are therefore not predicted to impair the ability of the EDGs to meet their intended function.

4. The replacement block for EDG 103 has been tested adequately. The replacement block is not a new design. It is simply a current production model that incorporates certain product enhancements, each of which has been shown to be beneficial by exhaustive testing in the R-5 engine.

II. Description of the Cylinder Blocks

6. What is the function of the cylinder block?

A. (Wells, ~~Taylor~~, Seaman) It forms the framework of the liquid cooled engine, provides passage for coolant and support for the cylinder liners and cylinder heads, and restrains the forces generated by gas loads.

7. Please describe the Shoreham TDI R-4 cylinder block configuration.

A. (Wells, ~~Taylor,~~ Seaman) In general, the dimensions of the block top are the same for TDI in line and V-configuration engines. Block top thickness, liner dimensions, cylinder head stud spacings and the boss region below the block top which supports the cylinder head studs are similar for all R-4 and RV-4 engine models. ~~The geometry of these components is depicted in the TDI engineering drawings which are attached as Exhibits B-1, B-2, B-3, B-4, B-5 and B-6, respectively.~~

The geometry of the cylinder block, cylinder liner, cylinder head and cylinder head studs is shown in Exhibit B-7. As you can see, the cylinder head nuts clamp the head onto the liner and block. The liner is supported vertically by the counterbore landing in the block. Two gaskets are located between the head and the cylinder block and liner. The gaskets crush to the depth of the gasket grooves and form a seal.

A plan view of the block top setting forth the location of the cylinder bore, cylinder head studs and the cylinder head is depicted in Exhibit B-8. Detailed drawings of the cylinder head stud and the cylinder head and block are depicted in Exhibit B-9 and B-10. Finally, a detailed drawing of the cylinder liner, including its dimensions, is depicted in Exhibit B-11.

8. What are the material specifications for the Shoreham TDI R-4 cylinder blocks?

A. (Rau, Wachob) The TDI R-4 series cylinder blocks are specified to be ASTM A48-64 Class 40 gray cast iron. ~~TDI drawing 03-315-03-AC depicting the material specifications is attached as Exhibit B-1.~~

The specified minimum tensile strength of the ASTM A48-64 Class 40 cast iron is 40 ksi in a 1.2 inch diameter test bar. The expected minimum tensile strength of cast iron, however, is a function of section thickness. Since the tensile strength of gray cast iron decreases with increasing section thickness, thicker sections have a lower yield strength than thinner sections. Thus, for Class 40 gray cast iron, the minimum expected tensile strength would be below 40 ksi. Specifically, the minimum expected tensile strength is 25 ksi for the thickness of the as-cast block top of 3 1/2 inches and a stud boss region having an approximate equivalent diameter of 7 inches. Both estimated and reported values of tensile strength for the appropriate thickness section are given in Exhibit B-12.

III. Operating Experience Of TDI Engines

9. Does LILCO have in place a program designed to evaluate and assure the capacity of the EDGs to perform their intended function?

A. (Wells, ~~Taylor,~~ Youngling, Seaman, Schuster) To assure that the diesel engines will meet their intended function of providing emergency standby power, LILCO has put in place an extensive Design Review Quality Revalidation (DRQR) Program. The DRQR Program verifies the design adequacy of the TDI engines in areas where known operational problems have occurred at Shoreham and in the nuclear industry. The program implements corrective measures through appropriate design reviews, and through independent verification of important quality attributes of the diesels' components. The program is designed to provide the requisite assurance that the engines will perform their intended function in nuclear standby service.

10. Has a testing procedure been implemented by LILCO as part of the DRQR Program?

A. (Wells, ~~Taylor,~~ Youngling, Seaman, Schuster) Yes. The DRQR program adopted an enhanced preoperational test program that goes far beyond minimum NRC requirements. As part of the preoperational testing, LILCO has run each engine for approximately 300 hours, with at least 100 of these hours at or above full power operation. LILCO has included an additional 100 fast starts on the EDG 102 engine to demonstrate further the reliability of the engines.

A test program limited to NRC requirements would result in only about 70 hours of operation, including 23 fast starts on each engine. LILCO's test program, on the other hand, exceeded the maximum service that any EDG at Shoreham would be subjected to during an entire operating cycle (<u>i.e.</u>, time between refueling outages), even assuming a seven-day LOCA.

In accordance with the DRQR program, the engine blocks were subjected to inspections. The results of these inspections were provided to the design task leaders for use in the design review of the block, and are discussed below in this testimony.

11. How many hours of operation have each of the TDI engines at Shoreham experienced?

A. (Wells, ~~Taylor,~~ Youngling) As of April 30, 1984, EDG 101 had operated for a total of 1,091.5 hours. Of these operating hours, 285 hours were at less than 75% of full load, 451.5 hours were between 75% and 100% of full load, 238 hours were at full load, 91.5 hours were between 100% and 110% of full load, and 25.5 hours were in excess of 110% of full load.

EDG 102 was operated for a total of 1,123 hours. Of these operating hours, 207.5 were at less than 75% of full load, 511.5 hours were between 75% and 100% of full load, 311.5 hours were at full load, and 63 hours occurred at load levels between 100% and 110%, and 29.5 hours were in excess of 110% load.

EDG 103 was operated for a total of 1,270.5 hours. Of these operating hours, 234.5 hours were at less than 75% load, 608 hours were at 75% to 100% of full load, 350.5 hours were at 100% of full load, 47.5 hours occurred between 100% and 110% of full load, and 30 hours of operation were over a load of 110%. Tables showing the operating hours of the Shoreham engines are attached as Exhibit B-13, B-14 and B-15.

12. Were cracks discovered in any of the engine blocks?

A. (Wells, Johnson, Youngling and Schuster) Yes. Ligament cracks were discovered in the blocks of all three engines. These cracks extended from the cylinder head stud holes to cylinder liner counterbore on EDG 101, EDG 102 and EDG 103.

13. How did LILCO determine the existence and location of the ligament cracks?

A. (Wells, Johnson, Youngling, Seaman, Schuster) The cracks were identified by the DRQR program. As part of the engine qualification testing, each engine was operated for 100 hours at or above full load and then disassembled and inspected. A series of liquid dye penetrant, eddy current and visual inspections were performed on the cylinder block tops, stud holes and cylinder liner landings. These tests and inspections permitted LILCO to map the location of the cracks and to measure their size. The location and size of the ligament cracks in EDG 101, EDG 102 and EDG 103 are depicted in Exhibits B-16, B-17 and B-18, respectively.

14. What do you mean by the term ligament crack?

A. (Wells, [redacted] and Seaman) The term ligament crack refers to a crack that extends from the cylinder head stud counterbore to the cylinder liner counterbore and lies in a vertical plane.

15. What size were the ligament cracks that you identified?

A. (Wells, Youngling, Seaman, Schuster) The ligament cracks appeared to extend from the block top surface downward. Sixty-seven percent of the ligament cracks were between 1 and 1 1/2 inches deep with the remainder less than 1 inch deep. None of the cracks extended below the corner formed by the counterbore and the counterbore landing in either EDG 101 or EDG 102. A typical example of a cross-section of a ligament crack is shown in Exhibit B-19.

16. Were the cracks the same on each of the three cylinder blocks?

A. (Wells, Johnson, Youngling, Seaman, Schuster) The cracking was similar on EDG 101 and EDG 102. In other words, all the cracks were ligament cracks confined to the area between the cylinder bore and the stud holes and were less than 1 1/2 inches deep.

On EDG 103, however, there were two types of cracks. First, like EDG 101 and EDG 102, there were ligament cracks. Second, there was a crack between the stud holes on the exhaust side of the block between cylinder nos. 4 and 5. This crack is depicted in Exhibit B-20.

As depicted in Exhibit B-20, the cracks between the two adjacent studs will be referred to as stud-to-stud cracking. The stud-to-stud cracking on EDG 103 between cylinder nos. 4 and 5 was measured by an eddy current technique to be approximately 1 1/2 inches deep after the qualification testing.

17. Were any tests performed on the EDGs to determine if the cracks were propagating?

A. (Wells, ~~Taylor,~~ Johnson, Youngling, Seaman, Schuster) EDG 102 was tested for crack propagation. After LILCO inspected all three engines following the preoperational testing for 100 hours at or above full load, EDG 102 was reassembled, started 100 times, and operated for more than 60 hours at loads greater than 50 percent. EDG 102 was then disassembled and reinspected. After 100 starts there was no discernible crack extension as measured by eddy current examination. This fact is documented in Exhibit B-21.

18. Were other tests performed to analyze crack propagation?

A. (Wells, ~~Taylor,~~ Seaman) Strain gage tests were performed on the cylinder block of EDG 103 in order to determine the stress state between cylinder nos. 4 and 5. During this test, strain gages were located as shown in Exhibits B-22 and B-23. As shown in the Exhibits, gages nos. 8-10, 11-13 and 3 responded to block top strains while gage no. 1 responded to the crack-mouth opening displacement of the stud-to-stud crack at the surface of the block top.

19. What does the "crack-mouth opening displacement" mean?

A. (Wells, ~~Taylor~~) If you envision a cross-section profile of the crack, it has a V-shape. The crack surfaces are farthest apart (open) at the top surface and narrow at the crack bottom. The crack-mouth opening displacement is the measure of the distance between the crack surfaces at the top of the V-shape. This is depicted in Exhibit B-24.

The crack-mouth opening displacement increases as engine load increases. It should remain in a constant range, when the engine is operated at a constant load level. If the crack-mouth opening displacement increases while the engine is running at a constant load, it implies that the crack is propagating.

20. What were the objectives of the strain gage tests?

A. (Wells, ~~Taylor~~) The objectives of the strain gage test were to record strains in order to predict the stress state that exists in the block top, and to monitor the crack-mouth opening displacement of the stud-to-stud crack during assembly of the cylinder heads to the block and during engine operation from zero load up through full load to 110% load.

21. What was the purpose of monitoring the crack-mouth opening displacement during the testing?

A. (Wells, ~~Taylor~~) The purpose of monitoring crack-mouth opening displacement was to determine if crack propagation occurred during engine operation testing. No long-term increase was observed in the crack-mouth opening displacement during the test. This indicates that the stud-to-stud crack did not measurably extend during testing.

22. After completion of the strain gage test, did operation of EDG 103 continue?

A. (Youngling, Seaman and Schuster) Yes. Pre-operational testing continued and the engine was run for an additional 89 hours. Of these hours, 36 were at or above full load.

During this period when LILCO was continuing with the qualification testing of EDG 103, the engine experienced an abnormal load excursion. The abnormal load condition occurred while EDG 103 was operating at full load. The power demand from the site load, which exceeded the diesel's capacity, was accidentally picked up by the engine. The diesel engine RPM slowed, at which time the engine generator output breaker tripped due to low RPM. The diesel continued to run at no load for ten minutes before it was shut off.

Upon restarting the engine and continuing with qualification testing at 3,900 kW, a crack at cylinder no. 1 was noticed, and the testing was stopped after 1 3/4 running hours. It is not known when the crack at cylinder no. 1 occurred. It should be noted, however, that at the time the crack was discovered, EDG 103's engine operating parameters were entirely satisfactory. The test was not discontinued because EDG 103 was incapable of producing power.

23. Was EDG 103 inspected after the abnormal load excursion was experienced?

A. (Wells, ~~Taylor~~, Johnson, Youngling, Seaman, Schuster) Yes, the block was inspected after the abnormal load condition. The inspection of the block top revealed that the original stud-to-stud crack between cylinder nos. 4 and 5 had extended to a maximum depth of ~~about 5 1/2~~ 3 inches, and one ligament crack~~s~~ between the cylinder liner counterbore and the stud holes at this location extended approximately one inch, as shown in Exhibit B-25. At another location, a crack that had previously extended 0.8 inch radially from one stud hole toward the adjacent stud hole grew to a maximum depth of ~~[illegible]~~ .85 inch~~es~~.

In addition, three cracks between the stud holes having a depth of 1 1/2 inches were found. These stud-to-stud cracks are similar to those shown in Exhibit B-20.

At five other locations, stud-to-stud cracks developed between the studs along the top surface. These cracks did not extend to measurable depths down the sides of the stud hole.

Also, cylinder no. 1 at the 4 o'clock position stud, which had a previously existing ligament crack, developed a new crack that extended from the opposite side of the stud hole toward the edge of the block downward 4.4 inches.

24. In your opinion, did the load excursion to which EDG 103 was subjected contribute to the growth of the stud-to-stud cracking?

A. (Wells, ~~Taylor~~) Yes. As mentioned earlier, during the strain gage testing of EDG 103, the crack-mouth opening displacement of the stud-to-stud crack was monitored. Crack-mouth opening displacement values were recorded during engine operation ranging from zero load to 3830 kW.

As previously stated, throughout the strain gage testing the crack did not appear to grow measurably during 19.1 hours of engine operation. Approximately 2.5 of those hours were at full load or greater. Therefore, the significant crack growth on EDG 103 occured after the strain gage testing. It is FaAA's opinion that a portion of the crack growth on EDG 103 is attributable to the unusual load excursion. FaAA's opinion is based on the fact that loads achieved during testing, including operation at 3,830 kW, did not result in rapid fracture. Since fatigue crack growth is proportional to a power of the applied stress and operation time, it is clear that some extension of the crack must have occurred due to fatigue at peak load.

25. In addition to examining the service experience of the engines at Shoreham, did FaAA investigate the operating history of other TDI diesel engines?

A. (Wells, ~~Taylor~~) Yes. Inspections were performed on ~~FaAA inspected~~ a number of blocks at other nuclear power stations, including Catawba, River Bend, Commanche Peak and Grand Gulf. In addition, FaAA obtained information regarding cylinder blocks on TDI diesel engines in non-nuclear service. This data included engines involved in marine use as well as engines in stationary non-nuclear use.

26. What was the purpose of examining blocks at other nuclear power stations and blocks in non-nuclear service?

A. (Wells, ~~Taylor~~) FaAA obtained the operating history of cylinder blocks in other nuclear power stations and in blocks used in non-nuclear service for several reasons. First, inspection of blocks in other nuclear power stations is utilized to determine whether block top cracking is generic to this model TDI engine. Second, this information is useful to determine at what point and under what operating conditions cracks are likely to develop.

With respect to engines in non-nuclear service, investigation of block top cracking is of less value in preparing analytical models for estimating cracking tendencies and operating conditions under which cracks may occur. This is because the operating conditions and stresses to which the engines are subjected, particularly in marine use, are not the same as engines in nuclear use.

On the other hand, knowledge of the operating experience of non-nuclear engines is helpful for bounding what effects cracks have on cylinder blocks over long periods of time. Since many engines in non-nuclear service experience operating hours far in excess of those that would ever be encountered at a nuclear power station, conservative estimates can be developed for engine operation reliability with a cracked block.

27. Was it appropriate for FaAA to rely at all on service experience from marine and other non-nuclear engines?

A. (Wells, ~~Taylor~~) As indicated above, information on non-nuclear engines is useful for some purposes, but not directly applicable for others. When FaAA prepared analytical models of the block top cracking, information on marine engines was not useful because marine users do not maintain sufficiently detailed records of loads, types of fuel, time of crack initiation, etc., to assist in computer models.

After FaAA completed its analytical model, however, information on marine engines was valuable in obtaining rough verification of predictions made in the model. Service experience is also valuable for determining the consequences of cracking. Of course, information on load conditions, etc., would still be helpful, but examination of the service experience of marine engines is useful even in the absence of such information for purposes of evaluating the consequences of block cracking.

IV. FaAA's Analysis Of Ligament And Stud-to-Stud Cracks In The EDG Cylinder Blocks

A. Evaluation of Load Factors

28. What caused the cracks in the Shoreham cylinder blocks?

A. (Wells, [redacted]) No one factor alone is responsible for the cracking of the cylinder blocks. The factor that primarily influences cracking is the loads to which the engine blocks are subjected and the time at these loads. These loads include the preload, thermal and firing pressure loads. The distribution of these loads and resulting stresses in the ligament and stud-to-stud cracking locations is affected by the distortion of the cylinder head, cylinder liner, and block top. Since the loading and distortion are interactive and very complex, strain gage measurements have been performed and analyzed and several analytical models have been prepared to help deduce the most significant factors contributing to block stress.

29. Please describe what causes preload and how preload affects cracking in the blocks.

A. (Wells, ~~Taylor~~) Preload forces come from clamping the cylinder heads onto the cylinder block by tightening the cylinder head stud nuts. As the cylinder stud nuts are tightened or torqued, axial tensile forces develop in the stud. On the adjacent block, the stud force acts upwards. In other words, each stud pulls up on the adjacent block top material. At the same time, the stud is pulling downward on the cylinder head. This causes the head to push against the block top and the cylinder liner collar. The cylinder liner in turn presses against the block counterbore landing. The net effect of the stud pulling upward on the block top in conjunction with the cylinder head and liner pushing down against the block top is to cause the block top to deflect. This deflection creates stress in the block top that we have called preload stress. The magnitude of this stress is governed by the deflection of the cylinder head and block top, which depends on the amount of cylinder stud nut torque and the protrusion of the liner above the block top. Preload affects crack initiation and propagation because the resulting block top deflection due to preload results in tensile stress perpendicular to the plane of the ligament and stud-to-stud cracking.

30. Please describe what causes thermal loads and how thermal loads affect cracking in the blocks.

A. (Wells, ~~Taylor~~) Thermal loads come from the non-uniform increase in temperature in the cylinder during combustion. Due to the high temperature within the cylinder and the cooler temperature of the metal outside the combustion chamber, thermal gradients are developed in the cylinder liner, cylinder block, cylinder head, and cylinder head studs. In other words, temperature at the cylinder bore is highest, and it decreases with distance into the block metal.

The temperature gradient and non-uniform mean temperature of each of the components mentioned results in creating thermally-induced stresses or thermal stresses. For example, as the temperature rises, the cylinder liner and block both expand in a radial direction. Because of different mean temperatures, the cylinder liner expands more than the block. This causes the liner-to-block clearance gap which exists at room temperature to close and adds interference stresses.

Thermal loads also cause the cylinder head to expand radially as the fire deck heats up. This motion is restrained by the block through friction between the cylinder head and the cylinder liner or block. In addition, the cylinder head studs may be pushed radially outward from the center of the cylinder. This creates added stress in the threaded region of the studs.

Depending on the initial clearance between liner and block counterbore, some fraction of the radial expansion of the liner will introduce stresses into the block. There is an optimum initial clearance between liner and block which assures that the cylinder liner is in continuous contact with the block during operation but minimizes the interference thermal stresses in the block.

31. Please describe how firing pressure affects cracking in the blocks.

A. (Wells, [redacted]) Firing pressure loads come from the gas pressure within the combustion chamber. These gas pressures act radially on the cylinder liner. During each firing cycle of the engine, the gas pressure ranges from slightly less than the intake manifold pressure of 27 psi to the maximum combustion gas pressure of approximately 1,670 psi. In FaAA's analytical modeling, 1,670 psi was used to compute alternating pressure induced stresses.

Assuming that the thermal loads have closed the clearance gap between the cylinder liner and block, the gas pressure creates circumferential hoop tensile forces in the block top. As is the case for thermal stress, circumferential hoop tensile stress in the block top is the stress that acts perpendicular to the plane of the ligament and stud-to-stud cracking. It is a key stress because it affects both crack initiation and propagation. Since gas pressure is not a constant value but varies with the combustion cycle, stress components associated with firing pressures alternate.

Further, gas pressure acts vertically on the cylinder head. This force deflects the cylinder head upwards and changes the contact force between the head and liner or block. Changing contact pressure on the liner and block results in alternating stresses due to changes in block top deflections.

B. <u>Strain Gage Testing</u>

32. How did FaAA measure the load factors that have been identified?

A. (Wells, ~~Taylor~~) FaAA performed strain gage testing to evaluate these factors.

33. Please describe the strain gage testing that FaAA performed.

A. (Wells, ~~Taylor~~) FaAA performed strain gage testing on EDG 103. The test procedure was to apply strain gages to the block and record strain values while the cylinder head stud nuts were tightened. At the completion of tightening all cylinder stud nuts, the recorded strains represent the preload stress condition.

The engine was then operated at various load levels ranging between no load and a maximum of 3,830 kW. Strain data associated with thermal and firing pressure were recorded at each of the load levels. The increase in mean stress from the preload condition to the value while the engine is operating represents the thermal strain. The gas pressure induced dynamic strains are those strains that vary during each cylinder firing.

34. What were the results of the strain gage testing during preload and operation of the engine?

A. (Wells, ~~Taylor~~) The results of the strain gage testing for gage nos. 8-10, 11-13 and 3 are depicted in Exhibit B-26, B-27 and B-28. These strain data were used to compute the stresses at the locations in the block where the gages were placed. The stresses during preload and operation of the engine for these three locations are shown in Exhibits B-29, B-30, B-31.

The stress data depicted in Exhibits B-26 to B-31 were used in conjunction with the finite element analysis performed by FaAA. The finite element analysis was used to predict the stresses present in the other block top locations, such as at the edges of the cylinder stud hole where the ligament and stud-to-stud cracks were shown to initiate and where no strain gages were located.

~~35. Were any other strain gage data used in the analysis of the cylinder blocks?~~

~~A. (Wells, Taylor) Yes. TDI provided strain gage data from independent tests which they performed. This included data on the preload and operating stresses in the cylinder liner counterbore region adjacent to the ligament. The location of TDI gage nos. 3 and 4 is shown in Exhibit B-32.~~

~~36. What does the TDI strain gage data demonstrate?~~

~~A. (Wells, Taylor) The data from TDI strain gage no. 1, as depicted in Exhibit B-32, demonstrates that the preload and pressure stresses at the counterbore and pilot diameter surface do not decrease rapidly from the block top. Preload stress is still near 10 ksi two inches below the block top. At the same time, the firing pressure induced stress range is 3 ksi.~~

~~This suggests that the apparent arrest of ligament cracks at a depth of about 1 1/2 inches, as was evident~~

~~in the block inspections, may be due to a displacement limit on the crack mouth opening. This is consistent with the theory that ligament cracks of any depth are fully contained between the intact liner and the region of the block top outside the stud hole circle. Once the load initially carried by the cracked ligament region is redistributed to the adjacent cylinder liner and the outer block top regions, there is reduced driving force for further crack growth~~.

C. <u>Metallurgical Analysis</u>

37. In addition to the strain gage data, did FaAA obtain any other data as input for its finite element analysis on the ligament cracks?

A. (Rau, Wells, ~~Taylor,~~ Wachob) Yes. FaAA performed a metallurgical analysis on the cylinder blocks to determine whether differences existed in the microstructure that might affect mechanical properties of the three blocks. Differences in the strength properties of the three blocks results in different boundary conditions for the finite element analysis.

38. Has FaAA performed any testing to determine if differences exist between the original EDG 103 block cast iron and the cast iron contained in EDG 101 or EDG 102?

A. (Rau, Wachob) Yes. Extensive testing has been performed to evaluate whether ~~the~~ differences exist between EDG 101, EDG 102 and the original EDG 103.

39. Has FaAA determined that there is a difference between the material properties of the original EDG 103 block and the blocks on EDG 101 and EDG 102?

A. (Rau, Wachob) Yes, FaAA has determined that significant microstructural differences exist between EDG 103, and EDG 101 and EDG 102.

40. How did FaAA reach this conclusion?

A. (Rau, Wachob) Areas associated with heavy-section portions of the EDG 101, EDG 102 and EDG 103 block tops were metallographically polished and examined in the microscope to reveal the microstructure. The actual graphite distribution and morphology, the size of the graphite/austenite eutectic cell, and the matrix structure were observed. Acetate (plastic) replicas were taken from polished surfaces of each block top for subsequent microscopic analysis in the laboratory. Replicas revealed an extensive amount of degenerate Widmanstaetten graphite was present in the EDG 103 block.

41. What is Widmanstaetten graphite?

A. (Rau, Wachob) Widmanstaetten graphite is a degenerate or abnormal form of graphite that occurs infrequently in heavy-section gray cast iron. It appears as sharp acicular (needle-like) clusters of graphite around the normal graphite flakes. The presence of Widmanstaetten graphite is influenced by cooling rate, presence of hydrogen and trace amounts of tramp elements. The presence of Widmanstaetten graphite is widely recognized and has been shown to significantly reduce the mechanical properties of gray cast iron.

42. Has FaAA done any additional testing to verify the existence of the Widmanstaetten graphite?

A. (Rau, Wachob) Yes. FaAA had LILCO remove corner pieces from the exhaust manifold support base from all the Shoreham engine blocks. These specimens showed the same metallographic characteristics as did the replica specimens previously removed from each engine block.

43. Please describe the differences between the microstructure of the iron in EDG 101, EDG 102 and the original EDG 103 block?

A. (Rau, Wachob) Representative photomicrographs from EDG 103 samples are shown in Exhibits B-33 to B-35 at various magnifications. They show in detail the distribution and morphology of the Widmanstaetten graphite.

The microstructural differences between EDG 103 and EDG 101 are clearly demonstrated when Exhibit B-33 is compared to photomicrographs of similar magnification taken of EDG 101 samples, which are attached as Exhibit B-36. Similarly, when Exhibit B-33 from EDG 103 and is compared to Exhibit B-37 taken from EDG 102, the same strong difference between the microstructural characteristics of the two blocks is apparent. In particular, the degenerate graphite near the tips of the graphite flakes is extensive in the EDG 103 block. EDG 101 and EDG 102 do not possess the microstructure of EDG 103, which is known to reduce significantly the tensile strength of gray cast iron.

44. Are the replicas and samples taken from each of the individual engine blocks at Shoreham representative of the overall microstructure present in each engine block?

A. (Rau, Wachob) The replicas from the block tops and the metallurgical sections taken from the exhaust manifold base corners are representative of the overall microstructure which is present in the heavy-section areas of the blocks. The cooling rate during solidification is the major factor in determining the local microstructure in the block. Since all the samples removed from the blocks were taken from thick-sections, they are representative of the entire thick-section microstructure of the blocks. This was confirmed by detailed sectioning and examination of the microstructure at various positions in the EDG 103 block top.

45. What is the significance of the microstructural differences observed in EDG 101, EDG 102 and EDG 103?

A. (Rau, Wachob) There are numerous references in the open literature to the fact that the strength and ductility of gray cast iron are reduced significantly by the presence of Widmanstaetten graphite. The presence of Widmanstaetten graphite in EDG 103 strongly suggests that the mechanical properties of EDG 103 would be measured to be substantially lower than those of typical Class 40 gray cast iron.

46. How does the presence of Widmanstaetten graphite influence the strength of the gray cast iron?

A. (Rau, Wachob) The mechanical strength of gray cast iron is influenced strongly by graphite morphology and distribution. Because the graphite flakes themselves are quite weak, the strength of the gray cast iron is primarily developed by the network of eutectic cell walls. If Widmanstaetten graphite concentrates in the eutectic cell walls, the strength of the cast iron is more seriously compromised.

47. What is a eutectic cell wall?

A. (Rau, Wachob) The eutectic wall is the material that forms the boundary between adjacent graphite/steel eutectic cells. Each cell nucleated and grew separately during the casting to form colonies (cells) of interconnected graphite flakes. Since the cell wall is the volume of material that is the last to solidify, the highest level of tramp and residual elements are contained within that region. Thus, the cell walls are particularly susceptible to Widmanstaetten graphite formation.

In addition, since the graphite flakes are quite weak, the interior portion of the eutectic cell is not capable of carrying significant load. As a result, cell walls are the primary load carrying component of gray cast iron.

48. Why is the strength of gray cast iron more seriously compromised if Widmanstaetten graphite concentrates in the eutectic cell wall?

A. (Rau, Wachob) All gray cast irons have eutectic graphite flakes in the microstructure. When the microstructure is subjected to a high tensile load, the graphite flakes crack. Cracking extends relatively easily across the interconnected graphite flakes within the eutectic cell until it reaches the eutectic cell wall boundary. The normal cell wall boundary does not contain graphite, and it provides a barrier against continued crack extension. Therefore, the eutectic cell wall strength determines the strength of the gray cast iron.

When a gray cast iron containing Widmanstaetten graphite is subjected to a significant tensile load, the graphite flakes crack. However, the Widmanstaetten thistles, which have collected in the eutectic cell wall, provide an easy path for crack extension through the cell wall and into the next eutectic cell. The overall result is to reduce significantly the load carrying capacity of the gray cast iron.

49. Did the original EDG 103 block have Widmanstaetten graphite concentrated in the eutectic cell wall.

A. (Rau, Wachob) Yes. Metallographic examination of the EDG 103 samples showed that the Widmanstaetten graphite thistles were generally located near the ends of the eutectic graphite flakes in the eutectic cell wall. These Widmanstaetten regions thus provide an easier linking mechanism for crack extension from one cell to another. In addition, the eutectic cell walls in specimens removed from EDG 101 and EDG 102 were examined. Comparison of representative regions, attached as Exhibit B-38, shows significant differences between the microstructure of EDG 103 and that of EDG 101 and EDG 102.

50. Do you have any evidence or experimental results showing that EDG 103 has inferior mechanical properties?

A. (Rau, Wachob) Yes. Subsequent to the abnormal load excursion that occurred at Shoreham on the EDG 103 block, FaAA obtained a portion of the EDG 103 block top. The section was removed from between cylinder nos. 6 and 7. Tensile, fatigue and compact tension specimens were removed from the block top in the locations depicted in the sketch attached as Exhibit B-39.

Tensile tests were performed to determine the tensile strength of the gray cast iron from EDG 103. Specimens taken from the thick section of the block top had tensile strengths as low as 14.5 ksi as compared to anticipated values in excess of 25 ksi. Specimens taken in the thinner web section just below the block top had a higher tensile strength, 21.5 ksi. A table summarizing these results is attached as Exhibit B-40.

The reduction in the tensile strength of the original EDG 103 block below nominal Class 40 gray cast iron was at least 40%. The reduction in the tensile strength clearly reveals the deleterious effect of the Widmanstaetten graphite microstructure.

51. Were there any other mechanical properties that FaAA analyzed?

A. (Rau, Wachob) Yes. The fatigue crack growth rate and the fatigue endurance limit were investigated since they provide input data to the crack propagation and crack initiation analysis.

52. Could the fatigue endurance limit have been estimated from the tensile strength of the gray cast iron?

A. (Rau, Wachob) Yes. Correlations between the tensile strength and the fatigue endurance limit are available in the technical literature. However, the endurance limit is also a function of the experimental test procedure. For example, the ratio of fatigue endurance limit to the tensile strength is higher for bending fatigue tests on small specimens than for axial fatigue tests on small specimens. The axial endurance limit can be 60-95% of that reported in bending. Thus, an axial endurance limit of 25% to 35% of the tensile strength can be used as a conservative estimate of the fatigue endurance value in subsequent analytical analysis.

For a Class 40 gray cast iron whose 1.2 inch diameter test bar strength was 40 ksi, the expected fatigue endurance limit is between 10 and 14 ksi. However, with the normally-expected, heavy-section reduction in tensile strength from 40 to 25 ksi, the estimated fatigue endurance limit is between 6 and 9 ksi.

Typical fatigue results for various gray cast iron are shown in attached Exhibit B-43. Although the data are not identified as experimental data from Class 40 gray cast iron, the corresponding tensile strengths range between 28 and 38 ksi, which are the range of values applicable to this gray cast iron.

53. Does the technical literature show a correlation between the Widmanstaetten microstructure and the fatigue properties of the gray cast iron?

A. (Rau, Wachob) No literature results of the effects of Widmanstaetten graphite on either the fatigue endurance limit or the fatigue crack growth rate were found.

54. Was FaAA able to determine the fatigue endurance limit and the fatigue crack growth rate for the Shoreham EDG blocks?

A. (Rau, Wachob) Yes. FaAA measured fatigue properties for the EDG 103 material in the original block as well as that in the replacement EDG 103 block. FaAA determined these properties by using smooth bar (circular cross section) fatigue specimens machined from the thick section of the block top. Axial-fatigue tests using constant strain-amplitude cycling were performed at room temperature. From these results, a strain range versus fatigue-life diagram was constructed. The data on the strain-life diagram are typically plotted as the cyclic strain amplitude versus the number of ~~strain cycles to failure~~ cyclic strain reversals (i.e., two times the number of ~~cyclic~~ strain cycles to failure ~~reversals~~). A plot of these experimental data is attached as Exhibit B-42. In addition, literature results on gray cast iron are also provided for comparison in Exhibit B-43.

The fatigue life of the original EDG 103 block material is significantly reduced compared to that reported for normal gray iron. Specifically, the fatigue lives of EDG 103 block cast iron are a factor of 10 to 1,000 times shorter than for the normal Class 40 gray cast iron. The larger differences result at higher strain (or stress) ranges because the EDG 103 material is more sensitive to strain level and has a slightly lower slope (-0.11 versus -0.15) on the strain versus life plot. Fatigue test results confirm that the presence of Widmanstaetten graphite in the EDC 103 block greatly reduces the fatigue properties of Class 40 gray cast iron.

In addition, the fatigue behavior of the replacement EDG 103 material (UTS approximately 43 ksi) and another heavy-section Class 40 gray cast iron (UTS approximately 27 ksi) was determined. The fatigue behavior of these materials is quite similar to that of the reported literature values, and it was significantly better than the original EDG 103 gray cast iron. These fatigue results are shown in Exhibit 3-~~41~~ 42.

Compact tension specimens were used to determine the fatigue crack growth rate for the EDG 103 block top gray cast iron. The testing was performed at room temperature and a cyclic frequency of 5Hz. These fatigue crack growth rate tests were performed at different positive R-ratios. The R-ratio is the ratio of the minimum cyclic stress to the maximum cyclic stress. The fatigue crack growth rate data are typically plotted as the crack growth rate per cycle, i.e., da/dN (inches/cycle), versus the alternating stress intensity. Some of these results are attached as Exhibit B-44. As with the smooth bar fatigue resistance, the original EDG 103 fatigue crack growth resistance was reduced as a result of the extensive Widmanstaetten graphite in the microstructure.

In addition, the tensile and compression moduli were measured for the original EDG 103 block cast iron. The average modulus value was 12.83 Msi as compared to the typical modulus value of 16 Msi.

55. Are the results of the strain-life fatigue test and the fatigue crack growth rate tests consistent with respect to the original EDG 103 block material?

A. (Rau, Wachob) Yes. We have correlated the strain-life and fatigue crack growth rate data. They are completely consistent in that the original EDG 103 block material has a much faster (10 to ~~1,000~~ 100 times) fatigue crack growth rate and correspondingly shorter fatigue life than typical Class 40 gray cast iron. This results from the fact that the failure of the smooth bar fatigue specimen is controlled by fatigue crack propagation.

56. In conclusion, were the strength and fatigue resistance properties for the original EDG 103 block below those of normal Class 40 gray cast iron?

A. (Rau, Wachob) Yes, the tensile and fatigue resistance properties of the original EDG 103 were measured to be much lower than the minimum expected tensile and fatigue properties of Class 40 gray cast iron. The microstructure confirmed that the original EDG 103 cast iron contained extensive amounts of degenerate Widmanstaetten graphite that were responsible for the degraded properties.

57. In your opinion, was the cast iron in the original EDG 103 block significantly more susceptible to crack initiation and propagation than the cast iron in EDG 101, EDG 102 and the new EDG 103 block?

A. (Rau, Wachob) Yes.

58. In your opinion, are the mechanical properties of EDG 101, EDG 102 and the new EDG 103 block significantly better than the old EDG 103 block?

A. (Rau, Wachob) Yes, in our opinion, the mechanical (fracture and fatigue) properties of EDG 101, EDG 102 and the new EDG 103 are significantly better than those measured for the original EDG 103 block material. The microstructure of EDG 101, EDG 102 and the new EDG 103 blocks do not contain extensive degenerate graphite microstructure that was responsible for the inferior strength and fatigue resistance that was apparent in the original EDG 103 material. Therefore, the mechanical properties of EDG 101 and EDG 102 ~~should be~~ are comparable to those typical of the equivalent heavy-section strength of Class 40 gray cast iron. ~~This would suggest that~~ Thus, the fatigue life of EDG 101 and EDG 102 would be approximately 10 to 1,000 times better than those measured for the original EDG 103 material.

D. <u>Finite Element Analysis</u>

59. Describe the finite element analyses that were performed by FaAA.

A. (Wells, ~~Taylor~~) FaAA conducted two finite element analysis of the cylinder block top. One analysis was performed assuming the presence of a ligament crack 1.5 inches deep. The other analysis assumed no ligament crack. The purpose of these analyses was to obtain a qualitative understanding of the effects of (i) preload, (ii) variable temperature and temperature gradients, and (iii) gas pressure on stresses in the stud-to-stud and ligament regions of the block top. Two and three dimensional finite element models were used to analyze these three load components in conjunction with cracked and uncracked ligament geometries.

Each of the models created by FaAA analyzed the block top and liner between the engine center line and the mid-plane between adjacent cylinders. The cylinder liner was assumed to have expanded due to thermal effects such that the clearance gap was closed.

A planar, two-dimensional model was used to analyze the effect of pressure and thermal loads on uncracked block tops. This model is illustrated in Exhibit B-45. Load was applied to the model as uniform radial pressure on the inside diameter of the liner.

The three-dimensional model is depicted in Exhibit B-46. This model was used to analyze the effect of stud preload on cracked and uncracked ligament geometries, and the effect of pressure and thermal loads on block tops with cracked ligaments.

For each of these models, which were assumed to be loaded via cylinder pressure, two sets of boundary conditions were used. First, the model was assumed to have symmetric boundary conditions, simulating internal pressure in adjacent cylinders concurrently. Results of this model were used for the analysis of thermal stresses. Then the model was analyzed again. This time, the model simulated anti-symmetric boundary conditions by assuming positive pressure on one cylinder and negative pressure of equal magnitude in the adjacent cylinder. The combination(s) of these two results allowed the analysis of pressure effects on the block tops.

To study the effect of stud preload a series of analyses were performed using the three-dimensional model. These analyses simulated preload by the application of pressure to the top surfaces of the block and/or liner. The condition with all the load applied to the liner, 60% of which was in the area of the boss supports, produced results similar to the Shoreham strain gage test results at gage 13. Additional analyses were performed to study the effect of preload distribution on stud-to-stud stresses.

Results of all load cases and geometries analyzed were used to determine scale factors to relate the stress at the strain gage location 13, which was between cylinder heads, to the stress at the edge of the stud hole where stud-to-stud and ligament cracks have been shown to initiate. These locations are on the model as shown in Exhibit B-47. The table attached as Exhibit B-48 presents the results of these analyses.

60. How were the analytical stress values used?

A. (Rau, Wells, ~~Taylor~~) These stress values are used to determine possible mechanisms of crack initiation.

61. What are the mechanisms of crack initiation in the block top?

A. (Rau, Wells, ~~Taylor)~~ There are three possible mechanisms of crack initiation, acting separately or in combination, in the block top. The first mechanism is low cycle fatigue (LCF) associated with the stress range from each startup to high load levels. The second is high frequency-fatigue (HFF) due to stress variations resulting from firing pressures. For both LCF and HFF, there is a high mean tensile stress resulting from thermal expansion and stud preloading. The sum of mean and alternating components may produce the third mechanism, overload rupture. All of the three mechanisms are potential mechanisms for initiating ligament cracks.

62. What were the results of the finite element analysis regarding the stress state at crack sites involving ligaments and crack sites involving stud-to-stud cracking?

A. (Rau, Wells, ~~Taylor~~) The results of the finite element analysis are shown in two modified Goodman (Smith) diagrams for blocks with minimum typical properties. Exhibit B-49 represents low cycle fatigue and Exhibit B-50 represents high frequency fatigue. Both exhibits show the increased stresses in the stud-to-stud region, assuming the presence of cracked ligaments.

The curves in the Goodman diagram are derived conservatively using the minimum tensile strength in thick sections of the gray cast iron, the minimum specified fatigue endurance level, which produces lives greater than 10^6 cycles, and the stress for low cycle fatigue failure in 100 cycles, which is derived from the crankcase ~~lowest~~ curve depicted in Exhibit B-42 ~~41~~. The Goodman (Smith) curve identifies the possibility that, for either high frequency fatigue or low cycle fatigue cracking may initiate at a load level of 100 percent.

63. Are the stresses shown on the Goodman diagram a conservative estimate of stress state for EDG 101 and EDG 102?

A. (Rau, Wells, ~~Taylor~~) Yes. The analysis is conservative, and in some cases, very conservative. This judgment is based on the modeling assumptions and the fact that many TDI engines have been operated for a substantial number of hours at high loads without developing ligament cracks or stud-to-stud cracks.

For example, in the EDG 101 and EDG 102 blocks, only some of the ligament areas and none of the stud-to-stud regions have initiated fatigue cracks after extensive engine operation. Even the original EDG 103, with inferior fracture and fatigue properties withstood extensive engine operation before stud-to-stud cracking initiated.

Similarly, a TDI engine at Catawba has over 300 total operating hours, of which more than 138 hours have been at loads greater than 100%. Nevertheless, Catawba does not have either ligament cracks or stud-to-stud cracks. Similarly, a TDI engine at Grand Gulf has over 1,400 hours, of which over 300 hours have been at loads greater than or equal to 100%. Again, contrary to the predictions made in the conservative Goodman diagram, no ligament cracks or stud-to-stud cracks have initiated. Finally, the TDI engines at Comanche Peak have not developed ligament cracks or stud-to-stud cracks.

On the other hand, other TDI engines which are known to have poor material properties, such as the original EDG 103 cylinder block and the St. Cloud block, have developed both ligament cracks and stud-to-stud cracks. Furthermore, these cracks have propagated substantially. Therefore, it is clear that other factors in addition to the state of stress, such as materials properties, play a major role in crack initiation and propagation. While the Goodman diagrams are useful for the purpose of determining whether crack initiation is possible, they do not predict rates of crack propagation.

64. Since the potential for crack initiation exists, does that mean that the EDGs at Shoreham are unsafe?

A. (Rau, Wells, ~~Taylor~~) Absolutely not. Crack initiation, in and of itself, is not the critical factor in determining whether the cylinder blocks are safe or whether they will reliably perform their intended function. Virtually every metal structure, when examined at a sufficient microscopic level, has defects/cracks of some size. Of more concern are the crack size and the rate of crack propagation. Since the Goodman diagram is limited to prediction of crack initiation, it is not useful in determining whether a defect or crack will propagate at a rate and to a point that it threatens the integrity of a structure.

E. Cumulative Damage Analysis

65. Did FaAA analyze whether cracks that were present in the Shoreham EDGs, or which might initiate in the Shoreham EDGs, would propagate at a rate that might threaten the ability of the EDGs to perform their intended function?

A. (Rau, Wells, ~~Taylor~~) Yes. FaAA performed a cumulative fatigue damage analysis to bound the rate of crack propagation in EDG 101 and EDG 102. The cumulative fatigue damage analysis of EDG 101 and EDG 102 blocks is conservative because it assumes the presence of stud-to-stud cracks in EDG 101 and EDG 102 even though no such cracks exist. Since the possibility that such cracks might initiate exists, the cumulative fatigue damage analysis concentrates on determining whether such cracks, if they did initiate, would develop at such a rate and grow to such an extent that they would threaten the ability of the EDGs to perform their intended function.

66. What standard did you use for determining whether the EDGs would meet their intended function?

A. (Rau, Wells, ~~Taylor~~) Again, since the cumulative fatigue damage analysis assumes that stud-to-stud cracks exist, the model was designed to determine whether such cracks would propagate at a rate that would impair the ability of the EDGs to perform during an emergency. Accordingly, FaAA prepared a model to bound the amount of stud-to-stud fatigue crack extension that might be expected to occur during a postulated LOOP/LOCA event by using cumulative damage analysis in conjunction with the known cracking and loading experience on EDG 103 between March 11, 1984 and April 14, 1984. The purpose of FaAA's analysis was to assess the ability of an engine, such as EDG 101 or EDG 102, which have cracked ligaments, to perform adequately its intended function as an emergency diesel generator during the postulated LOOP/LOCA in nuclear standby service.

67. How did FaAA perform the cumulative damage analysis?

A. (Rau, Wells, ~~Taylor~~) The cumulative damage analysis is based on the summation of fatigue crack growth (damage) done at different loading (or stress) conditions. Fatigue crack growth damage is bounded for a known load sequence experienced by EDG 103 and compared with the cumulative fatigue damage that would be introduced by the postulated load requirements during emergency service should a LOOP/LOCA event occur. In other words, it is possible to calculate the maximum cumulative damage that would be produced for potential emergency operating requirements and to compare that cumulative damage index calculated with the actual crack growth damage which was observed to occur during the known (cumulative damage index) operating history of EDG 103 during test operation at comparable power levels.

68. How is the cumulative fatigue damage index computed?

A. (Rau, Wells, ~~Taylor~~) To make the calculation, the relative fatigue damage under each engine power level is computed from the corresponding magnitude of the cyclic and steady stresses and the time at each power level. The accumulated damage from a series of different power levels are added together using the well-known, linear cumulative damage approach to obtain the total fatigue damage index. This computation incorporates the hours of operation at each power level and the corresponding mean stress and alternating stress affecting fatigue cracking at each power level. This index accounts for the effects of variations in stress range and mean stress on the rate of fatigue crack growth. The index also accounts for differences in material properties.

69. Did the cumulative fatigue damage analysis described in FaAA's June 1984 report consider the effect of variation in material properties of the blocks?

A. (Rau, Wells, [redacted] Wachob) Only in a general manner. At the time the June 1984 report was prepared, however, the specific material properties of the original EDG 103 material were not known. Accordingly, the computations were based on typical material properties.

Since the issuance of the June 1984 report, material from EDG 103 has been tested by FaAA and additional data regarding crack growth rate for typical gray cast iron has been obtained. Therefore, the cumulative fatigue damage analysis presented in the June report has been updated to allow comparison of damage experienced by EDG 103, which has poor material properties, to damage predicted during the postulated LOOP/LOCA on blocks with better material properties such as EDG 101 and EDG 102.

70. How was the cumulative damage index applied to predict service life of EDG 101 and EDG 102?

A. (Rau, Wells, [redacted] Wachob) To bound the maximum cumulative damage under the specified LOOP/LOCA conditions, a damage index was computed for EDG 103 for the period March 11 to April 14, 1984. The cumulative damage was computed at each power level. The damage as computed included factors which account for the duration of operation, the minimum and maximum stresses at the stud-to-stud location of gage no. 13, fatigue crack growth resistance based on the exponent in the materials fatigue crack growth law and the steady stress or R-ratio. The fatigue damage index is the summation of the fatigue damage for each power level. This analytical value represents the damage required for stud-to-stud cracks to grow. Then, using the same technique, the cumulative damage index for postulated LOOP/LOCA effect was computed for cylinder blocks with material properties the same as the original EDG 103 block.

The same computation was made to compute the cumulative damage index for EDG 101 and EDG 102 during a postulated LOOP/LOCA event. This computation was based on postulated power levels and duration during a LOOP/LOCA, minimum and maximum stresses predicted to exist for a block with typical material, and the exponent from the materials fatigue crack growth ~~loss~~ law for material representative of EDG 101 and EDG 102.

71. What was the result of the cumulative damage analysis regarding the ability of the old EDG 103 block to perform adequately during a postulated LOOP/LOCA?

A. (Rau, Wells, ~~Taylor~~, Wachob) FaAA's calculations show that the cumulative damage (index) to which the block would be exposed during a postulated

LOOP/LOCA event is ~~less than one-half~~ about two-thirds of the cumulative damage (index) to which EDG 103 was exposed during testing operation between March 11 and April 14, 1984. During that period of time, the block of EDG 103, which has been shown to contain inferior material, experienced a maximum crack extension of ~~3~~ 1½ inches, with the deepest stud-to-stud crack extending to a ~~total~~ maximum depth of ~~3 1/2~~ 3 inches. It is important to note, however, that even when this degenerate cast iron material was exposed to fatigue damage (loading) that is more than ~~twice~~ 150% of that which would be experienced during a postulated LOOP/LOCA, no operational problems occurred due to the ~~3 1/2~~ 3 inch deep crack.

72. What was the result of the cumulative damage analysis regarding the ability of the EDG 101 and EDG 102 blocks to perform adequately during a postulated LOOP/LOCA?

A. (Rau, Wells, ~~Taylor~~ Wachob) FaAA's calculations show that the cumulative damage index that would be accumulated on the EDG 101 and EDG 102 blocks during a postulated LOOP/LOCA event is less than ~~1/2~~ 2% of the cumulative damage index to which EDG 103 was exposed during testing operation between March 11 and April 14, 1984. Accordingly, the EDG 101 and EDG 102 blocks are predicted to develop less than ~~1/2~~ 2% of the fatigue crack growth damage during a postulated LOOP/LOCA than the block of EDG 103 developed and withstood during the testing between March 11 and April 14, 1984.

73. What are the assumed power levels and operating time for a postulated LOOP/LOCA?

A. (Rau, Wells, ~~Taylor,~~ Wachob) FaAA assumed that the power levels experienced during a LOOP/LOCA would be 0.2 hours at 3,881 kW, 0.8 hours at 3,409 kW, and 167 hours at 2,617 kW. The power levels assumed by FaAA for a LOOP/LOCA were calculated by Stone & Webster Engineering Corp. based on FSAR 8.3.1-1, which is attached as Exhibit B-51. A LOOP/LOCA event involves relatively little operating time at high levels. Indeed, the amount of damage that EDG 103 was predicted to sustain during a postulated LOOP/LOCA was about two-thirds of ~~less than half~~ the damage that EDG 103 actually sustained during the period between March 11 and April 14, 1984, when FaAA collected the data for its cumulative damage index. ~~The amount of damage that the original EDG 103 block would have sustained during a postulated LOOP/LOCA event is less than half the damage that EDG 103 sustained during operation over the test period March 11 and April 14, 1984 during which time FaAA collected the data for its cumulative damage index.~~

74. Did FaAA's analysis understate the stresses in the block because FaAA assumed a peak firing pressure of only 1,600 psi in its report?

A. (Rau, Wells, ~~Taylor~~) FaAA used a peak firing pressure of 1,600 psi in its June 1984 report. More recent data indicate, however, that a reasonable, if not conservative, estimate of average peak firing pressure is 1,670 psi. Since its report was issued, FaAA has rerun its calculations using 1,670 psi as the peak firing pressure. FaAA's conclusions remain the same.

As discussed in LILCO's testimony on pistons, the County overstates firing pressures when it asserts that the actual value is 1,700 psi or greater at full load. Nevertheless, the difference between the stresses using 1,600 psi rather than 1,700 psi is less than 1%. Accordingly, no change in FaAA's conclusions is necessary or required.

75. Does FaAA's analysis of the preload stresses on the block account for the existence of certain variables such as variations in liner collar proudness?

A. (Rau, Wells, [redacted]) FaAA has determined the preload stresses on the block and block top by strain gage testing techniques. These techniques measure the actual, existing state of stress in the block top. Accordingly, FaAA's strain gage data measured the effect of the existing liner proudness on preload. The value of preload was incorporated into FaAA's analysis. Consequently, the irregularity of liner collar proudness referred to by the County did not in any way adversely affect FaAA's calculations or conclusions.

76. Are FaAA's analyses and conclusions based on an assumed optimal clearance between the liner and block?

A. (Rau, Wells, ~~Taylor~~) No. FaAA determined the actual stresses on the block by strain gage testing without making any assumptions about the clearance between the liner and block. FaAA made no assumptions whatsoever regarding an optimal clearance gap, and its calculations were not based on any such optimal clearance gap. On the contrary, FaAA based its calculations on the stresses present in the block top as recorded by the strain gage testing. Thus, FaAA's analysis did not understate stresses in the block top.

77. Does FaAA's finite element analysis assume that thermal stresses on the block are symmetric between the cylinders?

A. (Rau, Wells, ~~Taylor~~) The only assumption regarding load was in the scaling factor computed based on the finite element analysis. In this case, the scaling factors from strain gage location to hole edge have come from a model with symmetric loads. No assumptions were made, however, with regard to the symmetry of the actual stresses on EDG 103. The strain gage data reflected the actual state of stress on the block top, which obviously accounted for any variance in stress due to thermal loads. Consequently, the data used to predict thermal stress was obtained experimentally and did not involve any incorrect or nonconservative assumptions regarding thermal stresses.

78. Does FaAA's analysis understate the stresses in the block top by assuming that the thermal stresses acted radially rather than longitudinally?

A. (Rau, Wells, ~~Taylor~~) Again, strain gages measured the actual state of stress on the block top. Thus, FaAA did not make any incorrect and/or nonconservative assumptions that affect its conclusions regarding ligament cracks and stud-to-stud crack initiation and propagation. FaAA's conclusions are based on actual measured stresses, not hypothetical, assumed or estimated stresses as alleged by the County.

79. Should FaAA have limited the linear fatigue damage index in its cumulative damage analysis?

A. (Rau, Wells, ~~Taylor~~) No. FaAA should not and does not limit the use of the linear fatigue damage index. The input data for the linear fatigue damage index were obtained by operating the engine at all load conditions from no load to 3,830 kW. Accordingly, it is appropriate to use the linear fatigue damage index for the full range of load at which the engine operates.

The cumulative fatigue damage index is expressly designed to account for the non-linear difference in the amount of damage produced at varying loads. The cumulative fatigue damage index accounts for these differences through mathematical formulas. The damage index is summed linearly, but the cumulative damage is computed nonlinearly such that the effect of operating the engine at high stress versus low stress is accounted for in the damage equation. Thus, FaAA has not assumed any faulty premises. The linear fatigue damage index should not be limited since the cumulative fatigue damage index accurately reflects the range of stress and load to which the engine has been subjected.

31. Do the ligament cracks present in EDG 101 and EDG 102 threaten the ability of these engines to meet their intended function of providing emergency standby power?

A. (McCarthy, Rau, Wells, ~~Taylor~~, Wachob, Youngling) It is FaAA's opinion that the ligament cracks present in EDG 101 and EDG 102 do not affect the ability of the engines to perform their intended function of providing emergency standby power. Operating experience has shown that ligament cracks are not likely to propagate below the counterbore landing. In addition, ligament cracks are benign because the cracked sections are fully contained between the cylinder liner and the region of the block top outside the stud hole circle. Strain gage testing, finite element analysis and field experience demonstrate that the existing ligament cracks have no direct effect on the operation of the engines or their ability to perform their intended function.

81. Will the presence of ligament cracks between the cylinder liner counterbore and the stud holes cause cracking to occur between stud holes of adjacent cylinders on the EDG 101 and EDG 102 similar to the cracking experienced on EDG 103?

A. (McCarthy, Rau, Wells, ~~Taylor~~, Wachob, Youngling) No. The presence of ligament cracks between the cylinder liner counterbore and the stud holes does increase the stresses present in the block top between the stud holes with ligament cracks. Therefore the possibility that cracking can initiate between the stud holes of adjacent cylinders during extensive additional operating hours at high load and/or a number of engine starts to high load conditions increases. However, service experience has shown that the increase in stresses does not necessarily cause stud to stud cracking nor does it render the cylinder blocks incapable of meeting their intended function even if such cracks should develop. First, the material properties of the original EDG 103 block were significantly inferior to that of the EDG 101 and EDG 102 blocks. Our analysis indicates that the metallurgical structure in the EDG 103 block included a degenerate graphite microstructure that reduced drastically the strength and fatigue resistance of the EDG 103 block as compared to EDG 101 and EDG 102. Accordingly, ligament cracks between the cylinder liner counterbore and stud holes that were sufficient to initiate crack development between some but not all of the stud holes of adjacent cylinders in EDG 103 would not initiate cracking between adjacent stud holes under the same or similar load profile in EDG 101 and EDG 102. Thus, while the possibility of cracking between stud holes of adjacent cylinders is not zero in the EDG 101 or EDG 102 blocks, cracking is not expected to occur without much more severe operation at high load and/or more engine starts to high load than were experienced by EDG 103.

Because EDG 103 was subjected to the unusual load excursion in which the operating stresses exceeded the limits to which EDG 101 and EDG 102 have ever been exposed, or are likely to be exposed, there is reason to believe that the EDG 101 and EDG 102 blocks will never experience stresses as high as those experienced by EDG 103.

Further, even assuming that EDG 101 and EDG 102 were subjected to conditions that did initiate cracking between stud holes of adjacent cylinders, the greater strength properties and fatigue resistance of these blocks as compared to the original EDG 103 block indicates that the amount of crack propagation would be much less. The block inspections intervals recommended by FaAA, which will be discussed below, provide a margin of safety for detecting significant crack propagation in blocks even if the block material properties were as poor as those of EDG 103. Therefore, the inspection intervals for more typical blocks such as EDG 101 and EDG 102, which have greater minimum material strength and fatigue resistance properties than EDG 103, provide a much larger conservatism and a larger margin of safety.

Finally, even in the worse case scenario involving the cracks in the EDG 103 that propagated to a depth of ~~3-1/2~~ 3 inches, in a block with poor properties, it did not degrade engine operation, result in stud loosening, or in any way affect the cylinder block.

Cracking is much less likely to develop between stud holes of adjacent cylinders in EDG 101 and EDG 102, and crack propagation is predicted to be much slower and less severe. Therefore, a crack (if it should occur) will not grow to the point where it would impair the operation of the engine during a postulated LOOP/LOCA event. Indeed, FaAA is not aware of any instance in which a crack in a cylinder block developed rapidly and forced an engine shutdown.

V. <u>FaAA's Analysis Of The Cam Gallery Cracks</u>

82. Were any cracks other than the ligament cracks and the stud-to-stud cracks identified in the TDI diesel engines at Shoreham?

A. (Wells, ~~Taylor~~, Johnson, Youngling, Seaman and Schuster) Yes. An inspection of the emergency diesel generators in the Spring of 1983 revealed crack indications in the cam galleries of all three TDI engines. These indications were of varying length, but generally much larger in EDG 103. ~~A typical cross-section of the cam gallery indicating the crack~~ region is displayed on Exhibit B-52.

83. What analysis did FaAA perform to evaluate the cam gallery cracks on the Shoreham TDI engines?

A. (Wells, Taylor) A fracture mechanics analysis was performed to evaluate the fatigue crack growth rate of the cam gallery indications based on stresses in the area utilizing strain gage measurements made by TDI. TDI installed strain gages on the experimental DSR-46 engine at the locations of the cam gallery indications in the Shoreham engines and recorded the dynamic strains in a running engine. TDI recorded the strains at load conditions from no load to full load. The strain gage data were reduced by TDI to obtain the mean and alternating stresses on the block in the cam gallery area. The stresses indicated by these tests are reproduced in Exhibit B-53.

84. How did FaAA perform the cam gallery growth analysis?

A. (Wells, Taylor) The longest potential crack size was estimated based on review of the cam gallery inspection reports. The size of the largest postulated defect was determined by surrounding discontinuous indications. The largest indications were found in EDG 103 and were 4 1/2 inches long. The defects in EDG 101 and EDG 102 were generally much shorter. The postulated defect shape is shown in Exhibit B-52.

Based on the stress values obtained from the TDI strain gage testing, fracture mechanics analyses were performed assuming the largest defect seen in the original EDG 103. The maximum crack growth of this postulated crack during a LOOP/LOCA was predicted to be less than .001 inches. Furthermore, the surveillance testing during a full fuel cycle was predicted to produce minimal crack extension.

85. What is the significance of crack propagation on this order?

A. (Wells, Taylor) The very slow predicted crack growth rate is important for two reasons. First, the rate of crack growth is so slight, both in terms of depth and length, that it will have no effect on engine operation.

Second, since the rate of crack propagation of the postulated defect is so slow, routine inspection of the cam gallery areas to monitor any cracking from defects can be conducted during periods when the engine is shut down for other scheduled maintenance.

86. Is there any reported instance where a cam gallery crack has impaired the operation of a TDI engine?

A. (Wells, ~~Taylor~~ and Youngling) No. The EDGs at Shoreham have been operated for 1 1/2 years at all load conditions without experiencing any problems associated with the cam gallery cracks. In addition, the component tracking system developed by the TDI Owners Group does not reflect instances where cam gallery cracks have propagated to the extent that they impair engine performance. Furthermore, TDI has reported to FaAA that it knows of no instance where cracks in cam gallery areas have affected engine performance.

87. Did the Paris empiricial relation used by FaAA in analyzing the cam gallery cracks take into account important parameters such as mean stress affects on fatigue crack propagation?

A. (Wells, ~~Taylor~~, Wachob) Although FaAA used a Paris empirical relation, this was only one aspect of its analysis. The Paris empirical relation is widely used in the fracture mechanics analysis because it accurately describes fatigue crack growth. The actual fracture mechanics analysis performed by FaAA, however, used the BIGIF computer code, which takes into account the effects of differing values of both mean and alternating stress during different operating conditions on fatigue crack propagation.

88. Did FaAA's evaluation account for the initial defects present in the cam galleries?

A. (Wells, ~~Taylor~~, Wachob) Yes. FaAA's fracture mechanics analysis did take into account the initial defect size in the cam galleries. Indeed, the first principal of fracture mechanics analysis is that the presence and size of existing defects in a structure must be considered. Accordingly, FaAA's analysis assumed the presence of defects/cracks in the cam galleries.

89. Did FaAA's analysis of the cam gallery cracks on EDG 101 and EDG 102 account for the physical properties of the block material?

A. (Wells, ~~Taylor~~, Wachob) FaAA's analysis specifically considers the material properties of EDG 101 and EDG 102. FaAA's metallurgical analysis of the material properties of EDG 101 and EDG 102 revealed that their microstructure is similar to that of typical Class 40 gray cast iron whereas EDG 103's ~~microstructure~~ microstructure was inferior because of the extensive degenerate Widmanstaetten graphite. FaAA's analysis of the cam gallery cracks in EDG 101 and EDG 102 is based on blocks with typical materials strength properties for ASTM A48-64 Class 40 gray cast iron such as exists in EDG 101 and EDG 102, but not the original EDG 103 block.

90. Has FaAA assigned different values to the Paris law exponent, "n," in its analysis, thereby understating predicted crack growth rate?

A. (Wells, ~~Taylor~~, Wachob) No. FaAA used the appropriate value for the Paris law exponent for typical Class 40 gray cast iron such as exists in EDG 101 and EDG 102. The value of this exponent is 5.5. ~~Therefore, FaAA's crack growth predictions for the cam galleries in EDG 101, EDG 102, and the replacement EDG 103 are appropriate.~~

Apparently, the County has confused crack initiation with crack propagation. Since FaAA did not perform a crack initiation analysis on the cam gallery cracks, the value of the exponent n = 9.6, which applies to fatigue crack initiation was not used. Accordingly, there is no confusion in FaAA's figures. ~~FaAA's analysis correctly states the predicted rate of crack propagation for the cam gallery cracks using the exponent n = 5.5.~~

91. Is there any analytical, empirical or other basis for concluding that cam gallery cracks will lead to catastrophic failure of the engines?

A. (Wells, ~~Taylor~~, Wachob) No. The County's conclusion that a catastrophic failure of the engine could occur as a result of the cam gallery cracks is completely unsupported by any analytical data. Indeed, this conclusion is squarely contradicted by FaAA's fracture mechanics analysis, which shows that rapid fatigue crack propagation will not occur.

FaAA is unaware of any operational experience or other empirical evidence that suggests that cam gallery cracks lead to catastrophic failures. In fact, all the empirical evidence available to date fails to identify even one instance where cam gallery cracks have impaired the operation of an engine, let alone led to a catastrophic failure.

Q2. Do the cam gallery cracks present in EDG 101 and EDG 102 threaten in any way the ability of those engines to meet their intended function of providing emergency standby power?

A. (McCarthy, Wells, Taylor, Wachob, Youngling) The ability of the Shoreham TDI emergency diesel generators to perform their intended functions will not be affected by the cam gallery defect. The predicted rate of propagation of a large assumed crack is so minimal that no degradation of the operating condition of the engine is predicted during the operation between refuelings. Further, because the rate of crack growth is so slight, maintenance performed at regular and scheduled intervals will permit inspections of the cracks to verify that cracks have not propagated significantly and that they do not present any threat to the ability of the diesel generators to perform their intended function. Contrary to the County's assertions, there is no evidence that catastrophic engine failure can or will result from the existence of the cam gallery cracks.

VI. The Replacement EDG 103 Block Has Been Adequately Tested

93. What are the modifications contained in the replacement cylinder block for EDG 103?

A. (Wells, ~~Taylor~~, Youngling, Seaman) The new EDG 103 cylinder block is simply a current production model, not a new design as alleged by the County. There are three principal product enhancements incorporated in the replacement EDG 103 cylinder block. All of these changes are relatively minor, and were adopted as a result of extensive testing and development by TDI on the experimental R-5 engine.

The first change incorporated in the replacement block involved lengthening the head stud bosses in the block. The lengthening of the head stud bosses moves the concentrated stress field, caused at the stud threads by the torquing of the cylinder head stud nuts, farther away from the counterbore landing where the cylinder liner is supported. This makes the block less sensitive to fatigue effects caused by high cycle fatigue generated as a result of engine firing pressures.

Second, the lengthening of the cylinder head bosses also involved a thickening of the material of the cylinder block top. The increase was approximately 1/2 inch. The previous block top had a nominal thickness of 2 1/2 inches. The replacement EDG 103 has a nominal 3 inch thick block top because it was originally designed for the R-5, which operates at a substantially higher firing pressure. Thickening the block top reduces stresses due to preload and gas pressure in the replacement EDG 103. This also involved a nominal increase in the weight of the block, but this increase is not significant, in our opinion, because it has no effect on any other component in the engine.

Third, the replacement EDG 103 block has a greater cold clearance gap between the cylinder liner and the cylinder block. Increasing the clearance reduces the stresses introduced in the block by thermal expansion of the cylinder liner. Similarly, this has the effect of reducing the stresses in the area between the cylinder liner counterbore and the stud holes.

94. Why was the material for the replacement cylinder block upgraded from Class 40 to Class 45 cast iron?

A. (Wells, ~~Taylor~~, Wachob, Youngling) LILCO agreed, as an option, to obtain blocks of greater strength, to upgrade from Class 40 to Class 45 cast iron. This change in material properties does not affect FaAA's analysis. As stated before, blocks with material properties meeting the minimum standards for Class 40 gray cast iron are sufficient to perform their intended function, including meeting the requirements of any

LOOP/LOCA event. The magnitude of the cracking observed in the original EDG 103 block was due to a combination of factors, including its inferior material properties and the stresses (strains) to which it was subjected.

In FaAA's opinion, the selection of Class 40 gray cast iron established by TDI is adequate provided that the blocks in fact meet the minimum standards for Class 40 designation and certain inspection criteria are met. Of course, by upgrading to Class 45 gray cast iron, LILCO has improved the block material of EDG 103 and provided additional margin against cracking. As indicated, however, this does not mean that the Class 40 material in EDG 101 or EDG 102 is inadequate.

95. Is the replacement cylinder block for EDG 103 a new design which is unproven and inadequately tested, as alleged by the County in its contention?

A. (Wells, [redacted]) No. As we stated above, only a few sections in the replacement EDG 103 block have been modified in any way. For example, the exterior geometry of the block remains the same in every regard.

Those few changes that have been incorporated into the replacement block have been tested extensively in the R-5 engine and have been shown to be of benefit. For example, the concept of the deeper stud hole with the thicker block top to accommodate the deeper stud hole has been employed by the R-5 engine and tested thoroughly.

Since the geometry of these components in the replacement EDG 103 block is virtually identical to the equivalent component in the R-5 engine, there is no question but that the components have been adequately tested and at much higher power loads than EDG 103 will experience. Similarly, the geometry of the core structure in the casting of the replacement EDG 103 block is virtually identical to the core structure in the R-5 engine, and the extensive testing of the R-5 engine is applicable.

VII. The TDI EDGs Are Qualified For Nuclear Service

96. Please describe the inspection and maintenance intervals that FaAA has recommended to LILCO.

A. (McCarthy, Rau, Wells, ~~Taylor~~) For EDG 101 and EDG 102, which are blocks with known ligament cracks, the absence of detectable cracks between the stud holes of adjacent cylinders should be established by eddy current inspection before returning the engine to emergency standby service after any period of operation above 50% load. In the unlikely event that cracking is detected between the cylinder heads, the adjacent studs must be removed and the depths of cracks measured along the stud hole counterbores. If the cracks are no more than 1 1/2 inches in depth, the block is adequate for continued emergency service.

For the replacement EDG 103 block the same inspection criterion applies until sufficient operating service without ligament cracks has been obtained to increase the inspection intervals. Until then the block of EDG 103 should conservatively be assumed to have cracked ligaments. When more operation time has been obtained (e.g., one half a refueling cycle), LILCO may remove the cylinder heads and inspect for block cracks. If no ligament cracks are found, then the requirement for inspection between the heads may be removed for an additional equivalent amount of operation (e.g., until the refueling outage).

97. Has LILCO adopted FaAA's recommendations regarding the inspections and testing of the EDGs at Shoreham?

A. (Youngling, Seaman) Yes. LILCO has reviewed FaAA's recommendations and has agreed to adopt the inspection and testing procedures recommended by FaAA. LILCO is now preparing the ~~Technical Specifications~~ operating procedures required to implement FaAA's recommendations.

98. Will the operation of the Shoreham TDI diesel generators with the present cylinder blocks result in failures of other parts or components of the EDGs?

A. (Rau, Wells, ~~Taylor~~) No. FaAA has reviewed the interaction of the blocks, heads, liners, studs and other components to determine whether any probable failure mode, based on known existing problems, would impair the operation of other components deemed vital to continued engine operation during an emergency event. We are aware of no probable failure mode that would immediately impair the operability of other components, thereby rendering the EDGs inoperable during an emergency event such as a LOOP/LOCA.

99. Should the present cylinder blocks on EDG 101 and EDG 102 be replaced with new cylinder blocks?

A. (McCarthy, Rau, Wells, ~~Taylor~~, Wachob) No. The analysis, materials testing and in-service experience have clearly demonstrated the adequacy of the existing blocks with Class 40 gray cast iron. Accordingly, EDG 101 and EDG 102 do not need to be replaced.

100. Do you have an opinion, based on a reasonable degree of engineering certainty, as to the adequacy of the Shoreham TDI engine blocks on EDG 101 and 102 for use in nuclear standby service at Shoreham?

A. (McCarthy, Rau, Wells, ~~Taylor~~, Wachob, Youngling) Yes. Based on strain gage testing, finite element analysis, cumulative damage analysis, and analyses of the other empirical test data and service experience of the cylinder blocks at Shoreham as well as other nuclear power stations and non-nuclear facilities, it is our opinion that the EDG 101 and EDG 102 blocks will permit the engines to meet their intended function of supplying emergency onsite power. GDC 17 requires that:

> An onsite electric power system and an offsite electric power system shall be provided to permit functioning of structures, systems and components important to safety. The safety function for each system (assuming the other system is not functioning) shall be 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 electric 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.

In our opinion, the current cylinder blocks of the Shoreham engines, meet the requirements of GDC 17 based on the ability of the cylinder blocks to perform their intended function in the event of a loss of offsite power, i.e., a postulated LOOP/LOCA event. Based on our analysis, EDG 101 and EDG 102 should perform their intended function, plus surveillance and periodic operational testing, until the first refueling outage without developing significant stud-to-stud cracking. Even though the possibility exists that stud-to-stud cracking may initiate during this period, it is our opinion that it is unlikely. This opinion is based on the materials testing and microstructural evaluation, cumulative damage analysis, and service experience.

Attachment 3

Failure Analysis Associates

CLIFFORD H. WELLS

Specialized Professional Competence

Structural lifetime prediction and reliability analysis, nondestructive evaluation, mechanics of deformation and fracture, elevated temperature design methods and analysis, mechanical test methods and fracture analysis, microstructural mechanisms of fatigue and material modeling, and integrated inspection and analysis systems for structural lifetime assurance.

Past research includes mechanical behavior of materials at high temperature and in aggressive environments, development of a turbine rotor fatigue lifetime prediction system, modeling of material deformation and fracture under complex stress states, development of mechanical testing methods.

Background and Professional Honors

B.S. (Mechanical Engineering), Yale University
M.S. (Civil Engineering), Yale University
Ph.D. (Applied Mechanics), Yale University
Oak Ridge School of Reactor Technology
Vice-President, Research and Development,
Failure Analysis Associates
Assistant to President and Director of Engineering Mechanics,
Southwest Research Institute
Assistant Manager, Materials Engineering and Research,
Pratt & Whitney Aircraft
Structural Engineer,
Oak Ridge National Laboratory
Research Assistant,
Yale University
Fellow, ASME
President-elect, Federation of Materials Societies
Chairman, Air Force Studies Board Panel on NDE, National Research Council
Chairman, National Materials Advisory Board Committee on Fatigue at Elevated Temperature
Member, National Materials Advisory Board Committee on Fretting Initiated Fatigue
Chairman, Executive Committee, Materials Division of ASME
EPRI Materials and Corrosion Committee
Metal Properties Council Subcommittee on Materials for Coal Conversion
Editor, Fatigue of Engineering Materials and Structures
Editor, Journal of Nondestructive Evaluation

Selected Publications

"Mechanical Test Methods for Coal Gasification Environments," Proceedings of Conference on Properties of Materials in Coal Gasification Environment, American Society for Metals (1981) (with L. A. Zeiss and R. D. Brown).

"Mechanical Properties of Alloys in Coal Gasification Atmosphere," Proceedings of Conference on the Properties of Materials in Coal Gasification Environment, American Society for Metals (1981) (with L. A. Zeiss and R. D. Page).

"Reliability of Steam Turbine Rotors," Proceedings of Conference on Residual Life, Copenhagen, Denmark (1980).

"Analysis of Life Prediction Methods for Time-Dependent Fatigue Crack Initiation in Nickel-Base Superalloys," National Materials Advisory Board Publication NMAB-347, National Academy of Sciences (1980).

"High-Temperature Fatigue," Fatigue and Microstructure, 1978 ASM-TMS Seminar, American Society for Metals, pp. 307-333 (1979).

"Development of an Automated Life Prediction System for Steam Turbine Rotors," ASME Paper 78-WA/DE-15, The American Society of Mechanical Engineers, New York (1978) (with T. S. Cook and H. G. Pennick).

In the event that cracking were to initiate during a LOOP/LOCA, the cumulative damage analysis and EDG 103 experience has shown that the crack would not progress to pose a threat to the operability or performance of the engine during the LOOP/LOCA.

101. Do you have an opinion, based on a reasonable degree of engineering certainty, as to the adequacy of the replacement EDG 103 cylinder block for use in nuclear standby service at Shoreham.

A. (McCarthy, Rau, Wells, ~~Taylor~~, Wachob, Youngling, Seaman) Yes. Based on knowledge and analysis of the loads and stresses on the EDG cylinder blocks, our testing of the material properties of the new EDG block and information regarding the exhaustive testing on the R-5 engine, and in light of the relatively minor changes in the cylinder block and its enhanced material properties, it is our opinion that the replacement block for EDG 103 is capable of performing its intended functions. This opinion is based on materials analysis and testing of the replacement EDG 103 block material, which showed markedly improved material properties, sufficient to assure that the cylinder block will perform its intended function.

102. Do the TDI diesel engines with the existing cylinder blocks present health or safety hazzards if a low power or full power license is granted to LILCO for the Shoreham Nuclear Power Station.

A. (Youngling) No. The replacement EDG 103 block, which obviously has no cracks, will undergo sufficient preoperational testing to ensure that its performance is satisfactory for providing emergency standby power. Further, the existing ligament and cam gallery cracks in EDG 101 and EDG 102 have been analyzed and were determined to be benign and present no operational hazards. Finally, as indicated above, there is reason to believe that the existing cylinder blocks will perform for at least one full fuel cycle, and perhaps much longer, without developing stud-to-stud cracking. However, as an added precaution to ensure that there is no health or safety hazard in the event that such cracking should initiate during an emergency service, FaAA has calculated that such block cracking will not limit operation. FaAA's analysis indicates that the blocks during that service would withstand a LOOP/LOCA with wide margins of safety. Therefore, based on the extensive analysis performed to date on the cylinder blocks, LILCO is confident that they will perform their intended function without creating any public health or safety hazards in the event of a LOOP/LOCA. In our judgment, the EDGs with existing cylinder blocks are capable of performing all their intended functions, and they should be licensed.

"Fundamental Mechanisms," Control of Fretting-Initiated Fatigue, National Materials Advisory Board Report NMAB-333, National Academy of Sciences (1977).
"Fatigue at Elevated Temperature," edited by C. H. Wells, A. E. Carden and A. J. McEvily, ASTM Special Technical Publication No. 520 (1973).
"Quantitative Lifetime Assurance of Turbine Rotors," Fatigue Life Technology edited by T. A. Cruse and J. P. Gallagher, ASME, pp. 37-51 (1977).
"Uniaxial Creep Behavior of Metals Under Cyclic Temperature and Stress or Strain Variations, Journal of Applied Mechanics, Vol. 98, pp. 445-449 (1976) (with P. R. Paslay).
"Mechanisms of Dynamic Degradation of Surface Oxides," Proceedings of Symposium on Mechanical Properties of Surface Oxides, Metallurgical Society of AIME (1975) (with P. S. Follansbee and R. R. Dils).
"Prospects of Lifetime Prediction in Creep and Fatigue," NSF Workshop on Inelastic Constitutive Equations for Metals-Experimentation-Computation-Representation, edited by E. Krempl, C. H. Wells and Z. Zudans (1975).
"Design Procedures for Elevated Temperature Low-Cycle Fatigue," Proceedings of the 38th Meeting of the Structures and Materials Panel, Advisory Group for Aerospace Research and Development, NATO, AGARD-CP-155.
"On the Applicability of Fracture Mechanics to Elevated Temperature Design," International Conference on Creep and Fatigue in Elevated Temperature Applications, Institution of Mechanical Engineers, London, England (with A. J. McEvily).
"Electrochemical Grinding of Cylindrical Test Specimens," Journal of Engineering for Industry, ASME Transactions, Vol. 93, pp. 1090-1092 (1971) (with T. W. Knight, R. B. Barrow and L. A. Williams, III).
"Creep of Single Crystal Nickel-Base Superalloy Tubes under Biaxial Tension," Journal of Applied Mechanics, ASME Transactions, Vol. 38, pp. 623-626 (1971) (with P. R. Paslay, G. R. Leverant and L. H. Burck).
"Mechanisms of Fatigue in the Creep Range," Metal Fatigue Damage Mechanism, Detection, Avoidance and Repair, ASTM Special Technical Publication No. 495, pp. 61-127 (1971) (with M. Gell and C. P. Sullivan).
"Fatigue of a Glass-Bead Blasted Nickel-Base Superalloy," Metallurgical Transactions, Vol. 1 (6), p. 1595 (1970) (with L. H. Burck and C. P. Sullivan).
"The Fatigue Strength of Nickel-Base Superalloys," The Achievement of High Fatigue Resistance in Metals and Alloys, ASTM Special Technical Publication No. 467, p. 113 (1970) (with M. Gell and G. R. Leverant).
"An Analysis of Primary Creep of Face-Centered Cubic Crystals," Journal of Applied Mechanics, ASME Transactions, Vol. 37 (3), p. 759 (1970) (with P. R. Paslay and G. R. Leverant).
"Elevated Temperature Testing Methods," Manual on Low-Cycle Fatigue Testing, ASTM Special Technical Publication No. 465, p. 87 (1969).
"Interactions Between Creep and Low-Cycle Fatigue in Udimet 700 at 1400°F," Fatigue at High Temperature, ASTM Special Technical Publication No. 459, p. 59 (1969) (with C. P. Sullivan).
"Low-Cycle Fatigue of Ti-6AL-4V," ASM Transactions Quarterly, Vol. 62, p. 263 (1969) (with C. P. Sullivan).
"An Analysis of the Effect of Slip Character on Cyclic Deformation and Fatigue," Acta Metallurgica, Vol. 17, p. 443 (1969).
"A Small-Strain Plasticity Theory for Planar Slip Materials," Journal of Applied Mechanics, ASME Transactions, Vol. 36 (1), p. 15 (1969) (with P. R. Paslay).
"The Control of Build-up and Diametral Growth in Shear Forming," Journal of Engineering for Industry, ASME Transactions, Vol. 90 (1), p. 63 (1968).
"Low Cycle Fatigue of Udimet 700 at 1700°F," ASM Transactions Quarterly, Vol. 61 (1), p. 149 (1968) (with C. P. Sullivan).
"An Analysis of the Bauschinger Effect in Some Engineering Alloys," Journal of Basic Engineering, ASME Transactions, Vol. 89 (4), p. 893 (1967).
"The Elastic Constants of a Directionally-Solidified, Nickel-Base Superalloy, Mar M-200," ASM Transactions Quarterly, Vol. 60 (2), p. 270 (1967).
"The Effect of Temperature on the Low-Cycle Fatigue Behavior of Udimet 700," ASM Transactions Quarterly, Vol. 60, p. 217 (1967) (with C. P. Sullivan).
"An Improved High-Temperature Extensometer," Materials Research and Standards, Vol. 6 (1), p. 20 (1966) (with D. N. Tishler).
"Low-Cycle Fatigue Damage of Udimet 700 at 1400°F," ASM Transactions Quarterly, Vol. 58 (3), p. 391 (1965) (with C. P. Sullivan).
"The Low-Cycle Fatigue Characteristics of a Nickel-Base Superalloy at Room Temperature," ASM Transactions Quarterly, Vol. 57 (4), p. 841 (1964) (with C. P. Sullivan).
"The Latent Strain Hardening of Aluminum Alloy in Monotonic and Cyclic Loading," Applied Materials Research, Vol. 2 (4), p. 193 (1963).

Attachment 4

Failure Analysis Associates

HARRY F. WACHOB

Specialized Professional Competence

Failure analysis and fractography (SEM, TEM and energy dispersive x-ray analysis); stress corrosion cracking, hydrogen embrittlement; environmental effects on mechanical properties of ferrous and nonferrous materials at room and elevated temperatures; fatigue, crack initiation and growth; brittle fracture; accelerated testing and life prediction; mechanical test system design and operation.

Background and Professional Honors

B.S. (Materials Science & Engineering), Cornell University
M.S. (Materials Science & Engineering), Cornell University
Ph.D. (Materials Science & Engineering), Cornell University (Phi Kappa Phi Honorary)

Senior Metallurgical Engineer,
Failure Analysis Associates

Member, American Society for Metals
Member, American Institute of Metallurgical Engineers
Member, American Welding Society
Outstanding Young Member of the Santa Clara Valley Chapter of ASM, 1981
Chairman, Santa Clara Valley Chapter of ASM, 1981-82
Vice Chairman, Santa Clara Valley Chapter of ASM, 1980-81

Selected Publications

"Very High Cycle Fatigue of a Forged Aluminum Alloy," Fatigue and Corrosion Fatigue up to Ultrasonic Frequency (October 1981) (with H. Nelson).

"Influence of Microstructure on the Fatigue Crack Growth of A516 in Hydrogen," Third International Conference on Effect of Hydrogen on Behavior of Materials, p. 703 (August 1980) (with H. Nelson).

"Effect of Strain Rate and Depressed Temperature on the Low Cycle Deformation Behavior of Alpha Iron," Metallurgical Transactions, Vol. 10 (3), p. 305 (1979) (with H. H. Johnson).

"Halogen Stress Corrosion Cracking of Zircaloy-4," Symposium on Environment-Sensitive Fracture of Engineering Materials (1979) (with H. G. Nelson).

"Effect of Alloying Elements on the Equilibrium Partition of Nitrogen or Carbon in Ternary Iron-Base Alloys," ARMCO Final Report (December 1979) (with A. J. Heckler and J. A. Peterson).

"A Stress Corrosion Cracking Model for Pellet-Cladding Interaction Failures in Light-Water Reactor Fuel Rods," ASTM STP 681, Zirconium in the Nuclear Industry (1978) (with J. T. A. Roberts, R. L. Jones, E. Smith, D. Cubicciotti, A. K. Miller and F. L. Yaggee).

"EPRI-NASA Cooperative Project on Stress Corrosion Cracking of Zircaloys," EPRI NP 717 Project 455-1, Final Report (March 1978) (with R. L. Jones, D. Cubicciotti and H. G. Nelson).

"Kinetics of Hydrogen Entry from $TiFe_{0.86}Mn_{0.11}H_x$," Proceedings of the DOE Chemical/Hydrogen Energy Systems Review, p. 409 (1978) (with H. G. Nelson).

Attachment 5

Failure
Analysis
Associates

DUANE P. JOHNSON

Specialized Professional Competence

Nondestructive evaluation and structural monitoring methods; production line inspection system development, field inspection and monitoring services, inspection and monitoring reliability analysis, nondestructive inspection procedure development and review, inspection level and interval optimization, eddy current instrument development, advanced electromagnetic sensor development, advanced signal processing, R&D on advanced nondestructive inspection and monitoring methods.

Background and Professional Honors

B.S. (Electrical Engineering), University of Minnesota, with High Distinction
M.S. (Physics), University of Washington
Ph.D. (Physics), University of Washington

Manager, Nondestructive Evaluation and Monitoring,
Failure Analysis Associates
President and Co-Founder,
Reluxtrol, Inc.
Supervisor, Nondestructive Inspection,
Pratt & Whitney Aircraft
Associate Professor of Physics,
American University, Cairo, Egypt

Member, American Society for Nondestructive Testing
Member, American Physical Society
Member, Institute of Electrical and Electronics Engineers

Selected Publications

"Review of State of the Art Inspections of Steam Turbine Blades," EPRI Steam Turbine Blade Reliability Workshop (1982) (with E. K. Kietzman).
"Electromagnetic Testing of Ceramic Materials," EPRI Report (1981) (with L. Y. L. Shen).
"Controlled Reluctance Eddy Current Inspection of Steam Turbine Components," EPRI Workshop on NDE of Steam Turbine and Electrical Generator Components (1980) (with S. Sarian and E. K. Kietzman).
"Assessment of Current NDI Techniques for Determining the Type, Location and Extent of Fossil-Fired Boiler Tube Damage," EPRI Report (1980) (with E. R. Reinhart and S. Sarian).
"Production Line Nondestructive Evaluation of Continuous Formed Metal Parts Using Controlled Reluctance Eddy Current Probes," ASNT Spring Conference (1979) (with S. Sarian).
"Reliability of Flaw Detection by Nondestructive Inspection," Metals Handbook, Vol. 11 (with several authors).
"Economics and Managerial Aspects of Nondestructive Testing Evaluation and Inspection in Aerospace Manufacture," Appendix C, National Academy of Science Publication NRAB-337 (with T. L. Toomay).
"Determination of Nondestructive Inspection Reliability Using Field or Production Data," Materials Evaluation, Vol. 36 (1978).
"Estimation of Defect Detection Probability Using ASME Section XI UT Tests on Thick Section Steel Weldments," ASM/ASTM/ASNT/ANS International Conference NDE in Nuclear Industry (1978) (with T. L. Toomay and C. S. Davis).
"A Workable Approach for Extending the Life of Turbine Rotors," Fatigue Life Technology, ASME Symposium (1977) (with P. M. Besuner).
"Optimizing NDI Sensitivity," Metals Progress, Vol. 112 (1977).
"Inspection Uncertainty: The Key Element in Nondestructive Inspection," Materials Evaluation, Vol. 39 (1976).

Attachment 7

CRAIG K. SEAMAN
358 CLUBHOUSE CT.
CORAM, N.Y. 11727
(516) 929-6050 BUSINESS
(516) 698-0503 HOME

SUMMARY

An aggressive, results-oriented engineer with extensive background in engineering supervision, mechanical and structural engineering, and construction. Most recent assignment requires management of 150 engineering, professional and technical personnel assigned to resolve design and quality concerns with a nuclear standby diesel generator manufacturer.

LONG ISLAND LIGHTING COMPANY
SHOREHAM NUCLEAR POWER STATION
(1979 - PRESENT)

AS PROGRAM MANAGER

. Established a program to provide an in-depth design review and quality revalidation of Transamerica Delaval diesel generators to qualify these units for nuclear emergency standby power. This program was required as a result of numerous engine failures and negative NRC audits of the vendor.

. Responsible for presentations to utility executives to enlist participation in the program - results: 11 of 11 utilities with operating licenses or active construction programs are contributing and participating.

. Managed the program utilizing a team concept involving over 150 personnel including engineers, scientists, diesel consultants, quality control inspectors and clerical support.

AS SENIOR PROJECT ENGINEER

. Managed an on-time and budget Pre-Service Inspection Program including providing expert testimony for the Atomic Safety and Licensing Board.

. Responsible for coordination of utility/architect engineer response to an Independent Design Review resulting in a clean bill of health for Shoreham.

. Supervised an engineering section responsible for all mechanical engineering, power systems, structural engineering, piping (including ASME) and pipe supports engineering.

AS ASSISTANT PROJECT ENGINEER

. Responsible for plant betterment program - one example is a radwaste system modification to back flushable etched disc filters which resulted in an over $200,000 savings.

. Assisted in development of the first domestic Induction Heating Stress Improvement Program for mitigation of stress corrosion cracking in Reactor Recirc System piping including coordination with NRC, G.E. and international firms.

. Engineering responsibilities included NSSS systems, radwaste systems, ASME piping and supports, and structural disciplines.

DANIEL INTERNATIONAL CORPORATION
ENRICO FERMI UNIT II
(1978 - 1979)

AS PROJECT ENGINEER

- Assigned to the Walbridge Aldinger Company (WACo) to establish the firm's ability to perform piping and mechanical installations. As a direct result, the WACo contract was increased 100% to $40,000,000.
- Supervised an engineering office responsible for ANSI B31.1 piping, fire protection piping, the biological shield wall and temporary facilities.

AS CONSTRUCTION ENGINEER

- Assigned to a task force established to review three quality assurance manuals and 40 construction procedures for effectiveness and efficiency - this effort resulted in a 20% increase in productivity in the field.
- Responsible for drywell piping including planning, engineering, materials procurement, and management of offsite programs in Michigan and California.

LONG ISLAND LIGHTING COMPANY
SHOREHAM NUCLEAR POWER STATION
(1975 - 1978)

AS CONSTRUCTION SUPERVISOR

- Responsible for the first on-time completion of a mechanical system at Shoreham - the Reactor Recirculation System in the Primary Containment.
- Established a coordinated construction team for piping and mechanical equipment installation in the Primary Containment including - contractor supervision, labor, quality control, cost engineering and scheduling.
- Assigned to a task force established to evaluate the construction program - the result was a major construction reorganization with significant improvements in progress, scheduling and cost control.

AS CONSTRUCTION COORDINATOR

- Provided a recommendation to purchase previously rented heavy construction equipment which resulted in a savings of over $500,000.
- Monitored civil/structural construction and field engineering activities including detailed reporting to management.

EDUCATION

Cornell University	B.S. Engineering
Brooklyn Polytechnic	18 Credits toward M.S. in Nuclear Engineering

PERSONAL —

Age - 31 Height - 5'9" Weight - 160
Married - 1 Child Health - Excellent

Attachment 8

Responsible for the finalization of the Shoreham Delaval Diesel Generator Design Review/Quality Revalidation Program.

Graduated from Lehigh University in 1966 with a Bachelor of Science Degree in Mechanical Engineering. From June 1966 to March 1968 attended Union College and achieved credits towards a Masters of Science Degree in Nuclear Engineering. Successfully completed the following training courses:

"Introduction to Nuclear Power" by NUS Corp., July 1970
"Boiler Control Fundamentals" by General Electric Co., January 1972
"Fundamentals of BWR Operation" by General Electric Co. at the GE Dresden Simulator, August 1972
"Process Computer Concepts and Practices" by General Electric Co., February 1973
"Shoreham Research Reactor Training Program" at Brookhaven National Laboratory Medical Research Reactor (NRC SROC License candidate research reactor training requirement), May 1975
"Planning for Nuclear Emergencies" by Harvard School of Public Health, May 1976
"Interagency Course in Radiological Emergency Response Planning in Support of Fixed Nuclear Facilities" by Nuclear Regulatory Commission, September 1978
"Customer Engineer Training Program in the Methods Used to conduct Maximum Turbine Capacity Tests and Analyze Results to Detect and Correct Cycle Losses" by the General Electric Co., Large Steam Turbine Division, September 1979
"Shoreham Nuclear Power Station On-Site Training Program" (NRC SROC license candidate plant systems training requirement), January - April 1979
"LILCO Advanced Supervisory Workshop", April 1979
"Assertiveness Training Workshop", November 1980
"LILCO Management Workshop", December 1980
"Shoreham General Employee Training", 1983

Achieved a Senior Operator Certification from the General Electric Company on the Duane Arnold Energy Center Boiling Water Reactor.

March 1981 - May 1984

Assigned as Startup Manager in March 1981. Responsible for the Preoperational test activities for the Shoreham Nuclear Power Station. Report to the Vice President-Nuclear. Responsible for coordinating all Checkout and Initial Operations and Preoperational Testing. Set initial construction priorities by system/subsystem and monitor construction progress as it relates to the startup schedule. Had the authority to modify construction schedule as conditions demand. Chaired construction release meetings at which status of construction, as it relates to systems scheduled to be released, was discussed. Member of the Joint Test Group. Ensured that the established procedures of documentation control were followed. Responsible for the review, monitoring, supervision and approval of Checkout and Initial Operations Tests, Preoperational Tests, and Acceptance Tests, review of all test results summaries and recommend acceptance, rejection or modification by the JTG according to results. Responsible for the production of all the software required for testing of Shoreham. Certified Level III per ANSI N45.2.6 - 1978.

In August 1983 named as Manager for the Shoreham Delaval Emergency Diesel Generator Crankshaft Failure Recovery Program. Responsible for coordinating the failure analysis, rebuilding, retesting and requalification of the three diesel generator units.

Prepared testimony, was depositioned and testified before the Atomic Safety and Licensing Board regarding Shoreham contentions dealing with quality assurance, startup testing and emergency diesel generators. Prepared testimony and testified before the New York State Public Service Commission. Responsible for direct interface with NRC Resident, Regional and Staff personnel for matters related to the preoperational test program and emergency diesel generators recovery effort.

May 1979 - March 1981

Assigned as Nuclear Services Supervisor in May 1979, reporting to the Manager, Nuclear Operations Support Division. Responsible for the management and coordination of those support services required by LILCO Nuclear Power Stations. These support services included coordination of major station modifications, performance of operational design reviews, coordinating the resources of other LILCO Departments and outside consultants to achieve a desired result assigned to the Division, coordinating long-range planning activities associated with plant maintenance, fuel cycle strategy and budget and cost control, monitoring overall plant and individual equipment performance, maintaining a current knowledge of federal regulations, industry codes and standards, and changes thereto applicable to the facility.

Participated on the LILCO Corporate Task Forces assessing Shoreham design and operations, corporate communications, crisis management and overall company emergency preparedness following the Three Mile Island Unit 2 accident. Chairman of the Shoreham Review Task Group, responsible for developing action plans for implementing post TMI recommendations. Responsible for the Shoreham Control Room human factors design review.

Developed the corporate policy manual defining interdepartmental responsibilities for the LILCO Nuclear Program.

Edward J. Youngling

February 1975 - May 1979

Assigned as Chief Technical Engineer of the Shoreham Nuclear Power Station - Unit 1 in January 1975. Responsible for the activities of the Instrumentation and Control, Health Physics, Radiochemistry and Reactor Engineering Sections of the plant staff, including the development of administrative and technical programs and procedures to meet regulatory, company and industry requirements; and the training of professional personnel and technicians to satisfy qualification standards. Served on the plant Review of Operations Committee (ROC) and when designated acted as Chairman of the ROC in the Plant Manager's absence. Served as a member of the plant Licensed Source User's Committee as stipulated in NRC Nuclear Material License No. 31-17432-01, February 1977.

August 1974 - January 1975

Reassigned to the plant staff as the Instrumentation and Control Engineer, then Acting Chief Engineer-Technical. Responsible for manpower planning and the development of the technical training programs for subordinate personnel. Participated in generating portions of the Shoreham Safety Analysis Report, and in the review and approval of plant operating procedures, lesson plans and system descriptions.

July 1973 - July 1974

Named the Instrumentation and Control Engineer for Shoreham Nuclear Power Station and assigned to the General Electric Company Startup, Test and Operations (STO) organization at the Duane Arnold Energy Center in Cedar Rapids, Iowa. Participated in the preoperational test program in the areas of in-core nuclear process radiation and reactor vessel (pressure, level and temperature) instrumentation. Acted as G.E. shift engineer during fuel loading operations and as assistant to G.E. shift engineer during startup testing and power ascension program. Participated in the G.E. shift engineer training program and sat for the G.E. Certification Examination for DAEC.

August 1972 - June 1973

Reassigned to Shoreham Nuclear Power Station Project as the Assistant Project Engineer, then Project Engineer. Responsible for overall plant design control. Coordinated design effort between LILCO, Stone and Webster Engineering Corporation, General Electric Co. Nuclear Energy Division, various major equipment suppliers and regulatory agencies.

November 1971 - July 1972

Reassigned to the Northport Power Station to participate in the startup of Northport Unit No. 3. Directly responsible for the startup of the boiler for this 380MW unit including the fuel safety system, the combustion and feedwater control systems and associated mechanical equipment. Assumed overall plant shift operations responsibility during the latter stages of startup. Was an instructor in the Unit No. 3 systems training program given to plant supervisors, operators, technicians, and mechanics.

November 1969 - October 1971

Assigned to the Shoreham Nuclear Power Station Project in the Nuclear Engineering Department. Participated in the engineering review of the Shoreham plant design in the following areas: plant equipment layout, equipment specifications, equipment selection, main control board design, plant operations logic, plant instrumentation, plant computers. Review included contacts with the A-E, Stone and Webster, NSSS supplier, General Electric Company, various vendors and visits to several nuclear stations.

April 1968 - October 1969

Employed by the Long Island Lighting Company and assigned to the Northport Power Station. During the period, assisted in the startup of Northport Unit 2, assisted in the station maintenance section supervising route and shutdown maintenance activities and acted as the station Results Engineer responsible for the repair and calibration of the station instrument and control systems and for monitoring station performance.

June 1966 - March 1968

Employed by the General Electric Company at the Knolls Atomic Power Laboratory. Stationed at the West Milton Site as a Mechanical Test Engineer on the S3G Prototype "USS Triton" submarine. While at the S3G plant my responsibilities were to prepare procedures for tests and operations which were not in accordance with normal plant operations; supervise the actual tests, analyze the results and issue reports to the AEC. The following specific activities were engaged in: completed selected sessions of the Engineering Officer of the Watch Training Course, participated in numerous plant tests including routing low power physics testing including directing reactor control rod movements through Navy reactor operators, maneuvering transients, main coolant pump tests, power runs, various engine room tests and ultrasonic testing to trend pipeline degradation. Participated in the Advanced Reactor Control Program as Lead Shift Test Engineer, including completion of required training program, and performing preoperational tests and integrated plant acceptance testing.

Member - American Nuclear Society. Held a Guest Associate Engineer appointment in the Reactor Division at Brookhaven National Laboratory. Member - Pi Tau Sigma. Hold an Engineer in Training Certificate - State of Pennsylvania (State Registration Board for Professional Engineers).

Edward J. Youngling
Manager, Nuclear Engineering Department

Assigned as Manager, Nuclear Engineering Department in May 1984. Report to the Vice President, Nuclear. Responsible for the overall operation of the Nuclear Engineering Department. The Nuclear Engineering Department is charged with providing the technical direction for engineering, fuel management, and radiation protection for the purpose of maintaining the design basis of the Shoreham Nuclear Power Station.

Responsible for the organizational development of the Nuclear Engineering Department and the definition of functions and responsibilities of the Nuclear Systems Engineering, Nuclear Fuel, Nuclear Project Engineering, Engineering Assurance and Radiation Protection Divisions.

Provide timely technical support to Shoreham plant operating staff for routine and abnormal operations in areas of nuclear engineering, core analysis, radiation protection, health physics, chemistry and radiochemistry. Administer programs and approve procedures to provide engineering and engineering management for plant modifications and engineering studies. Establish reliability and risk assessment capability aimed at improving plant safety and availability. Provide engineering support to Shoreham in the disciplines of thermal-hydraulics, heat transfer, stress analysis, systems engineering, instrumentation and controls, materials engineering, nuclear fuel design, core physics, safety and reliability analysis, risk assessment, radiation protection, shielding, health physics, radiation chemistry, non-destructive examination, corrosion analysis, and nuclear waste technology. Direct engineering work to the Office of Engineering on matters encompassing the disciplines of electrical, civil, power and environmental engineering for projects related to Shoreham. Direct activities related to nuclear fuel cycle management and establish nuclear material accountability. Establish core analysis systems to provide core follow support and advice on control rod withdrawal patterns. Provide technical direction for the Company's Radiological Environmental Monitoring Program. Provide radiation protection engineering and health physics technology assessments for incorporation in the Company's ALARA radiation dose reduction program. Responsible for the Company's ALARA radiation dose reduction program. Participate with Nuclear Operations Support and Plant Operating Staff in the development and implementation of the Corporate Licensing Policy.

Prepare and approve all budgets related to departmental activities necessary to comply with Corporate requirements. Prepare testimony and participate in appearances before federal, state and local hearing boards as required (PSC Prudency, PSC Rate Case, NRC Hearings, etc.). Administer R&D efforts within the Department in support of the Corporate R&D program.

Attachment 9

RESUME

NAME Milford H. Schuster

CURRENT WORK TITLE Chief Welding Supervisor

EDUCATION:

Academic Degree	Year Awarded	Name of Institution

SPECIAL TRAINING:

Type of Training	Year Taken	Administered By
Reactor Technology	1977	Brookhaven Labs
ASME III Boiler & Pressure Code	1977	Courter Co.
ANSI B31.1	1978	Courter Co.
10 CFR 50, App. B	1982	Lilco
Hydro Statiz Testing	1977	Courter Co.
QA QC, Welding	1982	Lilco
Stress Relieving	1977	Courter Co.

EXPERIENCE SUMMARY: (Commence With Least Recent)

Organization	Time Span in Years	Position Title
United States Air Force	4.0	Metals Processing Specialist
Brookhaven National Labs	16.0	Metallurgical & Welding Specialist
Any Car Auto Parts	5.0	Partner
Courter and Co.	1.0	Welding Supervisor
Courter and Co.	1.0	Piping Supervisor
Daniel International	1.0	Project Welding Supervisor
[illegible]sco Services Corp.	1.0	Welding Specialist
Long Island Lighting Co.	4.5	Chief Welding Supervisor

NAME Milford H. Schuster

SPECIAL RECOGNITIONS OR ACCOMPLISHMENTS: (Patents, Professional Engineers License, Special Certification, Society Awards, Government Awards, Publications, etc.).

EXPERIENCE DESCRIPTION: (In the same order as Experience Summary, describe the responsibilities of the most recent positions, noting significant accomplishments or problems encountered).

U. S. Air Force -General welding and specialty techniques and processes as requested from superior officers relating to aircraft components.

Aircraft Fabricators - Welder Instructor and Welder - Instructed personnel in welding of aircraft components using Tungsten Inert Gas welding techniques.

Brookhaven National Laboratories - Welding evaluation and qualification of various ferrous and non-ferrous welding techniques and experimental processes which encompassed Tungsten Inert Gas Welding, Metal Inert Gas Welding, Metal Arc Welding, Dry Box Welding and conduction of welding experiments related to corrosion properties of special reactor material piping and structural members. Coordination and liaison responsibilities with various production/manufacturing facilities related to subcontracted welding and nondestructive testing services.

NAME Milford H. Schuster

EXPERIENCE DESCRIPTION: (In the same order as Experience Summary, describe the responsibilities of the most recent positions, noting significant accomplishments or problems encountered).

Any Car Auto Parts

Partner in Auto Parts Firm

Responsible for ordering, delivering, maintaining and coordinating a profitable automobile parts distributorship.

Courter and Company

Welding Supervisor - Primary responsibilities included the evaluation of welding rejections by radiography, field evaluation of welding rejects and defects, evaluation of welders, the performance of welder audits and survellances, the coordination and evaluation of nondestructive testing. Requests and results all geared toward reducing overall welding rejection rate at the Shoreham Nuclear Plant Site.

Courter and Company

Piping Supervisor - Basic job responsibilities encompassed all scheduling; manpower requirements and piping installation for one-half of the Reactor Secondary Containment with the following specific duties: responsible for supervision and production of Craft welders, fitters, plumbers, etc., and deputy foremen. These responsibilities are primarily directed toward Safety Class 1,2,3 Piping Systems in the Reactor complex. Act as engineering/piping liaison between primary piping Contractor and Architect/Engineer. Request/Evaluate/Select correct piping materials, welding techniques and any design changes, pipe interference and neogatiation of contractor interface disputes. Supervisory duties also encompassed initiation of final piping isometrics and evaluation of surveyor's data to verify or initiate "as-built" drawings.

Daniel International Corporation

Project Welding Superintendent - Interface and monitoring of all field welding and welding related problems, relative to applicable site procedures and code requirements. Monitor welder qualification, welding rejecting rates and welding production rates. Interface with Customer, Contractor and appropriate Discipline personnel on an engineering level and regarding problems related to welding, piping and construction sequencing. Coordinate QC and Construction on non-conformance, rework and conformance to applicable site procedures, code and schedule requirements. Review Welding Procedures, Non-Conformance Dispositions, when required by Project Welding Engineer/Superintendent of act in his behalf when he is not present.

NAME Milford H. Schuster

EXPERIENCE DESCRIPTION: (In the same order as Experience Summary, describe the responsibilities of the most recent positions, noting significant accomplishments or problems encountered).

(cont'd)

Ebasco Services Corporation

Welding Specialist - Responsibilities included technical and practial orientation of Engineering and manual personnel in all aspects of Nuclear Grade Welding on the Unit #1 Reactor (BWR) at Laguna Verde, Vera Cruz, Mexico. Investigation and failure analysis of field related problems in welding affecting work under the following codes:

American Welding Society
"Structural Welding Code"
D-1.1
ASME "Boiler and Pressure Vessel Code"
Sections III, V, IX, XI, VIII
ANSI "Pressure Piping"
B31.1

Long Island Lighting Company

Chief Welding Supervisor - Ordering and maintenance of equipment/gases/electrode to support a 400 welder work force at the site. Responsible for interface on welding and metallurgy decisions site wide in scope for the utility. Conducted training programs for supervisory and manual personnel on industry codes, standards, and welding inspection. Failure analysis of welds and components. Administration of weld test booth for qualification testing. Interface with all mechanical contractors and architect engineering personnel on technical problems. Maintain welder qualifications, productivity and assignment tracking system for site. Evaluate and select welding techniques per design, specification requirements and code for all site contractors. Lead management/coordinating responsibilities [illegible] the following special assignments: Induction Heat Stress Im[illegible]nt, Diesel Generator Quality Revalidation Group; Pre Ser[illegible] In[illegible]ection, Reactor Pressure Vessel Internals and Control Rod Dri[illegible] I[illegible]llation.

6/84

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

Before the Atomic Safety and Licensing Board

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

ERRATA TO TESTIMONY ON BEHALF OF LONG ISLAND LIGHTING COMPANY REGARDING CYLINDER BLOCKS

I. Testimony of McCarthy, Rau, Wells, Wachob, Johnson, Taylor, Seaman, Youngling and Schuster

1. Page 9, lines 1-3 -- Delete the sentence "The geometry of these components is depicted in TDI engineering drawing which are attached as Exhibits B-1, B-2, B-3, B-4, B-5 and B-6, respectively."

2. Page 9, lines 23-24 -- Delete the sentence "TDI drawing 03-315-03-AC depicting the material specifications is attached as Exhibit B-1."

3. Page 12, lines 18-20 -- The phrase "and 92.5 hours occurred at load levels between 100% and 110% of full load" should read "63 hours occurred at load levels between 100% and 110%, and 29.5 hours were in excess of 110% load."

4. Page 16, line 23 -- Add "A. (Wells, Taylor)."

5. Page 18, lines 18-19 -- The phrase "extended to a depth of about 5-1/2 inches," should read "extended to a maximum depth of 3 inches."

6. Page 18, lines 19-20 -- The phrase "and ligament cracks between" should read "and one ligament crack between."

7. Page 18, line 24 -- "3.9 inches" should read ".85 inch."

8. Page 20, line 15 -- The phrase "FaAA inspected" should read "Inspections were performed on."

9. Page 21, line 26 -- After "A." add "(Wells, Taylor)."

10. Page 28, lines 8-26 -- Delete.

11. Page 29, lines 1-9 -- Delete.

12. Page 29, line 26 -- The word "the" should be deleted between the words "whether" and "differences."

13. Page 30, line 21 -- The word "graphite" should be inserted between "Widmanstaetten" and "is."

14. Page 37, Line 20 -- "Exhibit B-41" should read "Exhibit B-43."

15. Page 37, line 23 -- "38 ksi," changed to "33 ksi" on LILCO's errata of August 21, 1984, should be changed back to "38 ksi."

16. Page 38, lines 21-23 -- The phrase "strain amplitude versus the number of strain cycles to failure (i.e., two times the number of cyclic strain reversals)" should read "strain amplitude versus the number of cyclic strain reversals (i.e., two times the number of strain cycles to failure)."

17. Page 39, line 21 -- "Exhibit B-44" should be "Exhibit B-42."

18. Page 40, line 7 -- "Exhibit Q" should read "Exhibit B-44."

19. Page 40, line 22 -- "10 to 1000 times" should be "10 to 100 times."

20. Page 42, line 1 -- The phrase "should be comparable" should read "are comparable."

21. Page 42, line 3 -- The phrase "This would suggest that the fatigue" should read "Thus, the fatigue."

22. Page 46, line 1 -- The phrase "lowest curve depicted in Exhibit B-41" should read "crankcase curve depicted in Exhibit B-42."

23. Page 52, line 19 -- The word "loss" should read "law."

24. Page 53, line 1 -- The phrase "less than one-half" should read "about two-thirds."

25. Page 53, lines 6-7 -- The phrase "crack extension of 4 inches, with the deepest crack extending to a total depth of 5-1/2 inches" should read "crack extension of 1-1/2 inches, with the deepest stud-to-stud crack extending to a maximum depth of 3 inches."

26. Page 53, line 10 -- The phrase "is more than twice that" should read "is more than 150% of that."

27. Page 53, line 12 -- The phrase "due to the 5-1/2 inch deep" should read "due to the 3 inch deep."

28. Page 53, line 21 -- "1%" should read "2%."

29. Page 53, line 25 -- "1%" should read "2%."

30. Page 54, line 14 -- The phrase "less than half" should read "about two-thirds of."

31. Page 54, lines 17-23 -- Delete the sentence "The amount of damage . . . cumulative damage index."

32. Page 61, line 10 -- "5-1/2 inches" should read "3 inches."

33. Page 62, lines 5-25 -- Delete starting with "A typical cross section . . . ." This testimony has been replaced by the Supplemental Testimony.

34. Page 63 -- Replaced by the Supplemental Testimony.

35. Page 65, line 18 -- "Microstrucutre" should be "microstructure."

36. Page 66, lines 4-7 -- Delete the sentence "Therefore FaAA's crack . . . are appropriate." This has been changed by the Supplemental Testimony.

37. Page 66, lines 13-15 -- Delete the sentence "FaAA's analysis correctly . . . exponent n = 5.5." This has been changed by the Supplemental Testimony.

38. Page 67, lines 8-27 -- Replaced by the Supplemental Testimony.

39. Page 72, line 19 -- The words "Technical Specifications" should be replaced with "operating procedures."

40. Page 76, line 19 -- The word "incapable" should read "capable."

II. Testimony of Mathews, Lowrey and Wallace

1. Page 1, line 18 -- "8th Avenue" should be "85th Avenue."

2. Page 2, line 6 -- "Engineering Compressor Division" should be "Engine and Compressor Division."

3. Page 2, line 9 -- Add "A copy of my resume setting forth my professional qualifications is attached as Attachment 2."

4. Page 2, line 14 -- "Attachment 2" should read "Attachment 3."

5. Page 4, line 31 -- Put a period after "models" and delete "as depicted in TDI engineering drawings."

6. Page 5, lines 1-3 -- Delete.

7. Page 5, lines 23-25 -- Delete the sentence "TDI drawing . . . as Exhibit B-1."

8. Pages 6-9 -- Delete.

9. Page 10 -- Delete lines 1-19.

10. Page 13, line 24 -- After "A." insert "(Mathews, Lowrey)."

11. Page 18, lines 13-14 -- The phrase "to a depth of 5-1/2 inches" should read "to a maximum depth of 3 inches."

12. Page 21, line 24 -- "300 BMEP" should read "225 BMEP."

III. Supplemental Testimony of McCarthy, Rau, Wells, Wachob, Johnson, Taylor, Seaman, Youngling and Schuster

1. Page 2, line 3 -- "0.8 inch" should be "0.91 inch."

2. Page 8, lines 19-21 -- Delete lines 19-21 and add "FaAA did subsequently examine the remaining seven cam gallery locations on the EDG 101. This examination confirmed that all saddle areas had smaller weld regions and smaller crack indications. An . . . ."

3. Page 9, line 13 -- "0.8 inch" should be "0.91 inch."

IV. Exhibits

Replace Exhibits B-12, B-13, B-14, B-15, B-16, B-17, B-18, B-25, B-26, B-44, B-45, B-48, B-49 and B-50 with the attached Exhibits.

Delete Exhibits B-1, B-2, B-3, B-4, B-5, B-6, B-32, B-41, B-52, B-53, B-54, B-55, B-56, B-57 and B-58.

Respectfully submitted,

LONG ISLAND LIGHTING COMPANY,

By___________________________
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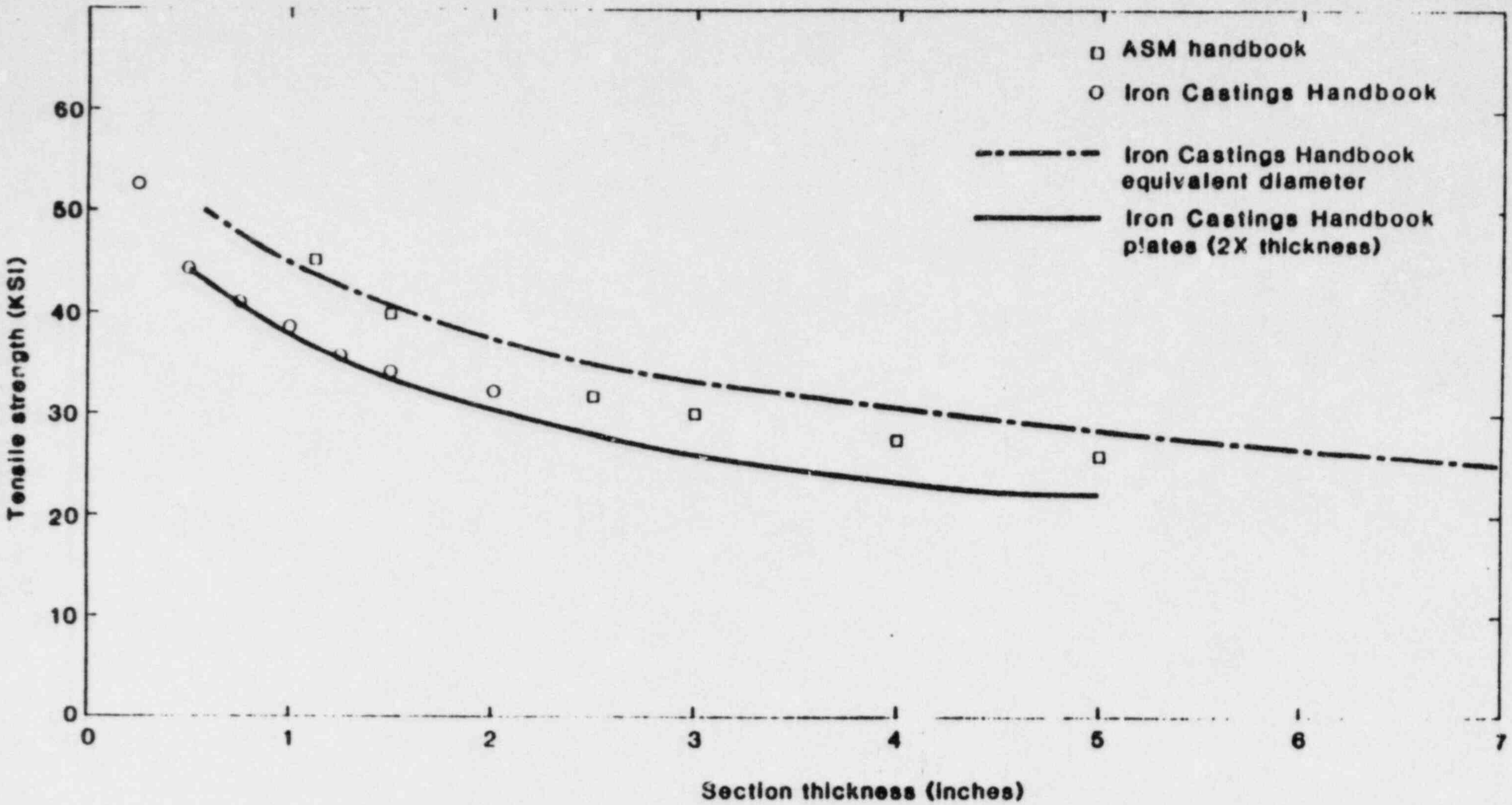
DATED: September 24, 1984



Effect of section thickness on the tensile strength of gray cast iron.

Exhibit B-13

ENGINE 101 LOAD HISTORY
SHOREHAM NUCLEAR POWER STATION

Event and Date	Hours at Load, L (%)					Total Hours, All Loads
	L<75	75<L<100	L=100	100<L<110	L>110	
Original Crankshaft Hours	164.0	262.5	188.5	--	19.0	634
Crankshaft replaced Restart 12/29/83 Testing Hours	78.0	179.0	20.0	91.0	4.5	372.5
Outage 3/18/84 Block Inspection 3/20/84						
Qual. Testing Hours 4/10/84	43.0	10.0	29.5	.5	2.0	85
Total	285.0	451.5	238.0	91.5	25.5	1091.5

Exhibit B-14

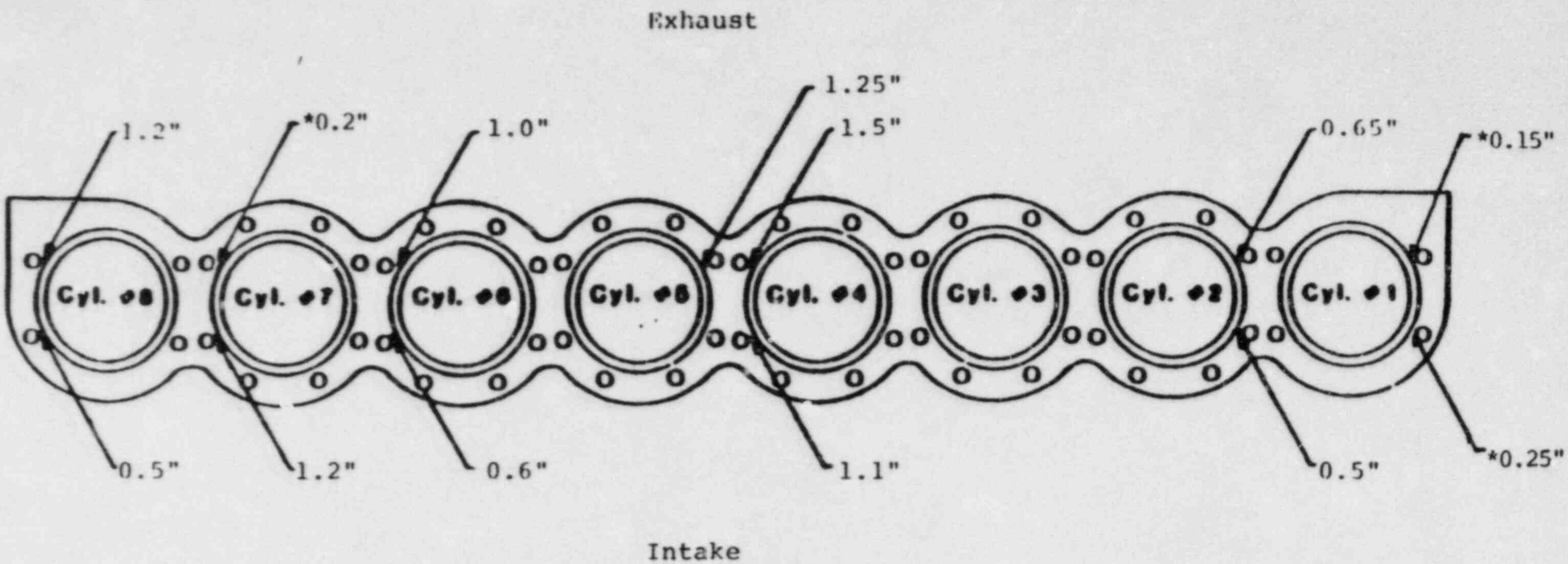
ENGINE 102 LOAD HISTORY
SHOREHAM NUCLEAR POWER STATION

Event and Date	Hours at Load, L (%)					Total Hours, All Loads
	L<75	75<L<100	L=100	100<L<110	L>110	
Original Crankshaft Hours	83.0	325.0	259.0	22.0	--	689
Crankshaft Replaced Restart 12-22-83 Hours	34.5	183.0	36.5	41.0	29.0	324
Outage on 2/09/84 for 1st Block Inspection on 2/10/84						
Qual. Testing from 3/9/84 thru 3/16/84 Hours	90.0	3.5	16.0	--	0.5	110
Post Qual. Test Outage for Block Inspection on 3/26/84						
Total Hours	207.5	511.5	311.5	63.0	29.5	1123

Exhibit B-15

ENGINE 103 LOAD HISTORY
SHOREHAM NUCLEAR POWER STATION

Event and Date	Hours at Load, L (%)					Total Hours, All Loads
	L<75	75<L<100	L=100	100<L<110	L>110	
Original Crankshaft Hours	103.0	432.0	257.0	---	23.0	815
<u>Crankshaft Replaced</u>						
Restart 12/17/83 Testing Hours	67.0	170.5	69.0	34.5	6.0	347
<u>Outage 3/11/84</u>						
Block Inspection 3/11/84						
Qual. Testing Hours	64.5	5.5	24.5	13.0	1.0	108.5
<u>Block Failure 4/14/84</u>						
Block Inspection 4/16/84						
Total Hours	234.5	608.0	350.5	47.5	30.0	1270.5

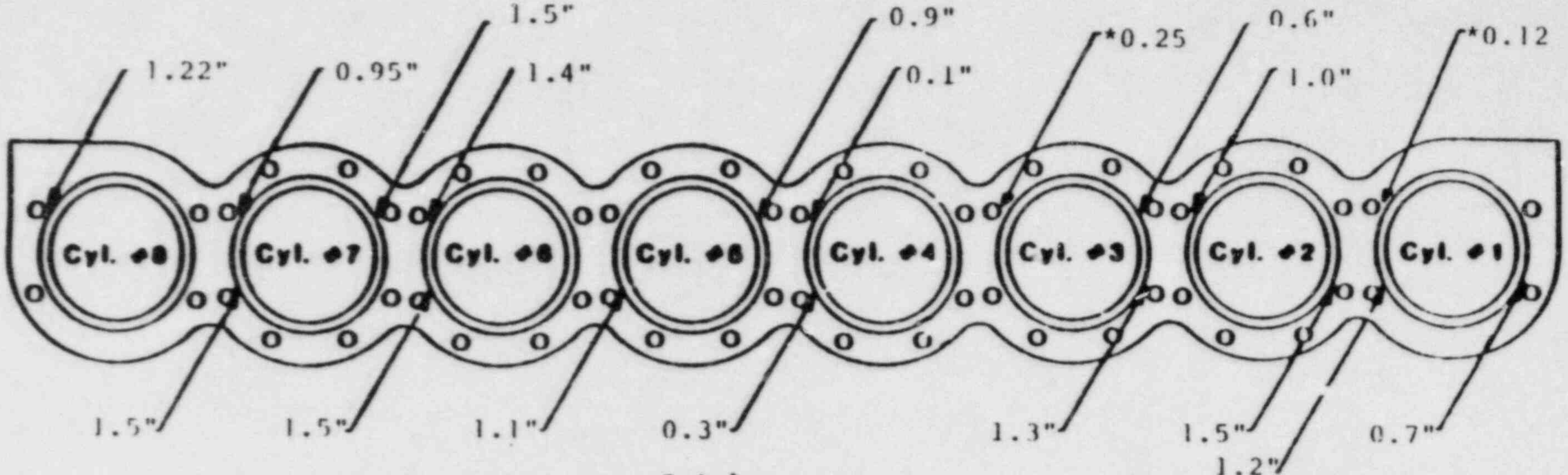


Dimensions indicate crack depth

* Top surface indication. Length recorded. Depth not measured.

SNPS DG101 crack map.

Exhaust

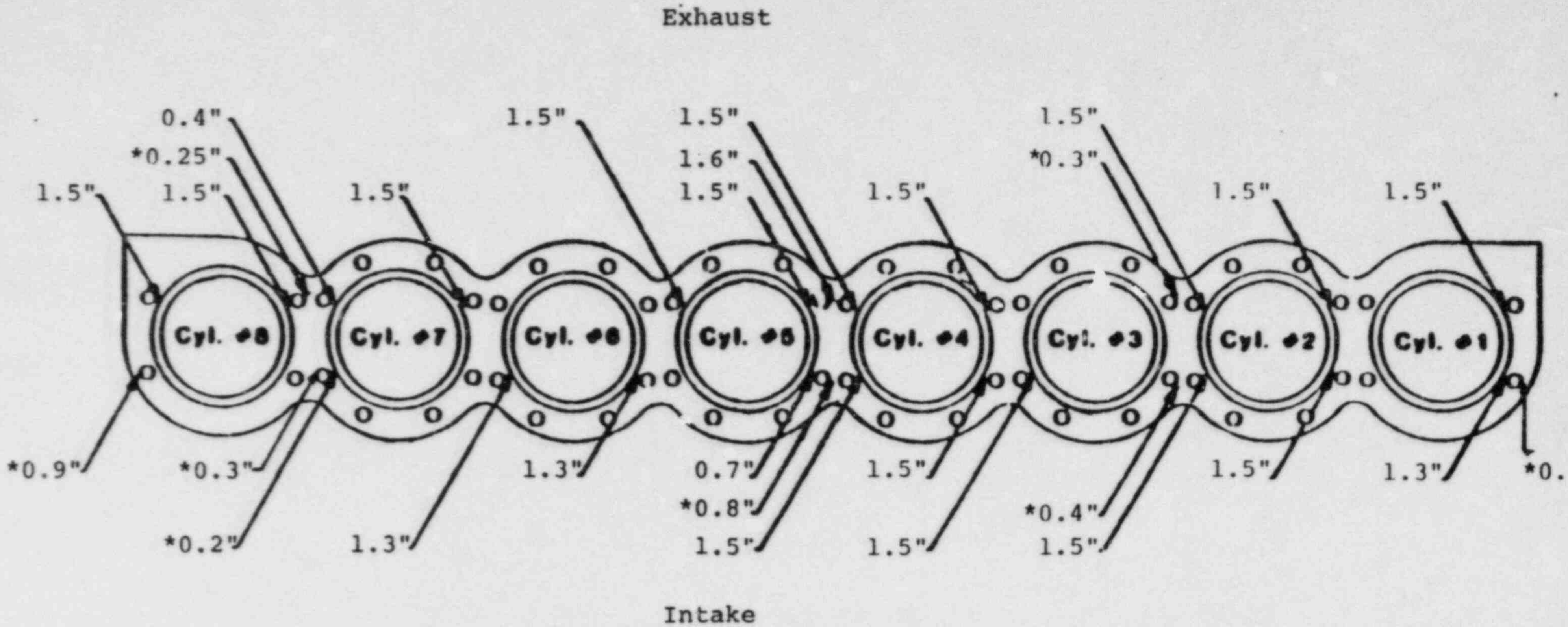


Intake

Dimensions indicate crack depth.

* Top surface indication. Length recorded. Depth not measured.

SNPS DG102 crack map.

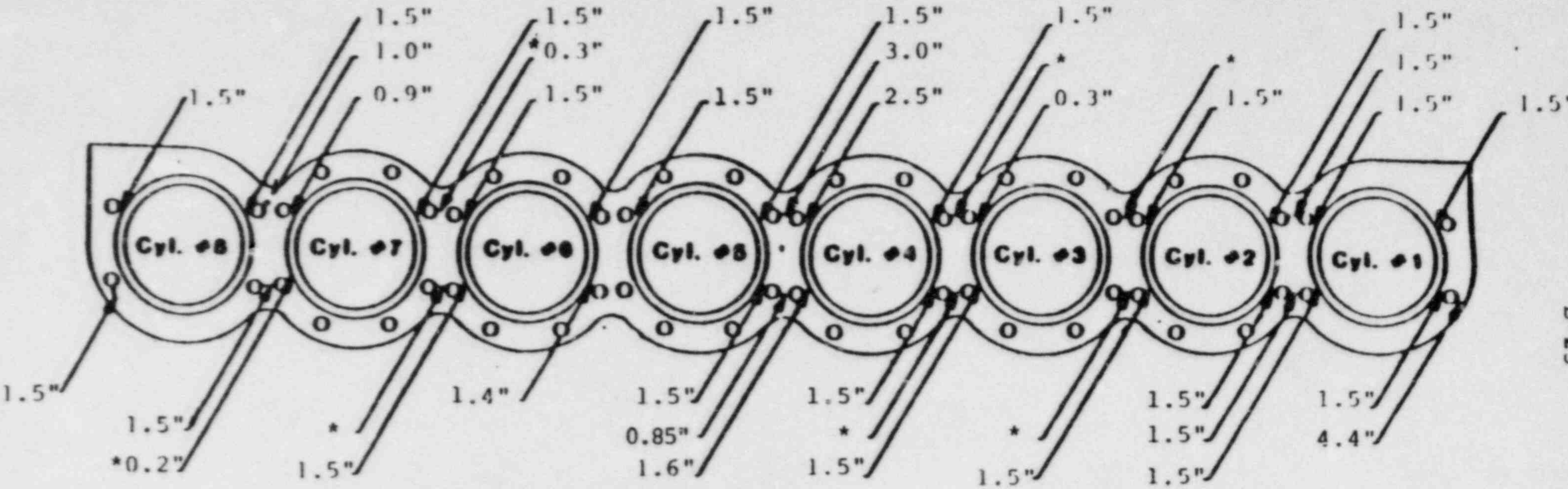


Dimensions indicate crack depth

* Top surface indication. Depth not measured, Length not recorded.

SNPS DG103 crack map.

Exhaust



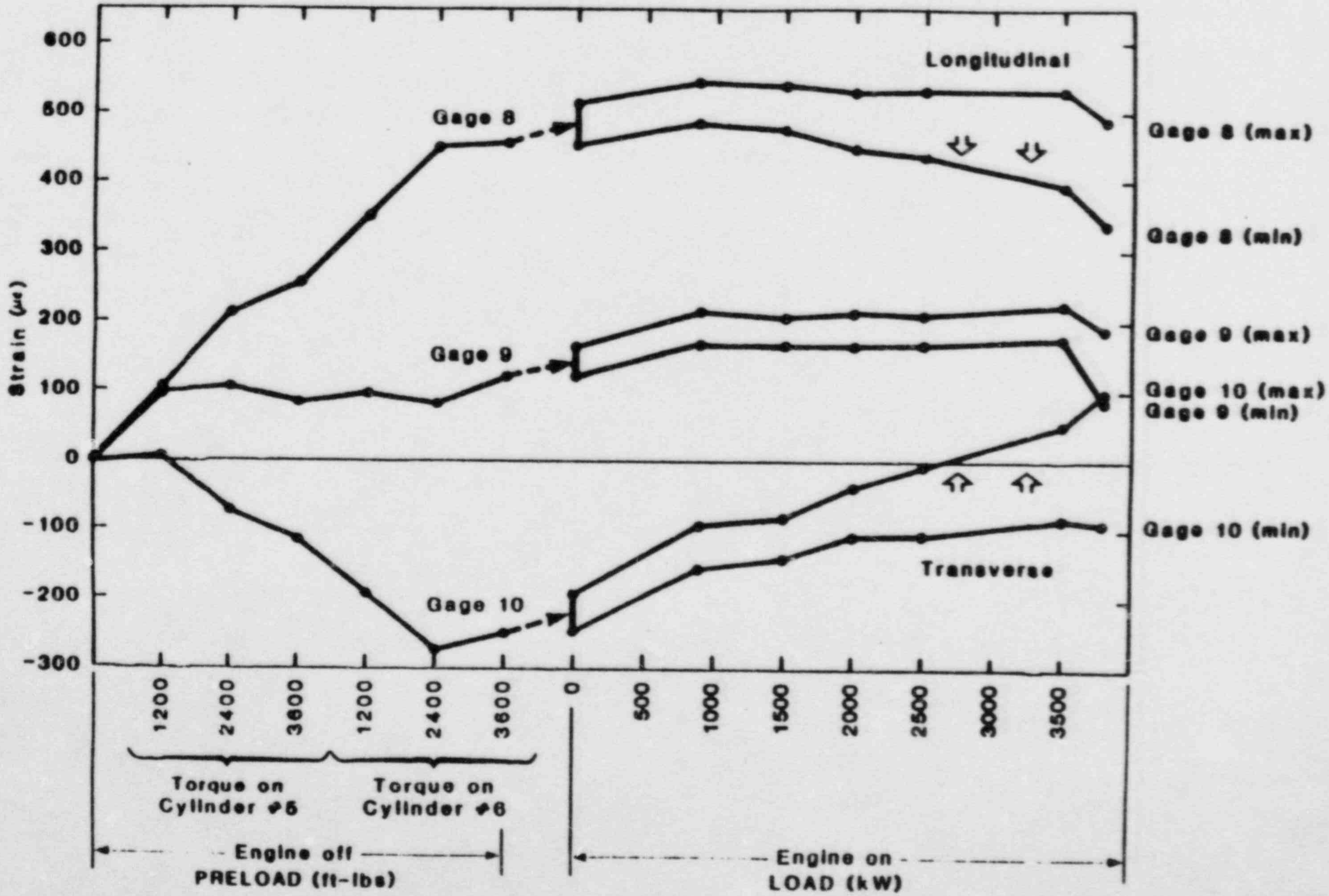
Intake

Dimensions indicate crack depth

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

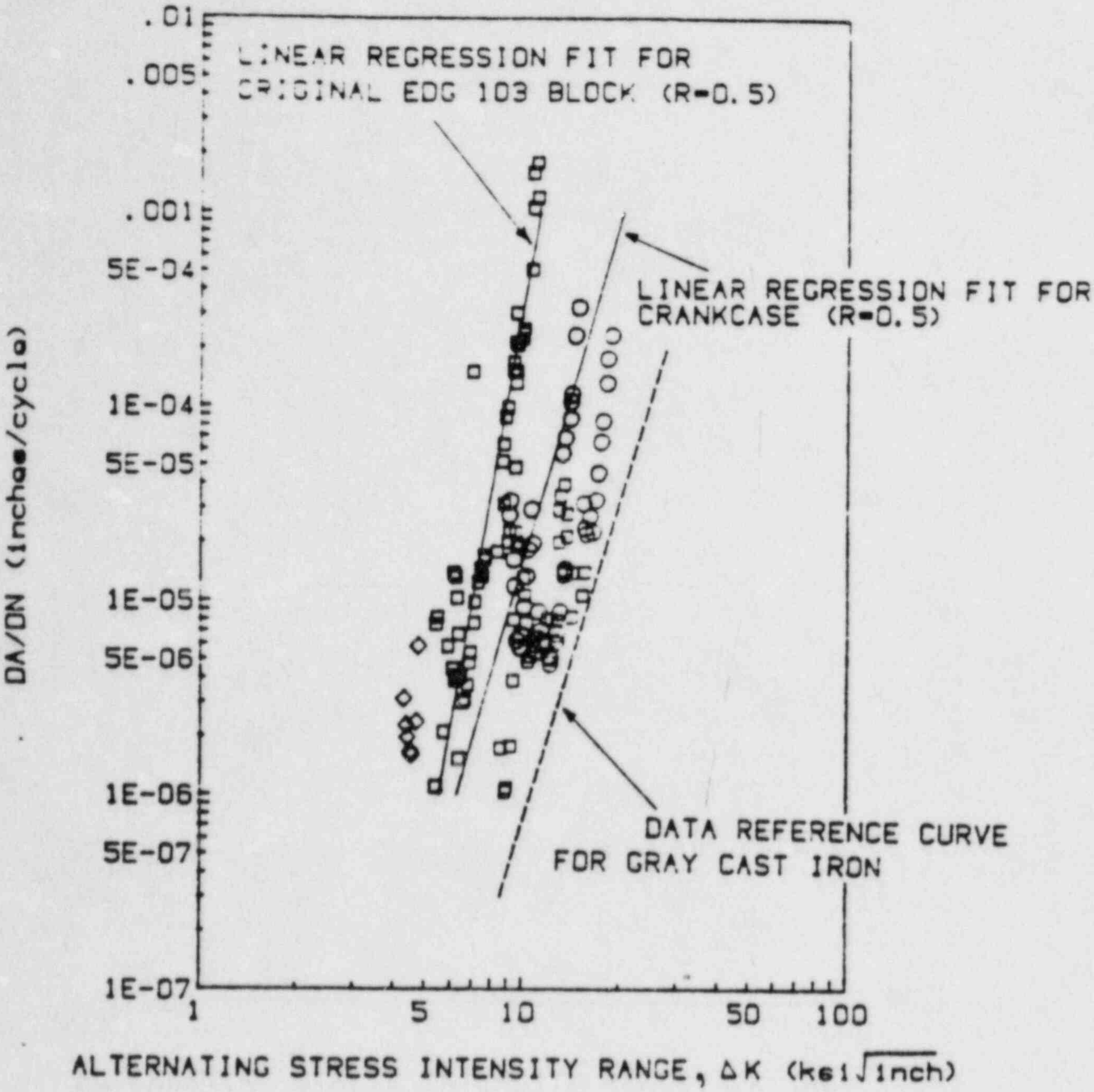
SNPS DG103 crack map as of 9/22/84.

Exhibit B-26



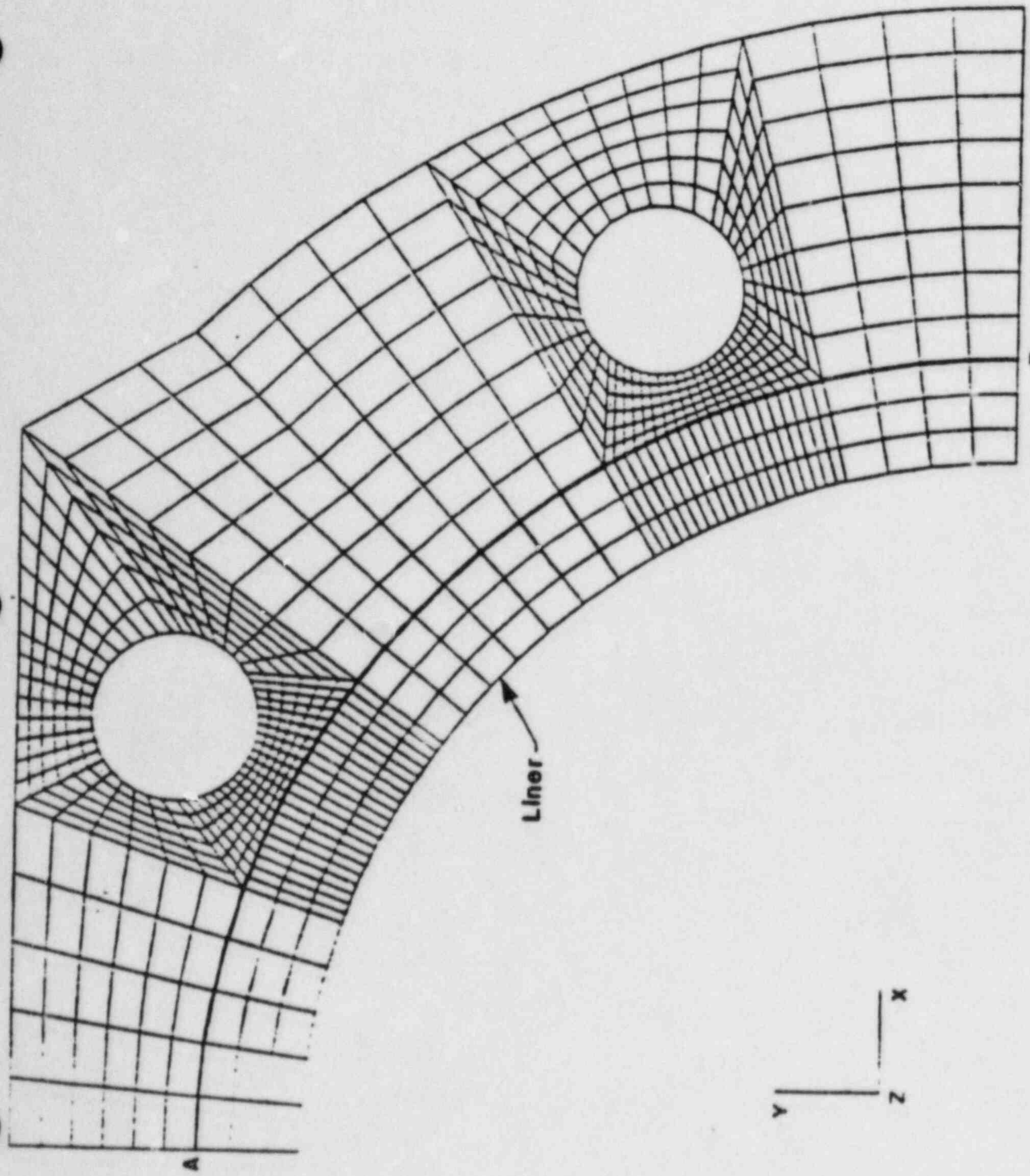
Strain vs. load for Gages 8, 9, and 10 (located on engine centerline)

FaAA-84-5-4



■ ORIGINAL EDG 103 BLOCK (R=0.5) SPECIMENS CT1A & CT2B
□ ORIGINAL EDG 103 BLOCK (R=0.05) SPECIMEN CT2A
◇ ORIGINAL EDG 103 BLOCK (R=0.8) SPECIMEN CT1B

● ST. CLOUD CRANKCASE (R=0.5) SPECIMEN OCT1B
○ ST. CLOUD CRANKCASE (R=0.05) SPECIMEN OCT2C


Liner
A
B
X
Y
Z

FACTORS RELATING STRESS MEASURED AT
SHOREHAM GAGE 13 to BLOCK TOP CRACK SITES

LOCATION - LOAD COMPONENT		UNCRACKED LIGAMENT	CRACKED LIGAMENT
Ligament Preload			
	100% on liner 3 to 1	1.21	-
Thermal		2.94	-
Pressure		7.15	-
Stud-to-Stud Preload			
	100% on liner 3 to 1	0.96	1.23
Thermal		1.99	2.05
Pressure		5.12	4.29

Additional relationships:

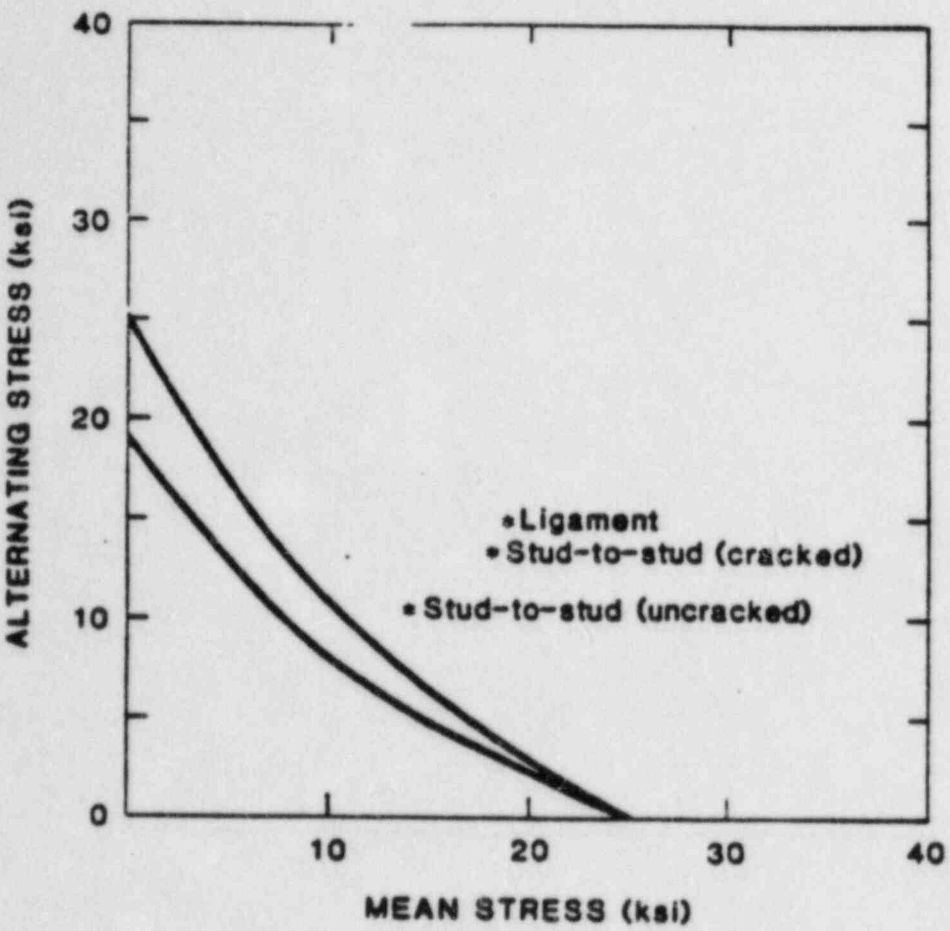
Good material/Poor material = 1.10

Cracked block/uncracked block = 1.26 Thermal

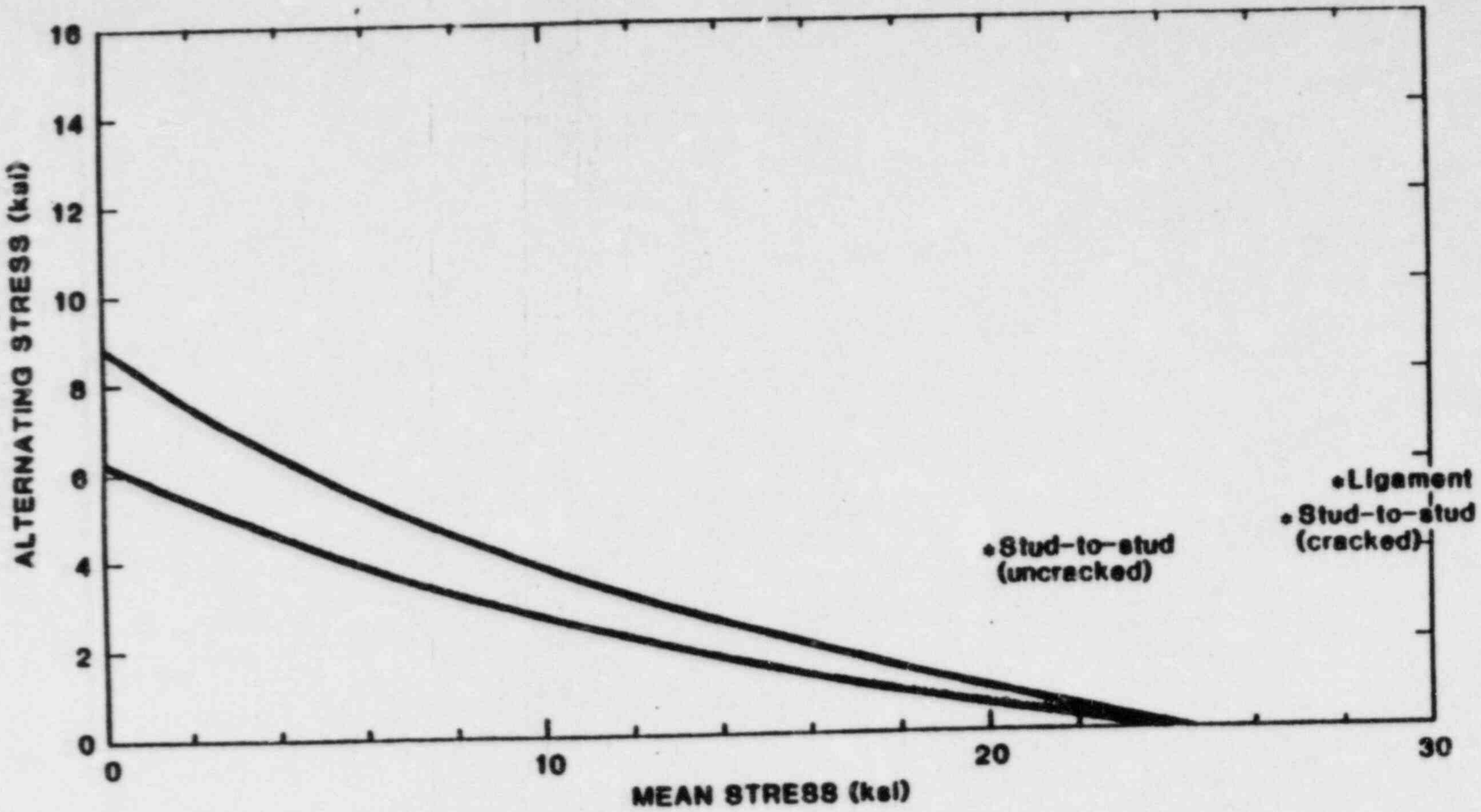
Cracked block/uncracked block = 1.06 Preload

Cracked block/uncracked block = 1.28 Pressure

Exhibit B-49



Goodman-Smith diagram for low cycle fatigue (100 cycles) at 100% load for Shoreham engines DG101 and DG102.



Goodman-Smith diagram for high cycle fatigue (>10^6 cycles) at 100% load for Shoreham engines DG101 and DG102.

FaAA-84-6-4

LILCO, September 20, 1984

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

Before the Atomic Safety and Licensing Board

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

SUPPLEMENTAL TESTIMONY OF ROGER L. MCCARTHY,
CHARLES A. RAU, CLIFFORD H. WELLS,
HARRY F. WACHOB, DUANE P. JOHNSON,
~~ROBERT K. TAYLOR,~~ CRAIG K. SEAMAN,
EDWARD J. YOUNGLING AND MILFORD H.
SCHUSTER ON BEHALF OF LONG ISLAND
LIGHTING COMPANY ON SUFFOLK COUNTY
CONTENTION REGARDING CYLINDER BLOCKS

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UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

Before the Atomic Safety and Licensing Board

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

SUPPLEMENTAL TESTIMONY OF ROGER L. MCCARTHY, CHARLES A. RAU, CLIFFORD H. WELLS, HARRY F. WACHOB, DUANE P. JOHNSON, ~~ROBERT K. TAYLOR,~~ CRAIG K. SEAMAN, EDWARD J. YOUNGLING AND MILFORD H. SCHUSTER ON BEHALF OF LONG ISLAND LIGHTING COMPANY ON SUFFOLK COUNTY CONTENTION REGARDING CYLINDER BLOCKS

I. Introduction

1. What is the purpose of this Supplemental Testimony?

A. (McCarthy, Rau, Wells, Wachob, Johnson, ~~Taylor,~~ Seaman, Youngling, Schuster). This testimony supplements our original testimony with new information obtained since August 14, 1984. The testimony revises the depths and crack characteristics previously reported for cam gallery cracks; revises the depths previously reported for stud-to-stud cracks; and reports on circumferential crack indications recently identified in the original EDG 103 block.

2. What conclusions have you reached?

A. (McCarthy, Rau, Wells, Wachob, Johnson, ~~Taylor,~~ Seaman, Youngling, Schuster). Our conclusions are:

1. The cam gallery cracks in the original EDG 103 block vary in surface length up to a maximum of six inches with a maximum depth of ~~[illegible]~~ 0.4 inch. Detailed fractography and metallography shows that the cracks are shrinkage cracks resulting from the casting process and have been present since the engine block was manufactured. The cracks have not propagated despite more than 1200 hours of operation, including more than 400 hours at or above 3500 kW. The cam gallery regions in the EDG 101 and EDG 102 blocks have been examined and the crack indications are less severe than in the original EDG 103 block. Therefore, it is our opinion that the cracks in the EDG 101 and EDG 102 blocks will not propagate.

2. FaAA has recently sectioned the block top of the original EDG 103 block in the area of the stud-to-stud crack. Measurements of the crack after sectioning revealed that the crack was actually a maximum of 3 inches deep rather than 5 1/2 inches. Accordingly, FaAA's conclusion that the EDG 101 and EDG 102 blocks can survive a LOOP/LOCA with substantial margins remains the same.

3. When FaAA sectioned portions of the original EDG 103 block, it identified shallow circumferential cracks that extended from the corner formed by the cylinder counterbore and cylinder liner landing 1/8 to 3/8 inch into the block top. Operating history on the original EDG 103 block demonstrates that circumferential cracks do not continue to propagate because they grow into a decreasing stress field. Since the cracks in the original EDG 103 block, with its inferior fatigue properties, did not impair engine operation, circumferential cracks, if any, in the EDG 101 and EDG 102 blocks will not impair the ability of the EDGs to perform their intended function.

II. <u>Examination Of The Cam Gallery Cracks In Old EDG 103 Block</u>

3. Please describe what work has been performed on the cam gallery cracks since August 14, 1984.

A. (Rau, Wells, Wachob, Johnson, ~~Taylor~~). FaAA has conducted extensive non-destructive and destructive examinations on the original EDG 103 cam gallery cracks. The non-destructive examinations began with a visual inspection of the surface of the cam gallery cracks and of the backside of the cam galleries to verify that none of the cracks had penetrated through the 1-1/4 inch thickness of the block wall at the inner cam gallery lining. Next, a liquid penetrant examination was performed on the cam gallery cracks to identify the size and the shape of the indications.

Destructive examinations were also performed. First, 1-1/4 inch diameter holes were drilled into crack indications in the saddle areas of cam gallery nos. 5 and 7. Next, the holes were polished, etched, and replicated to determine the depths of the cracks. In addition, a large piece of cam gallery saddle area no. 6, which included the entire crack indication and one section from the no. 7 cam gallery saddle area, were cut out and evaluated.

4. What did the non-destructive examinations reveal?

A. (Rau, Wells, Wachob, Johnson). They revealed that there were surface cracks on all nine of the saddle areas in the cam gallery. In addition, it was determined that none of the cam gallery cracks had perforated the block wall to the water jacket side of the cam gallery.

The epoxy paint applied to the cam gallery area was removed to reveal the metal surface of each saddle area of the cam gallery. Once the paint was removed, it was discovered that all nine of the cam gallery locations had been welded, apparently as a repair of cam gallery shrinkage cracks.

Non-uniform (constrained) shrinkage associated with the welding process resulted in cracks between the base metal and the weld metal itself. These cracks, which run along the boundary of the base metal and the weld, produced the surface crack indications that were detected and measured by previous non-destructive examinations of the cam gallery saddle regions.

5. Did the repair welds in the original EDG 103 block degrade the strength of the cam gallery?

A. (Rau, Wells, Wachob). No. The welds apparently were performed for cosmetic purposes. The welding process itself neither enhanced significantly nor degraded the strength of the cam gallery region.

6. How were cracks selected by FaAA for destructive examination?

A. (Rau, Wachob, ~~Taylor~~). FaAA identified cracks in cam gallery location nos. 5, 6 and 7 in the original EDG 103 block that appeared most severe for destructive examination to determine maximum crack depth and crack characteristics.

7. Please describe the destructive examination.

A. (Rau, Wachob, ~~Taylor~~). FaAA drilled through the crack location in the region that had previously been ground in the saddle area of cam gallery no. 5. The inside of the drill hole where the indications were present was then polished for metallographic examination. Plastic replicas were made of the sides of the holes to reveal the crack depth. Two 1-1/4 inch diameter holes were drilled into the cam saddle area of cam gallery no. 7 and prepared in the same way. In FaAA's laboratory, cam gallery no. 7 was sectioned to enable metallography of the crack indications, and a section was broken open to perform fractography of the crack surfaces.

8. What did the fractography of the crack reveal?

A. (Rau, Wachob). It revealed that the entire surface of the crack was covered with a thick oxide. This oxide was dark in color rather than a rust color. The thick, dark oxide indicates that the crack was present and exposed to air at elevated temperatures before the cam gallery region was filled with lubricant. The dark oxide, the presence of high concentrations of calcium, and the absence of a rust colored oxide indicate that the entire surface of the crack was introduced during casting and exposed to elevated temperature at that time. Furthermore, no new crack surface has been formed since the time of the initial oxidation.

9. What caused the dark oxide to form on the crack surface?

A. (Rau, Wachob). In our opinion, the majority of the oxide formed during cooling at the time of the casting process. Because this oxide could only have formed in elevated temperatures and in the presence of an air environment, the crack had to be present and surface connected during cooling.

Since very little oxidation would occur once the cam gallery cracks were bathed in oil after initial engine startup, the presence of the dark oxide layer is consistent with the conclusion that the crack is fabrication-induced and not operationally-induced. Thick, dark oxide would not have developed on a crack surface exposed as the result of subsequent fatigue crack propagation.

This conclusion is confirmed by examination of the fracture surface. Any service-induced crack propagation of the shrinkage cracks in the cam gallery would not be covered by thick, dark oxide. Since the oxide was present over the entire surface of the cam gallery cracks examined in the original EDG 103 block, it is clear that no crack propagation has occurred.

10. Did FaAA perform a metallographic examination of the cam gallery cracks?

A. (Rau, Wachob). Yes. Metallographic examination of the cracks indicated that there were multiple, parallel shrinkage cracks formed during casting. A family of cracks was observed in the metallurgical cross section rather than a single crack, and the heavy oxidation of the entire crack depth was appa ·nt.

An examination of the surface of the crack after it had been broken open did not reveal any beach marks, or other surface variations on the fracture surface which might indicate progressive crack extension.

11. Have the cam gallery cracks propagated since the block was manufactured?

A. (Rau, Wachob). No. FaAA's fractographic and metallographic examination of the sectioned portions of the cam gallery cracks indicated that the cracks were fabrication induced and that the cracks have not propagated since the time of initial fabrication. The existence of cam gallery cracks in other new block castings, the thick, dark oxide and calcium contamination on the entire crack surface, and the morphology of the cracks demonstrate conclusively that the cracks are fabrication-induced. The cracks have not propagated during more than 1200 hours of engine operation despite the extremely poor fatigue properties of the original EDG 103 block material.

12. Is the conclusion in FaAA's June 1984 Report that cam gallery cracks propagate very slowly correct in light of recent examinations?

A. (Rau, ~~Taylor~~). The June Report conservatively assumed uniform tensile stresses and therefore the fracture mechanics analysis predicted very slow crack propagation. Actual sectioning and examination of the cam gallery cracks demonstrates that FaAA's fracture mechanics analysis predicting crack propagation was indeed conservative. Even the very large cracks identified in the original EDG 103 block have not propagated.

13. Have you examined the EDG 101 and EDG 102 blocks for cam gallery cracks?

A. (McCarthy, Rau, Wells, Wachob, Johnson, ~~Taylor~~, Seaman, Schuster). Yes. Cam gallery nos. 8 and 9 on the EDG 101 and EDG 102 blocks were opened and the paint was removed from the surface of the cam gallery areas. A visual examination of the region revealed the presence of repair welds and crack indications, but the welds and crack indications were smaller and had less porosity than those found in the original EDG 103.

FaAA did subsequently examine the remaining seven cam gallery locations on the EDG 101. This examination confirmed that all saddle areas had smaller weld regions and smaller crack indications. An ~~FaAA did not examine the remaining seven cam gallery locations on the EDG 101 and EDG 102 blocks because access to those areas was blocked by the engine intercooler. However, an~~ examination of LILCO's inspection records indicates that the length of the other cracks in the EDG 101 and EDG 102 blocks are smaller than the largest cracks in EDG 103 block. This indicates that the cracks in the EDG 101 and EDG 102 blocks are less severe than those contained in the original EDG 103 block.

The somewhat smaller welds on the EDG 101 and EDG 102 blocks compared to the original EDG 103 block are entirely consistent with the known inferior fracture resistance of the original EDG 103 block.

14. Is it necessary to disassemble EDG 101 and EDG 102 to measure each of the cracks in those cam galleries?

A. (Rau, Wachob, ~~Taylor~~). No. EDG 101 and EDG 102, like the original EDG 103, have operated for more than 1200 hours with the cam gallery cracks without suffering an engine failure. Extensive examination of the original EDG 103 block revealed shrinkage cracks with a maximum depth of 0.91 inch, which are believed to be deeper than any cracks contained in the EDG 101 and EDG 102 blocks. These cracks had not propagated since the time the original EDG 103 block was cast, despite the inferior fatigue properties of that block. Accordingly, smaller casting defects (cracks) in the much more fatigue resistant block material of EDG 101 and EDG 102 pose no threat to the ability of the EDGs to perform their intended function.

15. As a result of FaAA's recent examinations, do you have an opinion, based on a reasonable degree of engineering certainty, as to the adequacy of the EDG 101 and EDG 102 cylinder blocks with the known cam gallery cracks?

A. (McCarthy, Rau, Wells, Wachob, ~~Taylor~~). Yes. The cam gallery cracks in the EDG 101 and EDG 102 blocks are shrinkage cracks induced during the casting process. Examination of similar but larger cracks in the original EDG 103 block demonstrated that the cracks have not propagated since the time the EDG blocks were cast. The extensive experience with the original EDG 103 block in conjunction with the differences in material properties of the EDG 101 and EDG 102 blocks has demonstrated that the cam gallery cracks in those blocks pose no hazard to the ability of the blocks to perform their intended function.

III. Laboratory Examination Of The Original EDG 103 Stud-To-Stud Cracks Establishes They Are Less Severe Than Previously Reported

16. Please describe what work has been performed on the block top cracks since August 14, 1984.

A. (Rau, Wachob, ~~Taylor~~). FaAA has measured some of the crack depths on the original EDG 103 block top in its laboratory by destructive sectioning. The stud-to-stud crack on the original EDG 103 block between cylinder nos. 4 and 5 on the exhaust side was sectioned in two places to measure the depth of the crack. Measurements of the crack revealed that the maximum depth was 3 inches, as compared to the 5-1/2 inches previously reported from field inspection.

17. What effect, if any, does the new data have on FaAA's cumulative damage analysis?

A. (Rau, Wachob, ~~Taylor~~). The fact that the actual depth of the cracks in the original EDG 103 block are shallower than previously thought does not in any way change FaAA's conclusions. In light of the more precise measurement, however, the cumulative damage index referenced in our original testimony changes slightly. Specifically, the number which needs to be revised occurs on page 53 of the testimony in response to question no. 72. That answer should now be revised to read "2%" rather than "1%."

IV. Circumferential Cracks Found In EDG 103 Will Not Impair The Ability Of The EDGs To Perform Their Intended Function

18. Have additional crack indications been identified since August 14, 1984?

A. (Rau, Wachob, ~~Taylor~~). Yes. When the stud-to-stud crack on the original EDG 103 block was sectioned in FaAA's laboratory to verify its depth, FaAA identified some shallow circumferential cracks. These cracks are located at the corner formed by the cylinder liner counterbore and the cylinder liner landing. The cracks identified were very shallow, extending to a maximum of 3/8 inch into the block top.

19. Are circumferential cracks present in the EDG 101 and EDG 102 blocks?

A. (Rau, Wells, Wachob, ~~Taylor~~, Johnson, Seaman, Schuster). The inspections performed to date have not identified any circumferential cracks in the EDG 101 and EDG 102 blocks. It is difficult to inspect for these cracks, however, 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, thus making interpretation of the results more difficult. Therefore, for purposes of its analysis, FaAA has conservatively assumed the presence of circumferential cracks in the EDG 101 and EDG 102 blocks.

20. Do you have an opinion, based on a reasonable degree of engineering certainty, as to whether circumferential cracks, if any, present in the EDG 101 and EDG 102 blocks affect the ability of the EDGs to perform their intended function?

A. (McCarthy, Rau, Wells, Wachob, ~~Taylor~~, Youngling). In our opinion, even if circumferential cracks are conservatively assumed to be present in the EDG 101 and EDG 102 blocks, they pose no threat to the ability of the EDGs to perform their intended function.

The operating history of the original EDG 103 block demonstrates that the circumferential cracks do not present a threat to the ability of the EDGs to perform their intended function. Even in the original EDG 103 block, which is known to have markedly inferior fatigue and fracture properties compared to the EDG 101 and EDG 102 blocks, the circumferential cracks are shallow. Despite more than 1200 hours of operation, including more than 400 hours at or above 3500 kW, the circumferential cracks in the EDG 103 block did not propagate to the point where they impaired engine operation.

Because of the superior material properties of the EDG 101 and EDG 102 blocks, any circumferential cracks in these blocks are predicted to be smaller. Thus, even if circumferential cracks are conservatively assumed to be present in the EDG 101 and EDG 102 blocks, they will not grow to the depth reached in the original EDG 103 block, and they will not result in fracture of the liner landing or impair engine operation.

Finally, empirical evidence derived from the original EDG 103 block is consistent with analytical predictions that the cracks propagate into a decreasing stress field. As the cracks move into the block top material, the stresses decrease, and there is a reduction in the driving force for continued crack growth. Accordingly, it is our opinion that any circumferential cracks in the EDG 101 and EDG 102 blocks will grow slowly, arrest, and will not cause any operational problems or impair the ability of the EDGs to perform their intended function of supplying emergency standby power for the Shoreham Nuclear Power Station.

Attachment 1

Failure
Analysis
Associates

ROGER L. McCARTHY

Specialized Professional Competence

Mechanical, machine, and mechanism design. Dynamic mechanical system design, analysis modeling, control (including dedicated computer control), and failure analysis. Custom product design. Human factors engineering and testing; design analysis of man/machine interface. Design analysis research. Risk analysis; quantification of hazards posed by design and construction of mechanical components, products, or system failure in the industrial and transportation environments. Design analysis through large scale accident data analysis and evaluation, including vehicle design and collision performance. Evaluation of mechanical/electrical design-related explosion hazard; heat transfer design. Reinforced polymer composite design analysis, including tires. Patent analysis relating to mechanical design.

Background and Professional Honors

A.B. (Philosophy), University of Michigan, with High Distinction
B.S.E. (Mechanical Engineering), University of Michigan, summa cum laude
S.M. (Mechanical Engineering), Massachusetts Institute of Technology
Mech.E. (Mechanical Engineering), Massachusetts Institute of Technology
Ph.D. (Mechanical Engineering), Massachusetts Institute of Technology

President,
Failure Analysis Associates
Principal Design Engineer
Failure Analysis Associates
Program Manager, Special Machinery Group,
Foster-Miller Associates, Inc.
Project Engineer, Machine Design and Development Engineering, Engineering Development Division,
Proctor & Gamble Company, Inc.

Registered Professional Mechanical Engineer, California, #M20040
Registered Professional Mechanical Engineer, Arizona, #13684
Phi Beta Kappa, Sigma Xi, James B. Angell Scholar
National Science Foundation Fellow
Outstanding Undergraduate in Mechanical Engineering, University of Michigan

Member, American Society of Metals, American Society of Mechanical Engineers, Society of Automotive Engineers, American Welding Society, National Safety Council, American Society for Testing and Materials
Member, American Society of Safety Engineers
Member, Human Factors Society, System Safety Society, National Society of Professional Engineers
Member, American Society of Heating, Refrigeration, and Air-Conditioning Engineers
Member, National Fire Prevention Association

Selected Publications

"School Bus Wheel Rim Safety — Multipiece vs. Single Piece," National School Bus Report, Springfield, Virginia (December 1982) (with G. E. McCarthy).
"Warnings on Consumer Products: Objective Criteria For Their Use," 26th Annual Meeting of the Human Factors Society, Seattle, Washington (October 25-29, 1982) (with J. N. Robinson, J. P. Finnegan and R. K. Taylor).
"Average Operator Inaction Characteristics with Lever Controls — Study of the Column Mounted Gear Selector Lever," 26th Annual Meeting of the Human Factors Society, Seattle, Washington (October 25-29, 1982) (with J. P. Finnegan, G. F. Fowler and S. B. Brown).
"Catastrophic Events: Actual Risk versus Societal Impact," 1982 Proceedings, Annual Reliability and Maintainability Symposium, Los Angeles, California (January 26-28, 1982) (with J. P. Finnegan and R. K. Taylor).

"Product Recall Decision Making: Valid Product Safety Indicators," Proceedings of the Fourth International System Safety Conference, San Francisco, California (July 9-13, 1979). Published by Professional Engineer Magazine (March 1981).

"Large Vehicle Wheel Servicing: Reduction of Risk Through Implementation of An OSHA Standard Governing Multipiece and Single Piece Rims: Phase IV," Published by the National Wheel and Rim Association (March 1981) (with J. P. Finnegan).

"Program to Improve Down Hole Drilling Motors: Task 2, Lip Seal Design," Failure Analysis Associates Report FAA-81-7-6 to Sandia National Laboratories (October 1980) (with V. Pedotto).

"A Safety and Fracture Mechanics Analysis of the Pneumatic Tire: A Perspective on the Firestone 500 Radial Tire," Presented at the International Conference on Reliability, Stress Analysis and Failure Prevention, of the American Society of Mechanical Engineers, San Francisco, California (August 18-21, 1980) (with W. G. Knauss).

"Multipiece and Single Piece Rims: The Risk Associated with Their Unique Design Characteristics: Phase III," Published by the National Wheel and Rim Association (June 1980) (with J. P. Finnegan).

"An Engineering Safety Analysis of the Steel Belted Radial Tire," Society of Automotive Engineers Paper #800840 (June 9-13, 1980).

"A Simple Technique to Improve the Allocation of Safety Inspection Resources," Proceedings of the Fourth International System Safety Conference, San Francisco, California (July 9-13, 1979) (with P. M. Besuner).

"An Engineering Analysis of the Risk Associated with Multipiece Wheels," National Highway Traffic Safety Administration, ANPR Docket No. 71-19, Number 7 (June 1979) (with J. P. Finnegan).

"Planar Thermic Elements for Thermal Control Systems," Journal of Dynamic Systems, Measurement and Control, Vol. 99, Series G, No. 1 (March 1977) (with B. S. Buckley).

Attachment 2

Failure
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ENGINEERING AND METALLURGICAL CONSULTANTS
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CHARLES A. RAU, JR.

Failure Analysis Associates
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Palo Alto, CA 94303
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HOME:
130 Croydon Way
Woodside, CA 94062

SPECIALIZED PROFESSIONAL COMPETENCE

Fatigue and fracture of metals, structural design and lifetime prediction, fracture mechanics analysis and testing, stress analysis, mechanical reliability and risk prediction, engineering management, failure analysis and fractography, metallurgy, corrosion, stress corrosion cracking, corrosion fatigue, mechanical testing, firearms, turbine materials, and structural integrity of rotating equipment.

EDUCATION

1967 **Ph.D. (Materials Science), Stanford University**
Thesis: "The Effects of Drilled Holes on Notch Toughness"
Minor: Engineering Mechanics

1965 **M.S. (Materials Science), Stanford University**

1963 **B.S. (Metallurgical Engineering), Lafayette College**

Awards:
- 1959-1963: Full scholarship, College Scholars Program
- 1963 Outstanding Metallurgical Engineering Graduate
- 1963 Stanford University Honors Fellowship
- Phi Beta Kappa, Tau Beta Pi, Alpha Sigma Mu

PROFESSIONAL AFFILIATIONS

Registered Professional Engineer, California, #CR835
Registered Professional Engineer, Province of Saskatchewan, Canada
Professional Societies: ASM, AIME, ASME, SESA, ASTM, ANS, NACE
Fellow, American Society of Metals (ASM)
Member, SESA Fatigue Committee
Member, SESA Fracture Committee
Member, ASTM Committee E24.04 on Subcritical Crack Growth
Member, AIME Structural Materials Committee
Editorial Board, Journal of Non-Destructive Evaluation

EXPERIENCE:

1982 to Present: **Group Vice President and Principal Engineer Failure Analysis Associates, Palo Alto, California**

Manage groups for Metallurgy, Failure and Risk Analysis, Fracture Mechanics, Human Performance, Laboratory and Testing Services; direct the regional offices in Houston, Texas and Detroit, Michigan; coordinate engineering consulting services of all technical groups and regional offices. Perform and supervise failure analyses and engineering evaluations of structures, materials, and mechanical equipment. Analyses are performed on a wide variety of components, including: 1) rotating equipment such as turbines, propellers, and pumps; 2) steel structures such as buildings, towers, bridges, offshore drilling platforms, and downhole equipment; 3) pressure vessels such as boilers, piping, storage tanks and tank cars; 4) transportation equipment such as highway, off-road, rail, and aircraft; 5) firearms, including rifles, pistols, and gunpowder-activated fasteners and perforators. Engineering projects utilize advanced structural analysis, detailed stress analysis, and fracture mechanics analysis computer codes in conjunction with instrumentation and testing to define cracking or fracture conditions to assess the suitability for continued service and the impact of restricted operation, maintenance, or additional monitoring or inspection.

1980 to 1982: **Executive Vice President and Fracture Mechanics Manager, Failure Analysis Associates, Palo Alto, California**

Supervised Fracture Mechanics Analysis, Stress Analysis, and Risk Analysis groups and management responsibility for other technical groups and regional offices. Work included failure analyses, research projects, and engineering evaluations of structures and equipment with known or postulated flaws. Research projects included developing: 1) advanced computer codes to perform crack progression and unstable crack size calculations for a wide range of loading conditions and crack geometries; 2) new methods to quantify the reliability of non-destructive inspection methods to detect flaws; 3) optimized reliability assurance programs to account for possible defects and the uncertainties that exist during operation and maintenance. Specific failure analyses and engineering evaluations were performed on various components, including: turbines, pumps, piping, tank cars, firearms, automobiles, trains, aircraft, and ships.

1976 to 1980: **Vice-President and Principal Engineer, Failure Analysis Associates, Palo Alto, California**

Managed the engineering staff. Coordinated and reviewed the activities of all regional offices and technical groups, including: Fluids and Dynamics, Fracture Mechanics, Reliability and Stress Analysis, and Design Analysis. Directly consulted for and supervised failure analyses and engineering projects involving turbines; propellers; pumps; pressure vessels; tank cars; piping; highway, rail, and aircraft equipment; nail guns; and consumer products.

1979 to Present: **Lecturer, Department of Engineering, Continuing Education, University of California at Los Angeles,**
Lecturer, Continuing Education and School of Engineering, San Jose State University

Prepared and presented short courses in failure analysis, failure prevention, risk assessment, and damage tolerance.

1974 to 1976: **General Manager, Contract Research and Engineering, Failure Analysis Associates, Palo Alto, California**

Marketed, technically supervised, and administered engineering projects and research contracts. Assembled project teams, recruited staff, and directly managed large projects. Supervised a major contract with the Electric Power Research Institute (EPRI), which provided detailed failure analysis of mechanical equipment, development of new methods for stress and fracture mechanics analysis, development of improved laboratory tools for nondestructive inspection and mechanical testing of materials and components, performance of risk assessments of components and systems, and development of failure prevention programs to improve reliability and availability of power-generating equipment. Other projects evaluated the integrity of bridges, railroads, aircraft, sewage treatment, petroleum products, and biochemical equipment.

1971 to 1974: **Supervisor, Lifetime Prediction Methods Group, Materials Engineering and Research Laboratory, Pratt & Whitney Aircraft, Middletown, Connecticut**

Developed improved design lifetime prediction methods by combining advanced materials engineering, applied mechanics, and laboratory testing expertise. Recruited and supervised a technical staff and marketed the services of the group. The group: 1) developed improved lifetime prediction methods employing fracture mechanics; 2) developed improved materials test methods; 3) generated materials design data; 4) performed research and development to better understand the micromechanics of deformation and fracture.

1967 to 1970: **Senior Research Associate, Mechanical Behavior Section, Advanced Materials Research and Development Laboratory; Pratt & Whitney Aircraft, Middletown, Connecticut**

Performed analytical and experimental research on the deformation and fracture of materials under complex stress states associated with stress concentrations. Research involved theoretical and experimental stress analyses in conjunction with experiment design to simulate usage conditions of jet engine components. Prepared technical reports, invited lectures, and published papers describing this work.

1967 to 1968: **Lecturer, Metallurgy Department, University of Connecticut, Stoors, Connecticut**

Prepared and taught a Graduate Course in Mechanical Behavior of Metals.

1964 to 1967: **Research Assistant, Materials Science Department, Stanford University, Palo Alto, California**

Performed research in fracture of metals; developed fracture testing apparatus; performed fracture testing of steels; and performed both analytical and experimental stress analyses.

1963: **Project Engineer, Wrought Alloys Group, Stellite Division, Union Carbide Corporation, Kokomo, Indiana**

Performed several short-term development projects to understand the behavior of nickel-based superalloys.

PUBLICATIONS

Co-author of more than 20 technical publications, hundreds of technical reports, and more than 30 invited lectures in the areas of failure analysis, lifetime prediction, and prevention of fatigue and fracture. Lists of papers, lectures, and reports are attached.

LIST OF PUBLICATIONS BY C.A. RAU, JR.

"The Effect of Small Holes on the Notch Toughness of Iron-Base Alloys," Proceedings of the First International Conference on Fracture, Vol. 2, p. 691 (1965) (with A. Tetelman).

"Strength Through Holes," New Scientist, Vol. 103 (April 14, 1966) (with A. Tetelman).

"The Effect of Drilled Holes on Notch Toughness," Ph.D. thesis, Stanford University (1967).

"A General Model to Predict the Elastic-Plastic Stress Distribution and Fracture Strength of Notched Bars in Plane Strain Bending," Engineering Fracture Mechanics, Vol. 1, p. 191 (1968) (with T. Wilshaw and A. Tetelman).

"The Critical Tensile Stress Criterion for Cleavage," International Journal of Fracture Mechanics, Vol 4(2), p. 147 (1968) (with A. Tetelman and T. Wilshaw).

"The Effect of Thickness and Drilled Holes on the Notch-Toughness of Charpy V-Notch Bars," Fracture, Chapman and Hall Ltd., London (1969) (with A. Tetelman).

"Elastic-Plastic Strain Concentrations Produced by Various Skew Holes in a Flat Plate Under Uniaxial Tension," Experimental Mechanics, Vol. 11(1), p 133 (1970).

"The Stress Distribution Around a Crack Perpendicular to an Interface Between Materials," International Journal of Fracture Mechanics, Vol. 6, p. 357 (1970) (with D. Swenson).

"Fatigue of Nickel-Base Superalloy Sheets Containing Various Diameter Small Holes," Engineering Fracture Mechanics, Vol. 2, p. 211 (1971) (with L. Burck).

"Correlations Between Fracture Surface Appearance and Fracture Mechanics Parameters for Stage II Fatigue Crack Propagation in Ti-6Al-4V," Metallurgical Transactions, Vol. 5(8), p. 1833 (1974) (with A. Yuen, S. Hopkins, and G. Leverant).

"A Critical Review of Anisotropic Fracture Mechanics," Prospections of Advanced Fracture Mechanics, Delft, Noordhoff, Leyden, The Netherlands (1974) (with T. Cook).

"The Combined Use of Engineering and Reliability Analysis in Risk Assessment of Mechanical and Structural Systems," Risk Benefit Methodology and Application, Asilomar, (September 1975) (with P. Besuner, G. Egan, and A. Tetelman).

"The Modelling of Flow Concentration in Two-Phase Materials," ASME H, Vol. 98(2), p. 180 (1976) (with T. Cook and E. Smith).

"The Effect of Various Programmed Overloads on the Threshold for High Frequency Fatigue Crack Growth," ASTM STP 595, Fatigue Crack Growth Under Spectrum Loads, (1976) (with S. Hopkins, G. Leverant, and A. Yuen).

"Failure Analysis and Failure Prevention in Electric Power Systems," Nuclear Engineering and Design, Vol. 43, p. 1, (1977).

"Flow Localization and the Fracture Toughness of High Strength Materials," Fracture, Proceedings of the Fourth International Conference on Fracture, Vol. 1, p.215, (1977) (with T. Cook and E. Smith).

"The Effects of Inclusions on the Fracture Toughness of High Strength Materials," Proceedings of NANCY Conference, p.490, (1977) (with T. Cook and E. Smith).

"Quantative Decisions Relative to Structural Integrity," Structural Integrity Technology, American Society of Mechanical Engineers, p. 1 (1979).

"The Impact of Inspection and Analysis Uncertainty on Reliability Prediction and Life Extension Strategy," Proceedings ARPA/AFML Review of Progress in Quantitative NDE, AFML-TR-78-205 (1979).

"Risk Analysis by Probabilistic Fracture Mechanics," Product Engineering, p. 41, (October 1979) (with P. Besuner).

"Quantitative Decisions Relative to Structural Integrity," ASME, Journal of Engineering Materials and Technology, Vol. 102(1), p. 56, (1980) (with P. Besuner).

"Personnel Errors and Power Plant Reliability," 1980 Annual Proceedings Reliability and Maintainability Symposium, IEEE (with J. Finnegan, T. Rettig, and J. Weiss).

"The Role of Micromechanics Models in Risk Analysis," , The Metals Society, London, England, p. 463, (1980) (with P. Besuner and K. Sorenson).

"Statistical Aspects of Design: Risk Assessment and Structural Integrity," The Royal Society, Philadelphia Transactions Royal Society of London, Vol A 299, p. 111, (1981) (with P. Besuner).

"Prediction of Structural Crack Growth Behavior Under Fatigue Loading," Fatigue Crack Growth Measurement and Data Analysis, ASTM STP 738, p. 256, (1981).

"Analyzing Failures - Some Advice and Examples," Mechanical Engineering, Vol. 106(7), p. 22 (1984).

LIST OF PRESENTATIONS AND INVITED LECTURES

First International Conference on Fracture, Sendei, Japan (1965)
Second International Conference on Fracture, Brighton, England (1969)
Third National Symposium on Fracture Mechanics, Lehigh University (1969)
ASME Sixth International Conference of Applied Mechanics, Cambridge, Mass. (1970)
Symposium on Fatigue at Elevated Temperatures, University of Connecticut (1972)
Fundamental and Applied Aspects of Metal Fatigue, Penn State University (1973)
Institute of Fracture and Solid Mechanics, Seminar Series, Lehigh University (1973)
Prospects of Fracture Mechanics, Delft, The Netherlands (1974)
Fatigue and Fracture of Two Phase Materials, USAF Workshop, Fairborn, Ohio (1974)
Review of Progress in Quantitative NDE, ARPA/AFML, San Diego, California (1978, 1979, 1980, 1981, 1982)
Structural Integrity Technology Conference, ASME, Washington, D. C. (1979)
Fracture Mechanics in Design and Service, The Royal Society, London, England (1979)
Micromechanisms of Crack Extension, University of Cambridge, England (1980)
Non-Destructive Testing Forum, Air Transport Association, Long Beach, California (1980)
Metal Treating Institute, Spring Meeting, Monterey, California (1982)

"A Dislocation Model of Inhomogenous Plastic Flow Around Cylindrical Voids in Single Crystals," RSM AIME, Philadelphia, Pennslyvania (October 1969) (with D. Swenson).

"Analysis of the Effect of Void Size and Dislocation Source Spacing on the Applied Stress Required to Initiate Slip," TMS AIME, Philadelphia, Pennslyvania (October 1969) (with D. Swenson).

"The Effects of Dislocation Character and Stacking Fault Energy on the Pile-Up of Imperfect F.C.C. Dislocations at an Interface," AIME (October 1970) (with D. Swenson).

"The Effect of Various Programmed Overloads on the Threshold for High Frequency Fatigue Crack Growth," United Aircraft Workshop on Fracture Mechanics (1973) (with S. Hopkins, G. Leverant, and A. Yuen).

"The Effect of a Monolayer of Surface Grains on the High Cycle Fatigue of Single Crystal and Directionally-Solidified Ni-Base Superalloy," AIME Spring Meeting, Philadelphia, Pennslyvania (1973).

"A Dislocation Pile-Up Model of Microyielding and Strain Hardening in Materials Strengthened by Ordered Precipitates," AIME Fall Meeting (1973) (with D. Swenson).

"Micromechanics of Yielding and Strain Hardening in Precipitation Hardened Materials, Part II - Comparison of Precipitate Types," AIME Spring Meeting (1974) (with T. Cook and E. Smith).

"Micromechanics of Yielding and Strain Hardening in Precipitation Hardened Materials, Part I- Ordered Precipitates," AIME Spring Meeting (1974) (with T. Cook, E. Smith, and D. Swenson).

"The Influence of Directional Solidification on the Thermal-Mechanical Fatigue Crack Propagation in Nickel-Base Superalloys," AIME Spring Meeting (1974) (with G. Leverant and B. Langer).

"The Influence of Hole Drilling Technique on the Low Cycle Fatigue Properties of a Wrought Nickel-Base Superalloy," AIME Apring Meeting (1974) (with B. Langer and G. Leverant).

"Fatigue Crack Propagation," Materials Science Symposium of AIME (October 1974) (with G. Leverant and S. Hopkins).

"Application of Fracture Mechanics to Fatigue Lifetime Prediction," Los Angeles Chapter, American Society for Metals (January 1975).

"Application of Fracture Mechanics to Nuclear Reactor Components," WESTEC 1975, Los Angeles, California (March 1975).

"The Modeling of Flow Concentration in Two Phase Materials, "Micromechanical Modeling of Flow and Fracture, Troy, N.Y. (June 1975) (with T. Cook and E. Smith).

"The Fracture Mechanics Approach to Life Prediction," Sacramento Valley Chapter Joint ASME and ASM Meeting (October 1975).

"Fracture Mechanics Technology in the Nuclear Power Industry," WESTEC 1976, Los Angeles, California (March 1976).

"The Application of Risk Analysis to Aircraft Product Litigation," Aircraft Builders Counsel, Toronto, Canada (October 1978) (for A. Tetelman).

"Quantitative Decisions Relative to Structural Integrity," ASME Conference on Structural Integrity Technology, Washington, D. C. (May 1979) (for A. Tetelman).

"The Impact of Inspection and Analysis Uncertainty on Reliability Prediction and Life Extension Strategy," Review of Progress in Quantitative NDE, ARPA/AFML, San Diego, California (July 1979)

"Quantitative Decisions Relative to Structural Integrity," Lawrence Livermore Laboratories (1979).

"Practical Applications of Damage Tolerant Designs," UCLA Short Course: Aspects of Damage Tolerance (April 1980).

"Failure Prediction and Accept/Reject Criteria for Jet Engine Inspections," Defense Advanced REsearch Projects Agency, Workshop on Retirement for Cause, Ames, Iowa (November 1980).

"Role of Microstructural Mechanisms on Structural Reliability," Joint ASM and SESA Meeting, Santa Clara, California (1980).

"[illegible]itative Basis for Optimizing Inspection Strategy," Air Transport [illegible] Forum, Long Beach, California (1980).

"[illegible]ower Generation Equipment," UCLA Short Course: Techniques for [illegible]alysis, Failure Prevention, and Risk Assessment (December 1980).

"Practical Fracture Mechanics and Failure Analysis," UCLA Short Course: Materials Aspects of Damage Tolerance (May 1981).

"Introduction to Practical Fracture Mechanics," United Nuclear - Naval Products Division (May 1981).

"Failure Analysis and Risk Assessment," American Public Works Association, San Francisco, California (1981).

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MR. FARLEY: The panel is ready for cross-examination.

JUDGE BRENNER: Mr. Dynner.

MR. DYNNER: Thank you, your Honor.

CROSS-EXAMINATION

BY MR. DYNNER:

Q Gentlemen, for the ease of this morning's cross-examination, there has been put on the table and I'm going to get another copy of the exhibits of Suffolk County regarding the blocks.

In addition, it would be helpful if you have on the table the cylinder block exhibits of LILCO as well as your own testimony to which I will be referring.

I am going to review for you very briefly the procedure for cross-examination.

If I ask a question of an individual by name, that individual should respond without and before consulting with any of this colleagues.

If I ask a question of that individual and after answering he wants to consult with a colleague, he should consult only with a co-sponsor of his testimony and not with someone who did not sponsor the subject matter that I am asking about.

In response to questions that I put to you that are capable of a Yes or No answer, you should answer first

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Yes or No, and you may then add an explanation if appropriate, for example by saying "Yes, but...." or "No, however,...."

These are the procedures that have been followed during the cross-examination of the panel put forward by Suffolk County, and I would ask that you comply with those procedures as well.

Now, gentlemen, on September 24th you submitted a filing to the Board and parties which was entitled "Errata to Testimony on Behalf of Long Island Lighting Company Regarding Cylinder Blocks," and by means of this device you made a number of substantive changes to the testimony that you had previously filed with the Board and the parties on August 14th, 1984.

One of the changes that we noted consists of the deletion in its entirety of Question and Answer 83 on page 62, 84 on page 62, and 85 on page 63. These questions and answers related to, as you will note, the fracture mechanics analysis that FaAA performed on the cam gallery cracks on the Shoreham Delaval engines.

It is true, isn't it, -- and I would direct this question to anyone from FaAA -- that the reason for the deletion of that testimony is that FaAA discovered that the Delaval strain gauge data which had been reduced from strain gauge testing conducted on a DSR 46 engine was wrong. Isn't

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that true?

JUDGE BRENNER: I want to start the day off on the right foot. I want to get answers more quickly than we have gotten in the past with some of these same members on the panel. Now certainly if something is complex and needs a lot of discussion that's fine, but if you could not predict that question coming I would be very surprised. Let's see if we can't get an answer without having 20 minutes of discussion among the witnesses first.

Mr. Wells, you are the only surviving on the panel co-sponsor of the testimony. Why don't you take a crack at it?

WITNESS WELLS: Yes, Judge Brenner. Let me start.

In the first place, the problems with the--

MR. DYNNER: Excuse me. I am going to interrupt.

BY MR. DYNNER:

Q I am going to ask that you follow the procedure that was used on cross-examination of the panel of witnesses put forward by Suffolk County, and that is that you respond Yes or No, and then you can give your explanation if appropriate.

A (Witness Wells) Thank you.

Yes, we did find that the TDI strain gauge results were in error. We found the error during the normal execution of our quality assurance program where we went back through their measurements and attempted to verify them. It was noted that some of the measurements were not completely consistent, and we did not have significant faith in them.

On further pursuit of the actual test records we did in fact conclude that the measurements were unreliable. That was one factor only in our conclusion that the previous testimony had to be modified.

Other factors--

Q Excuse me, Dr. Wells. My question was only whether or not in fact the strain gauge data that had been supplied by TDI was incorrect.

Will you answer that question?

MR. FARLEY: Judge Brenner, I object. I think the witness ought to be permitted to continue with his explanation.

JUDGE BRENNER: You asked him, Mr. Dynner, why they withdrew the testimony. If you would have just asked your simple question you could have restricted him. You might keep that in mind. It was kind of a long question which had some subsidiary comments by you in the course of it, so I'm going to give him some greater leeway.

If the questioner would shorten up the question, I can enforce much better a direct, concise answer requirement. And I say that for the general advice of all questioners.

So we will allow them to complete the explanation.

WITNESS WELLS: Thank you, Judge Brenner.

Other factors that contributed to our decision to modify the testimony include the fact that our own independent analyses came to the conclusion that there was nowhere in the cam gallery region any component of tensile stress that could cause cracked propagation in the cam gallery area, period.

MR. DYNNER: I move the strike the answer because there is nothing in the direct testimony or in the supplementary testimony of this witness or any of these witnesses to that effect. I think they are trying to use this answer to bring up matters that are not in the direct testimony. And you will remember previously when witnesses, on behalf of the Staff, were asked questions and attempted to bring in matters concerning additional analyses that they had done concerning the crankshafts and the classification society rules, that this Board ruled that because those matters were not in the direct testimony, they were not subject to cross examination.

I haven't asked a question concerning what this witness just said. It's not in the direct testimony. I think that the Board ought to be consistent and strike that answer.

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MR. FARLEY: Judge Brenner, I think it is in the direct testimony as supplemented and that constitutes the entire direct testimony.

MR. DYNNER: I beg to differ. It's not in the supplementary testimony, either.

JUDGE BRENNER: Wait a minute, Mr. Dynner.

Where is it in the testimony, Mr. Farley?

MR. FARLEY: Supplemental testimony on cam galleries begins at page 3, and page 7 specifically discusses the fact that the cracks in the cam gallery area have not propagated during the 1200 hours of engine operation. The reason for that is the compressive --

JUDGE BRENNER: All right.

We're going to deny the motion to strike. You've misstated our previous rulings, Mr. Dynner. When we either struck testimony or granted objections to questions before on the basis that it was not in the direct testimony, the case was either that the subject was not broached at all in the testimony of the Staff witnesses who were being offered at that time -- and that was on the metallurgy -- and you may recall to be sure, I asked the witnesses present whether, in fact, they had done any work in that area. And they said no.

The other subject on the classification societies was because it was the basis of a very precise contention

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definition process, whereas, certain things were specified in the contention and other things were not.

It is not correct, of course as you know, that the only testimony we're going to get orally is repeats of what's in the written testimony. If that were the case, we wouldn't need any oral testimony.

This is a subject that they have certainly more than touched, in the direct testimony. It's true that what we got in the oral answer is more than what is in the written testimony, but that's the purpose of the oral examination, both cross examination and direct and Board questions, to amplify the premises and bases.

So, there's quite a distinction between our previous rulings and this one, and we will deny the motion for those reasons.

WITNESS WELLS: Judge Brenner, if I may, I have a very --

JUDGE BRENNER: I thought you finished your answer, Dr. Wells.

WITNESS WELLS: I had begun to describe one of the additional factors, namely, that we had discovered that --not really discovered, that would overstate it -- that the stresses are nowhere tensile and therefore cracks could not propagate in the cam gallery area.

And if you would permit, Judge Brenner, it would

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take about 30 seconds or less, to describe precisely what this tensile stress problem is all about.

JUDGE BRENNER: All right. Go ahead. We're going to get it sooner or later, anyway.

WITNESS WELLS: The firing load is the only source of tensile stress in the sidewalls of the engine. Now, each cylinder is essentially supported by a box-like structure consisting of four walls that are an inch and a quarter in thickness and on a side approximately 12 inches -- excuse me -- 24 inches. If one adds up the total cross sectional area, this comes to -- let's see, 2 feet times 4 is 8 feet or 96 inches, times one and one-quarter inches of thickness, which gives on the order of 120 square inches. And as you previously heard the total filing load is on the order of 380,000 pounds. Therefore, the average stress transmitted through this area during firing is, on the order of 3,000, or slightly above, 3,000 pounds per square inch. And the strain gauge readings that we performed at Shoreham, in fact, indicate stresses remote from the vicinity of the notched area above the cam saddle, approximately 3,000 pounds per square inch in excellent agreement with what one would anticipate from this simple calculation.

MR. DYNNER: Judge Brenner, I'm going to move again to strike the last part of this witnesses testimony. He referred to strain gauge testing at Shoreham --

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JUDGE BRENNER: I'm going to cut you off. Let him finish and then I can make a better judgment. I'm not sure I know where he's going.

MR. DYNNER: All right.

WITNESS WELLS: The block top is bolted through the base by four bolts per cylinder. The bolts are preloaded well in excess of this firing load. In fact, the ratio of the compressive stress that still exists across the walls that I just described, during the maximum firing pressure to the preclamping load produced by these four bolts, is on the order of 25 to 30 percent.

There is, therefore, a margin of compressive stress at all times across this particular section and, in fact, across the entire 5-foot height of the block top from the top of the bolts, that is the nuts, down into the base of the engine. Therefore, there is no possibility that the particular area of the cam gallery can be subject to tensile stress of any kind during operation.

In addition, another factor, of course, has been the metallurgical evaluation of the cracks. We found that these cracks had not propagated over their entire life since fabrication. We also found that the cracks were, of course, substantially deeper than originally thought. If there had been any tensile stress in the vicinity of these deeper cracks, there would most certainly have been crack growth for these three observations: namely, that there must be at all times a compressive stress that would prevent crack growth in the first place; that, in fact, no crack growth had ever occurred; and that the cracks were substantially deeper were the primary reasons why we were obliged to modify our previous testimony.

Thank you.

JUDGE BRENNER: Now, Mr. Dynner, what's your problem with it?

MR. DYNNER: My problem with that is that it was a reference to strain gauge testing at Shoreham. The only strain gauge testing that appears in the testimony was the strain gauge testing that was referred to on page 62 in question 83 and thereafter, and was stricken. And there's no testimony -- and there certainly is nothing in the direct testimony about strain gauge testing at Shoreham.

JUDGE BRENNER: You mean, the testimony has been withdrawn?

MR. DYNNER: That's correct, sir. Sir, I move to strike his answer.

MR. FARLEY: That's an incorrect representation.

JUDGE BRENNER: I'm going to give you a chance to respond, Mr. Farley. Go ahead.

MR. FARLEY: All three things, the June report, the original testimony, and the supplemental testimony. And in the course of the discovery deposition that was permitted, Mr. Dynner knows that FaAA conducted strain gauge testing on the old 103 block.

JUDGE BRENNER: Do you want to point me to some place in the testimony?

MR. FARLEY: Sir?

JUDGE BRENNER: Can you point me to some place in the testimony where that's discussed?

MR. FARLEY: Yes, sir. In the supplemental testimony, there's the reference to metallurgical examinations and then there's a reference, on page 8, to the examination of LILCO inspection records.

WITNESS MC CARTHY: If it would help, question 76 specifically discusses our strain gauge testing on page 56, direct testimony, not the supplemental.

MR. DYNNER: The information on 56 does not have to do with the strain gauge, with any strain gauge strain -- strain gauge analysis of the cam gallery area. In fact, that begins testimony on page 61 at the bottom, sir.

JUDGE BRENNER: All right. Give us a moment.

(The Board conferring.)

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JUDGE BRENNER: We don't see any testimony on any strain gauge analyses performed by FaAA on the cam gallery and, if it is in there, we just don't understand the connection with the reference that Dr. McCarthy just gave us because it discusses other areas of the blocks.

WITNESS MC CARTHY: I didn't understand Mr. Dynner's question. Was it confined to --

JUDGE BRENNER: Dr. McCarthy, you were helpful before, but this is for your counsel now.

Well let me ask you, Dr. McCarthy: You are not claiming that that testimony relates to strain gauge testing -- not testing, but strain gauge measurements of the cam gallery, are you?

WITNESS MC CARTHY: You are correct, sir.

JUDGE BRENNER: We are going to grab the motion. In effect, we will ignore the reference to the strain gauge testing of the cam gallery. It happens, Mr. Dynner, that in the absence of any details it wasn't likely to weigh very heavily but you've got the ruling now, which more expressly gives our view.

MR. DYNNER: Just for clarification, sir --

JUDGE BRENNER: I am not striking the entire answer.

MR. DYNNER: I was going to ask for clarification in the sense that information in the answer, given the structure of the answer, was information that I think derived from the strain gauge testing.

JUDGE BRENNER: I am not going to parce it that fine.

He also answered your broad question as to why they withdrew the testimony and he agreed as to their stipulation as to where they withdrew it, which was presented in your question, and then he went on the explain, in effect, why they had no problem withdrawing it because they had all these other reasons to support the conclusion he gave. And some of those -- there are some supporting analyses and expert testimony on and presumably we will hear more about it at the oral hearing which is the purpose of our being here.

But we do agree with you on the limited point that, at the moment at least, we see no testimony on strain gauge tests by FaAA of cam gallery area presented in the testimony. And the only testimony on strain gauge tests in that area has been withdrawn by LILCO.

BY MR. DYNNER:

Q Now Dr. Wells --

JUDGE BRENNER: Wait. Let's get another question and then you can get another answer. And if something got left out in the shuffle, talk to your counsel --

WITNESS RAU: I think there has been --

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JUDGE BRENNER: Wait a minute. If something got left out in the shuffle, you can talk to your counsel and get back at it on redirect.

Mr. Dynner.

BY MR. DYNNER:

Q Dr. Wells, it's true, isn't it, that the fracture mechanics analysis that is referred to in your testimony on Question 83 and thereafter is wrong because it was based upon the incorrect DeLaval strain gauge data, isn't that true?

A (Witness Wells) I am confused, Mr. Dynner, obviously if a calculation is made with incorrect input data it could be considered wrong. However I don't think the calculations themselves that showed there would be no -- or negligible crack growth are incorrect. We still concur with that conclusion.

But as you know, if one puts a crack of any size into a compressive stress field in cast iron one will in fact predict that crack will not open and the crack will not propagate.

Q All right, Dr. Wells.

Your fracture mechanics analysis that is set forth in your testimony on page 62 and thereafter dependent upon on or relied upon -- Will you please, Mr. Rau, not consult with Dr. Wells when I am asking a question -- that

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that testimony referred to and depended upon -- for the conclusions of the fracture mechanics analysis -- the strain gauge data of DeLaval, that's true, isn't it?

A It is true that the calculation described, sir, in '83 was based on TDI gauge readings that were shown to be incorrect.

Q And therefore it is true, isn't it, that the conclusions of that fracture mechanics analysis set forth in your testimony are wrong, isn't that true?

A The conclusion --

Q Would you answer yes or no and then you can give your explanation?

MR. FARLEY: I object.

JUDGE BRENNER: Well let's see if we can get a yes or no, to the extent we can. If a witness says it is impossible to a question yes or no, we accept that.

But in good faith, let's see if we can get the try and then we will give you the opportunity, within reason of the bounds of still being within the question to give whatever explanation you think is necessary, Dr. Wells.

WITNESS WELLS: Thank you, Judge Brenner.

The numerical equations did in fact contain erroneous values. However, certainly the conclusions have not changed. I think I am troubled by a semantic problem as to what is wrong either with the conclusion or with the --

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or the actual data.

I would like Dr. Rau to assist me since he performed these calculations, if I may.

BY MR. DYNNER:

Q I am going to ask Dr. Rau this question.

It is true, Dr. Rau, isn't it that the fracture mechanics calculations which were done in the June 1984 FaAA block report are wrong, isn't it?

A (Witness Rau) No, that is not true, Mr. Dynner. As Dr. Wells was attempting to explain -- let me take another try at it -- the calculations for the conditions specified in the calculation are correct for the conditions of the strains reported by the TDI strain gauge results. Those calculations are precise and correct. It is in fact true that those input strains are not correct and therefore the precise numerical calculations therefore are not correct, but nevertheless the conclusions that there is no growth are correct.

Q Dr. Rau, I want to refresh your recollection and I want to read you part of your answer that was taken at your deposition on October 11, 1984 on page 83 where you said, and I quote:

"The conservative fracture mechanics calculations which were done originally in the preliminary June report, those are the same ones

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which we were referenced in the original testimony. We don't believe those are appropriate given what we have now discovered about the TDI strain gauge measurements. We have always thought they were conservative. We have now found out that they are incredibly conservative.

"Question: You found out they were wrong, didn't you?

"Dr. Rau: That is a true statement."

Do you remember giving that testimony, Dr. Rau, on October 11?

A Yes, sir.

Q You don't disagree with that testimony now today, do you?

A No, sir, that testimony is exactly what I just said, that the calculations done in the preliminary report reported at that time were conservative, they were based upon the strain gauge results performed by TDI, which indicated certain tensile stresses which we believed to be very conservative at the time and subsequently found out through out own calculations to be conservative. We have subsequently done additional calculations, as you know, based upon the stresses which we have calculated independently and verified in fact that the crack limitations, the cracks which are in fact present in the cam gallery are not and have not extended in operation.

Q Gentlemen, in addition to that change which I referenced in your errata filing on September 24, there were also changes made in certain of the exhibits and I am going to refer you right now to Exhibit B-16. These are the LILCO exhibits: B-16, B-17, B-18 and B-25. And as you can see those exhibits all consist of maps of the cracks on the top of the various Shoreham EDG's.

I would ask you for the moment to turn to Exhibit B-16, which is entitled "SNPS DG 101 Crack Map."

Can you tell me at what date that exhibit shows the cracks on the top of the block of DG 101? Anyone.

Let me clarify the question in order to speed things up, gentlemen.

It's true, isn't it, that based upon the data backup package which we received in discovery that the approximate date of that crack map is March 21, 1984, isn't that true?

Dr. Johnson?

A (Witness Johnson) That's the approximate date when the measurements -- or the inspections were done, yes.

Q The inspections that are reflected by this crack map, that's true, isn't it?

A Yes.

MR. FARLEY: I object, your Honor. I don't think the record is clear whether he is referring to the old one or to the new one.

JUDGE BRENNER: I assumed and hoped he was referring to the new one.

MR. DYNNER: Yes, I am. I have not yet referred to the previous exhibits.

BY MR. DYNNER:

Q It's true that the crack map that is your Exhibit B-16 is based upon the inspection data of approximately March 21, 1984, isn't that right, Dr. Johnson?

A (Witness Johnson) Yes, it is.

Q Thank you.

Now you look for a moment at Exhibit B-17. Now it's true, isn't it, Dr. Johnson, that the cracks that are shown on the crack map for EDG 102, which is Exhibit B-17, is based upon inspection records that were made on approximately February 10, 1984, isn't that right?

A No, that is not correct, it includes inspection results obtained in March of '84, late March of '84 after 100 starts also.

Q Also?

Well where is -- or is there a crack map which shows the cracks on the top of the block for EDG 102 on February 10, 1984 alone which is, as you can see by looking at Exhibit B-14, a time when a block inspection took place

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for EDG 102?

A I don't believe there is a crack map. The raw data exists for those inspections.

Q Well is it your testimony that the crack map which is Exhibit 17 -- Exhibit B-17, incorporates the results of the February 10 block inspection as well as the results of the March 26 block inspection?

A Yes.

Q Now by incorporating the cracks from both of those inspections in your current Exhibit B-17, which you did and what you accomplished was to disguise the fact that in reality there were ligament cracks that propagated between February 10 and March 26, isn't that right?

MR. FARLEY: I object to the form of the question.

JUDGE BRENNER: Overruled.

WITNESS JOHNSON: No, we did not attempt to disguise --

BY MR. DYNNER:

Q I didn't ask if you attempted to, I asked you did you, isn't that the result?

A (Witness Johnson) I don't believe so.

Q Well let's look for a minute, if you will, at the original Exhibit B-17 --

JUDGE BRENNER: Mr. Dynner, although I have my

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copies at the office and I kept them for just such a possibility I did not bring them here.

MR. DYNNER: We can either -- We can either take and break or I can tell you what the numbers are.

JUDGE BRENNER: I am telling you that for the latter purpose. And if it becomes a burden, then we will get copies.

MR. DYNNER: Sure.

Well the witnesses can take a look at it, anybody else who has it, and I will tell you that if you look at the crack map for EDG 102 at the area entitled "Cylinder Number 7," you will see two holes on the left-hand side at approximately eight o'clock and at approximately ten o'clock. And if one were to count the stud holes beginning with the one o'clock positions, they would be numbers six and seven. And you will see that number six is now shown to be 1.5 inches in depth and it originally was shown to be 1.1 inches in depth. And if you look at the --

JUDGE BRENNER: Wait a minute. Ask him if that's right.

BY MR. DYNNER:

Q That's true, isn't it?

A (Witness Johnson) You mean in the old crack map versus the new crack map?

Q Yes.

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A The old crack map is not characteristic of the inspection prior -- of 3/20 and the new one -- excuse me, of 2/11 and the new one of 3/26, they were both meant to characterize inspections, the total condition of that block at 3/26/84.

Q That wasn't my question, Dr. Johnson.

My question is: it's true, isn't it, that in the original Exhibit B-17 the crack, ligament crack at the stud hole at approximately the eight o'clock position is shown to be 1.1 inches, while in your revised exhibit it is shown to be 1.5 inches, isn't that true?

A Yes, it is true.

Q And it's true that the ligament crack at the stud hole in approximately the ten o'clock position in the original Exhibit B-17 was shown to be 0.5 inches and in the current exhibit it is shown to be 0.95 inches, isn't that right?

A Yes, it is.

Q Do you deny, Dr. Johnson, that the inspection records in fact shown that on February 10 the depth of the two cracks we are talking about were shown to be in fact 1.1 inches for the ligament crack in the eight o'clock position and 0.5 inches for the ligament crack in the ten o'clock position?

A Yes, I deny that. The reason these numbers

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changed is we included eddy current tests that were performed both at 2/11 -- in February of '84 and of March '84 and there was no change in the eddy current results. That is, in February '84 we got hole number two to be 1.5 inches, hole number six to be 1.5 inches and hole number seven to be 0.94 inches. Those inspections were repeated after the hundred starts and the hole number seven was 1.5 inches.

Now the second eddy current inspection was done in March after the hundred starts. We found it to be 1.5 inches, hole number one -- excuse me, hole number two. Hole number six was 1.5 inches and hole number seven was 0.97 inches.

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Excuse me, 0.96, I believe.

MR. DYNNER: Judge Brenner, I'm going to have distributed and ask that it be marked for identification, Suffolk County Diesel Exhibit -- can you help me, Judge Morris?

JUDGE BRENNER: This will be D-73, according to our notes. I hope that's correct.

MR. FARLEY: I understand from the previous ruling he can identify anything and when he gets around to try to introduce it, that's another question.

JUDGE BRENNER: Do you want to identify it a little better?

MR. DYNNER: It consists of two pages. At the top of the first page the title is, "LILCO Liquid Penetrant Examination Report." On the side it is identified as related to component -- the cylinder liner landing cylinder number 7 system R-43, and notation DG 102. At the bottom of the page there is a signature that is difficult to read over, "Responsible certified personnel." And the date is given as 2-10-84.

On the second page, there is a document which is entitled, "Quality Control Inspection Report." At the top it states, "Stone and Webster Engineering, Corporation." It is attached to the first page of the document which in the top righthand corner says, page 31 of 46. The second page

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page 32 of 46. The first page states, "See attached sketch, cylinder number 7, Eng. number 102." And the second page appears to be a sketch.

(Whereupon, the document hereby referred to was marked as Suffolk County Diesel Exhibit D-73, for identification.)

BY MR. DYNNER: Dr. Johnson, do you recognize this examination report?

A (Witness Johnson) It is one of the reports that we have reviewed in the process of drawing up the crack maps.

Q And in fact, it is a DR which was part of the DR-QR examination inspection procedure, isn't that true, if you look at the upper righthand corner?

A That's correct, sir.

Q Now, if you look for a moment at the sketch of cylinder number 7, you'll see identified there at the 10 o'clock stud hole it says, "Indication number 2." And down below, there is a schematic drawing. And under indication number 2 is the number .500. And that indicated that the depth of the ligament crack as shown in the schematic drawing for the indication at number 2 location was .500 inches, isn't that true, Dr. Johnson?

A That's correct, sir.

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Q Mr. Schuster, you are familiar with these documents also, sir?

A (Witness Schuster) Yes, I am.

Q Well, you can feel free to answer also, then.

A I'm sorry, I didn't mean to --

A (Witness Johnson) That's the PT indicated length, yes, for depth.

Q Thank you. And at the 8 o'clock stud hole where it -- states indication number 1. And if you look at indication number 1 in the schematic drawing below, it shows a depth of that ligament crack of 1.1 inches, doesn't it, Mr. Schuster?

A That's correct.

A (Witness Schuster) That's correct.

Q And those, in fact, are the numbers which the original Exhibit B-17 bears, isn't that right, for those two studholes?

A That's correct, sir. The point that I would like to make at this time is that DG-102 crack map reflects a very fair and accurate representation of the NDE data in the most conservative form and it reflects all the nondestructive examinations that were performed on that diesel generator cylinder block, not just a best case or a worst case, but the most conservative or the worst case.

Q Now, gentlemen, if you will turn for the moment to LILCO's Exhibit B21 --

A Could I also add, too, that this map does not reflect any timeframe within the inspection but is intended to provide an overview of what the inspections were on that block top.

Q You agree, Mr. Schuster, don't you, that the document is dated inside February 10, 1984; isn't that right?

A I'm referring to --

MR. FARLEY: Objection, your Honor, he's arguing with the witness. The witness has already told him there was more than one test that was dated and signed.

JUDGE BRENNER: Objection overruled. He's entitled to followup cross examination with reasonably argumentative-type questions within the bounds of good taste and decorum. It's litigation.

Let's get the answer now.

WITNESS SCHUSTER: I'm referring to the SNPS DG-102 crack map, which is Exhibit 17, both old and new -- not the old but the new corrected version of this.

WITNESS JOHNSON: What you're ignoring is the Eddy current data that was taken at the same period of time and that's what's included on the new crack map. The old crack map just had penetrant data on it. We now included additional data which is the Eddy current data. We included

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the most severe indication of the cracking that was present.

BY MR. DYNNER:

Q Dr. Johnson, approximately what date was the original Exhibit B-17 prepared, the one that appears on the testimony that was filed on August 14 by LILCO?

A (Witness Schuster) The cover sheet indicates that this document was presented August 14, 1984, I don't know when it was prepared.

Q Do any of you on the Panel know when that document, the crack map, the original Exhibit B-17 was prepared?

A (Witness Johnson) I understand it was in the original or the draft report that was prepared in June of '84.

Q Does anybody know what date this document was prepared? If you don't know, please say so.

(No response.)

Q Why don't you give them the relative timeframes you're interested in with reference to other events, because they may be under the impression that they need a precise date?

MR. DYNNER: I would like to get an approximate date, because I don't know exactly what the reference date is, so we'll find that out with my followup questions, sir.

JUDGE BRENNER: All right. It's your case. I don't mean to step in in the wrong way, but I thought what you wanted to ascertain was whether it was prepared after approximately February 9th, but before March 21st.

WITNESS RAU: Mr. Dynner, I think I can shed some light on the data preparation of the original 17 Exhibit.

In the preliminary FaAA report drafted in June, 1984, there was a figure number which is virtually identical to --

MR. DYNNER: It's figure 1-3, isn't it, Dr. Rau, in the FaAA June block report?

WITNESS RAU: Yes, it is. And the designations on that figure indicate that it was prepared in May of 1984.

MR. DYNNER: Thank you.

BY MR. DYNNER:

Q What you just referred to is a preliminary report. You were, in fact, referring to Suffolk County Exhibit 7, which is entitled "Design Review of TDI R-4 and RV-4 series, emergency diesel generator cylinder blocks and liners." And underneath it, it says, "This report is final pending confirmatory reviews required by FaAA's QA operating procedures," and it bears the date June 1984, is that correct?

A (Witness Rau) Yes, that's the draft report I'm

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talking about.

Q You're saying the report that says this report is final pending is a draft report, is that your testimony?

A Very definitely.

Q Now, Dr. Rau, let's continue with you for a minute.

This crack map which you say was prepared in May, was that based upon the inspection data that was done from the February 10 block inspection?

A Mr. Dynner, I'm not familiar with the specific dates or the specific inspection reports, except the conclusions therefrom as stated in the draft reports and the testimony. Dr. Johnson and Mr. Schuster are the ones who are familiar with the details.

Q Dr. Johnson?

A (Witness Johnson) The previous crack map did not include Eddy current results.

Q That wasn't the question.

A The Eddy current results were conducted also at that same time.

Q Your testimony is -- at what time were the Eddy current --

A The Eddy current --

Q Let me finish the question then you can answer. What data proximity were the Eddy current inspections that

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you're referring to carried out?

A Eddy current inspections were conducted on 3-8-84. This was after the 100 hour endurance run, specifically of cylinder 7, in order to monitor whether there was any crack growth between that point and after the 100 starts. Then a second Eddy current inspection was conducted, 3-28-84 of those same holes. And no growth was noted. And the results -- the change in the crack map that you've seen from the initial crack map to the crack map which we have submitted, simply includes the Eddy current test results for two reasons: we feel it's more accurate, they also represent the most severe representation of the cracking in the block.

Q Dr. Johnson, if you look at Exhibit B21, LILCO's Exhibit B21 that includes inspection data concerning the block of EDG 102, doesn't it?

A Yes, it does.

Q And there is nothing in that information, there is no Eddy current examination report for March 8, 1984. There is only a report for March 28, 1984; isn't that right?

A In that Exhibit, that's correct. But there is, of course, a report of 3-8-84 in the material that has been supplied to you.

In addition, the penetrant inspection that was done on the date of late March '84, after the 100 starts,

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only was of the top of the block. The liners were not removed. Therefore, you could not measure the depth of the indication down the liner landing, which was done with the PT in the previous inspection of early March -- or February -- of '84.

Q I put to you, Dr. Johnson, that there in fact is no Eddy current examination report for March 8, 1984, which shows a differing result than Suffolk County's Exhibit 73; isn't that right?

A There is such a report.

Q If there were such a report, why did you rely upon that report rather than the signed inspection report for liquid penetrant, which is dated February 10, 1984, and is Suffolk County Exhibit 73?

A The other report is also signed.

You have to understand that the penetrant test was done on the liner landing area. The Eddy current test was done under the bolt hole -- down the bolt hole. This crack -- for example, let's take the one which is on number 7, which is at 8 o'clock, for example -- is 1.1 inches on the liner landing area and in the bolt hole is 1.5 inches. So which dimension should I use? I used the larger dimension, 1.5 inches. That is all that's going on here. We have an exhibit where I can show you that very explicitly.

JUDGE BRENNER: Mr. Farley, are you going to give me three of those to keep forever?

MR. FARLEY: I think he just wants to use it for illustrative purposes.

JUDGE BRENNER: You're going to have to be very descriptive because what you're holding is not going to become part of the record, Dr. Johnson.

WITNESS JOHNSON: The ligament cracks run from the liner counterbore to the stud hold. So we have two opportunities to measure the depth of that crack. One is on the liner landing. The other is in the stud hole. The penetrant results, which have been referred to, were done on the liner landing and the Eddy current tests that were done were on the -- in the bolt hole and those numbers are slightly different because the crack does not have the same depth on the liner landing that it has in the bolt hole. So we recorded the deepest of those two numbers which were the numbers which you see in the newest -- our submitted crack map.

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BY MR. DYNNER:

Q Was the eddy current examination report that you are talking about carried out with a hand-held depth probe?

A (Witness Johnson) It was carried out with a hand-held probe, yes.

Q And it's true, isn't it, that was the same technique that you used in measuring the stud-to-stud crack between numbers 4 and 5 cylinders in EDG 103 which you found that the hand-held probe showed the depth to be 5.5 inches but you revised your testimony now to say that once you cut that crack apart you found it was only three inches, isn't that right?

A There are differences in the --

Q Can you answer yes or no and then you can explain?

A No, I can't answer yes or no.

The measurement of the full extent of that crack involved a different probe than the probe used to measure the depth of the cracks in the 102 block, because it is down in the threads and we used a different probe for determining the depth of crack as it traveled into the threads than we used on the smooth counterbore which was the full extent of this crack.

Furthermore the test procedure was set up on normal cast iron material. The material in the old DG 103

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was a degenerate graphite material. That material is significantly noisier than normal cast iron and that led to an overestimation of the crack depth on the old DG 103 material. It accurately detected the cracks and would accurately size cracks in normal cast iron material.

Q Dr. Rau and Dr. Wachob, it's true, isn't it, that in your deposition on October 11, 1984 you testified that the crack map -- all three of these crack maps, that is, particularly for 101 and 102, that the figures for depth given on those cracks were all done by liquid penetrant examination, isn't that true?

A (Witness Rau) I don't recall precisely that testimony. I may have said that. I am not intimately familiar with the details of all of the inspections and whether I said it or not, Dr. Johnson is the one who is intimately familiar with all of the inspections that were done and can testify which were done and when they were done.

Q Do you remember that, Dr. Wachob, do you remember your testimony?

A (Witness Wachob) I remember the statement that you made, but again I defer to Dr. Johnson in that he had been involved with those tests and at that time we had not been involved with the tests.

Q Who was involved with preparing and approving

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the crack map that went into the June block report and into your August 14 testimony?

A (Witness Rau) Well the revised crack map was in fact prepared by Dr. Johnson.

Q I didn't ask that.

A I thought you did.

Q I said the one that went into the June report and into your August 14 testimony, who was responsible for preparing that? Were you?

A No, I did not personally prepare that.

Q Did you approve it?

A None of the things in that report were approved, that was a draft report.

Q Did you review it?

A Well what do you mean by "review?"

I looked at it but I had no basis -- I did not examine in detail the individual inspection reports from which it was prepared and therefore, if that's what you mean by review, I didn't do that; Dr. Johnson did that and that formed the basis for his preparation of the final exhibit which was submitted.

Q Well Dr. Wells, you have testified that you had responsibility for review and approval of the results of technical matters, conclusions and reports.

A (Witness Wells) That's correct, Mr. Dynner.

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Q Did you have a responsibility and review and approve the crack map for EDG 102 that went into the June block report in the original testimony?

A I reviewed the information that was available at that time, but we did not approve this report because it had not been subject to our quality assurance program.

Q Did you find out who in FaAA was responsible for preparation of that crack map?

A The crack map is the responsibility of Dr. McCarthy, of mine and Dr. Johnson, in that order.

The current version of the crack map has been approved and is the correct one, has been reviewed under our quality assurance program. The previous one had not. In review of that crack map, we found there was additional information that had to be incorporated, so that the current version of the crack map would represent as correctly as possible the true situation of ligament cracking in the 102 block top.

Q Now I just want to be sure I understood your testimony, Dr. Johnson.

Is it your testimony that the original crack map was prepared utilizing all of the inspection reports that had been available up until the May date when that document was prepared in 1984?

A (Witness Johnson) No, that is not my testimony.

Q All right. Then why don't you tell me, clarify the record what inspection reports were and were not included in the crack map for EDG 102 that was originally submitted?

A The material that was available at that date included the liquid pentrant report that you have referred to and the eddy current test report that I have referred to. Apparently the eddy current test report was not -- the results of the eddy current test report were not included on the map, the original map, and I felt it would be more appropriate to include it.

Now you can use the data from the penetrant results alone and you will not find a later penetrant report which indicates anything has grown in that area.

We specifically did the penetrant -- excuse me, we specifically did the eddy current tests in cylinder number seven to monitor whether there was any crack growth between the -- after the hundred hour endurance test... Excuse me, between the hundred hour endurance test and the hundred start test. And we did one inspection before that test and one after and the results of the eddy current tests are reported in Exhibit 21.

Q Now it's true, isn't it, Dr. Johnson, that in Exhibit B-21, which purports to set forth information concerning the block top inspections of EDG 102, there is no liquid penetrant examination for the stud holes on cylinder number seven that we have been talking about, isn't that right?

A (Witness Schuster) We didn't perform liquid penetrant exams in the stud holes.

Q I'm not talking about stud holes. I am saying there is no liquid penetrant examination report for the two stud holes on cylinder number seven, isn't that right?

A (Witness Johnson) Would you repeat your question, please?

Q For the third time. In Exhibit 21 the information does not contain any liquid penetrant examination report for the stud holes that we have been talking about on cylinder number seven of EDG 102, isn't that right?

A (Witness Schuster) Sir, if you are referring to Q410 it in fact does. Q410, which identifies our quality report, does provide a penetrant report on cylinder number seven.

Q All right.

Would you please show me where that is and what the depth is?

A It does not provide that because we had indicated that the liner was installed at the time that that inspection was taken. That's the reason why I said that we

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did not perform a penetrant examination of the area in the stud hole. The eddy current inspection in fact did perform that function to record that depth.

Q Now let me see whether I understand what you said.

In fact you testified, Dr. Johnson, previously that the eddy current measured the depth of the ligament crack inside the stud hole, is that right?

A (Witness Johnson) Yes.

Q And you testified that the liquid penetrant examination report, which is Suffolk County's Exhibit 73, measured the depth of the crack in the counterbore on the cylinder, isn't that right?

A Yes, it is.

Q All right.

Now it is true, isn't it, that there was no measurement in your Exhibit B-21 of a liquid penetrant examination of the depth of the ligament cracks in the two stud holes we have been talking about in cylinder number seven running along the counterbore of the cylinder from which you could then compare that depth with Exhibit 73; that's true, isn't it?

A There was no penetrant inspection in the liner landing counterbore area which you could compare to the earlier tests in February, because the liner was in place.

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Q If in fact there is an eddy current examination report of March 8, 1984 which shows the measurement inside the stud hole of the depth of those two cracks that we have been talking about on cylinder number seven, I would like to request that you produce a copy of that inspection report and I represent I haven't seen a copy of it.

MR. FARLEY: I object, your Honor. He had the opportunity during regular discovery and I do not believe we ought to conduct discovery during the evidentiary hearing.

JUDGE BRENNER: Well I will leave it up to you initially -- and I say initially because if it comes back to us for a ruling we will rule. But Dr. Johnson answered a question about an hour ago saying And it has been provided to you, Mr. Dynner, and Mr. Dynner represents that if it has been provided to him he doesn't recall it and even after being refreshed that Dr. Johnson at least thinks he has it, he still doesn't recall it. So I will leave it up to you. And if you want to put a factor s then there is a particular discrete document that LILCO believe will do that, I would like to get it done.

While there has been an interruption I have a slight problem with being reassured that the reassembled exhibit pack of LILCO exhibits provided to me in fact has all of the corrected exhibits.

And the reason for my lack of assurance now is that I have been looking at my redone packet of exhibits, I have been looking at B-14, and I was trying to see a number on what I thought was the updated B-14, which indicated -- it's the left column, which would match up with the line of numbers under L-75 of 90, so it is the third column of numbers. And it is testing from some date that I cannot fully read through 3/16/84. And now, after checking the errata, it seems thare had been a replacement Exhibit B-14 that changes the designations so that it only lists qualification testing without the -- and the block inspection of 3/8/84 without the range of dates.

So I have two questions, one to you, Mr. Farley: which is the updated exhibit?

And the second one is: if I still have the old one, how many other old ones do I still have and does the official version have the right one?

And while you are thinking about that, the factual point that I wanted to figure out was whether the range of testing -- and I guess I will ask the witnesses -- which ended on 3/16/84, whether that starts on 2/9 or 3/9/84. It is the month that I cannot read.

WITNESS YOUNGLING: It starts on 3/9/84.

JUDGE BRENNER: All right.

So there is no operations between 2/10 and 3/8 of EDG 102?

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WITNESS YOUNGLING: Between 2/10 and 3/8 we were completing the DRQR inspections on other parts of the engine, re-assembling the enging and putting it back in service. It went back in service on 3/9 and operated between 3/9 and 3/16 for the hundred starts.

JUDGE BRENNER: So my question was so there was no operation of the engine between 2/10 and 3/9/84?

WITNESS YOUNGLING: That's a true statement.

JUDGE BRENNER: We can straighten out the exhibits later. I don't know if I have the new one or the old one.

MR. FARLEY: I would have to look at your book, Judge. It is my understanding that you have the new one.

JUDGE BRENNER: I guess I don't fully understand why the change was made either because the numbers seem to have stayed the same but the description has changed.

MR. FARLEY: The numbers do stay the same, it was a question of providing more information on the categories of the runs.

JUDGE BRENNER: Maybe somebody on the panel knows.

WITNESS YOUNGLING: Yes, Judge Brenner, maybe I can help you.

The previous version of the exhibit I felt was confusing in that it didn't make a clear distinction that there were two separate inspections with a qualification run in-between or a hundred start test in-between. So I chose to change the exhibit and show the two distinct inspections.

JUDGE BRENNER: Okay. So it is the new one that does not have the range that I earlier could not read of the 2/9 beginning date.

WITNESS YOUNGLING: Yes.

JUDGE BRENNER: I've got the old one, Mr. Farley, and I hope the official file with the Reporter is the new one. I did not match up, I relied on you. I will check them now.

MR. FARLEY: I will double-check them.

JUDGE BRENNER: We could break or you could continue your questions.

MR. DYNNER: I just have one or two more questions, sir.

BY MR. DYNNER:

Q Dr. Johnson, can you explain to me why, sticking for a moment with the Exhibit B-14, can you explain to me why the original Exhibit B-14 showed that this data was for the block inspection of March 8, 1984 and the revised shows the date as March 26, 1984? Why was that change made?

A (Witness Johnson) I can't answer the question. I think maybe someone else on the panel could.

A (Witness Youngling) Yes, Mr. Dynner. As I said, there was some confusion in the original exhibit. The original exhibit did not make a clear distinction in the dates that the two block inspection outages were performed. I corrected that by showing that there was a block inspection outage as part of the DRQR program that ran in the time frame of 2/10. Between then and 3/9, the engine remained out of service on 3/9, the engine was put in service, ran through the hundred starts until 3/16, accumulating approximately 110 hours as shown on corrected Exhibit Number 14.

On or about the 26th of March in '84, the engine was taken -- the engine had been taken out of service and a post-hundred-start-test block inspection was performed.

Q So is it your testimony that in fact there was no block inspection on March 8th as shown in the original Exhibit B-14?

Is that your testimony, Mr. Youngling, that that was wrong?

Would you answer the question, if you know?

A No, I am going to have to defer to Mr. Schuster for the exact date that that data was taken.

A (Witness Schuster) Ultrasonic examinations of the areas in discussion were performed 2/10 and 2/12 of 1984.

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Q My question still hasn't been answered.

Isn't it true that there was no block inspection on March 8th, and that there was a mistake in this exhibit?

A Eddy current inspections were done on 3/8/84 for DG-102.

A (Witness Youngling) Mr. Dynner, to the best of my knowledge there were no block inspections done on 3/8. There couldn't have been because the engine was returned to service on 3/9 and we couldn't have reassembled the engine in that quick a timeframe, although I wish we could do it that fast, but we couldn't.

JUDGE BRENNER: Somebody is going to have to come up and point and show me which is the new table because that't why I was confused as to the running hours, as to whether there were any hours run between 2/10 and 3/8.

Mr. Youngling, why don't you do it for me since it is your table? I'm sorry to make you get up.

I now have the LILCO errata and the table attached to that seems to be the old table, based on something Mr. Youngling just said.

Is this what you meant to be your new table, or this one?

Let me state for the record what apparently occurred now that Mr. Youngling was kind enough to point to what he intended his replacement B-14 to be.

WRBeb

In the copy that was put together by LILCO for me in fact the new one is in there, so that makes me feel a little better about the official version, although I would still like a check.

However, in the original errata supplied to us on or about September 24th by LILCO, the attached B-14 to that one in fact was the same old one. Perhaps I should not have resurrected the September 10th document but I did it to check.

All right. So just to straighten the record out finally, Mr. Youngling, any inference I may have drawn from the old B-14 that EDG 102 was run between 2/10/84 and 3/8/84 is an incorrect inference?

WITNESS YOUNGLING: Yes, it is, Judge.

JUDGE BRENNER: All right.

WITNESS YOUNGLING: Judge Brenner, Mr. Seaman just wants to clarify something or add something.

JUDGE BRENNER: All right.

WITNESS SEAMAN: What I wanted to add was the fact that on 3/8, although we didn't perform a block top inspection by taking some of the heads off, we did perform an inpection in the cylinder head's stud hole and the stud hole in the block top, so that was performed on 3/8.

JUDGE BRENNER: That was the eddy current inspection that Dr. Johnson talked out?

WRBeb

WITNESS SEAMAN: Yes, that's correct, Judge Brenner.

JUDGE BRENNER: I had the feeling you could have had a follow up from Mr. Dynner on that very point.

WITNESS JOHNSON: And the DRQR documentation is referenced at Q-460, I believe.

JUDGE BRENNER: I'm sorry, Dr. Johnson. I don't know what you mean. Maybe Mr. Dynner does, but why don't you tell me?

WITNESS JOHNSON: The DRQR report documentation number which documents the eddy current inspection performed on 3/8/84 is Reference Document Q-460 I believe.

JUDGE BRENNER: Q-460?

WITNESS JOHNSON: Yes, sir.

JUDGE BRENNER: Thank you.

MR. DYNNER: If you want to break now, this would be a good time.

JUDGE BRENNER: All right, let's take a break until 1:40.

(Whereupon, at 12:40 p.m., the hearing in the above-entitled matter was recessed to reconvene at 1:40 p.m. the same day.)

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AFTERNOON SESSION

(1:40 p.m.)

JUDGE BRENNER: Good afternoon. We're back on the record.

Whereupon,

ROGER LEE MC CARTHY,

HARRY FRANK WACHOB,

CHARLES A. RAU,

CLIFFORD H. WELLS,

EDWARD J. YOUNGLING,

CRAIG K. SEAMAN,

DUANE P. JOHNSON,

and

MILFORD H. SCHUSTER

resumed the stand and, having been previously duly sworn, were examined and testified further as follows:

JUDGE BRENNER: Mr. Dynner.

MR. DYNNER: Thank you, your Honor.

CROSS-EXAMINATION (Continued)

BY MR. DYNNER:

Q Gentlemen, if you will continue for a moment with me looking at Exhibit B-17, both in its original form and in its revised form.

The following changes were made by you in revising that exhibit in addition to the changes that we

WRBeb

discussed this morning on the two stud holes on cylinder Number 7 in the eight o'clock and ten o'clock positions, and they are as follows, and I would like you to confirm that this is correct, Dr. Johnson.

One cylinder Number 7, the stud hole in the two o'clock position, the depth of that ligament crack was changed from 1.3 inches to 1.5 inches.

The stud hole in the eight o'clock position on cylinder Number 5 was changed in depth from 1.5 inches to 1.1 inches.

And the stud hole in the two o'clock position was changed from 1.5 inches to 0.9 inches.

A new ligament crack was identified and noted in the ten o'clock position on cylinder Number 3, which now has an asterisk and notes 0.25 inch length recorded.

And a new ligament crack is identified on the stud hole in the ten o'clock position on cylinder Number 1 with an asterisk that indicates that there is a top surface indication with the length of 0.12 inches.

Are those changes that I have noted in fact the changes that were made?

MR. FARLEY: Judge, I would just like the record to be clear that there are no stud cracks on 102, and the reference to stud hole may be misleading in the record. We are talking about ligament cracks.

WRBeb

JUDGE BRENNER: Well, I wasn't confused.

All right.

WITNESS JOHNSON: Yes, those were the changes that were made in the crack map.

BY MR. DYNNER:

Q Why were those changes made?

A (Witness Johnson) To make the crack map an accurate reflection of our best knowledge of the cracks on DG-102.

Q Is it your testimony then that the original crack map for DG-102 as it appears in the June block report and as filed with the testimony of LILCO's witness panel on August 14th was incorrect?

A There was additional data which was not included on the original crack map.

Q Was it incorrect?

A (Witness Schuster) There were transcribing errors in that earlier crack map.

Q Is your answer that yes, it was incorrect?

A (Witness Johnson) There were some errors in transcribing.

Q Is your answer yes, it was incorrect? Can you give me a Yes or No answer? It's not hard.

A Yes.

Q Thank you.

WRBeb

Why did it take you until after your original testimony was filed on August 14th and until September 24th when you filed the errata sheet to find out that this crack map was incorrect and to take action to correct it, Dr. Johnson?

A It was at that time that I, myself, and Mil Schuster did a detailed review of the crack maps.

Q At what time?

A I don't know the exact date but it was prior to -- shortly before we submitted the corrections.

Q Would you turn for a minute to Exhibit B-18? And that is the crack map for EDG Number 103, isn't it, Dr. Johnson?

A Would you repeat the question, please?

Q Yes.

Exhibit B-18 is the crack map for the top of EDG-103, isn't it?

A This is a crack map of DJ-103.

Q And it is true, isn't it, that the cracks which this map purports to show are from inspection reports that were generated on approximately March 11th, 1984? Isn't that right?

A Approximately March 11th, yes.

Q And I am going to do the same thing now, and that's quickly put into the record and ask for you to

WRBeb

confirm the changes that were made in this crack map between the original submission of Exhibit B-18 with the August 14th testimony and the changes that were made on September 24th, Dr. Johnson.

In the stud hole in the eight o'clock position on cylinder Number 7, there is shown a new indication running from the stud hole to the left toward the adjacent stud hole of cylinder Number 8. There is an asterisk next to it which shows a length top surface indication of 0.3 inches, and that indication was not shown in t e original crack map.

The stud-to-stud crack between cylinders Number 5 and 4 in the upper position toward the exhaust side of the block was originally shown to have a depth of 1.5 inches and the change shows the depth of 1.6 inches.

The stud-to-stud crack-- Strike that.

The stud hole ligament crack in the four o'clock position on cylinder Number 1 was originally shown to have a depth of 1.5 inches. The revision shows a depth of 1.3 inches, and a new indication in the revised version of the crack map is shown on that same stud hole as a top surface indication running from that stud hole to the outside portion of the cylinder block. And that was not shown in the original crack map.

Are those indeed the changes which were made, Dr. Johnson?

A I don't think I quite understood your last change that you reported.

Was that in cylinder Number 1?

Q Cylinder Number 1, yes, sir.

A The figure says cylinder Number 4. That's the problem -- or 3. Excuse me.

Q I didn't say anything about cylinder Number 3. Cylinder Number 1 was the subject of my last comments, and the change I was referring to last was the top surface indication shown in the stud -- on the stud hole in the four o'clock position of cylinder Number 1. And it shows 0 with an asterisk next to it, and that in fact was not shown on the original crack map.

Are those changes that I have just recited in fact the changes which were made on this crack map?

A Those changes were made, yes.

Q And why were those changes made?

A Upon review of the data we felt that this was the best representation of the data that we had on the cracks found in DJ-103 before the load excursion.

Q When you say "before the load excursion," what are you referring to?

A I'm referring to the data we took after the 100-hour endurance run.

Q All right.

WRBeb

So this in fact would be corrected information as of the status of the block top on approximately March 11th, 1984. Is that right?

A Approximately, yes.

Q The crack map that was originally filed with the block report and with your testimony on August 14th was incorrect in these respects, wasn't it?

A Yes.

Q And what is the reason why you didn't do a review of this data before you filed your testimony on August 14th, Dr. Johnson?

A We reviewed our testimony after that date. I was reviewing that after that date, and I also wanted to get together with Mil Schuster to review this data.

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A (Witness Schuster) If I could add at this time earlier on in May, June, July of 1984 I was in the hospital, I had a foot operation and was not available to the personnel at the site to review some of the information that has been presented. I did review it but it was cursory. I did not have the data available to do an in-depth review of these representations of the non-destructive examination data.

When I was available to do this with Mr. Johnson what took place was we had some discussions about some non-destructive examination data and realized when we looked at this representation, which is the original one, there was some data that was not reflected in that information. There were some transcribing errors also in that data.

And at that time Mr. Johnson and myself spent some nine to twelve hours reviewing all of the data and I brought this to Mr. Farley's attention that we didn't feel that all of the data was in these representations. We spent about 12 hours going through all of the data and updating this so that this representation is the most conservative and is a fair and accurate and honest representation of what that non-destructive examination data is.

Q Dr. Johnson, when you conducted this review, did you rely upon what Mr. Schuster told you or did you rely upon the written inspection report?

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A (Witness Johnson) I relied on the written inspection reports.

Q Let's take a look at --

A (Witness Schuster) I would like to also add again that we spent nine to twelve hours, Mr. Johnson and myself, reviewing the non-destructive examination records, so that this representation that we have now would be as accurate as humanly possible.

Q Now let's take a look at Exhibit B-16 for a moment. And you have already testified that this crack map for EDG 101 shows the crack situation approximately as of March 21, 1984 and I am going to Dr. Johnson again to put into the record the changes which were made between the original crack map and the revised version.

In cylinder number seven, the ligament crack in the stud hole in the ten o'clock position now bears an asterisk to indicate that that 0.2 inch measurement is the length of a top surface indication rather than the depth of that crack.

In cylinder number four the depth of the ligament crack in the stud hole in the ten o'clock position has been revised from 1.1 inches to 1.5 inches.

In the same cylinder number for the crack in the stud hole in the eight o'clock position has been revised from 1.5 inches in depth to 1.1 inch in depth.

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And in cylinder number one in the stud holes in both the two o'clock and four o'clock positions there are now indications shown of ligament cracks with a top surface indication, length, of 0.15 inches in the two o'clock stud hole position and of 0.25 inches in the four o'clock stud hole.

Can you confirm to me that those are in fact the changes that were made, Dr. Johnson?

A (Witness Johnson) Yes, those were the changes made.

Q And were those changes made for the same reasons and at the same time as you testified with respect to the changes in the crack map for the EDG 103, which is Exhibit B-18?

A They were made at the same general time, yes, within a day or two.

Q And for the same reasons? That is, that the original crack maps were incorrect. Is that correct?

A The crack maps were incorrect, yes.

A (Witness Youngling) I think I would like to add something to that, Mr. Dynner. FaAA has said that the original maps were part of their draft report which had not been QA'd. I think Mr. Johnson's action is a part of that QA process, perhaps he can comment on that.

Q Well I am sorry to inform you, Mr. Youngling, but

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you are not asking the questions here, and I say that with respect. But I will ask the questions and Dr. Johnson has an opportunity, as he has had, to respond.

MR. FARLEY: I would like the record to show that the 103 is the original 103 block.

MR. DYNNER: I said that, of course.

JUDGE BRENNER: Well Mr. Youngling's interjection, for reasons other than what he intended, reminded me of one minor point I wanted to cover.

Is it correct -- and I guess I will ask Dr. Johnson -- that the original and since withdrawn Exhibit B-16 through 18 are identical to Figures 1-2, 1-3 and 1-4 respectively in the June 1984 FaAA block report?

WITNESS JOHNSON: I don't know they are identical. I believe they are very similar.

What I was reviewing is specifically crack maps that had been submitted.

JUDGE BRENNER: Does anyone else on the panel know? Don't do a comparison, I can do that.

None of these witnesses know the source of the original Exhibits B-16 through B-18?

WITNESS YOUNGLING: To the best of my knowledge, Judge, they were supposed to have come out of the block report. They should be identical.

JUDGE BRENNER: Okay.

BY MR. DYNNER:

Q I will now ask you to turn for a moment to Exhibit B-25 and I am going to ask you to look at both the revised version of Exhibit B-25 and the original version as it appeared as filed with your August 14 testimony.

Now the original Exhibit for B-25 is the crack map for EDG 103 as of April 23, 1984, isn't that right, Dr. Johnson?

A (Witness Johnson) Did you say the original?

Q Yes.

A The original crack map was of 4/23/84.

Q And that is the one that was filed with your testimony on August 14, right?

A Yes.

Q The revised version of Exhibit B-25 says that it is the crack map for EDG 103 as of September 22, 1984. I would like to know whether EDG 103 was run, was operated with this original engine block at any time between April 23 and September 22, 1984.

A No.

Q And in fact the crack map that we are looking at, Exhibit B-25, shows the original engine block for EDG 103 after it had failed and was taken out of service, isn't that true, Dr. Johnson?

Mr. Seaman, why don't you let Dr. Johnson answer

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the question I directed to him.

A The inspection was done after the overload -- the load excursion, yes.

Q My question was that that was the block as it appeared after it had failed and was taken out of service, isn't that true?

A I'm not aware that the block failed.

Q Dr. McCarthy, do you think the block failed and was taken out of service by April 23, 1984?

A (Witness McCarthy) I was not present when it was taken out of service but the answer would be no, the engine was capable of producing power. It was running and it was performing its intended service. When a block fails, you know it.

Q Dr. McCarthy, you are responsible, aren't you, for the quality assurance review and the quality in fact of the product that is put out by FaAA, aren't you?

A Yes, sir.

Q And are you now satisfied with the quality of the testimony and exhibits that have been put forward into evidence in this case when you did so this morning?

A I am pleased that none of the conclusions nor any decisionmaking use which our original report would have been put to would have been changed by any of the corrections that have been -- that have come about as a result of our

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own internal quality control system.

Q That wasn't my question. My question is real easy and you can give me a yes or no answer.

Are you satisfied with the quality of the testimony and exhibits which were put into evidence this morning and which you are sponsoring as president of FaAA?

A Well that can't be answered simply yes or no. I am not happy, obviously, that transcription and other errors occurred in the details of the various parts that were provided with our testimony.

As a result of increasing and more detailed analyses, our conclusions have only become more confirmed with time. I draw a great deal of satisfaction from that.

Q Let me clarify the question:

Are you satisfied with the quality and reliability of the revised versions that have been put into evidence this morning?

A Oh I'm sorry, you mean -- well currently the versions in evidence are as good as we can make them. And yes.

Q Okay.

Now take a look, if you will, at the revised version of Exhibit E-15. You-all had a chance to do your quality assurance and other reviews and that exhibit indicates that the load history of EDG 103 -- and it states

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outright -- that on April 14, 1984 there was a block failure, doesn't it, Dr. McCarthy?

A (Witness McCarthy) It says block failure and a date and there was material failure in the block, that is true.

Q Now let's go back to Exhibit B-25 for a minute. I want to focus your attention for a moment on a single crack whose depth was changed in the revised crack map.

And that is the crack running from stud hole to stud hole between cylinders number five and number four, specifically from the stud hole in the four o'clock position of cylinder number five to the eight o'clock position of cylinder number four. That stud to stud crack now shows a depth in the revised crack map of 0.85 inches and in the original crack map submitted with your August 14 testimony, Dr. Johnson, the depth shown was 3.9 inches, isn't that true?

A (Witness Johnson) That reflects the results of non-destructive -- excuse me, of destructive tests to evaluate the depth of those --

Q My question is isn't that true?

A Yes, it is true.

Q Thank you.

A (Witness Youngling) I would like to add something to --

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Q I would like to let Dr. Johnson finish because I didn't want anybody to think I cut him off.

If you would like to explain why you think it's true, go ahead, Dr. Johnson. I didn't want to cut you off. I wanted to make clear that I would like you as I indicated earlier to where possible follow the procedure of answering my question yes or no and then if you want to give an explanation please feel free to do so.

A (Witness Johnson) The changes in the crack map that we are talking about in this -- in the four, five area include the results of later destructive tests that were done on the cracks in this area. And the destructive tests indicated that the depths of the cracks are as indicated on the changes in the crack map.

The reason for those changes are that those numbers are based on eddy current tests. The original numbers were based on eddy current tests down the stud holes.

The eddy current test was set up to operate on normal cast iron material. The material in DG 103 is not a normal cast iron material, it is a degenerate graphite structure. This degenerate graphic structure produces a much noisier background than is characteristic of normal cast iron material. And in tracing the crack signal with the eddy current signal, the inspector traced eddy current

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signals which exceeded the acceptance criteria down to this depth.

Q Dr. Johnson --

JUDGE BRENNER: Wait, Mr. Dynner.

MR. DYNNER: I thought he was finished.

JUDGE BRENNER: But I want to give Mr. Youngling an opportunity if he had something else to add on your question as to the change between the original Exhibit B-25 and the present one. Maybe Dr. Johnson covered it, but we cut Mr. Youngling off before.

WITNESS YOUNGLING: No, Judge, I have nothing to add.

BY MR. DYNNER:

Q Dr. Johnson, LILCO's witness panel, of which you are a member, filed supplemental testimony on September 20, 1984 and on page 10 of that testimony Dr. Rau and Dr. Wachob and Mr. Taylor testified that as a result of the destructive examination of the original EDG 103 block there was a single stud to stud crack, namely the one that runs between the stud hole in the two o'clock position on cylinder number five to the ten o'clock position on cylinder number four and was originally shown to be 5.5 inches in depth and is in the revised map shown to be three inches in depth, and that's the only crack that your supplemental testimony addresses as having been changed because of the destructive testing.

Why didn't you include in the supplemental testimony the changes which occurred that you are now testifying occurred and were found as a result of the destructive testing, besides that one crack that you referred to in your supplemental testimony?

A (Witness Johnson) It wasn't clear --

Q Excuse me, I want to interrupt for a moment. Because before you answer that question I think that you should be aware of the fact, and that the Board and parties should be aware of the fact, that counsel for LILCO at my request sent a letter to me, dated September 28th, 1984, in response to my questions about the reasons for the changes in the crack maps as exhibits. And counsel stated in that letter that,

> "Replacement exhibits B-16 through B-18 and B-25 are revised crack maps. These exhibits correct depths reported on the initial crack maps after the maps were rechecked against inspection reports."

I want you to be aware of that before you answer the question.

Now, please go ahead and answer. --without the conference with Mr. Seaman, if you can.

A Well, of course, my name is not one supplementary Question No. 16, so you could address that to Mr. Wachob --

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Dr. Wachob, or one of the others.

Q Well, I'm addressing it to you, because I want to know whether or not you are now testifying that this one crack depth was changed from 3.9 inches to .85 inches because of destructive testing. I'm interested in whether you communicated that to your colleagues at FaAA, Drs. Rau and Wachob, and Mr. Taylor, who, in fact, sponsored the supplemental testimony, and whether you told your counsel about these changes.

A Certainly, Drs. Rau, Wachob and Mr. Taylor were aware of these changes; in fact, Dr. Wachob is the man who did the destructive test, so he certainly was aware. --or was responsible for the test.

Q Dr. Wachob, do you agree that besides the single crack and you referred to as having its measurement changed, as indicated on page 10 of your supplemental testimony, that there were in fact other cracks whose measurements were found to be different once you sectioned the original 103 block?

A (Witness Wachob) Only one section of the 4/5 cylinder block was sectioned, and that was the one that verifies that the 3-inch depth occurred between the stud-to-stud crack and not the 5.5-inch crack.

Q So you did not find that the crack I'm referring to that was originally shown to be 3.9 inches deep, was, as

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a result of sectioning, only 0.85 inches deep, did you?

A That analysis came from an inspection of the intake side of the piece between cylinders 4 and 5, and was done prior to the corrections on the supplemental maps.

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Q Well, who found it?

A Sorry?

Q I said, who found it?

A The nondestructive inspectors in Dr. Johnson's group provided an inspection of that piece using eddy current techniques to verify the depths between the 4/5 cylinder piece on the intake side.

A (Witness Rau) Mr. Dynner, let me add to that.

Dr. Wachob discovered and measured the largest of the cracks. That is the one they measured to be three inches deep between cylinders 4 and 5. That was measured destructively and confirmed to be shorter than the prior nondestructive inspection that eddy current had shown.

When the eddy current was set up and calibrated by conventional gray cast iron material, having discovered the fact that the original 103 block was not conventional gray cast iron but, rather, this degenerate Widmanstaetten graphite which produces very noisy signals and, in fact, makes distinguishing between the background noise and the crack signal very difficult. Dr. Johnson's people recalibrated -- readjusted the eddy currents to take into account the fact that we were dealing with an entirely different kind of material with entirely different kinds of background noise.

And that inspection was checked -- if you like, confirmed -- on the large crack for which we knew the depth

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now being three inches, and was subsequently used to reconfirm the smaller crack you've been asking questions about on the opposite side -- excuse me, the intake side -- between cylinders 4 and 5.

Perhaps Dr. Johnson would like to talk further about the precise way in which it was done.

Q I want to make sure I understand.

You say there were new eddy current inspections that were carried out in addition to those and that revised those that were originally carried out in April?

A (Witness Johnson) In the section of the block which was returned to the laboratory, yes, there was additional laboratory evaluation of the indications in 4 and 5. And Dr. Rau and Dr. Wachob are correct that that particular measurement, which is the change from 3.9 to 0.85 was due to laboratory evaluation of the indication with eddy current in the stud hole.

Q When was that done, those additional eddy current inspections or examinations?

A I would have to check the records but I think September of '84.

Just a moment, we'll get a better date on that.

(Pause.)

9-19 and 9-20 of '84.

A (Witness Wachob) Mr. Dynner, if you go through

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the request documents that you had requested of us you will find a copy of that in one of those requests.

Q Thank you.

Now you have testified, gentlemen, that until you sectioned the original 103 block that you didn't know that there were circumferential cracks which were present in EDG 103 or in any of the other Shoreham blocks?

Is it true that there were no inspection reports that indicated circumferential cracks in the Shoreham cylinder blocks prior to August of '84 when you sectioned the 103 block?

A (Witness Johnson) There were no reported circumferential cracks in DG 101, 102, or the old 103 prior to discovering it with the metallurgical sectioning.

Mr. Seaman would like to make an addition.

And Mil Schuster has something to add.

A (Witness Schuster) We went back to the original DG 103 block after it was identified through metallographic sectioning, that there were circumferential indications in the liner ledge and performed nondestructive examination on that liner ledge and were able to confirm that those indications were there. We did this on all the cylinders in the areas that were available, you know, certain sections have been cut out and were out at FaAA in California.

I would like to add that.

JUDGE BRENNER: Thank you.

Mr. Seaman, did you have something to add, too.

A (Witness Seaman) No.

Q All right.

I would like to circulate and have marked for identification as Suffolk County Exhibit 74, a document which I will identify for the record in a moment.

JUDGE BRENNER: So this will be Suffolk County Exhibit 74, for identification.

(Whereupon, the document heretofore referred to was marked as Suffolk County Exhibit 74, for identification.)

MR. DYNNER: The document on the first page states at the top, "Component Task Evaluation Report." Underneath it says, "priority." It is identified in the righthand corner as TER No. Q-308. It is dated --

JUDGE BRENNER: I have something different; I'm sorry.

JUDGE BRENNER: We've got 329.

MR. DYNNER: I'm very sorry. I am looking at the wrong -- it's my error.

JUDGE BRENNER: All right; no problem.

Strike the prior statement. It is identified -- it is stated at the top, "Recommended" and in the righthand corner, Q-329. It consists of 11 pages, the second page at the top says, "LILCO Liquid Penetrant Examination Report." It is identified as component cylinder block liner landing and further down on the righthand margin it's identified as "DG 101." There are two pages of that report, the second page being a schematic drawing. There follows a LILCO liquid penetrant examination report like the first one, signed and dated March 21, 1984. It also has a second page with a schematic drawing of a block top. And there are three more two-page liquid penetration examination reports similarly described and dated March 21, 1984.

JUDGE BRENNER: All right, let's number these pages 1 through 11 including the copies that are given to the court reporter. And, as we said, it is only marked for identification.

I can't read the first page. I don't know if it's going to become important. I will let it go for now, depending on what use you make of the document.

MR. DYNNER: Thank you.

Now, Mr. Schuster, it's true, isn't it -- or, Mr. Seaman -- that the Q-329 designation shows that this is a group of documents which were part of the DRQR inspection review process; isn't that right? Either one of you.

A (Witness Schuster) That's true.

I would like to also add that LERs LILCO

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deficiency reports 22622289 also addressed these same inspections. It has not been identified at this point that these two do that. Also, TER Q-371 would also be applicable to these inspections.

Q I would simply like to ask you whether the indications of drawings -- if you look at the drawing pages --

A I'm familiar with them.

Q -- of these documents, where it shows intermittent cracks, as you can see, running along the landing face.

A Can I correct, it says intermittent --

A (Witness Schuster) Intermittent linear is what it says in the inspection report. It does not say intermittent cracks.

Q Are any of these indications where it shows intermittent linear and then it shows a long line running along the landing face appears in some cases to be on or near the landing ledge. Are any of those indications indications of circumferential crack indications?

A No, sir, they are not.

Q Are these indications of --

A I would have to add that I'm basing my input to you on total knowledge of the evaluations that were done on these non-relevant indications by untrasonics and by redoing the inspection. This inspection report does identify that. These indications would be unsatisfactory in accordance with the LILCO procedure, but it does not identify the additional information you would find in LDRs 22, 62, and 2289 and Q-371, where the indications were reevaluated by penetrant and reevaluated by untrasonic inspection.

Incidentally, we also used the same techniques to verify that we could, in fact, see the indications which had been identified metalographically on the original DG 103 block using the same ultrasonic technique.

So we did some additional verification in that area.

Q Dr. Wells, was FaAA aware of these reports showing the linear indication of the liner landing?

A (Witness Wells) Yes, Mr. Dynner, absolutely. In fact, I was on the site at the time the indications were first seen when the particular contaminant scales were removed, and I looked at the results following the re-examination and I was satisfied that there are no cracks associated with those indications.

Q Are these indications shown on these documents in the same place as circumferential cracks as we have defined them in your FaAA block report would normally be located if they existed?

A I would like clarification from Mr. Schuster, but my understanding of those indications is that they are somewhat up the vertical wall from the corner.

A (Witness Schuster) They are up slightly, not right down in the root of that notch that's in that corner.

Q So I understand they are not in exactly the same place as the circumferential cracks as you've described them, is that right?

A (Witness Wells) That's quite correct.

Q Mr. Schuster, would you kindly explain why the determination was made that these indications were not relevant?

A (Witness Schuster) In accordance with our procedure we evaluated these indications utilizing ultrasonic examination. We also redid the penetrant doing additional cleaning to satisfy ourselves that we did not have indications that were relevant in that area. It was extremely important with this type of penetrant indication to ascertain whether that indication was relevant or not relevant, and we did this by redoing the penetrant.

Now, what we did differently from the first one is we just did additional cleaning. We got into that notch, that groove that's there, that collects graphite particles and debris, and can absorb dye and give you this indication. We cleaned that very thoroughly, redid that penetrant. At that point, we had even satisfied the procedure. We went one additional step and did an ultrasonic examination to satisfy ourselves that there, in fact, was nothing there. And this was all in accordance with our qualified procedure.

And it was done by a Level 3 certified person.

A (Witness Wells) Let me amplify a minute, if I may, Mr. Dynner, that we observed a carbonaceous scale to be removed from the bore of the liner with, I believe, a penknife. But it was very obvious that the indication was the result of the accumulation of debris and exposure to temperature and so on that left a very hard, tenacious scale that was not removable by the usual cleaning procedures and had to be removed by more force. It was also very apparent that when the surface was cleaned off there was no cracking associated with the sharp corner which is the initiator of the cracking in situations where circumferential cracks have been observed.

Q Dr. Johnson, I am not going to go over all the detailed changes, but I want to ask you about some of the changes that were made in Exhibit B25.

Now, can you identify for us which of these cracks on this map were changed as to their dimensions because of the eddy current inspections that were carried out on September 19 and 20 in 1984?

A (Witness Johnson) I believe the number which is

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changed because, solely because of tests conducted in the laboratory during that date or that period the stud-to-stud crack between hole number -- the stud hole and cylinder 4 stud hole number 6 running to cylinder 5, stud hole number 3.

Q I'm going to interrupt for a minute because I have to ask you how you're counting those stud holes. I have been identifying them for the record as in the positions of the clock and you're now putting numbers on them. So if you will clear that up for us?

JUDGE BRENNER: I hope one is the 11 o'clock position or I've been wrong before, but why don't you answer the question.

WITNESS JOHNSON: Number 1 is 1 o'clock going clockwise.

JUDGE BRENNER: I understood it when we were working with earlier series of exhibits.

BY MR. DYNNER:

Q What you call the number 6 stud hole is on cylinder number 4. The number 6 stud hole is in the 8 o'clock position, isn't that right?

A (Witness Johnson) Yes.

Q And the adjacent stud hole of cylinder number 5 would be in the 4 o'clock position and you're calling that stud hole number 3; is that right?

WRBpp

A Yes.

Q Is that the only crack that you did the eddy current, the new eddy current, examination on on September 19 and 20 in order to change its dimensions?

A That is not the only crack that we did eddy current on but it's the only one which we solely depended upon to change a result.

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Q You say "solely dependent on." Did you depend on the new September eddy current examinations with respect to changing dimensions of any other cracks on the crack map, which is Exhibit B-25?

A Other crack indications, particularly the ligament-to-ligament from Stud Hole No. 3 in Cylinder 5 -- excuse me; ligament crack in Stud Hole No. 5, Cylinder 3, and Stud Hole No. 6 in Cylinder 4, the eddy current results are consistent with the results. But we also, in that case, have direct observation of the depth of those cracks from the sections.

Q Any others?

A And the same is true of the section which includes Cylinder 5's Stud Hole 2, and Cylinder 4, Stud Hole 7.

Q So those cracks were sectioned, as well as having been subjected to a new eddy current examination; is that what you're saying?

A Yes. They were also subjected to a penetrant inspection in the laboratory.

Q When you did the sectioning, did you section the portion of the crack adjacent to the stud hole, or did you section the portion of the crack adjacent to the cylinder counterbore?

A The section of the-- Which crack are we referring to?

WRBwrb

Q Any of them. You tell me which ones you did where.

A Well, I didn't do the sectioning. I had a piece that was already sectioned. There is an example of it over there on the end of the table.

There is a section made between stud holes in the stud-to-stud hole region. And I think Harry ought to answer the location of the sectioning.

Q Dr. Wachob?

A (Witness Wachob) The section of the exhaust side of Cylinders 4 and 5 was cut up with three slices. The first slice was basically a quarter of an inch away -- I mean half an inch away from the stud hole. There is a half-inch slab in the dead center between the cut that is made here and the next cut. So there's a half-inch slab there. And then on the other side there's an identical mirror image of that piece, which is also on the order of a half-inch between the stud hole and the center slab.

So there are three sections that were made in the stud-to-stud region. Each of them is about a half-inch in width, thickness.

Q How about with respect to the ligament-- Excuse me; was that on both the stud-to-stud cracks between 4 and 5 cylinders?

A Only the exhaust side of the 4/5 cylinder was

WRBwrb

sectioned destructively with these three saw cuts.

Q That's the one you found was 3 inches instead of 5-1/2 inches?

A That's correct.

Q And was the 3 inches a consistent depth from stud hole to stud hole, or did it vary?

A The stud-to-stud runs from one side to the other. And in all four surfaces that have a cut exposing that stud-to-stud crack, it ranges between 2.8 and 3.0.

A (Witness Rau) I think you asked if it was the same from all the stud holes. It's clear there's only one crack of anywhere near that depth, and that is between Cylinders 4 and 5 on the exhaust side. That's it.

Q I'm about to ask you now how you sectioned the stud-to-stud crack between Cylinders 4 and 5 on the intake side? That's the one whose depth was change from 3.9 inches to 0.85 inches.

Did you section that one?

A (Witness Wachob) No destructive sectioning was done on the intake portion between the stud holes of Cylinders 4 and 5. The only measurements that were used there is, once we had physically verified with destructive testing on the exhaust side that the crack was 3 inches deep and that the eddy current signals then, when corrected for the correct calibration material, were also reading

3 inches, we went back and examined the intake side with an eddy current technique.

Q And did you find with your eddy current that that stud-to-stud crack was uniform in depth, or was it shaped diagonally?

A Dr. Johnson was involved with that inspection, and he would be best to address it.

Q Do you have an answer for that, Dr. Johnson?

A (Witness Johnson) Let me review the inspection report.

(Pause.)

According to the eddy current report, Stud Hole No. 3 in Cylinder No. 5 extends down .85 inches, and in Stud Hole No. 6 of Cylinder No. 4 it extends down .5 inches.

Q Excuse me; did you say that Stud Hole No. 3 of Cylinder No. 5 extended...how long? --how deep?

A .85

Q .85?

A Yes.

Q Did you personally do the eddy current examination in September, Dr. Johnson?

A No. Brian Holcomb did the eddy current inspection.

Q So those two measurements you just told me about are measurements taken at the stud hole itself, rather than

WRBwrb

half-way between the stud holes; isn't that correct?

A Those measurements are taken at the stud hole.

Q Can you explain to me the change that was made in the ligament crack on the stud hole in the four o'clock position on Cylinder No. 5, which was originally shown to be 2-1/2 inches in depth and is now shown to be 1-1/2 inches in depth?

A Once again, we have two places where we can measure the depth of the crack, the ligament crack: one is at the liner landing area and one is down the stud hole. The depth on the liner landing area was measured by penetrant, and eddy current-- Well, by penetrant. And the extent down the stud hole was measured by eddy current.

Eddy current measured 1.45, and the penetrant measured-- 1.45 in the stud hole. And the penetrant measured, I believe, 1.5 on the liner landing area.

Q Well, how did the 2.5 inches get in there in the first place? Didn't that come from a dye penetrant examination report on the side of the cylinder counterbore?

A No; that's a field-- You added something right in the middle. So will you repeat your question?

Q Didn't that 2-1/2-inch measurement come from a dye penetrant examination of the inside of the cylinder counterbore at that stud hole of Cylinder No. 5?

A No, it didn't; it came from field eddy current

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tests down the stud hole, on the side of the stud hole toward the liner landing.

Q Did you dc a dye penetrant examination of the depth of that crack in the cylinder counterbore, as you had done with EDG-102, for examp!e?

A There were penetrant tests done of the extent of the crack on the liner landing counterbore, and the results of those were that it was 1-1/2 inches on the counterborel. It came came to the liner landing ledge.

Q It's true, isn't it, that there was at least one ligament crack in EDG-103's original block which extended down below the liner landing ledge? Isn't that true?

A I don't believe so.

Q Well, tell me how you explain the ligament crack shown on the stud hole in the ten o'clock position on Cylinder No. 4, which is shown to be 2-1/2 inches i depth?

A That is not on the liner landing, that is in the stud hole.

Q Well, what's the measurement of that on the counterbore area?

A It would be 1.5 inches.

Q So that's a diagonal shape, it's deeper in one part than the other; is that your testimony?

A Yes.

Q Can you explain.... Dr. Wells, it's true, isn't

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it, that ligament cracking may lead to coolant leakage but not into the cylinder; isn't that right?

A (Witness Wells) Mr. Dynner, if the crack progressed to a depth below 23-1/2 inches on the liner side, yes, I guess it is conceivable that water could seep into the stud hole, in the clearance between the stud and the hole, and then leak out to the block surface; yes, sir.

I should emphasize, it is necessary for it to extend to the depth that is approximately an inch below the liner landing, because there is a tight fit between the liner down to that depth.

Q Now, it's true, isn't it, that the FSAR for the Shoreham plant requires that the performance standards that the EDGs must meet is continuous operation at 3500 Kw for a period of one year, and operation at an overload of 3900 Kw for a two-hour period in any twenty-four hours; isn't that correct, Dr. Wells?

A That's my understanding, Mr. Dynner.

Mr. Youngling may have more first-hand knowledge of that requirement.

A (Witness Youngling) The present FSAR cites that the specification for the engines requires that they have a continuous rating of 3-1/2 megawatts with a two-hour rating of 3.9 megawatts. However, during an accident condition that requirement is not required. There is a load profile which will be put in place which is bounded by the rating of the engine.

In addition, LILCO has done additional testing and verification and is in the process of making an FSAR submittal which shows that the load profile on the engines during an accident will not exceed 3300 Kw.

JUDGE BRENNER: But, Mr. Youngling, the testimony presented at page 54 of the initial testimony reflects the load profile in the present FSAR. Is that correct? Perhaps "load profile" is the wrong term as applied to that.

MR. DYNNER: It's stated on page 54, the power levels experienced during a loop LOCA.

JUDGE BRENNER: Let me get his answer.

WITNESS YOUNGLING: This is a worst-case load profile based on the present FSAR submittal -- I'm sorry, the FSAR that is presently docketed. The new submittal will show a load profile which is substantially lower than this, and has a peak value of approximately 3300 Kw.

JUDGE BRENNER: Mr. Dynner, would it disrupt you a lot if I backed up and tried to clarify some of the dimensions being referred to in the ligament cracks and the stud-to-stud cracks?

MR. DYNNER: Not at all.

I was about to move to strike the witness' last answer because it goes to information which is not in this record.

JUDGE BRENNER: All right. I'm going to cut it short and save some time. I am not going to strike it. He is entitled to refer to it as an expert in order to make his testimony fully true and correct as an individual giving testimony. But we've had a lot of discussion on this point. I don't think that the way to get at it is by your motion to strike.

I will note for the record that Mr. Ellis confused me quite a bit when he was referring to the numbers in the block testimony which I thought reflected the existing FSAR, and I don't need to repeat that discussion. But then when I went back and looked, in fact it did reflect I thought the existing FSAR and I just confirmed that. And Mr. Youngling was entitled to fill out the context as an expert witness in response to my question.

Let me back up. Maybe I'm the only one confused.

On the discussions in the written testimony primarily -- and I didn't hear a particular clarification in listening to the oral testimony -- when you discussed the

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stud-to-stud cracks and ligament cracks, one of the important dimensions referred to is depth. And I've looked at, among other things, your Exhibit B-20 which is intended to depict both stud-to-stud cracking and ligament cracking.

I also have in mind the testimony at page 14, which described the ligament cracks as being in a vertical plane.

What do you mean by the depth? Is that the dimension from the top of the block down, or is it actually an area within which the -- a dimension within which the crack occurs?

WITNESS WELLS: The use of the term "depth," Judge Brenner, is to indicate the distance below the horizontal plane on the block top.

JUDGE BRENNER: Okay.

WITNESS WELLS: You've heard two different ways of measuring depth at least I think so far. When we refer to determining the depth through an eddy current probe, you are no doubt aware that the eddy current probe is only effective to a very small dimension below the actual surface.

Therefore, when we talk about measuring depth with an eddy current probe we are talking about tracing the intersection of a vertical -- or with reference to the center line of the cylinder, the radial axial crack that is

WRBeb

in the plane of the radius of the cylinder and the axial or vertical center line of the cylinder, measuring the intersection of that crack with the counterbore of the stud hole.

The eddy current probe traces the intersection of this crack down the stud hole to a certain depth. We say that the depth of the crack at that particular location is the stated amount. We do not of course rely on the eddy current probe for any other information concerning the depth of the crack in either the ligament through its thickness or in the material that separates the two stud holes.

JUDGE BRENNER: All right.

So when I hear the dimension depth, nothing in that dimension tells me anything about the size of the crack, it is only telling me the location of the crack in the block. Is that right?

WITNESS WELLS: Not quite. Refer to our Exhibit B-20. If you imagine that this probe has traced the sides of the intersection of the crack with the sides of the stud hole then we know that at least on those two locations diametrically opposed that the crack has a certain depth.

Now generally we assume that the crack takes a more or less straight line and this is verified by destructive examination between those two intersepts. It could of course be slightly parabolic or slightly convex upward.

WITNESS JOHNSON: I would just like to add to that it is a dimension. These cracks run from the top surface down to the depths we're talking about, so it is a projection of the crack onto the two surfaces that we have access to.

WITNESS RAU: Judge Brenner,--

JUDGE MORRIS: If I might ask a clarifying question, referring to Exhibit B-20, if you look at the right-hand side where it says "ligament cracks," there is a series of roughly horizontal lines, sort of wiggley. Would you tell us what those lines represent?

WITNESS WELLS: Judge Morris, the only use of those lines is to indicate an irregular cracked surface. It is, if you will, cross-hatching to indicate the separating material from the sound material. That's the only reason that those lines are put on there.

In the stud-to-stud region just to the right of that you will see some diagonal lines or curved lines. That is to indicate, to the best of our ability, what the propagation direction of the crack would be. If the crack progresses in a series of jumps rather than one continuous propagation, it will leave behind it a number of lines that look somewhat like these marks that have been sketched on this schematic.

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JUDGE MORRIS: You see the problem that some of us lay people have is that these lines could be interpreted as horizontal cracks. But that is not the intent. Correct?

WITNESS WELLS: That is correct, Judge Morris.

JUDGE MORRIS: Thank you.

WITNESS RAU: Can I add to that, too, hopefully to clarify it?

The cracks which have been observed by the inspections have always been started or associated with the block top. Whether they be the ligament cracks between the counter bore and the stud hole or whether they be the cracks between adjacent stud holes, the stud-to-stud cracks, they tend to start at the corner, at the block top and the corner of the stud hole, and progress.

You can think of it as a thumbnail crack, both down the stud hole vertically and also horizontally between adjacent stud holes, and eventually the two thumbnails link together to produce a single crack which is continuous, if you like, across the block top, after which it can progress vertically down from the block top.

This is both physically observed and also consistent with the stress analyses that have been done. It suggests that the stresses are highest at the block top and highest at the stud hole when you're talking about a stud-to-stud crack, so you observe it there. And that is

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also where you would calculate the crack to start and to progress.

The depth dimension quoted is in fact the most important dimension. That dimension along the stud is the one which is most important because it is where the stresses are highest and it is where you would expect the crack to be deepest. In other words, you would not expect it to be any deeper in the center between two adjacent stud holes; if anything, it is going to be shallower there than it is at either of the two stud holes where the stress is, where the driving forces are higher.

MR. DYNNER: At the risk of interposing myself on the Board's questions--

JUDGE BRENNER: Go ahead. I'm going to let you do that in one moment. Let me suggest something and find out if the parties have no objection.

What the Board would like to do is take a look at that section of the block as kind of a site visit that has been brought to us, if you will, so as not to burden the record with it, but we would have Counsel for all parties of course present and just have somebody describe what we are looking at, not in terms of factual testimony but describe just what the section is from as we have done on site visits.

Maybe we could do that at some point right after the

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break today, and then maybe after that we might want to borrow it and look at it ourselves for just a very short amount of time --

MR. DYNNER: The County certainly has no objections to that.

JUDGE BRENNER: -- if it is not too heavy.

(Laughter.)

Otherwise we won't borrow it. I just wanted to let you know we're thinking of doing that if there was no objection.

Now why don't you proceed?

MR. DYNNER: I was simply going to refer you, because I think it is a helpful drawing, to the County's Supplemental Exhibit S-9, which is also Figure 1-1 in the County's Exhibit 7. It is a figure in the FaAA block report. It's a schematic drawing of the block top which I think is helpful in understanding the different types of cracks and the locations.

JUDGE BRENNER: Yes. I think that is also reproduced as a separate LILCO exhibit, but I'm not positive. In any event I saw it before seeing it in the County exhibits and it was helpful, also.

While I have interrupted with dimensions, looking at that same Exhibit B-20 I was trying to establish in my own mind what some of the dimensions were across the block top, and I did look at your block top figure which is Exhibit B-8, but there are two dimensions I wasn't sure of. Although I could do some addition and subtraction between figures presented, I wanted to get it correctly on the record.

What would be the distance across the block top between the two studs, that is, two studs adjacent -- associated with two different cylinders?

WITNESS MC CARTHY: If you look at LILCO Exhibit 8 you will see a dimension on the right-hand side set of stud holes where the distance between stud holes is called out as 1.787 inches, the lower right-hand side, the two stud holes in the lower right-hand corner of the picture. The distance between the center lines is also called out.

JUDGE BRENNER: So if I subtract-- What would I do, subtract 2.574 from 3.818?

WITNESS MC CARTHY: Which dimension are you looking for, sir?

JUDGE BRENNER: I want to get the dimension, not center-to-center, I want to get edge to edge.

WITNESS MC CARTHY: Right below is the edge to edge. 1.787 is below the 3.818 and you can see that's an edge to edge. Do you see the 1.787?

JUDGE BRENNER: Yes, but I thought that was the radius.

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WITNESS MC CARTHY: No, that's edge to edge of the holes.

WITNESS WELLS: In Exhibit B-20, that particular exhibit would be the width of that shaded area that is called stud-to-stud cracking.

JUDGE BRENNER: That's the dimension I wanted. I was misreading.

WITNESS WELLS: Just for the record, the ligament itself in the horizontal direction is 5/8ths of an inch.

JUDGE BRENNER: Thank you.

WITNESS MC CARTHY: Above the counter bore.

JUDGE BRENNER: We can take a break now, or you can follow up with a few questions if you wanted to, Mr. Dynner. As long as I interrupted you, this might be a good time.

Let's do this. Let's break until 3:30. Then we'll come back at 3:30 and perhaps we can take a look at the section with all Counsel present and get just a quick description of what it is we're looking at.

(Recess.)

JUDGE BRENNER: All right, we are back on the record.

We spent about 10 minutes looking at a section of the block from the original 103 block, with all the witnesses present, for the purposes we indicated before the break of getting oriented as to the geometry of what we were looking at in the context of some of the drawings we had seen. From time to time there was a mention of certain dimensions of cracks and so on and, needless to say, we won't be relying on that viewing of the block, which is not in the record, for any factual information as to the cracks, which are very much indispute as Counsel for the County had pointed out during that off-the-record briefing for us and the other Counsel.

Mr. Dynner?

BY MR. DYNNER:

Q Just a couple more questions concerning the revisions to the crack map for EDG 103 that is Exhibit B25.

Dr. Johnson, you said that when you conducted this, you say, September 19 and 20 additional eddy current inspections of the cylinder block top for the original EDG 103 block that you recalibrated the eddy current instrument, is that correct?

A (Witness Johnson) We always calibrate the eddy current instrument each time we do a test.

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Q Is it my understanding, from your testimony, that you recalibrated it especially to take into consideration what you regard as the existance of significant amount of Widmanstaetten graphite in the block material?

A The acceptance criteria for when you trace an eddy current indication was instead of going -- the change made in the procedure was instead of going all the way to the specified level, we went down to the noise level.

Q Could you explain that a little more clearly so that a layman could understand it?

A In eddy current testing and, as a matter of fact most nondestructive testing, if you increase the sensitivity sufficiently you will see some imperfections in the material. No material is perfect. All materials have imperfections. With regard to the eddy current testing, these imperfections show up as signal variations. In developing an eddy current test one selects a level of signal which you are now going to record. The level of the signal which we record is based on a standard containing, in this case, an EDM notch in the normal cast iron which is 20 thousandths deep. And the acceptance criteria that was used in the field test was to -- well, in all the tests -- well, the acceptance criteria is to call out then any signal which exceeds half of the signal which one gets from that 20 thou notch in normal cast iron.

After one has detected a defect in order to trace the defect to see the extent of the defect, the procedure calls out to trace the signal until it gets to 25 percent of the threshhold as opposed to 50 percent of the threshhold.

If you do that in degenerate graphite material at the 50 percent level -- if you trace a signal down to the 25 percent level, you will find lots of areas that have signals which are 25 percent of the standard.

Therefore, in tracing the signal, if you get into a heavy area of this degenerate graphite, you will see signals which exceed your 25 percent criteria. And that is why the extent of these cracks were overestimated in the original EDG 103 in the thread areas.

Q When you changed your acceptance criteria in order to be sure that you were keeping an accurate reading, you would have to have a rather precise indication of the effect of the Widmanstaetten graphite on the strength of the block top, wouldn't you?

A Our acceptance --

Q When you answer that I would like you to follow the pattern. It is very helpful if you could say yes or no but, or a yes or no however. It makes it clearer for everybody.

A The strength of the effect of the Widmanstaetten on the block top is not the basis for selecting how far we attempt to trace the signal down into the noise level.

I can't answer your question yes or no because --

Q I understand. What I am curious about is how do you know what to trace it to and how do you decide what that acceptance level is going to be?

A Well, based on the standard that we use we are able to detect defects which are 20 thou deep. Now, if you have imperfections which are less than 20 thou deep, the eddy current test will not detect those, while the tests have a threshhold below which imperfections will not be found. The imperfections that we have set up are very small compared to imperfections that would normally be considered relevant in a normal cast material.

Q Let me back up for a minute, Dr. Johnson. When you did the eddy current examination of the block, the original block of EDG 103 back in April, you used as your standard a cast iron gray number 40 cast iron standard. So you knew how to use your eddy current and how to read it, how to read those signals and translate those signals into depth measurements; isn't that right?

A Yes, we did use a piece or normal grade 40 cast iron material with an EDM notch in it 20 thou deep and the acceptance criteria -- or the recording criteria, excuse me -- was that in the indication which exceeded 50 percent of the signal which we got off as a 20 thou deep notch was recorded.

Q Now, when you did the eddy current examination again of some of the cracks in the original EDG 103 block in September, what standard did you use for your crack depth readings, that is, for your eddy current readings at that time?

A We used the same standard that we used previously and we had the same recording criteria. That is, we record any indication which exceeds 50 percent of the threshhold. But now having recorded an indication and now attempting to size the indication, that is, how long did that indication continue into the stud hole, the original procedures said that you scan it until it went down to 25 percent of the signal, which one gets off this 20 thou deep notch. In sizing the indications in the laboratory we scan it until you get down to the noise level, which is the procedure that was used for sizing an indication at the laboratory.

Q What was your basis for doing that? Why did you decide to make that change?

A Because the Widmanstaetten graphite you can scan many places in the Widmanstaetten area, areas which have been identified by metallography which do not have cracks but do have this degenerate structure, and you get small indications exceeding this 25 percent level.

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Q Did you measure the extent of the Widmanstaetten graphite in each one of the places that you took an eddy current reading?

A No.

A (Witness Rau) Can I add something to that answer, please, just for clarity. The way in which -- as Dr. Johnson has described the sizing procedure is done, is that once you have seen the indication you then attempt to use the eddy current probe and continue to see whether there's an indication greater than originally 25 percent of the threshhold signal and you keep walking deeper and deeper from the block top until such time as that signal drops below 25 percent.

Now what Dr. Johnson has said that has perhaps not come through clearly, is that in the really degenerate Widmanstaetten graphite the material is so garbagey, basically, that you get 25 percent signals forever. You could march on anywhere through the block and you keep getting 25 percent signals. So you can never tell when the crack indication ends.

What Dr. Johnson instead has done, is establish a threshhold above the noise level, which -- I don't know what the exact number is -- but, in point of fact it something higher than 25 percent. You do have a sharp signal above that while you have the crack at the block top and you march

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down and eventually it drops off to something. But you can't continue on with a threshhold criteria of 25 percent because you'll read it indefinitely. It has no meaning.

BY MR. DYNNER:

Q Dr. Rau, you didn't read it indefinitely the first time you did these eddy current examinations. In fact, your April examination reports are rather precise measurements of 3 7/8 inches and 1 1/8 inch. They don't go on forever, do they?

A Let me explain that --

Q Would you answer the question first and then you can explain it?

A I'm going to answer the question. You can't -- the inspector conservatively traced it out until such time as he thought he had a region where the signal had dropped below the 25 percent threshhold. Now, in point of fact, the Widmanstaetten graphite is all over the old -- the original 103 block. But it's magnitude, it's character, is not identical in all locations in that block. There are regions where there's more of it, there are regions where there's slightly less of it, there are regions where it's clustered togther more, there are regions where it's not, and the signal would go up and down and back and forth. And the inspector may have found a region when he's tracing along and the signals are all over were -- some small region that you could not trace the signal down that small. Therefore we had the -- we had to establish what the noise level was in this material and we said, okay, we'll trace it down to noise level. Now, that means it's possible that there are cracks or didn't material this continuity on the order of something less than 20 thousandths of an inch deep below that, and those indications of that size are not relevant in this material, I don't believe.

Q But Dr. Johnson, when you revised the crack map for EDG 103, you only revised some of the eddy current reading. You didn't revise all of the eddy current readings. In fact, there were more eddy current readings that you left alone than there are ones that you revised.

How is it that when you made these changes you didn't find that it was necessary to reduce the depth from the readings you made that you had previously found on the crack map as shown as Exhibit 25 originally?

A Exhibit 25 is not simply eddy current measurements, of course. Those are penetrant measurements -- include penetrant measurements also and, in fact, there are some other reductions in here and those reductions that were observed here are situations where we had eddy current measurement in conflict with the penetrant indications since we had demonstrated that the eddy current test overestimates the flaws in the old EDG 103. When we had alternative

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information we took the penetrant measurement. In all cases, the eddy current tests and the crack maps are certainly conservative in the extent of damage that was done. That is, there is at least this much damage done to the block after the load excursion.

Q Which is a more accurate picture of the crack depth for the same crack, the eddy current reading, which you revised to show the nature of the material -- or the nature you claimed the material to be -- or the dye penetrant examination for the same crack. Which would you rely on ?

A If I were to reinspect the area using the procedure which -- now being cognizant of the fact that it is this degenerate graphite material, I believe both methods would be quite reliable at detecting the extent or the depth of the crack and, in fact, would agree fairly closely to each other.

Q Are you saying that neither particular examination device is one which you would regard as more reliable than the other for determining the crack depth?

A Both techniques penetrant is certainly reliable at detecting the extent of the crack down where you have applied the penetrant and the eddy current even on EDG 103, the old material provided that you have modified the procedure to take into account the fact that you are dealing

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with this degenerate material. Both methods are reliable, both methods, for example on the exposed surface that one would see in some of the safest sections that we have both give the same results as to how deep or how far the crack extends along the -- whatever surface you have access to.

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Q Can you identify for me the cracks on this crack map where you have taken a new eddy current reading which you've modified in the way you've described and thereafter you've checked it with a dye penetrant examination and found that they were the same crack depth?

A I couldn't do that without reviewing the detailed reports. We did not-- There is not reflected in this crack map which you have dated 9/22/84 any additional eddy current tests on the block top other than the tests that were done on the section which was brought to our laboratory, which we have already discussed.

Q So the other changes that were made would be the result of erroneous readings from inspection reports. Is that right?

A There are instances, and I don't know exactly which ones, there are instances where we have an eddy current indication which says it is deeper than a penetrant indication. Now this was done when we were not aware that we were dealing with the degenerate graphite. And in instances where we have eddy current indications which were larger than the penetrant indications, we took the penetrant indication results.

There may also be some changes on the new plot which represent transcription errors also, but I don't remember at this time.

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(Counsel conferring.)

MR. DYNNER: I am going to distribute and ask that there be marked for identification as Suffolk County Exhibit 75 a document which is comprised of some 47 pages. I hope they are all numbered. They should be, in the lower right-hand corner.

The cover page of this document says "Shoreham Nuclear Power Station, Unit 1 - Emergency Diesel Generator DR/QR Program - Document Review Transmittal." It is dated 4/30/84.

The attached documents are identified as the Component Task Evaluation Report Number Q-465, and under that the number 03-315A.

BY MR. DYNNER:

Q Mr. Seaman, can you identify this document for us as in fact constituting TER Q-465 which was generated as part of the DR/QR program?

MR. FARLEY: Judge Brenner, I object to this procedure. I thought it was understood that when either side decides to use voluminous exhibits that they would present them to the other side in advance. There is no way we can comment on this particular 47-page document.

JUDGE BRENNER: I thought we were going to follow that procedure, too, Mr. Dynner.

MR. DYNNER: Judge Brenner, this arose only after my review resulting from the September 24th unexplained errata sheet which made these changes. I quite agree that most of these changes that are changes of substance would normally have been made by virtue of supplementary testimony where there would be an explanation of why the changes were made in the substantive matters like this.

I asked for an explanation and got a letter which I read you the portion of that talks about the crack maps. The unexplained changes required a great deal of additional work which we tried to shoehorn in, and there was simply no capability of getting into it. And I didn't really know until last week that I was going to have to use this document, or thought I might use this document.

JUDGE BRENNER: I'm not going to prevent you from using it, although I wanted to see if I could cut down on the paper in this record even in some modest amount. But even as recently as Friday there certainly would have been a benefit to have this done, rather than wait for now.

And if you are going to be using more of these through the cross-examination of these witnesses, I am directing you to let Counsel know after we adjourn today so the witnesses can get copies and know that you are going to ask about them, very much like the procedure that we followed in an earlier phase of the hearing.

It is not a matter of preventing you from using

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something. It is a matter, as you recognize, of making it more efficient for all of us.

Number two is as you have indeed described the document, and you will notice I have not yet said we'll mark it for identification. My question was going to be and will be now, do you need all these pages?

MR. DYNNER: I don't think so, and I will be quite willing, once the document has been identified as in fact being the TER that I have identified, that we can restrict the number that eventually do get marked for identification to those which I must question about.

JUDGE BRENNER: Why don't you continue your questions and then we'll get back to your pending question in a moment, and when it is done we will find out what we have to mark for identification for the record, if anything.

I observed, perhaps incorrectly, that as it turned out, for example, your Exhibit 74 for identification is probably not going to be the most earth-shaking document, given the answers from the witness. Of course you did not necessarily know what the answers would be in advance.

When we've got some of these external documents where you may not be sure that you are actually going to need them for something, depending on the witnesses' answers, maybe a better way to proceed is to distribute the document as you did and ask your questions, and then we'll

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entertain any request by you, or other Counsel when they do the same thing, to have it marked for identification or otherwise. All right?

We have got the document identified. We have not yet marked it for identification though, and the question-- Can you repeat the question to the witnesses?

MR. DYNNER: Yes.

BY MR. DYNNER:

Q Can you identify this document, Mr. Seaman or anyone, as being in fact a copy of TDR Q-465?

A (Witness Seaman) Mr. Dynner, in order to identify this document I would want to check my records and confirm that it is in fact Q-465.

MR. DYNNER: All right.

Does Counsel want to stipulate that?

JUDGE BRENNER: Without vouchsafing the accuracy of each and every page in this thick document, Mr. Seaman or anyone else on the panel, does it look like that is what it might be, physically?

WITNESS SEAMAN: Yes, it appears to be that.

JUDGE BRENNER: All right.

Mr. Dynner I'm sure is going to do his best now to zero in on a particular portion of this voluminous document for whatever use he wants to make of it, and then we could see if there was a problem there in the witnesses not being able to tell whether it is accurate or not.

WITNESS SEAMAN: Judge Brenner, there is one thing that disturbs me a little bit. Q-465, just from a quick review, is 32 pages long, and I notice that this exhibit --

JUDGE BRENNER: It is not an exhibit yet.

WITNESS SEAMAN: This document contains 40-some-odd pages.

JUDGE BRENNER: All right.

MR. DYNNER: I will note for the record that starting on page 33 there is a reference in the lower right-hand corner, part of which seems to say "As directed by DJ,' and then it says "TER Q-465." And I will represent to the Board that this is the form in which we received this document as part of the block package document request during discovery.

BY MR. DYNNER:

Q Would you look at page 11, please, Dr. Johnson?

Am I correct that this is an eddy current examination report dated April 18th, 1984, and it shows the measurement of 3-7/8ths inches in depth for stud Number 3 on cylinder Number 5?

A (Witness Johnson) It says length of indication, it doesn't say depth of indication.

I would need to review this material prior to

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commenting on it.

Q Turn the page to page 12, the following page which is attached. And that in fact shows that there is. It says "Crack in stud hole Number 3, and it shows a schematic drawing with the depth of 3-7/8ths inches, and above it it shows the location of that Number 3 hole, doesn't it?

A Once again I have to review this data to see which goes where.

MR. FARLEY: Judge, I don't think I have the same document that Counsel is referring to.

JUDGE BRENNER: Okay, let's take care of Mr. Farley's problem and then we will get back to the witness' answer.

Can you check that?

MR. FARLEY: The document I had so far matched up with what Mr. Dynner was referring to.

MR. DYNNER: Look in the lower right-hand corner, Mr. Farley. Those are the page numbers I am referring to.

MR. FARLEY: I'm sorry, Judge. I have it.

JUDGE BRENNER: Okay.

Now let's get back to the witness' answer.

Do you still remember, Dr. Johnson?

WITNESS JOHNSON: In order for me to comment on these results I would have to review them.

BY MR. DYNNER:

Q You can't answer whether that drawing shows a 3-7/8ths inch depth next to where it shows crack in stud hole Number 3 on page 12 without reviewing it further?

A (Witness Johnson) I really would have to be sure of the sequence of everything that is here. I read 3-7/8ths, yes.

Q This report is part of a report-- This was done by Failure Analysis Associates, wasn't it?

A The inspection was--

Q Wasn't it?

A The inspection was conducted by Don Johnson of Failure Analysis Associates.

Q And you've reviewed it, haven't you?

A This is the correct sequence, yes. We looked at all the inspection reports with Mr. Schuster. As he indicated, we spent 12 hours looking at these reports.

Q Well, then it should help you to determine the correct sequence that the FaAA numbering in the upper right-hand corner says 9/32 on one page and the next page says 10/32. Doesn't that indicate those two pages are in the proper sequence, Dr. Johnson?

A Once again I would have to review that that indeed is FaAA numbering.

Q How are you going to find out whether it is

FaAA numbering by looking at it for another five minutes?

A What I would need to do is look at the record which LILCO has of this report and then we can confirm that that is the sequence in which these things are in.

A (Witness Youngling) Mr. Dynner, you know Mr. Johnson is having difficulty. I don't see a page 11 of 32 even in this document -- I can see where he might be confused -- if you will look at the upper right-hand corner.

Q I didn't ask him anything about page 11 of 32, but you are quite right, it is missing.

(Laughter.)

JUDGE BRENNER: Mr. Dynner, next time--

BY MR. DYNNER:

Q Can you identify, Mr. Youngling, whether--

JUDGE BRENNER: Mr. Dynner, excuse me.

I could decide whether I think somebody could give you a better answer now or not, but even if I decided for the sake of argument that we might be able to get a slightly better answer now, subject to check, it might be just as efficient to hold the whole subject over until tomorrow and come back to it because they are going to make that check anyway, and that way we won't run the risk of getting part of it now, and then perhaps running into into, as the third or fourth follow-up question that you might have, the fact that we couldn't even get an answer subject

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to check.

MR. DYNNER: All right. Fine.

JUDGE BRENNER: LILCO is now on notice that you do want to ask about this set of document.

Of course I don't know immediately where you're going with it, although I know the general subject area. We did not put Counsel for any party to the extra burden of revising the cross plans in light of the revised testimony.

I must say I miss those cross plans today, and maybe I'm sorry I didn't do that, but nevertheless I didn't.

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JUDGE BRENNER: Off the record for a minute.

(Discussion off the record.)

JUDGE BRENNER: Back on the record.

MR. DYNNER: Before I forget, I would like to move into evidence Suffolk County's Exhibit 73 which was marked for identification this morning.

MR. FARLEY: I object.

JUDGE BRENNER: Let him finish the motion, and then we will let you object.

MR. DYNNER: As you know, it is the liquid penetrant examination report that was discussed earlier.

JUDGE BRENNER: Mr. Farley?

MR. FARLEY: Judge Brenner, I recall the testimony being -- indicating when it was marked for identification that this was part of an entire group of reports. Indeed, on the face of the two pages which have been selected, at the top right-hand corner the first page says "Page 31 of 46," and the second page says "Page 32 of 46."

Now, not having seen or been warned about this document until it was presented this morning, I have no idea whether this is a fair and accurate representation of what it purports to represent or not.

JUDGE BRENNER: Putting that point aside for the moment, we will come back to it if we have to; but, putting it aside for now, I would rather not admit it into evidence, AGBwrb

Mr. Dynner, as a practical call. Standing by itself, the document -- I don't want a document such as this, a source-type document standing by itself in the record and then to see findings later that have nothing to do with anything that was asked about. We have discussed that before.

And although I haven't maintained strict control on the large volume of exhibits that I have allowed the parties to move in with their testimony, some of which fall into this category also, we have alluded to -- we have said what our practice will be limited to later in at least one order.

My question to you is why do you need it in evidence for any practical reason? It was used in cross-examination, you've got the witnesses answers to the questions you wanted to use. I agree that marking it for identification was helpful and perhaps even necessary to orient the witness and the Board as to precisely what was being asked and answered and we do have it for identification for that purpose. But in terms of the substantive findings we have the witnesses' answers on the record. You were asking him about those indications one and two and what they meant and you've got his answers.

If there is anything beyond what you have asked about that you would like to use this document for, we

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wouldn't rely on it later anyway.

MR. DYNNER: I don't understand that. This document is the only, so far as I know, evidence, documentary evidence of the inspected depth of those particular crack indications. And I know that the witnesses testified that they think that there is some other document with different results but it is not here and it seems to me it is a very important piece of evidence, it is not elsewhere on the record of these proceedings.

It seems to me it is in fact as I identified earlier a portion of TER DR-220. It is, standing by itself, a signed and fully identified by the witnesses, liquid penetrant examination report dated February 10th, 1984 and I must say that I think it is an important piece of evidence in this proceeding and I don't understand why it shouldn't be admitted into evidence.

JUDGE BRENNER: Nothing that you would like to argue along the lines of what you just indicated would be precluded by what we already have on the record. That is, we know this document exists, it has been marked for identification. You've got the witnesses stating what the document was and you've got their answers as to the depths of the two indications and they identified what was being measured in answer to your question and I just want to avoid the problem of worrying about what this is excerpted from --

MR. DYNNER: It has been identified, sir, I must say and I must --

JUDGE BRENNER: Wait let me finish -- plus there are other things in here that I can't even read. And I don't worry about that type of thing when it is just for identification -- unless you are focusing in your questions on something I can't read, but you did not do that.

We'll deny the motion to admit it into evidence, it is marked for identification and you've got the witness' answers. And you have given me the benefit of a preview of at least part of your argument on this being a document supporting the measurements you asked him about, whereas there is no other document at this moment demonstrating the March 8th measurements that the witness talked about and you can make that argument with the state of the record.

I have also pointed out to LILCO at least initially why they might want to think about making the document available, if it exists, to you. And you've got your request outstanding for that document which I expressly did not rule upon.

MR. DYNNER: I respectfully would request an explanation for the standard for your overruling the motion, because, based upon what you said, I don't understand what the basis is for introducing evidence into this proceeding.

JUDGE BRENNER: Okay.

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The standard is there is a lot of documentation in these types of hearings -- we have been through it in this proceeding and in other proceedings. You may recall the QA portion of this proceeding that had extensive documentation. We allowed, after the cross-examination, certain portions of those documents into evidence that were precisely asked upon.

The consideration is partly a practical one, that to the extent feasible I want to avoid having basic source-type documents which are less than clear on their face for which we do not have full explanations on the record -- nor do we need them because in part they may deal with other things -- and I want those documents, when they are going to be introduced, to be used -- especially when they are being put in for the first time while we are at the hearing as opposed to being filed with the testimony where they are at least referenced so we can get some handle on what purpose they are being used for initially -- to get the testimony by the witnesses in answer to questions about the document. And then I understand very well as the evidence is coming in what is being asked about, what is being answered and I can understand where the argument and the facts might fall and be organized.

What I don't want is to have documents in evidence, the source-type documents, that deal with matters that we are not following at the moment, which were not even asked about, and then to get proposed findings based on those documents because they are in evidence.

Now I will admit we can control that to a reasonably large extent after the hearing, and I have put the parties on notice in one of my prehearing orders that we are not going to credit findings on controversial points which are based solely on exhibits which were never touched upon either in the written or oral testimony of witnesses. And that is part of my control process.

Another control process is, as these documents are coming in I want to control, to the extent reasonable, without prejudice to any party, the evidentiary record so that we know precisely what is being asked about. I admit this is only two pages but, nevertheless, I have indicated why there are things in here that have not been gone into, I don't know what they mean, they reference other sketches to "see sketch" beyond maybe just the one sketch attached, maybe not. I don't want to spend the time getting explanations either on redirect or on further cross from the witnesses as to what the context of page 31 and 32 or 46 is, what is being referenced, what else this document stands for and so on; it is not necessary. We have got the substantive evidence for which you have used it.

If there is any other finding area that you want

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to rely on for this document beyond what you indicated in your earlier explanation to me, you had better ask about the document through the witness.

As I said, as I understand the argument you made before, you can make it in findings, given the state of the record now, without any prejudice to you.

You want to say that on such and such a date an inspection was performed that showed indications of these depths. And you got that from the witness. And you want to say, in addition to the witness' answer, that was based on a document which is marked for identification, that the witness agreed represented that inspection as to the precise point you asked about.

And if you never get a document with a March 8th inspection, you also are going to argue that, contrary to that, you have nothing but the witness' say-so as to the March 8th inspection and, notwithstanding their extensive documentation of inspections when it seemed to suit their purpose, you were not presented with any documentation for that other inspection, contrary to the witness' belief that you had something like that. But LILCO is probably going to provide that document before we are done anyway --

MR. FARLEY: May I respond first --

JUDGE BRENNER: -- if it exists.

But that's the ruling, Mr. Dyrner. You may not

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like it but that is my best shot at an explanation. It is probably a practicality call and I am surprised that you are surprised because we did go through this on related points during the extensive QA documents during the previous incarnation of this hearing.

Mr. Farley?

MR. FARLEY: Judge Brenner, following up the examination in connection with the August 8, 1984 eddy current examination report, as I represented to the Board, our records show that this was produced to the County on July 24, 1984 and bears our document numbers A14184 through A14190.

JUDGE BRENNER: Okay. Maybe I heard you wrong. You said you said that before. I didn't hear that from you before.

It doesn't matter. Help him find it, okay?

MR. FARLEY: Yes, sir.

JUDGE BRENNER: Mr. Dynner didn't go so far as to say he is absolutely, positively sure he never received it, he just said he in effect did not presently recall.

Let's hear from the witnesses instead of the Board and counsel. Mr. Dynner, ask another question.

(Pause.)

BY MR. DYNNER:

Q Gentlemen, please turn to page 15 of your

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testimony.

MR. DYNNER: Judge Brenner, I am on page 22 of the cross plan.

BY MR. DYNNER:

Q There is reference in answer 17, Dr. Wells, to the effect that the EDG 102 was re-assembled and started 100 times.

How quickly at each one of these times did the engine come up to full load of 3500 Kw?

A (Witness Wells) Mr. Dynner, I recall the test series but I don't recall the precise rate at which the load was apply and I defer to Mr. Youngling for that information.

A (Witness Youngling) This test was done in conjunction with the FSAR and Reg. Guide requirement to perform 23 starts on the engine. We expanded that to include an additional 77 starts to give us the 100.

The Regulatory Guide requires that the engine be brought to speed in less than or equal to its rated time, which is 10 seconds. It does not, however, say how long you have to load the engine. In actuality --

Q I want to interrupt you, Mr. Youngling, because I think you are going further than the question.

My question was how quickly for each of these starts was the engine brought up to full load of 3500 Kw?

A I am going to answer that.

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Q Please answer that question and then I will ask you some follow-ups.

A In 97 of the starts, the engine was brought to 50 percent load or greater, not 3500, which is the requirement for the test.

Q Can you tell me how many of the loads --

A I'm sorry, Mr. Dynner, that's wrong. I have to correct that. Just give me a moment.

(Pause.)

Of the 100 starts, 77 of the starts, the engine was brought to greater than or equal to 50 percent load. In achieving that loading, there was no specified time interval and anywhere from 1 to 1-1/2 minutes were used to bring the engine to speed, around that number.

20 of the starts, the engine was brought to full load, or 3500 Kw, and held for one hour and the time that the engine was brought to speed was about the same time, about 1 to 1-1/2 minutes.

Three of the starts, the engine was brought to 3500 in less than or equal to 60 seconds and in actuality we loaded the engine probably between 20 and 40 seconds to 3500 Kw.

Q When you say 77 of the starts were at 50 percent or more load, can you tell me how many were right between 50 and 60 percent of load?

A All 77 were probably between 50 and 60 because that is generally where we kept the engine.

Q So that not one of these starts was consistent with the requirement for a loop LOCA that one of the engines might see, according to your testimony, of bringing an engine up to 3880 roughly -- over 3800 KW in ten seconds; isn't that right?

A No, that's not how it works at all. The engine has a requirement to go from dead stop to rated speed and voltage in less than 10 seconds. In actuality the engine will do that in about 5.5 to 6.5 seconds. At that time the engine will go on the bus and be in a condition to accept load. Once it starts to accept load the loads are sequenced on in an orderly sequence to allow for the voltage to recover between each loading process. And in actuality the loads are accepted on the engine in the matter of 30 seconds. Now, as I said, three of the starts were made in accordance with the technical specification requirements. The technical specifications say that periodically we have to go in and load the engine up to full load and load it in less than or equal to one minute. As I testified we actually loaded the engine in around 20 seconds to 40

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seconds. That is very consistent with what you would say in a loop LOCA event.

Q If you wanted to really test EDG 103 for crack propagation, why wouldn't you test it with 100 starts, all 100 seeing the requirements that the engine might have to see in the event of emergency. That is, bringing it up to 3500 KW within 60 seconds?

Mr. Seaman, you can add something after Mr. Youngling answers, okay?

MR. FARLEY: Judge, I think we were talking about 102.

MR. DYNNER: I meant 102. Thank you for the correction.

JUDGE BRENNER: That is on page 15 of the testimony.

A The diesel generator test program has many facets to it. The 100 start test is one of those facets. It proves to LILCO, to the NRC, to Suffolk County, to the community that the diesel generator has the capability to start and accept load in a quick fashion and to sustain that load.

In addition, under regulatory requirements in FSAR committal, we perform long duration runs on the engine. Some of these runs are for 24 hours, some of these runs were for three days. And in fact, one of the runs wa.

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for seven days. And that seven-day run was put in place to show that the engine could respond to a seven-day loop LOCA event.

LILCO made the decision that we would run a very, very conservative load profile in that loop LOCA demonstration. And in fact, in our submittal to Dr. Denton of the NRC in January of 1984, we described in some detail that seven-day run. The seven-day run consisted of operating the engine for one hour and 3900 KW for four hours at 3500 KW and 163 hours at 75 percent load which is 2650 KW, as I remember --

Q What engine are you talking about -- this seven-day?

A That was done for all three engines. It was also done for the diesel generator 103 after the replacement of the block. However, the load profile was slightly different. More in concern with the present submittal that we have going in to the NRC.

Q What was the timeframe of those seven-day run tests that you were talking about now?

A Diesel engine 103 performed that run in probably December or January of 1983 or '84.

Q You mean December '83 or January '84?

A Yes.

Diesel engine 103 was next and probably did it in

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January of '84 and diesel engine 101 was last and probably did it in January or February of '84.

Q What my question was about specifically --

A Let me --

Q Let me finish please.

MR. FARLEY: Mr. Youngling has not finished his answer.

MR. DYNNER: Because Mr. Youngling was talking about a totally different subject matter than my question was referencing.

JUDGE BRENNER: The first time I say hang on, that is my vernacular for saying stop and let me talk. All right. It happens I agree with Mr. Dynner. I think Mr. Youngling has gotten beyond the particular question which is about to be rephrased or reasked in terms of focusing on what support or materiality towards the crack propagation conclusion presented in answer 17, or the 100 starts given the load levels to which these load levels were conducted. And Mr. Dynner is going to put that more eloquently to Mr. Youngling and then we'll get it.

BY MR. DYNNER:

Q Mr. Youngling, I'm going to again repeat my question. I am referencing you to your answer 17 on page 15 where you, together with Dr. Johnson and Mr. Seaman, Dr. Wells and Mr. Schuster, have testified that EDG 102 was

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tested for crack propagation. And then you said one of the ways it was tested for crack propagation was to start it 100 times and you described those 100 starts. And my question to you was if you were really interested in testing EDC 102 for crack propagation, why didn't you test it at 100 starts with each one of them coming up to the reg guide requirement of 3500 KW in less than 60 seconds.

A (Witness Youngling) I'm going to ask Dr. Wells to add to my answer, but one of the major facets that we were looking at was the thermal growth and the thermal pressures placed upon the block during the rapid start of the engine and the loading of the engine. Those starts represented a mechanism for achieving that. And that's why those 100 starts were done.

Perhaps Dr. Wells can add to that.

A (Witness Wells) Mr. Dynner, at that time this was our first discovery of any block top cracks and the particular ligament cracks at that time were of considerable concern, because we were confronted with essentially a brand new problem, not totally unexpected because we had heard of the problem before in other engines, in other applications. Nevertheless, this was the first time we had seen cracks and there were ligament cracks. At that time, we felt that the crack growth was primarily the result of starts and stops. That is, low cycle fatigue accompanying both the application

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of thermal transients and of pressure, but primarily some effect of the heating that was not analyzed at that time and not understood. The objective of this test then, was essentially piggybacking on the FSAR test requirement to determine whether there was any detectable crack growth resulting from these 100 transients.

Q What month, approximately, were these 100 starts conducted in?

MR. FARLEY: Objection. Asked and answered.

MR. DYNNER: No, it wasn't.

JUDGE BRENNER: I just don't recall it if it was, Mr. Farley. He asked him about the seven-day test, but I don't recall a question about this one.

A (Witness Youngling) Mr. Dynner, if you go to Exhibit B 14, the amended exhibit, you will see that these 100 starts were performed between March 9, 1984 through March 16, 1984.

BY MR. DYNNER:

Q Just for the record, Mr. Youngling, it's true isn't it, that by just looking at Exhibit B 14, I couldn't possibly have known that those 100 starts were performed during that period, could I? Because it doesn't say so on that exhibit, does it?

A (Witness Youngling) No, I have no problem discerning that.

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Q That might be because you know the answer, Mr. Youngling. Your testimony is that it was during the period from March 9 to March 16 when the qualification testing was taking place, is that right?

A Yes, that's right. The 100 starts were done as part of the, "qualification testing of the diesel."

Q Now, in your testimony on page 15, you go on to say that the engine was operated for more than 60 hours at loads greater than 50 percent. If I can then infer from the information on Exhibit B 14 it would be true, wouldn't it, that of the 60 hours that you refer to in your testimony there were 3.5 hours at from 75 to 100 percent of load, 16 hours at 10 percent of load, and half an hour at up to 110 percent of load; is that right?

A Exhibit B 14 shows the loadings that --

Q Is that right?

A Yes.

Q Dr. Wells, I just want you to clarify for me the statement in your testimony in answer 17 where you say, "No discernible crack extension was seen as measured by eddy current examination." Was there any discernible crack extension as measured by any other way?

A (Witness Wells) There was no discernible crack growth by any means, Mr. Dynner.

Q And were those measurements made after the 100

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starts and after the completion the qualification testing that is identified on Exhibit B 14?

A The measurements for crack growth were based on careful eddy current measurements of the crack depths after the qualification run and before the 100 starts and then immediately after the 100 starts.

Q Was there at that time any measurement of the cracks, that is by that time, I mean after the 100 starts by liquid penetrant examination or did you just use eddy current?

A I would like to, if I may -- I'm not certain and I would like to refer that to Mr. Schuster.

A (Witness Schuster) There was penetrant and eddy current identified on Q 410 and reported on LDR 23-22. So penetrant examinations were performed on the block top. It is my recollection that the cylinder liners were still in place. That would be only if the block top and not the counter bore area as we indicated earlier.

Q So you couldn't tell by liquid penetrant examination the depth of the ligament cracks following the 100 starts, could you?

A You could not tell the depth but you could evaluate any changes in the length.

Q The length as seen from the blacktop meaning --

A Looking down at the blacktop.

Q It's true, isn't it, that most of the ligament cracks would appear to be the same length because they run from the stud hole all the way to the counter bore and you couldn't see any further than that, could you?

A That's true. But if I had a ligament crack that didn't run from the stud all the way to the edge and then down to the liner landing itself, I could still evaluate that 5/8 inch length.

We also did between the studs, too, from stud to stud. And in that area, again, you couldn't evaluate any changes in the indications and whether you had stud to stud cracks.

Subsequent to that, several studs were removed and eddy current was performed in a stud hole. I believe we discussed that earlier.

Q Mr. Youngling, in the three starts that were done within 60 seconds and brought up to 3500 KW, how long did you run the engine at each of those starts?

A (Witness Youngling) At least one hour.

Q And how soon after the engine had been shut down from one of those starts did you restart it?

A When the lubricating oil and the jacket water temperatures were returned to standby conditions.

Q Dr. Wells, in question 18 you make reference to a strain gage test performed on the cylinder block of EDG 103

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to determine the stress state between cylinder numbers 4 and 4. When were those strain gage tests performed?

A (Witness Wells) These tests that were performed were subsequent to the qualification tests of 103. I will get some help from Mr. Youngling if he can find the exact date.

A (Witness Youngling) I would say, Mr. Dynner, that those tests were performed in the second half of March of 1984.

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A (Witness Wells) These tests were performed subsequent to the qualification tests of 103. I would ask help from Mr. Youngling if he can find the exact date.

A (Witness Youngling) I would say, Mr. Dynner, that those tests were performed in the second half of March of 1984 or the -- yes, in the second half of March of '84.

A (Witness Wells) And if I may add, these tests were in fact conducted with simulated loop LOCA power excursions.

And of course subsequent inspections showed that those power levels did not cause the cracks to grow.

Q Well the cracks -- which cracks are you talking about that didn't grow based upon the strain gauge tests?

A The one of concern of course was the stud-to-stud crack between cylinders 4 and 5. And, of course, in our prior discussion that Mr. Youngling described the 100 fast starts, that was done on 102 which had no stud-to-stud cracks at all and he was referring to ligament cracks.

With, of course, the advantage of hindsight, we now would not expect ligament cracks to grow anyway in a series of starts. But confronted with the stud-to-stud crack between the stud holes in cylinders 4 and 5, we now were confronted with another situation and obviously potentially more serious than the ligament cracks. So at that time we decided we had better get quite serious

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about finding out what the nature of the cracking really was in that location.

Q But the strain gauge -- I'm sorry, were you finished?

A Yes, sir.

Q But the strain gauge information was used to do your analysis of the initiation of cracks, wasn't it?

A There were several tests done at the same time, Mr. Dynner. As you can see in our testimony, part of that test series was to determine whether the crack between the stud holes in cylinders 4 and 5 would propagate. And for that purpose we used a slightly different approach, it was a strain gauge but it was a strain gauge that was placed on a semi-circular strip of metal that straddled the crack and by that means we could tell how much the crack faces were separating during the tests and any increase in the range of this displacement at constant engine running conditions, of course, would be an indication that the crack was progressing in depth.

Q Just so I know we are talking about the same thing, Dr. Wells, is this strain gauge testing that you are referring to in your testimony in answer 18 the same as the strain gauge tests that are referred to in Section 3.1 on page 3-1 on the FaAA block report in June 1984?

MR. DYNNER: The block report also, again for

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those who are interested -- is Exhibit 7 of Suffolk County.

WITNESS WELLS: Yes, sir, that's correct. But the same tests were conducted for two different purposes, other related purposes. One, of course, was to define the state of stress in the uncracked region of the block of 103 which was similar in all respects to the location of the large crack that we observed in 103 but where the stresses were not perturbed by the existence of a pre-existing large crack.

At the same time we put this gauge that was referred to in our number 19 as a crack mouth opening displacement gauge, so that we could at the same time determine the range of crack gauge displacement, thereby we could obtain not only information on the mean and cyclic value of stresses but the consequence of those stresses during this test series on the propagation of the crack between the stud holes at Cylinders Nos. 4 and 5.

Q Now you only took this --

A (Witness Rau) Mr. Dynner, before you move on, you asked a question -- before you started this last one, the time before, about whether the strain gauge results were only used for crack initiation analysis.

And I wanted to make it clear that they certainly were not only used for crack initiation analysis, they were also used for the cumulative fatigue damage analysis of

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crack progression as well as for initiation calculations as well as for a general understanding of the stresses and strains in the block top region.

Q Thank you, Dr. Rau, we are going to get to that at some point.

Dr. Wells, I am curious: why is it that the strain measurements that you took during the strain gauge tests were only taken up through 3830 Kw instead of taking them up to the full required overload at 3900 Kw?

A (Witness Wells) I don't really recall, Mr. Dynner. I would like to ask Mr. Youngling to answer --

Q I would like to ask Mr. Seaman, since he is the sponsor of this testimony. Mr. Youngling is not. So maybe Mr. Seaman should know the answer to that question 18.

A (Witness Seaman) I would also have to defer to Mr. Youngling on this particular item. It deals with how the engine was run during the test, which Mr. Youngling was in charge of.

Q Dr. Wells, it's true, isn't it, that Mr. Taylor directed the cylinder block strain gauge testing, didn't he?

A (Witness Wells) That's correct, Mr. Dynner. Mr. Taylor was the site engineer responsible for directing that work.

He did not, however, direct how the engine should be run or how its load should be limited.

A (Witness Youngling) Mr. Dynner --

Q All right, Mr. Youngling, here's your chance.

A Good.

The test originally specified that we go up to the two-hour rating of the engine. However, at that particular time we were having difficulty with the engine achieving 3900 as a result of fuel that we had been delivered which had a change in heating value which did not get enough Btu's into the engine to allow us to get the full load.

As a result, when we did this test, we were only able to achieve 3830 kilowatts, which was sufficient for the FaAA people.

Q Are you going to tell me that you have fixed that fuel situation, Mr. Youngling?

A Yes, we did.

Q Dr. Wells, how did you determine the placement of the strain gauges which, I believe, are shown in Exhibits B-22 and B-23?

A (Witness Wells) We picked one location at the center of the crack mid-way between the stud holes, between Cylinders 4 and 5 because that -- of course, the midpoint of the crack is the location that would give us, we thought, the large range of crack opening displacement. Normally this is the case that the center of the crack will exhibit

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the largest opening. This was the compliance gauge. We wanted to know the comparable value of the strain in that direction where it was not perturbed by the presence of the crack.

It is one thing to measure the amount of opening and closing of a crack, but while the crack is there one cannot at all obtain the range of stress or the range of strain before the crack actually grew.

So we wanted a comparable measurement at a comparable location. Therefore we picked the location mid-way between the stud holes at Cylinders 5 and 6.

We also were interested in the distribution of stress and strain throughout the block top. Therefore, in addition to putting a gauge on the line between the centers of the stud holes, we also put a gauge at the symmetrical line down the center of the engine; that is, on the center line on the cylinders and mid-way between the two cylinders.

We also put a gauge at the front end of the engine at the block top in order to determine the possible strain concentrations that would exist because of the proximity of the end cylinders to the end of the engine.

Q I am curious: it is true, isn't it, that the ligament cracks that you noticed initiate from the stud hole, is that right?

A We believe that is the case, yes. It is known that all of the cracks that we have seen, initiation has been from an upper corner. I think the information is consistent -- and I will ask Dr. Rau or Dr. Johnson if they have any other information -- that cracks primarily do initiate at the corner of the stud hole whether ligament cracks or whether stud-to-stud cracks.

A (Witness Johnson) I believe that is primarily true. There may be an exception.

Q I am curious, Dr. Wells if, that being the case, why you didn't put a strain gauge at the edge of the stud hole location, or a stud hole location, to see what the strain was at that point?

A (Witness Wells) We have tried to calculate the distribution of stress throughout the block top. It would have been nice to have many gauges placed over a number of locations in areas of strain concentration. But the particular constraints in time of our program did not allow us to do significant machining to the block top or the underside of the cylinder heads or other work that would have been necessary in order to mount gauges around the particular stud hole or the liner counterbore.

More to the point, though, in the process of making changes like that, had we elected to do it, we would have perturbed the measurements by removing material in

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was our concern at the time.

Q You show here in these Exhibits B-22 and B-23 the locations of, I believe, if I am reading the numbers correctly strain gauge -- one of them says 11, 12 and 13 and the other I believe is 8, 9 and 10, is that right?

A That's correct, Mr. Dynner.

Q So 8, 9, 10, 11, 12 and 13 and then you have got 3, strain gauge 3 shown on Exhibit B-23.

What happened to the rest of them?

I am assuming that there were others since you've got Number 3 and then you jump to 8, 9, 10, 11, 12 and 13; is that right?

A You are certainly correct about the numbering system. We did have three gauges, if you will refer to this same B-22, that we placed between the stud holes between the Cylinders 4 and 5 diametrically opposite the large crack. Those gauges, however, failed during the test and we could not obtain readings from them.

Q I asked you before about why you didn't put a strain gauge at the edge of a stud hole.

In fact, you did do a calculation to determine what you thought was the stress at that point, didn't you?

A Yes, we certainly did. We made a number of calculations to enable us to predict from the strain gauge readings the stress distribution over the entire surface

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of the block and, of course, from that down through the thickness of the block.

Q And it is true, isn't it, that that information is set forth on Table 3-2 which is at page 3-9 of the FaAA block report, isn't that correct?

JUDGE BRENNER: Mr. Dynner, while they are checking that, I would like to adjourn after this answer unless there are one or two brief questions that you need before we adjourn.

WITNESS WELLS: Yes, Mr. Dynner, this appears to be a summary of the strain gauge data that we obtained during those tests.

BY MR. DYNNER:

Q And aside from the information on that Table 3-2 that refers to TDI and strain gauge numbers 3 and 4, is the other information on that page, to your knowledge, true and correct?

MR. DYNNER: For the record, Dr. Rau is consulting with Dr. Wells.

JUDGE BRENNER: Okay.

WITNESS WELLS: The information that is summarized in Table 3-2 represents a concise summary of the measurements that were done at, of course, the gauge locations. It certainly does not represent our efforts to extrapolate from the gauge locations anywhere else on the engine. And to the extent that we have referred at all to TDI gauges or gauge locations, as I believe you pointed out, we have not incorporated that information in our analyses.

BY MR. DYNNER:

Q Let me repeat the question:

Is the other information not included in TDI gauge information on that Table 3-2 true and correct to the best of your knowledge?

A (Witness Wells) I would like to be able to answer that affirmatively, Mr. Dynner, but this information was prepared before our QA process was completed and I need to check with the current QA version in order to give you a precise answer to your question.

Q Perhaps you can give me that information tomorrow morning.

A I will be happy to.

MR. DYNNER: Thank you, Judge Brenner.

JUDGE BRENNER: We will adjourn for the day.

As I had indicated before when we had that off the record examination of the section of the block, the Board also wished to borrow it for a short period of time to look at it among ourselves. I don't want to have custody of it overnight, so what we will do is borrow that during a break.

But I wanted to make clear our reason for doing

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that wasn't something that arose out of our examination before; we had always from the beginning intended to look at that among ourselves for a few moments, too, and we will borrow it during one of the breaks tomorrow if you are going to have it here. I don't want to be custodian of it, as I said, and thereby deprive you of your permanent ownership of it.

We will return at 9:00 tomorrow morning.

(Whereupon, at 5:11 p.m., the hearing in the above-entitled matter was recessed, to reconvene at 9:00 a.m., the following day.)

CERTIFICATE OF OFFICIAL REPORTER

This is to certify that the attached proceedings before the UNITED STATES NUCLEAR REGULATORY COMMISSION in the matter of:

NAME OF PROCEEDING:

LONG ISLAND LIGHTING COMPANY

(Shoreham Nuclear Power Station)

DOCKET NO.: 50-322 (OL)

PLACE: Hauppauge, Long Island, New York

DATE: Monday, 22 October 1984

were held as herein appears, and that this is the original transcript thereof for the file of the United States Nuclear Regulatory Commission.

(Sigt) William R. Bloom Anne G. Bloom

(TYPED) WILLIAM R. BLOOM ANNE C. BLOOM

Official Reporter

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