ORIGINAL

UNITED STATES
NUCLEAR REGULATORY COMMISSION

IN THE MATTER OF:	**DOCKET NO:**
LONG ISLAND LIGHTING COMPANY Shoreham Nuclear Power Station	50-322-OL

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UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

- X

In the matter of: :

SHOREHAM NUCLEAR POWER STATION : Docket No. 50-322-OL

(Long Island Light Company :

- X

State Office Building
Veterans Memorial Highway
Hauppage New York
Monday, September 10, 1984

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

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

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PROCEEDINGS

JUDGE BRENNER: Good morning. We are prepared to begin. Somebody close the back door, please.

Thank you.

Let's get the appearances of counsel starting on the Board's left. Staff?

MR. GODDARD: Richard J. Goddard for the NRC Staff.

MR. ELLIS: For the Long Island Lighting Company, Tim Ellis. Judge Brenner, I also should introduce in the courtroom other counsel for the Long Island Lighting Company who may also be addressing points if the Board wishes, if they come up. We have first on my far right, Milton Farley, Odes Stroupe, both counsel for Long Island Lighting Company who may speak this morning. Thank you.

MR. DYNNER: I am Alan Dynner, counsel for Suffolk County. On my right is Joe Brigati of my office. On my left is Douglas Scheidt of my office.

MR. JOHNSON: I am Adrian Johnson, Attorney General co-counsel with Mr. Palomino, representing New York State.

JUDGE BRENNER: Welcome back to some of

you, and nice to meet some of you I haven't met before. Off the record.

(discussion held off the record).

JUDGE BRENNER: Let the witnesses take the stand now. While the witnesses are being seated, we will go back on the record. I want to confirm the sequence that was agreed upon and/or directed by the Board, depending on how you look at it. During a conference call which took place this past Thursday among two of the Board members, the Staff, the Applicant and the County -- I'm sorry. The Staff was not on the call for some reason. I failed to add that. But LILCO represented that they would mention one or two things on behalf of the Staff. They did mention them, and we did nothing about it because the Staff was unavailable on the conference call for some unexplained reason. In any event, among the County and LILCO, it was agreed that we would be starting with the panel of LILCO witnesses on the subject of pistons. Thereafter, we would proceed with LILCO's panels, I guess it is, on the subject of crankshafts. We would be alert to the possibility of having to make an adjustment to possibly start LILCO'stestimony on crankshafts before completion of the testimony on pistons if it began to look as if we would not start crankshafts, I suppose, very early if not at the beginning of the second week. This was for the purpose of taking LILCO's crankshaft testimony to the extent feasible. So that its witness, Dr. Pischinger, could be here, because Dr. Pischinger it was represented to us on a conference call that he would only be available this week and next week. Am I correct so far?

MR. ELLIS: Yes, Judge Brenner, you are correct. I was hoping we could get to crankshafts this week.

JUDGE BRENNER: We have had conversations like this a long time ago, Mr. Ellis. You can hope all you want. Let me add on that note, we made no promises on the conference call. We said we would use our best efforts. If you don't make it, you would have to make other adjustments.

MR. ELLIS: We understand, Judge Brenner. We appreciate the accommodation to the extent it can be made.

JUDGE BRENNER: After that the sequence would be to take up LILCO's testimony on the heads, cylinder heads, and after that, on the cylinder blocks. Thereafter, we would go to the County's testimony. The sequence of the County's testimony has not been decided upon. The County would have its entire panel of witnesses on with respect to all four subjects, in any event, and we would ask LILCO to decide what order they wished to cross examine the County's witnesses and to discuss it with the County and inform the Board, and the Board is on the record so we would know well in advance when the County would begin its testimony.

In terms of the sequence of Staff testimony, we don't have to worry about it yet. Until somebody tells us we have to worry about it, we won't. The parties are going to have copies for each of the Board members of the testimony and the exhibits. The only case I am worried about immediately would be the P series of exhibits on the piston testimony for LILCO witnesses. If we could have that up here for each of us, we would appreciate it.

MR. ELLIS: We have furnished the court reporter with those three copies, Judge. Were there three in addition to that?

JUDGE BRENNER: Yes. You need copies for the official record. The secretary had sent out a memo asking for three copies aside from the official record.

MR. ELLIS: That's my best understanding, Judge Brenner. Is it three for the official record or just one.

JUDGE BRENNER: There is three if they are going to be an exhibit. If it is going to be bound in the testimony, it is only one.

MR. ELLIS: We have three copies here which I think should be used by the Board today. Then we will furnish the court reporter with three additional copies. We had brought one for the court reporter for the record. We will obtain two more.

JUDGE BRENNER: Can we get those for the Board, at least the P series?

MR. ELLIS: May I approach the Board?

JUDGE BRENNER: Yes. Maybe somebody else could do it for you while you take care of starting.

MR. ELLIS: All right, sir.

JUDGE BRENNER: For Judge Ferguson, you also need a copy of the piston testimony but the rest of us need only the P exhibits. Off the record.

(discussion held off the record).

JUDGE BRENNER: If there are no further preliminary matters --

MR. DYNNER: We have, I think, two matters that we ought to at least allude to. The first was the subject of discussion in our telephone conference regarding documents that we had requested from LILCO which are referred to in the LILCO testimony. Subsequent to that telephone conference LILCO informed us that in their opinion none of those documents were within the Board's order, and none of them will be furnished. We answered that in our opinion those are documents, some of which -- those are documents which LILCO's witnesses apparently are relying upon, and we would request that they be furnished, that we would raise the matter with the Board this morning. We requested LILCO to bring copies of those documents in the event that the Board should choose to take the matter up and order their production.

JUDGE BRENNER: I am not going to stop the proceeding now to discuss all the documents in the abstract. Let me say this: You will have to give me a list, Mr. Dynner. The key to the reference in the testimony as to where you think LILCO's witnesses have relied on these documents. In addition, this came up at the last moment in a conference call that was requested by the parties on another subject. So the Board is not prepared to go into it fully at that time, nor do we know and still do not know which particular documents are in dispute.

I would refer the parties to the Illinois Power Case which involved the Clinton Nuclear Plant decided by the Appeal Board in approximately 1975 or 1976. I don't have the cite. I didn't know this topic would come up again. We will follow the principles therein. They provide some guidance as to the situation with respect to documents that are relied upon. They are expressly referred to by the witness with regard to cross-examination, and the case made some distinctions between discovery and documents for the purpose of cross-examination. It also talks about a balancing test, and so on. If the documents are available, it would be the Board's desire that they be turned over because, frankly, we don't understand what the dispute is about. If the documents are not turned over, the party not turning them over is going to suffer the potential risk of delay and we could rule against them on any particular document. If LILCO has not read the case, they better read it.

MR. ELLIS: I think I am familiar with it. There are other circumstances here and I would like to address them.

JUDGE BRENNER: I don't want to digress at the beginning of the hearing.

MR. ELLIS: Yes, sir.

JUDGE BRENNER: It would be a somewhat abstract discussion. If I have the list, I will know what documents the dispute centers on. If you have a general principle that applies to all of them, I will hear it but at least I have done some preparation. Presumably you could work around the problem for today, Mr. Dynner.

MR. DYNNER: Yes, sir. The second issue which I wanted to raise relates to the Board's order striking certain portions of the County's direct testimony. I assume -- and you can tell me when you want me to raise issues of offers of proof, and that may be more appropriate immediately preceding the County's direct testimony or after.

JUDGE BRENNER: I think in the order the testimony ordered struck would be in the record, although delineated and indicated that it has been struck. That will be your offer of proof pursuant to the regulation.

MR. DYNNER: Okay. The related matter which I thought you might want to take up is the fact that there are portions, and in particular there is a portion of the direct testimony concerning the pistons which the Board struck.

There are portions of the LILCO testimony which we did not move to strike which are directly related and cover the same subject matter as testimony that the Board struck of the County. It seemed to us that it would be appropriate, perhaps, at this point to raise for the Board's consideration aspects of the LILCO testimony which if not stricken remain standing and without the rebuttal of the County's direct testimony which has been stricken.

JUDGE BRENNER: Depending on which portion of the order you are talking about, I thought I covered that eventuality.

MR. DYNNER: I am speaking specifically now about the portions of the County direct testimony --

JUDGE BRENNER: Tell me which portion of our order striking your testimony you think is related to LILCO testimony.

MR. DYNNER: Okay. It covers Page 42, and the first paragraph on Page 43 of the County's direct testimony.

MR. ELLIS: Judge Brenner --

JUDGE BRENNER: Wait a minute. I don't know about that eventuality with respect to their part. As of now the testimony has not been timely objected to which would get to it. You can cross-examine if you wish as long as it is in the record. We will make our judgment as to whether it is material or not. We did not sua sponte, go through the testimony to determine whether it all was material and notwithstanding the fact that no one objected. As always happens in the hearings, if we begin cross-examination in areas that we believe is not material, we will feel free to point that out. Depending on the extent as applied to a particular situation and not an abstract discussion, depending on the extent to which we think questioning is going to be material, the questioner might point out it is in the testimony and we could make a judgment by it. I want to deal with it as applied to a particular situation rather than the abstract.

An additional reason for doing it that way is, it seems to me, that that would be to the best advantage of your client, also, Mr. Dynner, rather than accept a general argument which would be quid pro quo to strike something that the County believes is related subject matter and also believes to be material. You will now have an opportunity to do something with it, however, rather than just taking it out completely. As you get into it, if we believe it is in fact immaterial, we will say so on our own or perhaps somebody will object.

I want to get to the witnesses, as you may sense.

MR. DYNNER: I have that impression. I would like to get to them, also.

MR. ELLIS: We may be able to help. If Mr. Dynner tells us what sections, and what his views on what he has in mind, and then we will be better prepared to deal with them as they arise in the context of the examination.

JUDGE BRENNER: That's something I had assumed, perhaps erroneously, but has been done already. Perhaps it wasn't timely in this instance. That's a good suggestion, and in the future and in all similar instances that should be done.

MR. ELLIS: I am ready for the panel, Judge.

JUDGE BRENNER: Why don't you introduce them first and then we will swear them in.

MR. ELLIS: All right. I would ask each of them to give their names beginning with Dr. McCarthy. Please state your names, your business addresses, your business affiliations, please.

DR. MC CARTHY: My name is Roger

McCarthy. I am with Failure Analysis Associates, 2225 East Bay Shore Road, Palo Alto, California.

DR. HARRIS: My name is David Harris. I am a managing engineer at Failure Analysis Associates. The address there is 2225 East Bay Shore Road, Palo Alto, California.

DR. SWANGER: My name is Lee Swanger, an engineer with Failure Analysis Associates at 2225 East Bay Shore Road, Palo Alto, California.

MR. YOUNGLING: My name is Edward Youngling, Manager of Nuclear Engineering with the Long Island Lighting Company, Shoreham Nuclear Power Station, Wading River, New York.

DR. PISCHINGER: My name is Franz Pischinger, president and owner of the FEV Company in Aachen, West Germany, and at the same time, full professor at the Aachen Technical University, address Aachen.

JUDGE BRENNER: 5110 Aachen, West Germany.

MR. ELLIS: I will furnish that for the court reporter's convenience. It is in the attachments.

MR. SEAMAN: My name is Craig Seaman, project engineer, Shoreham Nuclear Power Station, Wading River, New York.

MR. JOHNSON: My name is Duane Johnson, managing engineer of Failure Analysis Associates, 2225 East Bay Shore Road, Palo Alto, California.

MR. ELLIS: Dr. McCarthy, I think you were the only one who didn't give your position. You gave your business affiliation.

DR. MC CARTHY: Yes. I am the president of Failure Analysis Associates.

JUDGE BRENNER: Gentlemen, could you each please, all of you please stand and raise your right hand.

Whereupon,

ROGER MC CARTHY,
DAVID HARRIS,
LEE SWANGER,
EDWARD YOUNGLING,
FRANZ PISCHINGER,
CRAIG SEAMAN,
and
DUANE JOHNSON

were called as witnesses on behalf of the Applicant and, having been first duly sworn, were examined and testified as follows:

DIRECT EXAMINATION

BY MR. ELLIS:

Q. Mr. Youngling, let me address the first question to you, chairman of the panel. Do you have before you the testimony entitled "Testimony of David O. Harris, Duane P. Johnson, Roger McCarthy, Lee Swanger, Franz Pischinger, and Craig Seaman on behalf of the Long Island Lighting Company of Suffolk County contention regarding AF piston skirts on diesel generators at Shoreham, Volumes 1, with attachment, testimony of attachment, and Volume 2, Exhibits 1 through 34"?

MR. YOUNGLING: Mr. Ellis, in reading the title you referred to it as an AF piston. It is an AE piston.

Q. Thank you for the correction.

MR. YOUNGLING: Yes, I have that testimony in front of me.

Q. Do you also have Volume 2 entitled, the same title, rather than repeat it, and this is the Exhibits 1 through 34?

MR. YOUNGLING: Yes, I do.

Q. Are there any corrections to this testimony?

MR. YOUNGLING: Yes, there are. I have an errata sheet.

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JUDGE BRENNER: Are all these corrections the ones in the errata sheet that were previously received?

MR. ELLIS: These are in addition to, Judge Brenner.

JUDGE BRENNER: Are you going to bind in the earlier errata sheet?

MR. ELLIS: Yes, we are, Judge Brenner. This one we did for the convenience of the court reporter, we included those in these so that these that I am now handing to the -- to counsel and to the Board and the court reporter will be both the errata, the original errata and the latest.

JUDGE BRENNER: How many are there, the ones that have to be orally in addition?

MR. ELLIS: There are ten. Two were done originally. So eight would have to be done in addition. This venture with the Xerox machine, the backs of two of the qualification sheets were not copied. So they are attached with the backs copied.

JUDGE BRENNER: Of the errata how many are substantive that you have to make orally or otherwise not be mislead as to the meaning? Why don't you just give those. The others were done in pen and ink changes in the testimony which were

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copied and bound in. We will also bind in the cumulative errata sheet.

MR. ELLIS: Fine. There are three that should be done orally.

JUDGE BRENNER: Do them now.

Q. Mr. Youngling, will you read the corrections numbers 3, 4 and 6 from the pleading entitled "Errata to Testimony on Behalf of Long Island Lighting Company Regarding AE Piston Skirts", please.

MR. YOUNGLING: Yes. Errata Number 3 reads, Page 54. Answer: 85, line 2. Insert "greater than or equal to" before "100 percent load."

Errata 4, Page 55, question 87, line 1, insert "greater than or equal to" before "100 percent load."

Errata number 6, page 69, answer, 110. Lines 6 through 7, change "which" to "and." Change "allowing" to "experiencing', and change "cylinder liners" to "piston crown."

JUDGE BRENNER: Why don't you read that sentence as it should read as corrected.

MR. YOUNGLING: "In 1983 the Shoreham EDG's had Koppers piston rings and were experiencing an excessive amount of carbon build-up on the piston crown."

MR. ELLIS: Judge, there are also two corrections to exhibits, just two that I think would be worth reading in, if we may.

Q. Would you also read numbers 9 and 10, please, Mr. Youngling.

MR. YOUNGLING: Exhibit P-16, add a minus sign before the numbers not having a minus sign in the last column. Errata number 10, Exhibit P-29, delete the 12th through 16th pages.

Q. Mr. Youngling, are those the substantive corrections of the list 1 through 10 on the heading entitled "Errata of Testimony on behalf of Long Island Lighting Company," the most important corrections?

MR. YOUNGLING: Yes, they are.

JUDGE BRENNER: One moment. P-29, the pages are not numbered, unfortunately. I assume you removed those pages from the exhibits and will remove the incorrect exhibits. Are they removed?

MR. ELLIS: Not yet.

JUDGE BRENNER: Will you do that?

MR. ELLIS: Yes, Judge.

JUDGE BRENNER: For the official copy, number the pages P-29-1. For now is it the page that starts with the examination report?

MR. ELLIS: That's correct, Judge Brenner. Those are sheets that apply to Shoreham. The part deleted begins after the memo that is dated February 3, 1984.

JUDGE BRENNER: The memo is deleted, also?

MR. ELLIS: No, sir, the memo is not.

JUDGE BRENNER: That was page 16?

MR. ELLIS: Yes.

JUDGE BRENNER: So it should be pages 12 through 15?

MR. ELLIS: Yes. I thought I counted.

JUDGE BRENNER: There is no reason for counting it.

MR. ELLIS: I still count 16 but your suggestion has not lost its force and they will be numbered, by all means.

JUDGE BRENNER: Any examination report cover sheet? That's Page 12, reading .11.1.11, is that correct?

MR. ELLIS: .11.1.10.

JUDGE BRENNER: I counted wrong. The exhibit is not in order because I have .10 following. That explains it. So as another suggestion, you better take a look before you put the exhibits together.

MR. ELLIS: I will do that.

JUDGE BRENNER: It is in reverse order. I have 11 before 10. So the pagination was different.

MR. ELLIS: We will look at them.

JUDGE BRENNER: Number the other exhibits, too. So it will refer to it and we don't have to sit and count how many pages, particularly on P-29.

For the future, if there is going to be an errata in addition to the ones introduced by the parties, I want them written out in a cumulative list and given to the Board and the parties in advance of the day of the testimony it is going to be moved in. That way we will have all made it, the changes will be made by the parties sponsoring the evidence in pen and ink being moved in, and the errata will be moved in, also. Mr. Ellis.

MR. ELLIS: Also attached to the errata were the complete resumes of Doctors Harris and Swanger because the rear or the reverse side had inadvertently not been copied.

JUDGE BRENNER: All right.

BY MR. ELLIS:

Q. Let me ask each of you, beginning with

Dr. McCarthy, with the corrections that are stated in the pleading entitled, "Errata of Testimony on Behalf of Long Island Lighting Company Regarding AE Piston Skirts" including those attachments, is the testimony of Volumes 1 and 2 together with attachments of exhibits true and correct to the best of your knowledge and belief?

DR. MC CARTHY: It is.

Q. Dr. Harris.

DR. HARRIS: Yes, Mr. Ellis, it is.

Q. Let me ask each of you to save time. Do you adopt it as your testimony in this proceeding? Dr. McCarthy.

DR. MC CARTHY: Yes.

Q. Dr. Harris.

DR. HARRIS: Yes, I do.

Q. Dr. Swanger, is the testimony with the corrections in the errata true and correct to the best of your knowledge and belief including the attachments and the exhibits?

DR. SWANGER: Yes, it is.

Q. Do you adopt it as your testimony?

DR. SWANGER: Yes, I do.

Q. Mr. Youngling, is the testimony that I have described, Volumes 1 and 2, together with attachments and exhibits, given the corrections that are in the errata, true and correct to the best of your knowledge and belief?

MR. YOUNGLING: Yes, it is.

Q. Do you adopt it as your testimony?

MR. YOUNGLING: Yes.

Q. Dr. Pischinger, is the testimony and the corrections including the attachments and exhibits true and correct to the best of your knowledge and belief?

DR. PISCHINGER: Yes, it is.

Q. Do you adopt it as your testimony?

DR. PISCHINGER: Yes, I do.

Q. Thank you. Mr. Seaman, is the testimony with the corrections including the attachments and the exhibits true and correct to the best of your knowledge and belief?

MR. SEAMAN: Yes, it is.

Q. Do you adopt it as your testimony in this proceeding?

MR. SEAMAN: Yes, I do.

Q. Dr. Johnson, is the testimony, given the corrections on the errata, true including exhibits and attachments, true and correct to the best of your knowledge and belief?

DR. JOHNSON: Yes, it is.

Q. Do you adopt it as your testimony in this proceeding?

DR. JOHNSON: Yes.

MR. ELLIS: We would offer into evidence in the record of this proceeding volumes 1 and 2 entitled, "Testimony of David O. Harris, Roger McCarthy, Lee Swanger, Edward Youngling, Franz Pischinger, Craig Seaman, and Duane Johnson on behalf of Long Island Lighting Company on Suffolk County Contention Regarding AE piston skirts on Diesel Generators At Shoreham, Volumes 1 with attachments, and Volume 2, Exhibits 1 through 34, to be bound in, and included with that exhibit we would ask that the errata to the testimony on behalf of Long Island Lighting Company regarding AE piston skirts and its attachments be included with those exhibits as evidence in this proceeding.

JUDGE BRENNER: I asked this. I'm sorry. I don't recall the answer. Is the testimony marked up as to the errata changes?

MR. ELLIS: It will be, Judge. The testimony that you have, we will take at the break and mark it up.

JUDGE BRENNER: Do the reporter's copy.

MR. ELLIS: We will do it for the reporter's copy as well.

JUDGE BRENNER: Keep that in mind. There are comments on my copy that I don't want you to see. I will do it myself.

MR. ELLIS: You have to be charitable.

JUDGE BRENNER: All right. We will admit the evidence just offered into evidence. Mechanicaliy I would suggest we could handle it like this subject to the court reporter, unless he has a better suggestion. Let's take the errata sheet and with the attached two pages from the professional qualifications and bind that into the record as if read. Follow that also bound into the record as ifread with pen and ink changes made by Volume 1, which would be the written direct testimony and the attachments which are the professional qualifications. Do that at this point. We will thereafter handle the exhibits as exhibits ratherthan binding them in, since they are thick and pre-numbered. Is that all right?

THE REPORTER: Yes, sir.

JUDGE BRENNER: Bind in Volume 1 of 2 at this point and move it into evidence.

(Exhibits P-1 through P-34 are received.)

(The above-referenced document is inserted in the record.)

LILCO, September 10, 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)	)	
	)	

ERRATA TO TESTIMONY ON BEHALF OF LONG ISLAND LIGHTING COMPANY REGARDING AE PISTON SKIRTS

The following are changes to LILCO's testimony regarding AE piston skirts:

1. Page 23, answer 33, line 2 - change "P-9" to "P-10".

2. Page 31, answer 47, last line - change "P-9" to "P-10".

3. Page 54, answer 85, line 2 - insert "greater than or equal to" before "100% load".

4. Page 55, question 87, line 1 - insert "greater than or equal to" before "100% load".

5. Page 55, answer 87, second to last line - change "P-29" to "P-28".

6. Page 69, answer 110, lines 6-7 - change "which" to "and"; change "allowing" to "experiencing" and change "cylinder liners" to "piston crown".

7. Page 69, answer 110, line 18 - change "coat" to "coke".

8. Attachments 1 and 6 - the resumes of Dr. Harris and Dr. Swanger include two pages. A complete resume for each is attached.

9. Exhibit P-16 - add a minus sign before all numbers not having a minus sign in the last column.

10. Exhibit P-29 - delete the twelfth through sixteenth pages.

Respectfully submitted,
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DATED: September 10, 1984

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 DAVID O. HARRIS, DUANE P. JOHNSON, ROGER L. McCARTHY, FRANZ F. PISCHINGER, CRAIG K. SEAMAN, LEE A. SWANGER AND EDWARD J. YOUNGLING ON BEHALF OF LONG ISLAND LIGHTING COMPANY OF SUFFOLK COUNTY CONTENTION REGARDING AE PISTON SKIRTS ON DIESEL GENERATORS AT SHOREHAM

Testimony and Attachments

Volume 1 of 2

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I. Introduction of Witnesses

1. Please state your names, employers and business addresses.

A. (Harris) My name is Dr. David O. Harris. I am employed by Failure Analysis Associates (FaAA), 2225 East Bayshore Road, Palo Alto, California 94303.

(Johnson) My name is Dr. Duane P. Johnson. I am also employed by FaAA, 2225 East Bayshore Road, Palo Alto, California 94303.

(McCarthy) My name is Dr. Roger L. McCarthy. I am President of FaAA, 2225 East Bayshore Road, Palo Alto, California 94303.

(Pischinger) My name is Dr. Franz F. Pischinger. I am President of FEV (Research Society for Energy, Technology and Internal Combustion Engines) and full professor at the University of Aachen, Institute of Applied Thermodynamics. My address is Erkfeld 4, Aachen, West Germany.

(Seaman) My name is Craig K. Seaman. I am employed by Long Island Lighting Company (LILCO), North Country Road, Wading River, New York 11792.

(Swanger) My name is Dr. Lee A. Swanger. I am also employed by FaAA, 2225 East Bayshore Road, Palo Alto, California 94303.

(Youngling) My name is Edward J. Youngling. I am also employed by LILCO, North Country Road, Wading River, New York 11792.

2. Please state your responsibilities in your current employment relevant to the AE pistons at Shoreham and your educational and professional backgrounds.

A. (Harris) I am a Managing Engineer and manager of the fracture mechanics section of FaAA. I am responsible for the stress analysis and fracture mechanics analysis of various mechanical components. I am the principal investigator in a number of fracture mechanics contracts in which FaAA is involved, including one analysis of cracking in nuclear reactor piping that is being funded by the Nuclear Regulatory Commission. FaAA has also recently begun work on development of a computer code for NASA that will predict crack growth under a very wide variety of conditions. I have been involved in fracture mechanics analysis of crack growth for many years and, as can be seen from my resume (Attachment 1), have numerous technical publications in this area. I am the task leader for pistons for the TDI Owners Group. I am responsible for the stress and fracture mechanics of TDI pistons. My educational and professional backgrounds are detailed in my resume, Attachment 1 to this testimony.

(Johnson) I am nondestructive testing manager for FaAA responsible for all of its nondestructive testing. I am a qualified Level III inspector in eddy current and ultrasonic test methods. I supervised the eddy-current inspections of the AE pistons at TDI before shipment to LILCO and the inspections of the AE piston skirts after operation. My educational and professional backgrounds are detailed in my resume, Attachment 2 to this testimony.

(McCarthy) I am a registered professional engineer specializing in mechanical design. I am principal design engineer at FaAA. I have five degrees, culminating in a Ph.D. in Mechanical Engineering from MIT. My specialization and Ph.D. thesis was in mechanical and thermal design. My role in the piston program was to personally inspect various piston types at FaAA. I had executive oversight responsibility for FaAA's performance and performed final technical review of all the reports. I have ultimate management responsibility for the quality and caliber of FaAA's technical product. My educational and professional backgrounds are detailed in my resume, Attachment 3 to this testimony.

(Pischinger) I am familiar with the design, function and operation of pistons as a result of 26 years of experience in diesel engine design and testing. Specifically, FEV reviewed the pistons, cylinder liners and piston rings in the EDGs at Shoreham as a part of Phase II of the TDI Owners Group Design Review Quality Revalidation (DRQR) program. My educational and professional backgrounds are detailed in my resume, Attachment 4 to this testimony.

(Seaman) I am the Project Engineer with the Shoreham Nuclear Power Station. As Program Manager for the TDI Owners Group Program my responsibilities for the AE pistons included: review and approval of the quality revalidation task descriptions and Phase I and Phase II reports; review of component (AE piston) reports both for Phase I and Phase II reports; chairing the Component Selection Committee charged with the responsibility for selecting the pistons for inclusion into the DRQR Program and establishing minimum review requirements; and managing the overall program which included the design review and inspections on the AE pistons. My educational and professional backgrounds are detailed in my resume, Attachment 5 to this testimony.

(Swanger) I am a Managing Engineer for FaAA specializing in materials science. My responsibilities in reviewing the AE piston skirts included, to some extent, evaluation of metallurgical aspects, evaluation of manufacturing techniques, assessment of interaction with other components, specifically piston rings, cylinder liners, piston pin and piston pin bushing and the influence of diesel engine operation on the pistons. My educational and professional backgrounds are detailed in my resume, Attachment 6 to this testimony.

(Youngling) I am Manager of the Nuclear Engineering Department for LILCO. Since May 1984, I have held the position of Manager of the Nuclear Engineering Department reporting to the Vice President, Nuclear Operations. In this capacity, I am responsible for engineering support of the Shoreham station, including the three TDI Emergency Diesel Generators. From 1981 through 1984 as Startup Manager, I was responsible for implementing the preoperational test program for the Shoreham station. In particular, I was responsible for implementing initial operation and 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 generators. My educational and professional backgrounds are detailed in my resume, Attachment 7 to this testimony.

3. What issues have you been asked to address in your testimony?

A. (Harris, Johnson, McCarthy, Pischinger, Seaman, Swanger, Youngling) We have been asked to address the specific contentions admitted by the Board's July 17, 1984 Memorandum and Order regarding the AE piston skirts on the emergency diesel generators (EDGs) at Shoreham Nuclear Power Station (Shoreham):

> All AF piston skirts in the EDGs were replaced with TDI model AE piston skirts. The replacement AE pistons are of inadequate design and manufacturing quality to satisfactorily withstand operating conditions, because:
>
> (a) the FaAA report conclusion that cracks may occur but will not propagate improperly depends on a fracture mechanics analysis of an ideal situation which is not valid for the actual conditions which may be experienced by the Shoreham diesels,
>
> (b) excessive side thrust load, which could lead to catastrophic failure, has not been considered adequately, and
>
> (c) the analysis does not adequately consider that the tin-plated design of the pistons could lead to scoring causing excessive gas blow-by, and thereby causing a failure of proper operation.

Our testimony, in summary, is that:

(1) The FaAA conclusion that cracks may or may not initiate in the AE piston skirts, but if initiated, will not grow, is based on crack initiation and growth analyses considering the important loads and displacements reflected in the actual operating conditions to be experienced by the Shoreham EDGs.

(2) Actual operating experience shows no relevant indications in AE piston skirts.

(3) The side thrust load on the AE piston skirts is not excessive. Side thrust load is not a design or operation problem with the AE piston skirt.

(4) The tin-plated design of the AE piston skirt is intended to act as a protective covering for the piston skirt and is not the source of any excessive scuffing that could lead to failure. No known failures of pistons have been caused by tin plating.

4. Are you familiar with the testimony filed by the County on July 31, 1984 in support of its contentions regarding the pistons in this proceeding?

A. (Harris, Johnson, McCarthy, Pischinger, Seaman, Swanger, Youngling) Yes.

II. Background

5. Before proceeding to the specific points to be discussed in your testimony, please describe the AE piston skirts.

A. (Harris, Swanger, Youngling) Exhibit P-1 is a photograph of an AE piston skirt. The skirt is a cylindrical casting manufactured of 100-70-03 grade ASTM A536 ductile iron. The piston skirt fits within the cylinder and transmits the loads resulting from the combustion cycle of the EDG to the wrist pin and connecting rod, thereby exerting loads that produce torque to drive the crankshaft. The mechanical link between the crankshaft and the piston are the connecting rod and the wrist pin (connected to the piston skirt).

The complete piston consists of the piston skirt and a piston crown. Exhibit P-2 shows the top of the skirt and crown with studs that extend through the skirt to attach the crown to the skirt. Exhibit P-3 shows the crown to skirt mounting. At room temperature when no pressure is applied, the crown contacts the skirt only over an inner ring located just inside the stud bolt circle. To compensate partially for normal thermal distortion of the crown due to temperature differential, the crown is manufactured so that there is a cold clearance or gap between 0.007 and 0.011 inch between the outer contact rings on the crown and the skirt. The gap at the outer ring will close under certain pressure and temperature conditions thereby transmitting a portion of the load from the piston crown to the piston skirt through the outer contact ring. This provides a corresponding reduction in the load on the inner contact ring. In turn, this results in a reduction in the stresses in the stud boss region of the skirt where the stresses are the highest.

6. Were the gap sizes between the outer contact ring on the crown and skirt in the AE pistons at Shoreham measured?

A. (Seaman, Youngling) Yes. The gap size is measured as a standard practice pursuant to piston reassembly guidelines. For instance, gap sizes were measured when the AE piston skirts were installed in November 1983. More recently, the gaps in the ten pistons inspected during the DRQR program were measured during reassembly and were determined to be within the 0.007 and 0.011 inch range. Documentation of those measurements is included in Exhibit P-4.

7. Please describe the critical stresses on the piston skirts.

A. (Harris, McCarthy, Swanger) The pistons experience 1.35 million cycles of stress every 100 hours of engine operation. Therefore, cyclic stress levels that may produce crack initiation under high cycle fatigue conditions are of primary concern in evaluating a piston's ability to withstand operating stresses. The fatigue failure of metals, which involves the initiation of cracks, has been experimentally observed to occur as the result of repeated cycling between different stress levels. Therefore, the maximum and minimum stresses during a stress cycle are of primary interest in a fatigue analysis.

8. Please describe the factors that determine the minimum and maximum stresses in the Shoreham piston skirts.

A. (Harris, McCarthy, Swanger) Stresses in pistons are produced by various loads. The loading on the piston consists of pressure in the combustion chamber, friction and inertia. The largest loads that the piston sees occur at the top and bottom dead center. At top dead center and bottom dead center there is no relative motion between the piston and cylinder liner. Frictional forces are very small at these positions, and frictional loads are, therefore, not considered in analyzing minimum and maximum stresses. The minimum stress (largest negative or compressive stress) in the skirt is caused by the firing pressure, which occurs close to top dead center of the power stroke. The maximum stress (largest positive or tensile stress) occurs due to inertia at top dead center of the exhaust stroke. The stresses due to inertia at top dead center of the exhaust stroke are insignificant in the analysis of crack initiation, but do serve to define the opposite end of the stress cycle, i.e., the maximum stresses. Other factors such as thermal distortion, gap size and inertia loading also influence the minimum stress. The most influential factor, however, is the peak firing pressure. Gap size, thermal distortion, stud pre-load and the influence of these parameters on the possibility of momentary lift-off of the crown from the skirt are also other factors influencing the maximum stress, but the most influential factor is the inertia loading.

9. How did FaAA determine that peak firing pressure occurred at top dead center of the power stroke?

A. (Harris, Swanger) FaAA developed a pressure/crank angle diagram that shows the firing pressure for various crank angles. The largest firing pressure occurs close to top dead center of the power stroke, which corresponds to zero degree of crank angle. Exhibit P-5 is a copy of the pressure/crank angle diagram.

10. How was it determined that the maximum inertia loading on the piston occurs at the top dead center position?

A. (Harris) A kinematic analysis of the piston, connecting rod, and crankshaft assembly revealed that the maximum piston acceleration occurs at the top dead center position. The top dead center position at exhaust is of primary interest only because this is one of the loadings that influences the cyclic stresses.

11. Why did LILCO replace the AF design piston skirts with AE design piston skirts?

A. (Seaman, Youngling) In November 1983, LILCO replaced the AF skirts with the AE skirts. At that time, the Owners Group analysis of the AF piston skirt to determine the possible extent of crack propagation which could result from continued operation had not been performed. Although cracking had been observed in the AF skirts, no failures had been experienced in the Shoreham type AF skirts in nuclear operation. LILCO, however, in consideration of its engine rebuild schedule and the time required to complete the AF analysis, decided to replace the AF skirts with the improved AE design. The analysis (which was completed later) verified through optical metallography, scanning electron microscopy and fracture mechanics analysis that the cracks in the AF skirt had arrested.

12. What are the major differences in the design between the AE piston skirt now in the EDGs at Shoreham and the AF design originally in place at Shoreham?

A. (Harris, Seaman, Swanger) The major differences between the AF and AE designs are in the boss regions through which studs extend to attach the crown to the skirt. The stud attachment bosses are considerably enlarged in the AE design. The thickness of the material around the stud hole for the AE design was increased by 82% over the AF design. The extent of the thickened area around the stud hole was also increased. In addition to the modifications to enlarge the stud attachment bosses, the following changes were made:

(1) Thickening of the walls of a cavity that extends from the top of the wrist pin boss to the top of the skirt.

(2) Thickening and filling in the material around the wrist pin hole.

(3) Thickening and tapering of the circumferential rib that runs between the wrist pin bosses.

The major differences between the AF and AE designs are shown on Exhibit P-6.

13. Did the Owners Group review both the AE and AF piston skirts?

A. (Harris, McCarthy, Seaman) Yes. Even though the AE skirts had not demonstrated design or operational problems, the Owners Group decided to verify that the AE skirt design was, in fact, an improvement over the AF skirt design. The analyses showed that cracks in the AE skirt might not even initiate, but if they did, they would not propagate.

III. FaAA's Crack Initiation And Growth Analyses Show Cracks In The AE Piston Skirts Might Initiate, But Will Not Grow

A. General Approach And Assumptions

14. Please describe the FaAA analyses of crack initiation and growth in the AE piston skirt.

A. (Harris, McCarthy) The analyses included basically three steps. First, the minimum and maximum stresses in the stud boss region of the AE piston skirts were evaluated by both experimental procedures (strain gage measurements) and numerical procedures (finite element analysis). The stresses were determined for peak firing pressure and inertia at top dead center of the power stroke and for inertia loading at top dead center of the exhaust stroke. These two loading conditions provide the maximum and minimum stresses in the stud boss region and, therefore, serve fully to define the cyclic stress levels. The second step was to input these two sets of stresses into the fatigue analysis using a "modified Goodman diagram." The use of the experimental stresses, in combination with the modified Goodman diagram, predicted that cracks would not initiate in the piston skirt. Similar procedures using the numerical stresses, however, predicted that cracks could possibly initiate in the stud boss region. Therefore, a third step was necessary, i.e., a fracture mechanics analysis, to determine the growth behavior of the hypothesized initiated cracks. Fracture mechanics analysis would also determine growth behavior from any possible initial imperfections in the skirt. The growth behavior of the hypothesized cracks was evaluated from information on stresses in the uncracked piston skirt in combination with fracture mechanics procedures. The analysis showed that any cracks that could possibly initiate in the stud boss region would not grow.

15. Why were both experimental and numerical procedures used to evaluate the stresses in the stud boss region?

A. (Harris, McCarthy) The experimental observations provided checks on the accuracy of the idealizations of the finite element analyses and verified that they provided conservative results. The use of the two approaches provided cross-checks and, therefore, provided results in which we have more confidence. Furthermore, a combination of experimental and numerical procedures was believed to be necessary to provide a complete understanding of the stresses in the critical regions of the skirt and to provide information on the combined behavior of the crown/skirt assembly.

16. Please describe why stresses in the stud boss region were considered as opposed to other areas of the piston skirt.

A. (Harris, McCarthy, Swanger) The numerical analysis did consider stresses in the entire piston skirt, but the analysis was concentrated in the stud boss region. The stresses derived from the experimental procedures also considered several regions of the skirt, but also concentrated on the stud boss region. The stud boss region was emphasized for two reasons. First, inspection of all of the AF piston skirts originally installed in the Shoreham EDGs disclosed linear indications in one or more of the skirt-to-crown stud attachment bosses in each of these skirts. Second, a stress coat test performed on the AE skirt identified precisely this region as the most highly stressed area of the AE skirt.

17. Please describe the stress coat test.

A. (Harris, Swanger) The stress coat test consisted of applying a brittle lacquer on the inside of the piston skirt, stressing the skirt with hydraulic pressure and looking for cracks in the lacquer. The lacquer used is commercially available and is specifically intended for experimental determination of the location of maximum stresses. The regions where the lacquer first cracks as pressure is applied are the regions of highest stress. The piston was subjected to hydraulic pressures as high as 2,000 psig, well above any reported for the Shoreham EDGs. Only the lacquer in the stud boss region cracked, thereby indicating this region to be the most highly stressed.

18. What is wrong with the County's five criticisms of the assumptions it alleged FaAA made in its fracture mechanics analysis?

A. (Harris, McCarthy, Swanger) The County criticized FaAA's fracture mechanics analysis because it assumed (1) "complete adherence to TDI drawing dimensions;" (2) AE piston material free from imperfections; (3) "a non-corrosive operating environment free of gasses, water or vapor;" (4) a maximum peak firing pressure of 1,670 psi; and (5) a uniform skirt temperature. First, FaAA did not make the assumptions alleged by the County in (1) and (2). Second, the assumptions in (3) through (5) are reasonable.

19. Why is the County's allegation wrong that the FaAA analysis assumed "complete adherence to TDI drawing dimensions?"

A. (Harris, McCarthy, Swanger) FaAA made measurements from an actual AE piston skirt in addition to reviewing dimensions on TDI drawings. Furthermore, FaAA verified some of the dimensions used in its analysis with actual field measurements of AE piston skirts made during the engine rebuild program and the DRQR program. Representative measurements taken by these programs are included in Exhibit P-7.

20. Why is the County's allegation incorrect that FaAA assumed the AE piston material was free from any small imperfections?

A. (Harris, Johnson, McCarthy, Seaman, Swanger) Fracture mechanics analysis will actually show what level of imperfection can be tolerated in the material. The FaAA fracture mechanics analysis of the AE piston skirt, which will be discussed in detail below, showed that a crack up to 1/2 inch deep would not propagate. This also means that cracks would not grow from any possible initial imperfection under 1/2 inch in size. In addition, to preclude any significant imperfections, all AE piston skirts were inspected by liquid dye penetrant and eddy-current at the TDI factory in Oakland prior to shipment to LILCO. TDI performed the liquid dye penetrant inspections which were witnessed by LILCO and Stone & Webster. FaAA performed the eddy-current testing. Piston skirts were rejected, prior to shipment to Shoreham, for any linear indications for which the liquid dye penetrant exceeded 1/32 inch in length. Exhibit P-8 includes documentation regarding the liquid dye penetrant testing, the certificates of compliance and the receipt inspections for the AE piston skirts at Shoreham.

21. Did FaAA consider the effect of corrosion in the operating environment in its fracture mechanics analysis?

A. (Harris, McCarthy, Swanger) Yes, and FaAA concluded that the environmental conditions inside the crankcase are not expected to have an influence on the crack growth characteristics of the piston skirt material. The vapors present in the crankcase are not the type that are commonly observed to accelerate crack growth. Furthermore, environmental enhancement of crack growth is not expected at the higher frequency (225 cycles per minute) experienced by the Shoreham EDGs.

22. Does LILCO have procedures to control the environmental conditions in the crankcase that might lead to corrosion?

A. (Youngling) Yes. LILCO takes routine oil samples from the Shoreham EDGs to check for any acidity and moisture.

23. Did the AF piston skirts in the Shoreham EDGs show any signs of corrosion?

A. (Youngling) No. After 600-800 hours of operation, the AF piston skirts in the EDGs at Shoreham showed no signs of corrosion.

24. Is 1,670 psig a reasonable representation of the peak firing pressures actually experienced by the Shoreham EDG's?

A. (Harris, Youngling) Yes. The 1,670 psig peak firing pressure is reasonable based on independent FaAA and Stone & Webster measurements, TDI factory tests and the preoperational qualification test procedures.

25. Please describe the FaAA and Stone & Webster measurements of the peak firing pressures.

A. (Swanger) FaAA and Stone & Webster conducted a joint test to measure the pressure versus crank angle relationship which included measuring the peak firing pressure. A piezo-electric transducer was used directly to measure the pressure inside the combustion chamber. The angle of the crankshaft was recorded simultaneously on a separate channel of the instrumentation recording the firing pressures. The position at top dead center was recorded for every revolution.

Measurements were also taken simultaneously at the pressure cocks on the side of the cylinder using a Kiene gage to measure the cylinder firing pressure. Exhibit P-5 is the pressure/crank angle diagram developed by FaAA.

26. What peak firing pressures did TDI measure in their factory tests as reported to LILCO in the TDI instruction manual?

A. (Seaman, Youngling) The County's Exhibit 46, Document No. 6 (DSR-48, Engine No. 74011) details these measurements. During actual operation of an engine, peak firing pressure was measured at 25%, 50%, 75%, 100%, and 110% of rated power. These measurements were made for each cylinder and provided to LILCO as a part of the TDI instruction manuals supplied with the engines. The maximum pressure shown on Document No. 6 for 100% is 1,650 psig. The County incorrectly characterized some TDI measurements as high as 1,750 for 100%. As shown on the County's Exhibit 46, Document No. 6, the 1,750 psig value was actually taken at 110%. The County used this erroneous interpretation of the TDI measurements to help support its conclusion that the Shoreham EDG peak firing pressure was as high as 1,750 to 1,800 psig.

27. Please describe the measurement of peak firing pressure in the preoperational qualification test procedures.

A. (Youngling) During the preoperational qualification test, the engine was run at 3,500 kW, and a full set of firing pressures was taken at each of the eight cylinders using a Kiene gage. Exhibit P-9 includes the peak firing pressures measured before and after the crankshaft replacement. Exhibit P-9 also includes an example of the preoperational test procedures. These recorded data indicate a range of average firing pressures between 1,522.5 psig and 1,671 psig.

28. Did the FaAA analysis consider peak firing pressure under overload conditions?

A. (Harris, Swanger) The static experimental procedures considered pressures as high as 2,000 psig, which is well in excess of reported peak firing pressure. Contrary to the County's understanding, strain gage measurements were not limited to a maximum of 1,600 psig and strains corresponding up to 2,000 psig were reported on Figures 3-5 through 3-8 of the FaAA Piston Report. These figures are included in Exhibit P-10. In its numerical procedures, FaAA did not consider peak firing pressure at overload because the engine operates a relatively small amount of time under overload conditions and, therefore, would have little effect on the initiation and growth of cracks.

Subsequent analyses, using the crown/skirt interaction model described below, were performed on the cracking behavior of AE piston skirts subjected to higher hypothesized firing pressures. It was found that pressures above 2,200 psig are required before possible initiated cracks could grow.

Therefore, the conclusion drawn in the initial analysis that employed a peak firing pressure of 1,670 psig is valid for pressures up to 2,200 psig, which is well above any reported peak firing pressures in TDI R-4 engines, even under overload conditions.

29. Why is it reasonable to assume a uniform skirt temperature?

A. (Harris, McCarthy, Swanger) Temperatures measured by TDI, and independently verified by FaAA as being reasonable, indicate temperatures on the bottom of the crown are nearly constant and equal to about 200° F. This suggests the piston skirt is nearly isothermal under steady-state operating conditions where the surrounding cooling water and oil range in temperature between 190° F and 160° F.

30. How were the temperatures measured by TDI independently verified by FaAA?

A. (Harris, Swanger) TDI measured peak temperatures in the crown and furnished those temperatures to FaAA in the form shown on Exhibit P-11. FaAA made independent calculations using transient radiative and convective heat transfer analysis to verify these measurements. The analysis utilized reasonable values for coolant temperatures, convective heat transfer coefficients and combustion gas temperatures derived from the pressure/crank angle diagram (Exhibit P-5). Key features of the calculated temperature field, including peak temperature and temperature gradient through the central portion of the crown, were in agreement with TDI measurements of temperature.

31. Did the FaAA analyses consider the operating conditions experienced by the EDGs at Shoreham?

A. (Harris, McCarthy, Swanger) Yes. FaAA determined the critical loads and areas to be studied and applied the analyses and procedures to predict and evaluate the stresses in these areas. The FaAA analyses contain assumptions that closely approximate the key factors concerned with the operating conditions at Shoreham relevant to a determination of cyclic stress levels and cracking behavior. As the procedures and analyses are described below, it will become clear that the factors considered produced a realistic evaluation of the stresses experienced under operating conditions.

B. Experimental Procedures

32. Please describe the experimental procedures used to evaluate the maximum and minimum stresses in the stud boss region of the AE piston skirts.

A. (Harris, Swanger) Foil resistance strain gage rosettes were mounted on the piston skirts in several areas, including those of highest stress reflected by the stress coat test described above. Exhibit P-12 shows the location of the strain gages. The gages were connected to data acquisition and recording equipment. An actual cylinder liner was used in the test with two opposing pistons placed crown-to-crown within the liner. The region between the crowns was pressurized with a hydraulic pump to as high a pressure as 2,000 psig. The pressure load on the instrumented skirt was reacted through the wrist pin and a short piece of connecting rod to a support plate. The connecting rod was in a vertical position, thereby simulating the top dead center position of the piston.

Two separate test series were conducted using this procedure. One series was conducted with a conventional crown, and one series was conducted with a crown that was modified to widen the gap at the outer ring between the crown and the skirt so that it would not close under the applied maximum pressure of 2,000 psig.

33. What conclusions did you draw from a comparison of the experimental results from the conventional and modified crown?

A. (Harris) A comparison of the strains observed at one of the stud bosses in the piston shown in Exhibit P-~~8~~ 10 indicates that the crown-skirt gap closes at approximately 1,000 psig and distributes about 12% of the load at peak firing pressure on the outer ring. Strain gage measurements at numerous locations on the AE skirt also shows that the gap closed nearly simultaneously around the circumference of the piston, because the inflection point in the strain-pressure results always occurred at about 1,000 psig. This measured information showed gap closure at pressures below the 1,670 psig peak firing pressure measured for Shoreham and showed simultaneous closure around the ring. These experimentally observed results provided guidance in the construction of the crown/skirt interaction model discussed below. Exhibit P-13 summarizes the experimental observations related to the closure of the gap due to pressure and stress reduction due to gap closure in the AE piston skirt.

34. Under what temperature conditions were the experimental procedures performed?

A. (Harris) The experimental procedures were conducted at room temperature or, in other words, under isothermal conditions.

35. Why was this a reasonable condition when the pistons do not operate at room temperature?

A. (Harris, McCarthy) Apart from contributing to the closure of the gap and consequent redistribution of the gas firing pressure load, temperature gradients play a relatively minor role in the analysis because they do not contribute to the cyclic stress range. At operating temperatures, the top of the crown is hotter than the underside of the crown, thereby producing thermal distortion that will tend to close the gap. This results in more load being transmitted through the outer ring as is seen by the comparison of the modified and normal crown experimental results. Since the stress on the stud attachment boss is governed by the load applied to the inner contact ring, thermal distortion reduces the peak stresses due to firing pressure at the critical point (the stud boss region). A numerical analysis of thermal distortion of the crown discussed below confirmed that thermal distortion decreases the portion of the firing load carried on the inner ring and, therefore, reduces the cyclic stresses in the stud boss region.

36. What were the results of the experimental testing?

A. (Harris, Swanger) Exhibit P-14 summarizes the strain readings and calculated stresses for the complete stud boss gage rosettes. The principal strains and stresses were calculated from the rosette strain readings using the conventional equations for rectangular rosettes specified in Experimental Stress Analysis and Motion Measurement by R. C. Dove and P. H. Adams. Exhibit P-14 describes the significant stress value, the sigma III or the third (algebraic minimum) principal stress. The fracture initiation analysis showed that the experimentally derived stress would not cause cracks to initiate.

C. Numerical Procedure

37. Please describe the numerical procedure used to determine the maximum and minimum stresses in the stud boss region.

A. (Harris, McCarthy) The numerical analysis consisted of three-dimensional finite element calculations. The finite element method is an approximate technique to apply the theory of elasticity to determine how a body will perform in response to specific loads or displacements applied to it. Those loads or displacements are termed "boundary conditions" and they define what factors come into play on the boundary of the piston skirt.

38. Please give some examples of the use of finite element analysis.

A. (Harris, McCarthy) Finite element analysis has been used in the design of a very wide range of structures such as the New York World Trade Center, the space shuttle, various commercial aircraft and nuclear reactor pressure vessels and piping.

39. Please describe the finite element analyses of the AE piston skirts.

A. (Harris) The finite element analyses of the piston skirt were composed of the following two parts:

Part 1. Isothermal Analysis: An isothermal analysis of a piston skirt with a crown mounted on it was performed. Closure of the gap at the outer contact ring and thermal distortion were not considered. This part of the analysis provided base line stresses for a skirt with a pressurized crown. These stresses were adjusted for gap closure and thermal distortion by use of a crown/skirt interaction model described in Part 2.

Part 2. Crown/Skirt Interaction Model: The second part of the finite element analysis provided a means of accounting for thermal distortion, gap closure and possible momentary lift-off of the crown from the skirt. This part of the analysis consisted of the following steps:

a. Construction of a crown/skirt interaction model to provide a means of calculating cyclic stresses in the stud boss region from information on the crown and skirt stiffnesses. This model considered the crown and skirt as coupled elastic springs, whose stiffnesses were evaluated by the finite element analyses described in b. below.

b. Evaluation of the stiffnesses used as inputs to the crown/skirt interaction model. This process involved

i. Evaluation of the relevant stiffnesses of the skirt.

ii. Evaluation of the stiffnesses and thermal distortion of the crown when subjected to steady-state operation temperature.

c. Evaluation of the peak stress when momentary lift-off of the crown from the skirt occurs.

The crown/skirt interaction model of Part 2 used the stress information from Part 1 to provide cyclic stresses under steady-state operating conditions.

40. What is the major value of the crown/skirt interaction model?

A. (Harris, McCarthy) The major value of the crown/skirt interaction model is its ability to predict cyclic stresses in a piston skirt at operating temperatures.

1. Isothermal Analysis

41. What boundary conditions were involved in the FaAA isothermal finite element calculations?

A. (Harris) The following boundary conditions were assumed:

(1) a rigid wrist pin;

(2) displacement on the inner contact ring between the skirt and the crown varying linearly with the radial position at any value of angular coordinates;

(3) frictionless interface between the top of the skirt and the crown; and

(4) frictionless interface between the piston assembly and cylinder wall.

42. Please discuss why the boundary condition of a rigid wrist pin is reasonable.

A. (Harris, Swanger) A rigid wrist pin exhibits no deformation. The wrist pin in actual operation is elastic and, therefore, exhibits some deformation thereby redistributing stresses in the stud boss area. A rigid wrist pin is actually conservative in the present case, because it assumes that the deformation will occur in the piston and not in the wrist pin.

Furthermore, the wrist pin in reality is actually thicker than the piston and, therefore, more resistant to deformation than the piston.

Modeling an elastic wrist pin in finite element analysis results in a more complicated model. Therefore, FaAA made the conservative rigid wrist pin assumption initially based on constructing a tractable, but reasonable finite element model. A subsequent analysis assuming a soft wrist pin confirmed that this assumption is conservative. The soft wrist pin analysis showed that peak stresses in the stud boss of the piston skirt assuming a soft wrist pin are decreased in comparison to the stresses assuming a rigid wrist pin.

43. Please describe the comparative analysis performed using the assumed types of wrist pins.

A. (Harris) In the original analysis with a rigid wrist pin, the boundary condition in the area of contact between the wrist pin and the piston skirt was a uniform displacement (*i.e.*, a rigid wrist pin). In order to estimate the influence of elasticity of the wrist pin, another analysis was performed in which the boundary condition in the area of contact between the wrist pin and the piston skirt was a uniform pressure. This is the opposite extreme from a rigid wrist pin and represents a soft wrist pin. The calculated peak stud boss stresses in the AE piston skirt were reduced by 39% when a soft wrist pin was used. This demonstrates the conservative nature of the assumption of a rigid wrist pin.

44. Please decribe the reasonableness of the assumption that the displacement on the inner contact ring between the crown and the skirt varies linearly with the radial position at any value of the angular coordinate.

A. (Harris) This assumption provides a simplification of the boundary conditions that is accurate because the approximate 1 inch width of the support ring is small relative to the 17 inch piston diameter. The assumption of linearity provides a good approximation over such a small distance.

45. Please discuss why the assumption of a frictionless interface between the piston skirt and crown and the piston assembly and cylinder wall is reasonable.

A. (Harris) The inner contact ring between the crown and skirt is clean upon assembly of the piston, and the region is well lubricated during operation of the engine. Therefore, the assumption of no friction at the crown-skirt interface is reasonable. Assuming no friction between the piston and cylinder wall is also reasonable because the relative velocity between these two components is very low at the top dead center position of interest.

46. What other factors were considered in the finite element procedure?

A. (Harris) The magnitude of the pressure load (379,000 pounds) created by the peak firing pressure was considered. At top dead center of the power stroke, this pressure load is somewhat offset by the inertia load (9,727 pounds), which is exerted by the crown on the top of the skirt. The inertia force, therefore, was subtracted from the magnitude of the gas pressure load to determine a maximum net force on the top of the skirt of 369,300 pounds, which corresponds to an effective pressure of 1,627 psig.

47. What were the major results of of the isothermal finite element analysis using the boundary conditions described above?

A. (Harris) The peak stress (sigma III) in the stud boss region of the AE piston skirt at top dead center of the power stroke for a rigid wrist pin was calculated to be -68.1 ksi. The corresponding cyclic stress was evaluated by determining the stress at top dead center of the exhaust stroke and accounting for gap closure during the power stroke. The stress at top dead center of the exhaust stroke was determined by multiplying the top dead center power stroke stress value by the ratio of the inertia load to the pressure-minus-inertia load. Gap closure was accounted for by multiplying the finite element stress value by 88% (in accordance with Exhibit P-~~8~~10).

48. How do the results from the numerical procedures compare with those from the experimental procedures?

A. (Harris) The cyclic stress levels under isothermal conditions in the AE piston skirt that were estimated from the experimental and numerical results are presented in Exhibit P-15. As you can see, the numerical values are higher than the experimental values and, therefore, more conservative.

49. Can you explain why there is a difference, albeit on the conservative side, between the numerical and experimental results?

A. (Harris) The assumption of a rigid wrist pin is the main reason for the variance. As was described above, this assumption is conservative because an elastic or soft wrist pin would result in decreasing the stresses in the stud boss region. In fact, as shown in Exhibit P-16, the assumption of a soft wrist pin results in numerical stresses smaller than those experimentally measured.

2. Crown/Skirt Interaction Model

50. Please describe the crown/skirt interaction model.

A. (Harris) The numerical procedures that were described above analyzed stress levels under isothermal conditions. Load transfer between the skirt and the crown is influenced by thermal distortion of the crown and the initial size of the gap between the crown and the skirt. FaAA directly measured the effect of the gap on piston stresses in its experimental work, and used the experimental results on gap closure to adjust the numerical results to reflect gap closure. These were considered reasonable assumptions to evaluate the stresses, erring, if at all, to overestimate the stresses.

As time permitted, the crown/skirt analysis was conducted to consider directly the influence of thermal distortion and initial gap on cyclic stress levels and the possibility of momentary lift-off of the crown from the skirt. These factors were estimated by combining the results of the isothermal finite element stress analysis with a crown/skirt interaction model.

51. Please describe the crown/skirt interaction model used to determine the influence of thermal distortion on the load split between the loading rings and the possibility of momentary lift-off of the crown from the skirt during the exhaust stroke.

A. (Harris) The crown skirt interaction model is a simple engineering model that accounts for all the factors influencing the maximum and minimum stresses such as initial outer ring gap, thermal distortion of the crown, pressure loading, inertia loading, stud preloads and possible momentary lift-off of the crown from the skirt during the exhaust stroke. Finite element results alone do not directly provide this information. Thermal distortion was included as a thermally-induced displacement or boundary condition that was calculated by finite elements using a steady-state temperature field in the piston assembly based on experimental measurements. The interaction model treated the crown and the skirt as springs whose stiffness was estimated by finite element techniques based on the assumption that the loading rings on the crown and skirt remain parallel to one another. The stiffnesses and crown thermal distortion result from the finite element analyses provided the necessary inputs to the crown/skirt interaction model.

52. What were the basic conditions in the crown/skirt interaction model?

A. (Harris) Two basic conditions were considered in the interaction model:

(1) top dead center of the compression stroke (or beginning of the power stroke) where the maximum compressive stresses in the piston skirt occur; and

(2) top dead center of the exhaust stroke where momentary lift-off of the crown may occur.

Isothermal and steady-state operating temperatures were considered for both of these load cases.

53. Please describe the boundary conditions employed in the finite element steps in the crown/skirt interaction analysis of the skirt.

A. (Harris) This analysis of the skirt utilized the following three sets of boundary conditions:

(1) Uniform vertical displacement on the inner crown/skirt contact ring of a magnitude to react the load corresponding to 1627 psig effective pressure on the crown;

(2) Uniform vertical displacement on the outer crown/skirt contact ring of a magnitude to react the load corresponding to 1627 psig effective pressure on the crown; and

(3) A stud load applied on the stud washer landing area and reacting on the outer loading ring which is constrained to have a uniform vertical displacement.

The results of the analyses using boundary conditions (1) and

(2) above provided estimates of the skirt spring constants or stiffnesses that were required for the crown/skirt interaction model. Boundary condition (3) provided the stress levels due to inertia at top dead center of the exhaust stroke appropriate for crown/skirt lift-off. In the isothermal analysis no lift-off between the crown and skirt was considered. Therefore, the peak stress due to inertia could be obtained from the peak stress due to firing pressure simply by multiplying by the ratio of the inertia force to the peak pressure-minus-inertia force (changing the sign to account for the different direction of the loads).

54. Why is the boundary condition regarding uniform vertical displacement reasonable?

A. (Harris) A uniform vertical displacement boundary condition is simply a convenience for calculating the stiffnesses of the skirt, and this assumption is not key to the FaAA evaluation of stresses. Comparison with finite element calculations where the displacement was not required to remain uniform provides similar results. In addition, the experimental results shown in Exhibit P-10 indicate that gap closure will occur uniformly around the circumference of the piston/skirt.

55. In addition to the three sets of boundary conditions, were any other factors considered in the expanded finite element analysis of the skirt?

A. (Harris) There were basically three other factors. First, a rigid wrist pin was assumed in the first and second sets of boundary conditions. No wrist pin was utilized for the third set, i.e., stress when momentary lift-off occurs. Second, all of the finite element runs on the skirt models were performed for uniform temperature, reflecting the true operating condition of the skirt. Third, a stud preload of 6,600 pounds was used based on strain gage measurements obtained by measuring the strain in a stud when a crown was mounted on a skirt in accordance with manufacturer's specifications. This measurement was made by FaAA using strain gages.

56. Please describe the finite element analysis of the crown performed as a portion of the development of the crown/skirt interaction model.

A. (Harris) Three parameters related to the crown were of interest in the crown/skirt interaction model. These were the stiffness of the crown when subjected to pressure on the combustion side, stiffness of the crown when subjected to a load on the outer contact ring and thermal distortion of the crown when subjected to steady-state operating temperature. The stiffnesses of the crown were evaluated by finite elements by subjecting the crown to the load of interest (pressure or load on the outer ring) and calculating the resulting movement of the outer contact ring relative to the inner contact ring. The stiffness (or spring constant) is then equal to the load divided by the corresponding displacement.

The thermal distortion (as measured by the thermally induced relative displacement of the two concentric load rings) was calculated to be 0.0106 inch. This value was obtained by using the experimentally determined crown surface temperature measurements as boundary conditions for a steady-state heat conduction analysis of the temperatures in the interior of the crown. These temperatures were then used in a finite element thermoelastic calculation of the thermally induced displacement in the crown.

57. What were the major results drawn from the crown/skirt interaction model?

A. (Harris) The major results drawn from the crown/skirt intereaction model were the cyclic stress levels in a piston skirt at isothermal and steady-state operating temperatures considering the influences of the initial gap and the possibility of momentary lift-off of the crown from the skirt. Exhibit P-17 summarizes the isothermal and steady-state operating temperature cyclic stresses for an AE piston skirt with various initial gap sizes. Results are presented for several sets of estimated skirt stiffnesses.

58. How do the cyclic stresses under isothermal and steady-state operating temperatures compare?

A. (Harris) The results presented in Exhibit P-17 show that the cyclic stresses are less severe under steady-state operating conditions, because the minimum stresses are increased (less compressive) without a corresponding increase in the maximum stress. Therefore, the cyclic stresses are actually largest under isothermal conditions.

59. How do the gap closure pressures and load splits evaluated for the crown/skirt interaction model compare to those observed experimentally as a result of the strain gage measurements?

A. (Harris) The gap closure pressure and load split between the rings were calculated from the crown/skirt interaction results by an equation that assumes the peak stress is governed by the load on the inner ring. Exhibit P-18 shows that this assumption is a good approximation because the stresses for a given load that are applied by a uniform displacement on the inner ring are much higher than the corresponding values for the loading on the outer ring. Exhibit P-19 summarizes the calculated gap closure pressure and load split at nominal, minimum and maximum values in comparison to the experimental observations. The nominal, minimum, and maximum values in the column of experimental results provide the range of values actually observed. The corresponding values in the column of calculated values were calculated using the nominal, minimum, and maximum values of the initial gap. The comparison between the experimental and numerical results can also be made by estimating skirt stiffness from experimentally observed load splits and gap closure pressures by using equations developed for the crown/skirt interaction model. Exhibit P-20 compares the results of the estimated skirt stiffness from experimentally observed results with the finite element stiffnesses. Experimental values of the outer skirt stiffness are generally lower than the numerical value. Overall, the agreement between the experimental and numerical sets of data are quite good, which verifies the validity of the crown/skirt interaction model.

60. How do the different sets of stiffnesses affect the important results drawn from the crown/skirt interaction model?

A. (Harris) The calculated cyclic stresses, which are the most important results of the crown/skirt interaction model, are not strongly dependent on the values of the skirt stiffnesses. This can be seen from Exhibit P-17 which presents calculated cyclic stresses in the stud boss region for various initial gap sizes and loading conditions that were calculated using different sets of skirt stiffnesses. For a given gap and loading condition, the cyclic stresses are nearly the same for each of the sets of stiffnesses.

D. Fatigue Crack Initiation Analysis

61. What was the next step in the evaluation of the integrity of the piston once the cyclic stresses had been defined?

A. (Harris, McCarthy) The next step was to determine if cracks can initiate when the material is subjected to these cyclic stresses.

62. Please describe the analysis you performed to determine whether cracks would initiate in the AE piston skirts.

A. (Harris, McCarthy) As noted, the pistons experienced 1.35 million stress cycles every 100 hours of operation. Therefore, crack initiation under high cycle fatigue conditions is the main consideration. The fatigue property called the endurance limit of the material is of primary interest. The Iron Castings Handbook, edited by C. F. Walton and T. J. Omyer, indicates that the endurance limit of ductile cast iron with the properties of the 100-70-03 material used in the AE piston skirt is conservatively 30 ksi. Comparison of this fatigue property of the skirt material with the cyclic stresses evaluated from experimental measurements and finite element calculations allowed us to predict whether cracks would or would not initiate.

63. Please explain the procedure you followed to predict crack initiation behavior.

A. (Harris, McCarthy) The endurance limit of a material is directly applicable to the case where the mean stress is zero and the stress system is uniaxial. In order to perform the analysis on the AE piston skirt, procedures to account for a non-zero mean stress were employed. Non-zero mean stress was treated in the standard manner using a modified Goodman diagram. The Goodman diagram is the means by which the allowable cyclic stress for infinite life (or no crack initiation) for a given mean stress can be plotted. These conditions are summarized in Exhibit P-21. The results in Exhibit P-21 are for uniaxial stress, and are directly applicable to the current problem because the experimental results discussed above show that stresses are nearly uniaxial in the highly stressed region of the stud boss area. The crack initiation criterion was used in combination with the cyclic stresses shown on Exhibit P-17 to evaluate the possibility of crack initiation for various gap sizes. The mean stress and stress amplitude for a given condition were plotted on a figure such as the one shown in Exhibit P-21. If the plotted point falls inside the solid lines (stress envelope) then crack initiation will not occur. An endurance limit of 30 ksi was used, and a modified Goodman diagram was used to adapt this endurance limit for cases other than zero mean stress. This same procedure was utilized in evaluating crack initiation from the experimental measurements and finite element results from both the isothermal and crown/skirt interaction calculations.

64. Please describe the modified Goodman diagram?

A. (Harris, McCarthy) The modified Goodman diagram is a plot defining the relationship of mean stress and cyclic stress for an infinite life. It is primarily based on experimental observations of the failure of fatigue specimens that were subjected to a given cyclic and mean stress. A considerable amount of experimental data has been generated over the last several decades that provides the basis for using the modified Goodman diagram for analysis of fatigue with non-zero mean stress. In developing the modified Goodman diagram, failure (or crack initiation) was considered to occur if the material permanently deforms (plastically deforms or yields) as opposed to actually breaking.

65. Please describe the results of the fatigue analysis using the stresses evaluated from the experimental measurements and the isothermal finite element calculations.

A. (Harris) Exhibit P-22 is a plot of the allowable stress envelope for infinite life with the stresses at various gap sizes indicated. The stresses for isothermal conditions are shown. Exhibit P-22 shows that cracks are predicted not to initiate in AE skirts under cyclic stresses corresponding to the experimental results for any gap size and that cracks may or may not initiate under cyclic stresses corresponding to the finite element results depending on the yield strengths and gap size. The modified Goodman diagram is drawn for the range of values of yield strength from 63.5 to 70.5 ksi that bound the results of measurements of the yield strength of material taken from an AE skirt drawn from the lot of skirts now in use at Shoreham.

66. Did the results of the fatigue analysis using the stresses evaluated from the crown/skirt interaction model confirm that isothermal conditions are more severe than steady-state operating conditions?

A. (Harris) Yes. Exhibit P-23 shows the results for 0.007 and 0.011 inch initial gaps for isothermal and steady-state temperature distribution conditions. The results on Exhibit P-23 show that conditions for crack initiation are more severe under isothermal conditions. Therefore, cracks are more likely to initiate under isothermal than steady-state conditions. Exhibit P-23 also shows that cracks might initiate in the AE skirts under certain conditions, such as under isothermal conditions with a 0.011 inch gap in a piston of relatively low yield strength. A smaller initial gap is beneficial in reducing the cyclic stress under isothermal conditions, but contributes to the possibility of momentary crown lift-off. Such lift-off is not detrimental, however, because it does not have an adverse influence on the operation of the AE piston skirt at Shoreham and does not increase the cyclic stress.

67. Do the results of the finite element analyses showing that isothermal conditions are more severe than steady-state operating conditions support a conclusion that the experimental results are applicable to operating temperature conditions?

A. (Harris) Yes. The overall conclusion based on the experimental measurements is that cracks will not initiate in the stud boss region of the AE piston skirt. The fact that the crown/skirt interaction model predicted lower cyclic stresses under steady-state temperatures supports a conclusion that the experimental results showing no cracks under isothermal conditions also applies to operating temperature conditions.

E. Fatigue Crack Growth Analysis

68. Does the initiation of a crack mean that the piston will eventually fail?

A. (Harris, McCarthy, Swanger) No. The initiated crack may or may not grow. Even if it does grow, it may do so only for awhile and then arrest before growing to the point where the piston would fail. Fracture mechanics analysis is commonly employed to make this determination. Fracture mechanics is the body of engineering knowledge that is applicable to the analysis of the growth and stability of cracks in solids.

69. What is the purpose of fracture mechanics analysis?

A. (Harris, McCarthy) Modern design analysis is able to insure the safe operation of such structures as aircraft, spacecraft, pipelines and turbines, etc. through the application of engineering fracture mechanics. It is now common to design and operate critical structural components in such a manner that the initial presence of crack-like defects is assumed, and the possible growth of the defects due to fatigue is calculated. For example, even the highly-stressed rotating parts of military aircraft gas turbine engines are designed assuming the presence of small cracks that grow in fatigue. In fact, the United States Air Force has a formal procedure that expressly requires the manufacturer to adopt this design approach. Many other structures, i.e., civil, mechanical and marine, are designed with the same philosophy. This philosophy merely reflects the fact that all materials and structures contain crack-like defects on some scale and that the primary objective of design analysis is, therefore, not to prevent initiation but to assure that such cracks cannot grow to significant size. Fracture mechanics analysis provides this assurance.

70. Please describe the methodology FaAA employed to determine whether cracks would grow in AE piston skirts.

A. (Harris) Because the crack initiation analysis using the conservative numerical finite element results predicted that crack initiation could possibly occur, a fracture mechanics analysis of the growth (and possible arrest) behavior of the hypothesized initiated cracks was performed. Not all crack tips are unstable, contrary to the County's testimony, and fracture mechanics provides the means of analyzing the stability and possible growth of cracks in solids. In the case of the AE piston skirt, the solid was considered as an elastic body. Standard linear elastic fracture mechanics procedures were used to evaluate the stresses near the tip of the crack from information on stresses in the uncracked skirt. The stress intensity factor provided the measure of the stresses near the crack tip. Elastic-plastic behavior of the material in the highly stressed region of the stud boss was accounted for by appropriate procedures. The fracture mechanics properties of the AE piston material were compared with the fracture mechanics parameters computed by the finite element analyses, stress and fracture mechanics evaluation.

71. What were the fracture mechanics properties required in this analysis?

A. (Harris, McCarthy) Two fracture mechanics properties were necessary for this analysis: the fracture toughness of the material and the fatigue growth crack characteristics of the material.

72. Please describe the fracture toughness property utilized in this analysis?

A. (Harris) Exhibit P-24 summarizes some relevant fracture toughness data from the literature. A fracture toughness of KIC of 40 ksi-in 1/2 was considered a reasonable, but conservative, value of fracture toughness. This value is conservative because it represents a temperature of 70°F. Fracture toughness of cast iron is influenced by temperature within a range (room temperature to approximately 300°F). As temperature increases, the fracture toughness increases. As noted above, actual measurements of temperature during operation indicated that the temperature of the piston skirt is a uniform 200°F. Therefore, the use of a value measured at 70°F is conservative.

73. Please describe the fatigue crack growth characteristics used in this analysis.

A. (Harris) For a given material operating in a given environment, the rate at which a fatigue crack will grow is dependent mainly on the cyclic value of the stress intensity factor (Delta K = Kmax - Kmin). Other factors, such as the mean value of the stress intensity factor (represented as R = Kmin/Kmax) also influence, to a lesser degree, the rate at which a fatigue crack grows. The threshold cyclic stress intensity factor below which cracks will not propagate is expressed as Delta Kth. The Delta Kth of a particular material is a function of the R-value. The Foreman relation for crack growth (which is a widely used relationship in fracture mechanics analysis) was combined with the treatment of the influence of the R-value on Delta Kth from Metallurgical Transactions by A. Yuen, S. W. Hopkins, G. R. Leverante and C. A. Rau, to determine the influence of R on Delta Kth. Cracks are considered not to propagate for a given Delta K and R if Delta K is less than the Delta Kth at the given R-value.

74. Please describe the procedures used to perform the fracture mechanics analysis.

A. (Harris) The fracture mechanics properties described above and the calculated stress intensity factors from the finite element stresses were used in this analysis. The finite element results represented elastically calculated stresses.

The plastically redistributed stresses corresponding both to the isothermal and steady-state operation were analyzed. Two sets of calculations were performed, one for nominal tensile properties and one for poorer case tensile properties bound from the measurements of tensile strengths of the AE skirt drawn from the lot of skirts now at Shoreham. The BIGIF fracture mechanics code was used to obtain the elastic-plastic redistributed stress fields that exist after yielding. Residual tensile stresses were predicted by the use of BIGIF in the localized region where the cracks could possibly initiate. The BIGIF calculations accounted for the variation in Delta Kth with the stress ratio, the R-value. BIGIF was also used to calculate the stress intensity factor range, Delta K.

75. What is the BIGIF fracture mechanics code?

A. (Harris, McCarthy) BIGIF is a general purpose fracture mechanics code that is used in the analysis of crack stability and fatigue crack growth. It is based on linear elastic fracture mechanics, but does contain capabilities for treating contained plastic deformation. BIGIF is used by many different organizations on a wide variety of problems. In addition to its use on pistons and crankshafts of the TDI engines, it has been applied to cracking problems in pressure vessels, pipes, steam turbine and generator rotors, spacecraft components and gear teeth. Its great versatility makes it applicable to a very wide range of problems.

76. Did the fracture mechanics calculations show that the cracks that could possibly initiate in the AE piston skirts would not grow?

A. (Harris) Yes. For the AE skirt, the fracture mechanics calculations revealed that the Delta K and R values for all crack depths do not exceed the threshold conditions. Therefore, the cracks in the AE skirt that were predicted possibly to initiate based on the conservative finite element results were shown not to grow under isothermal or steady-state conditions. Exhibit P-25 shows the representative values of R and Delta K for various hypothesized crack depths for an AE piston skirt with a 0.007 inch gap operating under steady-state temperature conditions. This is the most severe condition from a crack propagation standpoint. Exhibit P-25 also shows the corresponding threshold condition for crack growth. It is seen that the operating conditions are always below the threshold condition. Therefore, any cracks that may initiate will never grow, even if they were as deep as 1/2 inch. Furthermore, contrary to the County's erroneous hypothesis, any imperfections introduced during fabrication of the piston also would not grow, even if they were as deep as 1/2 inch.

77. Do you consider your analytical results to reflect the possibility of crack growth under actual operating conditions?

A. (Harris, McCarthy, Swanger) Yes. The stresses upon which the fracture mechanics analysis was based considered the major loads and displacements actually influencing the piston skirts under operating conditions. Assumptions required in the analytical process were conservative and resulted in overestimating the stresses. Those assumptions have been discussed above and include, for instance, the use of a rigid wrist pin. The conservative nature of the assumptions can be seen by comparing the experimental results with the finite element results. The finite element stresses were invariably higher. Even the use of these conservative stresses indicated that cracks will not grow in the AE piston skirt. FaAA also considered the operating environmental conditions inside of the crankcase of the Shoreham EDGs and concluded that they would not be expected to have an influence on the crack growth characteristics of the piston skirt material.

IV. Operating Experience

78. Are you aware of any failures of AE piston skirts in operation?

A. (Harris, Seaman, Swanger) No. The DRQR created a computerized component tracking system to gather nuclear and non-nuclear experience on TDI R-4 engines, as well as additional information on other EDGs in nuclear service. No AE piston failures were reported in the component tracking system.

79. Have inspections of AE piston skirts after operation been conducted?

A. (Johnson, Seaman, Swanger, Youngling) Yes.

Inspections using eddy-current and liquid dye penetrant were performed on a total of fourteen skirts including ten AE piston skirts from the Shoreham EDGs and four AE piston skirts at two non-nuclear installations.

80. What was the significance of these inspections?

A. (Harris, McCarthy) Each inspection added an additional piece of information that the AE piston skirts are successfully operating without developing cracks. These inspections are merely data points and are not used to prove, but do serve to confirm, the validity of the fatigue crack initiation or fracture mechanics analyses. Conclusions from these analyses stand on their own.

81. What is a liquid dye penetrant inspection?

A. (Johnson, Swanger) Liquid dye penetrant inspection is a method of nondestructive testing used to detect and indicate discontinuities that are open to the surface. It can be used for the inspection of most structural materials. Examination by liquid penetrant testing is accomplished in five basic steps:

1) Precleaning. Each item to be inspected must have contaminants, such as dirt and oil, removed form the surface to be inspected.

2) Applying the penetrant which is colored red for high visibility.

3) Removing the penetrant quickly after it is set. Penetrant will be left within the discontinuities for lack of time to escape.

4) Applying the developer. As the penetrant is pulled into the developer an indication appears.

5) Visual examination and interpretation. Qualified inspectors can tell whether an indication is from a crack, lamination, lack of fusion, porosity, etc.

This test method is sensitive to imperfections such as cracks, shrinkage cracks, surface porosity, cold shuts, grinding and heat-treat cracks, seams, forging laps and bursts, cold lap, lack of fusion, etc.

82. What is an eddy-current inspection?

A. (Johnson, Swanger) Eddy-current tests are high-resolution NDE procedures that were used on the AE piston to determine if a liquid dye penetrant indication corresponded to a significant size crack-like defect or not. FaAA used its Procedure NDE 11.5, Rev. 0 in its inspection of the EDG 102 pistons and NDE 11.5, Rev. 1 in its inspections of the EDG 101 and 103 pistons. Because of the purpose of eddy-current tests, its use was limited to portions of the skirt where liquid dye penetrant had revealed an indication that needed further examination. In this case, a penetrant indication 1/32 inch or longer required eddy-current examination.

The eddy-current test itself involved scanning a coil over the test area and monitoring the electrical impedence of the coil. Material defects cause a change in the coil impedence which generates a signal. A signal generated from a crack or a simulated crack was used as the crack standard. When the material at issue was scanned, all eddy-current crack indications exceeding a specified fraction of the crack standard were recorded.

83. Why it is reasonable to apply the 1/32 inch length criteria to determine what indications shown from the liquid dye penetrant will be subjected to further analysis?

A. (Harris, Johnson, Swanger) The presence of small imperfections in any cast material is normal. Contrary to the County's assertion, indications smaller than 1/32 inch in length cannot contribute significantly to the possibility of crack initiation and propagation. This is supported by the results of the fracture mechanics analysis of crack growth, which predicted that cracks less than 1/2 inch deep would not grow. Cracks of 1/2 inch depth would be expected to be at least 1 inch in surface length.

84. Please describe why it is reasonable to record signals exceeding a certain fraction of the signal from the crack standard.

A. (Harris, Johnson) For instance, the crack standard for piston skirt inspection per NDE 11.5, Rev. 1 is 1/16 inch in length by 1/32 inch in depth. At the rejection level of fifty percent of the signal from the standard specified in Rev. 1, subcritical defects (1/2 inch deep by 1 inch long) are easily detected. The Rev. 0 inspection was approximately a factor of two more sensitive than the Rev. 1 inspections.

85. Please describe the inspections of the ten AE piston skirts from Shoreham.

A. (Johnson, Seaman, Youngling) After 300 hours total operation, including 100 hours at 100% load, liquid dye penetrant and eddy-current inspections were conducted of the stud boss region of AE piston skirts from EDGs 101, 102 and 103. LILCO and Stone and Webster performed the liquid dye penetrant test at the stud boss attachment areas for all three engines utilizing approved LILCO procedures. The results of those inspections are included in Exhibit P-26. FaAA conducted the eddy-current inspections which were observed by representatives from LILCO. The results of these inspections for all three engines and the FaAA eddy-current procedures are included in Exhibit P-27. The inspections revealed no relevant indications.

86. Describe the characterization of a nonrelevant indication.

A. (Harris, Johnson, McCarthy) It is important to remember that some surface liquid dye penetrant indications are common in all iron castings. They can result from superficial features such as tool marks, pits, inclusions and other irregularities in the surface of the casting. These indications do not have any effect on fatigue behavior of an AE piston at Shoreham due to their bluntness and/or small depth.

87. Why are inspection results after 100 hours at 100% load meaningful in assessing the reliability of the AE piston skirts?

A. (Harris, McCarthy, Swanger) Each AE piston skirt incorporates 8 individual highly-stressed fillets in the intersections of the four stud attachment bosses with the wrist pin bosses. There are, as in all cast articles, minor variations in material composition, dimensions and physical properties as well as minor differences in stresses that result from the expected variations in temperature and pressure in the cylinders, stud preload and machining tolerances. Thus the 192 highly-stressed areas (24 piston skirts x 8 boss fillets) in the 3 Shoreham EDGs represent a population of similar fatigue samples with a distribution of endurance limits, <u>i.e.</u>, stress levels below which the samples exhibit infinite fatigue lifetime. Conventionally, the endurance limit is accepted to be the stress level corresponding to 10 million stress reversals. Information contained in the <u>Iron Castings Handbook</u>, by Walton and Olpar, 1981, (p. 341) (Exhibit P-29) shows that the cyclic stress for cracking in 10 million cycles is 93% of the cyclic stress for cracking in 1.35 million cycles. Scatter of 7% on stress is commonly observed in fatigue data. Therefore, it is likely that cracking indications would be observed in the population of inspected stud bosses if they had been operated for 1.35 million cycles at stresses above the endurance limit.

88. Please describe the inspections performed on the AE pistons in non-nuclear operation.

A. (Johnson) FaAA inspected two AE skirts from a RV-16-4 engine at Kodiak Electric Association in Alaska. This engine had experienced over 6,000 hours of service at an average peak firing pressure reported by the utility to be approximately 1,200 psi. FaAA also inspected two AE piston skirts from the TDI R-5 prototype engine after approximately 622 hours of operation at 2,000 psi. Neither the Kodiak nor the R-5 prototype engine inspections revealed any relevant indications. These inspection reports are included in Exhibit P-29.

89. Are the AE pistons in the TDI R-5 engine significantly different from those in the EDG's at Shoreham?

A. (Harris, Johnson, Swanger) No. There are variations reflecting design evolution between the R-5 AE piston skirts and the Shoreham piston skirts. These variations involve an area that is irrelevant to the analysis of crack initiation in the stud boss region. The County specifically stressed the fact that the R-5 engine has an operating speed of 514 RPM while the operating speed of the Shoreham EDG's is 450 RPM.

The increased inertia associated with the increased RPM reduces the effective peak firing pressure. For the R-5 engine, the effective peak firing pressure at 450 RPM would be 1,957 psig as opposed to its actual value of 1,944 psig at 514 RPM. The effective peak firing pressure on the R-5 engine at 450 RPM is still approximately 20% higher than the Shoreham peak firing pressure. The County ignored the more important point, i.e., the fact that the R-5 has operated successfully for over 622 hours at 2,000 psig. The fact that an AE piston skirt in the R-5, which represents an earlier stage in the evolution of the design, withstood that operation without relevant indications is the more persuasive point about the integrity of the AE piston skirts at Shoreham.

90. Please describe why the Kodiak operating experience is meaningful in evaluating the suitablity of the AE piston skirt for safe operation at Shoreham.

A. (Harris, McCarthy) As mentioned above, the Kodiak experience with AE piston skirts involved 6,000 hours at a reported average peak firing pressure of 1,200 psi. In spite of the lower peak firing pressure, this experience is relevant because it involves a large number of stress cycles (about 80 million). The fact that no indications of excessive wear or fatigue cracking were observed after so many cycles provides additional evidence of the integrity of the AE piston skirt.

V. Side Thrust Load
Is Not A Design Or Operation
Problem With The AE Pistons At Shoreham.

A. Shoreham AE Piston Skirt

91. Please describe side thrust load.

A. (Pischinger, Swanger) All piston engines generate a side thrust load between the piston and the cylinder as the result of the balance of forces between the piston, the connecting rod and the cylinder wall. During the power stroke, as the piston descends in the cylinder from the top dead center position, the motion of the connecting rod causes it to assume an increasing angle greater than zero degrees with respect to the axis of the cylinder. The longitudinal force in the connecting rod is resolved into axial and transverse components in the piston. The axial component is generated by the net pressure force acting on the piston. The transverse component is the geometric result and is manifested as a force between the piston and the cylinder wall. This latter force, which varies with cylinder gas pressure, speed of the engine and the crankshaft angle, is the piston side thrust.

92. Is side thrust load a significant consideration in the design of a diesel engine?

A. (Pischinger) No. In current diesel engine design, side thrust, much less the excessive side thrust alleged by the County, is simply not a consideration. Proper lubrication incorporated in the piston design makes side thrust load a nonissue. With adequate lubrication, the consequences of side thrust load will never reach the level described by the County. Pistons, including the AE pistons, are designed to lubricate the skirt to reduce friction. Exhibit P-30 details the lubrication system on the Shoreham EDGs.

93. Will side thrust load dramatically increase the temperature on one side of the piston?

A. (Pischinger, Swanger) With an adequately lubricated piston, side thrust will not create a dramatic temperature differential. In order to create the temperature effect described by the County, the piston and skirt would have to come into unlubricated contact. Lubrication minimizes the piston skirt/cylinder contact and facilitates heat flow from the piston to the liner.

94. Has operational experience shown that side thrust load is not a problem with pistons in nuclear service?

A. (Harris, McCarthy, Seaman, Swanger) Yes. The component tracking system does not indicate adverse consequences from side thrust on any pistons in nuclear service. Furthermore, the component tracking system does not indicate any failure on R-4 engines in either nuclear or non-nuclear service. This R-4 experience is helpful because the factors influencing side thrust load, crank angle, reciprocating piston weight and connecting rods, are the same on all R-4 engines and are not affected by individual piston designs.

95. Why do you disagree with the County's dramatic conclusions regarding the effect of piston side thrust load?

A. (Pischinger, Swanger) As described above, current design experience has indicated that side thrust is not a problem. The County characterizes the side thrust as excessive based on an outdated standard. Most modern engines would exceed this outdated standard. It has no meaning to current engine design. The County's standard is drawn from Diesel Engine Design by T.D. Walshaw, 1949 (County's testimony, p. 48, footnote 60). The dated value of this 35 year old source is exemplified by various information drawn from the reference. For example, for a roughly 17 inch bore four stroke diesel, a peak firing pressure of 700 psig (p. 80) and BMEP of 70 psig (p. 71) are given. The County's reference also states that two stroke diesels are "used universally for the higher powers, say above 3000 BHP per unit" (p. 47). These statements are at odds with more modern design practices and show the dated nature of the 85 psi limit on unital side thrust loads. Similar problems are found in the County's other reference on side thrust, Internal Combustion Engine by V. L. Maleev, 1945 (County's testimony, p. 49, footnote 61) when the reported BMEPs (pp. 352, 353, 355) and peak firing pressure (pp. 206, 207, 355) are compared with modern practice. Improved materials in more modern engines allow higher operating pressures to be attained. For instance, Maleev describes cast iron piston material with a tensile strength of 20ksi - 30ksi (p. 499), whereas the nodular iron in TDI engines is approaching 100 ksi in tensile strength. The textual references noted from both references are included in Exhibit P-31.

In summary, the 35-40 year old material from which the County obtained its values of recommended side thrust does not reflect modern design practices. As noted above, design and operating experience indicates that side thrust load is simply not a consideration.

96. Is there any evidence of excessive side thrust on the AE piston in the EDG's at Shoreham?

A. (Seaman, Swanger) No. The County cited several reports by the DRQR of scuffing on the AE piston skirts. These reports, however, include not only a report of scuffing, in some cases, but a conclusion that it was acceptable or normal wear. Copies of the reports cited by the County are attached to this testimony as Exhibit P-32. Furthermore, as the County pointed out, DRQR personnel visually inspected the AE skirts at Shoreham and did not observe excessive side load wear.

97. On what basis did the County challenge the conclusion of the DRQR inspections?

A. (Seaman, Swanger) The County stated that during its June 1984 inspection the County's consultants noticed a "heavy wear pattern" on one AE skirt. The County also indicated it noticed that the tinplated area showed indications of "abraded surfaces and evidence of debris that had been previously imbedded in the plating, but since removed." As will be discussed below, the purpose of the tinplating is to capture and absorb minute particulate material from the combustion chamber so that it will not harm the cylinder liner.

98. Why is the County's belief wrong that there may have been side thrust markings in some of the cylinder liners?

A. (Seaman, Youngling) The only reason the County offered in support of its belief is that its consultants "surmised" that deglazing observed was necessitated by the side thrust markings. The County went on to describe deglazing as "a maintenance operation in which the cylinder liner surface is honed." The County's June 1984 inspection was of EDG 103 during the block replacement. The cylinder liners had just been rehoned at TDI as a part of that engine rebuild. This is normal practice in an engine rebuild and has no relationship to the piston skirt performance prior to the rebuild. The rehoning certainly does not support a conclusion that there have been adverse consequences of side thrust on the AE piston skirt at Shoreham.

99. Was there any evidence of excessive side thrust in the AE skirts in the DSRV-16-4 engine at Kodiak Electric Association in Alaska?

A. (Johnson, Swanger) FaAA observed no evidence of excessive side thrust during the inspections of the Kodiak skirts after more than 6,000 hours of operation.

100. Would you anticipate that adverse effects of side thrust would evidence themselves on the Kodiak engine even at 1,200 psi?

A. (Harris, Swanger) According to the County's standard for acceptable unital side thrust, the Kodiak engine should have experienced excessive side thrust even at 1,200 psi. Assuming the County's calculation of the side thrust load at Shoreham is correct, the side thrust for Kodiak can be derived by multiplying the County's side thrust result times the ratio of the Kodiak and Shoreham peak firing pressures. As noted, Kodiak had not evidenced any symptoms of excessive side thrust.

101. Did inspections of the modified AF piston skirts removed from Shoreham after 600 - 800 hours of operation reveal any indication of excessive side thrust?

A. (Harris, Johnson, Swanger, Youngling) No. Both visual and nondestructive examination revealed no signs of the County's alleged excessive side thrust. The nondestructive evaluation (liquid dye penetrant and eddy current testing) showed that the cracks in the modified AF skirts were randomly distributed on all sides of the skirt in the boss area. The liquid dye penetrant test results are included in Exhibit P-33. If there had been excessive side thrust, the cracks would have shown some side to side variation indicating adverse effects of side thrust load. The same side loads were experienced on the AF piston skirts as the AE pistons skirts because the factors affecting side loading, i.e., firing pressure and the geometry of the crank connecting rod and piston, are the same in both skirts.

102. Is the side thrust load on the Shoreham piston acceptable?

A. (Pischinger) Yes. Based upon the dimensions of the piston skirt, crank radius and the connecting rod length, I conclude that the Shoreham piston is an extremely low side-load piston. Moreover, based on current design practice, side thrust should not even be an issue in this proceeding.

B. FaAA Analysis

103. Did FaAA consider side thrust load in its analysis of the stresses on the AE piston skirt?

A. (Harris, McCarthy) No. As discussed above, cyclic stresses were the key factor FaAA considered in analyzing crack initiation in the AE piston skirts. The cyclic stresses are the differences in the minimum and maximum stresses. Pressure and stress have a linear relationship. Side thrust load is produced when the connecting rod angle varies from zero degrees. In this case, a portion of the load due to pressure on the piston is reacted through the wrist pin at an angle as contrasted to directly through the connecting rod to the crankshaft as would occur at top dead center. The pressure/crank angle diagram that FaAA developed (Exhibit P-5) shows that peak firing pressure during the power stroke occurs near the position when the connecting rod is vertical and parallel to the cylinder axis, a position corresponding to top dead center. The minimum load (inertia) is exerted when the piston is at top dead center of the exhaust stroke, which also corresponds to a zero degree angle between the connecting rod and crankshaft.

104. Would side thrust load change the cyclic stress amplitude?

A. (Harris, McCarthy, Swanger) No, not significantly. The pressure/crank angle diagram shows that the pressure drops off rapidly as the piston moves away from top dead center. Therefore, the forces on the piston decrease rapidly away from top dead center, and consequently the stresses in the stud boss region decrease. The side thrust load is zero at top dead center, which is close to where the peak pressure loading occurs. By the time the crank angle has increased to the point where the side component of the load is appreciable, the pressure has decreased to the point where the total pressure load has greatly descreased.

105. Would the FaAA conclusions that cracks in the AE piston skirts at Shoreham may initiate, but would not grow under operating conditions, be changed if side thrust load were considered a significant contributor to cyclic stresses?

A. (Harris) No. In the unlikely event that side thrust loads were determined to be a significant contributor to cyclic stresses in the stud boss region, such increases would not alter the FaAA conclusions. This is borne out by calculations made by FaAA on cracking of the AE skirt when subjected to peak firing pressure as large as 2,400 psig. These calculations, performed using the methodology described above, revealed that crack growth would not occur even at pressures of 2,200 psig. The maximum and minimum stresses and fracture mechanics analysis results from these calculations are shown on Exhibit P-34.

The small increases in estimates of cyclic stresses that may possibly occur if side thrust loads were included in the analysis would certainly be insufficient to increase the cyclic stresses to levels corresponding to 2,200 psig. Therefore, explicit consideration of side thrust loads would not alter our conclusions regarding the possibility of crack initiation but no growth of cracks in the AE piston skirt.

VI. The Tin Plating On The AE Pistons At Shoreham Will Not Lead To Failure

106. Please describe the purpose of the tin plating on the AE piston skirts.

A. (Pischinger, Swanger) Tin is a soft, low-friction material electroplated on piston skirts to facilitate a smoother break-in period for an engine. During break-in, piston rings and skirt surfaces are required to adapt themselves to new and non-broken-in cylinder liner and bore surfaces. Soft tin plating provides a low friction run-in surface similar to that provided by the overlay on the connecting rod bearing shells or on main bearing shells. In other words, the tin plating provides a running-in surface between the new skirt and the new liner. In addition, due to its soft quality, the tin plating captures minute particulates created by the running-in process and absorbs these materials. This process, therefore, protects the honed cylinder liner. In summary, the purpose of the tin plating is to provide a smooth break-in period and to protect the cylinder liner and the piston skirt. Contrary to the County's allegation, the purpose of the tin plating on the skirt is not to offset the assumed bad effects of alleged excessive piston side thrust. In fact, the County's own reference, Internal Combustion Engines (p. 498), states that "cast iron pistons produce less cylinder liner wear than aluminum ones, especially if they are tin plated."

107. Does the experience collected in the component tracking system indicate that tin plating of piston skirts is not an operational problem?

A. (Seaman, Swanger) The component tracking system contained no evidence of any failures or adverse operational problems resulting from tin plating of piston skirts in nuclear or non-nuclear service. Furthermore, the County did not document any actual failures or operational problems caused by tin plating. The County was merely theorizing based on incorrect assumptions as to the purpose of tin plating.

108. The County alleged that the scoring it observed can result in gas blow-by and, therefore, perhaps eventual piston seizure. Has excessive gas blow-by ever been experienced in the EDGs at Shoreham?

A. (Seaman, Youngling) No. LILCO monitors crank case pressure which would increase if gas blow-by were experienced. If excessive blow-by were to occur, the pressure sensor would alarm and then trip the unit. Shoreham has never tripped due to excessive gas blow-by.

109. The County was also concerned about alleged problems that might occur from the electroplating process. Why is the County's concern about electroplating ill-founded?

A. (Pischinger, Swanger) The County stated its concern about failure because of enbrittlement caused by hydrogen escaping into the metal during the electroplating. The County stated that hydrogen embrittlement has been responsible "for many dramatic failures of ferrous metals" and is a problem in "all plated metal components." This is incorrect. Hydrogen enbrittlement is not a concern in relatively mild nodular cast iron which had relatively low ultimate tensile strengths as compared to steel. It is a consideration only in high strength steel with ultimate tensile strength in excess of 150,000 psi. The tensile strength values of the AE piston skirt measured by FaAA were 85,360 psi to 90,210 psi. Furthermore, any cathodically charged hydrogen in the piston would diffuse out of the iron matrix in less than 100 hours at the operating temperature of the AE piston at Shoreham.

110. The County seemed concerned about tin plating because of scoring it observed in several cylinders during the County's trips to Shoreham in 1983 and 1984. Was this scoring due to the tin plating?

A. (Seaman, Youngling) No. The County hypothesized, based on its 1983 observations, that the scoring was caused by an accumulation of imbedded material in the tin plated surface of the skirt. The accumulation of material, however, was not caused by the tin plating. In 1983, the Shoreham EDGs had Koppers piston rings which were allowing an excessive amount of carbon build-up on the cylinder liners. As the result of a recommendation of the DRQR program, those rings have been replaced, however, with Muskegon piston rings. The Phase II DRQR of the piston rings concluded the Muskegon rings were appropriate for the intended use at Shoreham and that minor scuffing score marks on the cylinder liners were within an acceptable range indicating acceptable performance. In addition to replacing the Koppers piston rings with Muskegon piston rings to assure freedom from unacceptable scuffing, LILCO has adopted the following practices:

1. Inspection of the cylinder liners at each fuel outage to evaluate liner wear and ~~coat~~ deposits.
2. Use of a high detergent oil.
3. Use of 135° fuel injection tips.

111. Who performed the review of the Muskegon piston rings.

A. (Pischinger, Seaman) FEV performed the Phase II review which included an evaluation of the service conditions versus the ring design specification and an analysis of the actual performance of the rings, pistons and liners.

112. How was this review performed?

A. (Pischinger, Seaman) FEV considered the results of quality revalidation inspections and numerous task evaluation reports. Furthermore, FEV performed detailed engineering inspections at Shoreham, and more general inspections at Catawba, the TDI Manufacturing Plant in Oakland, California and the Muskegon Piston Ring (MPR) Manufacturing Plant in Muskegon, Michigan.

113. Please describe the inspections performed of the Shoreham pistons, rings and liners.

A. (Pischinger, Seaman, Youngling) The Shoreham rings, pistons and liners were inspected following a 24-hour test run and a 7-day test run and after about 100 hours at greater than or equal to full load. In addition, the components on EDG 102 were reinspected following a 100 start test.

114. What were the results of the FEV evaluation of the service conditions against the ring design specifications?

A. (Pischinger) FEV concluded that the design specifications for the MPR piston rings used on the Shoreham engines are typical of industry practice and conservatively rated for turbocharged and aftercooled medium speed diesel engines and are, therefore, appropriate for the intended use at Shoreham.

115. What were the results of the FEV inspection of the Shoreham pistons, rings and liners?

A. (Pischinger) Buildup of coke in the upper area of the liner and piston down to the second compression ring was noted. The coke buildup resulted in wear on the ring and the liner, and minor scuffing score marks were observed on them. Linear wear was also present, as well as some mirror-like bright areas on a high percentage of the cylinder liners. The magnitude and types of wear observed on the rings and liners, however, are within acceptable ranges, indicating acceptable performance.

116. Based upon the FEV review, do you conclude that the MPR piston rings are adequate for their intended function at Shoreham?

A. (Pischinger) Yes.

117. Does the tin plating in any way reflect a design deficiency?

A. (Pischinger, Swanger) No. The tin plating is an accepted mechanism to facilitate engine break-in and to protect the piston and cylinder liner from scoring from minute particulates escaping from the combustion chamber. There is simply no support for the allegation that tin plating has ever led to scoring, much less that it has caused excessive blow-by affecting the operation of the piston.

VII. Conclusion

118. In light of the County's piston contentions, is it your conclusion that the AE piston skirts are safe and reliable for their intended service?

A. (Harris, McCarthy, Swanger) Yes. The analysis of AE piston skirts using the higher, more conservative stresses predicted that fatigue cracks could possibly initiate. The analysis by engineering fracture mechanics predicted that these cracks cannot grow in the Shoreham EDGs. These same design analysis procedures have been successfully applied in other industries, including highly sophisticated aircraft gas turbine engines, as well as to other critical components of nuclear power plants.

119. Is it unusual to operate structural components where the presence of fatigue cracks is assumed?

A. (Harris, McCarthy) It is now common to design and operate critical structural components such that the initial presence of crack-like defects is assumed and the growth of these defects in fatigue is calculated. The possibility of fatigue crack initiation in the stud attachment bosses of piston skirts poses no new or unusual problems when compared to common design practice in other industries, such as aerospace. For example, even the highly-stressed rotating parts of military aircraft gas turbine engines are designed assuming the presence of small cracks that can grow in fatigue. As noted above, the

United States Air Force has a formal procedure that expressly requires the manufacturer to adopt this design approach. Many other structures - civil, mechanical, marine - are designed with the same philosophy. This philosophy merely reflects the fact that all materials and structures contain crack-like defects on some scale and that the primary objective of design analysis is therefore not to prevent "initiation" but to ensure that such cracks cannot grow to a significant size. It is important to appreciate the fact that all critical structural components in our common experience, such as aircraft, bridges, pipelines, tanks--even elevator cables--contain such defects. Modern design analysis is able to ensure the safe operation of all these structures through the application of engineering fracture mechanics. Contrary to the County's contention, the fracture mechanics analysis of AE piston skirts showed that they are safe and reliable.

Attachment 1

Failure
Analysis
Associates

DAVID O. HARRIS

Specialized Professional Competence

Fracture mechanics analysis and testing, fatigue and stress corrosion cracking in nuclear reactor piping, probabilistic fracture mechanics, stress analysis, acoustic emission testing and applications.

Background and Professional Honors

Ph.D. (Applied Mechanics), Stanford University
M.S. (Mechanical Engineering), University of Washington
B.S. (Mechanical Engineering), University of Washington

Managing Engineer, Fracture Mechanics Group,
  Failure Analysis Associates
Division Manager,
  Science Applications, Inc.
Director of Research,
  Dunegan/Endevco
Mechanical Engineer,
  Lawrence Radiation Laboratory

Member, American Society of Mechanical Engineers
Member, American Society for Testing and Materials
Member, Acoustic Emission Working Group
Member, Tau Beta Pi, National Engineering Honorary Society
Member, Sigma Xi, Scientific Research Honorary Society

Selected Publications

"Characterization of Acoustic Emission from Crack Growth in Steam Turbine Rotor Steels," to appear as Electric Power Research Institute Report, Palo Alto, California (with D. D. Dedhia and T. C. Mamaros).

"Stress Intensity Factors for Surface Cracks in Pipes: A Computer Code for Evaluation by Use of Influence Functions," Electric Power Research Institute Report NP-2425, Palo Alto, California (June 1982) (with D. D. Dedhia).

"Stress Corrosion Crack Growth in the Presence of Residual Stresses," *Residual Stress and Stress Relaxation*, 28th Sagamore Army Materials Research Conference, Plenum Press (1982).

"Probabilistic Analysis of the Influence of Vibratory Stresses on Piping Reliability," *Reliability and Safety of Pressure Components*, pp. 17-34, PVP—Vol. 62, American Society of Mechanical Engineers, New York (1982) (with E. Y. Lim).

"Fracture Mechanics Models Developed for Piping Reliability Assessment in Light Water Reactors," Report NUREG/CR-2301, U.S. Nuclear Regulatory Commission, Washington D.C. (1982) (with E. Y. Lim and D. D. Dedhia).

"Application of a Fracture Mechanics Model of Structural Reliability to the Effects of Seismic Events on Reactor Piping," *Progress in Nuclear Energy*, Vol. 10, (1) pp. 125-159 (with E. Y. Lim).

"The Influence of Nondestructive Inspection on the Reliability of Pressurized Components," *Fracture Tolerance Evaluation, Proceedings of U.S.-Japan Joint Symposium on Fracture Tolerance Evaluation*, Honolulu, Hawaii (December 1981) pp. 257-265.

"Applications of a Probabilistic Fracture Mechanics Model to the Influence of In-Service Inspection on Structural Reliability," to appear in the *Proceedings of ASTM Symposium on Probabilistic Methods for Design and Maintenance of Structures* (with E. Y. Lim).

"Approximate Influence Functions for Part-Circumferential Interior Surface Cracks in Pipes," presented at 14th National Symposium on Fracture Mechanics, Los Angeles, California (June 1981) (with E. Y. Lim and D. D. Dedhia).

"Crack Growth Trajectories for Fatigue of Part-Circumferential Interior Surface Cracks in Pipes," presented at 14th National Symposium on Fracture Mechanics, Los Angeles, California (June 1981) (with D. D. Dedhia and E. Y. Lim).

"Stress Intensity Factors for Complete Circumferential Interior Surface Cracks in Hollow Cylinders," *Fracture Mechanics: Thirteenth Conference*, ASTM Special Technical Publication No. 743, pp. 375-386, Philadelphia, Pennsylvania (1981) (with E. Y. Lim).

"Probability of Pipe Fracture in the Primary Loop of a PWR Plant, Vol. 5: Probabilistic Fracture Mechanics Analysis," Report NUREG/CR 2189, Vol. 5, U.S. Nuclear Regulatory Commission, Washington D.C. (1981) (with E. Y. Lim and D. D. Dedhia).

"On-Line Acoustic Emission Monitoring of Fossil Steam Power Plants: A Critical Assessment," Electric Power Research Institute Report CS-1896 (June 1981) (with D. E. Leaver).

"Acoustic Emission Leak Detection and Location Systems Technology Review," Electric Power Research Institute Report NP-80-7-LD (December 1980) (with R. G. Brown, D. D. Dedhia and D. E. Leaver).

"The Influence of Crack Growth Kinetics and Inspection on the Integrity of Sensitized BWR Piping Welds," Report EPRI NP-1163, Electric Power Research Institute, Palo Alto, California (September 1979).

"A Means of Assessing the Effects of Periodic Proof Testing and NDE on the Reliability of Cyclically Loaded Structures," *Journal of Pressure Vessel Technology*, Vol. 100 (7) pp. 150-157 (May 1978).

"A Means of Assessing the Effects of NDE on the Reliability of Cyclically Loaded Structures," *Materials Evaluation*, Vol. 35 (7) pp. 57-65 (July 1977).

Attachment 2

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 3

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
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President,
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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 4

CURRICULUM VITAE

Professor Dr. techn. Franz F. Pischinger
Date of Birth: 18.07.1930, Waidhofen/Thaya, Austria

1948 to 1952 studies and graduation in mechanical engineering at Graz Technical University. From 1953 to 1958 (1954 doctors degree) technical assistant at Graz Technical University. Then Head of Research Department of AVL (Institute for Internal Combustion Engines, Professor List, Graz). 1958 habilitation. 1962 to 1970 leading positions in research and development at Klöckner-Humboldt-Deutz AG, Köln (last position: Director of Research and Development Department). Since 1970 Director of the Institute for Applied Thermodynamics at Aachen Technical University. Supervising Research and Teaching in the field of internal combustion engines and thermodynamics of combustion. Also (1978) president of the FEV Forschungsgesellschaft für Energietechnik und Verbrennungsmotoren mbH, Anchen.

Attachment 5

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 6

Failure
Analysis
Associates

LEE A. SWANGER

Specialized Professional Competence

Failure analysis of materials; metallurgical engineering, physical and mechanical metallurgy, and thermodynamics; foundry process development including ferrous and non-ferrous castings; powder metallurgy and powder rolling; electrochemistry, including electroplating and corrosion; materials testing, fatigue, and fracture; metal matrix and polymer matrix composites; tribology, friction, wear, and lubrication; internal combustion engine and compressor component design and testing; sleeve bearing design, manufacture, and failure analysis.

Background and Professional Honors

Ph.D. (Materials Science and Engineering), Stanford University, with Distinction
M.B.A. (Marketing/Finance), Cleveland State University
M.S. (Materials Science and Engineering), Stanford University
B.S. (Metallurgy), Case Institute of Technology, with Highest Honors

Managing Engineer,
 Failure Analysis Associates
Director, Research and Development,
 Imperial Clevite Inc.
Associate Director, Product Development,
 Gould Inc., Engine Parts Division
Manager, Tribology and Bearing Research,
 Gould Laboratories, Materials Research
Associate Senior Research Metallurgist,
 General Motors Research Laboratories
Lecturer, Metallurgical Engineering,
 Cleveland State University
Visiting Research Associate, Metallurgical Engineering,
 Ohio State University

Registered Professional Engineer, State of Ohio, #44024
Member, Tau Beta Pi, Engineering Honorary Fraternity
Member, Sigma Xi, Scientific Research Honorary Fraternity
Member, Beta Gamma Sigma, Graduate Business Honorary Fraternity
National Merit Foundation Scholarship
Xerox Corporation Fellowship
IBM Corporation Fellowship
Hertz Foundation Fellowship
Member, American Society for Metals
Member, Society of Automotive Engineers
Interviewer, Hertz Foundation Fellowship Project

Selected Publications

U.S. Patent No. 4,333,215: "Bearing Material and Method of Making," issued June 8, 1982.
"Compacted Graphic Cast Iron Components for Improved Thermal Fatigue Resistance," Imperial Clevite Inc., Internal Report (January 1982).
"Marketing Strategies to Achieve Cash Flow Objectives," M.B.A. thesis, Cleveland State University (June 1982).
"Squeeze-Cast Pistons for Heavy-Duty Applications," Gould Inc., Internal Report (February 1981).
"Evaluation of Graphite-Epoxy and Graphite-Babbitt Composite Sleeve Bearings," Gould Laboratories, Phase Report (October 1977).
"Environmentally Induced Blistering of Aluminum P/M Components," Gould Laboratories, Project Completion Report (December 1976).

"Inhomogeneous Thermodynamics and Spinodal Decomposition," Ph.D. dissertation, Stanford University (August 1972).

"On the Necessary Conditions for Homogeneous Nucleation of Gas Bubbles in Liquids," Journal of Crystal Growth, pp. 323-326 (1972) (with W. C. Rhines).

"The Elastic Energy of a Straight Dislocation in an Infinite Anisotropic Elastic Medium," Physica Status Solidi (B), pp. 419-428 (1971) (with D. M. Barnett).

"Computer Simulation of One-Dimensional Spinodal Decomposition," Acta Metallurgica, pp. 9-14 (1970) (with P. K. Gupta and A. R. Cooper, Jr.)

Invited Lectures

"Bearing Materials Update," presented to SAE Off-Highway Conference, Milwaukee, September 1981.

"Developments in Bearings and Pistons," presented at *O Motor no Futuro* (The Engine of the Future), Sao Paulo, Brazil (September 1980).

"Selection of Crankshaft Materials for Optimum Bearing Performance," presented to Society of Manufacturing Engineers Conference, Los Angeles, CM80-392 (June 1980).

"Heavy Duty Bearings: Materials and Process," presented at Carnegie-Mellon University (March 1980).

"The Linear Team and Spinodal Decomposition," presented at the University of Florida (February 1978).

Attachment 7

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.

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.

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).

Failure
Analysis
Associates

DAVID O. HARRIS

Specialized Professional Competence

Fracture mechanics analysis and testing, fatigue and stress corrosion cracking in nuclear reactor piping, probabilistic fracture mechanics, stress analysis, acoustic emission testing and applications.

Background and Professional Honors

Ph.D. (Applied Mechanics), Stanford University
M.S. (Mechanical Engineering), University of Washington
B.S. (Mechanical Engineering), University of Washington

Managing Engineer, Fracture Mechanics Group,
    Failure Analysis Associates
Division Manager,
    Science Applications, Inc.
Director of Research,
    Dunegan/Endevco
Mechanical Engineer,
    Lawrence Radiation Laboratory

Member, American Society of Mechanical Engineers
Member, American Society for Testing and Materials
Member, Acoustic Emission Working Group
Member, Tau Beta Pi, National Engineering Honorary Society
Member, Sigma Xi, Scientific Research Honorary Society

Selected Publications

"Characterization of Acoustic Emission from Crack Growth in Steam Turbine Rotor Steels," to appear as Electric Power Research Institute Report, Palo Alto, California (with D. D. Dedhia and T. C. Mamaros).

"Stress Intensity Factors for Surface Cracks in Pipes: A Computer Code for Evaluation by Use of Influence Functions," Electric Power Research Institute Report NP-2425, Palo Alto, California (June 1982) (with D. D. Dedhia).

"Stress Corrosion Crack Growth in the Presence of Residual Stresses," *Residual Stress and Stress Relaxation*, 28th Sagamore Army Materials Research Conference, Plenum Press (1982).

"Probabilistic Analysis of the Influence of Vibratory Stresses on Piping Reliability," *Reliability and Safety of Pressure Components*, pp. 17-34, PVP—Vol. 62, American Society of Mechanical Engineers, New York (1982) (with E. Y. Lim).

"Fracture Mechanics Models Developed for Piping Reliability Assessment in Light Water Reactors," Report NUREG/CR-2301, U.S. Nuclear Regulatory Commission, Washington D.C. (1982) (with E. Y. Lim and D. D. Dedhia).

"Application of a Fracture Mechanics Model of Structural Reliability to the Effects of Seismic Events on Reactor Piping," *Progress in Nuclear Energy*, Vol. 10, (1) pp. 125-159 (with E. Y. Lim).

"The Influence of Nondestructive Inspection on the Reliability of Pressurized Components," *Fracture Tolerance Evaluation, Proceedings of U.S.-Japan Joint Symposium on Fracture Tolerance Evaluation*, Honolulu, Hawaii (December 1981) pp. 257-265.

"Applications of a Probabilistic Fracture Mechanics Model to the Influence of In-Service Inspection on Structural Reliability," to appear in the *Proceedings of ASTM Symposium on Probabilistic Methods for Design and Maintenance of Structures* (with E. Y. Lim).

"Approximate Influence Functions for Part-Circumferential Interior Surface Cracks in Pipes," presented at 14th National Symposium on Fracture Mechanics, Los Angeles, California (June 1981) (with E. Y. Lim and D. D. Dedhia).

"Crack Growth Trajectories for Fatigue of Part-Circumferential Interior Surface Cracks in Pipes," presented at 14th National Symposium on Fracture Mechanics, Los Angeles, California (June 1981) (with D. D. Dedhia and E. Y. Lim).

"Stress Intensity Factors for Complete Circumferential Interior Surface Cracks in Hollow Cylinders," *Fracture Mechanics: Thirteenth Conference*, ASTM Special Technical Publication No. 743, pp. 375-386, Philadelphia, Pennsylvania (1981) (with E. Y. Lim).

"Probability of Pipe Fracture in the Primary Loop of a PWR Plant, Vol. 5: Probabilistic Fracture Mechanics Analysis," Report NUREG/CR 2189, Vol. 5, U.S. Nuclear Regulatory Commission, Washington D.C. (1981) (with E. Y. Lim and D. D. Dedhia).

"On-Line Acoustic Emission Monitoring of Fossil Steam Power Plants: A Critical Assessment," Electric Power Research Institute Report CS-1896 (June 1981) (with D. E. Leaver).

"Acoustic Emission Leak Detection and Location Systems Technology Review," Electric Power Research Institute Report NP-80-7-LD (December 1980) (with R. G. Brown, D. D. Dedhia and D. E. Leaver).

"The Influence of Crack Growth Kinetics and Inspection on the Integrity of Sensitized BWR Piping Welds," Report EPRI NP-1163, Electric Power Research Institute, Palo Alto, California (September 1979).

"A Means of Assessing the Effects of Periodic Proof Testing and NDE on the Reliability of Cyclically Loaded Structures," *Journal of Pressure Vessel Technology*, Vol. 100 (7) pp. 150-157 (May 1978).

"A Means of Assessing the Effects of NDE on the Reliability of Cyclically Loaded Structures," *Materials Evaluation*, Vol. 35 (7) pp. 57-65 (July 1977).

Failure
Analysis
Associates

LEE A. SWANGER

Specialized Professional Competence

Failure analysis of materials; metallurgical engineering, physical and mechanical metallurgy, and thermodynamics; foundry process development including ferrous and non-ferrous castings; powder metallurgy and powder rolling; electrochemistry, including electroplating and corrosion; materials testing, fatigue, and fracture; metal matrix and polymer matrix composites; tribology, friction, wear, and lubrication; internal combustion engine and compressor component design and testing; sleeve bearing design, manufacture, and failure analysis.

Background and Professional Honors

Ph.D. (Materials Science and Engineering), Stanford University, with Distinction
M.B.A. (Marketing/Finance), Cleveland State University
M.S. (Materials Science and Engineering), Stanford University
B.S. (Metallurgy), Case Institute of Technology, with Highest Honors

Managing Engineer,
    Failure Analysis Associates
Director, Research and Development,
    Imperial Clevite Inc.
Associate Director, Product Development,
    Gould Inc., Engine Parts Division
Manager, Tribology and Bearing Research,
    Gould Laboratories, Materials Research
Associate Senior Research Metallurgist,
    General Motors Research Laboratories
Lecturer, Metallurgical Engineering,
    Cleveland State University
Visiting Research Associate, Metallurgical Engineering,
    Ohio State University

Registered Professional Engineer, State of Ohio, #44024
Member, Tau Beta Pi, Engineering Honorary Fraternity
Member, Sigma Xi, Scientific Research Honorary Fraternity
Member, Beta Gamma Sigma, Graduate Business Honorary Fraternity
National Merit Foundation Scholarship
Xerox Corporation Fellowship
IBM Corporation Fellowship
Hertz Foundation Fellowship
Member, American Society for Metals
Member, Society of Automotive Engineers
Interviewer, Hertz Foundation Fellowship Project

Selected Publications

U.S. Patent No. 4,333,215: "Bearing Material and Method of Making," issued June 8, 1982.
"Compacted Graphic Cast Iron Components for Improved Thermal Fatigue Resistance," Imperial Clevite Inc., Internal Report (January 1982).
"Marketing Strategies to Achieve Cash Flow Objectives," M.B.A. thesis, Cleveland State University (June 1982).
"Squeeze-Cast Pistons for Heavy-Duty Applications," Gould Inc., Internal Report (February 1981).
"Evaluation of Graphite-Epoxy and Graphite-Babbitt Composite Sleeve Bearings," Gould Laboratories, Phase Report (October 1977).
"Environmentally Induced Blistering of Aluminum P/M Components," Gould Laboratories, Project Completion Report (December 1976).

"Inhomogeneous Thermodynamics and Spinodal Decomposition," Ph.D. dissertation, Stanford University (August 1972).

"On the Necessary Conditions for Homogeneous Nucleation of Gas Bubbles in Liquids," Journal of Crystal Growth, pp. 323-326 (1972) (with W. C. Rhines).

"The Elastic Energy of a Straight Dislocation in an Infinite Anisotropic Elastic Medium," Physica Status Solidi (B), pp. 419-428 (1971) (with D. M. Barnett).

"Computer Simulation of One-Dimensional Spinodal Decomposition," Acta Metallurgica, pp. 9-14 (1970) (with P. K. Gupta and A. R. Cooper, Jr.).

Invited Lectures

"Bearing Materials Update," presented to SAE Off-Highway Conference, Milwaukee, September 1981.

"Developments in Bearings and Pistons," presented at *O Motor no Futuro* (The Engine of the Future), Sao Paulo, Brazil (September 1980).

"Selection of Crankshaft Materials for Optimum Bearing Performance," presented to Society of Manufacturing Engineers Conference, Los Angeles, CM80-392 (June 1980).

"Heavy Duty Bearings: Materials and Process," presented at Carnegie-Mellon University (March 1980).

"The Linear Team and Spinodal Decomposition," presented at the University of Florida (February 1978).

JUDGE BRENNER: With respect to exhibits, let's call them LILCO diesel exhibits, P-1 through P-34, and we will refer to all exhibits with the prefix "diesel" so we could start a new numbering system. When you reference these in your findings, though, you can leave out the word "diesel" since that encompasses all of them.

There is an index of the exhibits starting at the beginning of Volume 2. As I say, you have at least one copy for the court reporter now, I believe. The court reporter, in the index, can simply copy the designations given in this index and we will for all future exhibits for parties, also need a typed out list of the exhibits so the court reporter can do exactly as he is going to do now.

MR. ELLIS: Judge Brenner, with the admission of the testimony and the attachments, the panel is now ready for cross-examination.

JUDGE BRENNER: All right. Mr. Dynner, we alluded to this on the conference call. You may tell me it is premature to ask you. If so, we will accept that as an answer. We are going to have to decide what adjustments we may have to make, as indicated at the outset. Do you have an educated guess as to how long your cross-examination of LILCO's panel on pistons will take?

MR. DYNNER: No, sir.

JUDGE BRENNER: I will ask you again and insist on an answer probably later in the week, as to how long.

MR. DYNNER: Yes, sir.

JUDGE BRENNER: At this time you may begin your cross-examination.

Cross-examination

BY MR. DYNNER:

Q. Dr. McCarthy, what experience have you had, if any, in the design of diesel engines?

DR. MC CARTHY: I have not designed a diesel engine. I have had a substantial background in mechanical design. Which part is your question related to?

Q. You have answered the question. Thank you.

Dr. Harris, do you have any experience in the actual design of diesel engines?

DR. HARRIS: Mr. Dynner, my background in design goes back to my undergraduate years in training as a mechanical engineer. I do have training in the design of mechanical components. I don't have any specific design experience with diesel engine components.

Q. Dr. Harris, do you have any experience in the manufacture of diesel engines?

DR. HARRIS: No, Mr. Dynner, I don't.

Q. Do you have any experience — when I ask these questions, gentlemen, to the entire panel, I am excluding experience you have had working on the Shoreham emergency diesels.

Have you had any experience in operating a diesel engine?

DR. HARRIS: I of course have considerable experience in operating internal combustion engines. I have no experience on diesel engines.

Q. Dr. McCarthy, do you have any direct experience in either the manufacturing or operation of diesel engines?

DR. MC CARTHY: The operation, yes, sir.

Q. But not the manufacture of a diesel engine, is that correct?

DR. MC CARTHY: Well, no. I have had substantial experience in analyzing — I have had some experience analyzing past failures of diesel engines of this size that have been related to manufacturing errors.

Q. Would you briefly describe that experience.

DR. MC CARTHY: Well, confining it to back-up diesel generators in nuclear power plants for the moment, I have worked on failure analysis programs for Fairbanks Morse diesels, Arkansas Nuclear 1, and currently working on a failure of a back-up diesel generator at the WPPS system.

Q. What kind of diesel was that?

DR. MC CARTHY: Stewart Stevensen.

Q. What exactly did you do in connection with the Fairbanks Morse diesel issue?

DR. MC CARTHY: Well, the first Fairbanks Morse failure I looked at was a combined crankshaft connecting rod failure, in a 12 cylinder crank. This was a 24 piston two opposed crankshaft system and essentially involved a complete tear down of the diesel, laser alignment check of the bearing saddles, a complete journal orbit analysis of the piston loading on the connecting rod and crankshaft, lubrication film thickness, and numerous other incidental inspection tasks of various manufacturing aspects of the diesels.

The second Fairbanks Morse diesel failure

I looked at involved a main bearing failure of the coupling between the EDG and the generator.

Q. By EDG you are referring to emergency diesel generators, is that correct?

DR. MC CARTHY: That is correct.

Q. Did you ever work for a diesel manufacturer?

DR. MC CARTHY: No.

Q. Did you ever operate a large medium speed diesel of the type found at Shoreham?

DR. MC CARTHY: Close, not identical.

Q. I'm sorry?

DR. MC CARTHY: Close, not identical. I used to be heavy maintenance platoon leader in my ordinance service, and we generally had responsibility for operation of all fixed diesel generators for battalion or brigade size operation. It was my responsibility for overseeing the maintenance.

Q. How big were those diesels?

DR. MC CARTHY: The biggest were 1000 to 2000.

Q. 1,000 to 2000 what?

DR. MC CARTHY: Horsepower. I'm sorry.

Q. Do you know what the horsepower is rated for the EDG's at Shoreham?

DR. MC CARTHY: I read it on the name plate. It is approximately 5. It is 4 and some change. I would have to check the name plate.

Q. When you said 5 you meant 5000 horsepower, is that correct?

DR. MC CARTHY: Yes. It is a -- I don't recall the specific number. I have to look at my pictures.

Q. You consider yourself an expert on large medium speed diesel engines of this size and type at Shoreham?

DR. MC CARTHY: I have expertise relating to some. Perhaps one could say many aspects of it. I would not say I was an expert in certainly every phase of such a large engine design.

Q. It is true, isn't it, Dr. McCarthy, that when FaAA got this job it decided it had to retain the services of a diesel engine expert, and that's why you retained FEV, isn't that true?

DR. MC CARTHY: As the questions that were asked expanded into questions that the client had about design and design practice, we felt that to provide the caliber of service that our firm is noted for, we had to retain an expert, to ask an expert to give us the benefit of his opinion of a design caliber that was consistent with our failure analysis expertise. We felt it necessary to ask Mr. Pischinger's aid in that event.

Q. You don't have anyone on the FaAA staff that worked on this problem that has the kind of diesel expertise that Dr. Pischinger has, do you?

MR. ELLIS: May we have some definition of what he means by diesel expertise? I think it is excessively vague. We will object to it on that basis. That can cover a wide range of failure analysis.

JUDGE BRENNER: I think an expert witness can handle something like that. If there is an ambiguity, we can clear it up later.

DR. MC CARTHY: We have no one on the staff with Dr. Pischinger's extensive background in terms of experience in design practices throughout the industry. The questions that we required his input for related extensively to that subject. There is a rare number of people with that experience. I seriously doubt we will have been able to find one.

Q. It is true, isn't it, Dr. McCarthy, that there is no one else in the FaAA organization that has the level of expertise with diesel engines comparable to that of FEV?

DR. MC CARTHY: With regard to design experience and design practices, no one on our staff has seen anything close to the number of diesels designed that Dr. Pischinger has. I think we perhaps have seen perhaps more, if you will, of the errors that can happen from incorrect diesel design.

Q. How about expertise --

MR. ELLIS: May I have that last answer read back, the last sentence?

(read by the reporter)

Q. Dr. Swanger, have you had any experience in designing diesel engines?

DR. SWANGER: In my past employment with Imperial Clevite, Incorporated and its predecessor company, Gould, Incorporated, I had experience in the design of key components of a diesel engine, the sleeve bearings, the pistons and the cylinder liners.

Q. Could you briefly describe your experience in connection with the design of the pistons.

DR. SWANGER: As director of the product development department of the engine parts division of Imperial Clevite, one of the projects under my direction was the design of an aluminum piston for diesel engines of approximately 50 to 70 horsepower per cylinder made by a casting technique called squeeze casting. The design involved finite element analysis of this piston to determine the state of stress within various key areas of the piston and was specifically aimed at metallurgical improvements to solve problems that the competing piston suppliers were experiencing in terms of those pistons.

In addition, the product line included cast iron pistons for customers such as Cooper Bessemer. These cast iron pistons were as large as, I believe, 15 to 16 inches in diameter, and perhaps 20 to 22 inches high.

Q. Dr. Swanger, you refer to the fact that the aluminum piston was for an engine of approximately 50 to 70 horsepower per cylinder. What is the rated horsepower per cylinder of the EDG's at Shoreham?

DR. SWANGER: The name plate rating at 100 percent load is 610 horsepower per cylinder.

Q. What size speed with respect to horsepower engine were the cast iron pistons to be used in?

DR. SWANGER: I don't know the specific horsepower rating of the engine for the cast iron pistons. But based on my recollection of that time and my knowledge of the general size dependence of diesel engines, I think it would be on the order of 400 to 500 horsepower per cylinder.

Q. Specifically what did you do with respect to the design of these cast iron pistons?

DR. SWANGER: These pistons were provided to Cooper Bessemer for original equipment and were sold into the aftermarket to owners of Cooper Bessemer engines.

In the case of the OEM piston, the bulk of the design would be provided by the engine manufacturer, Cooper Bessemer, and would be manufactured to their specifications. For other engines or other pistons which would be sold for engines in the aftermarket, Clevite would have to engineer that piston in terms primarily of developing what the proper tolerances would be on such key dimensions as the OD of the piston, the dimensions of the piston grooves, the dimensions of the wrist pin bore so that it would work properly in the engine.

The other key factor would be the

metallurgical aspects of cast iron pistons. This is where my particular expertise would lie, in the metallurgy. Colleagues of mine that I would be working with would have done the design work in terms of the tolerances.

Also, Clevite was continually working to improve its processes in terms of its foundry and casting processes that were used in order to improve the quality and yield of the cast iron pistons that they manufacture in their foundry.

Q. Dr. Swanger, my question to you was specifically what did you do concerning the design of the piston, the cast iron piston. Specifically what did you personally do?

DR. SWANGER: I provided input on to the selection, into the selection of the iron from which the piston should be made and also provided advice on improvements in the foundry processes.

Q. So your input was confined to metallurgical matters, is that correct?

DR. SWANGER: I'm sorry. Could you repeat the question for me, please.

Q. Your input was confined to metallurgical matters, is that correct?

DR. SWANGER: My input was confined to

two areas: The metallurgical matters that I discussed in terms of the selection of the proper materials and the manufacturing process as well as the area known as tribology, friction wear and lubrication, in terms of the specification of coatings for the pistons, either tin plating or manganese and zinc phosphates.

Q. When did you have this experience with the selection of materials coating for the cast iron piston?

DR. SWANGER: Gould merged two divisions in June of 1980. I was head of product development for the engine parts division and became director of product development for the surviving combined division. So my experience with pistons would have been between June of 1980 and the time I joined failure analysis in June of 1983.

Specifically with respect to the cast iron pistons for the Cooper Bessemer, I believe that would have been about 1981.

Q. Dr. McCarthy, when did you perform the work that you described on Arkansas Nuclear EDG?

DR. MC CARTHY: The work at Arkansas was two separate EDG failures. The first occurred in January of 1980. The second occurred, I believe, in the spring of 1980. The work involved stretched over the first three quarters of 1980.

Q. Dr. Johnson, have you had any experience in designing a diesel engine?

DR. JOHNSON: No, I have not. My area of expertise — I have not had any experience in designing diesel engines. My area of expertise is in the area of non-destructive evaluation.

Q. So you haven't had any experience in manufacturing diesel engines either; is that right?

DR. JOHNSON: That is correct.

Q. Or in operating them, is that correct?

DR. JOHNSON: Yes.

Q. Yes, you have had no experience?

DR. JOHNSON: I have no experience in operating diesel engines.

Q. Mr. Seaman, have you had any experience in designing a diesel engine? That is other than your experience in connection with the Shoreham EDG's.

MR. SEAMAN: No, I have not had direct experience designing diesel engines, but I have been involved in the design of other components that are similar which I believe are relevant to diesel engines.

Q. What would they be?

MR. SEAMAN: Well, as you know, we have relied upon finite element analysis and fatigue analysis, and a lot of our design reviews of the TDI engines have been involved in that type of calculation in the past. I have supervised and performed those type of calculations.

Additionally, I have been involved in material and metallurgical evaluations and investigations in the past. I have supervised the large NDE programs such as the pre-service inspection program at Shoreham, which is directly related to design review and evaluation of the components in the diesel engine. I have been involved in mechanical equipment design for approximately ten years.

Q. Mr. Seaman, what specific component have you worked on the design of that goes into a diesel engine of comparable size to those at the Shoreham plant?

MR. SEAMAN: I have not worked on a comparable size diesel engine component prior to the Shoreham experience.

Q. Have you ever had any experience in the manufacture of diesel engines?

MR. SEAMAN: Again, while I have not had experience directly with the fabrication of diesel engines outside of Shoreham, I have been involved in other mechanical equipment that is similar.

Q. What mechanical equipment are you referring to that's similar?

MR. SEAMAN: There are various mechanical equipment that would be similar that use a lot of cast products. For example, such as valves, pumps where lubrication is also important. Again, it is not directly applicable but the general principles involved are similar.

Q. What experience have you had in manufacturing valves?

MR. SEAMAN: While I have never directly manufactured a valve or been involved in the manufacture of a valve, there are many instances where we have had problems with valves that require evaluations, investigations into those designs and manufacturing processes that I have been involved with.

Q. What experience have you had in manufacturing pumps?

MR. SEAMAN: Again, the answer would be essentially the same.

Q. No experience in manufacturing those components, in fact, but you have had, as I understand your testimony, experience in reviewing failures of those items, is that correct?

MR. SEAMAN: Again, in order to understand a failure adequately, it is very important that you understand the manufacturing process, particularly if a manufacturing, characteristic, is critical to the failure of that component. So that would require the knowledge of the manufacturing process in order to evaluate those instances.

Q. Is that knowledge a prerequisite to doing an adequate job of analyzing the failure?

MR. SEAMAN: While that knowledge can be important, it certainly is not the only important attribute when you perform such an investigation.

Q. If you didn't have any experience at all with respect to that component or machine, would that be significant?

MR. ELLIS: I object to the question. I don't see its relevance. You are not talking about any specific component. He is just saying, if you don't have any knowledge, would that be relevant. I don't think that's sufficiently specific to permit the witness to answer with any precision.

JUDGE BRENNER: Objection sustained. It is too abstract to be helpful. I am going to confine you. Unless you get to it with more precision, we are going to spend time on things that are a little too abstract, some of which time has been spent already, I think.

Q. Mr. Youngling, do you have any experience in designing diesel engines?

MR. YOUNGLING: Mr. Dynner, my experience is in the area of operation, maintenance and repair of rotating equipment which has included diesel engines. As part of that process we have worked with design personnel and I have worked with design personnel in implementing those repairs and providing the necessary feedback to them on the adequacy of the design changes.

Q. Are you talking about the Shoreham EDG's now?

MR. YOUNGLING: This relates to prior experience at other facilities within LILCO.

Q. With diesel engines of the size we are talking about at Shoreham in the EDG's?

MR. YOUNGLING: The particular diesel we worked on was not as large as the Shoreham diesel but operated on the same principles.

Q. What did you do with respect to designing that diesel engine?

MR. YOUNGLING: As I said, I related to the repair and testing of diesel, and working with the design personnel to provide the necessary feedback as to the adequacy of the design changes.

Q. So you personally have no experience in designing the diesel engine, is that correct?

MR. YOUNGLING: As I said, my area of expertise is in the operation, maintenance and repair and providing the feedback to the design personnel on the adequacy and making suggestions.

Q. So you personally have had no experience in designing a diesel engine, is that correct?

MR. ELLIS: I object. That was asked and answered.

MR. DYNNER: He hasn't answered.

JUDGE BRENNER: You may answer. Otherwise you are just talking to each other. There was no answer to the question. You may recall, he is entitled to a direct answer, as direct an answer as you can give at the outset. Then you can give the rest of your explanation if you feel it is necessary. Let's get a yes or a no and then understand the answer you previously gave to be your explanation.

MR. YOUNGLING: I have not performed design work. However, I have participated in the design feedback with the design engineers through my operating, testing and maintenance expertise.

In addition, I think that any problem such as the problem of dealing with any piece of rotating machinery which has suffered a failure or suffered a design problem requires that you bring in place various expertise. That expertise needs to complement one another.

I think what you see before you is a panel which has and does complement one another in bringing specific expertise to solving the problem.

Q. Have you had any direct experience, Mr. Youngling, in manufacturing a diesel engine?

MR. YOUNGLING: No, I have no experience in manufacturing a diesel engine. However, I have worked with manufacturing personnel to provide feedback to them on the adequacy of the manufacturing process or problems that have occurred as a result of the manufacturing process.

Q. Dr. Pischinger, what direct experience have you had, sir, in designing diesel engines?

DR. PISCHINGER: I have been working in the field of diesel engines since 1958, and my work was always related with defining the shape, the make-up of the engines, and as far as I am aware, to define how a component or an engine is built, what shape, and is called design.

So I was from the beginning of my career, 1958 until now, always involved and also responsible of a longer period for the design of diesel engines.

Q. Dr. Pischinger, can you tell us what size diesel engines that you have designed or participated in the design of?

DR. PISCHINGER: A large range, from small, very small diesel engines for cars up to diesel engines of about 6000 kilowatt.

Q. Dr. Pischinger, starting with 1958, would you describe what was your employment in 1958?

DR PISCHINGER: From 1958 to 1962 I was with the AVL Company in Graz, Austria. This is a company which is designing engines, mainly diesel engines, but also gas engines, but mainly diesel engines for industry. In this connection I was responsible for the research department.

Q. Specifically what did you do in the research department during those years?

DR. PISCHINGER: We took, or we did basic work in order to design the combustion system and the mechanical system of the engines, which were under design of this company. That means as well as on the process side of the engine, the process of the engine, combustion process, as well as mechanical behavior of the engine. We had to solve problems which could not be addressed so easy. There have been in depth investigations where necessary to address these problems, solve it, and by this, input into the design.

Q. Were those diesel engines, sir?

DR. PISCHINGER: Yes.

Q. What size engines were they?

DR. PISCHINGER: I cannot tell to the millimeter, but roughly a little above 200 millimeter diameter was the largest.

Q. What horsepower were they, sir?

DR. PISCHINGER: I cannot tell.

Q. Approximate horsepower rating.

DR. PISCHINGER: About 300 per cylinder.

Q. What speed were those engines, approximately?

DR. PISCHINGER: 600 rpm up to 1,000 rpm.

Q. Was that range generally considered to be at a high speed diesel engine rather than medium speed?

DR. PISCHINGER: No. This is medium speed diesel engine.

Q. How do you define a high speed diesel engine?

DR. PISCHINGER: The high speed diesel engine is an engine with high piston velocity, and is, by definition, at least, if I translate it into the German definition, the only thing which I can do, an engine in the field of application up to of highway transportation, the largest of highway transportation vehicles from application side, and at the same size for smaller generator sets.

Q. Approximately how many rpm would a high speed engine be, in your definition?

DR. PISCHINGER: Usually the range of above 1,000 rpm.

Q. In 1962 did you leave that employment that you had from 1958 in Graz?

DR. PISCHINGER: Yes.

Q. What did you do then?

DR. PISCHINGER: I then was employed by KHD, German, the abbreviation for Klockner-Humboldt-Deutz, AG which is a major German diesel manufacturer in Koln, and I stayed from 1962 to the end of 1970 with this company.

Q. What was your specific position in 1962?

DR. PISCHINGER: The specific position in 1962, starting position was a manager of a department of research and development, development, and then I, about two years after joining this company, I advanced and became head of the so-called pre-development department, which was dealing with the new or preparing the new designs. Again, three years later I was appointed head of the engineering development of this company.

Q. So your work there was principally in the design area for diesel engines, is that correct?

DR. PISCHINGER: I worked in the whole development field. That means not only being responsible for correct design but also for testing the engine, and being responsible for, in cooperation with the production department for the quality of the product of the customer.

Q. What was the horsepower of that engine per cylinder that you worked on during those years?

DR. PISCHINGER: Again, the range of the diesel engine of this company is a wide range. It was about 10 horsepower per cylinder up to -- just a moment -- about 500 horspowers. That's the number.

Q. How many engines that you worked on were in the range of 500 horsepower?

DR. PISCHINGER: It was mainly one engine family. That means an engine family from 6 cylinder up to 16 cylinder. 6 cylinder, 8 cylinder, 12 cylinder, 16 cylinder.

JUDGE BRENNER: Excuse me, Dr. Pischinger. Can you bring your microphone a little bit closer, perhaps in a straight line the way you are faced.

DR. PISCHINGER: Sorry.

JUDGE BRENNER: Thank you.

Q. Perhaps you didn't understand my question. My question is, of the engines you worked on from 1962 to 1970 at KHD --

DR. PISCHINGER: Yes.

Q. -- how many of those types of engines had a horsepower in the range of 500 horsepower per cylinder?

DR. PISCHINGER: Of course, at one time only one because a company never designs its own competition.

Q. And this single engine design or type --

DR. PISCHINGER: It changed, of course,

in the years.

Q. The design evolved, is that what you mean?

DR. PISCHINGER: Yes. An engine being in existence was replaced by new engine of about the same size, a little larger size.

Q. What was the speed in rpm of that engine?

DR. PISCHINGER: 600 rpm. That means maximum speed. Of course, the engine was also rated at lower speeds. So -- it was operated and sold, also, at lower speeds.

Q. In 1970 you became director of The Institute for Applied Thermodynamics at the Technical University, is that correct?

DR. PISCHINGER: That's true.

Q. And your particular responsibilities at the institute were involved with internal combustion engines and thermodynamics of combustion, according to your resume.

How much of that experience was directed with diesel engines?

DR. PISCHINGER: I have to mention, in order to answer your question, that this institute in the Aachen University is the largest engine institute in European universities, and, of course, I had to cover both fields of diesel engines and the spark engine. The field was, of course, divided up between these two types.

Q. Specifically what work did you do on diesel engines during your time at Aachen Technical University?

MR. ELLIS: Judge Brenner, I will have to object to that. He is asking this gentleman what he did during an eight-year period when he already said he worked on diesel engines and the spark engines. If he would like to give that answer in advance, I'm sure this gentleman, as we all have over an eight year period, done a substantial amount of work. That's not a fair question.

JUDGE BRENNER: That's a parade of horribles objection. I don't think the question calls for a day-by-day recitation of Dr. Pischinger's diary, if that's what you are implying. I think there is room for Dr. Pischinger to state his answer. He can tell him a little more about what he did with respect to the diesels without going to the extreme as your objection suggests. We will overrule the objection and take my comment as advice, Dr. Pischinger. See if you can provide a little more specificity without going into the unnecessary.

DR. PISCHINGER: Thank you. I will try

to do it. Of course, the work in these years, since 1970, the Aachen Institute, was very manifold. I was permanent consultant at the same time for my former company. So I was permanently involved in the further development of these diesel engines just mentioned. In addition, I have to lead the whole laboratory with 20 engine test benches for engine testing. Of course, I was responsible for the education of the students, and giving lectures in this field, passing my experience to young people.

This work related to, as it was expected in the university, about half, or let's say a little more than half, to diesel engines. My part was not diesel engines, but I may mention that even in the large engine fields, engines which can be operated as diesel and at the same time spark engines, those are mechanics of the engines to be completely the same.

Q. Dr. Pischinger, is most of your time at the university spent teaching?

DR. PISCHINGER: No.

Q. Well, approximately what percentage of your time is spent teaching?

MR. ELLIS: Objection to the relevance of that unless he is talking about teaching other than in internal combustion and diesel engines.

JUDGE BRENNER: I will allow him to answer. Mr. Dynner, it could have been posed more specifically. I mean not to stop you, but to get you moving a little bit. Your questions of Dr. Pischinger seem inconsistent with point one of your cross plan. Bring out his expertise as well as the others.

MR. DYNNER: There is an exception in my cross plan point 1, sir. I am moving now, so you can follow it, I am on Page 2 point 7.

DR. PISCHINGER: So you want an answer to my question?

JUDGE BRENNER: Let's do it this way. Why don't you rephrase it, Mr. Dynner. You want to know whether he teaches at all?

Q. Aside from your teaching duties at the university, did you also engage in research?

DR. PISCHINGER: Yes. Let's say the major part. My teaching duty is about, during lecture time, like an American university, two parts of the year during lecture time, and about six hours a week.

Q. What was the research that you were involved in?

DR. PISCHINGER: All types connected with engines. I think the research list would cover from mechanical problems to combustion problems to acoustics problems, all problems which are connected with developmental phase of the diesel engines. I think I am proud to state that there is nearly no topic left out in my research.

JUDGE BRENNER: Dr. Pischinger, while Mr. Dynner is considering his next question, give the English translation, what it would be for the full name of your firm.

DR. PISCHINGER: Yes. This is research society, or if you want a better translation, limited company, for energy research and internal combustion engines.

JUDGE BRENNER: Thank you. Also in your curriculum vitae, you indicated habilitation 1958. Can you explain that to me?

DR. PISCHINGER: I beg your pardon?

JUDGE BRENNER: I am looking at your curriculum vitae.

DR. PISCHINGER: Yes. This is the right to lecture at a university.

JUDGE BRENNER: Go ahead.

Q. Dr. Harris, could you briefly describe to us what is fracture mechanics.

DR. HARRIS: Fracture mechanics is the field of solid mechanics that's involved with the analysis of the stability and growth of cracks in solids.

Q. Were fracture mechanics techniques used in connection with the FaAA analysis of the AE piston?

DR. HARRIS: Yes, fracture mechanics techniques were employed in the analysis of the AE piston analysis in order to determine the possible growth and instability of hypothesized defects in the AE piston skirt.

Q. Is fracture mechanics used to predict the initiation of cracks in metal?

DR. HARRIS: To my way of thinking, fracture mechanics is not involved in the prediction of the initiation of cracks. Fracture mechanics is involved with analysis of cracks once they are formed.

JUDGE BRENNER: Mr. Dynner, I wanted to find a convenient stopping point and we will adjourn for lunch.

MR. DYNNER: If that's a clue, we could stop now or I could ask a few more questions on this general area if the Board wants me to for five minutes. Otherwise we could stop now.

JUDGE BRENNER: Why don't you run for another five minutes and stop at a convenient stopping point.

Q. Dr. Harris, I notice -- Dr. Swanger, if you want to add anything after Dr. Harris answers a question specifically, please feel free to add your thoughts as well.

Dr. Harris, speaking generally about the science of fracture mechanics, is it a science which can have 100 percent accuracy in its prediction of crack behavior? Dr. McCarthy, if I could interject, I think that we have followed the practice here-- and it is up to the Board how they want to proceed -- if I direct a question to a particular witness, he should respond and then you can consult and add something or you can add something. I would like to get the witness' answer before he consults.

JUDGE BRENNER: Since I interrupted, let me stop your questioning at this point. After my next statement, it would be time for lunch. I was hoping not to have to repeat the panel procedure. There are as many pages as we have had in different phases of the proceeding. I don't know how the other boards have run it. But the parties know how this

Board has run it. Use the lunch break to tell the witnesses, and I'm sure you have told them, but remind them again as to how the panel procedure works. If there is any need for clarification, I will go over it again when we come back.

MR. ELLIS: I think, sir, unless he indicates that he wants that particular witness' answer, they are entitled to consult. In this instance, where more than one --

JUDGE BRENNER: He did direct the question to Mr. Harris.

MR. ELLIS: Yes, but in any event, this is a situation where more than one witness participated in fracture analysis.

JUDGE BRENNER: I think Mr. Dynner took care of that by indicating that another witness could add after. I will go over this and point it up.

The questioner can direct a question to a witness as he sees fit, within reason. We will allow him to state the answer to that question and follow up. Not to go too far in time if another witness wants to add something on the subject because we know it is difficult to keep the point in mind. So be reasonably aggressive after it has gone on for some time and work out the dynamics of how you want to do it if someone else wants to add something on the subject, and the witness wants to add something to it themselves. If there is no identification by the questioner on asking the question of a particular witness, the panel is free to consult before the answer and to give the answer through one or two witnesses, whatever the panel desires. We recognize when you have a large panel, it is difficult for the witnesses on the panel. We will try to be flexible within limits to allow the questioner to get the answer he wants from a particular witness or witnesses, if he has a limitation in mind. On the other hand, we ask your indulgence in the fact that it is difficult for a questioner, also, when there is a panel this large. So you have to try to work it out that way.

I hope that explanation helps. I understand that as far as a particular situation sometimes it becomes difficult. You will have to help, Mr. Dynner. As a courtesy, you use the witness' name when you have a witness in mind. You can drop that courtesy if you don't intend that as a limitation. Keep that in mind, also.

MR. DYNNER: I am going to try in an

effort to deal with these panels, to indicate the witness that I'd like to respond to the particular question. If another witness who has worked in that area or wants to add something then wants to answer, at that point he can answer. But I am following the procedure of addressing the question to a particular witness if I want that witness to answer initially.

JUDGE BRENNER: Counsel, in my broad statement, it is permissible. What I am asking to you to do is bear in mind whether it makes sense from the point of view of efficiency to do that for each and every question. The questions, as you know, cut across areas of different witnesses. We know we will allow them to add when they want to and when it is likely for another witness to add, you may indicate that flexibility. Another way to do that is not indicate the witness' name by limitation. Those questions will be directed to the whole panel will come a little later. I know at the beginning you want to establish for our benefit and for your own benefit just what each witness has done and how adept they are at explaining it. So we will look at the witness' flexibility and the attorney's flexibility, also. We recognize nothing untoward was intended by the witnesses consulting because it is normal for them to consult and in fact permissible at some point, sometimes before the answer, and sometimes after the first answer or two.

MR. DYNNER: All right.

JUDGE BRENNER: Why don't we break at this point.

MR. DYNNER: There is a pending question. Can we get an answer?

JUDGE BRENNER: You will have to repeat the question anyway. Why don't we just break and repeat the question after lunch. At least I would need the question repeated. We will break until 1:35.

I would appreciate it if at some point during the lunch break the Board members could get the copy of the cumulative errata of LILCO because we haven't received our personal copies of that.

We will be back at 1:35.

(Whereupon, at 12:05 p.m., the hearing was recessed, to reconvene at 1:35 p.m., this same day.)

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AFTERNOON SESSION. 1:35

JUDGE BRENNER: Continue your cross at this point.

MR. DYNNER: Judge Brenner, as a convenience to the witness panel, we are going to make available to them two copies, bound copies of the Suffolk County's direct testimony. We may from time to time be referring to those exhibits and it will be for everybody's convenience if they can have them handy, so we can place them over wherever they're convenient on the witness table.

JUDGE BRENNER: Give us our copy of your exhibit.

MR. DYNNER: You don't have them yet?

JUDGE BRENNER: You were going to have three copies available for us in the hearing room.

MR. DYNNER: They're on their way.

MR. ELLIS: Also in keeping with past practice, if some particular exhibit is voluminous or something with no advance notice what is in an area as we did with the QA and other proceedings, it might helpful saving time to have the witness review an entire document when asked a question about it.

JUDGE BRENNER: It seems different. If you can get a focus among yourselves, fine, but we are dealing with a population here only of the County exhibits.

MR. BRIGATI: Okay. May I approach the witnesses?

JUDGE BRENNER: Sure.

Q. As we proceed it may Help to refer to your own copy of your own direct testimony because in the course of the cross-examination I'll be asking you questions about your direct testimony. You may want to have copies in front of you.

JUDGE BRENNER: What are we waiting for now?

MR. DYNNER: I'm sorry. I was waiting for you. I thought you were reading something.

JUDGE BRENNER: Okay.

MR. DYNNER: I'll proceed.

CONTINUED CROSS-EXAMINATION

Q. Dr. Harris, will you please look at pages 2 and 3 of LILCO's direct testimony.

On page 3 you state that you were the task leader for the pistons for the TDI Owner's Group. Please briefly describe your responsibilities in that position.

JUDGE BRENNER: We've been through this before lunch. He wants Dr. Harris' answer, what he did now and not anyone else's yet.

DR. HARRIS: My responsibilities as task leader for pistons for the TDI engine Owner's Group consisted of supervising and participating in the finite element analysis of the AE and AF piston skirts. The finite element analysis was completed, the stresses that were derived therefrom were used as inputs to the fracture mechanics analysis of the possibility of crack growth in both of these piston types.

I was involved intimately in the fracture mechanics analysis and the modeling of the crack growth in the piston skirt.

The finite elements stress results were also used in the analysis of crack initiation in the piston skirts were chiefly involved in that work also.

As another part of my responsibilities I participated directly in the experiments that were performed to determine by strain gage techniques, what stresses and strains were both in AE and AF piston skirts, and the actual testing itself, which consisted of handling these pistons, spending a fair amount of time at the TDI factory in Oakland in assembling the test fixtures, in inserting pistons in the cylinder liners and, running the tests.

Then, of course, I was also involved in the analysis of the experimental test results.

Another part of my responsibilities included reviewing TER's and the results of inspections at both the Shoreham Nuclear Power Plant and other power plants involved in the TDI engine Owner's Group, TER's that were relevant to the piston skirts in the nuclear power plants.

JUDGE BRENNER: Was that technical evaluation, TER?

DR. HARRIS: I believe the TER is technical evaluation.

MR. YOUNGLING: Technical evaluation.

MR. SEAMAN: Task evaluation report, in essence. What it did transfer --

JUDGE BRENNER: You've answered my question. Watch the jargon the first time it comes up in the hearing. After that we'll be keyed in on the record.

DR. MC CARTHY: One thing I would like to add to Dr. Harris, lest there be any confusion, his responsibilities for modeling the crack growth in the piston, all models even for the AF or AE design, the AF design did not predict crack growth and AE marginal. Whether cracks were initiated, they certainly will not grow in both designs. Fracture mechanics was merely an analysis of the possibility in prediction if there would be crack growth.

Q. Dr. Harris, I would like to get a little more specific if I may with you in your description of what you did with regard to the finite element analysis of the AE piston skirt.

Did you yourself perform that analysis or any part thereof?

DR. HARRIS: All of the finite element analysis on the AE piston skirt was performed under my supervision. Due to the magnitude of the task I did not do all of the work on that particular aspect of the problems solely by myself. I participated in certain aspects of the finite element analysis and all of the analysis was performed under my supervision.

Q. Who did you supervise?

DR. HARRIS: You want specific names?

Q. Yes.

MR. HARRIS: The primary people who assisted me in the finite element analysis of the AE piston skirt were David Muir and Robert Sire. Other personnel at Failure Analysis Associates participated in the finite element analysis of the piston skirt on a periodic basis.

Q. Messrs. Muir and Sire are both employees of FAA; is that correct?

DR. HARRIS: Yes, that is correct.

Q. Dr. Harris, are you yourself an expert in finite element analysis in terms of their preparation?

DR. HARRIS: Yes, I consider myself to be an expert in finite element analysis and in the preparation of the analysis. In my background in solid mechanics, my educational training, I had a number of courses in solid mechanics, the application of these disciplines to stress analysis of various mechanical components and the process of learning finite element analysis. I personally wrote a computer code that was suited for the finite element analysis of linearly elastic bodies. These days I'm not all that initimately involved in the analysis itself because of the magnitude of the work involved in setting up these complex three dimensional models applied to the piston TDI. It's much more than what one person can do.

Q. The work you did or supervised in

connection with the finite element analysis of the AE piston skirt reported in the FaAA report on the AE piston skirt which is set forth in Suffolk County's Exhibit 8 dated June, 1984 -- I beg your pardon. The date I believe is May 23rd, 1984 and not June as I originally said.

DR. HARRIS: Yes. Mr. Dynner, the report that's included as the County Exhibit 8 is the report of the finite element analysis performed on the AE and AF piston skirts.

Q. Dr. Harris, are there other finite element analyses that were performed on the AE skirt that are not reported in this May 23rd piston report?

DR. HARRIS: In the process of assembling the work that is reported in the County Exhibit 8, additional finite element runs were performed that were not included as part of this exhibit. We also have performed finite element analysis runs since this report came out. So the results that are reported in this Exhibit 8 are not the sum total of all the finite element analyses failure performed in this area. For instance, in LILCO's exhibits there has been an analysis performed on the, what we call soft wrist pin, the results of finite element analysis performed since this particular report was written.

Q. Now, was there an earlier report issued by FaAA on the AE piston skirt that referred to the finite element analysis, Dr. Harris?

DR. HARRIS: There was an earlier version of the finite element analysis. It was reported in a preliminary report dated February 27, 1984. As stated on the cover of that report it was not a final report. It was issued pending confirmatory reviews by Failure Analysis Associates QA operating procedures. Therefore, there is only one final piston report reporting the result of the finite element analysis.

I might also add in thinking back that there was another report that has been put out, a final report on finite element analysis that addresses the thermal distortion aspect of the problem. That is the second report that I'm sure you're aware of, Mr. Dynner, that is dated June, 1984 and discusses the influence of thermal distortion on fatigue performance of AE piston skirts.

Q. Are the conclusions of the February piston report that you referred to as preliminary, different from the conclusions of the final AE piston report of May 23rd, 1984?

DR. HARRIS: Anybody?

Q. Anybody.

DR. HARRIS: The substantial conclusions that are contained in the May 1984 report are unchanged from the conclusions that were obtained in the February report.

The conclusions are that the cracks may well initiate and will propagate in the AF piston skirts, but will arrest at fairly shallow depths.

The conclusion regarding the AE piston skirt is that cracks may initiate but will not propagate in the AE piston skirt.

There might be some small differences between the conclusions on the AE piston from these two reports, but the substantial bottom line is cracks are not going to grow to a critical point in the AE piston skirt. That conclusion which is the important conclusion remains unchanged.

DR. SWANGER: If I might answer the question?

The conclusion that Dr. Harris discussed in terms of the finite element analysis combined with his fracture mechanics analysis are confirmed by other work that Failure Analysis has done that includes the experimental stress analysis that Dr. Harris did and also includes the 100 percent pre-operational inspection of the pistons followed by a confirmatory examination of ten of the pistons after 100 hours of operation at or above full load.

In addition, the design concept of the AE piston was proven in tests in the R-5 test engine run for almost ten to the seven cycles at high brake mean effective pressure which we call BMEP of about 305 pounds per square inch as compared to the 225 BMEP that the Shoreham engines develop as a nameplate rating.

We feel that all of these demonstrate to a high degree of engineering certainty our conclusions that the AE skirts will not experience any crack propagation or any crack growth in their intended use at Shoreham.

Q. Is the percentage of disagreement between the finite element analysis reported in the February report different from the disagreement between the finite element analysis and the strain gage experiments reported in the May piston report?

MR. ELLIS: May I have question read back, please?

(Read by the reporter.)

DR. HARRIS: Could we please have the question repeated?

MR. DYNNER: I'll rephrase the question

and that will make it easier.

Q. Was there a difference between the results of the finite element analysis in the May piston report and in the results from the strain gage experiments insofar as the initiation of cracks in the AE piston skirt is concerned?

DR. HARRIS: As stated in LILCO's testimony and as stated in the report that has been entered as Exhibit 8 of the County's exhibits, there is a difference between the finite element analysis and experimental results on the AE piston skirt of as I recall, 28 percent. And we feel that this agreement of 28 percent is adequate in applying a complex three dimensional finite element analysis to a body as complex as an AE piston skirt.

The bottom line conclusion that the cracks will not grow in the AE piston skirt is independent of whether you use the finite element stress results or the experimental stress results.

Furthermore, since this report was originally written and issued in May 1984, and as I pointed out a few moments ago we have done subsequent analysis that changes one of the boundary conditions in the finite element analysis and the boundary condition that was changed was to alter the assumption of a rigid wrist pin.

We went to the other extreme of what we call a soft wrist pin which assumes that the load reacted in the top of the wrist pin is reacted as a uniform pressure in the wrist pin bushing rather than a uniform displacement which is what you get when you assume a rigid wrist pin.

When you perform the finite element analysis using the soft wrist pin results, you obtain a peak stress in the stud boss region that are lower than the experimentally observed value.

We feel that this demonstrates that the assumption of a rigid wrist pin is one of the major contributors to the 28 percent disagreement between the rigid wrist pin finite element analysis results and the experimental results. I think it's important to again emphasize, however, that the final conclusions obtained regarding the integrity of the AE skirt are the same regardless of which of these sets of stresses are used. I think this is very convincing evidence of the conservative nature of the boundary conditions and assumptions that were used in the finite element analysis of the AE piston skirt.

Q. So in your original part of your answer, Dr. Harris, you indicated that the difference between the finite element analysis result and the experimental strain gage result was 28 percent and in fact the difference between the finite element analysis result reported in the February FaAA report in the strain gage experiments, was 33 percent, wasn't it?

MR. ELLIS: I haven't raised this before because I didn't think it was going to be necessary.

If he is questioning on preliminary, we would object because I think it was the Board's previous indication or ruling that litigation would proceed on final reports. not on preliminary reports even though preliminary reports were made available to the County.

JUDGE BRENNER: That point was made in your motion to strike. A report is available for use in terms of what it tells us as to validity and certainty of the results. The analyses done by FaAA, and it's useful to both in the County's testimony, which we left it, that was not withstanding the point in the motion to strike and also useful for the same or similar purposes under cross-examination. I think to accept your argument disports that particular context of our previous ruling on discovery to which you're referring for support. So we understand your argument, but we do not accept it.

Q. Can you answer the question? The question was that the disagreement in the February report was 33 percent, wasn't it?

DR. HARRIS: If you give me a moment, please, I'd like to check the February report to refresh my memory. I've been dealing with the more recent results for the last four months and the earlier report is somewhat stale in my memory.

MR. DYNNER: Page 5-7 of the February report, gentlemen, if it helps you.

DR. PISCHINGER: May I add something to this very point?

JUDGE BRENNER: Let's see if we can get a particular answer to the question. Are you going to answer that question or point?

DR. PISCHINGER: Yes, it is related to this question.

JUDGE BRENNER: But the particular answer that is being sought at this point, I want to get that first.

DR. PISCHINGER: It's related to it.

JUDGE BRENNER: But let's see if we can nail down the answer first, 33 percent difference,

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and if you could I'll ask you to hold your point and we'll get to it.

DR. HARRIS: Thank you for pointing me to the relevant page here.

Yes, the disagreement was 33 percent at that time.

JUDGE BRENNER: Now, let's let Dr. Pischinger answer.

DR. PISCHINGER: I want to point out regarding the reality the wrist pin is not rigid. Very conservative model. This is well known in engine industry. Models have been employed since years by piston manufacturers for instance in Germany. We have two well known and a -- it is well known if you apply rigid wrist pin you get a very conservative answer. Frequently stresses are higher and, therefore, I myself am in favor to use the conservative model and to that means there must be a difference with experimental results because conservative higher stresses predicted by the model is just a -- in fact, it is quite reasonable.

I wanted to point out there is no contradiction between measurement and calculation. It has to be expected when you use these boundary conditions.

MR. DYNNER: Dr. Pischinger, when dealing with the reliability of a diesel engine which is to be used for emergency power nuclear, power plant, do you think that it is appropriate to use a conservative approach as you've described?

May I have this answer without Mr. Seaman commenting, please.

DR. PISCHINGER: In this case, I think it is for safety reasons appropriate to use a conservative approach because if this conservative approach predicts, as it does in this case, growth and reality, predicts no cracks or no growths of cracks, then you are on the safe side. I in favor, just inclination, with this matter, yes.

Q. Dr. Harris, was the difference between the 33 percent disagreement and the 28 percent disagreement the result of using a different model for the wrist pin?

DR. HARRIS: Please clarify what 28 percent disagreement it is you're referring to.

Q. You testified in the May piston report this agreement was 28 percent. February report it was 33 percent. Is that difference attributed to the fact that you used a different finite element analysis of the wrist pin and that you did not use a rigid wrist pin in the second analysis?

DR. HARRIS: No, that's not true. In both cases we used a rigid wrist pin.

Q. Would you explain why when you got the 33 percent disagreement in the first piston report you went back and did another finite element analysis?

DR. HARRIS: After performing the finite element analysis reported in the earlier results, looking at the results, comparing them with the experimental observations and looking back on the boundary conditions that we assumed in doing the earlier analysis, we felt we wanted to refine the earlier analysis and further expand our finite element models to produce a set of results in which we have even more confidence than the earlier reports.

Q. Did anybody at LILCO or TDI Owner's Group suggest maybe you ought to redo the finite element analysis to get a little bit closer agreement?

Anybody from FaAA can answer that.

DR. HARRIS: Absolutely not. Not to my -- this was a decision made within Failure Analysis Associates.

Q. Everybody with FaAA agree?

DR. SWANGER: Yes, yes, everybody at FaAA does agree and as Dr. Harris testified it was earlier when the original report was still in draft form and was subjected to Failure Analysis' quality assurance procedures that the decision was made that a better calculation could be done.

Q. Can you in layman's terms describe what you did to make the calculation better?

DR. HARRIS: The second version of the finite element analysis calculations that were performed on the piston skirts utilized an actual elastic crown placed upon top of the skirt. This was the primary difference.

In the earlier analysis we used engineering simplifications of the boundary conditions that accounted for the contact between the crown and the skirt.

In applying these boundary conditions we were not satisfied with the results we obtained and decided that we wanted to take analysis the one step further and place an elastic crown on top of the skirt. In actuality, the two-piece piston used in TDI engines has two pieces. There's a piston skirt and piston crown. Both of these bodies are elastic and they interact with one another and the elastic interaction between these two bodies became apparent to be an important part of the problem.

That's the major modification that we made in our analysis and the major expansion we made to further enhance the accuracy of the results.

In the process of constructing to improve the finite element model that included the elastic crown, we took advantage of that time in order to further refine the finite element model in the region of the stud boss which is the region in which cracks were observed to occur in the AF piston skirts. So we did do some refinement of the skirt model itself.

DR. MC CARTHY: I perhaps should add for clarification of nontechnical people, refinement of the finite element upon which Dr. Harris just spoke, it means adding more detailed calculation points, not in the sense of refinement as removing impurities like you would implement, refine, you add more in more calculation points and areas where you have greater interest and as you work more with the model this is a common result as you get the whole model working at increments of precision of the finite elements.

Q. Now, after you came up with the initial finite element analysis disagreement of 33 percent, and before you came up with the final report number of 28 percent, you reported much lower disagreement to a TDI Owner's Group meeting; do you recall that? By you I mean FaAA.

DR. HARRIS: I personally cannot comment on any numbers that were given at TDI Owner's Group meetings. I did not participate in them. Anybody else care to comment on that?

JUDGE BRENNER: Excuse me. Here again you can be more precise with the opening question instead of taking three questions to get to it.

Q. In fact, at TDI Owner's Group on March 22nd 1984, Dr. Wells of FaAA reported that FaAA has now completed its own quality assurance check of all the numbers in the finite element calculations and in the difference between the experimentally determined stresses and the predicted stresses under the imposed uniform displacement between the crack and the skirt now is 11 percent. I think it was 30 percent in the initial analysis, so it's better and probably within reasonable agreement.

Are you aware of the report that Dr. Wells of FaAA made that I just quoted from?

MR. ELLIS: For my benefit, Mr. Dynner,

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tell me what you're reading from.

MR. DYNNER: Reading from a transcript of the Thursday, March 22, 1984, TDI Owner's Group meeting, pages 87 and 88.

MR. SEAMAN: Could he see a copy of those transcripts?

JUDGE BRENNER: Wait a minute. See if you can answer the question. He's given you this information. If you need more, we'll see. I don't want to stop here and read documents unnecessarily. The question is addressed to witnesses who are familiar, employees of the same company to which the representatives of -- if you don't know anything about it, take it from there. Let's see what you can do.

JUDGE BRENNER: Dr. Harris, do you know anything about that?

DR. HARRIS: Those numbers don't sound familiar to me at all.

JUDGE BRENNER: All right. They don't know anything about it.

Anybody else?

MR. SEAMAN: Well, Judge, the reason I asked to look at the transcripts is we had talked about various designs of pistons and it would be important to know exactly which one. I guess it wasn't clear from what was read.

JUDGE BRENNER: All right. Mr. Dynner, zero in.

Q. Mr. Seaman, were you at the meeting on March 22nd, 1984?

MR. SEAMAN: I don't recall that specific meeting but I was at a majority of the Owner's Group meetings.

Q. You don't remember anything about anybody reporting 11 percent disagreement; is that correct?

MR. SEAMAN: No, I don't recall that figure.

JUDGE BRENNER: That's as far as we're going with this witness until you give them an opportunity to look at the transcript. I'm not going to stop now while they're reading the transcript.

MR. DYNNER: Okay.

JUDGE BRENNER: If you intend to pursue it, tell their counsel and during the next break they can have time to, between now and the next session, to take a look at it.

MR. DYNNER: Okay.

Q. Do any of you remember a figure of 18

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percent disagreement that was used in an interim report on the piston skirt issue by FaAA?

DR. HARRIS: I know of no Failure Analysis report that reports 18 percent disagreement. At least at this point I don't recall any report that has that number in it.

Q. Anybody else?

JUDGE BRENNER: Mr. Dynner, the reference to the meeting does fall under Mr. Ellis' comment. If you're going to be cross-examining from documents like that, there are many documents in this case, unless you are worried about the surprise element -- I certainly didn't perceive that in the last series -- let them know in advance so they will have time to look at the documents.

You knew of this many, many weeks in advance of this hearing and I am going to weigh that in terms of time spent in delay to allow witnesses to look at things to refresh their recollection. It's different than what I said before about a limited population of proposed County exhibits.

MR. DYNNER: I'm not -- I wasn't questioning about --

JUDGE BRENNER: I don't want to debate it.

MR. DYNNER: All right.

Q. Now Dr. Harris, in connection with the fracture mechanics analysis, you said you personally were involved in performing some of those analyses. Is that correct?

DR. HARRIS: I was personally involved in performing the fracture mechanics analysis in the piston skirts yes.

Q. Anybody else in FaAA assist you in the fracture mechanics analysis?

DR. HARRIS: Yes. Once again, the magnitude of the analysis required more than one person to be involved. In this I was assisted by a number of other persons within Failure Analysis Associates.

Q. Who were the principal people that assisted you in that analysis?

DR. HARRIS: The principal person who assisted me in that analysis is Robert Sire.

JUDGE BRENNER: Spell his name, please.

DR. HARRIS: S I R E.

Q. Would you briefly describe personally what you did in connection with the strain gage measurements?

DR. HARRIS: I supervised the placement and selection, the placement of the strain gages on the piston skirts. I was involved in selecting where to place the gages, how to perform the tests and what instrumentation to use. The strain gages themselves were then applied by people under my supervision. We then took the piston skirt to the test fixture and I assisted in installing the piston in the test fixture and wiring up the strain gages and gathering of the data. After the data was gathered we took the raw databack to our facility where I participated in the analysis of the data, plotting of the data and interpreting of the data.

As far as the experimental program went, I also participated in the stress coat test performed on the AE piston skirt, the test that was used to precisely determine the location of the maximum stresses in the AE piston skirt.

Q. Dr. Harris, were you responsible for writing any portion of the piston report? When I say piston report, I'm going to be referring to the final May 1984 piston report by FaAA.

DR. HARRIS: Is the question was I responsible for writing the report?

Q. Did you write any portion?

DR. HARRIS: I wrote the major portions. Once again, it was a group effort and several people participated in the writing. I was the major author of that report.

Q. Who else participated in writing the report?

DR. HARRIS: I might point out that many people can make contributions to a report without actually writing the words in a report. And if you expand the definition of people that participated in the preparation of the report to include the people that read the report, made comments, suggestions or revisions, there were a great number of people involved in both writing the report and in processes of proofing it within Failure Analysis Associates, also outside Failure Analysis Associates.

Q. My question goes to who else wrote it rather than who was involved in editing or doing background material or parts of the tests. Who else wrote the report besides yourself?

DR. HARRIS: Robert Sire, Cliff Wells, Harry Wachob, John Shyne. Those were just the people that put words down on paper and there may have been more, but those are the names that immediately come to mind.

Q. Dr. Johnson, on page 3 of your direct testimony you state that you supervised the eddy-current inspections of the AE piston at TDI before shipment to LILCO.

Who actually conducted the eddy-current inspections that you supervised?

DR. JOHNSON: Don Johnson conducted the inspection at LILCO under my supervision using a procedure developed by me and I also gave him training on the use of this procedure and also reviewed the results of that inspection.

Q. You said Don Johnson?

DR. JOHNSON: Yes.

Q. Who did he work for?

DR. JOHNSON: Mr. Johnson works for me.

Q. An FaAA employee?

DR. JOHNSON: Yes.

Q. Is it correct that you performed the eddy-current inspections on all of the AE pistons before they were shipped to LILCO?

DR. JOHNSON: Excuse me?

Q. Is it correct you performed, you meaning FaAA under your supervision, performed eddy-current inspections on all of the AE pistons before they were shipped to Shoreham?

DR. JOHNSON: That is correct.

Q. Was Mr. Don Johnson a qualified

eddy-current inspector, was he qualified to perform eddy-current inspections?

DR. JOHNSON: Yes. He's qualified according to the American Society for Non-Destructive Testing, level two eddy-current inspector.

Q. Is he qualified to perform this in accordance with an FaAA quality assurance program?

DR. JOHNSON: Yes, he is.

Q. What procedure, what written procedure, if any, was used to conduct the eddy-current inspections?

DR. JOHNSON: The procedure that was used was FaAA Failure Analysis Associates NDE procedure 11.5.

Q. What does that procedure define as a non-relevant indication? What doesn't have to be reported? Is there a size indication that you don't have to bother reporting?

DR. JOHNSON: The acceptance criteria in that procedure is such that crack like indications greater than 1/16th inch long by 1/32nd inch deep would be reported. That's a factor of 16 less than the size which has been, which calculations say will not grow.

Q. Did you know that at the time that you conducted these eddy-current inspections, that is, did you know that this was much smaller than the size crack that's predicted not to grow?

DR. JOHNSON: I think at that time we did not have a number for the actual size, but it was -- we felt it was much smaller than the flaw size predicted to grow.

Q. You felt it was much smaller? What's the basis for feeling that at the time?

DR. JOHNSON: The precalculations in the process, the feedback I was getting was that the flaw size of concern was quite large.

MR. SEAMAN: If I can add?

That point in time we had had an opportunity to evaluate the indications in the AF piston and our judgment based on the observations of the metallurgical investigations that we conducted on the AF piston indicated that those cracks were not growing. Therefore, we knew what size those cracks were.

We had some judgment as to what size cracks in the improved AE piston design would be relevant indications that we would be concerned with. So we did have some feel for what that number was at that time.

MR. DYNNER: When you say we, Mr. Seaman, who are you referring to?

MR. SEAMAN: I'd be referring to the Owner's Group as a whole, which would include obviously Failure Analysis as well as LILCO and the inspectors that were out there.

Q. Dr. Johnson, when did you perform these eddy-current or supervise these eddy-current inspections at TDI? Approximately what month? I don't mean the exact day.

DR. JOHNSON: Exactly the piston, which piston are you referring to?

Q. The AE piston skirts that you said you supervised the eddy-current inspections of at TDI before shipping to LILCO.

DR. JOHNSON: I think November of 1983.

DR. HARRIS: If I can add something?

MR. DYNNER: Yes.

DR. HARRIS: It's possible to make a fairly simple fracture mechanics calculation as to what size of a crack will be of concern in a structure from knowledge of what an estimate of what the stresses are, what the cylinder test model is for fatigue crack; in simpler terms, some threshold condition for crack growth. It's possible to make a conservative estimate what size crack would be required in order to grow in the structure.

In making the conservative assumption the cyclic test is unequal to the ultimate strength of the material, you can then make a conservative estimate of the initial crack size required for crack growth.

If you use a delta-K threshold condition for technique, crack growth of six ksi root inch somewhat below the value we used in our subsequent analysis, you can determine that the crack size for crack growth for the threshold conditions of crack is well in excess of 32nd of an inch. So I believe the original estimate of the crack depth that would have to be reported was based on some of these conservative simple fracture mechanics considerations.

Q. Did you make that calculation, Dr. Harris?

DR. HARRIS: As I recall, we did.

Q. When?

DR. HARRIS: Roughly November.

Q. Did you write it down?

DR. HARRIS: I may have written it down but I doubt if it any longer exists. It's a type of three lines.

Q. Somebody ask you to do that calculation?

DR. HARRIS: Just a type of calculation you would normally do in selecting a reportable size for your NDE procedure.

Q. Did you tell Dr. Johnson about it?

DR. HARRIS: I cannot recall specifically whether or not I told Dr. Johnson about it, but there was a number of failure analyses involved in such analysis and decisions. I'm sure I didn't make calculations and throw it away without telling anybody.

Q. Why did you make that calculation in November?

DR. HARRIS: To obtain an estimate of what size cracks would be required in order for a crack to grow within the piston skirt.

Q. Mr. Johnson, when was the procedure 11.5 with the 1/32nd inch deep acceptance criteria written?

DR. JOHNSON: The NDE procedure 11.5 revision 1 was written on 1-31-84. The revision 0 which is the precursor to it and one used at that time was written November 2nd, '83, signed off a little later.

Q. Do do you know who wrote it?

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DR. JOHNSON: Yes. I know who wrote it. I wrote it.

Q. Before you wrote that procedure, did Dr. Harris tell you about his calculations concerning crack initiation in the AE pistons?

JUDGE BRENNER: Excuse me, Mr. Dynner. Can I ask the materiality of this line of questioning?

MR. DYNNER: Materiality of this question?

JUDGE BRENNER: Yes.

MR. DYNNER: It goes to a couple of things. Credibility, number one, and goes into the terms of the FaAA procedures followed. And it goes to the issue of the size of these crack initiations and the numbers of flaws which could now be relevant which may be in those pistons that were accepted because of a procedure that was written without any relevancy to studies that were later made.

JUDGE BRENNER: I don't understand, though, any of your questions.

They've testified that if you have a crack of 1/32nd of an inch or less it is not going to propagate in their opinion, whether it occurred after or preexisted. If you're going to controvert either that through your own testimony and get your turn on that or through cross-examination, you're going to have to challenge them on the basis of their conclusion and in that regard and it is not going to be material whether or not they've got cracks under 1/32nd of a inch which passed the eddy-current inspections and it doesn't matter if they have on pure luck or whether they did it knowingly.

The point we're going to have to decide is whether flaws of that size or less, either preexisting or which may occur later, are going to make a difference in the fracture mechanics analysis.

I don't want to sit here for 11 more minutes on something that is a lot of glorious detail with the witness until you make a decision on the materials of this as opposed to glorious detail on material points, which I will be pleased to listen to if it's going to matter.

MR. DYNNER: I'll be happy to, later on. We're going to raise the issue of --

JUDGE BRENNER: Wait a second. Unless you can tell me where I'm terribly wrong in my last point, I'd like to have you move on to another point.

MR. DYNNER: Numbers and proximity of

cracks.

JUDGE BRENNER: You're going to have to challenge both by cross-examination and in your own testimony their assumption to the benigness, if you will, of cracks 1/32nd of an inch or less.

MR. DYNNER: Sure.

JUDGE BRENNER: Unless you do that, all this other questioning as to whether they had their criterion for the eddy-current inspections knowingly or by dumb luck or based on our rough calculation or detailed calculation and what sequence they arrived at all this isn't going to matter. It's a lot of detail taking a lot of time which isn't at the moment helping me.

MR. DYNNER: Okay.

JUDGE BRENNER: I don't think it helps Suffolk County.

MR. DYNNER: Aside from the correct point going to go into numbers and proximity of cracks, our testimony, and we'll show this and it's been raised already, is that it may well be relevant. We raise this in connection with the fracture mechanics approach to whether it takes in consideration the real world or not that the number of very small cracks may well have a bearing on crack propagation if there are numbers of small cracks within close proximity. That's one of the reasons why this acceptance criteria is material aside from the credibility issue.

JUDGE BRENNER: You know, you're using a lot of words, Mr. Dynner, but not addressing the central point in my view. I understand that the criteria may be relevant. In fact, I started out pointing out in what light it might be relevant, but you've got an agreement that their eddy-current procedure would permit cracks or indications, whatever you want to call them, 1/32nd of an inch or less to get by using my layman's description, if you will. So you got that as a starting point.

Take it from there as opposed to saying, well, when did you say 1/32nd would be okay and so on. The rest of it doesn't matter. You have an agreement that's the criterion.

Now after cross-examination you can try to challenge why they should have had a different criterion and we know as a given there could be indications smaller than that they're not reporting in the results of the eddy-current. You can have your own witnesses tell us why that's a terrible thing. All of that is relevant.

Any of your questions on who shot who when does not bear on any of those material points.

MR. DYNNER: From long experience I have learned that when you're not interested in something I should move on, so I will.

JUDGE BRENNER: I resent your remark that I'm not interested. I'm interested in anything that's material.

MR. DYNNER: That statement was made in a semi-humorous way certainly. I certainly didn't mean to suggest you're not interested in all of the testimony of these witnesses, but I am going to move on that.

JUDGE BRENNER: I am very interested in the testimony and unless you help me focus on that which is important, you're going to lose the forest because of all the trees.

MR. DYNNER: Okay.

Q. Dr. Johnson, did you write any portion of the piston report?

DR. JOHNSON: No, I didn't.

Q. Dr. Swanger, on page 5 of the direct testimony you state what your responsibilities were with respect to the AE piston skirts. I'd like to ask you to develop a little more detail what you did.

Specifically, what did you do in terms of the evaluation of the metallurgical aspects of the AE piston skirt?

DR. SWANGER: I think there are two major areas that I was directly involved in on the metallurgical aspect of the AE skirts in addition to the other work. I contributed to the two specific areas in the characteristics of the nodular iron material from which these skirts were made.

Under my supervision laboratory tests were done to completely characterize the nodular iron actually in an AE piston from the lot of piston delivered to Shoreham. We did independent chemical analysis of the nodular iron, we did metallographic analysis to characterize the nodularity of the iron and the nature of the pearlitic, mostly perlitic matrix of the iron.

We also did make tensile testings which determined the ultimate tensile strength, the yield strength, the elongation of the iron which was actually in the pistons.

This complete characterization of nodular iron allowed Dr. Harris then to go to the scientific literature on the fracture mechanics of cast irons and in a conservative manner to select the proper fracture mechanics parameters, the threshold, the stress intensity factor for evaluating whether or not hypothesized cracks would grow and also the growth kenetics themselves referred to as DA/DN properties for the cast iron.

In addition, I was involved in the comparative analysis between the AE and the AF piston skirts and in particular the analysis of the cracks that were found in the AF skirts to establish that the cracks which were found in the AF skirts had arrested. Careful metallographic work, and I think the best way to show that is to refer to the piston report that was done, County Exhibit 8, figure 2-15 on page 2-16. This is an example of the scanning electron microscopy work done to the striations, the approximate growth of the cracks found in the AF skirts per each stress cycle. As stated there the growth rate was approximately ten to the minus fifth inches per cycle.

We used this information in conjunction with other information to demonstrate that the cracks found in the AF's had indeed arrested.

I can address a little bit how we are certain that those cracks had arrested as follows: There were 23 AF piston skirts at Shoreham and cracks in the stud boss ligaments were found in all 23 of the pistons.

I can refer to another figure on this, figure 2-4 on page 2-9, which shows an inspection of one of the original AF skirts at Shoreham. In the arrow that figure indicates the kind of arrested crack we're discussing when we discuss the AF piston. It's important to notice that every one of the AF pistons in all three of the emergency diesel generators at Shoreham had such crack-like indications in them but that we think that the maximum depth of any crack-like indications was about a quarter of an inch.

Take as an assumption what I think is a reasonable engineering assumption that the fatigue striation shown in figure 2-15 gives us a reasonable approximation for the rate of growth of the crack. Then the kinds of cracks that were found in all 23 of the pistons would have grown to the depth of one quarter of an inch in about five hours of operating time. These engines had various amounts of operating time on them at the time they were dissassembled to replace the pistons, between I think 600 hours and 800 hours and perhaps Mr. Youngling or Mr. Seaman can confirm that.

In fact, we were running three entirely independent tests because each one of the engines had experienced a different histogram of load and hours, yet by almost a remarkable coincidence five hours before all three of these engines were taken apart these cracks decided to start growing and we happen to catch all of them just at the point where they were all just five hours old and just quarter of an inch deep.

That alone with the fracture mechanics analysis that Dave Harris has done we feel demonstrates certainly that the cracks in the AF's had arrested and then a similar kind of analysis, a comparative analysis, the same kind of analysis shows the cracks in the AE's would not have arrested -- would not have propagated. I have to correct my testimony. I misspoke. The conclusion, in using the same kind of analysis, hypothesized cracks in the AE's even if they were up to a half an inch deep would not grow.

I think that summarizes the metallurgical aspects of my involvement in the AE piston skirts.

MR. DYNNER: I want to move to strike the witness' answer.

My question regarded what he did on the

AE piston. He gave a long answer about AF piston cracks, why they won't propagate and we have no testimony on that.

JUDGE BRENNER: All right. I'm not going to strike it because your question was quite vague and you're going to learn to make your questions more specific.

I agree with you it went beyond what I think was necessary to answer the question what you did do with respect to the piston.

MR. DYNNER: I didn't say that. The question could be reread, what did you do on the AE piston skirts, on the metallurgical aspects of the AE skirt.

JUDGE BRENNER: And it was too broad.

I'll assume for the sake of argument you've correctly given me the question just now. It's a broad question. I think the answer went beyond what I would have expected the answer to contain. Nevertheless, I can see from the witness' point of view how it was pertinent and I am going to allow it to stand. Make your questions more specific if you want shorter answers.

If any counsel believes any of these figures which are in fact photographs are pertinent and necessary, they're going to have to make them separate exhibit numbers for the particular photographs only. I'm not going to assume they're pertinent. It may be for all purposes the witness this time and in the future description will say what is contained is sufficient, but Xerox copies which are certainly not accurate to see what is on those figures.

MR. ELLIS: On that last point I think it's very difficult to tell from the copies.

JUDGE BRENNER: I am not going to stop the hearing now to decide whether we need the photographs. I'm giving you time to think about it and pick out certain photographs. If you think they're necessary, put them into evidence.

I'm not -- I don't believe they're necessary right now. The witness not only referred to the photographs but described fully his opinion of what they stand for.

MR. ELLIS: I have them here if the Board would like it for convenience. It is difficult to tell.

JUDGE BRENNER: We have them in our office, too, the originals that is. You decide whether you want them in the record and appreciate your convenience too.

MR. ELLIS: Okay.

JUDGE BRENNER: Go ahead, Mr. Dynner.

MR. YOUNGLING: Like to confirm --

JUDGE BRENNER: Wait. I don't think you can add much to the answer about what Dr. Harris, Dr. Swanger did.

MR. YOUNGLING: He asked if I would confirm the number of engine hours on the engine at the time of the discovery of the AF cracks, between 650 and 820 hours between the three engines.

JUDGE BRENNER: All right. Thank you.

Mr. Dynner, go ahead.

Q. Dr. Swanger, could you briefly describe what you did to evaluate the manufacturing techniques of the AE piston skirts?

DR. SWANGER: Yes. My evaluation involved a number of things. For instance, I performed numerous visual inspections of the piston skirts myself at the Shoreham Nuclear Power Station, both coming out of the engine and as they were disassembled on the turbine deck. The purpose of my visual inspection was to gain a feel for the foundry practices, specifically the molding practices that were used in conjunction with these pistons.

Looking at the as-cast surfaces which are the surfaces on the AE piston which the finite element analysis and the stress coat test demonstrated are the most highly stressed areas, I felt that was important for me to assess the manufacturing techniques.

Also, the metallurgical aspects that I described earlier were related to that in that I reviewed the heat treatment process that the AE pistons are given, the normalization and the tempering treatment they were given to develop the desired metallurgical properties which they have to have to be suited for the purpose that they're being used for at Shoreham.

Looking at the nodularity the pearlitic structure with the degree of pearlite in the structure and the mechanical properties, it allowed me to assess the correctness of the heat treatment part of the manufacturing technique for these pistons.

Thirdly, I witnessed and evaluated a number of the measurements of the tolerances on these pistons. The tolerances in dimensional aspects of the piston are important so that they properly function in conjunction with the other components of the engine and also are indicative of the machining portion of the manufacturing aspects and from the measurements that were done as part of the DRQR, design review quality revalidation effort at Shoreham. I reviewed a number of these dimensional tolerances and found them to be appropriate for pistons in a large medium speed diesel.

The fourth thing I did was review the inspection results done both by eddy-current and by dye penetrant techniques because they are a better indication of the foundry practice than the initial visual inspection I gave.

And again, with my experience in foundry practice with my former employer who manufactured, as I testified earlier, components for large diesel engines of the type used at Shoreham, I wanted to assure myself that the appropriate techniques were in use.

The last thing I did was visual inspection of the tin plating which is applied to the piston at Shoreham by the manufacturers to assist in the break-in process and to protect the piston in inventory and in storage prior to installation in the engines.

My previous experience also includes knowledge of the electroplating process, the electroplating process used not only for Clevite but also manufacturers of sleeve bearings where I picked up my particular expertise. And by recognizing the uniformity of the surface condition of the as-plated plane on the piston I can tell from a lack of nodularity or too rough surface tin was not too thick and on the other hand from its uniform color and lack or complete coverage of the modular that was pla[illegible] the tin was not too thin either. I think that is a description of my evaluation of the manufacturing techniques of the AE piston.

Q. Dr. Swanger, did you write any portion of the piston report?

DR. SWANGER: No, I did not write a portion of the piston report, but as Dr. Harris testified, a number of our people at FaAA contributed to the thoughts and conclusions that are represented in the report.

Q. Dr. McCarthy, on page three of your direct testimony you testified that you personally inspected various piston types at FaAA?

DR. MC CARTHY: That's correct.

Q. What types of piston skirts did you

inspect?

DR. MC CARTHY: Portions of the various AF piston I inspected and also Failure Analysis Asscoiates was given an AE piston for material evaluation which I also had.

I also had an opportunity to inspect the AE that we ultimately strain gaged and tested.

Q. When you say you personally inspected those piston types, was that a visual inspection with respect to the AE piston?

DR. MC CARTHY: Yes. Primarily involved multiple visual inspections because not only Failure Analysis Associates inspect them when they arrived but as they were being strain gaged I would drop in and periodically inspect the placement and the workmanship on gages and wiring and things of that nature.

Q. Do you consider yourself an expert in the placement of strain gages?

DR. MC CARTHY: Yes, I've done hundreds and hundreds.

Q. Were these inspections that you carried out documented?

DR. MC CARTHY: No, in the sense they were not part of our procedure. They were in addition to the normal QC procedure. They were not part of our QC procedure. They were, in addition to all our other quality control checks. I occasionally inspect basically the operation and what's going on apart from all the other checks and balances in the system.

Q. Dr. Mc Carthy, you testified that you're responsible for the quality and caliber of FaAA's technical product. Is the May 1984 piston report accurate in all respects?

DR. MC CARTHY: Accurate or very conservative. There is a sense in which I think draws were made in this report and in another analysis that were this a design job for a manufacturer instead of a hearing on an important matter like a backup emergency diesel generator, we would have been far less conservative in our approach. I think we would have been more likely to rely on experimental values which were clearly lower because we would judge -- just a best engineering judgment. This basis would probably provide more realistic characterizations, but recognizing the importance and the need for conservatism in this analysis this report is more conservative than a normal effort for a manufacturer would be.

Q. Aside from the conservatism in the report, are there any deficiencies in the piston report?

DR. MC CARTHY: I guess, you define what you mean by deficiency, typographical error? What is a deficiency?

Q. Any deficiencies in the analyses which are reported in the piston report?

MR. ELLIS: I still don't think that's adequately specific and I object to it on being excessively vague. It can be a wide range and lengthy report. If he has a specific deficiency in mind, he should get at it and see what it is.

JUDGE BRENNER: I agree with the objection, Mr. Dynner, and the context that these are now followup questions you're examining. He did have the original question as to whether he thought, Dr. Mc Carthy thought, the report was accurate and he gave you his answer. Now, you're following up. Given that context, you can be more specific other than that it's just a repeat of your earlier question.

MR. DYNNER: All right. Let me go beyond accuracy.

Q. Dr. Mc Carthy, are there any omissions of any facts in the report which might have affected the conclusions and recommendations of the report?

DR. MC CARTHY: There's no negative or I

would say cloudy omissions of the fact that would color the conclusions of the report. I think once again in the interest of conservatism we omitted a lot of analysis and perhaps understated some values where a greater nominal would have been used. I think the report is too conservative, but --

DR. PISCHINGER: It's conservative.

JUDGE BRENNER: A greater nominal did you say?

DR. MC CARTHY: Yes.

DR. HARRIS: If I could add to that, further address some of the conservatisms?

The nominally used endurance limit is a very important property in regards to the crack initiation. In the fatigue crack growth analysis thresholds, stress intensity factor is very important as far as the crack growth goes. Both of those values were also conservatively selected in order to build conservatism into the results. Nonetheless, we still found cracks up to depths of half an inch would not propagate in the AE piston skirt; therefore, the use of these conservative values did not have any influence on the final end result we obtained by the finite element analysis.

It is important also to keep in mind that there were separate and independent efforts going on to give us additional confidence in the results that we were obtaining. These include operating history of the AE skirt in actual operation as well as tests performed on the AE skirt in an operating engine at the TDI plant in Oakland, and the inspections that were made on all of these skirts and also the experimental analysis that was done.

So we have this multi-pronged approach to the problem, so that the final conclusion to be drawn was not dependent on any one of these particular aspects of the procedure that we went through.

DR. MC CARTHY: Probably in the report, to label something what do I think is closest to an error, we say in the report the cracks may initiate in the AE. I personally don't think that's true. At best it's a border-line prediction given our results. It's highly dubious to make that assumption and be conservative.

Q. Why didn't you, given the disagreement of 28 percent in the final report between your finite element analysis and your experimental results, why didn't you recommend that the EDGs with the AE piston be run and tested for considerable number of additional hours in order to find out whether, empirically, whether your finite element analysis result was more accurate or less accurate than the strain gage readings?

DR. MC CARTHY: Because of my background in design and my knowledge of testing and performance of engine components, I knew that the hundred hours of testing that we did was in fact the substantial empirical verification that flows from the character of the fatigue behavior of steel parts and don't want to extrapolate to other materials to steel. Steel has a very interesting characteristic called a knee. After so many cycles as you get farther and farther out to more and more cycles, eventually the steel will, if the stresses are low enough, survive essentially infinite number of cycles and fatigue. After you get to one million cycles and bringing 100 hours at 1.35 million cycles you -- at least from my -- that's only about seven percent above the stress level for infinite life of the part. Now, seven percent is a relatively small amount when you figure the normal scatter of strengths of parts.

In addition, we had a population of pistons that had been carefully inspected before they were put into operation. We knew the character of the indications in the size of the flaws, if any.

And they were all found to be less than accepted criteria, testified to previously. We ran these piston 100 hours and took them out and reinspected and again found no relevant indications.

By testing ten pistons you essentially tested 40 bosses or 80 highly stressed regions, the statistical probability of 80 of these fillets in ten different pistons all being substantially above the specified stress and therefore not cracking is so vanishingly small it just didn't happen. So in fact by going to 1.35 million cycles and having not even an indication of crack growth, we're very confident that ten million or 100 million cycles will achieve once again no indications and no crack growths.

I don't believe personally they will ever crack. Take the stress analysis as the least conservative assumption and still they aren't going to grow.

MR. SEAMAN: If I could add one further --

JUDGE BRENNER: All right.

MR. DYNNER: Let me follow up.

Q. Are you an expert in statistics, Dr. Mc Carthy?

DR. MC CARTHY: I have had significant formal training in statistics through various statistically-related design courses. Also at Failure Analysis I have assembled the largest body of accident and failure statistics in the entire nation, nobody of — the government, no private agency, no insurance company has more statistical records than I have at Failure Analysis on failures and records which I routinely analyzed for trends and indices with regard to failure. I think it is a correct statement that in the area of statistics relating to failure, we are the cutting edge.

Q. Do you have any statisticians on your staff?

DR. MC CARTHY: Yes, several.

Q. Any of them look at this issue of these ten pistons in order to determine whether your conclusion as to what is or is not statistically probable is correct or not?

DR. MC CARTHY: Not as a formal assignment. I'm certain I discussed it with each one.

Q. Who did you discuss it with?

A. Dr. Caleb Davis.

Q. When did you have that discussion?

DR. MC CARTHY: I don't recollect. It was a relatively small point.

Q. Okay. Mr. Seaman, go ahead

MR. SEAMAN: Well, what I wanted to point out was the R5 operating experience where we had a piston, actually two pistons that had been subjected to peak firing pressures even higher than the Shoreham pistons would ever see, 2000, and also inspected and found to be free of cracks after having sustained over 600 hours of operation. So there's further justification for the conclusions that Dr. Mc Carthy has elaborated on with respect to the formation and propagation of cracks in AE pistons.

Q. Dr. Mc Carthy, your testimony is that the FaAA report is not only accurate in all respects but also complete in all respects; is that correct?

MR. ELLIS: I object to that. The question has been asked and answered. The witness gave several answers, gave an extensive answer on what he thought might be added in terms of conservatisms and what he might disagree with.

JUDGE BRENNER: I agree with the objection. Sustained.

Q. Dr. Mc Carthy, aside from the additional finite element analysis that was done, assumming the non-rigid wrist pin that you alluded to, has any other work been done by FaAA with respect to the AE piston skirts that does not appear in the May piston report?

I should add to clarify my question, I also mean in addition to the two other reports that you talked about, the preliminary report and also thermal report on pistons.

DR. MC CARTHY: There are some additional things which I will allow Dr. Harris and Dr. Swanger to address in a moment done subsequent to these reports. And there is individual work I guess in terms of analyses, checks on my part that are not reported formally in the report that I did as part of my general oversight of the program and I'm certain observations, checks, made by other individuals in Failure Analysis in addition to all those reported here that are just a normal part of the operation of a large and sophisticated engineering firm.

DR. HARRIS: I would also like to take this opportunity to point out that under Exhibit P-34 of the diesel exhibits there's the result of some additional analysis on the performance of the AE piston skirt at peak firing pressures greater than originally considered in the earlier analysis. Subsequent analyses have been performed on the crack initiation and the possibility of crack propagation in the AE piston under pressures in excess of 1670 psig used in the earlier analysis. We took the opportunity after the reports came out to look in more detail at the influence of increased firing pressure. We performed analyses of crack initiation and propagation for pressures up to and exceeding 2200 psig.

Q. That's in your direct testimony?

DR. HARRIS: I believe it is.

JUDGE BRENNER: Point Mr. Dynner to the page so we don't repeat it. That's why it's written direct. You have the page Mr. Dynner needs?

MR. DYNNER: No. I wanted to know what else was done.

JUDGE BRENNER: I don't know if he completed his answer.

DR. HARRIS: Dr. Swanger pointed out this is discussed in LILCO testimony question number 105.

DR. MC CARTHY: We apologize the testimony was not cited in the things about -- in your question you asked about work not reported in the various reports and the testimony is -- we didn't think of it as one of our reports.

JUDGE BRENNER: I'm not criticizing the answer. You're right, he left it out. It was fine to put in the answer. I'm trying to give you time to reference it. Go ahead.

DR. SWANGER: I would like to add that question 105 is in the section which deals with the alleged effects of side thrust on the pistons.

JUDGE BRENNER: There was earlier reference in your testimony to that, but go ahead.

DR. SWANGER: I was going to point out that that question contains the conclusion that peak firing pressures up to 2200 pounds per square inch did not cause cracks to propagate in the AE pistons.

JUDGE BRENNER: I could not find the reference I had in mind.

MR. DYNNER: I can find the reference later. I want to --

JUDGE BRENNER: Anything in the testimony is in evidence also.

MR. DYNNER: Sure.

JUDGE BRENNER: Anything else beyond the testimony and the three reports Mr. Dynner is interested in?

Q. Are you currently at FaAA doing any

additional work regarding the AE piston skirts or the AE piston as a whole?

MR. ELLIS: Judge Brenner, I assume the question refers specifically to Shoreham and not with respect to other nuclear stations, because if it doesn't I would object to it to the extent that it refers to other nuclear stations.

JUDGE BRENNER: Well, we've got the question. Ask him about the AE pistons. If you want to object to that, you can.

The answer and the question stands.

JUDGE BRENNER: While considering that, Mr. Dynner, we can take an afternoon break whenever you're ready.

DR. MC CARTHY: One more item. To conclude now, confining ourselves to Shoreham related work on AE's?

JUDGE BRENNER: The question was any other current work on AE pistons.

DR. HARRIS: We do have some additional work that has been performed upon AE piston skirts that we have not discussed or not been reported in any Failure Analysis reports. This has to do with the estimates of the influence of side thrust on cyclic stresses in the stud boss region of AE piston skirts.

Also we have recently been looking at stresses in circumferential ribs of various design piston skirts.

Q. I'm sorry. I did not hear the second part of your answer. I heard you say side thrust on cyclic stresses in the bosses and I didn't hear the second part.

DR. HARRIS: We also have ongoing studies of stresses in the circumfrential rib wich goes between the wrist pin bosses in various design skirts including the AE. Failure Analysis Associates works on pistons as an ongoing effort for the TDI Owner's Group.

Q. You have any preliminary results concerning your analysis of the side thrust on cyclic stresses in the bosses?

DR. HARRIS: Yes.

Q. Would you briefly describe them?

DR. HARRIS: We have found that the inclusion of the side thrust loads in the analysis of the cyclic stresses in the stud boss region in which the largest stresses occur in the AE piston skirt has virtually no influence on the cyclic stresses themselves. This was an expected result but the question had been brought up a number of times in discussions with various other organizations and we felt it was important to get quantitative results. I believe Professor Pischinger would like to comment on that.

DR. PISCHINGER: If I may?

This is a usual experience, usual experience if you apply side thrust to piston stresses. No influence on the peak and highest stresses in this region has been experienced and documented in literature, also well known, so it's not unexpected.

Q. What are your preliminary conclusions, if any, or other conclusions concerning the work you're doing on the circumferential rib in the skirt, in the AE skirt?

MR. ELLIS: I object to that question on the ground that's not in the contentions so far as I'm aware, I may be mistaken; therefore, not relevant or material.

JUDGE BRENNER: Mr. Dynner, do you want to address that?

MR. DYNNER: Well, I don't really know what work they're doing on the circumferential rib and how it might be related to cracks in the AE piston skirt that are part of the contention.

I don't know anything about it. I'm trying to find out what it is they've done and what the conclusions are.

JUDGE BRENNER: You have to tell me more than that. This is the trial, not discovery. You had a lot of discovery in this case where you could have asked him anything and everything about the work on circumferential rib.

MR. DYNNER: We could take a break now. I can discuss perhaps that question with my consultants and give you an answer after the break.

JUDGE BRENNER: If you want, you can show me how it ties into any point in your testimony which we had to start first and tied in with the details within your contention.

All right. Let's break until 3:35.

(Recess had at 3:20.)

JUDGE BRENNER: Mr. Dynner?

MR. DYNNER: The question about the circumferential rib is directly relevant to the contention on the side thrust. My understanding is that the circumferential rib is part of the piston skirt design that's intended to help resist the side thrust load and prevent excess deflection. Therefore, the question is directly relevant to the contention.

JUDGE BRENNER: What question do you want to ask about it?

Q. What are your preliminary or other conclusions concerning the work you've done on the design of the circumferential rib of the AE piston skirt?

MR. ELLIS: I don't know that -- I don't think the witness heard the question. I assume the objection has been sustained. They didn't realize it was being asked again. Is the Board going to --

JUDGE BRENNER: I'm going to allow it, but get it tied up sooner rather than later.

MR. ELLIS: May I have the question read to the panel then, please?

JUDGE BRENNER: Mr. Dynner, please.

MR. DYNNER: What are your preliminary or other conclusions regarding the work that you've done on the circumferential rib on the AE piston skirt?

MR. ELLIS: Is that the AE piston?

JUDGE BRENNER: Yes. I'll add: in the context of excessive side thrust load. That way if there is no context we'll find area right away.

DR. PISCHINGER: Circumferential rib out of the design keeps a connection between the two -- two wrist pin bosses, the two wrist pin bosses. If you load wrist pin, the whole load on the piston is given to the wrist pin, then two bosses tend to deviate and this ring gives a connection of two bosses. This ring is certainly not needed to counteract very low side thrust tension.

JUDGE BRENNER: Dr. Pischinger, am I correct if I infer from your answer that the work on the circumferential rib is not being done as part of any analysis of excessive side thrust load?

DR. PISCHINGER: Yes.

JUDGE BRENNER: All right.

Q. Dr. Pischinger, are you involved --

JUDGE BRENNER: Let me stay with it.

MR. DYNNER: The question was asked of FaAA.

JUDGE BRENNER: Let me stay with it a little more. I recall a reference to the circumferential ribs in testimony.

I'll allow anybody on the panel to answer. Can you tell me succinctly what work, why is some analysis being done of the circumferential rib on the piston? I'm trying to get an understanding what context it would have.

MR. ELLIS: Judge Brenner, your question

is the AE piston?

JUDGE BRENNER: Yes.

MR. ELLIS: I'm not sure that's been established.

JUDGE BRENNER: My question is to the AE piston.

DR. HARRIS: The analysis on the influence of side thrust load on stresses in the ribs in the AE piston has been done to allay -- to provide quantitative results in regards to allegations referring to the influence of side thrust loading.

We feel that the side loading is certainly not excessive, and the NRC staff testimony at Exhibit 7 further supports this, however, in order to be able to quantitatively address the influence of side load on cyclic stresses, we have performed additional supportive analysis.

JUDGE BRENNER: Is this analysis of the stresses on the rib?

DR. HARRIS: It includes also stresses in the rib in the AE piston, yes, in addition to stresses up at the stud boss region which is the region we are more concerned with because the stress coat testing and also the finite element results tell us the largest stresses occur up in the stud boss region.

JUDGE BRENNER: Do you discuss the circumferential rib in your testimony in the context of the testimony on side thrust load in your written direct testimony?

DR. HARRIS: As I recall we do not.

JUDGE BRENNER: You have some reference to it somewhere.

DR. PISCHINGER: May I add, the AE piston as a circumferential rib has been no problems at Shoreham present with the thin dimension.

JUDGE BRENNER: Given that, Mr. Dynner, you're going to tell me a little bit about where you want to go. I don't have that in front of me in cross.

MR. DYNNER: I'm going to ask some questions about what the nature of the work that they're doing is on the study on the circumferential rib and what they're -- whether they have preliminary or other conclusions of what those conclusions are.

With respect to the side thrust issue they testified, in fact FaAA's I believe just testified, that it does relate to the side thrust

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issue.

JUDGE BRENNER: Stay with that subject, not a lot of jumping around from the subject on questions I did not get in your cross plan. Side thrust subject, stay with it.

MR. DYNNER: No. I can pick it up when I get to side thrust.

JUDGE BRENNER: Do that. When you get to it, ask the conclusions, not to tell me about what work you've done and complain about the fact they've put too many self-serving statements in their answer.

For example, you ask them some of the things you're going to ask them about side thrust load directly in that context of a particular point. Ask them what about the effect of the rib on that kind of impact or load, instead of having an abstract discussion and only come back to put it together at side thrust load anyway. All right? Where are you in your cross plan?

MR. DYNNER: Right now I'm at the bottom of page two.

Q. Dr. Mc Carthy, what is the AE piston skirt made out of, what material?

DR. MC CARTHY: Iron.

Q. Any particular kind of iron?

DR. MC CARTHY: I don't recall. I'd have to look it up.

Q. Dr. Mc Carthy, given the fact that the AE piston skirt is made out of iron, what was the relevance of your answer to my question about testing where you talked about 100 hours of testing being substantial for a part made out of steel?

DR. MC CARTHY: Both have almost identical forms. I thought I used the term ferrous materials. If I didn't, I meant to talk about ferrous materials as opposed to other materials exhibiting the knee in the endurance limit curve and I meant to distinguish ferrous materials, iron being a ferous material and steel. I probably used the word steel. Both exhibit the phenomena, the basis of the whole discussion.

DR. SWANGER: I can add to that.

We specifically referred to the iron casting handbook at page 341 where the properties of ductile iron are shown, that an endurance limit doesn't indeed exist at ten of the seven cycles for nodular iron and in fact it was from this reference that we determined the seven percent between the indurance limit and the limit — the stress at which cracking would be observed at 1.35 times ten to the sixth cycles.

DR. HARRIS: If I could further add to that, the particular figure Dr. Swanger was referring to is included as Exhibit P-28 in the LILCO diesel exhibits.

Q. Is the material of the AE piston and the earlier material of the AF piston both 100-70-03 at ASTM A536 ductile iron as stated with respect to the AE skirt on page seven of your direct testimony?

DR. SWANGER: A536 ductile, both pistons are ASTM 536. We know for certain that the AE skirts are 100-70-03 grade. We're not sure if the AF's that particular strength level, or, as described in A536, are one of the other strength levels. We'll check for you and get back to you with that answer.

Q. If you'll turn for a moment to page 2-7 of the piston report, table 2-7 entitled tension tests of specimens taken from pistons, in that table the yield strength ksi is the range in the AF pistons which were tested from 53.6 to 64.5. The yield strength of the AE pistons that were tested ranges somewhat higher from 63.5 to 70.5. Is there any significance concerning those differences between the yield strength ranges of the AE piston as opposed to the AF piston?

DR. SWANGER: In referring to the data shown in table 2-7, the title of that is tension tests of specimens taken from pistons. If you actually refer to the ASTM standard A536, it specifies that test coupons used for the determination of nominal strength properties for iron castings. Hence, the 70 designation for 70,000 yield 100 designation for 100,000 ultimate and three for three percent elongation, applies to a test coupon and not necessarily to specimens actually taken from the pistons.

Due to differences in the thermal history of an actual component relative to the test coupon, there are expected and understandable variations in the metallurgic properties of certain parts. We felt it important to take specimens from the actual pistons in doing our conservative fracture mechanics analysis so we would have the right values of the material. We characterized it properly for the particular area in the piston that we wanted to model.

Q. Is your testimony then that there is no significance in the fact that the yield strength of the AE pistons has a somewhat higher range than the yield strength of the AF specimens in that table?

DR. SWANGER: There is a significance to the difference and that the origin of that -- significant origination of that difference is the heat treatment given to the AF pistons was slightly different than the heat treatment given to the AE pistons. The AF pistons are normalized and still air cooled,, whereas we believe the AE pistons were normalized and force air cooled. Both pistons are subsequently tempered at 1,050 degrees for three hours prior -- subsequent to that normalization. But the difference in the heat treatment does develop the difference in the yield strength that's shown in the table.

Q. And what is the significance of the fact that the ultimate strength numbers or range given for the AF piston specimens varies from the specimens for the AE pistons?

DR. SWANGER: Within any given group of castings we would expect some variation from sample to sample and in my opinion these variations that are shown here are reasonable for the grade of nodular cast iron used in the AF and AE pistons. I don't think there is any substantial significance to the difference in the ultimate strengths.

Q. That wouldn't relate to the heat

treatment being different; is that correct?

DR. SWANGER: It shows that the heat treatment had some effect. I think the greater effect of the heat treatment is shown in the last column, the percent elongation fracturing which the AE shows to have little more ductility than the AF.

The heat treatment of nodular iron has influence on its properties. Any castings are going to have some expected variation in their properties which is why we used lower bounds on the measured properties to add a degree of conservatism to the fracture mechanics analysis which concluded that the AE pistons will not have propagating cracks.

Q. So that if one were to be conservative when dealing with the yield strength of this particular kind of nodular iron, both these pistons are made of one, would take a range for yield strength 53.6 to 70.5; is that correct?

DR. SWANGER: No. I don't think that's correct. The reason I don't think it's correct is because there was an intentional change in the heat treatment process going from the AF piston to the AE piston. I think to analyze the AE piston it is appropriate to take the range of properties determined for it, to analyze the AF piston it is appropriate to use the range of properties determined for the AF pistons.

Q. These specimens according to this table were taken from four AE pistons, is that correct, or some smaller number?

JUDGE BRENNER: I don't want to wait this long for a point that may or may not be important. At this point I don't think it's important. It may later. Why don't you move on. We'll get the answer supplied later and you can have it put on the record if you need it on the record.

DR. SWANGER: I believe that we have determined that the results reported in table 2-7 are results of samples taken from two AF pistons and two AE pistons. I refer to material which was used in the support package for the piston report which I believe was made available to the County for their examination.

Q. Does the size of the specimen taken have any effect on the UTS or yield stress calculated from the specimen?

DR. SWANGER: The ASTM 536 specifies a standard size for the sample when it's taken from a keel block and that is the reason it specifies, for cast products, a standard size for the sample.

Taking a sample smaller than specified by the ASTM will result in lower properties being measured which is an extra degree of conservatism in the analysis.

Q. Took a smaller sample than that specified, is that what your testimony is?

JUDGE MORRIS: I'm afraid there might be confusion between what we mean by sample, geometrical size or the number sampled.

MR. DYNNER: I'm talking about I think the size of the specimen from the —

JUDGE BRENNER: Ask him.

Q. Which one did you mean?

DR. SWANGER: I was referring to the geometrical size of the sample and we took the largest possible sample we could from an actual manufactured piston. Due to the thickness of the walls in it there's a limitation on the size of the specimen you can take. We took the largest. In checking the records, it was smaller than the size, geometrical size of samples by the ASTM.

Q. Lower strength; is that correct?

DR. SWANGER: Yes, in my experience with testing of metallurgical properties over the past 15 years that would give lower numbers for the strengths and lower numbers for the elongation.

Q. Is the AE skirt shot peened?

DR. SWANGER: I believe there is a cleaning procedure involved to remove foundry sand and oxide from the surface of the piston. It's a grit blasting type of operation. I think it would be unfair to characterize it as shot peening.

Q. So that process would not have any impact on the strength of the skirt; is that correct?

DR. SWANGER: I'd have to disagree with that statement. I think thorough proper cleaning of the piston allows very thorough inspection of the piston to be made to be certain no piston with any flaw, even so — 16 times smaller than the size of flaw we know is non-propagating in these skirt, is present in the cast surface. I disagree with the statement.

Q. Does the process that you referred to as grit blasting, aside from making the piston skirt cleaner, have any impact on the yield strength or ultimate strength of the skirt material?

DR. SWANGER: As I testified earlier, I would not characterize grit blasting in the same vein as shot peening because the impact energies of the particles are much lower. Therefore, my opinion is the effect on the properties of the skirts would be very small, but I don't know what it is because I've not recently reviewed it to see if there is any scientific literature available on the effect of grit blasting as opposed to shot peening.

Q. Mr. Seaman, on page eight of your testimony you testified that the gap sizes between the outer contact ring on the crown and skirt in the AE piston at Shoreham were measured when the piston skirts were installed in November of 1983. Who measured those gap sizes?

MR. SEAMAN: Measurement of these gap sizes is a study that is made during the assembling of the pistons at LILCO and it is something that was measured by the startup. Re-assembling the pistons was verified by our operational quality assurance.

Q. What was the acceptance criteria of the gap sizes?

MR. SEAMAN: The acceptance criteria I believe was seven to 11 mills., and we have documents that indicate that the ranges were in between those values.

Q. So all those measurements are documented as part of LILCO's inspection process: is that correct?

MR. SEAMAN: Yes, we have Exhibit P-5,

we've listed those or we have — excuse me. Talking about the initial inspections that were performed in November; is that correct?

Q. Yes. That's the question on the bottom of page eight of your testimony.

MR. SEAMAN: That's not what's in the exhibit.

We do repair reworks that indicate that the measurements that were taken during the assembly were between that range, yes. They are repair rework documents which is an RR standard form that's used out in the Shoreham site and are signed inspection hold points that indicate the measurements were taken and were within these values and witnessed by our quality assurance department and signed by them also.

Q. Gentlemen, could you turn for a moment to Exhibit P-5 which is referenced at the bottom of page ten of your written testimony. Who prepared this document?

DR. SWANGER: That document was prepared by Failure Analysis Associates.

Q. Why was it prepared, that document?

DR. SWANGER: That document was prepared to confirm that 1670 psi is a reasonable value to use to the peak firing pressure in the diesels at Shoreham at 100 percent load.

Q. Was this document prepared given a particular load on the diesel engine?

DR. SWANGER: I believe that this document presents data taken during testing of the engines for purposes of determining stresses in the crankshaft.

Q. Was it taken on any particular load?

DR. SWANGER: We don't have backup material here to confirm the exact load it was at, but I believe it was at 100 percent load.

Q. What engine was it taken for?

DR. YOUNGLING: That test was performed on diesel engine 103.

Q. Do you agree with that, Dr. Swanger?

DR. SWANGER: Yes, I was present during that testing and 103 was the engine tested at the end of December, early January.

Q. Dr. Harris or Dr. Swanger, since this is your testimony on this pressure crank angle diagram, could you explain to me how it was generated?

DR. SWANGER: It was generated by placing a pressure transducer into one of the air start valves placed into the cylinder number seven during the engine testing. As I had said earlier, it was used in the piston analysis just to confirm that 1670 psi was a reasonable number to use for analysis. As we have testified earlier today, we have subsequently shown that 2,200 psi peak firing pressure could be used for the analysis and the conclusion would be the same, no cracks that can propagate in the AE pistons.

Q. What kind of pressure transducers were used?

DR. SWANGER: Dr. Pischinger will answer that because Heir Reiter from his firm came in from Germany with the transducer.

DR. PISCHINGER: This was AVL watts pressure transducer. It was one of the, I think, the most used transducer in diesel engine testing in the world now.

Q. Would the placement of that pressure transducer, Dr. Swanger, be important in the results for the pressure diagram?

DR. SWANGER: There had been a question as to earlier testing if the cylinder cocks on the side of the cylinder head were a proper position for measuring peak pressures and because there was some question as to whether they were appropriate, then this transducer which was put right in the face of the fire deck in the combustion chamber was used to be the final adjudicating authority for demonstrating that either location for measuring peak pressures were accurate.

Q. The placement of this pressure transducer in the combustion chamber then would be important; is that correct?

DR. SWANGER: It turned out not to be important just for the reason I told you. Professor Pischinger -- I just reiterate that there were questions as to whether the test cock on the side of the cylinder was adequate. The position within the combustion chamber, there is no doubt that would give a proper measure within the combustion chamber. We wanted to be sure that our analysis was done properly, so we did a confirmatory test with the quartz piezo transducer right in the fire deck as close to the middle of the combustion chamber as we could get it. I'll let Professor Pischinger comment further.

DR. PISCHINGER: In some diesel engines high pressure rise was-- pressure versus time can give rise to oscillations in pipes to the pressure tranducer or to the pressure and if this is the case, you can get wrong readings. And for this purpose, to compare this AVL pressure transducer it was flush mounted, which means its surface was part of the surface of the combustion chamber wall. Then the generally accepted clear, you get exact reading, complete exact reading. In this case it was found to other source of getting pressure reading, gave same reading, and so this was confirmed you can use either position.

Q. When you look at this document, what does it tell you the peak firing pressure is?

DR. SWANGER: The curve itself cannot be read exactly, but I believe it appears to indicate peak pressure of about 1580 psi.

In addition, this curve was generated from data which was recorded on magnetic tape and as part of the further analysis for other components that magnetic tape was digitized and complete charts of the pressure versus crank angle were developed.

However, for analysis the piston -- it's only important that we know what the peak pressure is. And as I said earlier, we had subsequently demonstrated that it really doesn't matter for the

Shoreham diesels what peak pressure we use up to the extremely conservative 2200 psi.

Q. Are you certain that this pressure chart was taken at full 100 percent load?

DR. SWANGER: As I said earlier, we don't have the documentation available to confirm that, so I can't be certain.

Q. Such documentation exists?

DR. SWANGER: Certainly it exists within FaAA.

DR. PISCHINGER: I think one of the most important points here is it shows peak pressure is very near to the top dead center, because this assumption or this factor is needed for the calculation of the forces on the piston. I think this is a most important point here, not the figure reading, but the position of the peak can read it as about estimate ten degrees, but it was a higher degree, ten degrees after the top.

Q. Dr. Pischinger, did your colleague confirm to you that this peak pressure was taken at 100 percent load on the diesel?

DR. PISCHINGER: No. There was a complete series of measurements with different loads and I do not know what this one is.

Q. Did you have to change the cooling arrangement for the placement of the transducer when you put the transducer in the combustion chamber?

DR. PISCHINGER: This is a cooled transducer.

Q. So you did not have to change the cooling arrangement for the engine?

DR. PISCHINGER: No.

Q. Did you change the transducer from one which was air cooled to one which was water cooled?

DR. PISCHINGER: No, as far as I was involved, no. We only used for this purposes water cooled transducers which are the most accurate measuring equipment.

DR. SWANGER: To clarify the experiments that were done as we had said earlier, this test was done to assure ourselves that taking pressures from the test cocks was also accurate and at the time we had air cooled transducers on the pressure test cocks but we also had a water cooled transducer in the air start.

DR. PISCHINGER: Of course, I only referred to this transducer in answer to that question.

Q. Did you have any failures on any of the transducers during this test series?

DR. SWANGER: I don't recall if we did or not.

JUDGE BRENNER: Mr. Dynner, has not your cross line served it's purpose in not using it? You can't use it to follow you?

MR. DYNNER: I'm about to --

JUDGE BRENNER: As a result I can't use it for its most important purpose; that is, in evaluating where you were going as the most important purpose. You asked one question on this subject and that was 20 minutes ago and asked it as your first one. Here we are. We haven't got to the next question in the cross plan.

MR. DYNNER: I'm about to suggest that I skip ahead to page 11 of the cross plan on this same subject matter.

JUDGE BRENNER: All right. Tomorrow morning if you're going to bury the cross plan as much as you did today, you get me an oral outline at the outset of the whole purpose of cross plan rather than have digressive questions of opportunity which may seem inspirational to you at the moment, but the cold reality of analysis may turn out to be not very material.

You should have the cross plan and usually that purpose is for pro se questioners, frankly, rather than lawyers. I want it planned out and stay with things that develop into material points. Of course, you can vary it as you have to adjust to an answer, but the percentage, if you will, of variance versus what is in the plan varies to much degree. If you want to go that way, go ahead.

MR. DYNNER: All right.

Q. Gentlemen, if you turn for a moment to page 18 of your direct testimony. Dr. Harris, what did you mean in your answer 24 by peak firing pressures?

Is the peak firing pressure the highest firing pressure that particular engine sees?

DR. HARRIS: The peak firing pressure is the highest pressure that the piston sees during the four strokes of the four-stroke engine. Firing pressure can be a function of the operation of the engine and load. The peak firing pressure, you have to specify more things than just peak firing pressures. Say maximum pressure the piston ever sees. For instance, in our estimation of peak firing pressure applicable to piston analysis of the Shoreham pistons, we relied in addition to the pressure crank angle diagram we discussed short time ago, on independent measurements supplied by the engine manufacturer and other measurements made by other LILCO consultants.

We have considerable amount of information that is provided by the engine manufacturer in regards to peak firing pressure at 100 percent rated load in Shoreham engines as well as other similar engines of the same manufacturer. So that the 1670 psig peak firing pressure does not come from any one single source. It represents what we believe to be a reasonable and somewhat conservative value of the peak firing pressure that can be used to provide representative cyclic stresses in the operation of the Shoreham engines.

Once again, it's important to keep in mind that analyses were performed with pressures up to 2200 psig and tests were performed both in operating engines and in static tests at pressures up to 2000 psig, each at higher pressures. The bottomline conclusion regarding the integrities of the AE skirt is not altered: that is, the AE skirt will not propagate cracks and is suitable for infinite life in the Shoreham engines.

DR. PISCHINGER: May I add something?

JUDGE BRENNER: Yes.

DR. PISCHINGER: By the way, this firing pressures measured for 100 percent load or high load is in the range of experiences of diesel engines of this size. Out of say air pressure and the compression ratio and mean effective pressure of the engine, you can say by experience and within certain firingpressures and these measured firing pressures in these range of experiences, no, I have no doubt that we are on the safe ground.

DR. HARRIS: If I may, I'd like to further add, the NRC staff assembled some information on peak firing pressures on other modern diesel engines similar to the TDI engines -- excuse me, Exhibit 7 indicates that peak firing pressure in the Shoreham engines and other engines of the TDI design are very much in the range of TDI peak firing pressure, very much in the range of modern practice assembled in NRC staff Exhibit 7.

Q. What I am getting at, Dr. Harris, you used peak firing pressures several times. You used it in 1670, is that correct, at one point in your piston report?

DR. HARRIS: Yes.

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Q. Would you look for a moment at LILCO's Exhibit P-9. On the bottom of the page it says 37, but if you turn to the sixth page in, putting together the same pages, top says PT.307.04A-2, appendix F, engine cylinder pressure log. At the very top it says EDG 101. Now, for example, that which you presented shows 100 percent load of 3,500 KQ the firing pressure on cylinder one was 1720 psi. Why wouldn't that be the peak firing pressure for this engine?

DR. MC CARTHY: An excellent point. Let's look at the preceding other engine charts. You can see same cylinder on various engines being measured various times are in fact 1530 -- various other measurements also at Shoreham measured pressures 1530, 1550 as shown in page 19C of Exhibit 6, 1550 is shown on page 19C, the 1720 just mentioned in the question, 1620 on the following page, the 1620 and various pages.

When you're doing an analysis based on a long-term fatigue design related phenomena and going to choose a site of stress, choose a high number conservative relative to the average.

The various peak pressures found here which are consistent with the chart you brought to our attention, 1550 peak firing 100 percent load and look at all the peak measurements, I think you would agree that 1670 for your entire fatigue analysis is in fact conservative and higher than the bulk of the measurements measured for peak pressure even on the test on these engines which is a number you choose for fatigue analysis, ten to the sixth cycle, higher than your average.

Q. You didn't use peak firing pressure to do that?

DR. MC CARTHY: By peak firing pressure, peak pressure in a given cycle, any diesel engine, any cylinder over a large number of cycles is not going to see precisely the same pressure each firing For a number of normal operating reasons.

Thus, if you're going to do a fatigue analysis trying to predict, if you will, the load from a large number of cycles, you want to choose an average loading, if you will, an average peak pressure per cycle that is going to be more stringent than the engine is likely to really see. We believe 1670 represents that number.

Q. Did you make a calculation of this average somewhere, of this average peak pressure?

MR. ELLIS: I also have another objection

I'd like to state to the whole line of questioning. It is irrelevant and immaterial also used 2200 and found the same result of no propagation, so I don't see where all of this is getting us.

JUDGE BRENNER: They want to strike all their testimony.

MR. DYNNER: Concerning firing pressures and what they say on the page about the 2200, they can do so. Otherwise, it seems to me we're entitled to cross-examine on this testimony.

JUDGE BRENNER: That's it, the answer, Mr. Ellis. I cannot make a determination at least on my own at this point that we should rely only on that additional testimony as to the effect of the approximately 2000, all this other testimony and for the measured pressures and what it could withstand and so on.

If you want to simply start with getting a stipulation right now that the firing pressure pertinent to our decision would be 2,000 psig, we can take it from there.

MR. ELLIS: No, because I think that would be inaccurate.

JUDGE BRENNER: That will be the effect of my granting your objection. At the moment that is my view.

MR. ELLIS: I understand, Judge.

JUDGE BRENNER: It's immaterial if you allow us to base everything on the stipulation 2,000 psig is the material pressure.

MR. ELLIS: I understand, Judge.

JUDGE BRENNER: Maybe when we value the whole record and put it altogether, hopefully I'll be a lot smarter about it than I am at this given moment while still getting the testimony in, but for now the feeling is --

Do you recall the question?

DR. MC CARTHY: Yes.

The 1670 was a decision we made after it was basically a number received as input from TDI and literature with regard to a reasonable design pressure for diesel engines. We, of course, did a lot of instrumenting and confirmatory tests in nature after testing and reviewing other test data. We were satisfied 1670 was a conservative assumption for a million cycle peak pressure. The actual numbers in our measurements during tests were below that.

So once again, if this were as a design job for a diesel manufacturer we would have gone with the actual engine test data which would have used lower peak pressure. Given the nature and conservativism requirea, we chose a number that we are confident that looking at all the measurements is higher than the average pressure really seen by the cylinder over years or any number of cycles of operation.

JUDGE BRENNER: Dr. Mc Carthy, maybe I lost something somewhere as a result of the dialogue I had with Mr. Ellis. The same answer you gave earlier, I think the question is -- I understand you think that that's conservative for a fatigue phenomena for many cycles.

The question is, how did you arrive at that. What's the basis for your conclusion that 1670 is a conservative number to use for that purpose?

DR. MC CARTHY: Because of actual measurements that were made of the engine during firing and other measurements not made by us over the engines in the past years generally came into values substantially below that.

JUDGE BRENNER: Did you read all the numbers and say that value looks like higher ones or did you do some mathematical -- did you apply that magical process in drawing an average or what? Anybody can answer.

DR. PISCHINGER: May I clarify something? This firing pressure which is shown here is, of course, quite usual in the diesel, as great as five percent. Of course, if you do calculation, fatigue calculation, whatever calculation for component, this mean pressure which is quite usual in the industry, then you have to look for conservative calculations on this component out of other sources. This has been done very rigidly in this conservative model. So I think 2.5 percent should not play any role with such a lot of additional safety which is in the model.

DR. MC CARTHY: In answer to your Honor's question, once again the individual who did this work is not here. But my recollection when we did this work is that we did indeed mathematically analyze the test results that was done jointly by Stone & Webster and Failure Analysis on the engine and mathematically and electronically arrived at firing pressures, saw nothing as high as 1670 in either basis and accepted this number that was suggested to us by TDI as their design target as conservative in light of our measurements.

JUDGE BRENNER: I'm sorry. Nothing as high as 1670 and what?

DR. MC CARTHY: In our testings.

JUDGE BRENNER: Whose testing shows numbers higher than 1670?

DR. MC CARTHY: Shoreham Nuclear Power Station, not by us.

MR. YOUNGLING: These tests are part of the pre-operational testing done on the engines as part of the recovery effort after the crankshaft replacement.

DR. MC CARTHY: I perhaps missanswered the question with regard -- we did not -- I'm sorry.

We certainly add this data, it's in the exhibit book and reviewed it. As Dr. Pischinger pointed out, the difference between this and 1670 assumptions were extremely small and overwhelming number of these are below the 1670 number. Therefore, we did a fatigue analysis based on the 1670. If you go to much higher pressures, the conclusions are just totally insensitive to this assumption.

JUDGE BRENNER: Is 1720 the highest individual point that was seen by anybody?

DR. PISCHINGER: I'm sorry?

JUDGE BRENNER: Is 1720 the highest individual point that was seen by anybody?

DR. PISCHINGER: 100 percent, yes.

DR. MC CARTHY: I could calculate to within -- I have never seen a higher entry that I can recollect.

MR. YOUNGLING: For the purpose of this testing, to accumulate final base line data prior to the conclusion of pre-operational testing these three sets of data, one for each engine with last pieces of data taken and that is the highest number, yes.

JUDGE BRENNER: I wasn't limiting my question to the pre-op testing performed under your supervision, though. I'm not worried about 1620 versus 1720. I'm talking about higher numbers, 1800, for example.

DR. MC CARTHY: No. That would have had implications for other analyses, not the least of which is the crankshaft.

JUDGE BRENNER: Dr. Mc Carthy, tell me again what the definition of peak firing pressure was that would permit you to record 1670 in your testimony under that definition rather than 1720.

DR. MC CARTHY: Peak firing pressure is

that peak pressure that occurs during a firing cycle and that is a number. Every cycle has a pressure that is a peak value. With every firing cycle the individual pressure in a cylinder is not identical. It always varies a little bit, a few percent.

Now, when you do a fatigue analysis you're looking at the potential damage of millions of cycles of load.

JUDGE BRENNER: I understand that.

MR. Mc CARTHY: The question is now to choose the value that's going to be representative of the millions of cycles because in real life some are going to be higher, some lower, you're request is going to determine the target of your fatigue analysis, that's your average peak pressure; in other words, what you might think is average peak for a large number of cycles.

Not every individual cycle has a peak and different value, but when doing a fatigue or cumulative damage or fracture mechanics analysis what is the number you're going to use as the long-term damage number. That's what the 1670 represents, a choice we believe after looking at the data at the high end of the peak pressures that have been measured in the testing of this engine.

JUDGE BRENNER: Go ahead.

Q. Just for clarification, Dr. Mc Carthy, previously in answer to one of my questions you read some numbers from engine cylinder pressure logs which you said were page 19C of Exhibit P-9 that were in the 1500s. It's true, isn't it, Dr. Mc Carthy, that those three pages for EDG 101, 102 and 103 are pressure logs with the original crankshaft; isn't that correct?

DR. MC CARTHY: I believe that is correct. I would have to rely on that.

Q. Turn to the page immediately preceding 19C which says pre-crankshaft failure. Those numbers for cylinder pressures are generally lower than the numbers following for the post-crankshaft replacement numbers; isn't that true?

DR. MC CARTHY: I haven't conducted a statistical average. If you look on page -- on this particular set, pre/post, look on page 37. Again, the one appendix EDG 103, 1500, 1550, these are the new crankshafts.

Q. In fact, on the page that you referred to for EDG 103 is from 1500 for peak pressure in cylinder number four and at 3595 KW 100 over the -- or 95 over the rated load up to 1680?

DR. MC CARTHY: That's correct.

Q. Now, you referred in answering some of Judge Brenner's questions the fact that you relied on the actual measurements that FaAA took of the peak firing pressure. How many cylinders did FaAA take actual measurements in for peak firing pressure?

DR. SWANGER: At the time of the test on EDG 103 in late December, early January, we had the instrumented air start valve in cylinder number seven and we also used the pressure gage, the external pressure gage at cylinder taps of all eight cylinders to demonstrate that cylinder number seven was operating properly and was representative of the pressures of all of the cylinders.

Q. Were the pressures of all other cylinders 1580 psi or were some of them higher at full load?

DR. SWANGER: I don't have that, I don't think we have that data available for you right now.

I think it says in our testimony we did determine that all eight of the cylinders were operating within the normal selected variation that Dr. Pischinger has told us about and, therefore, the data from number seven was in our judgment reasonable.

Q. What is the normal variation you're

referring to?

I'd like first to get Dr. Swanger to answer the question because it's about his testimony.

DR. SWANGER: There are two sources for what's considered normal variation. First is the TDI specification for the normal variation in measured peak firing pressures from cylinder to cylinder and the specification that TDI provides that cylinder to cylinder variations of 200 psi in peak firing pressure are considered indicative of normal engine operation.

The other indication is as Professor Pischinger has calculated, and I believe that he would be a better person to determine what those are, but their origin is the cycle to cycle variation within one cylinder Dr. Mc Carthy has been talking about earlier and I don't have a number in my mind myself for that, but I believe Dr. Pischinger would have.

Q. Well, when you said normal variation in your answer to my question referring to 200 psi --

DR. SWANGER: No, I was not.

In fact, in the deposition of Paul Johnston, he related the procedure that was used is that many, many cycles of operation of the number seven cylinder were recorded on magnetic tape as Dr. Mc Carthy testified today. The data from that tape are electronically averaged over a large number of cycles to determine the kind of an average pressure that is needed for doing fatigue analysis.

So the normal variation that I was referring to would be the cycle to cycle variations and not 200 psi cylinder to cylinder variation, which is a different type of variation.

Q. Did the measurement that you talked about using the piezo electric transducer which was referred to on page 18 in answer 25 of your direct testimony, was that reading done at an average temperature?

DR. SWANGER: I don't understand your question about average temperature.

Q. Was the transducer at an average temperature?

DR. SWANGER: The transducer was water cooled with deionized water to keep it at the proper temperature for the operation to be accurate and I believe Dr. Pischinger can add to that.

DR. PISCHINGER: Of course, the question is which transducers, reference AVL, watts transducer or air cooled transducer on the cocks.

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Q. I am speaking about the piezo electric transducer that is referred to in the answer to question 25 on page 18.

MR. PISCHINGER: The cooling provides for environment which provides -- which prevents shifting of the properties of this transducer.

We have wide experience in this range. Even if you change cooling temperatures from 20 or 30 degrees centigrade it would be no influence on the reading of the transducer and my colleague who was present, of course, is accustomed to watch that the cooling temperatures stays the same. So from this source there will be no deviation expected.

Q. At the top of page '9 of your testimony is referenced to measurements that were taken simultaneously at the pressure cocks which I think Dr. Swanger had testified to earlier.

MR. DYNNER: Judge Brenner, this is one of the documents that is giving these measurements that were simultaneously taken that we had requested LILCO to produce which they've refused to produce. I don't know. I would hold this back until particularly each relevant issue came up. This is one of the documents that we had asked for.

JUDGE BRENNER: Ask the question you want to ask about it and give them the opportunity.

MR. DYNNER: I previously asked Dr. Swanger what those measurements were and he said there was documentation but that he did not recall.

Is that correct, Dr. Swanger?

DR. SWANGER: As I testified earlier, this data was taken as part of the dynamic strain gage testing of the crankshaft and would be included in the documentation associated with the testing of the crankshaft. However, I think it is important to point out that FaAA did not rely on these measurements of peak pressure to do the piston analysis.

We offered at this time merely as an additional confirmation that the peak pressure that we used was a reasonable peak pressure for the analysis. We have independent sources outside of the data taken during the crankshaft testing, the TDI factory logs and the LILCO startup records for what the actual peak pressures were in three diesel generators used at Shoreham. Those numbers can be used to substantiate the piston analysis.

Q. Well, Dr. Swanger, you testified previously that the piezo electric transducer that led to the real pressure versus crank chart that we had looked at earlier which we asked you about, Exhibit P-5, was confirmed by these other measurements. We don't know what those measurements are, that's why I'm asking if you can either specifically identify what were the measurements taken on each cylinder at the pressure cock using the Kiene gage to measure the cylinder firing pressure and if you don't have that information in your head we'd like to see the documents that give that information.

MR. ELLIS: Judge Brenner, I think that's an incorrect characterization of the testimony. I've also reviewed Mr. Dynner's letter, that is not the fact what he asked for. He asked for the documents that were used to develop P-5. He did not ask for the other.

JUDGE BRENNER: I'm going to have to wait until I have the request in front of me then. Since this is a dispute as to what was requested, let alone what's reasonable, and I can't get you to agree on what day of the week it is.

Let me ask something of the witnesses. I'm looking at the same question and answer, 27, Mr. Dynner just referred to, and it relates to the information that the engine was 3500 KW and full set of firing pressures was taken at each of the eight cylinders using a Kiene gage, next sentence says Exhibit P-5 includes the peak firing pressures measured before and after the crankshaft replacement. In fact Exhibit P-5 did not include those pressures, does it?

DR. HARRIS: Yes, it does

DR. MC CARTHY: Pages we're been using of discussing have pressures on them.

JUDGE BRENNER: I know.

MR. YOUNGLING: P-9 are the log sheets that are referenced in the answer to 27, question 27.

Also, if memory serves me correctly of the discovery with the County, I believe we agreed to give the County the results of testing and --

JUDGE BRENNER: I don't want to get into that. I'm trying to understand what is suppose to be in exhibit P-9 as at least stated in answer 27. It says full set of firing pressures. Was that the full set P-9 measured by the Kiene gage.

DR. YOUNGLING: Yes, it is. There is one firing pressure associated with each of the eight cylinders taken at a specific load on the engine.

JUDGE BRENNER: One cycle? Is that the peak for all cycles?

DR. YOUNGLING: That is the peak firing pressure measured while the engine is running. The man has the gage on the engine and he is reading the pressure and the pressure will peak and he is taking that average peak firing pressure for that particular cylinder because he's got the gage on there and seen many, many cycles actually.

JUDGE BRENNER: But that's the peak pressure only of the cycles that occurred while the man had the gage there; is that it?

DR. YOUNGLING: On that cylinder, yes.

JUDGE BRENNER: All right. I understand what you mean better by full set of firing pressures. Thank you.

MR. YOUNGLING: Also if I could comment on the testing.

I believe under the discovery we did provide the County the results of strain gage tests, both before and after crankshaft failures. They should have the data referenced in the answer to question number 25.

JUDGE BRENNER: All right. On that point let me suggest you get together with your counsel in case we have to hear about this again. You can remind them as to what was turned over on discovery.

MR. DYNNER: To clarify, Judge Brenner, if I may with the witness?

Q. Mr. Youngling, the Kiene gage measurements that are referenceed in your answer number 25 on top of page 19 are different from the Kiene gage measurements referenced in answer 27 at the top of page 20; isn't that correct?

MR. ELLIS: Judge Brenner, I would point out that it is not Mr. Youngling's answer, it's Dr. Swanger's answer.

JUDGE BRENNER: Mr. Youngling just referred to the previous answer 25, though, and helping you out in your discovery dispute which may or may not come. I can't believe that two parties cannot work out this dispute. It is going to be time lost talking about the dispute, let alone the risk of time lost if we rule against you, Mr. Ellis.

MR. ELLIS: I agree.

JUDGE BRENNER: Stop here.

MR. ELLIS: I would like to point out that the dispute came two working days before this hearing started.

JUDGE BRENNER: Talking about taking it forward from this point on. I said not one word about the fact that it was -- had it been resolved I wouldn't have said one word it was resolved at the last minute. My comment is it's unresolved.

MR. ELLIS: We are going to review that case this evening and review the request.

JUDGE BRENNER: All right.

I haven't read the case recently myself. After you come up with a sterling argument, if that's necessary, I hope it's not necessary, I want you to work it out; but otherwise, I'll maybe have to reread the case myself.

MR. ELLIS: I understand, Judge.

JUDGE BRENNER: I will tell you right now, my recollection of the case is in that case the cross-examiner asked for the documents for the first time during cross-examination as opposed to in advance of the trial and nevertheless the appeal board went through a balancing test.

MR. ELLIS: They did and I'm not sure he got the documents.

JUDGE BRENNER: He didn't get the documents, I'll tell you that.

MR. ELLIS: I think the problem was the witness couldn't answer. That's a little different.

JUDGE BRENNER: That's why I reminded you about it again. We were talking about delay in the

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case as opposed to advanced notice and talking about a large computer run in one case. I think you can put it together. I don't have the list of documents requested. I may agree all of Mr. Dynner's requests are unreasonable and given what happened, but I'd rather you work it out instead of having to depend upon a ruling from us that maybe none of you will like.

You will have to go back to -- we'll get to the pending question, allow the question of any witness, either Mr. Youngling or Dr. Swanger or anyone. The question is, whether the test referred to in answer 25 is the same as referred to in answer 27.

DR. YOUNGLING: They are different data.

JUDGE BRENNER: You want to break now, Mr. Dynner, or do you have some questions you like to ask before we adjourn?

MR. DYNNER: I think we can break now.

JUDGE BRENNER: All right.

Let me give you some advance notice as to scheduling considerations beyond what we've already told you in written orders.

If this hearing is still going on by the week of October 8th, we will not have a hearing session that week based on the way things stand now. If there's a change, we'll, of course, tell you sufficiently in advance of that week. But as of now, you can operate on the assumption that there will not be a hearing that week. Don't take that as an absolute, however. If there's a change, we'll let you know.

We also in response to repeated requests during the conference call or at least one request during a conference call, really it was the subject of a lot of conversations between counsel and among the parties, as to when we would adjourn on the last day of each week. The general plan to adjourn was at 12:45 p.m. on the last day of a hearing session for any given week. For most weeks that's Thursday. For at least one week, that's going to be Wednesday. I emphasize that general plan circumstances may cause us to change that on short notice.

As of now it's a general plan. If we change it on longer notice, of course, we will have the decent courtesy to let you know. As soon as we know you'll know if there's a change.

MR. ELLIS: Judge Brenner, does the Board have -- perhaps Mr. Dynner has some sense of when we might get the crankshafts. We have a number of witnesses coming. I know it may not be possible to know now given you have cross plans and we don't -- we've had a day now. Some sense of when that might occur?

JUDGE BRENNER: Ask Mr. Dynner on the record early tomorrow and ask Mr. Dynner to discuss it with the other parties off the record before we go on the record tomorrow. You've heard me on the record as to comments about how unhelpful the cross plan has been to me in terms of estimating the pace.

When I put it altogether I may be able to - it may have been unfair, I wasn't able to adjust as Mr. Dynner did go into a different part of his cross plan. When you jumped to the other part I thought it was for a question and jump back. Sometimes he stayed in the other part, sometimes he didn't. So I couldn't tell. Sometimes the questions were in no part.

So we're going to ask you for a time estimate. The case is going to have to improve. You know what I'm talking about. Not the speed with which questions are asked, but the pace at which we'll get useful information per unit of time as a result of the cross-examination.

MR. DYNNER: Pace of the answers, isn't

that what you meant?

JUDGE BRENNER: I gave you my lecture. You got the answer you deserved to one of your questions.

All right. We'll adjourn until 9 o'clock tomorrow morning.

(Adjourned at 5:03 p.m.)

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:

SHOREHAM NUCLEAR POWER STATION

Long Island Lighting Company

DOCKET NO.: 50-322-OL

PLACE: Hauppauge, New York

DATE: September 10, 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)

(TYPED)HEYWOOD WAGA, C.S.R.

THOMAS L. LA FERA, C.S.R.

Official Reporter

Reporter's Affiliation