UNITED STATES
NUCLEAR REGULATORY COMMISSION

ORIGINAL

IN THE MATTER OF:

LONG ISLAND LIGHTING COMPANY

SHOREHAM NUCLEAR POWER STATION

DOCKET NO:

50-322-OL

Corrected Copy

LOCATION: HAUPPAUGE, NEW YORK

PAGES: 23096 - 23198

DATE: THURSDAY, SEPTEMBER 20, 1984

TR-01 0/1

Additional 2 copies to ASLPB, E/W-439

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UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

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In the matter of: :

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

(Long Island Light Company :

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State Office Building

Veterans Memorial Highway

Hauppage, New York

Thursday, September 20, 1984

The hearing in the above-entitled matter was convened at 9:00 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

APPEARANCES:

On behalf of the Applicant:

ODES STROUPE, Esq.

TIM ELLIS, ESQ.

MILTON FARLEY, ESQ.

Hunton and Williams,

700 East Main Street,

Richmond, VA. 23219

On behalf of the Nuclear Regulatory Commission Staff:

RICHARD J. GODDARD, Esq.

Office of the Executive Legal Director

On behalf of the Intervenor, Suffolk County:

ALAN ROY DYNNER, Esq.,

DOUGLAS J. SCHEIDT, Esq.,

Kirkpatrick, Lockhart, Hill,

Christopher & Phillips

1900 M Street, N.W.,

Washington, D.C. 20036

CONTENTS

CONTENTS (Cont'd)

P R O C E E D I N G S

JUDGE BRENNER: Good morning.,

Why don't we get the appearances of counsel since we have a new court reporter and we can keep it straight, and not all the parties are here, as I observe.

Staff?

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

MR. ELLIS: Tim Ellis for the Long Island Lighting Company, also Odes Stroupe and Milton Farley for the Long Island Lighting Company.

MR. SCHEIDT: Douglas Scheidt and Alan Dynner for Suffolk County.

JUDGE BRENNER: We have pending before us a motion filed by Suffolk County to strike a portion of the Staff's prefiled written testimony. The testimony which is the subject of the motion to strike consists of one question and answer, the first one appearing on page 53 of the Staff's testimony. It involves the issue of piston side thrust, and relies upon a portion of a proposed Staff Exhibit 7.

The County's motion is less than clear, but it appears to us that, in addition to moving to strike the question and answer, the County is moving to strike Exhibit 7 in its entirety.

Am I correct?

MR. SCHEIDT: Yes, Judge Brenner.

JUDGE BRENNER: I would like to ask the Staff a question.

Based on the board's review of the Staff's testimony the only place in which its proposed Exhibit 7 is referenced is in this question and answer, am I correct?

MR. GODDARD: That's correct.

JUDGE BRENNER: And only a portion of the Exhibit is relied upon in the question and answer, correct?

MR. GODDARD: That's correct also, your Honor.

JUDGE BRENNER: Incidently, there's a typo: I believe it should be page 6 of Exhibit 7 rather than page 5 of Exhibit 7. Am I correct in that regard also?

MR. GODDARD: That I will have to check.

It is page 6.

JUDGE BRENNER: Before even dealing with the County's motion, then is it not correct that the only portion of Exhibit 7 which should even be proffered for evidence by the Staff would be the particular table and drawing relied upon?

MR. GODDARD: That's also correct.

JUDGE BRENNER: Then without further ado the rest of Exhibit 7 will not be admitted into evidence and Exhibit 8, which is there solely to identify some of the portions of Exhibit 7, will not be admitted into evidence with the possible exception as relates to the table, depending on our ruling on the particular motion which I will now give:

We're denying the County's motion to strike the question and answer on page 53 of the Staff's testimony for the reasons expressed in the Staff's written answer of September 7, 1984. We find all of those reasons correct and persuasive.

Of course, once we get to the cross examination we may learn that, indeed, contrary to the Staff's answer the Staff's witnesses cannot supply sufficient information to enable us to credit with any reliability whatever support is being relied upon by the Staff for that table in Exhibit 7. But we'll deal with that if and when it comes to that point.

We agree with the Staff that the witnesses certainly have sufficient apparent expertise at this stage of the game. That's based on the papers submitted and their qualifications to testify to the matters stated in the question and answer on page 53, and we'll see where it goes from there.

They've crossed the threshold as expert witnesses and by reliance on Federal Rule of Evidence 703 among other principles, that is sufficient to permit the particular portion of Exhibit 7 to be admitted into evidence.

To be more particular, at the time the Staff's testimony -- or more particularly, at the time the Staff's exhibits are moved into evidence, I want the copies conformed such that only page 6 of Exhibit 7 along with the drawing -- which I imagine is page 7 -- is moved into evidence.

To avoid the necessity of excerpting portions of Exhibit 8, what the Staff should do is mark up page 6 so that the identity of the engines are given directly on page 6. At that point the Staff's Exhibit 7 will consist of page 6 and page 7. You can simply remove the rest of it. The parties have it. If there's any question as to the identity of the source, we're past that point.

You don't need it for an offer of proof because as I understand it, it was not your intent to offer it into proof.

MR. GODDARD: That's correct.

JUDGE BRENNER: That takes care of that.

The matter I wanted to get to next was the schedule.

Our particular pending question is what order the LILCOs witnesses should be cross examined by the County with regard to whether we should take the cylinder blocks or the cylinder heads first. And of course involved in that question is the status of the possible settlement discussions on the subject of cylinder heads.

MR. DYNNER: Judge Brenner, yesterday we had extensive discussions with LILCO. A document has been prepared and I think it's fair to say that, subject to final approval of my client, that this cylinder head issue -- and, of course, submittal to the Board and its approval -- that this cylinder head issue will be settled.

I would expect that Mr. Ellis will have a final corrected copy that encompasses the pen and ink changes we've agreed to by today. And I'll promptly submit it for approval, final approval, by my client, so that the document should, in my estimation, be able to be signed and filed with the Board by Monday or Tuesday of next week, probably Monday.

MR. ELLIS: Judge Brenner, I will have it easily in an hour. I think that we do have an agreement. I think that Mr. Dynner indicated that he does not expect any difficulties. The agreement that he and I have reached involved extensive discussions, and I would hope perhaps we could even get it to the Board today so that the Board could have the weekend to review it.

We certainly will handle the typing and have the typing all done and distributed to the parties. Mr. Goddard has informed me that the agreement is satisfactory to the staff and so within an hour I'll have final copies here for Mr. Dynner to check with his client. And I would hope that before you adjourn today that we will all have signed it and submitted it. It could be done today possibly.

JUDGE BRENNER: You anticipated a suggestion I was going to make. I think it would be helpful if we could get it at least in our offices by tomorrow, if not today. I'm not ordering that, I'm just pointing out that it would be helpful. That way if we have any questions or concerns with regard to it you can hear about it at the beginning of next week in the event something further needs to be done.

MR. DYNNER: Let me make just two other comments on this.

Number one is, I have endeavored, but unsuccessfully, to reach representatives of New York State concerning this document. Number two: while I'm not sure I will be able to have this document signed today, I certainly would see no objection whatsoever to have unsigned copies given to the Board today when Mr. Ellis circulates the copies to us so the Board will have an opportunity to look it immediately.

JUDGE BRENNER: Thank you.

Of course, if you had an objection to showing it to us at this stage we would understand it.

We also understand that it's not a final settlement and it may be something would change. But as I said, this would give us a head start, so we can give you our comments, if we have any, at the beginning of next week.

MR. ELLIS: I do want to say though that neither Mr. Dynner nor I anticipate any changes or we wouldn't submit it to you. We think it's final.

JUDGE BRENNER: All right.

Based on that, clearly, after we have completed the Staff's testimony on crankshafts we would then be going to the cross-examination of LILCO's panel on the cylinder blocks; is that correct?

MR. ELLIS: Yes, sir. And in that connection I need to report to the Board that we will, before the conclusion of today's proceedings, submit to the Board the motion and supplemental testimony relating to the block concerning information since the filing of testimony originally on August 14.

JUDGE BRENNER: All right. We'll receive it and read it.

We may get to the blocks next week.

MR. ELLIS: Yes, sir. We know that.

JUDGE BRENNER: All right, that takes care of our preliminary matters.

You indicated you wanted to address one of our previous questions, Mr. Ellis?

MR. ELLIS: Yes. Let me address the question you asked about the length of time for which LILCO was seeking findings with respect to the TDI diesels. As I believe

Mr. Youngling indicated to the Board when he was testifying, it is the Company's current intention to complete the qualification of the TDI diesels and to retain the TDI diesels for the long term to use them in conjunction with the Colt diesels so that the site would ultimately have six diesels rather than three.

However for this proceeding LILCO is only seeking findings for the first refueling outage with respect to the TDI diesels.

JUDGE BRENNER: Do you intend to define that by any timeframe or only as you have defined it in your sentence right now?

MR. ELLIS: I think that it cannot be defined with precision as to a time period. It is generally thought to be about 18 months from the period of time beginning with fuel loading.

JUDGE BRENNER: What I meant was, -- and I'm sorry I was not precise -- I have sometimes seen such timeframes, when they were imposed, expressed as no later than such-and-such an event: in this case the first refueling outage or "X" months, whichever comes later.

MR. ELLIS: That was not our intention. We would intend to have it to the first refueling outage because of the indefiniteness of that time.

JUDGE BRENNER: All right.

MR. ELLIS: Keeping again in mind that I think the testimony was, in the piston that the number of hours that the engines would be expected to accumulate during that period would be on the order of 288 even assuming -- that assumes a LOCA occurs and that they operate for an entire 7-day LOCA period.

JUDGE BRENNER: All right.

Mr. Dynner, did you want to say something. I wasn't quite finished.

MR. DYNNER: Please go ahead.

JUDGE BRENNER: Mr. Ellis, yesterday when Mr. Stroupe was sitting where you are sitting I asked him, or pointed out it might be helpful to include as part of this discussion just what LILCO intends in the context, or effect on this proceeding, by its letter to the Staff which on contested issues is just one of the parties before us.

MR. ELLIS: Yes I agree, Judge Brenner.

As the result of the additional analysis and the integrated electrical test which was completed in August -- mid-August -- LILCO now has sufficient information to be able to establish with more precision what the loads on the diesels will or would be in the event of a loop/LOCA.

And that has led to the preparation and submission of the letter SNRC 1077. The work that --

JUDGE BRENNER: Maybe you should reference the date of the letter.

MR. ELLIS: Yes. September 11, 1984 to Mr. Denton from Mr. Leonard.

I think that letter describes the analysis, and the integrated electrical tests indicate that the maximum short-term load that one would expect after a loop/LOCA would be 3300 Kw, which is going to be termed continuous -- FSAR continuous load. In fact, we would expect --

JUDGE BRENNER: Let me cut you off and then I'll let you get back to it if you think you need to.

We've read the letter. I'm not saying I understand everything in it or the bases for everything in it. I want to know what effect you think it has in this case by waiting until the date of that letter to send it to the Staff and then just send a copy to us, which I deem an informational copy? There is nothing before us.

I asked your counsel at the time what was intended. Because we were about to start an issue -- crankshafts, to be precise, a I recall -- for which it might be pertinent and might have been pertinent for an issue we completed LILCO testimony on. And I was told LILCO was proceeding on the basis of its testimony: which of course is inconsistent with the letter.

MR. ELLIS: Well --

JUDGE BRENNER: The testimony is inconsistent with the letter.

MR. ELLIS: The testimony is consistent with the FSAR as it exists. LILCO intends to submit an FSAR amendment to change the loads to 3300, 3500, and 3200. And as I was going to describe what those three figures were.

That FSAR amendment is in the approval chain now and will ultimately be submitted in the near future to the Staff for the Staff's approval. When the Staff approves it, of course, it will become a part of the FSAR.

For the purposes of this hearing, we are currently bound by the existing terms of the FSAR. However, as I think the Board has already done farsightedly, it is not irrelevant to consider questions on both the current and the projected loads as it did in the crankshafts.

JUDGE BRENNER: You misunderstood my remarks. We have done no such consideration as to any lower loads. We've had a proceeding scheduled since June. You knew about some of the changes in the numbers back in June and you did nothing. You, being LILCO, did nothing in terms of filing anything before us for those many months.

You didn't seek to amend any testimony on a timely basis before the hearing started, and opposed a schedule delay by the Staff, which delay was requested for another reason.

I'm not in the habit of sitting here in litigation for three weeks of hearing and then finding out that a party expects us to go back over testimony on a different premise when such premise could have been put forward earlier on, or when the preceding schedule could have been adjusted to accomodate such a premise.

We are considering nothing other than the testimony before us. I want you to know that very clearly.

MR. ELLIS: Well, I do understand that. But let me also be clear that it could not have been done in June because the integrated electrical test had not been done. The integrated electrical test was not done until August. It would not have been appropriate at that time in June for us to have come forward. There's a tremendous amount of analysis that goes into this. There are a lot of people working very hard on it.

I, to some extent, have firsthand knowledge of the process, and it is not for want of hard labor and a lot of people caring to try to get this thing done.

We've been working very hard. I regret we were not able to do it sooner. I can assure you we have moved with great vigor and alacrity and will continue to do so.

JUDGE BRENNER: That was not my total point. My point was you knew this was in the offing in June. You had estimates of the changes in June. I understand you had further work to do to support with greater precision what the changes would be.

You had the option, and it was your option that if you wanted to try to take advantage of those lower numbers as they were developing in the June through August timeframe, to indicate that that's what you wished to do in this proceeding and to move for any schedule adjustments at the start of this proceeding so that that could have been considered.

However, LILCO sat silently by while the proceeding was scheduled and, as I said, we've been here for three weeks now. A lot of work went into testimony by all parties in the August timeframe and before. There were things you could have done. You wanted to go ahead on this schedule, and that's the proceeding that you're going to live with.

If you want to stop the proceeding --

MR. ELLIS: We're entirely happy to live with that proceeding. And I can assure you that we have worked very hard and we're not asking for -- we're going to go ahead with the FSAR amendment as rapidly as we can. We understand the Board's view and we accept the Board's view that we are now proceeding on the basis of the current FSAR.

JUDGE BRENNER: To state it bluntly we are not about to re-open the proceeding and back up a month or two from now when you get your formal FSAR change done.

As you know, it's just a formality on completing the printing process now that you've completed the analyses. We in the past have never had to wait for formal publication of FSAR changes in order to consider something in testimony; in fact, quite the contrary.

Usually when things were happening close to the issues we were litigating in the other phase of the hearing, we handled the evidence in the hearing and the FSAR changes were made later to conform to the evidence.

MR. ELLIS: Yes, sir. There is even additional analysis and there will be additional testing as well going on. We don't want to go with those numbers until we are confident of them. And we're very close to that now.

And I say again I regret that we were not able to move quicker.

JUDGE BRENNER: All right.

A few simple precepts. You could have asked to delay the start of the proceeding in order to consider -- give you time to justify and then consider the lower loads. You did not do that.

You are not seeking now to defer the proceeding in order to give you time to complete whatever analysis you want to complete to support the lower loads; am I correct so far?

MR. ELLIS: Yes, sir.

JUDGE BRENNER: All right.

I don't want to hear two or three or four weeks from now that you want to re-visit all the testimony we've been through by that point in order to consider lower loads; all right?

MR. ELLIS: I understand that.

JUDGE BRENNER: Okay. In which case I continue to be mystified as to the effect -- at least on the contested issues before us -- you believe that letter to the Staff will have.

My point, Mr. Ellis, is, it takes long enough to try a case one time without trying the case two times.

MR. ELLIS: I think it's important to say that the reason the information was sent both in June and later on, we send all NRC communications to the Board and we believe it is our obligation to keep the Board advised of the developments.

JUDGE BRENNER: That's right; but when something becomes-- We appreciate that; in fact, that's consistent with our orders in this case.

I'm not criticizing you for giving us a copy of the letter, all I'm saying is, when one of the letters out of the mass of letters has obvious pertinence -- possible pertinence to the hearing, we have also said that the information copies of that correspondence does not serve as any formal notice to the Board of anything that should be done.

We had a conversation like that with LILCO attorneys way back when, in discussing the then-proposed shipment of new fuel to the site.

So my point was, you have not formally asked us to do anything with respect to t. lower loads, and you are allowing the proceeding to go ahead on a premise different than the premise in that letter, and that's what we're doing. And we don't expect to hear three weeks from now that you want to change the premise.

MR. ELLIS: I understand, Judge Brenner, and I will report that to the company.

JUDGE BRENNER: I'm saying you're three weeks late already. You understand that?

MR. ELLIS: Yes, sir. That's what I'll report.

JUDGE BRENNER: All right.

Mr. Dynner.

MR. DYNNER: Judge Brenner, this may be premature, and it's really just a question in my mind about the significance of the comment that was made by Mr. Ellis that LILCO is seeking findings only with respect to the period up to the first refueling outage, and yet it intends to operate the Delaval diesels if it gets a license for a period beyond that.

The County's contentions obviously have been submitted on the basis of the requirements of GDC-17 for operation of the plant up to full power with the Delaval diesels, and I don't really understand the significance of the statement that the findings should be limited to the first refueling outage, as to whether that is some intent to somehow alter the standards for the acceptability of the diesels, and I don't understand it in terms of what impact it might have on the contentions, and whether that is an open door to renewal of these contentions at the first refueling outage with respect to the same diesels.

I'm just raising the issue because I'm confused by the statements that were made.

JUDGE BRENNER: Well, we would have to apply some of what you're saying at the time of your proposed findings and then at the time of our decision to the record before us. But that situation is different than the kind of situation I just discussed with Mr. Ellis, much different.

With respect to the possible limitations on the time of use of the TDI diesels, we are getting all kinds of evidence in from the experts, and we'll be hearing from the County's witnesses on that subject also as to what the proven limits might be when you're talking about a phenomenon that, in the view of some experts, would only develop over the very long term, if at all, in terms of fatigue problems, whether it be torsional fatigue to the crankshafts or other fatigue on other parts.

Now, we may find that the time does not matter, either because everything is okay for any time frame, given the evidence, or because it is not okay for any time frame. Those extremes are there. But between those extremes we might find that certain things have been proven by the party with the burden of proof, which is LILCO, to be okay at least through 'x' number of cycles. And then it might be pertinent to look at how many cycles there would be for a certain time frame.

Now, if we came to such a conclusion, there would obviously be a condition requiring a limitation on the use of the diesel as not being able to be relied on beyond that time frame to satisfy the NRC requirements.

Beyond that, if we made such a finding then LILCO could not rely on the TDI diesels to satisfy the requirements. However, it would certainly be open for them to have this backup, backup diesels, if you will, as long as they were not the diesels being relied upon to fulfill the requirements.

So I don't see a problem that we have to address in the abstract now, and all parties are free to propose whatever findings they want.

The time frame question is obviously in some parties' minds and, in some witnesses' testimony, material to some of the conclusions that the parties would seek to have us find.

MR. DYNNER: Thank you.

JUDGE BRENNER: We have nothing else, and we can get to the witnesses now.

MR. STROUPE: Judge Brenner, if I may proceed.

DIRECT EXAMINATION

BY MR. STROUPE:

Q Mr. Cimino, starting with you, would each of you give your names, your business affiliations and your business address for the record?

A (Witness Cimino) My name is Dominic Cimino. I work with Metal Improvement Company. Since the time of the written testimony I've been promoted, and am Division Manager of the Long Island Division, Metal Improvement, at 280 Adams Boulevard, Farmingdale.

Q Dr. Wachob?

A (Witness Wachob) My name is Harry Wachob. I work for Failure Analysis Associates. The address is 2225 East Bayshore Road, Palo Alto, California.
Q Dr. Wells?
A (Witness Wells) I am Clifford Wells. I also work for Failure Analysis Associates at 2225 East Bayshore Road in Palo Alto, California.
Q Mr. Burrell?
A (Witness Burell) I am N. K. Burrell. I am Regional Sales Manager for the Metal Improvement Company. My office is located at 678 Winthrop Avenue, Addison, Illinois.
A (Witness Seaman) My name is Craig Seaman. I'm a project engineer with the Long Island Lighting Company. My business address is the Shoreham Nuclear Power Station, Wading River, New York.
A (Witness Johnson) My name is Duane Johnson. I work with Failure Analysis Associates. The address is 2225 East Bayshore Road in Palo Alto, California.
JUDGE BRENNER: All right. We'll have the witnesses sworn.
MR. GODDARD: Dr. Spencer Bush is also present. Did you want him to identify himself at this time?
JUDGE BRENNER: Fine.
BY MR. GODDARD:

Q Will you similarly state your name, your business address and affiliation?

A (Witness Bush) My name is Spencer Bush. I'm the owner of the Review and Synthesis Associates. The address is 630 Cedar, Richland, Washington.

JUDGE BRENNER: All right. Let's swear the entire panel, then, including Dr. Bush.

If you would all please stand and raise your right hands, please.

Whereupon,

CLIFFORD H. WELLS

DUANE P. JOHNSON

HARRY F. WACHOB

CRAIG SEAMAN

DOMINIC CIMINO

N. K. BURRELL

and

SPENCER BUSH

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

JUDGE BRENNER: Be seated.

It is certainly courteous of Mr. Cimino to move closer to the locus of the hearing for your benefit.

MR. STROUPE: Judge Brenner, we have previously filed an errata sheet which I believe has actually been bound in as part of the original crankshaft testimony, because it also contained on it a section relating to the shot peening specifically. We will be more than happy to have Mr. Seaman read those changes in the record this m rning if you so desire.

JUDGE BRENNER: It's not necessary; I realized it at the time that we were doing that. I take it that the changes have been mace on the testimony that will be part of the record.

MR. STROUPE: They have been penned into the testimony. As far as I recall, there were no changes to the exhibits.

JUDGE BRENNER: Fine.

Off the record.

(Discussion off the record.)

JUDGE BRENNER: Back on the record.

BY MR. STROUPE:

Q Mr. Cimino, do you have in front of you testimony dated August 14th, 1984, filed on behalf of Long Island Lighting Company, entitled "Testimony of Clifford H. Wells, Duane P. Johnson, Harry F. Wachob, Craig Seaman, Dominic Cimino and N. Ken Burrell on behalf of Long Island Lighting Company concerning shotpeening of the replacement crankshafts," along with Volume IV of the Crankshaft exhibits?

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A (Witness Cimino) Yes, I do.

Q To the best of your knowledge, is that volume of testimony and exhibits true and correct?

A Yes, it is.

Q And do you adopt it as your own?

A I do.

Q Dr. Wachob, I would ask you the same question with regard to both the testimony and the exhibits.

JUDGE BRENNER: Mr. Stroupe, I wonder: maybe we could note in the record at this point that the exhibits are LILCO Diesel Exhibits C-27 through C-39.

MR. STROUPE: Exactly.

WITNESS WACHOB: Yes, I do have copies and I do adopt them as my opinion.

BY MR. STROUPE:

Q Dr. Well, I would ask you the same two questions.

A (Witness Wells) I have copies of the testimony, and I do adopt it as my own.

Q Is it true and correct to the best of your knowledge?

A It is true and correct to the best of my knowledge.

Q Mr. Burrell, I would ask you the same question.

A (Witness Burrell) I also have copies, and I adopt them as my testimony.

Q It is true and correct to the best of your knowledge?

A Yes, it is.

Q Mr. Seaman, I would ask you the same questions.

A (Witness Seaman) Yes, I have copies of the testimony, and I do adopt them, and they are true and correct to the best of my knowledge and belief.

Q Dr. Johnson, the same question for you, sir.

A (Witness Johnson) I have a copy of the testimony. I believe they are true and correct. I adopt them as my testimony.

Q Would that be the same answer for the exhibits, C-27 through 39, also, Dr. Johnson?

A Yes.

MR. STROUPE: At this time Long Island Lighting Company would move the admission of the testimony previously indicated, and exhibits C-27 through 39.

(Whereupon, the documents referred to were marked for identification as Exhibits C-27 through C-39.)

JUDGE BRENNER: All right. We will admit the testimony just identified into evidence and bind the testimony into the record at this point as if read. We will also admit LILCO Exhibits C-27 through C-39 into evidence. Of course, we will not bind the exhibits in. And three copies will become part of the official record.

(Whereupon the documents referred to, previously marked for identification as Exhibits C-27 through C-39, were received in evidence.)

(The testimony of Witnesses Wells, Johnson, Wachob, Seaman, Cimino and Burrell follows.)

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 CLIFFORD H. WELLS, DUANE P. JOHNSON, HARRY F. WACHOB
CRAIG SEAMAN, DOMINIC CIMINO, AND N. KEN BURRELL
ON BEHALF OF LONG ISLAND LIGHTING COMPANY CONCERNING
SHOTPEENING OF THE REPLACEMENT CRANKSHAFTS

TABLE OF CONTENTS

I. INTRODUCTION OF WITNESSES

1. Please state your name, business address and present employment.

A. (Wells) My name is Clifford H. Wells. My business address is 2225 E. Bayshore Road, Palo Alto, California and I am employed by Failure Analysis Associates (FaAA) as Vice President.

(Johnson) My name is Duane P. Johnson. My business address is 2225 E. Bayshore Road, Palo Alto, California and I am employed by FaAA as Nondestructive Examination Manager.

(Wachob) My name is Harry F. Wachob. My business address is 2225 E. Bayshore Road, Palo Alto, California and I am employed by FaAA as Manager of Materials and Testing Laboratory.

(Seaman) My name is Craig Seaman. My business address is North Country Road, Wading River, New York and I am employed by Long Island Lighting Company (LILCO) as Project Engineer for Shoreham.

(Cimino) My name is Dominic Cimino. My business address is 427 Barell Avenue, Carlstadt, New Jersey and I am employed by Metal Improvement Company, Inc. (MIC) as a Program Manager.

(Burrell) My name is N. Ken Burrell. My business address is 678 Winthrop Avenue, Addison, Illinois, and I am employed by MIC as Midwest Regional Sales Manager.

2. Please summarize your professional qualifications and your role in the shotpeening of the replacement crankshafts at Shoreham.

A. (Wells) I hold a D.Engr. in Applied Mechanics from Yale. My professional qualifications are set forth in Attachment #1.

My role in the shotpeening of the replacement crankshafts at Shoreham was to recommend shotpeening the crankpin fillet radii areas of the three replacement crankshafts and to recommend re-shotpeening the two replacement crankshafts originally shotpeened by TransAmerica Delaval Inc., (TDI). Additionally, I observed the shotpeening performed by MIC and the inspections performed by LILCO and Stone & Webster during and after the shotpeening to satisfy myself that the shotpeening was done correctly.

(Johnson) I hold a Ph.D. in Physics from the University of Washington. I am a qualified Level III Inspector in eddy current and ultrasonic testing. My qualifications are set forth in Attachment #2.

My role in the shotpeening of the replacement crankshafts at Shoreham was to conduct nondestructive examinations of the replacement crankshafts after they had been shotpeened by MIC and had been operated for 100 hours in the EDGs.

(Wachob) I hold a Ph.D. in Material Science and Metallurgical Engineering from Cornell University. My professional qualifications are set forth in Attachment #3. While I did not participate in the shotpeening, I have been asked to render certain opinions as to the shotpeening.

(Seaman) I hold a B.S. in Engineering from Cornell University. My professional qualifications are set forth in Attachment #4. I am employed by LILCO as Project Engineer at Shoreham.

My role in the shotpeening of the replacement crankshafts was to initially recommend shotpeening these crankshafts and to subsequently, recommend that the crankshafts be re-peened. As a LILCO representative concerned with various components of the Shoreham Emergency Diesel Generators (EDGs), I had the responsibility of ensuring that the shotpeening performed by both TDI and MIC met LILCO's quality assurance requirements.

(Cimino) I have a B.E. in Mechanical Engineering from The Stevens Institute of Technology in Hoboken, New Jersey. I have been employed by MIC since February of 1980 and have since that time been engaged in the shotpeening of various types of metals for various types of application. I am a Program Manager for MIC and I have supervisory responsibility for all types of shotpeening.

My role in the shotpeening of the replacement crankshafts at Shoreham was to recommend re-shotpeening of the two crankshafts shotpeened by TDI and to supervise a team of MIC employees that re-peened the fillet areas of these two crankshafts and originally peened the third crankshaft. My qualifications are set forth in Attachment #5.

(Burrell) I hold a B.S. in Mechanical Engineering from the University of Illinois. I have been employed by MIC for over seventeen (17) years. For thirteen (13) of those years I was

Manager, Technical Service for the Chicago Division. A great deal of my shotpeening experience is with shotpeening of fillet areas of crankshafts of all sizes. My professional qualifications are set forth in Attachment #6. While I did not participate in the shotpeening I have been asked to render certain opinions as to this shotpeening.

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

A. (All) We have been asked to address emergency diesel generator contention 1(b) admitted by the Board in its July 17, 1984 Memorandum and Order which states:

> The shotpeening of the replacement crankshafts was not properly done [Sic] as set forth by the Franklin Research Institute Report, Evaluation of Diesel Generator Failure at Shoreham Unit 1, April 6, 1984, and the shotpeening may have caused stress nucleation sites. The presence of nucleation sites may not be ascertainable due to the second shotpeening of the crankshafts.

At the outset it should be noted that while it is not clear what the County intends by the use of the words "stress nucleation sites" or "nucleation sites," we assume the County is attempting to describe a surface discontinuity that might provide the nucleation site for a fatigue crack. Thus, whenever the words "stress nucleation site(s)" or "nucleation site(s)" are used herein we are using them in this assumed context.

In summary this testimony will demonstrate that the original shotpeening of the replacement crankshafts by TDI, while not in accordance with the required specifications, did not cause any "stress nucleation sites" and that the re-peening by MIC corrected or eliminated any problem with TDI's peening. Additionally this testimony will demonstrate that the re-peening by MIC of two of the crankshafts and the original peening by MIC of the third crankshaft accomplished the intended purpose of increasing compressive stresses in the fillet areas. Finally, the testimony will demonstrate that the shotpeening resulted in a significant increase in the fatigue or endurance limits of these crankshafts.

II. BACKGROUND

4. Why was the recommendation made to shotpeen the fillet areas of the replacement crankshafts?

A. (Wells, Seaman) The original 13" x 11" crankshaft failed due to a fatigue crack which initiated at the surface of the machined fillet radius where the crankpin blends into the web. FaAA's analyses show that the fatigue crack which resulted in the failure of the EDG #102 crankshaft began at a score mark on the crankpin fillet. The transitional area from crankpin to web and web to main journal is an area where the highest applied surface tensile stress range occurs in the crankshaft. The 13" x 11" crankshaft that failed and the other two that had fatigue cracks in a similar location were not shotpeened. It was FaAA's and LILCO's opinion that shotpeening the fillet areas of the replacement crankshafts would reduce mean surface tensile stresses in the fillet area of the crankshaft by placing the fillet surfaces in compression. Shotpeening renders the surface less susceptible to handling damage such as the score mark where cracking initiated on the original EDG #102 crankshaft. In addition, shotpeening eliminates machine imperfections by blending, as a result of plastic flow of the metal, and prevents initiation of cracks on the machined fillet surface thus providing a higher endurance limit for this area and correspondingly for the crankshaft. While TDI, the manufacturer of the Shoreham diesel generators did not believe that the replacement crankshafts required shotpeening, it did concur in the view that this was an acceptable application for shotpeening. It should be noted also that TDI normally shotpeens crankshaft fillet regions for its "V" configuration engines.

5. What exactly is shotpeening?

A. (Cimino, Burrell, Wells, Wachob) Shotpeening is a surface cold-working process that is used primarily to lengthen fatigue life and prevent cracking of metal parts. Shotpeening is also used to shape parts, overcome porosity, work harden surfaces, protect against stress corrosion or corrosion fatigue and for many other purposes. In shotpeening, the surface of the finished part is bombarded with round steel shot by special machines under fully-controlled conditions. Each piece of shot acts as a tiny peening hammer. When the surface has been peened all over by the multitude of impacts, the resultant residually stressed surface layer, which is in compression, prevents the growth of microscopic defects.

It is well known that a crack will not initiate in, nor propagate through a compressed layer. As nearly all fatigue, stress corrosion and corrosion fatigue failures originate at the surface of a part, the layer of compressive stress induced by shotpeening produces a significant increase in the endurance limit, which many industries have learned to use in their designs. The maximum compressive residual stress produced at or near the surface is at least as great as one-half (½) the ultimate tensile strength of the material. Shotpeening is used to eliminate failures in existing designs, or to allow the use of higher stress levels.

6. Why were the two replacement crankshafts previously shotpeened by TDI, re-shotpeened by MIC?

A. (Wells, Seaman) When the two crankshafts shotpeened by TDI arrived at Shoreham in early September 1983, they were visually examined by Dr. Wells of FaAA, Craig Seaman of LILCO and personnel from Stone & Webster. This examination revealed that the shotpeening did not meet the requirements of LILCO. There were holiday areas where coverage was only 80% to 90% and not all peening intensity tests (Almen strips) were accounted for, which raised possible questions as to the coverage and the intensity of the peening. This resulted in the issuance of an E&DCR, noting the failure to comply with specifications. Exhibit #C-27. The concern was that full credit for the beneficial effects of shotpeening could not be taken.

As a result of the concern over the shotpeening TDI performed, FaAA and LILCO sought the services of someone with expertise and experience in the application of shotpeening to obtain advice as to what should be done to these two crankshafts.

After inquiries made by FaAA and LILCO, MIC was retained as someone with the necessary expertise and experience in the application of shotpeening to areas such as the fillet areas of the replacement crankshafts.

7. What did MIC do after being retained by LILCO?

A. (Cimino) At LILCO's and FaAA's request, Dennis Weiss (also of MIC) and I traveled to Shoreham on September 15, 1983 and examined the shotpeening done by TDI on the fillet areas of the two replacement crankshafts. After such examination we recommended that the fillet areas of the crankshafts be re-shotpeened because the peened areas were not within the tolerances required from the fillet areas to the edge of the journals and/or pin surfaces, there was unequal dimpling, indicative of use of irregular sized shot, and there were holiday areas where only 80% to 90% coverage was present. As a result of our advice and the concurrence of FaAA, LILCO determined to have us re-shotpeen the fillet areas of the replacement crankshafts at the Shoreham site.

III. THE RE-SHOTPEENING AND ITS EFFECT UPON THE CRANKSHAFTS

8. Describe the manner in which the replacement crankshafts were re-shotpeened by MIC?

A. (Cimino) I supervised a team from MIC that re-shotpeened the two replacement crankshafts. We began work on Friday night, September 17, 1983.

The crankshafts were placed on pedestals or stands which allowed rotation of the crankshafts so that all fillet areas could be completely saturated with shot. To prepare the crankshafts for re-shotpeening, they were washed with a chemical solution to remove all traces of oil or other preservatives and the areas on both sides of the fillets were taped in accordance with the tolerance specifications required by LILCO in MIL Spec. No. 13165B. Exhibit #C-28. A tent was set up over each of the crankshafts so that shot could be contained within the tent. In addition, Almen strips were set up for measuring shotpeening intensity. Almen strips are flat pieces of metal which are clamped to a solid block and exposed to a stream of shot. Upon removal from the block the Almen strip will be curved. The curvature will be convex on the peened side and the height of the curved arc is measured on a special Almen gauge which serves as a measure of the intensity. A .008-.010 C strip was utilized for the Shoreham replacement crankshafts which provides surface compression to a depth of .027"-.034" on ASTM A-668E metal such as the replacement crankshafts. While MIL Spec. No. 13165B required intensity to be checked by Almen strips every eight hours of peening, MIC, in fact, checked peening intensity every four hours of actual peening.

9. The report entitled "The Evaluation Of Diesel Generator Failure At Shoreham Unit 1, Final Report, Failure Cause Evaluation, April 6, 1984", by Franklin Research Center ("FRC Report") indicates that one test strip or Almen strip used to measure intensity exceeded the specified intensity by measuring 0.011 inch. How does this affect the shotpeening that was done by MIC?

A. (Cimino) The Almen strip that had an arc height of 0.011 inches as indicated by the FRC Report was outside the specified peening intensity of 0.008-0.010. However, this was a strip that MIC utilized to test saturation prior to the time any actual peening was performed on the fillet areas of the crankshafts. The definition of intensity requires that saturation be reached. Saturation is the point at which the peening time can be doubled without increasing the arc height more than 10%. The strip measuring .011 inch was the strip peened at twice the time required to reach a .010 inch arc height thereby proving that the saturation of the .010 inch strip had been reached. Thus, all Almen strips used to test peening intensity during actual peening were within the required specification of 0.008-0.010.

10. Please continue your description of the manner in which MIC re-shotpeened the replacement crankshafts.

A. (Cimino) MIC utilized a patented process called "peenscan," approved by USA Military Specification, MIL - 13165-B Amendment 2, to ensure uniformity and full coverage on the area being shotpeened. In peenscanning a particular area being shotpeened is coated with a flourescent dye-type liquid prior to the shotpeening and allowed to dry. All areas covered with dye will show a green glow under a blacklight. After shotpeening is completed the area is placed under this blacklight to see if any green glow remains. If any glow remains the coverage is not 100%. In this case all fillet areas were checked for any green glow and peened until all traces of the dye were completely gone.

MIC began shotpeening the replacement crankshaft fillet areas on Friday September 17, 1983, and completed it on Tuesday morning, September 20, 1983.

11. How can one be certain that the shotpeening which MIC performed on the two replacement crankshafts was in accordance with MIL Spec. No. 13165B and placed the surface stresses in the fillet radii area of the crankshaft in compression?

A. (Cimino) As indicated above, MIC checked the shotpeening intensity by use of Almen strips every four peening hours and peenscanned all fillet areas of both crankshafts. In addition, every two hours the shot was screened to ensure that no broken shot was used and to ensure that the shot was uniform in size and shape. Also, examinations under a microscope at the site were conducted at the same time as the screening to further ensure uniformity of shot shape and size. Finally, in addition to these procedures LILCO Operational Quality Assurance (OQA) inspected and observed all aspects of the shotpeening from the beginning to end. The OQA reports are attached as Exhibit #C-29. MIC also documented its compliance with the specification and issued a certification to LILCO that the peening was done in accordance with MIL Spec. No. 13165B. Exhibit #C-30.

12. Do you agree that some photographs of the TDI shotpeening show what appear to be cracks in the shotpeened surfaces?

A. No.

13. Why not?

A. (Wells, Seaman) These two crankshafts were subjected to magnetic particle testing after machining by Krupp Stahl, (the manufacturer) and no relevant indications were found. Exhibit #C-31. Additionally, at the time the two crankshafts shotpeened by TDI were received at Shoreham, both shafts were subjected to magnetic particle testing and liquid penetrant testing. This testing revealed no relevant surface cracks or indications. Exhibit #C-32. Thus, the County's interpretation of these photographs cannot be correct.

14. Have you reviewed the photographs of the re-peened fillet areas that were reviewed by Franklin Research Center and referred to in its report dated April 6, 1984?

A. (Wells, Seaman) Yes.

15. Are the shotpeened surfaces shown in these photographs representative of all crankpin and main journal fillet shotpeening?

A. (Wells, Seaman) Yes. As a result of MIC's re-peening of the fillet areas of both crankshafts, the peening is uniform, equally dimpled, and the shotpeening at all fillet areas looks exactly as it does in these photographs.

16. How can one be assured that the re-shotpeening of the two replacement crankshafts did not mask or cover "nucleation sites" caused by previous shotpeening of the crankshafts by TDI?

A. (Burrell) As described above, the problems with regard to the TDI shotpeening related to use of an irregular sized shot, holiday areas indicating irregular surface coverage of shot, unaccounted for Almen strips indicating insufficient evidence of intensity and failure to comply with the tolerances specified in the MIL Specification. The possibility of these types of problems causing "stress nucleation sites" is extremely remote and negligible. Additionally, as indicated above by various witnesses, visual and other nondestructive examinations of the TDI-peened fillet areas revealed no surface indications or deficiencies which could reasonably be expected to cause a "stress nucleation site." Finally, even if there had been surface "stress nucleation sites" such as the County speculates may exist, proper repeening of the fillet areas would correct or eliminate any such problem. Therefore, there is absolutely no rationale for, and certainly no evidence supporting the County's Contention 1(b) that there may have been "stress nucleation sites" caused by the first shotpeening which may have been masked or covered by the second shotpeening.

(Wells) Based upon my examination of the crankshafts prior to their being re-peened by MIC and the nature of the problems I observed with TDI's shotpeening, and based upon my review of the records of the nondestructive examinations performed upon these two crankshafts, I am of the opinion that there were no "stress nucleation sites" present, to be masked or covered by re-peening. It is also my opinion that the re-peening by MIC would have corrected or eliminated any "stress nucleation sites" such as the County contends "may" have existed rather than masking them. This is quite simply because any surface "stress nucleation site" small enough to escape detection by magnetic particle testing and/or liquid penetrant testing would be eliminated as a result of the plastic flow of the surface metal caused by the re-peening.

(Wachob) Based upon the factual observations of the problems of the TDI shotpeening set out by the witnesses above, upon my review of the shotpeening records of TDI, and upon my review of the various nondestructive examination records, it is my opinion that the possibility of a surface "stress nucleation site" being present in the fillet areas of the two replacement crankshafts subsequent to TDI's peening and prior to MIC's peening is extremely remote. It is also my opinion again, after my review of nondestructive examination records of these two crankshafts, that proper re-peening would have eliminated any "stress nucleation sites" such as the County contends "may" have existed for the reasons given by Mr. Burrell and Dr. Wells.

17. Do you have an opinion based on your experience and expertise in shotpeening as to whether the surface stresses in the fillet areas of the crankshafts have been placed in compression by virtue of the second shotpeening?

A. (Burrell) Yes, based upon my review of TDI's shotpeening records, MIC's shotpeening records, the records of the nondestructive examinations performed upon the fillet areas of the crankshafts, the visual observations previously described by other witnesses and based upon my experience, it is my opinion that the surface stresses in the fillet areas of the Shoreham replacement crankshafts have been placed in compression and that any cut, scratch, flaw, machine mark, etc. no deeper than the compression area itself, will not be the initiation point of a fatigue crack. Thus, any undesirable effects of the previous shotpeening have been corrected. This, of course, is consistent with the conclusion reached by the Franklin Research Center.

(Wells) I agree with the opinion expressed by Mr. Burrell.

(Wachob) Based upon my review of the relevant records, Dr. Well's, Mr. Seaman's and Mr. Cimino's description of the original peening and the re-peening and based upon my training and technical knowledge, I agree with Mr. Burrell's opinion.

18. On pages 135-136 of its testimony, the County states:

> [S]hotpeening raises the stresses below the compressed surface. When shotpeening introduces compressive residual stress on the surface layer, the adjacent underlying layers are put under tensile stress. This shotpeen-induced tensile stress is additive to the already present calculated stresses. A fatigue failure does not necessarily have to begin on the surface of the fillet; it may begin in a sub-surface area....

Do you agree?

A. (Burrell, Wells, Wachob) We agree that shotpeening does increase the residual tensile stress in the area below the compressed or shotpeened area. However, this residual tensile stress is additive only to the mean value of the operating stress and not to the range of dynamic stress. Additionally, fatigue cracks such as occurred in the failure of the original 13" x 11" crankshaft, in almost all instances, initiate at external surface areas. Subsurface fatigue cracking is very unusual and requires the presence of a significant void or inclusion and a given stress state, for initiation of a fatigue crack. There is always a possibility that any cast or forged piece of metal may contain a subsurface inclusion or void. The only protection against this risk or possibility are the manufacturer's quality control procedures for the melting, casting and forging processes and its quality assurance procedures during and after the manufacturing process. The replacement crankshafts for the EDGs were manufactured by the West German firm of Krupp Stahl, A. G. Krupp is a reputable manufacturer or forger of large metal parts such as these crankshafts, whose forging and machining of these crankshafts was certified by the American Bureau of Shipping as evidenced by its stamp on the Krupp certificates. See Exhibit #C-31 and Exhibit #C-37. Additionally, Krupp's quality assurance in the form of ultrasonic testing and magnetic particle testing of these crankshafts revealed no relevant inclusions or voids. Exhibit #C-31. All of this provides as much reasonable assurance as is possible, that no subsurface voids or inclusions of sufficient size to initiate a subsurface fatigue crack are present in these crankshafts. Therefore, we conclude that the possibility of this type of fatigue crack initiating in the subsurface area is indeed quite remote.

[LILCO's ultrasonic testing as well as magnetic particle and liquid penetrant testing likewise revealed no relevant inclusions or voids. See Exhibit C-33 and Exhibit C-32, respectively.

19. Do you agree that the depth of the undercut areas for machined tool runout appears in the photographs to be excessively deep in some areas of the fillets and that shotpeening would exacerbate the problem of "stress raisers" created by the deep runout and may mask the critical point in the way of the tool runout so that residual compressive stress in these areas would be insignificant?

A. (Wells, Seaman) No.

20. Why not?

A. (Wells, Seaman) Prior to MIC's re-peening of the fillet areas all fillets were closely inspected by LILCO for "stress raisers" and none were found. The undercut areas for tool runout were not excessively deep, but to the contrary blended smoothly into the edges of the pins, journals and the webs. Thus if there were "stress raisers" at those points they would be insignificant. Further, the maximum stress concentration in the fillet has been shown to be well removed from the intersection of the fillet with the journals, pins and webs. Additionally, since the entire fillet areas of the crankpin and main journal were shotpeened by MIC to within 0.03125" of the edge of the pins, journals and webs, any "stress raisers" in the undercut areas would be placed in compression by the shotpeening.

(Burrell) I would agree with Dr. Wells and Mr. Seaman's testimony that since the fillet areas were shotpeened within 0.03125" of the edge of the pins, journals, and webs any "stress raisers" in any so-called "undercut areas" would be placed in compression by the shotpeening.

21. Do you agree that some deep, single shot impacts from shotpeening may have occurred and may act as "stress raisers" because the areas around them go into tension?

A. No.

22. Why not?

A. (Wells, Seaman) To begin with, we found no evidence of any isolated, single shot impacts on any of the fillets on the crankshafts that would result in tensile stress on the surface. Further, even if there had been any such impacts, the re-shotpeening by MIC has eliminated any "stress raisers" which could have been produced.

(Burrell) I agree that any "stress raiser" created by any such isolated, single shot impacts would be eliminated by MIC's re-peening.

23. The County contends that the shotpeening has resulted in stressed and unstressed areas adjacent to each other which can be the driving force for corrosion and environmental attack of the fillet and for stress cracking. The County further contends that the rate of corrosion is increased because of the cathode-anode area law. Do you agree?

A. No.

24. Why not?

A. (Burrell, Wells, Wachob) The surface of the pins, journals and webs of the crankshafts are machined and are therefore plastically deformed. Residual compressive stresses rather than tensile stresses were found in these surfaces from FaAA's analyses of the original 13" x 11" crankshaft. Therefore any major difference in surface energy between peened and unpeened surfaces in this area is unlikely. Also, we do not believe that corrosion and environmental attack of the fillet area will occur in an oil environment such as the crankcase of the Shoreham EDGs. The cathode-anode electrochemical principle applies only in the presence of electrolytes which are not extant within the crankcase of the Shoreham diesels. In addition there are many authoritative references in the technical literature that indicate corrosion or corrosion fatigue resistence can be improved by shotpeening the surface. As an example, see Exhibit

#C-34. Thus, we conclude that cracking due to environment and corrosion is not within the realm of possibility.

25. After the re-peening of the replacement crankshafts were there any further tests performed to determine if any surface indications or nucleation sites were present?

A. (Johnson, Wells) Yes, after 300 hours of operation of which 100 hours of operation were at 3500 KW or above in the Shoreham diesel generators, the eight (8) crankpin fillet areas of highest torsional stress on each of the three crankshafts were subjected to high resolution eddy current testing. The eddy current test recording thresholds were such that a 1/32" long x 1/64" deep or larger crack-like defect would be detected. No such defect/indications were found. Exhibit #C-8.

(Seaman) In addition, the eight (8) crankpin fillet areas of highest torsional stress on each of the three crankshafts were subjected to liquid penetrant testing after this 300 hours of operation. No relevant indications were found. Exhibit #C-8.

26. Would you consider this additional evidence of the absence of masked or covered "stress nucleation sites"?

A. (Wells) Yes. The crankshafts were subjected to more than one million torsional peak stress reversals during this 300 hours of operation of which 100 hours were at 3500 KW or above. It is highly likely that any "stress nucleation site" which had not been detected by previous nondestructive testing would have initiated a fatigue crack during this 300 hours of operation of such size that the high resolution eddy current testing and/or liquid penetrant testing would have detected it. Thus, this is additional evidence of the absence of "stress nucleation sites" in these crankshafts.

27. Why were only two of the replacement crankshafts re-shotpeened by MIC?

A. (Wells, Seaman) The third replacement crankshaft was received by LILCO directly from Krupp Stahl, A. G., without being shotpeened by TDI. Consequently, in late October, 1983, MIC shotpeened the fillet areas of the third replacement crankshaft in accordance with MIL Specification No. 13165B in the same manner previously described in this testimony. A copy of the documents indicating the quality assurance checks by MIC and LILCO OQA are set forth in Exhibit #C-35 and #C-36 respectively. Additionally, the pertinent nondestructive examination records from Krupp and LILCO which revealed no relevant indications, are attached as Exhibit #C-37 and #C-38 respectively.

28. Is it true that proper shotpeening of crankshaft fillets does not significantly increase their fatigue resistance?

A. (Burrell, Wells, Wachob). No.

29. Why not?

A. (Burrell, Wells, Wachob). The benefits of shotpeening can be attributed to the resultant residual compressive surface stress. This region although small in respect to the crankshaft diameter is significant with regard to preventing the initiation of a fatigue crack in the surface region. Given the residual compressive stresses and the actual operating stresses in the fillet region, a fatigue crack will neither initiate in the fillet area nor will any flaw or defect contained within the shotpeened volume propagate. Additionally, the County mistakenly equates the hardened depth of shotpeening with the effective depth.

Finally, the County alleges that the effectiveness of any shotpeening will be further reduced if the material is subject to appreciable heat as the crankshafts are. This is preposterous and utterly absurd. In order for heat to appreciably affect shotpeening, temperature levels of at least 500° F must be attained. This temperature is completely unattainable within the normal operating limits of the Shoreham diesels. The crankshaft temperature is normally approximately 200° - 240° F and under unusual circumstances it may go as high locally as 260° F. Recent results on thermal relief of shotpeening residual stresses show that at 392° F approximately 18% of the residual stress is relieved in one hour at that temperature. Exhibit #C-39. Since stress relief is a time-temperature related phenomenon, an estimate of the time required to relieve the same amount of residual stress at 240° F can be made. These calculations indicate that more than 22,000 hours at 240° F would be required to reduce residual stress by 18%. Therefore, the County's assertion has no technical basis.

30. Do you have an opinion as to whether the fatigue endurance limit of all three (3) of the crankshafts has been increased as a result of the shotpeening of the fillet radii?

A. (Burrell). Yes. Based upon my experience, in my opinion the shotpeening of the three (3) replacement crankshaft fillet areas has resulted in an increase of approximately fifteen (15%) to twenty percent (20%) in the fatigue endurance limit of the crankshafts.

(Wells, Wachob) Yes. Although we cannot precisely quantify the amount of the increase in fatigue endurance limits due to shotpeening, we are of the opinion that it is a significant increase, not inconsistent with the range indicated by Mr. Burrell.

IV. CONCLUSION

31. Please summarize your conclusions.

A. (Wells, Wachob, Burrell) We conclude as follows:

1) The original shotpeening of the replacement crankshafts by TDI while not adding the full beneficial effect did no harm to the crankshaft.

2) The re-peening by MIC corrected any "alleged" problems that could have existed as a result of the TDI peening.

3) The compressive stresses in the fillet regions of all three replacement crankshafts have been increased, as was intended.

4) The fatigue or endurance limit of the replacement crankshafts has been significantly increased as a result of shotpeening.

5) There is no basis for the County's contention 1(b).

Attachment 1

Failure Analysis Associates

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Specialized Professional Competence

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

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

Background and Professional Honors

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

Selected Publications

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

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

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

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

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

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

"Fundamental Mechanisms," Control of Fretting-Initiated Fatigue, National Materials Advisory Board Report NMAB-333, National Academy of Sciences (1977).

"Fatigue at Elevated Temperature," edited by C. H. Wells, A. E. Carden and A. J. McEvily, ASTM Special Technical Publication No. 520 (1973).

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"Uniaxial Creep Behavior of Metals Under Cyclic Temperature and Stress or Strain Variations, Journal of Applied Mechanics, Vol. 98, pp. 445-449 (1976) (with P. R. Paslay).

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"Electrochemical Grinding of Cylindrical Test Specimens," Journal of Engineering for Industry, ASME Transactions, Vol. 93, pp. 1090-1092 (1971) (with T. W. Knight, R. B. Barrow and L. A. Williams, III).

"Creep of Single Crystal Nickel-Base Superalloy Tubes under Biaxial Tension," Journal of Applied Mechanics, ASME Transactions, Vol. 38, pp. 623-626 (1971) (with P. R. Paslay, G. R. Leverant and L. H. Burck).

"Mechanisms of Fatigue in the Creep Range," Metal Fatigue Damage Mechanism, Detection, Avoidance and Repair, ASTM Special Technical Publication No. 495, pp. 61-127 (1971) (with M. Gell and C. P. Sullivan).

"Fatigue of a Glass-Bead Blasted Nickel-Base Superalloy," Metallurgical Transactions, Vol. 1 (6), p. 1595 (1970) (with L. H. Burck and C. P. Sullivan).

"The Fatigue Strength of Nickel-Base Superalloys," The Achievement of High Fatigue Resistance in Metals and Alloys, ASTM Special Technical Publication No. 467, p. 113 (1970) (with M. Gell and G. R. Leverant).

"An Analysis of Primary Creep of Face-Centered Cubic Crystals," Journal of Applied Mechanics, ASME Transactions, Vol. 37 (3), p. 759 (1970) (with P. R. Paslay and G. R. Leverant).

"Elevated Temperature Testing Methods," Manual on Low-Cycle Fatigue Testing, ASTM Special Technical Publication No. 465, p. 87 (1969).

"Interactions Between Creep and Low-Cycle Fatigue in Udimet 700 at 1400°F," Fatigue at High Temperature, ASTM Special Technical Publication No. 459, p. 59 (1969) (with C. P. Sullivan).

"Low-Cycle Fatigue of Ti-6AL-4V," ASM Transactions Quarterly, Vol. 62, p. 263 (1969) (with C. P. Sullivan).

"An Analysis of the Effect of Slip Character on Cyclic Deformation and Fatigue," Acta Metallurgica, Vol. 17, p. 443 (1969).

"A Small-Strain Plasticity Theory for Planar Slip Materials," Journal of Applied Mechanics, ASME Transactions, Vol. 36 (1), p. 15 (1969) (with P. R. Paslay).

"The Control of Build-up and Diametral Growth in Shear Forming," Journal of Engineering for Industry, ASME Transactions, Vol. 90 (1), p. 63 (1968).

"Low Cycle Fatigue of Udimet 700 at 1700°F," ASM Transactions Quarterly, Vol. 61 (1), p. 149 (1968) (with C. P. Sullivan).

"An Analysis of the Bauschinger Effect in Some Engineering Alloys," Journal of Basic Engineering, ASME Transactions, Vol. 89 (4), p. 893 (1967).

"The Elastic Constants of a Directionally-Solidified, Nickel-Base Superalloy, Mar M-200," ASM Transactions Quarterly, Vol. 60 (2), p. 270 (1967).

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"The Low-Cycle Fatigue Characteristics of a Nickel-Base Superalloy at Room Temperature," ASM Transactions Quarterly, Vol. 57 (4), p. 841 (1964) (with C. P. Sullivan).

"The Latent Strain Hardening of Aluminum Alloy in Monotonic and Cyclic Loading," Applied Materials Research, Vol. 2 (4), p. 193 (1963).

Attachment 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

HARRY F. WACHOB

Specialized Professional Competence

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

Background and Professional Honors

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

Senior Metallurgical Engineer,
Failure Analysis Associates

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

Selected Publications

"Very High Cycle Fatigue of a Forged Aluminum Alloy," Fatigue and Corrosion Fatigue up to Ultrasonic Frequency (October 1981) (with H. Nelson).
"Influence of Microstructure on the Fatigue Crack Growth of A516 in Hydrogen," Third International Conference on Effect of Hydrogen on Behavior of Materials, p. 703 (August 1980) (with H. Nelson).
"Effect of Strain Rate and Depressed Temperature on the Low Cycle Deformation Behavior of Alpha Iron," Metallurgical Transactions, Vol. 10 (3), p. 305 (1979) (with H. H. Johnson).
"Halogen Stress Corrosion Cracking of Zircaloy-4," Symposium on Environment-Sensitive Fracture of Engineering Materials (1979) (with H. G. Nelson).
"Effect of Alloying Elements on the Equilibrium Partition of Nitrogen or Carbon in Ternary Iron-Base Alloys," ARMCO Final Report (December 1979) (with A. J. Heckler and J. A. Peterson).
"A Stress Corrosion Cracking Model for Pellet-Cladding Interaction Failures in Light-Water Reactor Fuel Rods," ASTM STP 681, Zirconium in the Nuclear Industry (1978) (with J. T. A. Roberts, R. L. Jones, E. Smith, D. Cubicciotti, A. K. Miller and F. L. Yaggee).
"EPRI-NASA Cooperative Project on Stress Corrosion Cracking of Zircaloys," EPRI NP 717 Project 455-1, Final Report (March 1978) (with R. L. Jones, D. Cubicciotti and H. G. Nelson).
"Kinetics of Hydrogen Entry from $TiFe_{0.86}Mn_{0.11}H_x$," Proceedings of the DOE Chemical/Hydrogen Energy Systems Review, p. 409 (1978) (with H. G. Nelson).

Attachment 4

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

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

Attachment 5

DOMINIC CIMINO
757 East Main Street
Bridgewater, New York 08807
(201) 560-8323 HOME

EDUCATION	Stevens Institute of Technology, Hoboken, New Jersey B.E. Mechnical Engineering, 1975
WORK EXPERIENCE	Springfield Industries (1976 - 1980) Administrative and Technical Sales of Steel Wire Products
	Metal Improvements Company, Inc. 472 Barell Avenue, Carlstadt, New Jersey (1980 - Present) Responsible for plant operation and administration of programs including wingskin forming as well as other experimental programs. Responsible for small satellite plant. Temporary Division Manager responsible for complete metal improvement company for three months.

Attachment 6

METAL IMPROVEMENT COMPANY, INC.
SUBSIDIARY OF CURTISS-WRIGHT CORPORATION

Shot Peening Service

678 WINTHROP AVENUE
ADDISON, ILLINOIS 60101
TELEPHONE: (312) 543-4950
TELEX: 721450

RESUME

N. K. BURRELL

EDUCATION: BSME UNIVERSITY OF ILLINOIS 1950

SHOT PEENING EXPERIENCE:

Employed by Metal Improvement Company for over seventeen years, thirteen of those functioning as Manager Technical Service for the Chicago Division. Responsibility required consultation with Engineering and Metallurgical Personnel as to solution of fatigue problems on various metal parts. Have been involved in many investigations of effects of shot peening on crankshafts, and many production programs as a result thereof. Have never seen a case of shot peening being detrimental to endurance limit of crankshafts. Currently Midwest Regional Sale Manager.

Author of many articles and technical papers on shot peening the latest being "Controlled Shot Peening to Increase the Fatigue Properties of Crankshafts". Delivered to the second International Conference on shot peening in May, 1984 (copy enclosed)

MR. STROUPE: At this time the witnesses are tendered for cross-examination.

JUDGE BRENNER: All right.

We'll get the Staff's testimony sworn in a moment.

As a minor thing, there are a few answers in the LILCO shot-peening testimony for which the witnesses are not identified; they are almost always the answers that are "No," and then there's a followup question and answer, "Why not?" And for the followup the witnesses are identified.

I am inferring that the witnesses on the followup answer are the same ones as on the initial one.

MR. STROUPE: That's exactly correct.

JUDGE BRENNER: All right.

Mr. Goddard.

MR. GODDARD: Thank you.

BY MR. GODDARD:

Q Dr. Bush, do you have a copy of the NRC's testimony in this proceeding?

A (Witness Bush) I do.

Q As to each of the answers therein which identify in parentheticals as being provided in whole, or subscribed to in whole, by you, are each of these answers true and orr[illegible] best of your knowldge, and do you adopt them [illegible]timony in this case?

[illegible] do.

Q And do you similarly adopt Exhibit 5 as being true and correct to the best of your knowledge as being an exhibit referenced in your testimony on shot-peening?

A Yes.

(Whereupon the document referred to was marked for identification as Exhibit 5.)

MR. GODDARD: The Staff would move that this testimony and exhibit be bound into the record as though read at this point in the proceeding.

Judge Brenner, because of the assembly of the Staff testimony and exhibits, is it permissible to bind the entire Staff testimony in at this point in the record?

JUDGE BRENNER: Yes, we can do that, with the indication that the only portions of that which we are actually admitting into evidence are the portions sponsored by Dr. Bush. But I want you to give a better identification of which portions particularly you are seeking to be admitted into evidence, other than the general reference to those sponsored by him.

MR. GODDARD: At this point, the portion that is to be considered in evidence, and for which Dr. Bush is tendered for cross-examination, is the shot-peening testimony at pages 18 through 21 of the Staff testimony.

JUDGE BRENNER: Well, what about the last question

1 WRBwrb

and answer on page 15 and the first question and answer on page 16?

MR. GODDARD: I would move that the cross-examination on those be withheld until after the cross-examination of the entire panel on shot-peening, but I want to make Dr. Bush available for cross-examination on those two at that time.

If you feel it would be more efficient to include that at this time, the Staff does recognize that Dr. Bush is the sole sponsor of that testimony on the material properties of the crankshafts.

JUDGE BRENNER: Well, let's admit that at this time, too, and the parties can cross-examine him in whichever sequence they want.

MR. GODDARD: Thank you, Judge Brenner.

JUDGE BRENNER: All right; the Staff's motion to admit the portion of testimony just identified as being sponsored by Dr. Bush is admitted into evidence. Of course, any conclusions elsewhere in the testimony that depend on those portions are ripe for cross-examination at this time, also. They are just summaries which occur mostly in the beginning. For convenience, however, we will bind in the entire joint testimony of Carl H. Berlinger, Spencer H. Bush, Adam J. Henriksen, Walter W. Laity and Professor Arthur Sarsten on contentions concerning TDI

1 WRBwrb

diesel generators at the Shoreham Nuclear Power Station, Volume 1, which consists of fifty-five pages plus attachments which contain the witnesses' professional qualifications, and we will bind that in at this point.

(Joint testimony of Carl H. Berlinger, Spencer H. Bush, Adam J. Henricksen, Walter W. Laity, and Professor Arthur Sarsten on contentions concerning TDI emergency diesel generators at the Shoreham Nuclear Power Station follows.)

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)	)	

JOINT TESTIMONY
of
CARL H. BERLINGER, SPENCER H. BUSH,
ADAM J. HENRIKSEN, WALTER W. LAITY, AND PROFESSOR ARTHUR SARSTEN
on
CONTENTIONS CONCERNING TDI EMERGENCY DIESEL GENERATORS
at the
SHOREHAM NUCLEAR POWER STATION

VOLUME 1

CONTENTS

CONTENTS cont

INTRODUCTION

Q. Please state your names, your business addresses, and your professional qualifications.

A. (Berlinger) My name is Carl H. Berlinger. I am the NRC Project Group Manager for matters pertaining to Transamerica Delaval, Inc., emergency diesel generators. A summary of my professional qualifications and experience is included as Attachment 1.

A. (Bush) My name is Spencer H. Bush. I am self-employed, under the firm name of Review and Synthesis Associates. A summary of my professional qualifications and experience is included as Attachment 2.

A. (Henriksen) My name is Adam J. Henriksen. I am self-employed, under the firm name of Adam J. Henriksen, Inc. A summary of my professional qualifications and experience is included as Attachment 3.

A. (Laity) My name is Walter W. Laity. I am employed by Battelle Memorial Institute at the Pacific Northwest Laboratory in Richland, Washington. A summary of my professional qualifications and experience is included as Attachment 4.

A. (Sarsten) My name is Arthur Sarsten. I am a member of the faculty of the Norwegian Institute of Technology at Trondheim, Norway. A summary of my professional qualifications and experience is included as Attachment 5.

Q. What is the subject matter of your testimony?

A. (Berlinger) My testimony addresses comments by the NRC staff on the testimony presented by NRC's consultants.

A. (Bush) My testimony addresses metallurgical considerations related to crankshaft fabrication and shotpeening, crack initiation and propagation, and nondestructive examination.

A. (Henriksen) My testimony addresses the technical adequacy of the four components discussed in Suffolk County's contentions, excluding analytical methods for fracture mechanics and stress analysis.

A. (Laity) My testimony addresses the technical assistance that the Pacific Northwest Laboratory is providing to the NRC staff in the review and evaluation of Transamerica Delaval, Inc. (TDI) emergency diesel generators.

A. (Sarsten) My testimony addresses stress analysis of diesel engine components and standards for the design of crankshafts.

Q. How is this testimony organized?

A. (Berlinger, Laity) First, the technical assistance that the Pacific Northwest Laboratory (PNL) is providing to the NRC staff is discussed. This is followed, in turn, by a summary of the testimony presented by the witnesses, and a summary of the premises on which this testimony is based. Suffolk County's contentions admitted by the Atomic Safety and Licensing Board are then addressed.

Role of the Pacific Northwest Laboratory

Q. What is PNL's role with the NRC staff on matters pertaining to TDI diesel engines?

A. (Berlinger, Laity) PNL is providing technical assistance to the NRC staff in reviewing the program established by the TDI Diesel Generator Owners' Group for assessing the adequacy of TDI diesel generators as emergency power sources for safety-related nuclear systems. I (Laity) head the project management team established at PNL for this effort.

PNL's role is to evaluate the technical adequacy of reports and related information submitted to the NRC staff on TDI diesel generators, and to identify any matters that require clarification or elaboration. While PNL's reviewers may perform calculations as appropriate for the review process, it is not the role of PNL to perform independent analyses of the components in question.

PNL has secured the services of several consultants who have extensive experience in the design, testing, operation, and maintenance of medium-speed diesel engines. The PNL project management team also calls upon experts as necessary in areas such as metallurgy, fracture mechanics, stress analysis, nondestructive testing, and heat transfer. These experts provide advice and counsel to PNL and to the NRC staff on the numerous issues that have been raised in regard to the adequacy of TDI diesel generators as emergency power sources for nuclear systems.

In the preparation of this testimony, the witnesses have reviewed the testimonies filed by Suffolk County and by Long Island Lighting Company

(LILCO). The witnesses have also reviewed various relevant documents submitted by the TDI Diesel Generator Owners' Group to the NRC staff, and participated in meetings of the Owners' Group with the Staff. Two of the PNL witnesses (Laity and Henriksen, a PNL consultant) have examined key components of the TDI diesels at the Shoreham Nuclear Power Station during engine disassemblies.

Summary of Testimony

Q. Please summarize your testimony on the four components in contention.

A. (All) In summary, the information available for our review from LILCO and from the TDI Diesel Generator Owners' Group did not provide an adequate basis for us to reach an unequivocal conclusion regarding the overall adequacy of the Shoreham TDI diesel generators as emergency power sources for nuclear systems. Our reservations pertain to two of the four components in contention: the crankshafts, and the cylinder blocks for the 101 and 102 engines. The following is a brief summary of our position on these components and on the other two components in contention.

Crankshafts

We have concluded that, at rated engine load, the torsional stresses in the crankshafts exceed the DEMA Standard Practices. Although the crankshafts may still perform satisfactorily, we believe that the information available for our review is not conclusive in this regard. One approach that would resolve our concern about the crankshafts would be to test an engine (either the 101 engine or the 102 engine to also resolve concerns about the cylinder blocks) to 10^7 cycles (about 740 hours) at rated load, with the engine operated at 110% of rated load for 2 hours out of every 24 hours.

On the basis of information presented in LILCO's testimony, we have concluded that neither the first shotpeening nor the second shotpeening of two of the crankshafts degraded their fatigue resistance. Rather, the second shotpeening may have enhanced the crankshafts' fatigue resistance. However, in our opinion, the effect is not quantifiable from available information.

Cylinder Blocks

Our reservations about the cylinder blocks stem from unresolved questions as to whether or not existing cracks in the camshaft gallery are benign. Pending a more definitive explanation of the origin of these cracks, the stresses in the area where they are located, and the predicted path of crack propagation, we do not have an adequate basis for drawing a conclusion about the suitability of these blocks for nuclear standby service. In our opinion, conclusive information about the behavior of these cracks could be obtained from an engine test as described above for the crankshafts, provided the cracks are characterized as to length, depth, and direction before and after the test, and appropriate strain gage measurements are taken during the test.

Operating experience with the Shoreham engines and with TDI engines at other nuclear power stations suggests that ligament cracks present in the 101 and 102 blocks between the cylinder liner conterbore and the head studs will arrest. This assumes that the material in the cylinder blocks conforms to specifications for ASTM class 40 gray-iron castings. If the ligament cracks arrest, the probability of a crack initiating between studs for adjacent cylinders and propagating into the blocks is, in our opinion, very low because of a limited driving force. However, the blocks should be monitored for this type of cracking with an appropriate nondestructive examination technique. It is difficult to predict the location of crack initiation, which conceivably could start at the threads in the holes for the head studs rather than at the surface of the block. Accordingly, the potential for subsurface cracks should be considered in the selection of the most appropriate NDE technique.

Cylinder Heads

On the basis of known operating experience with TDI heads, we have concluded that problems in service are indicative of manufacturing defects rather than design deficiencies. Subject to nondestructive examination of the firedecks of all cylinder heads at Shoreham, use of heads with no through-wall weld repairs of the firedeck, and surveillance after each time the engine is operated to detect coolant leaks into the cylinders, we have concluded that the heads are suitable for nuclear service through to shutdown for the first refueling.

Piston Skirts

On the basis of operating experience in the R-5 test engine at TDI with piston skirts similar in design to the AE piston skirts installed in the Shoreham engines, and subject to nondestructive examination of all pistons in the area of the stud bosses, we have concluded that the AE piston skirts are suitable for nuclear service through to the shutdown for the first refueling.

Based on the testimony summarized above, the NRC staff believes that these components may be qualified for nuclear standby service at Shoreham if: 1) an engine (either the 101 or 102) is tested at its rated load (either the current FSAR value or a new lower value), 2) the engine block is inspected using nondestructive techniques before and after the test to characterize the cracks in the block, and other key engine components are inspected after the test, 3) the engine block is instrumented during the test with strain gages, 4) the applicant provides additional information to resolve outstanding Staff questions concerning the crankshafts and engine blocks, and 5) the applicant performs limited destructive examinations of the old 103 engine block to resolve outstanding Staff questions concerning cracks in the blocks. The successful completion of these actions is considered to be confirmatory in nature as they are expected to provide a basis for concluding that these components are satisfactory for their intended service.

Premises on Which This Testimony is Based

Q. Have the witnesses in this testimony identified any premises common to their evaluation of all of the contentions to be addressed?

A. (All) Yes. Our principal premise is that the TDI diesel generators at Shoreham will be reassessed at the time of the first refueling, or after about 1 1/2 years of operation. We anticipate that all phases of the Owners' Group Plan for TDI diesel generators and the plant-specific Design Review and Quality Revalidation of the Shoreham engines will be completed and implemented by the first refueling. In our opinion, it would be more appropriate to decide questions of long-term reliability and operability of the TDI diesels as that time approaches, rather than now.

Other premises on action to be taken before the engines are placed in nuclear standby service are as follows:

- nondestructive examination of all piston skirts, cylinder heads, oil holes in all crankshaft main-bearing journals, and oil holes in the most heavily loaded crankpin journals
- nondestructive examination of the top surface of each engine block to verify that no stud-to-stud cracks are present between adjacent cylinders
- preoperational crankshaft deflection tests under hot and cold conditions.

An additional premise is that, following each time an engine is operated, the engine will be rolled over with the air-start system 4 to 8 hours after shutdown, 24 hours after shutdown, and before each planned start to check for water in the cylinders.

CRANKSHAFTS

Contention

a. The replacement crankshafts at Shoreham are not adequately designed for operating at full load (3500 kW) or overload (3900 kW), as required by FSAR Section 8.3.1.1.5, because they do not meet the standards of the American Bureau of Shipping, Lloyd's Registry of Shipping, or the International Association of Classification Societies. In addition, the replacement crankshafts are not adequately designed for operating at overload, and their design is marginal for operating at full load, under the German criteria used by FEV.

Q. Have you reviewed the testimony filed by the County on July 31, 1984, in support of its contentions regarding the crankshafts in these proceedings?

A. Yes.

Q. How are the design rules promulgated by the various classification societies used to assure the adequate design of a diesel engine crankshaft?

A. (Henriksen, Sarsten) A number of organizations provide rules or limits for the design of diesel engines. Some of these organizations are:

- Diesel Engine Manufacturers Association (DEMA)
- American Bureau of Shipping (ABS)
- Lloyd's Registry of Shipping
- International Association of Classification Societies (IACS)
- Det Norske Veritas
- Germanischer Lloyd
- Nippon Kaiji Kyokal (NKK).

All of these organizations with the exception of DEMA have formed design rules as a guideline for the insurability of diesel engines in marine service. The design rules established by each of these organizations represent the experience of the organization on the design/analysis procedures, materials, fabrication techniques, and testing methods that would produce an adequate engine design. Because these rules were formulated by different people under different circumstances, they differ somewhat in approach and detail. The rules are often subject to, or often require, interpretation and discussion with the classification society. These societies provide a mechanism whereby a diesel engine manufacturer who comes up with a design that does not comply strictly with the societies' rules can apply for and receive approval for the design upon submission of stress analyses or other supporting data. These rules may change with time as new design techniques, materials, and fabrication methods are developed.

DEMA is an American trade association of diesel engine manufacturers. In a publication titled Standard Practices for Low and Medium Speed Stationary Diesel and Gas Engines, DEMA describes various aspects of the design, operation, and testing of diesel engines. For crankshafts, DEMA provides guidelines only for allowable stresses associated with torsional vibratory conditions. DEMA does not provide any guidance for crankshaft dimensions, material properties, or methods of fabrication.

Q. Should a crankshaft satisfy the rules or design guidelines of several classification societies?

A. (Henriksen, Sarsten) Not necessarily. There is no requirement for this. A designer may choose to follow the design rules of one or more classification societies in accordance with potential market preferences. In the case of the Shoreham engines, the applicable standard is IEEE Std 387-1977, "IEEE Standard Criteria for Diesel-Generator Units Applied as Standby Power

Supplies for Nuclear Power Generating Stations." This standard invokes DEMA Standard Practices as one of the reference standards. No other rules or standards for the design of diesel engines are invoked.

Except for the DEMA Standard Practices referenced above, the rules of the classification societies are for engines designed to operate in marine applications. Marine engines are exposed to conditions far different from those for standby engines at nuclear power plants. In is not neccessary for good design practice that nuclear standby engines meet any of the rules established by classification societies for marine engines.

Q. Have you reviewed the County's analysis of compliance of the crankshafts with rules of the American Bureau of Shipping, as documented in Exhibit 40 of the County's testimony?

A. (Henriksen, Sarsten) Yes. We do not agree with the County's interpretation of the ABS rules regarding the section modulus of the crank webs, and we do not agree with the County's conclusion that the crankshaft dimensions do not meet the ABS rules. In our opinion, the County's interpretation is not consistent with the interpretation explained by Mr. R. Woytowich during the County's deposition of R. Woytowich, H. C. Blanding and R. A. Guiffra of ABS on July 18, 1984 (pages 129-130 of the transcript). We checked the crank web dimensions of the Shoreham crankshafts on the basis of the interpretation of Mr. Woytowich, and concluded that they do, indeed, meet the ABS requirements at both 3500 kW and 3900 kW. Our evaluation is included as Exhibit 1.

Q. Have you reviewed Dr. Simon Chen's analysis of compliance of the crankshafts with DEMA guidelines for torsional stresses, as documented in Exhibit C18 of LILCO's testimony?

A. (Sarsten) Yes, I have.

Q. What is your assessment of Dr. Chen's analysis?

A. (Sarsten) First, the program employed in Dr. Chen's analysis was limited to the vector sum of only six orders of vibration, but had been expanded to 12 orders by a special subroutine added by him. This accounts for only half of the 24 orders now normally used. Although the 12 orders include the most significant ones, the remaining 12 contribute to the accuracy of the analysis and should be considered.

Second, the harmonic coefficients (T_n) employed in the analysis are based upon a table appearing in Lloyd's Registry of Shipping standards ("Guidance Notes on Torsional Vibration Characteristics of Main and Auxiliary Oil Engines" 1976) rather than on values based upon actual cylinder pressure measurements taken on one of the TDI engines at Shoreham. (The latter values were used in an analysis performed by Failure Analysis Associates.) The free-end amplitude of 0.59 degrees calculated by Chen differs from the measured value of 0.693 degrees on a Shoreham engine by 14.9%. With current calculational methods, the calculated and measured values should be in much closer agreement.

Q. Have you reviewed the crankshaft analysis performed by Failure Analysis Associates (Exhibit C17 of LILCO's testimony)?

A. (Sarsten) Yes. FaAA used harmonic coefficients based upon actual measurements referred to in the previous answer. Furthermore, FaAA's computer program employed a modal superposition of an undamped system using a slight modal damping, and combined 24 excitation harmonics. FaAA concluded that the stresses meet DEMA Standard Practices, which limit stresses to less than 5000 psi for any single order of vibration and to less than 7000 psi for the summation of the orders. FaAA's results are much closer to DEMA limits than are Chen's results.

Q. Did you perform an analysis of the torsional stresses for the sum of 24 orders of vibration?

A. (Sarsten) Yes. These results are plotted in Exhibit 2. My analysis is for engine operation at 3500 kW, and employs the same T_n values (TDI Owners' Group harmonic data) used by FaAA. The results are preliminary, and are subject to some slight refinements and checks. However, I anticipate that any changes in my results are unlikely to affect my conclusions to any significant degree.

For Section No. 6 of the crankshaft (i.e., the torsional spring representing the crankshaft elasticity between cylinders 5 and 6), my analysis shows that the stresses for the sum of all orders exceed the DEMA limit of 7000 psi over the entire speed range called for by DEMA, i.e., from 5% below rated speed to 5% above rated speed.

Q. Did you also calculate the stress levels for single orders?

A. (Sarsten) Yes. These results are plotted in Exhibit 3. At the rated speed of 450 rpm, the maximum torsional vibratory stress in the crankshaft occurs for the 4th order. My calculated value for this stress at 450 rpm is approximately 3800 psi. Values of this stress remain below the DEMA limit of 5000 psi throughout the speed range called for by DEMA. The rise of the $5\frac{1}{2}$ order above the 5000-psi limit at 95% of rated speed is not considered important, as the actual stress values so near resonance will depend upon the damping values assumed. Thus, in my view, the crankshaft does meet the DEMA requirements for single orders.

Q. By what means were these stress values computed?

A. (Sarsten) I employed a computer program called COMHOL[a] (acronym for COMplex HOLzer), which calculates the steady-state forced vibration of damped linear systems subjected to periodic forcing functions represented by a Fourier series of harmonics. The shaft and mass damping are represented by complex constants.

Q. How do your results compare with those reported by FaAA?

A. (Sarsten) The stresses that I have calculated for the sum of all orders are somewhat higher than those predicted by FaAA. For example, at the rated speed of 450 rpm, my calculations for the sum of all orders predict a torsional stress of 7096 psi in comparison to the 6626 psi predicted by FaAA. My calculations predict a front-end vibrational amplitude of 0.690 degrees in comparison to 0.662 degrees predicted by FaAA. The Stone & Webster Engineering Corporation measured a front-end amplitude of 0.693 degrees on a TDI engine at full load (as referenced in Exhibit C17 of LILCO's testimony).

(a) Nervik, N. R., and A. Sarsten. January 1981. User's Manual: Computer Program COMHOL2 for Analysis of Forced Torsional Vibrations of Linear Damped Systems. Department of Marine Technology, The Norwegian Institute of Technology, Trondheim, Norway.

Q. How do your results compare with ABS rules?

A. (Sarsten) In addition to its requirements for crankshaft dimensions, the ABS also requires that the cyclic torsional stresses be held below specific limits that depend upon factors such as engine speed, material, etc. TDI has calculated these values for the Shoreham engines[a] and arrived at 3357 psi for a single order, and 5035 psi for total vibratory stresses as the limits that would be allowed by paragraph 34.47 of the 1984 ABS Rules. According to my calculations, these stress limits are exceeded (3608 and 7096 psi, respectively, corrected for front-end measured amplitude).

Q. Does the method of crankshaft fabrication enter into the evaluation of its adequacy?

A. (Sarsten) Yes, for some of the classification societies (e.g., Det Norske Veritas).

Q. How were the replacement crankshafts fabricated for the Shoreham engines?

A. (Bush) It is our understanding that a forged-slab, hot-twisted fabrication process was employed. PNL (S. Dahlgren) was informed during a telephone conversation with W. Coleman of the TDI Diesel Generator Owners' Group on August 9, 1984, that this process was used.

(a) These values are documented on page 21 of the report enclosed with a letter dated May 3, 1984, from ABS (R. Giuffra) to TDI (R. Yang). The letter and the applicable page of the report are included as Exhibit 4 of this testimony.

Q. How does this hot-twisted fabrication process compare with a closed forging process?

A. (Bush) A closed-forged[(a)] crankshaft will have isotropic properties, whereas a slab-forged and hot-twisted crankshaft will yield anisotropic mechanical properties. An appropriate heat treatment will improve the properties, but not to the degree possible with closed forging.

A more significant factor is the property gradient across the slab. In a closed forging the maximum mechanical properties exist throughout the overall surface, subject to the degree of machining. A slab-forged and twisted crankshaft will display a definite gradient in mechanical properties from centerline to surface. This means that some areas of the crankshaft will display lower properties in some regions.

The nondestructive examinations, both ultrasonic and magnetic particle, confirm there were no gross slag inclusions near the centerline, which is a positive factor.

Q. FaAA has analyzed the crankshaft safety factor for the replacement crankshaft, and arrived at the conclusion that the crankshaft was adequate. Is this not sufficient proof of adequacy?

A. (Sarsten) The failure of the original crankshaft gave a bench mark for the calculation of the factor of safety of the replacement crankshaft. The result reflects only a single point of reference. I would prefer to assess the adequacy of the crankshaft based upon the large amount of data represented by

(a) We are defining closed forging as using shaped dies to hot form the metal after an initial hot forging breakdown to homogenize the formed ingot.

the appropriate classification societies' rules and their experience in the interpretation of these rules. This should provide a conservative basis for the evaluation.

Q. Is there any way to assess the crankshaft adequacy through testing?

A. (Sarsten) Yes. One could, of course, operate the engine for a sufficient number of cycles. The figure of 10^7 cycles is often accepted as a sufficient number in such cases. This number of cycles for a four-cycle engine at 450 rpm corresponds to around 740 total running hours. If a subsequent detailed inspection of the crankshaft fails to reveal any deleterious effects, the crankshaft could then be accepted as adequate for the load and conditions at which it had been operated for these 10^7 cycles.

Q. Can you summarize your conclusions regarding the adequacy of the crankshaft?

A. (Sarsten, Henriksen) Based upon my (Sarsten's) analysis, the crankshafts do not meet DEMA Standard Practices regarding torsional stresses at the rated load of the engine. This does not necessarily imply that the crankshafts are inadequate for their intended service. However, from the information we have reviewed, we do not have a sufficient basis for concluding that the crankshafts are adequate.

The crankshafts do not have to meet the requirements of any or all of the classification societies for this application. On the basis of our review, we believe that they in fact do meet the requirements of ABS with regard to physical dimensions. In my (Sarsten's) opinion, they do not meet the ABS requirements regarding torsional vibration stresses.

It is also our opinion that crankshaft adequacy for a given load and conditions could be established by running a crankshaft under those conditions for 10^7 cycles.

We believe that nondestructive tests to confirm that the crankshafts are sound should include, in addition to the tests already performed, examinations of all oil holes in main bearing journals and the oil holes in the most heavily loaded crankpin journals.

Contention

b. The shotpeening of the replacement crankshafts was not properly done as set forth by the Franklin Research Institute report, "Evaluation of Diesel Generator Failure at Shoreham Unit 1, April 5, 1984," and the shotpeening may have caused stress nucleations sites. The presence of nucleation sites may not be ascertainable due to the second shotpeening of the crankshafts.

Q. Do you believe that shotpeening of the Shoreham crankshafts was necessary?

A. (Bush) In my opinion, shotpeening of the Shoreham crankshafts probably was not necessary. The fillet radii are quite large, on the order of 0.75 inch, so the stress concentration factors at the fillets should be low. With low stress concentration factors, the probability of crack initiation by fatigue is reduced. Shotpeening of the fillet region is effective in inducing localized compression zones at and slightly below the surface to minimize local tensile or bending stresses at the fillets while undergoing cyclic loading during operation. I consider shotpeening, if done correctly, to be beneficial. Shotpeening has been performed on millions of rotating parts such as camshafts and crankshafts in automobiles, etc., as well as on many millions of springs, and the operational histories have been very good.

Q. Do you consider the original shotpeening adequate?

A. (Bush) No. Surface coverage was inadequate; furthermore, the QA records on the original shotpeening, at least those we have seen, do not yield sufficient information. A definite plus was the report of visual examination and of magnetic particle testing at LILCO that confirm that the as-received surface condition after original shotpeening at TDI was acceptable. A concern with shotpeening is shot breakage and embedment so that the surface contains many indentations. As reported, this was not the case.

Q. Do you consider reshotpeening as deleterious?

A. (Bush) No. There have been experiments on high strength steel, which would be much more susceptible to small indentations serving as stress risers for fatigue crack propagation than would be true with the lower tensile strength material in crankshafts, and there was no perceptible decrease in fatigue resistance after five shotpeening cycles. In fact, Kohls et al. (Exhibit 5) found that the fatigue resistance was enhanced with added cycles through three, and did not deteriorate with five cycles. The surface compressive layer is a major deterrent to the initiation and propagation of fatigue cracks under cyclic fatigue loads.

Q. Can shotpeening lead to a deterioration of properties below the surface, leading to internal crack propagation and ultimate failure?

A. (Bush) I doubt this would occur unless there was a large embedded flaw. This would have been detected by the extensive ultrasonic testing conducted during fabrication. I am aware of embedded flaws in structures other than crankshafts where the surface was in compression, and there has been no evidence of crack growth after 10 years, even with definite cyclic bending stresses occurring in the structure.

Q. Do you consider the resnotpeening to be adequate?

A. (Bush) Yes. According to testimony of D. Cimino (on page 11 of LILCO's testimony of C. Wells, D. Johnson, H. Wachob, C. Seaman, D. Cimino, and N. Burrell concerning Shotpeening of the Replacement Crankshafts), the shotpeening met military specification MIL-S-13165B or exceeded the specification in all critical aspects. The fluorescent penetrant test confirmed the adequacy of the shotpeening.

Q. Do you consider the argument on "nucleation sites" as significant?

A. (Bush) No. My previous comments indicate extensive use of shotpeening of automotive crankshafts, etc., and experimental evidence confirms that repetitive shotpeening is not deleterious.

Q. If the Suffolk County arguments are valid concerning the existence of "nucleation sites", could flaws of metallurgical significance be detected?

A. (Bush) We have not conducted an independent fracture mechanics analysis of the crankshaft; however, fatigue analyses on analogs of crankshafts confirm that a compression zone will minimize propagation of an existing flaw. Extensive work with the ASME XI Code indicates that flaws of significance with regard to fatigue crack propagation would approach ~0.25 inch depth and similar length in the zone influenced by shotpeening. Any flaws of this size would be detectable by magnetic particle testing. I see no reason why such flaws should exist, based on the reported nondestructive examination results.

In conclusion, I do not consider that the second shotpeening degraded the fatigue resistance. In fact, I consider that such fatigue resistance should be somewhat enhanced, but it is not quantifiable. Obviously there is a major caveat. Professor Sarsten's calculations indicate torsional stresses in excess of DEMA Standard Practices. If torsional and/or bending loads are high enough, cracks will initiate and propagate, regardless of fillet design and shotpeening. The ultimate test is to operate the crankshaft to 10^7 cycles at the proposed power rating to see if cracks initiate.

CYLINDER BLOCKS

Contentions

The County contends that the emergency diesel generators (EDGs) are inadequate because:

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

Q. Have you reviewed the testimony filed by the County on July 31, 1984, in support of its contentions regarding the cylinder blocks in these proceedings?

A. (Bush, Henriksen) Yes.

Q. Have you reviewed the testimony filed by LILCO[a] on August 14, 1984, which concludes that:

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

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

(a) Testimony of R. McCarty, C. Rau, C. Wells, H. Wachob, D. Johnson, R. Taylor, C. Seaman, E. Youngling and M. Schuster on Suffolk County Contention Regarding Cylinder Blocks.

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

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

and, further[(a)], that:

1. The ligament cracks present in EDG 101 and EDG 102 are benign. There is no evidence that the cracks will propagate beyond a depth of 1-1/2 inches. Accordingly, the ligament cracks in EDG 101 and EDG 102 do not and will not impair the ability of the EDGs to perform their intended function.

2. The crack that propagated down the front of the old EDG block and the large cracks that developed between the stud holes of adjacent cylinders on the old EDG 103, do not threaten the integrity of EDG 101 or EDG 102. TDI believes that EDG 103 was subjected to abnormal high stress as a result of an unusual load excursion and that this caused additional extensive cracking in EDG 103.

3. The cam gallery cracks in the Shoreham EDGs were discovered more than 1-1/2 years ago. These cracks have not propagated significantly despite hundreds of hours at full load and overload conditions. It is TDI's opinion that the cam gallery cracks will not propagate significantly and that they will not impair the ability of the EDGs to meet their intended function.

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

A. (Bush, Henriksen) Yes.

(a) Testimony of C. Mathews, M. Lowrey, and J. Wallace.

Q. Please summarize your conclusions regarding the cylinder blocks.

A. In summary, we conclude that:

- Presently, the information regarding the cracks in the camshaft gallery on the cylinder blocks for EDG 101 and EDG 102 is incomplete. Consequently, no conclusion can be made as to the suitability of these two cylinder blocks for the operation stated.
- The replacement block for EDG 103 is not a new design; it has been proven. Further, if it is certified to be free of stud-to-stud cracks between adjacent cylinders and in the camshaft gallery and if it is inspected for cracks after each operation, it will be suitable for nuclear service for one refueling cycle.

Q. Do you know the material specifications for the cylinder blocks on the Shoreham TDI 101 and 102 engines?

A. (Bush, Henriksen) Yes. Drawing #03-315-03-AC of the cylinder blocks for the Shoreham TDI 101 and 102 engines specify an ASTM-A48-64 class 40, gray-iron casting.

Q. Was the material specification for the original cylinder block on the Shoreham TDI 103 engine also ASTM-A48-64 class 40, gray-iron casting?

A. (Bush, Henriksen) Yes.

Q. What are the material specifications for the replacement cylinder block on the Shoreham TDI 103 engine?

A. (Bush, Henriksen) Drawing #03-315-05-AD of the cylinder block for the Shoreham TDI 103 engine specifies an ASTM-A48-76 class 45B, gray-iron casting.

Q. What is the significant difference between an ASTM-A48-64 class 40, gray-iron casting and an ASTM-A48-76 class 45B, gray-iron casting?

A. (Bush, Henriksen) The tensile and yield strengths of an ASTM-A48-76 class 45B, gray-iron casting are superior to those of an ASTM-A48-64 class 40, gray-iron casting.

Q. Have you reviewed the portion of the FaAA report that deals with the metallurgical analysis performed on cylinder blocks of the Shoreham TDI 101, 102, and 103 engines?

A. (Bush, Henriksen) Yes.

Q. Do you consider the quality of the gray iron in the original cylinder block of the Shoreham TDI 103 engine typical of standard casting practice?

A. (Bush) No. The morphology of the graphite flakes, as evidenced from the photomicrographs presented, was not typical. Such flakes would lead to degraded mechanical properties.

Q. Did you find the quality of graphite in the cylinder blocks from the TDI 101 and 102 engines similar to that in the original block from the 103 engine?

A. (Bush) No. The microstructure of the samples from the cylinder blocks of the 101 and 102 engines is typical for an ASTM class 40, gray-iron casting.

Q. Have you reviewed the portion of the FaAA report that deals with the physical tests that were performed on samples from the cylinder block of the Shoreham TDI 103 engine?

A. (Bush, Henriksen) Yes.

Q. What did you conclude from your review?

A. (Bush, Henriksen) That the results from the physical test confirm the conclusion drawn from the metallurgical analysis. The material in the original cylinder block from the Shoreham TDI 103 engine is substandard as compared to ASTM class 40, gray-iron castings.

Q. Can it be assumed that, since the photomicrographs indicate that the cylinder blocks from engines 101 and 102 indicate typical class 40, gray-iron castings, their physical properties such as tensile and yield stresses are, in fact, typical of class 40, gray-iron castings?

A. (Bush, Henriksen) The assumption may certainly be made that the material in the cylinder blocks for engines 101 and 102 is superior to the material in the original 103 cylinder block. Whether or not the 101 and 102 blocks actually have the physical properties of class 40, gray-iron castings can be confirmed only by actual tests. We have no knowledge that this testing was ever done.

Q. Assuming that the material in the cylinder blocks for engines 101 and 102 conforms to the specifications for ASTM class 40, gray-iron castings, would you consider the ligament cracks presently observed in the blocks between the cylinder liner counterbore and the cylinder head studs as benign?

A. (Bush) The empirical evidence would indicate that these cracks grow to the size cited, then arrest. This empirical evidence is based on repetitive examinations of cracks in both ship and stationary diesels. There is one substantial difference between such diesels and emergency diesels tested periodically. Basically, the first group operates at near steady-state conditions, whereas the emergency diesels will reach peak loads rapidly and operate with variable thermal gradients. Because of this difference, one cannot unequivocally state that the cracks will arrest. A definitive three-dimensional finite element analysis with valid load inputs through the thickness of the block, covering hoop stresses, thermal loads, bolting loads, etc., would confirm whether the crack has arrested because of a rapidly decreasing stress gradient.

Q. If the ligament cracks from cylinder liner to studs could be shown to have been arrested, what, in your opinion, would be the probability of a crack initiating between studs of adjacent cylinders?

A. (Bush) If the liner/stud crack can be shown to have arrested, the probability of a crack initiating between the two studs and then propagating into the block is very low because there is a limited driving force. The initial cracks in the 103 block are believed to be due to the degraded mechanical properties; the very severe overloads because of the load transient are believed to have caused rapid crack growth. In essence, this would correspond to a low-cycle fatigue problem where every cycle drives the crack a substantial distance.

Q. In your opinion, will the ligament cracks presently observed between the counterbore and the studs render the cylinder blocks on engines 101 and 102 unsuitable for nuclear service?

A. (Bush) The nature of the loss of power/loss of coolant accidents is such that demand for high diesel generator-related power is quite short-lived; thereafter, the power demands are much less. Even if the diesel generators were to be derated and it became necessary to meet LOOP/LOCA conditions above the derated rating but no higher than the nameplate rating, the limited duration at higher power should not pose a major problem.

Q. Do you consider checking for cracks between studs of adjacent cylinders after each operation above 50% load as adequate?

A. (Bush, Henriksen) No. As stated earlier, we do not have an adequate basis for concluding that all present cracks are arrested. Therefore, we feel this inspection should be performed after any operation.

Q. Do you consider the suggested eddy-current test as adequate to detect cracks of sufficient size to lead to detorquing of the studs?

A. (Bush) It must be recognized that the eddy-current test with ferritic materials is limited to the "skin" of the metal. All testing of the block surface must be done through the restricted access between cylinder heads. Although eddy-current testing will be difficult, it is not impossible, provided the surface between the two studs is sufficiently smooth (i.e., a machined surface).

The more fundamental issue is the initial locus of crack initiation. The most probable location would be between stud hole and cylinder, which is impossible to examine without disassembly. In my opinion, on the basis of a limited review, the most probable location for cracks to initiate would be at the corner of the counterbore at the start of the threads. Depending on the stress distribution, such a crack could progress down the threads or up to the surface. Based on LILCO testimony for blocks 101, 102, and the original 103 plus blocks for other TDI diesels, cracks exist at the surface and to depths of 1.5 inches. It is possible that the liner/stud cracks might grow down the threads under the start-stop loading typical of emergency diesels. If this occurred, there could be a redistribution of stresses so that cracks may initiate between the studs. We suspect that such cracks would initiate at the corner adjacent to the top thread. However, unless the cracks propagate to the surface, eddy-current testing will be useless. An alternative technique that might work is a zero degree ultrasonic wave commonly used in metals as a depth gage. If the external surface area and geometry are adequate to insert the ultrasonic tranducers, cracks between the studs have the potential of detection. This technique has the advantage of measuring the depth dimension whether the crack reaches the surface or remains subsurface.

Q. Mr. Berlinger, do you agree with the previous response?

A. (Berlinger) Not completely. With regard to the issue of crack initiation sites, limited hard evidence has been submitted by LILCO in their exhibits B-16, B-17, B-18 and B-25. These crack maps indicate that some block cracks which extend down into the block from the block top surface had not been observed to the depth of the stud threads (1 1/2 inches). Conversely, no cracks have been observed at the depth of the threads which did not extend up to the block top surface.

FaAA and LILCO have stated during recent technical discussions that they have used eddy current probes to inspect stud counterbore and thread areas in stud holes in the 101, 102 and old 103 Shoreham blocks. In those cases for which no surface crack indications had been observed, these inspections did not find any subsurface cracks. These measurements/ inspections would confirm that cracks which would initiate below the surface would propagate and be evidenced at the block top surface.

The staff believes that it is difficult to predict the locations of crack initiation, and that the potential exists for crack initiation in the block stud area from subsurface initiation sites (e.g., stud threads). However, the evidence from previous inspections of the Shoreham cylinder blocks would indicate that crack initiation would not be subsurface. Therefore, monitoring of the block top surface for stud-to-stud cracks should be done using the most appropriate nondestructive examination technique which should not be limited to consideration of only ultrasonic techniques.

Q. Do you consider the position suggested by LILCO that stud-to-stud cracks to depths of 1.5 inches are acceptable as justified?

A. (Bush) No. The only basis for such a position is believed to be the existence of stud-to-stud cracks in the original 103 block. Cracks of unkown geometry were known to exist prior to the severe overload that drove a crack to a depth exceeding 5 inches. As noted previously, we believe the probability of stud-to-stud cracks is very low, assuming the cast iron is not atypical as was the case with the original 103 block.

The appearance of a stud-to-stud crack in normal quality cast iron would indicate that too little is known concerning the stresses and stress distributions leading to such a crack. A deliberate decision to continue operation without repair of such a crack is not justified because the presence of such a crack indicates that the current analytic techniques do not accurately model crack initiation and growth.

If a well designed three-dimensional finite element analysis using stresses validated by experimental methods were conducted, it might be possible to justify the conscious operation with stud-to-stud cracks. Personally, I doubt it, because of difficulty in establishing local stresses.

Q. Have you had occasion to review the LILCO testimony and exhibits referring to the cracks in the camshaft gallery?

A. (Bush, Henriksen) Yes.

Q. Based on this testimony and relevant exhibits, have you formed an opinion as to why these cracks initiated in the first place?

A. (Bush, Henriksen) No. We believe this point has not been addressed in the testimony or the exhibits.

Q. Have you formed an opinion as to crack growth rate in the camshaft gallery based on FaAA's analysis on this subject?

A. (Bush, Henriksen) No. The FaAA analysis approach probably is correct, provided the input data are correct. However, we have some reservations as to the correctness of the strain gage data supplied by TDI. These data constitute the main basis for the FaAA analysis.

Q. Is your concern regarding the TDI strain gage data related to the fact that the data were obtained from a 6-cylinder rather than an 8-cylinder engine, a slightly larger fuel injection pump, and a little faster rising fuel cam?

A. (Bush, Henriksen) No. These are minor issues of no consequence.

Q. What is your concern then?

A. (Bush, Henriksen) First, referring to LILCO Exhibit B54, Gage #1 is not located in the area in question; yet the values obtained from Gage #1 are presented in the testimony as the stresses found in the cracked area.

Second, again referring to LILCO Exhibit B54, Gages #2 and 3 appear to be located in the same area. As can be noted in LILCO Exhibit B53, there is a difference of over 50% at 110% load, and over 100% at 100% load in mean stress between the two gages.

Third, and most important, we do not understand how, for the same mode of operation, the stresses can change from tension to compression as a function of engine load. The fuel injection pump is positively loaded every second revolution regardless of load. The vectors in the loading diagram do not change direction as a function of load. Thus, in our opinion, the stresses should not change direction as a function of load.

Q. In your opinion, do the cracks in the cam gallery pose a potentially serious problem?

A. (Bush, Henriksen) Yes. Depending upon the depth of the cracks and the anticipated growth pattern, the cracks may or may not pose future problems. Examination of TDI drawing #03-315-03-AC indicates that cracks may possibly propagate into the cylinder cooling water space, which could result in water entering into the camshaft housing. Lube oil in that housing drains into the engine crankcase. Leakage in this area is unlikely to be noticed during engine operation. Thus, enough water may mix with the lube oil in the crankcase to cause serious damage to bearings, shafting, etc.

Q. In your opinion, do the cracks in the camshaft gallery of the cylinder blocks for engines 101 and 102 render these engines unsuitable for nuclear service for one refueling cycle?

A. (Bush, Henriksen) Yes, until the questions raised regarding the TDI strain gage measurements and the reversal of direction of stresses are answered such that we have a reasonable assurance that the cracks in the cam gallery are benign or grow at such a slow rate that they are of no concern.

Q. Mr. Berlinger, does the staff believe that the concerns, relative to the cracks in the camshaft gallery can be resolved?

A. (Berlinger) Yes, the staff believes if an engine were tested as suggested to resolve the concerns regarding the crankshafts, that data obtained during that testing could provide information regarding the stresses and crack propagation in the cam gallery area.

Assuming that either EDG 101 or 102 was to be tested, if the cam gallery area were thoroughly inspected to characterize the existing cracks by determining the length, depth and direction of existing cracks before and after the suggested 10^7 cycle test, and, if the crack area were instrumented with strain gages and measurements were taken during these tests, the staff believes that conclusive information about the behavior of the cracks could be obtained which would resolve the existing concerns.

Q. In your opinion, is the replacement cylinder block for EDG 103 of a new design?

A. (Henriksen) No. Drawing #03-315-05-AD indicates that the replacement cylinder block is a modified version of the original cylinder block drawing #03-315-03-AC.

Q. Other than the change in material, which you have stated earlier was an improvement, have you reviewed LILCO's testimony with regard to the other changes to the replacement cylinder block?

A. (Henriksen) Yes.

Q. Do you consider any of these changes or modifications detrimental?

A. (Henriksen) No.

Q. Do you consider any of these changes or modifications beneficial?

A. (Henriksen) Yes. All changes to the replacement cylinder block, as listed in LILCO's testimony, are considered beneficial.

Q. Do you have any remarks regarding any of the changes or modifications?

A. (Henriksen) Yes. LILCO's testimony indicates that the replacement block has a greater cold clearance gap between the cylinder liner and the cylinder block. This change is not reflected in block drawing #03-315-05-AD. However, we understand from a TDI (R. Johnston) letter dated May 4, 1984, to Stone & Webster Engineering Corporation that TDI has recommended this change be made to the cylinder liners. (The TDI letter is Exhibit 6 of this testimony.)

Q. As a design, do you believe the EDG 103 replacement cylinder block inadequately proven?

A. (Henriksen) No. We have compared drawing #03-315-05-AD of the replacement cylinder block with drawing #02-315-05-AW, which depicts the cylinder block for the R-5 prototype test engine. We found that, in the area affected by the changes, with the exception of the dimension regarding the cold gap clearance as mentioned earlier, the two drawings indicate the two cylinder blocks appear to be exactly alike. The R-5 cylinder block has been extensively tested at a load level higher than the EDG 103 will ever experience. Thus, we believe that, provided the R-5 cylinder block did not develop cracks during its extensive testing, as a design the EDG 103 cylinder block has been proven.

Q. Does the fact that the R-5 is a V-engine and the EDG 103 is an inline engine in any way enter into your evaluation when comparing the two cylinder block designs?

A. (Henriksen) Yes. However, for the area of interest there is no difference in cylinder block design between a V-engine and an inline engine.

Q. Have you drawn any final conclusion regarding the EDG 103 replacement cylinder blocks?

A. (Henriksen) Yes. Provided preoperational inspection reveals no cracks between studs from adjacent cylinders or in the camshaft gallery, and provided inspections for cracks are conducted after each operation, the EDG 103 replacement cylinder block is considered suitable for operation through to shutdown for the first refueling.

CYLINDER HEADS

Contention

The replacement cylinder heads on the Shoreham EDGs are of inadequate design and manufacturing quality to withstand satisfactorily thermal and mechanical loads during EDG operation, in that:

a. the techniques under which the replacement cylinder heads were produced have not solved the problems which caused the cracking of the original cylinder heads on the Shoreham EDGs;

b. the "barring over" surveillance procedure to which LILCO has committed will not identify all cracks then existing in the replacement cylinder heads (due to symptomatic water leakage);

c. the nature of the cracking problem and stresses exacerbating the cracks are such that there can be no assurance that no new cracks will be formed during cold shutdown of the EDGs;

d. there can be no assurance that cracks in the replacement cylinder heads and concomitant water leakage occurring during cold shutdown of the EDGs (which would not be detected by the barring-over procedure) would not sufficiently impair rapid start-up and operation of the EDGs such that they would not perform their required function;

e. there can be no assurance that cracks in the replacement cylinder heads occurring during operation of the EDGs would not prevent the EDGs from performing their required function;

f. variations in the dimensions of the firedeck (and waterdeck) of the replacement cylinder heads create inadequate cooling, where too thick, and inadequate resistance to mechanical loads, where too thin, and create stress risers at their boundaries;

g. the design of the replacement cylinder head is such that stresses are induced due to non-uniform bolt spacing [and the different lengths of the bolts];

[h. the replacement cylinder head design does not provide for adequate cooling of the exhaust valves;]

i. at least one replacement cylinder head at Shoreham has an indication;

[j. the design of the replacement cylinder heads provides inadequate cooling water for the exhaust side of the head];

k. the replacement cylinder heads at Shoreham were inadequately inspected after operation, because:

1. a liquid penetrant test was done on the exhaust and intake valve seats and firedeck area between the exhaust valves on only nine of 24 cylinder heads, and such tests were done after only 100 hours of full power operation;

2. ultrasonic testing was done on the firedeck areas of only 12 cylinder heads;

3. visual inspections were performed on the valve seat areas of only 32 of the 98 valves, and on only seven firedecks of the 24 cylinder heads for indications of surface damage.

Q. Have you reviewed the testimony filed by the County on July 31, 1984, in support of its contentions regarding the cylinder heads in these proceedings?

A. (Henriksen, Sarsten) Yes.

Q. Are there any portions of the County's contentions that are not addressed in the County's testimony?

A. (Henriksen, Sarsten) Yes. The bracketed portions were not addressed in the County's testimony, as noted on page 61 of that testimony.

Q. Have you reviewed the testimony filed by LILCO on August 14, 1984, which concludes that:

1. There is reasonable assurance that leakages will not occur in the new cylinder heads because of: (i) improved casting techniques, (ii) the application of stress-relief techniques, and (iii) additional and more frequent inspections of the heads.

2. The replacement cylinder heads are adequately designed, since (i) the ranges and dimensions of the firedeck provide for adequate cooling of the firedeck and adequate resistance to mechanical loads; (ii) stress risers are not created at their boundaries; and (iii) non-uniform bolt spacing has no effect on stresses in the cylinder head.

3. The successful operating history of the new heads demonstrates that the new heads should not develop leaks.

4. Even if cylinder head leakage should occur during operation of the engine, it will be detected.

5. Leakage will not initiate after shutdown because leaks of cylinder heads will not develop when the diesel engines are in a standby condition and, in any event, such leakage would be detected by LILCO's barring-over procedure.

6. Even if leakage of the cylinder heads were to develop during standby or go undetected during operation, resultant leakage will not impair the rapid start capability of the diesels.

7. Even in the unlikely event that a new cylinder head were to leak during operation, the leakage will not impair the operation of the diesel engines.

8. None of the replacement cylinder heads at Shoreham has any relevant indications.

9. The replacement cylinder heads were adequately inspected because the heads were subjected to (i) a 100% factory inspection by TDI which was audited by LILCO, (ii) additional pre-operational inspection by the NRC, and (iii) post-operational inspections including liquid penetrant tests on 10 cylinder heads, ultrasonic testing on 13 firedeck areas, and visual inspections on 7 firedecks.

A. (Henriksen, Sarsten) Yes.

Q. Please summarize your conclusions regarding the cylinder heads.

A. (Henriksen, Sarsten) A summary of our conclusions is as follows:

- On the basis of known operating experience with TDI heads, problems in service are indicative of manufacturing defects rather than design deficiencies. Of course, the design of the heads affects the complexity of manufacture, which, in turn, affects the capability of the foundry to produce castings free of unacceptable defects. However, operating experience does not suggest that the design itself is inherently deficient.

- In the absence of further evidence of their reliability, cylinder heads with any through-wall weld repair of the firedeck should not be placed in nuclear standby service if the weld repair is performed from one side only. The coolant side of the firedeck is not readily accessible for weld repair. Without such access, a repair from the combustion side might leave defects on the coolant side that would be difficult to detect, and that might compromise the integrity of the head.

- The following inspections should be completed at Shoreham on <u>all</u> cylinder heads before the engines are placed in nuclear standby service:
  - ultrasonic inspection of the entire firedeck to verify that the minimum thickness requirement (0.400 inch) is met
  - surface inspection (i.e., liquid penetrant or magnetic particle) of the firedeck and the valve seats to verify that they are free of unacceptable surface defects.
- Each time an engine is operated, it should be rolled over with the air-start system to detect for coolant leaks into the cylinders at least 4 hours, but not more than 8 hours, after engine shutdown. A second rollover should be performed in the same manner approximately 24 hours after shutdown. In addition, the engine should be rolled over immediately prior to any planned start.
- Subject to the above comments on weld repairs, inspection, and surveillance, the cylinder heads are considered to be adequate for nuclear service for one refueling cycle.

Adequacy of Design and Manufacture

Q. Have you reviewed the evaluation by Failure Analysis Associates of thermal and pressure stresses in the cylinder heads, which is presented in the FaAA report titled Evaluation of Cylinder Heads of Transamerica Delaval Inc. Series R-4 Diesel Engines?

A. (Henriksen, Sarsten) Yes.

Q. Have you reached any conclusions on the basis of FaAA's evaluation?

A. (Henriksen, Sarsten) No. The flat-plate model used in the FaAA evaluation of thermal and pressure stresses does not, by itself, provide an adequate basis for confirming the design adequacy of the cylinder head, which is much more complex than the model.

Q. Have you any reason to believe that the replacement cylinder head design provides inadequate cooling of the exhaust valves?

A. (Henriksen, Sarsten) No. There is no failure history in evidence to support this claim.

Q. Have you any reason to believe that the replacement cylinder heads provide inadequate cooling water for the exhaust side of the head?

A. (Henriksen, Sarsten) No. There is no failure history in evidence to support this claim.

Q. Have you reviewed the component history of the R-4 cylinder head presented in the FaAA report on this component and in the LILCO testimony?

A. (Henriksen, Sarsten) Yes.

Q. What conclusions have you drawn from that review?

A. (Henriksen, Sarsten) We concur that the changes made in the manufacture of the cylinder heads from those classified as "Group I" (cast prior to October 1978) through "Group III" (cast after September 1980) should improve the reliability of the heads. Operating experience cited in these reports confirms that the changes have made the heads more reliable.

Q. From which group are the heads that are currently installed at Shoreham?

A. (Henriksen, Sarsten) We understand from the LILCO testimony and the FaAA report that all of the heads currently installed are from Group III.

Q. Do you believe that the operating experience is sufficient to conclude that Group III heads will not develop cracks through which coolant could leak into the cylinders?

A. (Henriksen, Sarsten) No. While we agree with LILCO that the Group III heads are superior to heads from Groups I and II, we do not believe that the operating experience with Group III is sufficient to demonstrate that leakage cracks are unlikely to form. Therefore, for precautionary purposes, it is our opinion that the heads should be checked for leakage via the rolling-over procedure described in the summary of our conclusions on this component.

LILCO'S "Barring Over" Surveillance Procedure

Q. Have you reviewed LILCO's procedure for barring-over the engine?

A. (Henriksen, Sarsten) We have reviewed LILCO's Exhibit H24 titled "Emergency Diesel Generator Cylinder Head Leak Detection Test," SP Number

27.307.02, Rev. 2, dated January 18, 1984. This procedure calls for turning the engine over 4 hours and 12 hours after shutdown, using the barring-over device. It also calls for turning the engine over 24 hours after shutdown, using the air-start system.

Q. Do you consider this procedure adequate?

A. (Henriksen, Sarsten) No. Water may not be detected when the engine is rolled with the barring-over device, because of the slow rotational speed. The air-start system rolls the engine much more rapidly, and is mandatory for detection of water leakage because the higher rate of compression will vaporize any water in the cylinder and the vapor will be very noticeable when it is expelled through the indicator cocks. Therefore, we recommend that the surveillance for water leakage be conducted only with the air-start system.

Crack Formation During Cold Shutdown

Q. What is your opinion on the propagation of cracks in a cylinder head and/or the formation of new cracks during cold shutdown?

A. (Henriksen, Sarsten) If a crack, through which water could leak into a cylinder, does not open sufficiently for the water to be detected 24 hours after engine shutdown, it is highly unlikely, in our opinion, that the crack will propagate to the degree that water would leak before the next engine startup. Similarly, we believe it is highly unlikely that a new crack that might leak water would remain undetected after 24 hours and then leak before the next startup. However, we recommend that the engine be rolled over to detect water leakage immediately preceding any planned start, to ensure that no leakage has occurred.

Q. Do you believe that corrosion products in a cylinder head crack could cause the crack to propagate or grow after engine shutdown?

A. (Henriksen, Sarsten) No. We agree with LILCO's testimony on this subject (Volume 1, page 77 of LILCO's testimony "...Regarding Cylinder Heads on Diesel Generators at Shoreham") that corrosion products within a crack will tend to plug the crack, and that no technical foundation exists to suggest that low-strength carbon steels (of the type used in the Shoreham cylinder heads) are susceptible to corrosion product crack wedging.

Effects of Undetected Leakage on Rapid Start Capability

Q. Could leakage undetected by the barring-over procedure affect rapid start capability?

A. (Henriksen, Sarsten) It is our opinion that, if rolling-over procedures are performed with the air-start system, leakage undetected after 24 hours will not be sufficient to impair rapid start capability. In a test described by LILCO on page 83 of the above-referenced testimony and documented in Exhibit H-26 of that testimony, water in an amount that occupied 98% of the clearance volume of the piston was intentionally placed in a cylinder. According to LILCO, this water did not affect rapid start capability, nor did it adversely affect the head studs or gaskets. This reinforces our opinion that leakage undetected as described above will not impair rapid startup.

Effects of Cracks Occurring During Engine Operation

Q. Could cracks that might occur during engine operation prevent the EDGs from performing their required function?

A. (Henriksen, Sarsten) No. Since the cylinder pressure far exceeds the water jacket pressure, in the event a crack were to develop during engine operation it is unlikely that coolant would enter the cylinder. It is much more likely that the combustion gases would leak into the coolant. This would cause noticeable pulsations in the coolant pressure, which would be noticeable on the applicable gage in the control room but would not lead to engine shutdown nor impair engine performance. In the very unlikely event coolant were to leak into the cylinder during operation, it would be turned to vapor and exit with the exhaust gases. Accordingly, it is highly unlikely that coolant would leak in any amount that would impair lubrication in the cylinder or cause seizure or fracture of the piston.

Effects of Variations in the Dimensions of the Firedeck

Q. Are the maximum firedeck thicknesses measured on the Shoreham cylinder heads large enough to cause inadequate cooling?

A. (Henriksen, Sarsten) It is our understanding that the maximum firedeck thickness measured on the Shoreham cylinder heads is 0.881 inch. Since the thermal resistance of the metal is not the controlling thermal resistance for the combustion gas-to-water-side heat transfer, the reported overthickness of the firedecks will have no significant effect on the amount of cooling.

Q. Are the minimum firedeck thicknesses measured on the Shoreham cylinder heads small enough to create stress risers at their boundaries?

A. (Henriksen, Sarsten) The minimum firedeck thickness reported at Shoreham is 0.460 inch in an area of nominal 0.500-inch thickness. This 8% decrease in thickness is not felt to cause unacceptable reduction in cylinder head strength or stiffness. None of the reported failures for Group II and III cylinder heads indicates that the reduction in strength due to reduced thickness is a concern.

Stresses Induced Due to Nonuniform Bolt Spacing

Q. In your opinion is the nonuniform bolt spacing on the cylinder heads likely to create any serious problems?

A. (Henriksen, Sarsten) No. Nonuniform cylinder head bolt spacing is common practice for most diesel engine manufacturers building both V and inline engines of identical bore and stroke. There is no evidence that the nonuniform bolt spacing has been the cause of any damage of the kind that would necessitate an engine to be shut down.

Indication Found in a Replacement Cylinder Head

Q. Is the 3/8-inch long indication found in cylinder head S/N H-34 in an area of concern?

A. (Henriksen, Sarsten) No. Referring to LILCO Exhibit H15, the 3/8-inch indication found on cylinder head S/N H-34 is located in one of the plates welded onto the side of the head and not in the firedeck. Even if this indication were to propagate through the plate, it could not provide a path for leakage of coolant into the cylinder.

Adequacy of Inspection of Replacement Cylinder Heads After Operation at Shoreham

Q. Did you review the testimony regarding the nondestructive testing performed on the cylinder heads at Shoreham after 100 hours of operation at full load?

A. (Henriksen, Sarsten) Yes.

Q. The County contends that the replacement cylinder heads at Shoreham were inadequately inspected. Do you agree?

A. (Henriksen, Sarsten) Yes, but only because not all of the cylinder heads were inspected.

Q. Do you agree with the testimony of Youngling, Seaman, Kammeyer, and Wells (Vol. 1, page 94 of LILCO's testimony "...Regarding Cylinder Heads on Diesel Generators at Shoreham") that "...results of these inspections provide the required level of assurance that operational stresses will not induce cracking, and support FaAA's conclusions that the cylinder heads at Shoreham are qualified for unlimited operation."?

A. (Henriksen, Sarsten) Not entirely. The 100 hours of operation at full load was surely a step in the right direction. However, adequacy of an unverified design must be established using a data base of many hundreds or thousands of hours. The testing at Shoreham is only one point in that data base.

Q. What then, is the conclusion you can draw from this testing?

A. (Henriksen, Sarsten) The principal conclusion is that there is a high probability that there are currently no cracks that could leak water into the cylinders.

Q. Could cracks develop?

A. (Henriksen, Sarsten) Perhaps, but without the existence of an adequate data base it would be impossible to say definitively. However, if such cracks would occur, they would most certainly be detected by the proposed barring-over procedure.

Q. What further testing should be done, then, to qualify these heads for unrestricted operation?

A. (Henriksen, Sarsten) A statistical sampling inspection program should be established that would build up a data base over several thousand hours of operation. These inspections could be performed on the Shoreham engines and other TDI engines in nuclear service after each fuel cycle or during other maintenance periods.

Q. Have you drawn any final conclusions regarding the cylinder heads on the three EDGs at Shoreham?

A. (Henriksen, Sarsten) Yes. Provided preoperational inspections of the firedecks of all cylinder heads reveal no significant indications, the heads used have no through-wall weld repairs of the firedeck, and proposed surveillance procedures using the air-start system are followed to detect coolant leakage into the cylinders after each time an engine is operated, we conclude that the cylinder heads on the three EDGs at Shoreham are suitable for operation through to the shutdown for the first refueling.

PISTON SKIRTS

Contentions

All AE 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, therefore, causing a failure of proper operation.

Q. Have you reviewed the testimony filed by the County on July 31, 1984, in support of its contentions regarding the pistons in these proceedings?

A. (Henriksen, Sarsten) Yes.

Q. Have you reviewed the testimony filed by LILCO August 14, 1984, on AE piston skirts which concludes 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 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.

A. (Henriksen, Sarsten) Yes.

Q. Please summarize your conclusions regarding the piston skirts.

A. (Henriksen, Sarsten) Our testimony, in summary, is that, provided a 100% inspection proves the piston skirts to be free of defects, the piston skirts will be suitable for operation through to shutdown for the first refueling.

Q. Have you reviewed the FaAA analysis (FaAA-84-2-14 dated May 23, 1984, included as Exhibit 8 of the County's testimony) which concludes that AE piston skirts may or may not develop cracks, but if cracks initiate, they will not propagate?

A. (Henriksen, Sarsten) Yes.

Q. Have your drawn any conclusions from your review of the FaAA analysis with regard to crack initiation in the piston skirts?

A. (Henriksen, Sarsten) No. The area in question is of intricate design, and some of the determining values, although claimed to be conservative, are admittedly assumed. As stated in the conclusions of the FaAA report (page 8-1), the analysis is inconclusive as to whether cracks will initiate or not.

Q. Have you drawn any conclusions from your review of the FaAA analysis with regard to crack growth if cracks are initiated in the piston skirts?

A. (Henriksen, Sarsten) No. Since the analysis of crack growth is based largely on the same input data as was the crack initiation analysis, we have been unable to draw a firm conclusion regarding whether or not cracks that might initiate will grow.

Q. Have you reviewed the operating experience presented by LILCO as relevant to AE piston skirts?

A. (Henriksen, Sarsten) Yes. We have reviewed LILCO's testimony and the FaAA report on this subject.

Q. Have you had occasion to personally see some AE piston skirts that have been in operation?

A. (Henriksen) Yes. I had occasion to see AE piston skirts at both Grand Gulf (16 skirts) on June 4 and June 5, 1984, and Shoreham (8 skirts) on May 23, 1984.

Q. To the best of your knowledge, did any of the piston skirts you have seen show any indication of cracks?

A. (Henriksen) No. At Shoreham the pistons were assembled, so the contested areas could not be viewed. At Grand Gulf, however, I viewed all 16 pistons of the Division I engine, and no indications were evident. These 16 pistons had been inspected earlier, and no indications were reported.

Q. Do you consider all evidence of operating experience with AE piston skirts of equal importance?

A. (Henriksen, Sarsten) All evidence of operating experience is important. However, some is more relevant than others. For instance, experience obtained at a high load level is obviously more relevant to future operation at Shoreham than experience obtained at a relatively low load level.

Q. Is there any piston skirt experience presented that is of special significance for the process of evaluating the performance of the AE piston skirts?

A. (Henriksen, Sarsten) Yes. According to LILCO's testimony on piston skirts (Vol. 1, page 56), two AE skirts from the TDI prototype R-5 engine were inspected by FaAA after approximately 622 hours of operation at 2000 psi maximum cylinder pressure. The inspections revealed no relevant indications.

Q. What, if any, are the differences between the operating parameters of the R-5 engine and the Shoreham engines?

A. (Henriksen, Sarsten) Other than the higher load of the R-5 engine, the only other difference we are aware of is that the R-5 was operated at 514 rpm, while the Shoreham engines are operated at 450 rpm.

Q. What effect does the difference in rpm between the R-5 engine and the Shoreham engines have upon the evaluation of the piston skirts?

A. (Henriksen, Sarsten) Very little. All other conditions being equal, there will be an increase in inertia due to the increase in speed from 450 rpm to 514 rpm. This will decrease the effective load on the pistons accordingly. However, this slight decrease in effective load does not alter the fact that, for an extended period, the two AE piston skirts from the R-5 engine experienced loads in excess of any which the Shoreham piston skirts will ever experience.

Q. Are the AE piston skirts as installed in the R-5 engine dimensionally the same as the AE piston skirts installed in the Shoreham engines?

A. (Henriksen, Sarsten) No. A study of TDI drawings #03-341-04-AE (R-5 piston skirt) and #03-341-04-AE (Shoreham piston skirt) reveals no differences externally or in the critical areas around the stud holes. However, inside the piston skirt in the area of the wrist pin boss, piston skirt #03-341-04-AE (Shoreham piston skirt) appears strengthened as compared to piston skirt #03-341-04-AE (R-5 piston skirt).

Q. Do you consider the differences between the piston skirts installed in the R-5 engine and those installed in the Shoreham engines to be significant in evaluating the applicability of the operating experience in the R-5 engine?

A. (Henriksen, Sarsten) No. If anything, the piston skirts installed in the Shoreham engines appear to be superior to those installed in the R-5 engine.

Q. Are you familiar with the term "piston skirt side thrust load"?

A. (Henriksen, Sarsten) Yes.

Q. Do you consider the County's contention regarding excessive side thrust to be a matter of concern for pistons installed in the engines at Shoreham?

A. (Henriksen, Sarsten) No. In our experience with medium-speed, high brake mean effective pressure, 4-cycle engines, piston skirt side thrust has never been a problem in piston skirt design.

Q. In your opinion would the AE piston skirt be considered unique in design for diesel engines of this size, speed, and load requirements that would make it vulnerable to excessive side thrust load?

A. (Henriksen, Sarsten) No. Through Ricardo Consulting Engineers, Ltd., Shoreham-by-Sea, England, consultants to PNL, we have available a tabulation (page 5 of Exhibit 7 enclosed with this testimony) accompanied by a sketch (page 7, Exhibit 7), of seven piston skirts, made by different manufacturers. The tabulation includes cylinder bore, data to accurately locate the wrist pin in the piston skirt, maximum firing pressures, and rated BHP/cylinder. The data clearly indicate that there is no drastic difference in design criteria and operating conditions between the AE piston skirts and the other six piston skirts represented in the tabulation. Furthermore, the data indicate that the side thrust load likely to be experienced by the AE piston skirt will be representative of what is demanded of piston skirts in medium-speed, high BMEP diesel engines today.

Q. Are you aware that the AE piston skirts at Shoreham are tin-plated?

A. (Henriksen, Sarsten) Yes.

Q. Do you know why tin plating is applied on piston skirts?

A. (Henriksen, Sarsten) We can see two reasons. One reason would be for conservation purposes, i.e., to prevent iron skirts from rusting during storage and transit, etc. This would likely be a minimal coating and considered sacrificial when running the engine. The second reason would be to assist in the initial break-in period.

Q. Have you any opinion as to how thick the tin plating of the piston skirts should be in order to assist in the initial break-in?

A. (Henriksen, Sarsten) This becomes a matter of judgment. The operating conditions enter into this judgment. Assuming no problems are experienced with lube oil coking on the piston crown and in ring grooves, the fuel the engine will have to burn becomes a major factor in deciding the tin plating thickness. For example, for gas-burning engines, a relatively heavy tin plate coating may be used. On the other end of the spectrum, a heavy fuel-burning engine which will have a fair amount of carbon particles passing by the piston rings down to the crankcase can tolerate only a thin coat of tin plating in order to minimize carbon embedding in the tin plating. We believe a tin plating thickness range of 0.001-inch to 0.0015-inch to be acceptable for piston skirts operating on a good grade number 2 diesel fuel.

Q. Do you know what the thickness of the tin plating is on the AE pistons?

A. (Henriksen, Sarsten) The drawing calls for plating of 0.003 inch on the diameter, which, if properly controlled during the electrolysis procedure, converts to 0.0015 inch on the radius.

Q. On your visit to Shoreham on May 23, 1984, did you have occasion to inspect the AE piston skirt exterior surfaces?

A. (Henriksen) Yes. I found signs of scuffing on most pistons. None of the scuffing, which was judged to be the result of carbon particles embedded in the tin plating, was judged to be serious. There were no signs of distress such as hot spots or discoloration indicating that the skirts had been overloaded.

Q. Did you also have occasion to inspect the cylinder liners for signs of scuffing?

A. (Henriksen) No. The cylinder liners were reportedly at TDI in Oakland, California, where they were to be installed in the new cylinder block.

Q. Have you drawn any final conclusion regarding the AE piston skirt?

A. (Henriksen, Sarsten) We have concluded that, on the basis of presently available information, the AE piston skirts will be suitable for nuclear service for one refueling cycle. This conclusion is based on the conditions that all pistons will be examined by dye penetrant in the area of the stud bosses and that the pistons are as represented by TDI drawing #03-341-04-AE.

ATTACHMENTS

WITNESSES' PROFESSIONAL QUALIFICATIONS

ATTACHMENT 1

Professional Qualifications

Carl H. Berlinger

Division of Licensing
Office of Nuclear Reactor Regulation
United States Nuclear Regulatory Commission

Education

B.S.	Mechanical Engineering, Clarkson College of Technology	1960
M.S.	Mechanical Engineering, Clarkson College of Technology	1962
Ph.D	Mechanical Engineering, University of Connecticut	1971

Current Position

Since January 1984, Dr. Berlinger has been the Group Manager of the TDI Project Group. In this position, he manages the activities of the Project Group Staff and coordinates the efforts of NRR and other offices, interfaces with industry and licensees, and, as appropriate, keeps the ACRS, hearing boards, and the Commission informed regarding the status and resolution of this issue.

Detailed Experience Record

September 1981 - January 1984

UNITED STATES NUCLEAR REGULATORY COMMISSION

Division of Systems Integration - Core Performance Branch

Branch Chief -

Duties included

1. Management of the activities of a branch engaged in the review, analysis and evaluation of calculational methods used by applicants for the licensing of nuclear power plants in the fuel and core design areas of reactor plant engineering.

2. Responsible for development and application, in conjunction with consultants, of independent calculational methods including complex computer codes for the analysis of fuel and reactor core performance during steady-state, transient, and accident conditions.

3. Participates as a technical specialist on various NRC committees, subcommittees, panels, task force assignments, and on technical, industrial and professional society committees.

4. Represents the Commission in dealings with other governmental departments and agencies, national laboratories, industry and industry organizations in discussion of complex technical matters in the areas of new or proposed reactor systems.

November 1980 - September 1981

UNITED STATES NUCLEAR REGULATORY COMMISSION

Division of Licensing - Systematic Evaluation Program Branch

Section Leader - Systems Engineering

Duties included:

1. Supervised senior technical staff in the Systems Engineering section.

2. Responsible for the analysis, evaluation and safety reviews in the areas of thermal hydraulics, physics, site hazards, and safety analyses aspects of the reactor core, primary and secondary plant systems, electrical and auxiliary systems.

January 1980 - November 1980

UNITED STATES NUCLEAR REGULATORY COMMISSION

Division of Licensing - Operating Experience Evaluation Branch

Branch Chief -

Duties included:

1. Organized newly formed branch; formulated goals and objectives.

2. Established procedures and significance criteria for systematic screening and technical review of domestic and foreign licensee event reports and operating experience reports, respectively.

3. Initiated staff reviews of significant licensee events.

4. Developed licensee event reporting requirements.

4. Responsible for making technical recommendations and formulating technical positions regarding standards, regulatory guides and codes as related to reactor safety.

August 1970 - September 1973

COMBUSTION ENGINEERING CORPORATION

Nuclear Power Division - Accident Analysis Department

Principal Safety Engineer -

Duties included:

1. Responsible for the development of analytical tools for analysis of LMFBR maximum hypothetical accidents.
2. Performed quality assurance of complex computer codes and plant safety analysis (including LOCA and plant transients).
3. Presented testimony before ACRS regarding the San Onofre Units 2 and 3 plants.
4. Developed a transient steam generator/superheater model for the once-through steam generator with integral economizer.

February 1969 - August 1970

UNIVERSITY OF CONNECTICUT

Mechanical Engineering Department

Graduate Teaching Assistant -

Duties included:

1. Taught undergraduate heat transfer course.
2. Designed, procured, constructed and operated all equipment and instrumentation required for Ph.D dissertation.
3. Administered a research budget of $20,000.

August 1961 -
February 1969

PRATT AND WHITNEY AIRCRAFT

Advanced Power Systems

Senior Analytical Engineer -

Duties included:

1. Planning and coordinating research and development of advance engineering products.
2. Analyzed heat transfer, thermodynamic and aerodynamic problems.
3. Supervised the design, manufacture, testing and evaluation of new design concepts.

ATTACHMENT 2

Professional Qualifications

Spencer H. Bush

Review and Synthesis Associates
630 Cedar
Richland, Washington 99352

Education

B.S.	Metallurgical Engineering, University of Michigan	1948
B.S.	Chemical Engineering, University of Michigan	1948
M.S.	Metallurgical Engineering, University of Michigan	1950
Ph.D.	Metallurgy, University of Michigan	1953

Employment

1940-42	Assistant Chemist, Dow Chemical Company
1942-46	U. S. Army (1944-46: Manhattan Project)
1951-53	Instructor, Dental Materials, U. of Michigan
1953-54	Senior Scientist, General Electric Company Hanford Atomic Products Operation (HAPO)
1954-57	Supervisor, Physical Metallurgy, General Electric HAPO
1957-60	Supervisor, Fuels Fabrication Development, GE/HAPO
1960-63	Metallurgical Specialist, General Electric HAPO
1963-65	Consulting Metallurgist, General Electric HAPO
1965-70	Consultant to the Director, Battelle-Pacific Northwest Laboratories
1970-83	Senior Staff Consultant, Battelle-Pacific Northwest Laboratories
1983-	President, Review and Synthesis Associates, Richland, WA
1968-	Affiliate-Adjunct Professor, Metallurgical Engineering--Joint Center for Graduate Study, University of Washington, Washington State University, Oregon State University
1973-74	Regents Professor, University of California, Berkeley

Affiliations (active only)

U.S. Nuclear Regulatory Commission Advisory Committee on Reactor Safeguards (Member 1966-1977, Consultant 1978-)
Executive Committee, Welding Research Council Pressure Vessel Research Committee
Member, ASME Section XI Subcommittee on Nuclear Inservice Inspection
Executive Board, ASME NDE Engineering Subdivision
U. S. Representative, OECD PISC-II Managing Group
Chairman, Washington State Board of Boiler Rules
Sigma Xi
Tau Beta Pi
Phi Kappa Phi

Society Memberships

Fellow, American Nuclear Society
Fellow, American Society for Metals
Member, American Institute of Mining, Metallurgical and Petroleum Engineers
Fellow, American Society of Mechanical Engineers
Member, National Academy of Engineering

Awards and Honors

National Academy of Engineering 1970
Regents Professor, University of California, Berkeley 1973-74
ASTM Gillett Lecturer 1975
ASNT Mehl Lecturer 1981
ASME Certificate, Boiler and Pressure Vessel Code
ASME Bernard F. Langer Award 1983

Licenses

Registered Professional Engineer, Metallurgical Engineering-267 and Nuclear Engineering-292, State of California

Author or co-author of one book, 16 chapters in books, 30 journal articles and numerous other documents and technical papers.

Summary of Current Areas of Expertise

Consultant on materials and safety with particular emphasis on environmental effects such as stress corrosion and radiation damage as they affect material properties and component design in nuclear reactors. Scientific contributions have been primarily in the physical and mechanical metallurgy of nuclear materials. Specific experimental work has been in temper embrittlement of steels. Work in reactor materials included kinetics studies of oxidation in zirconium alloys, effect of fabrication variables on properties of zirconium alloys, irradiation effects in uranium alloys and reactor structural materials, and stress corrosion. Substantial work has been done in reactor safety, particularly on failure mechanisms in pressurized systems.

A major role has been in the synthesis of available information to develop a coherent picture of the relative roles of materials, fabrication and nondestructive examination on the reliability of nuclear components. Based on such a synthesis of data generated throughout the world, it is possible to suggest changes leading to an improvement in reliability with a comparable improvement in system safety. Consulting on special assignments has become increasingly significant since 1978 for both government and private organizations. Typical activities have been in the areas of component reliability, seismic design of pressure boundary components, seismic fragility values, reactor system reliability under faulted conditions, turbine reliability and valve performance.

ATTACHMENT 3

Professional Qualifications

Adam J. Henriksen

Adam J. Henriksen, Inc.
Diesel Consultants
7731 N. Fairchild Road
Fox Point, Wisconsin 53217

Education

Horten High School, Horten, Norway
Graduated in 1934

Royal Norwegian Naval Academy, Engineering Branch
Graduated in 1940

American Management Association (four weeks)
General Management Course 1968-1969

Service Record

Royal Norwegian Navy
Midshipman Engineer 1937-1940
Engineering Officer (Lieutenant S.G. at time of discharge) 1940-1946

Societies and Registrations

The American Society of Mechanical Engineers, Member
Registered Professional Engineer in the State of Wisconsin

Publications

A.S.M.E. Paper Number 60-WA-185, "Supercharging of a Large Two-Cycle, Loop-Scavenged Diesel Engine"

Experience

May 1980 to Date	Consulting Engineer, Diesel Engines
March 1975 - May 1980	Rexnord Inc. Nordberg Machinery Group, Process Machinery Division Milwaukee, Wisconsin

March 1975 - May 1980	<u>Manager, Service Department</u> Responsible to Division Customer Service Manager for all phases of installing and servicing the Company's product lines of crushers, screens, mills and hoists. Further responsible for all administration of up to 24 authorized repair facilities.
November 1953 - March 1975	<u>Rexnord Inc. Nordberg Machinery Group, Power Machinery Division</u> Milwaukee, Wisconsin
September 1966 - March 1975	<u>Manager, Test and Service Department</u> Responsible to Division General Manager for all phases, inclusive financial and contracting, involved in testing, installing and servicing the company's line of diesel engines and gas turbines. The department consisted of five subsections.
September 1965 - September 1966	<u>Chief Field Engineer</u> Responsible to Manager, Test and Service Department for all field testing, including field R/D work on the company's line of diesel engines. Further responsible for solving problems arising in the field, and for reducing no-charge costs resulting from problems occurring in the field as well as in the factory.
February 1964 - September 1965	<u>Assistant Chief Engineer</u> Responsible to the Chief Engineer for Administrative and Technical leadership of the Engineering Department's R/D and Application groups. Further served as head of a group consisting of shop, service, and engineering personnel for the purpose of solving problems and reduce no-charge costs.
May 1963 - February 1964	<u>Head, Application Engineering</u> Responsible to the Chief Engineering for the Administrative and Technical leadership of the Engineering Department's Application group. This entailed stationary, marine, electrical, and automatic control application engineering.
1961 - 1963	<u>Head, R/D Department</u> Responsible to the Chief Engineer for the Administrative and Technical leadership of the Engineering Department's R/D group. During this period the group was heavily engaged in R/D work required to upgrade the company's line of four-cycle diesel engines including conducting tests on heavy fuel on these engines.
1955 - 1961	<u>Senior R/D Engineer</u> Project Engineer in charge of supercharging the company's line of two-cycle diesel, duafuel and spark-fired engines. The commercial rating of the entire product line increased by over thirty percent.

1953 - 1955 Marine Project Engineer
Marine Project Engineer, planning and drawing in connection with marine installations. Calculating and specifying auxiliary equipment pertaining to above installations.

1952 - 1953 Yarrows, Ltd., Shipbuilders & Engineers, Victoria, B. C. Canada
Position and duties as for above.

1950 - 1952 Messrs. Zetlitz-Nilsson, Ziegler and Bang, Marine Consulting Engineers, Oslo, Norway
Marine Superintendent Engineer, planning of new vessels, examination of building specifications and drawings, charge of supervision of ships in service, examination of engineering reports, etc., prepare detailed specifications for tenders in connection with repairs and class surveys of ships.

1947 - 1950 Messrs. Harland & Wolff, Ltd., Shipbuilders and Engineers, Glasgow, Scotland
Test and Guarantee Engineer, testing marine propulsion and auxiliary diesel engines in the manufacturer's plant, supervising marine machinery installations and sea trials at home and abroad. Guarantee Engineer aboard three vessels for a total of twenty months.

1946 - 1947 Fred Olsen, Ship Owner, Oslo, Norway
First Assistant Engineer aboard S/S EK.

1937 - 1946 Please refer to service record

1936 - 1937 Wilhelm Wilhelmsen Lines, Ship Owner, Oslo, Norway
Apprenticeship required for entrance to the Royal Norwegian Naval Academy. Shipboard duties.

1934 - 1936 Horten Naval Yard, Horten, Norway
Apprenticeship required for entrance to the Royal Norwegian Naval Academy. Machine Shop practice.

ATTACHMENT 4

Professional Qualifications

Walter W. Laity

PNL Project Manager
Diesel Engine Operability/Reliability Project
Battelle, Pacific Northwest Laboratory

Education

B. S. Mechanical Engineering, University of Washington
M. S. Mechanical Engineering, Oregon State University
Ph.D. Mechanical Engineering, Oregon State University

Experience

Dr. Laity joined the staff of Battelle-Northwest in November 1974. His academic background and experience are primarily in the fields of the thermal sciences, transport phenomena, and advanced energy conversion systems.

Dr. Laity served a 5-year tour of duty (1962-1967) as a Naval officer in the headquarters organization of the Naval Nuclear Power Program, where he was involved in the engineering of machinery for Naval nuclear propulsion plants. Machinery for which he was responsible included propulsion and auxiliary turbines, reduction gears, condensers, heat exchangers, propeller shaft bearings, pumps, blowers, air conditioners, and distilling plants. During the last 3 years of that assignment, he was a technical leader for the design, manufacture, testing, and installation of steam plant components of a new design Naval nuclear plant.

Dr. Laity has gained significant additional experience at Battelle as a technical contributor, project manager, and manager of an R&D section of 38 people. His attention has been focused on fundamental and applications-oriented research in the fluid and thermal sciences, and the application of these disciplines to the evaluation and development of energy systems for both well-established and new technologies.

Professional Registration

Registered Professional Engineer, Oregon, No. 7440.

Professional Affiliations

American Society of Mechanical Engineers
Accreditation Board for Engineering and Technology (ASME Visitor)
Sigma Xi

ATTACHMENT 5

Professional Qualifications

Arthur Sarsten

Professor of Internal Combustion Engines
The Norwegian Institute of Technology (NTH)
7034 Trondheim, Norway

at

Division of Combustion Engines and
Marine Engineering, Marine Technology Center
Department of Marine Technology
Hakon Hakonsons gt34
N-7000 Trondheim, Norway

Practical Training

1942 - 1945 Apprentice, A/S Wichmann, Rubbestadneset, Norway. Machine shop work in engine factory in various lathes, drill presses, shaping etc. One year in diesel engine assembly work.

Education

- 1939 N.Y. Public Schools + 1 Year High School
1940 - 1945 Voss off. Landsgymnas, Voss, Norway
1949 - 1953 The Norwegian Institute of Technology, Trondheim, Norway. B.Sc. in Mechanical Engineering, diploma thesis in I.C. Engines.

1958 - 1960 Renesselaer Polytechnic Institute, Troy, N.Y. Post graduate work evenings, later full time. M.Sc. in ME 1960.

1960 - 1963 R.P.I., Troy, N.Y. full time. Thesis in field of nonlinear vibrations D.Sc. 1963.

Memberships

Society of Automotive Engineers
American Society of Mechanical Engineers
The Institute of Marine Engineers
The Royal Norwegian Society of Sciences and Letters
The Norwegian Academy of Technical Sciences

Experience

1954 - 1959 Wichmann Motorfabrikk A/L, Rubbestadneset, Norway (Manufacturer of two-stroke marine diesel engines up to ca.

2500 bhp.) Position would correspond to project engineer for AC type (280 x 420 mm). Design, calculation and follow-up to production stage of this type of loop-scavenged engine and hydraulic c.p. propeller units. Supervision of 1-2 detail draftsmen.

1958 - 1960 ALCO Products Inc., then at Schenectady, N.Y. Calculation of stress and vibrations in engine components. Cam design and dynamics. R&D work accumulator fuel injection.

1963 - 1964 Gebr. SULZER, Winterthur, Switzerland. Mainly 2-stroke diesel engines. Design calculator rotating through various departments. Design of cams and related computer programming, FORTRAN II for IBM 1620. Balancing and torsional vibration calculation, some test bed work.

1964 - 1978 Professor of Internal Combustion Engines, The Norwegian Institute of Technology, Trondheim, Norway, and head, Division of I.C. Engines (Institutt for forbrenningsmotorer) staff ca. 20. Also research and consultant work, mainly for foreign engine firms. Engaged in computer work FORTRAN IV, UNIVAC 1107-1108. We have been active in engine dynamics, valve dynamics, torsional vibrations, thermal loading problems, use of finite element technique for temperature and stress field calculations, sale of TESTRAN FEM-package to various engine and component firms. Lab does radioactive wear tests, bearing work, consumer tests and research on outboard engines. Headed Norwegian Large Bore Research Project 1965 - 1968 ($200 000,-) for research on thermal damage on certain crosshead engines. Awarded (with 3 co-authors) The Herbert Ackroyd Stuart Award 1968'9 from The Institute of Marine Engineers for paper reporting results of this research.

1971 - 1973 Dean, Department of Mechanical Engineering, Norwegian Institute of Technology. 14 Divisions, ca. 600-700 students.

1974 Prof. invité, Départment de génie mécanique, Université de Sherbrooke, Canada.

1978 - present Professor of Internal Combustion Engines, Division of Combustion Engines and Marine Engineering, at the new Marine Technology Center. Staff approx. 40. Head of Division 1978 - 1980, (rotates).

1983 - 1984 Visiting professor at Lawrence Berkeley Laboratory, One Cyclotron Road, Berkeley, CA 94720.

<u>Partial List of Relevant Publications</u>

Sarsten, A. "A Computer Programme for Damped Torsional Vibrations Using a Complex Holzer Tabulation", European Shipbuilding No. 6. 1962. Vol. XI, p. 138-146.

Sarsten, A., Valland, H. "Computer-aided Design of Valve Cams." Int. Comb. Engines Conf., Bucharest 1967, Paper 11-19, p. 761-786.

Fiskaa, G., Iversen P., Sarsten, A. "Computer calculation of stresses in axi-symmetric thermally loaded components." Inst. of Mech. Engineers Symposium Computers in I.C. Engine Design, Manchester. April 1968, Proc. 1967-68, Vol. 182, Part 3L, p. 152-168.

Sarsten, A., Hansen, A, Langballe, M., Martens, O. "Thermal Loading and Operating Conditions for Large Marine Diesel Engines." IMAS69 Conference, London, Sect. 4, p. 38-49. Given Herbert Ackroyd Stuart Award 1968'9 by The Institute of Marine Engineers.

Hansen, A., Rasmussen, M., Sarsten, A. "Thermal Loading of Diesel Engine Components and Its Prediction." Paper A30, 9th Intern'l Congress on Combustion Engines (CIMAC) Stockholm, Sweden 1971, 25 pp.

Wacker, E., Strecker, E., Sarsten, A., Haaland, E. "Finite Element-Programme zur Berechnung von Brennraum-Bauteilen", Motortechnische Zeitschrift (MTZ) 32. Nr. 8, Aug. 1971, p. 267-279.

Sarsten, A., Holth, T., Øvbrebo, A. "A Method for Direct Solution of Steady-State Forced Vibration of Linear Systems." ASME paper 13-DGP-12, presented at Diesel and Gas Engine Power Conf. Washington, D.C. April 1973.

Sarsten, A. "Massekrefter og massemomenter ved stempelmaskiner. (Inertia forces and moments in piston engines). 176 pp., Tapir Forlag, Trondheim, 1968.

Sarsten, A. "A Direct Method for Calculating the Steady-State Vibration of Marine Shafting Systems." Report IF/R15, Div. of I.C. Engines, NTH, Trondheim, 1974.

Valland, H., Sarsten, A. "Application of the direct solution method to engine vibration problems," Norwegian MARITIME RESEARCH No. 1, 1980, Vol. 8, pp. 39-50.

Sarsten, A. "A reduction method for calculation of the forced vibration of large, free systems with multiple branch points." Report IFMM 81, Div. of Comb. Eng. and Mar. Engrg., 35 pp.

Chen, T., Sarsten, A. "Combustion simulation of medium speed diesel engines and result analysis." 2nd Congress of IMAEM, Trieste, Sept. 21-26, 1981.

Einang, P. M., Koren, S., Kvamsdal, R., Hansen, T. and Sarsten, A. "High-Pressure, Digitally-Controlled Injection of Gaseous Fuel in a Diesel Engine, with Special Reference to Boil-Off from LNG Tankers," Paper, CIMAC '83 Conference, Paris, June 1983.

JUDGE BRENNER: We are also granting the Staff's motion to admit into evidence Staff Diesel Exhibit 5.

Would you identify that exhibit more fully?

MR. GODDARD: Yes, I will, Judge Brenner. It is an article by Kohls et al entitled "Effects of Multiple Shot-Peening/Cadmium-Plating Cycles on High-Strength Steel."

Judge Brenner, for the purpose of convenience, in view of the Staff--

JUDGE BRENNER: Finish the identification, please. What is the article from?

MR. GODDARD: The article is contained in "Residual Stress Effects in Fatigue," ASTM STP 776, published by the American Society for Testing and Materials, 1982, pages 158 through 171, inclusive.

JUDGE BRENNER: All right.

I cut you off, Mr. Goddard. You wanted to say something?

MR. GODDARD: Yes, Judge Brenner.

In view of the relative brevity of the Staff's exhibits, and for convenience, I wonder if we might also bind in the exhibits and other Staff testimony at this point in the record? We'll make reference to them subsequently.

JUDGE BRENNER: Do you mean all the exhibits?

MR. GODDARD: Yes, Judge Brenner.

JUDGE BRENNER: No; I don't want to bind the other ones in. It's going to get confusing. It's bad enough that we have the testimony far in proximity from the witnesses in the transcript.

We can take Exhibit 5, if you like. All right: in addition to having it as an exhibit we can bind in Exhibit 5 for convenience at this point in the transcript.

MR. GODDARD: Thank you, Judge Brenner.

(Whereupon the document referred to, heretofore marked for identification as Staff Exhibit 5, was received in evidence.)

(Staff Exhibit 5, "Effects of Shot-Peening/ Cadmium-Plating Cycles on High-Strength Steel," by J. B. Kohls, et al. follows.)

EXHIBIT 5

J. B. Kohls,[1] *J. T. Cammett,*[1] *and A. W. Gunderson*[2]

Effects of Multiple Shot-Peening/Cadmium-Plating Cycles on High-Strength Steel

REFERENCE: Kohls, J. B., Cammett J. T., and Gunderson, A. W., **"Effects of Multiple Shot-Peening/Cadmium-Plating Cycles on High-Strength Steel,"** *Residual Stress Effects in Fatigue, ASTM STP 776,* American Society for Testing and Materials, 1982, pp. 158-171.

ABSTRACT: A study was made of the effects of multiple shot-peening and cadmium plating operations on high-strength AISI 4340 steel used in aircraft landing-gear applications. N[illegible]imental effects were observed on surface microstructure and tensile properties or on fa[illegible] and unnotched stress corrosion resistance in high-humidity air. An apparent degradation in stress corrosion life of fatigue precracked specimens was observed after four and five peening and plating operations.

KEY WORDS: shot-peening, cadmium plating, fatigue, stress corrosion, tensile, high-strength steel

High-strength steels are used widely for load-bearing components in aircraft landing gear. Typically, such components are shot-peened after machining, then are plated with cadmium and chromium followed by painting, all to enhance resistance to fatigue and corrosion. Overhaul rework procedures for such components include stripping platings, inspecting for cracks, build-up and remachining of worn areas, followed by shot peening and plating as for the original finishing sequence. Landing-gear components typically are subjected to several such overhaul procedures during their service life.

The objective of this program was to establish the effects of the original and overhaul rework peening and plating cycles on fatigue and stress corrosion resistance of high-strength AISI 4340 steel which is commonly employed in aircraft landing-gear components. Experimental evaluations involved metallography and tension testing in addition to fatigue and stress corrosion testing in high-humidity environments. The remaining sections of this paper are devoted to descriptions of material and specimen preparation, test procedures, results obtained, and interpretation thereof.

[1] Metcut Research Associates Inc., Cincinnati, Ohio 45209.
[2] U.S. Air Force, AFWAL/MLLX, Wright-Patterson Air Force Base, Ohio 45433.

Procedure

Material and Specimen Preparation

The material employed in this work was vacuum-melted AISI 4340 steel per requirements of MIL-S-8844. This material, heat-treated nominally to a 1790 to 1830 MPa ultimate strength level, was used in landing gear of many earlier aircraft. The material was procured in the form of forgings 25 by 108 by 1829 mm. Each forging was cut into eight specimen blanks approximately 12 by 102 by 460 mm. Specimens were rough machined about 4 mm oversize prior to heat treatment. The geometries of tension, fatigue, and stress corrosion specimens are shown in Fig. 1. Following rough machining, all specimens were heat-treated.

The heat treatment consisted of oil quenching from 1085 K and tempering at 480 K. The resulting hardness was 52 to 54 Rc. The average results from tension tests were 2070 MPa ultimate tensile strength, 1397 MPa 0.2 percent yield strength, 51 percent reduction of area, and 12.4 percent elongation (25 mm gage length). After heat treatment, the specimens were finish machined. The final 0.5 mm of material was removed from all surfaces by a controlled low-stress grinding procedure [*1*].[3] This introduces low-level compressive stresses at the surface and within about 0.1 mm beneath the surface. Further, this grinding procedure does not produce any overtempering or re-transformation of the martensitic surface microstructure. After finish grinding, the edges of the specimen gage sections were radiused to about 1 mm and hand polished through 600 grit SiC paper to a surface roughness of about 0.2 μm AA.

Shot-Peening

Following heat treatment and machining, specimens other than those tested in the baseline condition (no shot-peening or cadmium plating) were shot-peened per MIL-S-13165B. Specimens were clamped in a vertical position and rotated at 10 to 15 rpm. Six nozzles were used to propel the shot simultaneously at the specimen. These nozzles oscillated during peening to ensure consistent overall coverage of the surface. After peening for 3 min, each specimen was flipped end for end and then peened for an additional 3 min. Peening was performed with hardened size 230 steel shot. Coverage was 200 percent. The resulting Almen strip intensity was 6A to 8A.

Cadmium Plating

Cadmium plating was performed per MIL-C-8837, Type II. The procedure involves vacuum deposition of cadmium followed by a supplementary chromate treatment to form a protective oxide film. Specimens were cleaned in a solvent and were lightly dry-blasted prior to insertion in the vacuum chamber to ensure

[3]The italic numbers in brackets refer to the list of references appended to this paper.

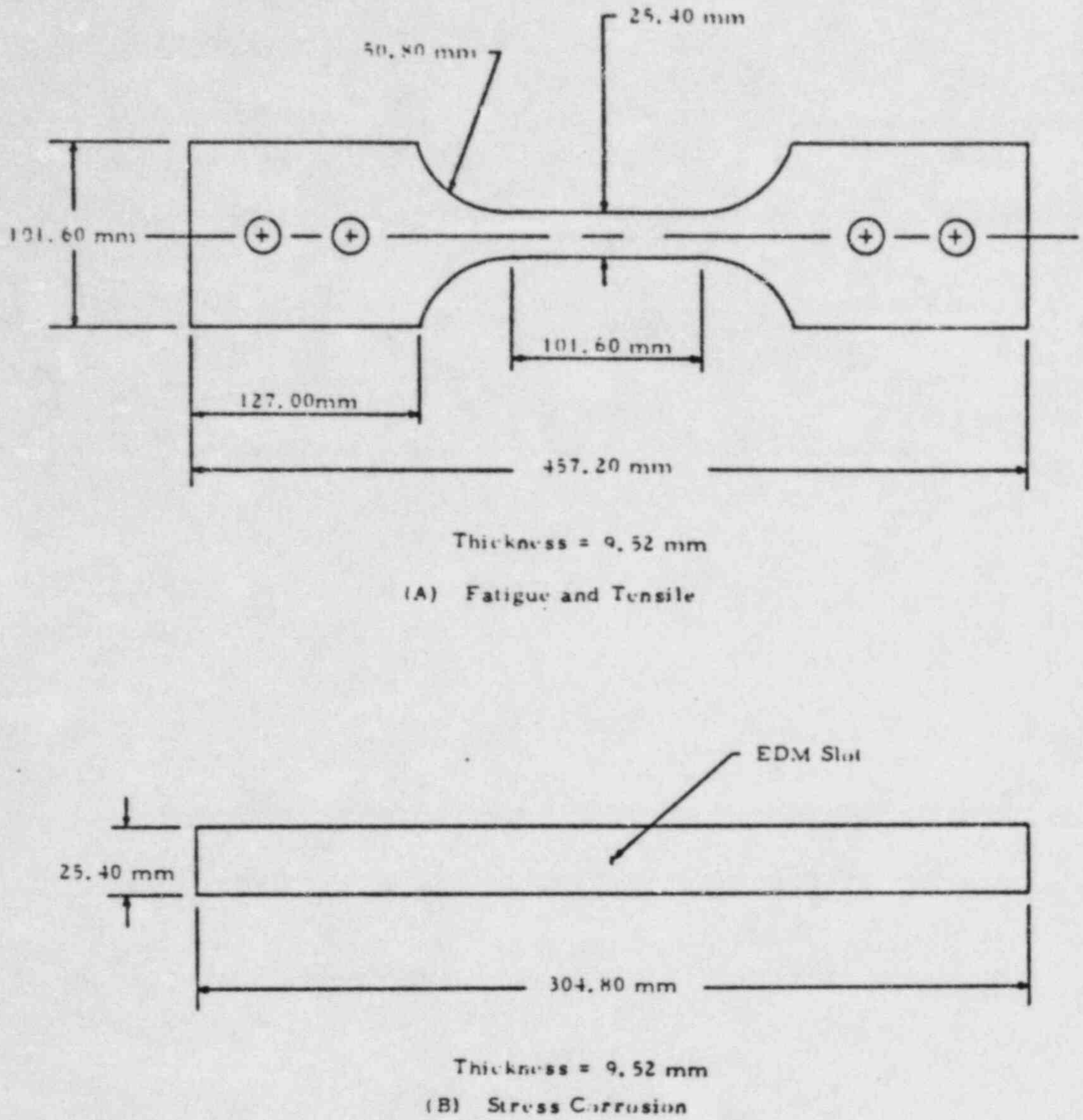


FIG. 1—*Specimen geometries.*

cleanliness of surfaces. The blasting did not roughen the surface beyond the finishes specified in Fig. 1. The plating on specimens selected for multiple shot-peening and plating cycles was stripped between each cycle.

Tension and Fatigue Testing

Tension and fatigue tests were performed on a servocontrolled closed-loop hydraulic universal test machine. The load cell and all support equipment were calibrated immediately before and after this program using secondary standards whose calibrations were traceable to the National Bureau of Standards. The loading grips and associated fixtures were aligned using a strain gaged specimen of the same geometry as the test specimen.

Tension tests were performed per ASTM Methods of Tension Testing of Metallic Materials (E 8) in ambient air at about 293 K and 50 percent relative humidity.

The strain rate for all tests was 0.005 min^{-1} to failure. Strain measurement was performed via an LVDT extensometer attached to the specimen gage section over a 25 mm gage length.

Fatigue tests were conducted under constant load amplitude conditions at stress ratio $R = 0.1$ and -0.3 in a high-humidity air environment. The environment was maintained by bubbling compressed air slowly through a column of water and then passing the air into a plastic jacket surrounding the specimen gage section. All testing was performed at a frequency of 2 to 4 Hz using a sinusoidal load-time waveform. Tests were terminated after 10^6 cycles if fracture had not occurred beforehand.

Stress Corrosion Testing

Stress corrosion testing was performed per ASTM Practice for Preparation and Use of Bent-Beam Stress-Corrosion Test Specimens (G 39) with the exception that tests were conducted under constant load rather than constant displacement in four-point bending. Testing was conducted in deadweight-loaded test frames, commonly used for creep and stress rupture testing. The frames were outfitted with four-point bend fixturing specially designed for this program. The constant bending moment test section of each specimen was the central 75 mm of its 300 mm length.

The test environment was 293 K air at 80 to 100 percent relative humidity produced by slowly bubbling compressed air through a water reservoir and then passing it into a plastic bag surrounding the specimen test section. Both unnotched and fatigue precracked specimens were tested. The fatigue precracked specimen had been manufactured with 1.2 mm wide by 0.6 mm deep electrically discharge machined (EDM) notch in the geometric center of one surface. These specimens were fatigue precracked before any shot-peening or plating cycles. Fatigue precracking was performed in ambient air under three-point bend loading at a frequency of 30 Hz and a stress ratio R of about 0.1. Fatigue cracks were initiated at a calculated maximum surface stress of 100 ksi and were permitted to grow until the total surface notch plus crack length reached 2.5 mm.

Results and Discussion

Residual Stresses

No residual stress measurements were included in the scope of this work. In previous work, however, Metcut Research Associates performed residual stress measurements on quenched and tempered AISI 4340 (50 Rc) [*1*]. Residual stress results from that work, characterizing surface and subsurface residual stresses parallel to the grinding direction, are shown in Fig. 2. Please note that this figure, reproduced from Ref *1*, is in customary English units rather than the SI units used otherwise throughout this paper. As can be seen, the gentle grinding produced relatively low compressive stresses to a depth of less than 0.05 mm (0.002 in.), while the shot-peening produced relatively large compressive stresses to a depth

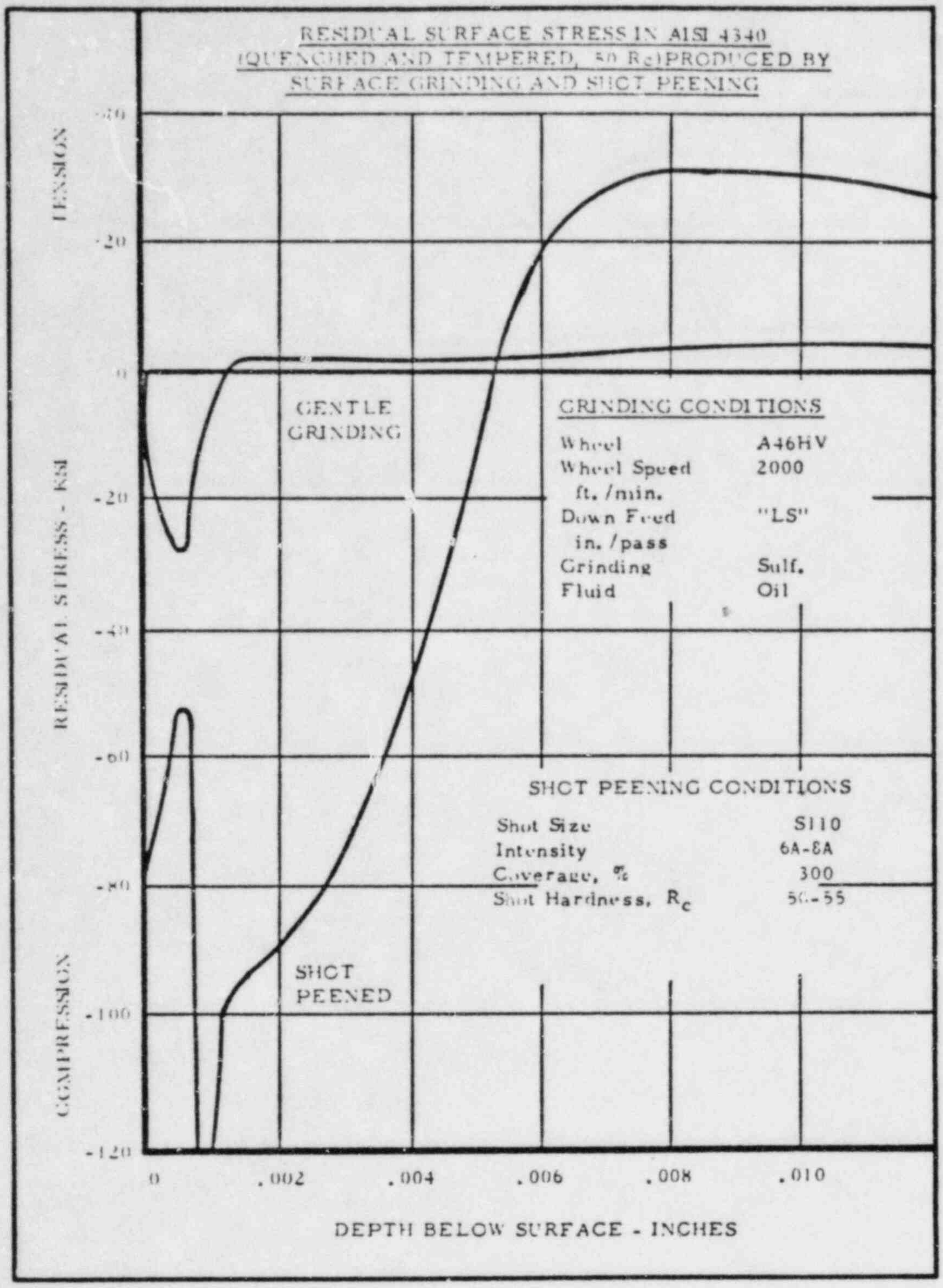


FIG. 2—*Residual stress data for AISI 4340 steel, 50 Rc (1 ksi = 6.9 MPa; 1 in. = 25.4 mm)* [1].

in excess of 0.1 mm. It is believed that the residual stress data shown in Fig. 2 are representative of residual stresses created in the AISI 4340 steel employed in the current study, since the same grinding and shot-peening parameters were used.

Tension Test Results

Tension test results from baseline specimens (as-heat-treated and gently ground) and from specimens subjected to from one to five shot-peening and plating cycles are summarized in Fig. 3. As can be seen, no degradation of tensile strength, yield strength, or elongation occurred as a result of shot-peening and plating cycles.

Fatigue Test Results

Fatigue testing was performed axially at maximum stress levels of 1170 and 1380 MPa at stress ratios R of 0.1 and −0.3. Results representing each combination of stress level and stress ratio are presented in Fig. 4. It is evident that the

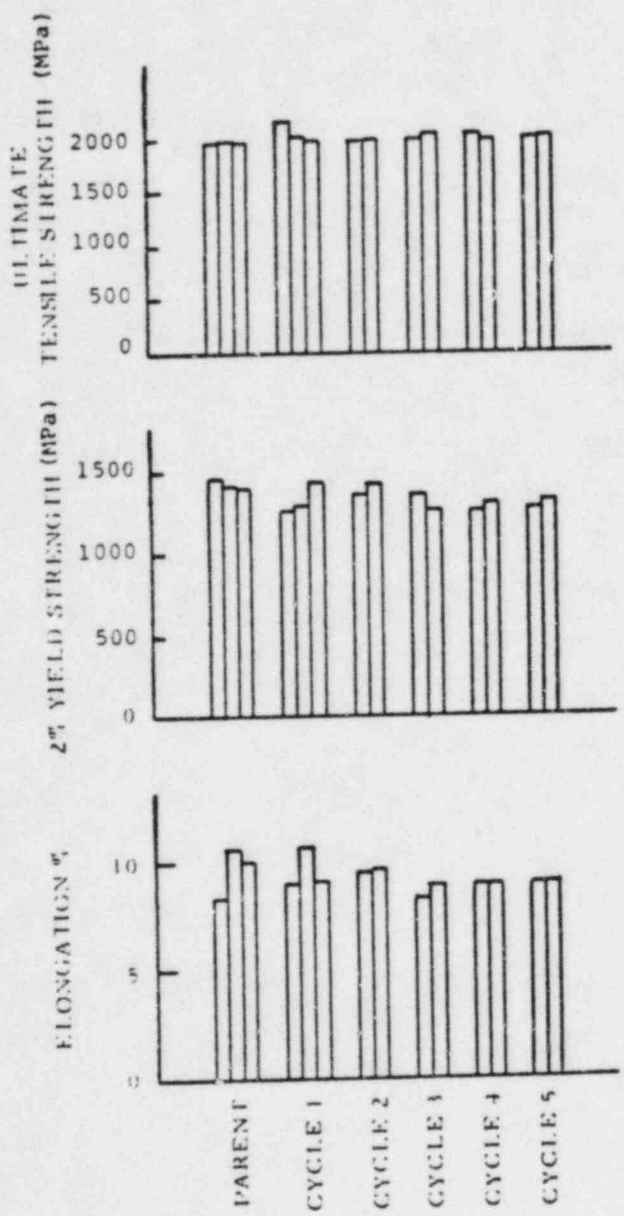


FIG. 3—*Tension test results.*

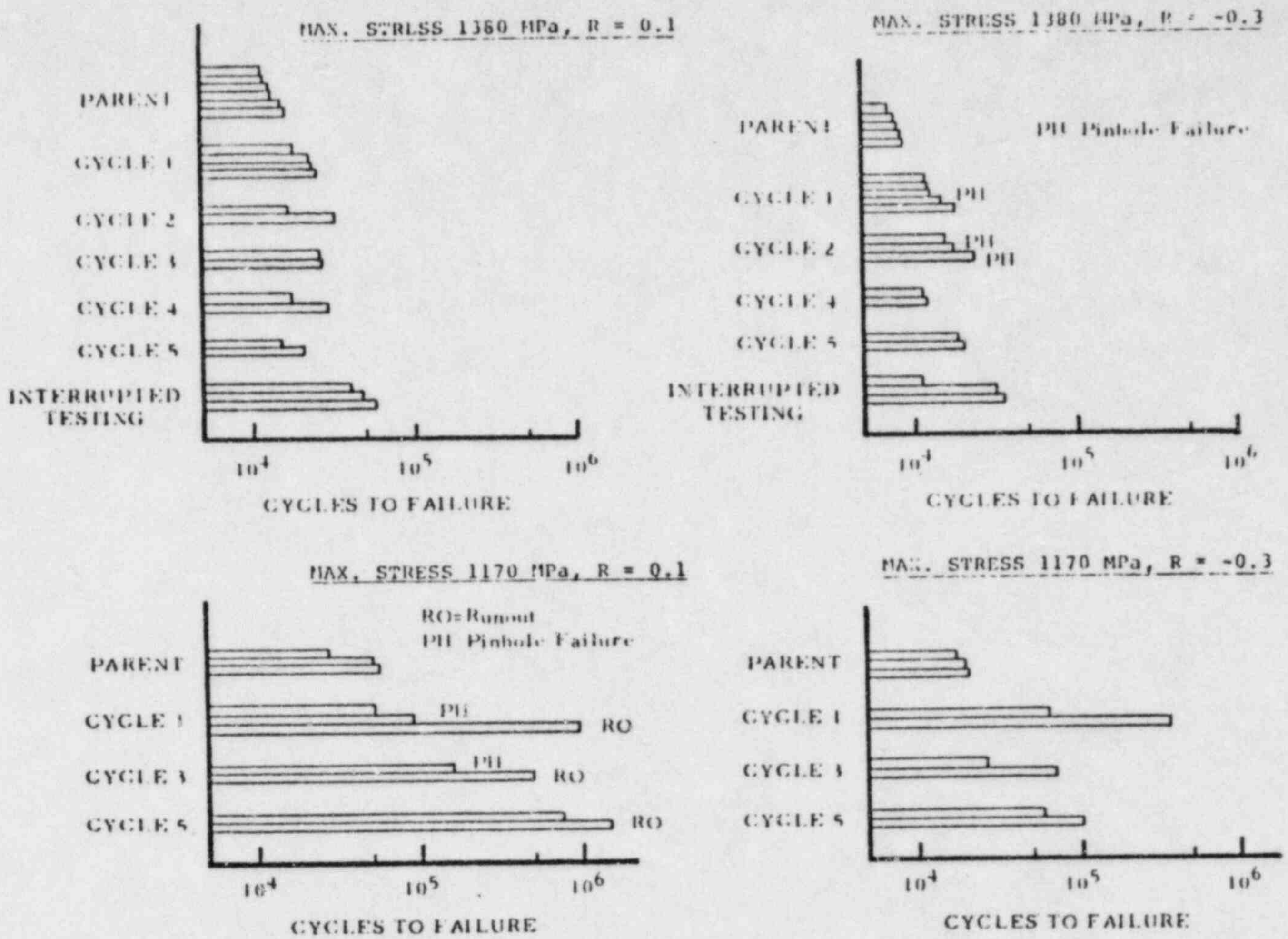


FIG. 4 — *Fatigue test results.*

average fatigue lives of specimens subjected to one to five shot-peening plus plating cycles exceeded the average lives of all baseline specimens tested at the same stress level and stress ratio. This effect, however, was greater for specimens tested at the lower stress level (1170 MPa) than for specimens tested at the higher stress level (1380 MPa).

The greater fatigue life after shot-peening is consistent with the residual stress patterns presumed to be in the specimens, since previous work by Metcut has shown a strong correlation between peak residual stress and fatigue strength in AISI 4340 steel [2]. It is believed further that the effect of shot-peening is less pronounced for the higher testing stress level (1380 MPa) because this is close to the magnitude, though opposite in sense, of shot-peening residual stresses presumed to be in the surface and subsurface layers.

It is also evident from the results in Fig. 4 that fatigue lives of specimens subjected to from three to five shot-peening and plating cycles were generally lower than lives of specimens subjected to one or two such cycles. Determination of the reason for this was beyond the scope of this investigation. It is believed, however, that the observed behavior resulted either from an over-peening effect or from hydrogen accumulation with repeated stripping, peening, and plating operations. It is re-emphasized, however, that fatigue lives of shot-peened and plated specimens generally exceeded those of baseline specimens regardless of the number of shot-peening and plating cycles.

Also shown in Fig. 4 are fatigue results from "interrupted testing" wherein specimens were cycled in fatigue between successive shot-peening and plating cycles. The number of fatigue cycles applied after each shot-peening and plating cycle was one fourth the average fatigue life of specimens tested at the same stress level and stress ratio to failure after just one shot-peening and plating treatment. After three such increments of fatigue cycling and four cycles of shot-peening and plating, the specimens were tested to failure. It is evident that the lives of specimens thus treated exceeded those of all baseline specimens and generally exceeded those of specimens subjected to from one to five shot-peening and plating cycles without intermittent fatigue cycling.

Stress Corrosion

A total of 24 stress corrosion tests were performed, 14 on smooth specimens and 10 on fatigue precracked specimens. All multiple shot-peening and plating cycles were performed on individual specimens prior to stress corrosion testing. All precracking of notched specimens was performed prior to shot-peening and plating cycles.

Initially, the maximum bending stress level for testing was chosen to be equal to the 0.2 percent offset yield stress (1415 MPa) for the material. This level subsequently was increased to 1655 MPa when no specimen failures were observed at the lower stress level. Therefore the surface stress level as reported here is a pseudo-elastic stress level calculated per simple beam theory rather than an actual stress level. Specimens were held at load in the moist air environment for at least 200 h or until fracture, whichever occurred first.

Stress corrosion results for smooth specimens are presented in Table 1. These results are inconclusive with respect to the influence of shot-peening and plating on stress corrosion resistance, since no stress corrosion failures occurred. Visual examination of specimens after testing revealed neither any cracking nor any general corrosion on the specimens.

Stress corrosion results from notched and fatigue precracked specimens are presented in Table 2. It is evident that lives of specimens subjected to four or five shot-peening and plating cycles were lower than for baseline specimens or those subjected to a lesser number of such cycles. As was mentioned previously in discussion of fatigue results, it is believed that this behavior resulted either from an over-peening effect or from hydrogen accumulation during successive stripping, peening, and plating operations. The extent of fatigue precracking in specimens so prepared greatly exceeded the depth to which any shot-peening would have influence. Therefore the belief is favored that hydrogen accumulation was responsible for the observed behavior.

Metallography

The metallographic specimens prepared for this program were oriented parallel and perpendicular to the machining lay. The specimens were mounted in epoxy material embedded with aluminum oxide pellets for optimum edge retention. They were polished by conventional means and examined in the unetched and etched conditions at magnifications of up to approximately ×1000. The etchant used was a 2 percent Nital solution.

Baseline 4340 samples and five groups of samples with varying number of shot-peening and plating cycles were examined. Surface structural features are briefly described and characterized by photomicrographs shown in Fig. 5. Traces of a thin white layer were observed on the surfaces of the peened samples. These

TABLE 1—*Stress corrosion results—smooth specimens.*

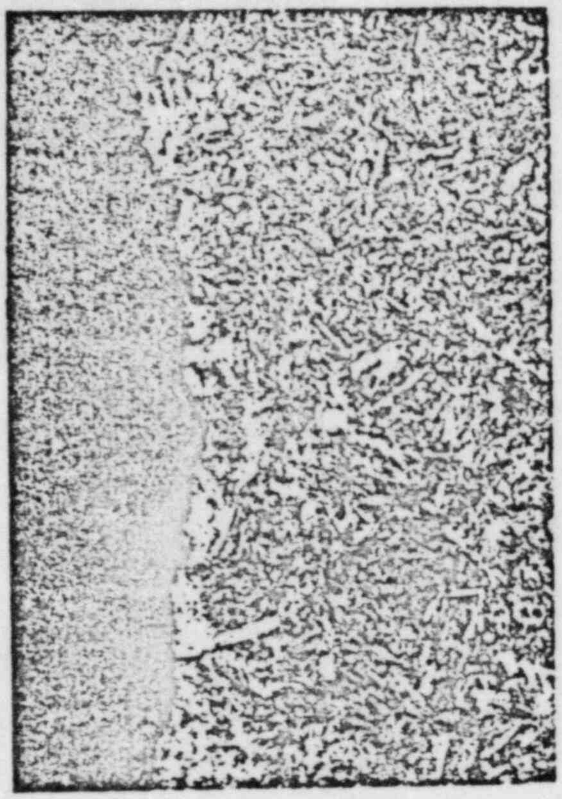
Specimen Number	No. of Shot-Peening and Plating Cycles	Nominal (Pseudo-Elastic) Surface Stress, MPa	Test Duration, h	Result[a]
11	none	1415	258	N
12	none	1415	257	N
13	none	1415	279	N
14	none	1415	279	N
16	1	1415	259	N
23	1	1415	259	N
18	2	1655	214	N
21	2	1655	209	N
19	3	1655	209	N
24	3	1655	213	N
17	4	1655	215	N
22	4	1655	215	N
15	5	1655	200	N
20	5	1655	200	N

[a]N = No cracking observed; test terminated.

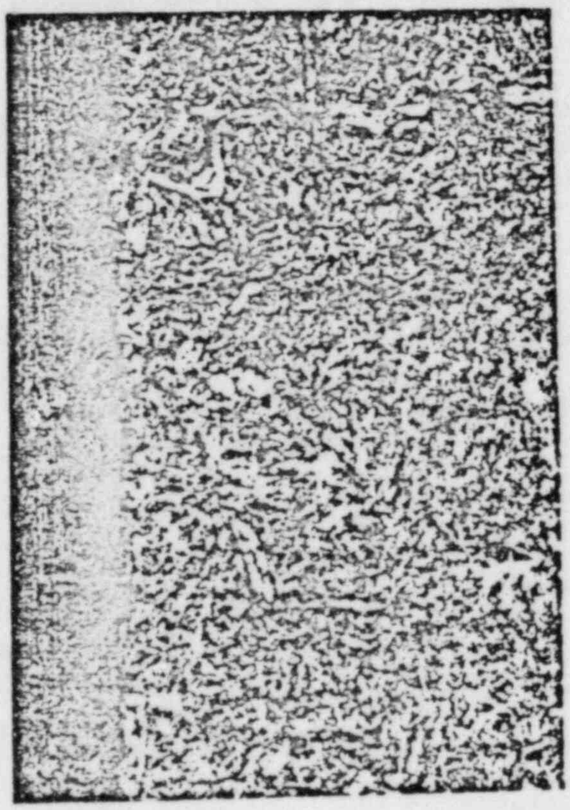
TABLE 2—*Stress corrosion results—fatigue precracked specimens.*[a]

Specimen Number	No. of Shot Peening and Plating Cycles	Nominal (Pseudo-Elastic) Surface Stress, MPa	Nominal Surface Stress Intensity Factor,[b] $MPa \cdot m^{1/2}$	Test Duration, h	Result[c]
9	none	1415	46	266	N
10	none	1415	46	266	N
9[d]	none	1550	50	216	N
10[d]	none	1655	54	214	F
7	1	1655	54	362	N
8	1	1655	54	350	F
6	2	1655	54	213	N
3	3	1655	54	233	N
5	3	1655	54	204	F
1	4	1655	54	42	F
2	5	1655	54	97	F
4	5	1655	54	2.2	F

[a]Precracked nominal crack length = 2.5 mm.
[b]Calculated per A. F. Grandt, Jr., and G. M. Sinclair, *Stress Analysis and Growth of Cracks, ASTM STP 513*, American Society for Testing and Materials, 1972, pp. 37-58.
[c]N = No crack extension observed (precracked specimens); test terminated. F = specimen fractured.
[d]Retest of a specimen from a terminated test at a lower stress.



After One Shot Peening/Plating Cycle



Baseline: As-Ground

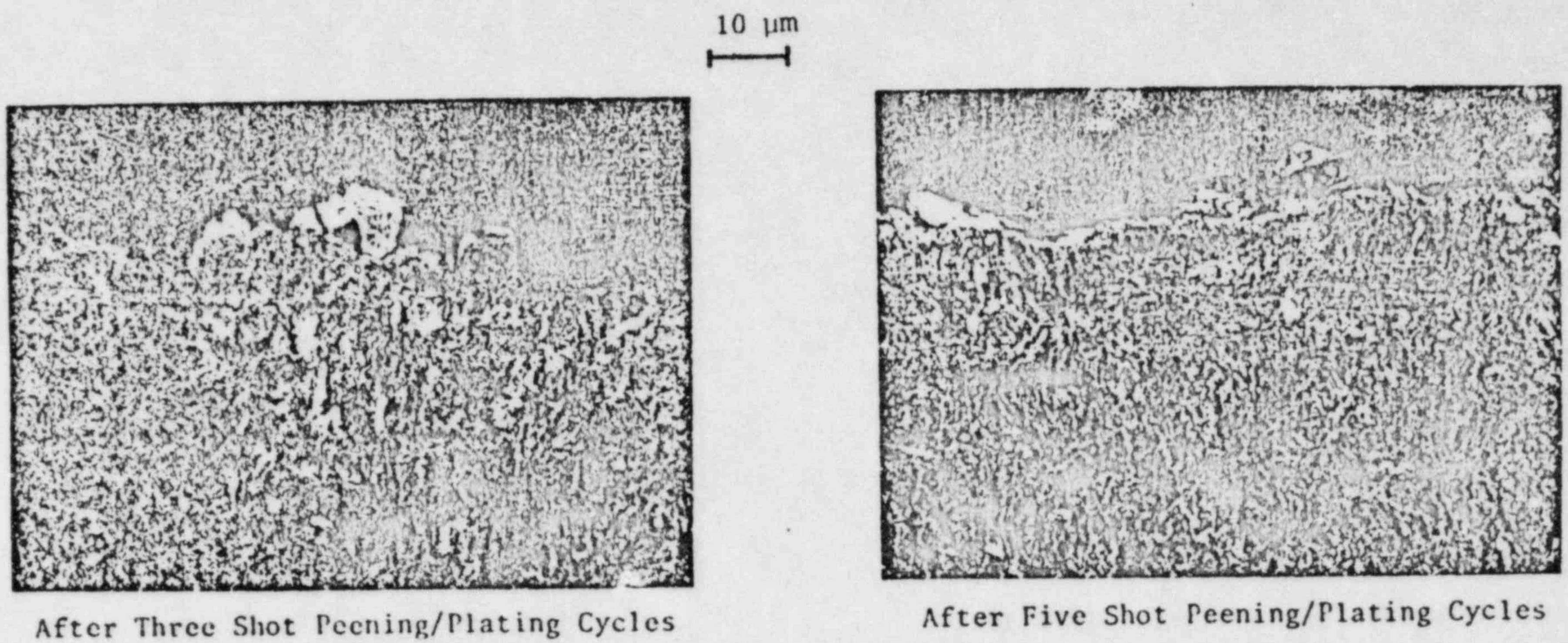


FIG. 5—*Metallographic sections through AISI 4340 steel specimen surfaces; all sections parallel to grinding direction.*

white or light etching layers and stringers may be attributable to a high degree of surface plastic deformation. The thin layers probably represent highly deformed material rather than untempered martensite, which has a similar appearance.

In addition to the preceding general characterization of surface features, a metallographic study was performed on several failed test specimens in an attempt to ascertain whether or not the observed white layer influenced the failure process. The specimens selected for this study represented parent or baseline material and extremes in test life for various fatigue and stress corrosion test conditions.

Before proceeding with metallographic examination of the test specimens, a test blank and the two baseline specimens were macro-etched to investigate whether or not any significant grinding burn had occurred. This was done in order to resolve the issue of whether the presence of a white layer could be traceable to machining in the manufacture of the specimens. The three specimens were etched by a multi-step procedure widely used in industry, which consisted of a dilute solution of 4 percent nitric acid in water and a solution of 2.5 percent hydrochloric acid in acetone. One of the parent specimens was also etched with a 2 percent Nital solution. None of these etching techniques revealed the presence of grinding burn on the specimens.

The test specimens were first examined on a binocular microscope at magnifications of up to approximately ×40 in order to locate failure origins. Examination of the fatigue specimens revealed that failure origins were located either at one of the corners of the specimen or on the sides of the specimen. Failures in the stress corrosion specimens initiated from the pre-existing fatigue crack that was introduced at the bottom of the EDM notch.

Metallographic sections were made approximately through the center of each failure initiation site and examined in the unetched and etched conditions at magnifications up to approximately ×1200. Observations indicated that the white layer was not associated exclusively with the initiative area of specimens exhibiting the lowest fatigue lives. Fatigue initiation was apparently also influenced by other forms of surface degradation, such as microcrack and slivers, and by specimen geometry (that is, the corner areas).

Conclusions

Specific conclusions from experimental results were as follows:

1. Shot-peening/cadmium-plating cycles up to five in number had no influence on tensile properties relative to those from as-heat-treated material.

2. Fatigue resistance in high humidity air at stress ratios R of 0.1 and -0.3 was enhanced by shot-peening/cadmium-plating cycles up to five in number. The increase was most noticeable after one to three such cycles.

3. Stress corrosion results from unnotched specimens in high-humidity air were inconclusive since both as-heat-treated and shot-peened/cadmium plated specimens survived 200-h exposure at up to a 1650 MPa elastic surface stress level without cracking.

4. Fatigue precracked stress corrosion specimens subjected to four and five shot-peening/cadmium-plating cycles exhibited shorter lives than as-heat-treated specimens and specimens subjected to fewer shot-peening/cadmium-plating cycles. All specimens were fatigue precracked to a surface crack length of about 2.5 mm after heat treating, prior to any shot-peening/plating cycles. Stress corrosion testing of precracked specimens was performed in 293 K, 80 to 100 percent relative humidity air at a pseudo-elastic surface stress level of 1650 MPa.

5. No microstructural changes of significance relative to mechanical properties were observed to result from shot-peening/cadmium-plating cycles. White stringers observed metallographically at the surface tended to increase in prominence with increasing cycles. These stringers were believed to be an etching phenomenon related to plastic deformation in the peened surface layers.

Acknowledgments

Sponsorship of this work by the Air Force Wright Aeronautical Laboratories/ Material Laboratory, AFWAL/MLSA, under Contract F33615-78-C-5201 is gratefully acknowledged. One of the co-authors, A. W. Gunderson, of the Materials Integrity Branch, Systems Support Division, served as project monitor. Also acknowledged are the contributions of various Metcut Research Associates personnel, in addition to the co-authors, who were instrumental in performance of the experimental work: W. J. Stross, Tensile and Fatigue Testing; L. R. Gatto, Metallography; and T . E. Arnold, Stress Corrosion Testing.

References

[1] Koster, W. P. et al., "Surface Integrity of Machined Structural Components," AFML-TR-70-11, March 1970.
[2] Koster, W. P. et al., "Surface Integrity of Machines Materials." AFML-TR-74-60, April 1974.

MR. GODDARD: Dr. Bush is similarly tendered for cross-examination.

JUDGE BRENNER: Off the record.

(Discussion off the record.)

JUDGE BRENNER: Back on the record.

As we had stated yesterday, the sequence of examination by the parties would be: the County, to be followed by LILCO, and then the Staff.

Do you have any estimate you could give us at all at this point, Mr. Scheidt about how long the cross-examination will take?

MR. SCHEIDT: It should be less than two hours, your Honor.

JUDGE BRENNER: I realize that's a preliminary estimate, and that's all I was seeking.

You may proceed.

MR. STROUPE: Could I ask one question for clarification? LILCO will be going second in the cross-examination sequence. Does that mean that at that point in time we will also have to ask redirect?

JUDGE BRENNER: Yes.

MR. STROUPE: But we will get an additional opportunity after the Staff has cross-examined?

JUDGE BRENNER: Yes.

MR. STROUPE: Thank you.

CROSS-EXAMINATION

BY MR. SCHEIDT:

Q Dr. Wells, the FaAA report on the replacement crankshaft, dated April 19th, 1984, stated that a conservative range of values of an increase in the fatigue endurance limit is from 5 percent to 20 percent. But this reference was deleted in the final version of this report dated May 22nd, 1984, which is contained in Exhibit C-17.

The reason for this change, Dr. Wells, was that the FaAA quality assurance program deleted the reference--

This is a long question. I'll start all over, Judge Brenner.

With respect to the two reports -- versions of the reports I just mentioned, why was the reference to a conservative range of values for the effect of the endurance limit from shot-peening deleted?

A (Witness Wells) The reason for deleting the reference was that we had no direct measurements, no test data, to support a number in the process of assuring the quality of this report.

JUDGE BRENNER: Off the record.

(Discussion off the record.)

JUDGE BRENNER: Back on the record.

BY MR. SCHEIDT:

Q So you're saying, Dr. Wells, that no tests have been conducted to verify whether, in fact, a conservative range of values is 5 percent to 20 percent; isn't that true?

A (Witness Wells) Yes; we were unable to support any quantitative improvement in the endurance limit of the peened crankshaft.

Q Can you describe to me, Dr. Wells, what the quality assurance process is as it related to this particular reference in the April version of the report?

A The quality assurance process at Failure Analysis in general consists of qualified experts in the particular subject performing an independent review of the analysis and of the concluding statements in the reports.

If they are unable to document any numbers, any quantitative conclusions, then that information is deleted from the report in the process of our quality assurance review.

Q Can you identify the persons at FaAA who performed this review with respect to this particular portion of the April version of the report?

A With respect to the endurance stress range improvements, the fatigue numbers were reviewed by Mr. Robert Sire and, I believe, by Dr. Paul Johnson.

Q And can you describe their independent review for me?

A In general, the independent review would attempt to locate test data or documentation in the technical literature that would be a basis for comparing the properties of the original 13x11-inch crankshafts with those of the as-peened 13x12-inch crankshafts.

Q And did this review uncover any documents from the technical literature which would serve as a basis for that comparison?

A There are many documents in the technical literature, as Mr. Burrell may identify, that deal in general with the improvements afforded by shot-peening.

The problem with the assessment of the actual improvement afforded to the 13x12-inch crankshafts depends on certain unknown factors. And, of course, each particular machine component, such as the crankshaft, is an individual case not treatable by any general technical literature.

In this case, the question of the degree of improvement would depend on a rather precise knowledge of the residual stresses in the as-machined fillets of the crank pins, and on knowing quite precisely the surface condition in terms of machining irregularities, and other factors which could not be measured at the time that the crankshafts were received by LILCO.

Q Why couldn't they be measured at the time those crankshafts were received by LILCO?

A Primarily because of the massive size of the crankshafts. It was not practical, for example, to perform x-ray diffraction analysis of residual stresses on the crankshafts.

Generally, many of these parameters that affect the fatigue endurance limit of crankshaft fillets would have required some destructive examination. For obvious reasons there was no attempt to obtain that precise information.

Q Mr. Burrell, you have testified that based upon your experience your opinion is that the shot-peening of the fillet areas in the replacement crankshafts has resulted in an increase of approximately 15 to 20 percent in their fatigue endurance limits; isn't that true

A (Witness Burrell) Yes, that's correct.

Q And what experience are you basing your opinion on?

A Fatigue tests performed on many different sizes and types of crankshafts.

Q What is the largest crankshaft that fatigue tests have been performed on that you are relying on?

A To the best of my knowledge, journal bearing diameters of about 6-1/4 inches.

Q Journal bearing diameters of 6-1/4 inches?

A That's correct.

Q And do you know how large the journal bearing diameters are on the replacement crankshafts at Shoreham?

A Yes, sir; 12 inches.

Q So you have no information from fatigue tests on crankshafts of the size at Shoreham, do you, Mr. Burrell?

A No, sir; but the effects of peening are well known on crankshafts in general. It's rather impractical to fatigue test a crankshaft that large.

Q Are these fatigue tests that you're relying on performed by you or Metal Improvement Company?

A No, sir; they were performed by the manufacturer, or, in one case, performed by an outside testing laboratory.

Q And what were the specific tests that were performed?

A Typically, crankshaft fatigue testing consists of sectioning out a single journal and--

Q I'm sorry; could you go more slowly?

A Typically, fatigue tests -- testing on crankshafts consists of sectioning the crankshaft to include one journal bearing and a half of each of the adjacent main bearings, and setting them up in a cycling mode until failure occurs.

Q This is the type of test that was performed on the largest crankshaft that--

A Yes, sir.

Q Thank you.

What type of stress was applied in these fatigue endurance tests?

A Well, I have to make some calculations. All I have here is the applied load in the data I'm referring to. But that can readily be determined.

Q Okay. Can you tell me at this time what loading you're referring to?

A Well, the run-out of the S-N curve appears to be in the area of about 77,000 psi.

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Q Who performed the specific test on the largest crankshaft that we're referring to?
A That was done by an outside testing organization.
Q And what's the name of that entity?
Mr. Seaman, do you know?
(No response.)
A (Witness Burrell) I'm a little reluctant, because the data given to me was given to me as proprietary information, and I would prefer not to divulge the testing lab unless I must.
Q Who gave the information to you, then?
A The manufacturer of the engines.
Q And what manufacturer was that?
A They are the people who asked me not to divulge the source. It's published information.
Q We need to know who the manufacturer of this engine is, Mr. Burrell.
MR. STROUPE: Judge Brenner, I don't understand why he needs to know specifically the manufacturer as long as he can obtain the details from Mr. Burrell about the testing.
JUDGE BRENNER: Well, the answer is that some independent outfit did the testing, and in order to know whether to judge that you need to know what outfit, it seems to me.

If you want my personal opinion, at this point in the testimony it's not going to be that important. But in saying that I'm informing you, Mr. Stroupe, of the personal view of one judge as to the kind of credit I'm going to give for a particular percentage improvement asserted for the crankshaft based on data on another crankshaft based on an unidentified entity; if you understand what I'm saying.

You're nodding yes.

MR. STROUPE: I understand fully what you're saying, Judge Brenner.

JUDGE BRENNER: All right; based on that, if you want to take the position that LILCO sees no reason for him to identify the entity, I'm willing to rest with that.

MR. STROUPE: Well, I don't have any control over whether Mr. Burrell wishes to reveal who these people are or not. That's obviously your ruling.

JUDGE BRENNER: No, no; I didn't ask you about control. You made the objection, you said you see no reason why he needs to disclose the entity. I went through a discussion just now, and, based on that, if you still see no reason, we'll stay with that.

MR. STROUPE: I would stay with that.

JUDGE BRENNER: All right.

WITNESS BURRELL: If I may add, this data is published in Reprints of the Second International Conference on Shot-Peening.

JUDGE BRENNER: Well, does the published data reveal the source that you don't want to give now?

WITNESS BURRELL: It's my data. I mean, I wrote the article. I was given the data from the manufacturer based on my not divulging the source.

As you might suspect, --

JUDGE BRENNER: My question is simple: In the published article written by you you disclose the source that you do not want to disclose here?

WITNESS BURRELL: No; the source is not disclosed, only the data.

JUDGE BRENNER: Okay. Thank you.

Let me make clear what happened. We made no ruling that the data was entitled to proprietary treatment. We allowed LILCO to voice its position as to whether we should pursue disclosure of the data, and LILCO does not seek to do that. And, based on that and on what I've already discussed, I see no reason to put Mr. Burrell, who is here as a witness and not with his own counsel, through any discomfort, given the nature of that point way off on the side to the important points that we're trying to get at in this hearing.

MR. SCHEIDT: That's fine, Judge Brenner.

WITNESS BURRELL: I will modify my testimony and give you the name of the testing organization, which is Standard Pressed Steel in Jenkinstown, Pennsylvania.

BY MR. SCHEIDT:

Q What use -- what application, I should say, was this largest crankshaft intended for?

A (Witness Burrell) I'm not totally sure, but I believe this family of engines is used for marine duty as well as stand-by power requirements.

Q And can you tell me now what stress was applied in these fatigue tests?

A Let me do some calculations and I'll get back to you.

Q Go right ahead.

(Pause.)

A Can we come back to that question after I've had some more time to calculate?

JUDGE BRENNER: Mr. Burrell, there'll be at least one fifeen-minute break this morning while you're still on the panel. So you can defer it until then, if you want to concentrate on what's going on, and not have to do two things at once.

BY MR. SCHEIDT:

Q Mr. Burrell, can you tell me the size of the engine that this crankshaft is intended for?

A (Witness Burrell) You mean horsepower? No, sir. I cannot.

Q Okay.

Do you know the torsional vibration characteristics of that engine?

A No, sir.

Q Do you know the number of cylinders?

A Sixteen cylinders.

Q Do you know the rpm's of that engine?

A No, sir.

Q Is that a diesel engine that it's intended to be used in?

A What was that again?

Q Is the crankshaft intended to be applied in a diesel engine?

A Yes, sir.

Q And who is the manufacturer of the crankshaft?

A The engine manufac+urer I prefer not to identify.

Q How large is Standard Press?

A I have no idea; it's a multi-plant organization.

Q And do you know who in the organization performed the testing?

A No, sir, I do not know the organization personally, only by name.

Q Where did you derive the information that you have concerning those fatigue tests?

A I was given the information verbally shortly after the tests were performed.

Q And when was that?

A I'm going to guess: around five years ago.

Q And what did they tell you about those tests?

A They told m· the increase in fatigue strength was in excess of 17 percent. In preparing a paper for the Second International Conference I asked them for the data in printed form; which they gave me. --again, with the proviso that I not identify the source.

Q What did they tell you about the test process itself?

A Basically what I described earlier.

Q Do you know what kind of analyses were performed

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to ascertain the alleged increase in endurance limit?

A Well, a typical procedure involving an S-N curve, of running various samples at different stress levels to generate such a curve.

Q Do you know whether they performed x-ray diffraction on the crankshaft before they performed those tests?

A I do not know. I doubt it, because as Dr. Wells said earlier, it's rather impractical to take x-ray diffraction readings on large objects without sectioning them, and, therefore, destroying the part.

Q Do you know whether x-ray diffraction was performed on those crankshafts after the test?

A No.

Q Did they run that shaft to failure?

A Yes. In all speed tests you run to failure.

Q Did they run an identical crankshaft which had not been shot-peened to failure?

A Yes, they have; that's how they generated the difference in fatigue results.

Q Do you know what destructive examinations were performed on the crankshafts?

A No, I do not.

Q Do you know, Mr. Burrell, whether the parameters of the testing for each of those crankshafts were identical?

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A They would have to be to make a correlation.

Q But do you know?

A They ran peened and unpeened crankshafts at the same stress levels to generate the S-N curves.

Q Do you know whether all the other parameters that -- all the other involved parameters were identical?

A Within the limits of good testing practice they would have to be.

Q But you don't know for sure, do you, Mr. Burrell?

A I was not there.

Q So you don't know?

A No.

A (Witness Wells) May I point out that in the data shown here in Mr. Burrell's paper the only variable is a mechanically applied load. It's not precisely clear what the nature of the applied load is, but the endurance change is represented as a percentage increase in the range of applied mechanical loading.

It should be clear that these are not diesel engine tests, but tests performed under mechanically controlled loading environments.

Q And, Dr. Wells, which article are you referring to? Is that the article cited in the FaAA report?

A I refer to an article by Mr. Burrell entitled "Controlled Shot-peening to Increase the Fatigue Properties of Cranksnafts," appearing as pages 361 through 364 in the publication entitled "Reprints, Second International Conference on Shot-Peening," Chicago, 14 through 17 May 1984, published by the American Shot-Peening Society.

Q So, Dr. Wells, that's not the article that is cited in Exhibit C-17, but it is the article that is included in the LILCO testimony as -- or exhibits; excuse me -- as C-39; is that true?

A This particular citation is different from the one contained in the LILCO Exhibit No. 39, but on the same subject.

JUDGE BRENNER: While there's a pause I want to clarify something in the testimony of LILCO before we get too far into it.

I'm correct, am I not, that it was Crankshaft 102 that severed, of the old crankshafts; correct?

WITNESS WELLS: That is correct, Judge Brenner.

JUDGE BRENNER: And that, of course, is indicated at the top of page 6 of the testimony. But on page 5 of the testimony, in the middle of the answer there, the fifth line, you refer to the fatigue crack which resulted in a failure of the EDG No. 101 crankshaft.

Did you mean the 101 crankshaft tested to failure after the crack, or did you mean 102?

WITNESS WELLS: We did mean 102.

JUDGE BRENNER: All right.

Mr. Scheidt.

BY MR. SCHEIDT:

Q Dr. Wells, FaAA's quality assurance reviewers, therefore, did not rely on Mr. Burrell's article citing 17 percent as an increase in the fatigue endurance limit?

A (Witness Wells) Mr. Scheidt, the particular article was not published -- not available at the time we prepared our report in April.

Even if we had had this particular article, as I stated before, it would have been very difficult to support a percentage increase in the endurance limit because of the unknown manner in which the particular crankshaft specimens in this article were machined.

As pointed out by Mr. Burrell, the test results here are relative only; they show an increase in fatigue strength from the as-manufactured unshot-peened condition, which is not specified, to the final shot-peened condition, which, of course, would be much easier to identify. But, nevertheless, our reviewers would not have been able to extrapolate from this proportional increase to the increase in the LILCO Krupp-manufactured crankshafts.

Q If you would like to, Mr. Burrell, if you could figure out what the type of stress that was applied in this test, you can do so now while I review my notes.

JUDGE BRENNER: Well, he said it might take him a while. I hate to take a break this early because I want to take only one break and then run until twelve-forty-five.

Can't you move on to another part?

MR. SCHEIDT: Yes, Judge Brenner. There are very few other areas that I will delve into.

JUDGE BRENNER: All right; if you want a break now I'll grant one.

MR. SCHEIDT: I can go ahead and cover those areas, and we can break if Mr. Burrell--

JUDGE BRENNER: Cover the areas you think you can cover, and then whenever you think you want a break I'll let you have it.

BY MR. SCHEIDT:

Q On page 6 of this testimony, Dr. Wells and Mr. Seaman, you state that shot-peening prevents initiation of cracks on the machined fillet surface.

Do you mean that in all circumstances shot-peening will prevent cracks from initiating in those areas?

A (Witness Wells) Well, it increases the range of stress at which cracks will initiate. There is always a certain stress range below which cracks will not form, and, of course, a sufficiently high range of stress above which they will form whether or not shot-peened.

Q So cracks may initiate in shot-peened areas if the stresses are too high?

A If the stresses are in excess of the endurance limit of the crankshaft fillet, yes. However, the preponderance of evidence on all applications of shot-peening, including applications to crankshaft fillets, as Mr. Burrell has explained, shows substantial increases in this threshold level of stress, or endurance level limit, for fatigue crack initiation.

Perhaps more important is the resistance afforded by shot-peening to the extention of very small surface cracks, if they are produced by any reason, including handling damage.

In making the recommendation to LILCO to add shot-peening to the crankshaft fillets, we had in mind -- I had in mind at the time affording an extra measure of safety in the resistance to propagation of small surface defects such as the very small mark that we identified as the origin of the torsional fatigue failure of the DG-102 crankshaft.

MR. SCHEIDT: Judge Brenner, this is a very convenient time to take a break.

JUDGE BRENNER: Let's break until ten-forty, and then you'll want to come back and finish up with your followup on Mr. Burrell's calculations, as I understand it: is that right?

MR. SCHEIDT: Yes, your Honor.

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JUDGE BRENNER: All right; we'll be back at ten-forty, then.

(Recess.)

JUDGE BRENNER: Back on the record.

BY MR. SCHEIDT:

Q Mr. Burrell, have you determined the type of stress that was applied in the fatigue test on the 6-1/4-inch crankshaft?

A (Witness Burrell) No, I realized, after I made my earlier statement, that I don't have enough information, such as the force radius which determine stress concentration; however, force is directly proportional to stress, and, therefore, an increase in force would give the same increase in stress.

Q So you don't know whether the type of stress that was applied-- Let me start all over:

Isn't it true that the type of stress that was applied is a bending stress and not a torsional stress?

A That's correct. That is a standard procedure in testing all crankshafts, and I would like to add that in my 17 years of experience I have been privy to many, many fatigue tests on crankshafts, all of which show very significant improvement. And we have performed peening also on other large components, as large as the journals on these crankshafts, for example. I don't have any quantitative data, other than the fact the field failures were occurring before peening and not after.

Q Thank you, Mr. Burrell.

MR. SCHEIDT: The County has no further questions of the LILCO panel.

JUDGE BRENNER: Well, I'd like you to ask questions of Dr. Bush also.

MR. SCHEIDT: Okay. Thank you, Judge Brenner.

JUDGE BRENNER: I guess I misunderstood. I thought you were almost complete with your entire cross.

MR. SCHEIDT: I am almost complete with my entire cross.

JUDGE BRENNER: All right. Dr. Wells?

WITNESS WELLS: Could I add one comment in response to Mr. Scheidt's question?

JUDGE BRENNER: Yes.

WITNESS WELLS: The state of stress in the crankshaft fillets, whether it be bending or torsion or, as in the case of the Shoreham crankshafts, a combination of bending and torsion, is irrelevant to the increase in the endurance limit, for the reason that the cracks initiated, in any case, in the Shoreham fillets under a tensile stress and propagated in the direction of the maximum range of loading perpendicular to the tensile stress range in the crankshaft fillets. Therefore, in my opinion, based on much related work at Pratt & Whitney Aircraft over a period of 17 years, for instance, on gas turbine main engine shafts, the endurance limit improvement would be the same, regardless of whether the stress is applied in torsion or bending.

MR. SCHEIDT: I have no further questions of the LILCO panel, Judge Brenner.

BY MR. SCHEIDT:

Q Dr. Bush, can you explain the basis for your statement that any increase in the fatigue resistance for the replacement crankshafts is not quantifiable?

A (Witness Bush) The basic reason would be an understanding of the load conditions -- and I'm now discussing it in the context of the specific crankshafts here. One would have to know not only the maximum level of, for example, the torsional stresses but their distribution, because they may achieve a maximum below the surface and not at the surface. You would have to know the bending moments and bending stresses, and you would have to know whether they are in phase or out of phase with the torsional stresses. You would have to know the level of the residual stresses, and you would have to know the condition of the fillets.

That gives you a multiparametic problem, and I don't think we unequivocally know the values. There's one other major parameter, and that is that there may be a marked anisotropicity in the crankshaft because of the fabrication process, and that would introduce another very major variable into such a calculation. Therefore, all I could say is that you bound the value, but I don't believe that you could come up with the precise value.

Q Can you explain what the effects of anisotropic mechanical properties are?

A Well, let me give an example, and I'll use an analog that isn't related specifically to a crankshaft, but I think will show the problem. This is extensive data generated under an Atomic Energy Commission/NRC program known as Heavy Section Steel Technology. In this instance, plates in thickness analogous to this crankshaft were fabricated either by rolling or by forging, and then extensive property data were collected by measuring the properties at the surface, at the 1/4 and 3/4 thickness positions and at the mid-thickness position in this, and they also were measured not only in the direction of forging but also transverse to the direction of forging.

In such instances, you would see a very pronounced change in the properties because of the difference in working levels, et cetera, through the thickness of the material. This was aimed more at pressure vessels, but I think for a forging process or any fabrication process, if you measure the properties at the surface and then measure them through them, you will see a marked difference, and the method of forging will give a strong directionality in these properties, which would be the anisotropic effect.

Q Dr. Bush, would the cut-out area for the crank pin on the replacement crankshaft be a weaker area than the bulk of the crankshaft, due to the anisotropic effects?

A You lost me on your first word. What area did you say?

MR. STROUPE: I would object to it on that basis. I don't know what you mean by "cut-out area."

JUDGE BRENNER: Given the witness' comments, we're going to find out right now.

WITNESS BUSH: If you will define what you mean by "cut-out area," I may be able to answer. I wouldn't guarantee it. I'm not sure what you mean when you say "cut-out area."

MR. SCHEIDT: Okay. I will move on to another area.

BY MR. SCHEIDT:

MR. SCHEIDT: Dr. Bush, you testified that the ultimate test would be to operate the crankshafts to 10 to the 7 cycles; isn't that true?

A (Witness Bush) That's correct. That's the ultimate test, not only for the crankshafts but for a diesel, insofar as I think we are concerned under the circumstances.

Q Isn't the value of 10 to the 7 cycles in this connection more appropriate for simple idealized geometries than complex geometries?

A No, I don't believe so. I believe that if you go through a sufficiently large number of repetitive cycles, you should establish whether you are above or below the endurance limit, which is what you're concerned with here. And I would say that that would apply regardless of the geometric configurations. Obviously, this would depend on the fact that it is loaded appropriately, but I can't think of any better test than to operate it under the conditions it's supposed to operate under.

Q Will not simple geometries...

(Pause.)

MR. SCHEIDT: The County has no further questions of Dr. Bush.

JUDGE BRENNER: LILCO?

MR. STROUPE: Your Honor, do I proceed in any particular order, with LILCO or with Dr. Bush?

JUDGE BRENNER: Whatever you prefer, and you're free to go back and forth.

REDIRECT EXAMINATION

BY MR. STROUPE:

Q Dr. Bush, I believe you indicated on page 21 of the NRC Staff's testimony that you consider fatigue resistance should be somewhat enhanced, but it is not quantifiable; is that correct?

A (Witness Bush) That's correct.

Q Are you able to quantify in any fashion the enhancement of the fatigue resistance by shot-peening?

A The answer, obviously, is yes. Given a knowledge of the material and appropriate testing data, the level of enhancement for one material, say, with 180,000 yield strength would be totally different than one with a 70,000 yield strength. So one would have to know most of the values, in my estimation, to quantify that.

There would be a gain, I anticipate; however, this is so related to the stresses that the object sees -- this was brought up earlier, in fact by Judge Brenner: if you exceed certain stress levels, you can get failure. If you are at low stress levels, then doing shot-peening is probably a waste of money. You don't need to do it. Obviously, there is something in between, where you may feel it is worth doing. It certainly is done. It's done on many millions of parts a year, as a for-instance.

Q Have you made an attempt, Dr. Bush, to try to ascertain any of these variables, such as material strength, yield strength, things of that nature, with regard to the replacement crankshafts?

A I've looked at the information. If you mean, have I attempted to sit down and do a calculation on there, the answer is no. In the first place, I am not a diesel expert by any stretch of the imagination. I am mainly a metallurgical engineer. And to me, the most critical parameter would be the actual stresses that exist and the stress distribution that would exist, particularly in the fillet regions.

Q Have you attempted to read any of the FaAA reports on either the 13" x 11" crankshafts or the 13" x 12" crankshafts to ascertain what those stresses may be in the fillet surfaces or beneath the surfaces?

A I believe I've read all of them at this time. I haven't-- I don't believe I'm up-to-date on perhaps the testimony that has been submitted lately. But any FaAA report, formal report, I have reviewed and commented on.

Q Dr. Wells, Mr. Scheidt asked you several questions this morning about a figure which FaAA originally had with regard to the increase in endurance limits in its April report on the replacement crankshafts and the fact that in the May report no quantitative figures was given.

Do you recall that series of questions and answers?

A (Witness Wells) I do, Mr. Stroupe.

Q Since the time of those reports, have you had occasion to form any opinion as to whether or not the endurance limits of the replacement crankshafts at Shoreham have been increased as a result of the shot-peening by

Metal Improvement?

A Certainly, I have an opinion. The opinion is based on the fact that for many years, as I previously stated, I was responsible for mechanical properties of materials and structures at Pratt & Whitney Aircraft, which is and has been one of the foremost companies involved both in the development and, certainly, the application of shot-peening to critical rotating parts. In fact, the aircraft that all of us will be flying on eventually you will find upon close scrutiny to have shot-peened splines, shot-peened discs, to hold the blades in place. And all this experience was essentially compiled during the time that I was in responsible charge of much of this work at Pratt & Whitney, including original research that we conducted on the effects of shot-peening on the properties of steels and other alloys.

In my professional opinion, the effect of shot-peening, and the basis on which I made the recommendation in the first place for LILCO to have the crankshafts shot-peened, would be that the endurance limit increase at a minimum would be 10 percent, and could conceivably be as high as 20 to 30 percent.

MR. STROUPE: I have no further questions.

JUDGE BRENNER: Staff.

MR. GODDARD: Thank you, Judge Brenner.

CROSS-EXAMINATION

BY MR. GODDARD:

Q Mr. Burrell, do you know the location of maximum stress in the fillets?

A (Witness Burrell) It will typically be in the center of the fillet.

Q By "center," you are referring to from one edge of the fillet to another; is that correct? I'm just asking for a clarification of your use of the term "center." Or are you talking in terms of depth?

A I'm talking about the center of the circular radius.

Q The center of the circular radius.

Do you know whether the location of maximum stress on those fillets is surface or subsurface?

A It should be surface.

Q If the location of maximum stress was removed from the surface of the fillet, what effect would the shot-peening procedure have on the fatigue endurance limit of the crankshaft?

A How would the stress be moved from the surface?

Q If the point of maximum stress, in fact, were below the surface, what effect would shot-peening have on the fatigue life of the crankshaft?

Do you understand the question?

MR. STROUPE: I would object on the basis that I don't know what is meant by "below the surface." Located how far below the surface?

JUDGE BRENNER: We will allow the question as phrased, and there can be a follow-up by Mr. Goddard or others, if necessary.

WITNESS BURRELL: Well, that's the problem I'm having right now. Like Mr. Stroupe, I don't quite understand "removed from the surface." The stress point will be the surface.

JUDGE BRENNER: "Removed" is a word that can have two meanings, and I think you're ascribing a different meaning than Mr. Goddard had in mind. He, therefore, asked a different question. He, therefore, asked the question in a different way, which did not contain that word "removed" in it. Maybe you had better ask it again, Mr. Goddard.

MR. GODDARD: Yes.

BY MR. GODDARD:

Q If the location of maximum stress was a location below the surface of the fillet, what effect would the shot-peening have on the fatigue endurance limit of the crankshaft?

A (Witness Burrell) It's not below the surface. It is at surface. Your maximum bending moment or torsional moment is at surface.

A (Witness Wells) May I respond to that?

Q Yes, please.

A FaAA was responsible for carrying out the experimental and analytical evaluation of the stress distribution through the critical areas, and the stress, most assuredly, is maximum. Range of stress is highest at the surface of the fillet in very specific locations with respect to the angle along the arc of the fillet and the angle about the polar axis of the crankshaft. In addition to that, FaAA did perform detailed investigation of the origin site of the failed 102 crankshaft, and looked in great detail, as much as was possible, at the other cracks that developed in the crankshafts from the 101 and 103 engines, and found that, in fact, initiation occurred at the surface from no subsurface origin. Therefore, I don't -- I believe this question is rather hypothetical.

Q Thank you.

MR. GODDARD: The Staff has no further questions for the panel.

EXAMINATION BY THE BOARD

BY JUDGE FERGUSON:

Q I would like to direct a question to you, Mr. Burrell. The question has to do with the part of your testimony that is found on page 14, and I read part of that statement in answer to Question No. 17. Do you have it before you?

A (Witness Burrell) Yes.

Q And I'm going to start reading from the part that says "It is my opinion." Okay; and I quote now.

"It is my opinion that the surface stresses in the fillet areas of the Shoreham replacement crankshafts have been placed in compression and that any cut, scratch, flaw, machine mark, and so forth, though deeper than the compression area itself, will not be the initiation point of a fatigue crack."

The question I would like to ask is: Can you tell me what is the nominal depth of the compression area produced by the shot-peening process?

A Based on the shot-peening parameters used, I would estimate it to be 30 to 35 thousandths.

Q 30 to 35 thousandths?

A Somewhere in that range.

Q All right.

Mr. Burrell, you are also co-sponsor of the testimony found on the following page, page 15, and this is in answer to Question No. 18. It is my understanding from reading the answers to your questions, that the effect of shot-peening, in effect, produces a compression stress on the surface; is that correct?

A That's correct.

Q And the last part of the statement that we just read indicates -- well, maybe I should ask whether or not the last part of the statement that we just read, namely, the part that says that cracks, that scratches, that a cut -- any cut, scratch or flaw will not initiate -- will not be the initiation point of a fatigue crack.

Can you tell me what you rely on for that particular statement?

A I'm relying on the fact that, being at the surface, a place of very high magnitude residual stress, which is an area of 50 to 60 percent of the ultimate tensile strength, that as long as the flaw on the surface is not deeper than that layer, the compressive stress from the shot-peening will mediate the notch effect of the imperfection.

Q So then is it true that you're relying on the compression -- the compressive stress on the surface when you make the statement that a crack will not initiate?

A It's a well-known fact that a crack, a fatigue crack will not initiate in nor propagate through a compressively stressed area.

Q So that's the basis for your statement there; is that correct?

A That's correct.

Q Thank you.

Now let's turn to page 15. In the answer we referred to earlier, part of that answer is -- and I quote, "residual tensile stress which may occur below -- " and I would like to correct this, since that is really not part of your quote.

Let me make a statement. The picture that I gather from your answer is that the surface is in compressive stress -- is that right? -- as a result of shot-peening?

A That's right. The surface and a depth of about 30,000, 35,000 below surface.

Q But at depths deeper than the number you just quoted there may be tensile stresses; is that correct?

A That is correct. It's a fact. However, when one looks at the fact that we only have 35 -- 30, 35 thousandths on each side or, say, a total of 60 to 70 thousandths under compression, you have the rest of that 13 inches over which to distribute the offsetting tensiles. And therefore, they become very insignificant.

Q In the last statement were you thinking of the engine running or not running or what situation were you thinking of?

A Which last statement? About the subsurface tensiles being very low and insignificant. That's in a running condition

Q In a running condition?

A Right.

Q You then say that in the answer to question number 18, that this residual tensile stress is additive only to the mean value of the operating stress and not to the range of dynamic stress. Can you tell me the basis of that statement?

A Yes. That was Dr. Wells' statement in the first place. But it has to do with the fact that the range may shift as a result of those tensiles but the actual range will not be affected.

Q Well, that's what the statement says. But I was wondering why -- what was the basis of it?

A (Witness Wells) Could I amplify that response, Judge?

Q Go ahead.

A The statement means that the maximum range of stress which causes the reversal of microstrain is maximum at the surface of the fillet. The range of stress as we have shown by analysis, and confirmed the maximum range experimentally, dies off quite rapidly below the external surface of the fillet.

Now, superimposed on this range of stress which comes from the torsional dynamic oscillation of the crankshaft, there is a mean value of the stress. There is of course a mean value of stress associated with the transmission of torque through the crankshaft to drive the generator.

In addition to that, but precisely the same physical consequence, is the mean stress that results from the plastic deformation introduced by machining and shot-peening.

The mean value of this stress does affect, somewhat, the endurance limit. But the effect of the mean stress is much less significant than the effect of the range of dynamic stress that produces the microscopic irreversible motions that lead to the nucleation of a crack.

Q Dr. Wells, thank you. That's very helpful in answering that question.

Very good. I have no further questions.

BY JUDGE BRENNER:

Q Dr. Bush on page 19 of your testimony, in the first answer appearing on that page, you are discussing the original shot-peening on two of the crankshafts performed under the auspices of TDI and you state, quote, "A definite plus was the report of visual examination and of magnetic particle testing at LILCO that confirm that the as-received surface condition after original shot-peening at TDI was acceptable."

I'm wondering why you assume that was the case, particularly given, among other things, LILCO's testimony and its answer 7 on page 8, discussing some of the problems with the as received condition of those two crank shafts after the initial shot-peening?

A (Witness Bush) Probably the answer was incomplete. I was concerned with whether there were either embedded flaws immediately below the surface that would have been detected by magnetic particle testing, or whether there had been a large percentage of broken shot with surface embedment, which would have been detected by visual. I was not so concerned with the incomplete coverage of the shot-peening in this instance.

I was, in essence, attempting to respond to the question about the covering of prior defects by the second shot-peening. And the answer in that instance was probably not complete.

Q Well, your answer was complete as to surface coverage because you covered that in the second phrase of that answer. What I was wondering about though, was the report in LILCO's testimony of unequal dimpling indicating the use of irregular sized shot and whether that is not inconsistent with the part of your answer that I did read to you.

A I don't consider such types of defects as having particular significance. There's been extensive work primarily by the British Welding Institute looking at planar flaws versus, what I would call volumetric defects -- of which dimpling would be an example -- where extensive fatigue testing was conducted, and even at levels of porosity in this instance, which would be an analog of this dimpling, far above what would be permitted a welder, there was little or no impact on the fatigue properties or the endurance limit.

In fact, the evidence was so conclusive that the British standard relating to this was changed and relaxed considerably. In other words they permit more. So these types of defects, I think, are inconsequential.

Q All right. On page 20 of your testimony, in the second full question and answer there, you begin to discuss the argument on, quote, "nucleation sites," close quote. I understand what you're saying there and in the testimony which follows that.

I don't see anything in your testimony directly discussing the County's argument that if there were such nucleation sites present the second shot-peening would cover up the evidence, so to speak, and you would not be able to find them. What do you think of that point?

A I guess that goes back to the question that you asked previously which was an attempt to answer that. And I considered that the testing that had been done, in essence, established the absence of nucleation sites.

I am starting out with an a priori assumption that I think I know what they mean by nucleation sites. This is usually used in a totally different context. But I'm assuming what they're considering here are sufficiently small, quote, "flaws" of a planar nature, that could serve as a point or a locus for fatigue to occur. So that you essentially get through the initiation process and start with the other one. But that's an assumption on my part.

Q Yes. I maybe should have started with that assumption. Also expressly I, too, was operating on that assumption which is consistent with the assumption made expressly in the LILCO testimony.

If there were such nucleation sites -- that is the incipient flaw that could later lead to failure -- present after the initial shot-peening -- is it feasible that such sites could be covered up, quote/unquote, by this second shot-peening, in the sense that they are still there but no longer ascertainable, whereas they would have been ascertainable before the second shot-peening? Or is that kind of a metaphysical concept, in the sense that if there was anything like that it might -- covering up might, in effect, be a curing by the second shot-peening?

A I would say this: That if the examination were limited to a penetrant test, which would only tell you if there was something at the surface, the answer is, conceivably, yes, you could cover something up.

If the "nucleation site" or defect exists within the disturbed zone, the zone of compression, and it is what I will call a real -- it has physical dimensions of a reasonable size, I would expect magnetic particle testing to detect it. I can visualize that such could occur.

A classic example is where you get a fold-over in something and then you peen on top of it, and if you have not removed that lap you certainly could get a condition such as we're discussing here.

Q In your conclusion -- you have already been asked about it -- you discuss your view that the ultimate test would be to operate the crankshaft to ten to the seven cycles and you've explained how that also relates to other aspects of the diesel engines and testimony by other staff witnesses.

But putting the other purposes aside and just focussing on the crankshaft, do you have any concern that testing to that extent could cause the early failure of the crankshafts after that -- by operation, after testing to ten to the seven cycles, even though examination of the crankshaft at ten to the seven cycles showed that they were still acceptable?

A I do not believe so, provided that there is an appropriate examination after the completion of the ten to the seven cycles. The answer is based on that premise. It has to be a good examination because what you are attempting to establish is whether you have gone through the initiation phase so far as crack formation is concerned and have not gone too far into the propagation phase. That assumes that there are loads sufficiently high to initiate a crack.

I would say that a careful penetrant and/or magnetic particle test should reveal this there. The reason I say it in that fashion is that ten to the seven cycles, if there is no evidence whatsoever of cracking, would indicate that we indeed are below the endurance limit, and therefore testing to ten to the eighth or ten to the ninth cycles under the same stress conditions, shouldn't have any particular effect. That's inherent in that premise.

Q All right. The other side of the coin -- and what I would like to ask you -- is why do you have to go as far as ten to the seventh cycles? Your previous answer leads to the inference that any problems you're going to have in terms of miscalculating the endurance limits would have showed up by ten to the seventh cycles. Why would that assumption not be true, let's say, at ten tc the sixth cycles?

A Well, let me go back a step further and take ten to the fifth cycles as a for instance. That's not very many hours of testing and it is quite possible that one could be

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well above the endurance limit but not across the line for intitiation of a crack under those circumstances.

I wouldn't argue whether one needs to test to ten to the seventh or say five times ten to the sixth, or something like that. I think it is simply some measure of conservatism because that would fairly clearly prove that we're below the point at which the curve flattens out and is parallel. That's really what we're concerned with under the circumstances.

Q Can you more precisely tell me when you're past the point where the curve flattens out?

A It's usually between ten to the sixth and ten to the seventh in most such fatigue curves. That presumes you don't have an original crack. That covers a period of initiation in there. If you have a crack then it's a totally different situation. It's a totally different situation under the circumstances and you're now not considering initiation, you're considering propagation. And you might say all bets are off under those circumstances.

Q All right. I don't want to go further with this at this time. I think we may get back to it with the Staff witnesses -- other Staff witnesses -- on crankshafts, and try to put together some of the testimony we heard already with respect to the knee of the curve and so on.

Changing the subject to the other portion of your testimony, Dr. Bush, you discuss the forging processes on page 15 to 16 of your testimony in just two questions and answers. I don't know what you're trying to tell me.

Are you trying to tell me that TDI used a process that they should not have used for forging the crankshaft?

A If I were to classify a series of processes to fabricate a crankshaft, this would not be my first choice, I guess is what I'm saying.

As I understand the process -- and you realize that I have not physically seen it. I had to interpret what was written on it in the documents.

Q You have not physically seen it?

A No. I have seen processes similar to this but I have not seen a TDI crankshaft fabricated in this nature. But I believe I understand what is done, namely, it is slab forged and then hot twisted. I would prefer a forging process that, in essence, works all sides of the billet so that the properties at the surface when I form it are more uniform. That would be a personal choice, preference, on my part.

Q We're talking about crankshafts that were fabricated by Krupp for TDI, correct?

A That's correct. I would say in that respect that I re-examined the available data and the billets apparently were quite clean. I looked at all of the available ultrasonic data, the magnetic particle testing, eddy current testing data, and generally I was somewhat surprised to see that they were as clean -- they were reported to be as clean as they were. I would have expected more stringering, possibly, even with that melting process near the center.

Q All right. Thank you, that's all I have.

A (Witness Wells) Judge Brenner, could i comment on this.

We are fairly familiar with the fabrication process on the crankshaft that failed, of course. The records show that these ori inal crankshafts were essentially forged the same way, albeit, by a different vendor that is Elwood City. The failed crankshaft 102, we understand, was forged as a slab and then hot twisted.

Dr. Wachob performed extensive mechanical and metalurgical evaluaticns to identify some of the concerns that Dr. Bush expressed here, such as mechanical anisotropy of properties. And I'd like to ask if he would comment on the extent to which that was a problem.

JUDGE BRENNER: All right. Let me make sure that I understand. When you say anisotropic properties, you mean non-uniform properties?

WITNESS WELLS: Not so much non-uniform but different properties in different directions. Inhomogeniety would be the --

A (Witness Wachob) In the 13 by 11 crankshaft that we did examine, we took tensile specimens in a variety of directions. And they were relatively close to one another and do not show any effect of antisotropy. So therefore, I would believe that the concerns possibly of seeing variations in mechanical properties around the fillet area are very slim and very small. Just from the normal process, and then eventually the heat treatment that was followed.

Q Well, let me ask you and also Dr. Wells, together do you agree, however, with Dr. Bush that it would have been better to have used the other process in the first instance, the closed forging process?

Let me ask Dr. Wells and Dr. Wachob, since they followed up before.

A I believe that the idea is that the strength levels are met through the design of that crankshaft, and that this process provides an adequate product to do that.

You may have been able to pick another process that would have given you a little better, you may have been able to pick another process that would have given you a little worse.

But this is a quite adequate processing for this product.

Q That's the explanation, but you didn't answer my question.

I want the professional opinion of each of you as to whether from your point of view it would have been better in the first instance for TDI to have selected the process which Dr. Bush believes would have been a better process as an initial selection.

I understand all the work you've done on these crankshafts after they were made.

A (Witness Wells) My opinion is that far more important than the hot working processes is the question of the cleanliness and the qualities of the as-machined surface; that is to say, the cleanliness of the material throughout the ingot: initially this is where defects occur if they occur at all; primarily, though, the condition of the crankshaft at the outer surface.

Now, in the event that a higher strength level had been achieved by whatever type of forging operation or, perhaps, by different chemistry -- yes -- that could have been an advantage. But for the particular strength level that was specified, I do not believe that the method of forging has a significant effect. And on that basis I would not say that TDI would have been advised -- well advised -- or we would be better off now had the crankshaft been forged by a different process.

A (Witness Wachob) I agree with Dr. Wells' statement that the processing is very good. And I would not have believed that it was necessary to go to a quote/unquote, "closed forging process."

Q Do you agree with the first sentence of Dr. Bush's first answer on page 16 of his testimony, that the closed forged process crankshaft will have isotropic properties whereas the slab forged and hot twisted crankshaft will yield anisotropic mechanical properties?

A That was the portion of the work we did on the 13 by 11 failure, which is a hot twisted slab forged process -- shows that there is very, very little anisoptropic mechanical property in that forging. Therefore I -- although theoretically, closed forged produces more uniform working and therefore produces a more uniform product -- in this instance the slab forge and the hot twisted crankshaft had good isotropic properties for the size that we're dealing with.

Q All right. Thank you.

BY JUDGE MORRIS:

Q Dr. Bush, I have just one question. Before I ask it, out of an abundance of prudence, I should tell the parties that I've known Dr. Bush for at least a couple of decades, and during my service on the AEC Staff. But I assure there has been no ex-parte communication or no conflict of interest here.

Dr. Bush, at the bottom of page 19 the last answer which goes on over to page 20, you make a very general conclusion.

A (Witness Bush) Yes. Do you want me to clarify that?

Q And I'm wondering in reaching this conclusion you did examine it in enough detail to know that the kinds of materials, manufacturing processes, the magnitude and nature of the stresses, strengths of materials and so on, were applicable to a conclusion with respect to the Shoreham replacement crankshafts?

A I would say yes, in a general sense. The basis for this is I've chaired an ASME subgroup since its inception about 12 years ago, as a result of Hatch -- which you're well aware of, the Hatch problem with the flaw -- where we have used fracture mechanics procedures for the evaluation of the significance of flaws as a function of the material, the size of the flaws, the orientation of the flaws, and the location of the flaws.

And this is basically a follow-up, utilizing fracture mechanics principles to either elastic plastic fracture mechanics or linear elastic. In this case it would generally be elastic plastic fracture mechanics.

And we have done extensive parametric studies, as a precursor to writing code positions that are utilized in the analysis. The material compositions are not the same, but they aren't that much different. They're typical of low alloy steels.

The mechanical properties are within what I call the normal band. So I believe that one could extrapolate well.

And what one sees is that the significance from a stress intensity factor, as soon as the flaw is handled as an imbedded flaw, and as a rule of thumb that would occur perhaps half an inch or so below the surface, and even with severe bending moments. We did an analysis where we considered pure bending and then combinations of bending and tension.

I admit we didn't look at torsion because the objects we're concerned with didn't worry about torsion.

But I agree with Dr. Wells that the stresses are stresses, and you're concerned with direction; and not necessarily the initial source. And an embedded flaw in the significance of crack propagation has a probability of propagation -- assuming it exists -- that is a very, very small fraction of what occurs with the surface flaw. So that's one reason for my confidence in this statement.

The other one, of course, is that if you look at the distribution of bending moments in here --and I would agree that the bending stresses should maximumize at the surface -- as soon as you move down an inch below the surface, there's a very substantial difference.

And so everything tends to move you toward the direction where you would indicate that they're there. So the inference is from a different data source.

But I believe that the conditions are such that it would be a valid extrapolation to something such as a crankshaft.

Q Dr. Wells, is that conclusion consistent with your opinion?

A (Witness Wells) Yes, it is, Judge Morris.

Q Gentlemen, do you have the County's testimony handy?

Will you please turn to page 141 and I will read from about the middle of the page.

Quote: "The shot-peening procedure used for the Shoreham crankshafts will produce some real reliability problems. Prior to shot-peening, areas adjacent to the fillet radii are masked off. This results in stressed (shot-peened) areas located directly next to unstressed (unshot-peened) areas. This difference in surface energy is the driving force for corrosion and environmental attack of the fillet and stress cracking." And so on.

I address the question to the Panel and any one or more of you may respond:

Do you agree with this statement or do you not?

A (Witness Wells) Judge Morris, let me begin. There are several points at issue here.

The first is that, although shot-peening does stress the surface of the part, it is also true that the journals and the unshot-peened areas that have been produced by machining -- by standard manufacturing lathe-turning procedures followed by polishing -- those processes have also left a surface stress, albeit confined to a very, very much shallower depth.

From a chemical standpoint then, I do not feel there is a, quote/unquote, "driving force" for electrochemical attack.

Furthermore if such situations did occur, obviously the presence of an electrolyte would be required in order to produce any mechanism for any type of corrosive action, since the only environment we know of in the crankcase in fact is, lubricating oil. And since the surfaces of the shaft are well passivated and are not chemically active I personally would find no basis for this particular concern.

Dr. Wachob, I believe, has familiarity with the electrochemical aspects of this alleged problem.

A (Witness Wachob) I think it is well recognized in the literature that cold working -- therefore shot-peening in this instance -- shows no difference on the corrosion behavior to that of an annealed material.

So therefore putting these two areas -- the cold worked shot-peened area in conjunction with the normal crankshaft area -- does not produce sufficient driving energies to result in significant corrosion of either one.

And again, in agreement with Dr. Wells, the fact that you need a strong electrolyte there to cause most of these problems, if you had a significant difference in energy levels, that's needed.

We don't have that.

So I believe that the statement here is not correct.

Q Thank you.

That's all the questions I have.

JUDGE BRENNER: Any follow-up since you last had a chance to question? First, by the County?

MR. SCHEIDT: Yes, Judge Brenner. Some brief questioning.

JUDGE BRENNER: All right.

FURTHER CROSS EXAMINATION

BY MR. SCHEIDT:

Q Dr. Wells, you stated you have an opinion about the increase in the fatigue endurance limit from shot-peening, based upon your experience at Pratt & Whitney concerning components such as splines and discs, isn't that true.

A (Witness Wells) Yes, but a great variety of parts not just related to shafts and discs and blading.

Q And how thin are those sections on those components?

A Well, it is not material. Of course, the effect of fatigue is confined to a very shallow depth, effectively the surface of the part.

But in any event, in answer to your question, some of these parts have hub thicknesses of several inches.

Q And what would be the largest section that was shot-peened in the materials that you're discussing?

A Well, the largest section would be for instance, the rim of a titanium fan hub for one of the larger fan engines such as the JT9D that powers the Boeing 747 aircraft. I don't recall the precise thickness of that rim.

The part itself, though, starts as a forging that is essentially a foot thick. And then it is machined down to something on the order of a six-inch or seven-inch or so section at the rim. And as I recall, it's thicker than that at the hub.

And this particular part is machined to prevent both corrosion, corrosion assisted fatigue, and fatigue damage that would result from poor tuning or poor match of the compressor stages that would result in the flutter and vibration of the blading.

Q Dr. Wells, FaAA's quality assurance program does not agree with your opinion, does it?

MR. STROUPE: I object to the question.

MR. SCHEIDT: His opinion that shot-peening increases the fatigue endurance limit of the shaft by 10 percent or more.

JUDGE BRENNER: Do you have an objection now that he finished the question.

MR. STROUPE: I withdraw the objection.

MR. WELLS: Mr. Scheidt, I hope the point is clear that the quality assurance program has to provide a basis for any numerical conclusion. It has to provide a measurement or a calculation.

It certainly does not apply to professional experience and professional opinion. I think all of us on this panel have a strong opinion as to the minimum amount of improvement that one could obtain by the shot-peening of a surface of a crankshaft or, for that matter, any other critically stressed part.

However, the quality assurance program is written very strictly and in fact our manager of the quality assurance program, Dr. Dwayne Johnson, is here on this panel. He may want to comment on what precisely is required, in order to obtain the quali' ' assurance of a FaAA report.

JUDGE BRENNER: Do you want that?

MR. SCHEIDT: I don't want that, Judge Brenner.

JUDGE BRENNER: All right. You can move on to your next question.

MR. SCHEIDT: Thank you.

JUDGE BRENNER: We will accept that as an offer and the way it works -- let me explain since it went beyond the particular question -- is if your own counsel thinks it's important, he can come back and pick it up.

BY MR. SCHEIDT:

Q Dr. Bush, isn't shot-peening generally more effective on thin sections of approximately one-inch, as opposed to thicker sections of approximately one foot?

A (Witness Bush) Not necessarily. You're concerned with a load condition. And fundamentally, what you are depending on in any process that puts the surface in compression and shot-peening, is only one of these. What you hope to do is, essentially, neutralize or reduce the surface stresses induced by the operation of the component. In this instance, I would consider that bending would probably be a major contributor and with torsion very close thereto, in regard to the surface stresses.

And since the point of initiation of the crack that you're considering generally will be at the surface -- I won't say invariably, but in most instances the -- I don't think the fatigue mechanism recognizes thickness per se, whether it were four inches or six inches or a foot. There is a point below which that is not true. In very, very thin sections it's difficult. But I'm talking of very, very thin sections in this instance.

I wouldn't anticipate any particular difference from two inches on up given the loading conditions.

A (Witness Wells) Could I point out that I think there is an erroneous assumption made here that it is section size that's important at all. Basically, fatigue critical areas are areas of stress concentration. These are small notches, small radii. And it is the scale of the stress concentrations that is pertinent to the fatigue behavior, and not the mass size of the part in which these machine details are accomplished.

MR. SCHEIDT: The County has no further questions, Judge Brenner.

JUDGE BRENNER: Does LILCO have any follow-up?

MR. STROUPE: Just a couple.

RECROSS-EXAMINATION

BY MR. STROUPE:

Q Dr. Wells, I believe you stated -- when you were testifying in response to one of Mr. Scheidt's questions relating to a 747 part -- you used the word "machined." Did you mean to use the word "shot-peened?"

A (Witness Wells) Mr. Stroupe, I was referring to the fact that a fan disc is machined from a large forging. Clearly it is shot-peened after the final machining of the part and final heat treatment.

Q Did you mean to say that the shot-peening -- rather than the machining -- was the application applied to increase the fatigue endurance limits?

A Yes, indeed. In virtually every component of an aircraft gas turbine, there has evolved over many years, applications of shot-peening originally to address some problem -- that is, a generic fatigue problem with a particular part.

But that has now advanced to the design of parts where the shot-peening is specified now as the final manufacturing operation in order to impart additional fatigue margin of safety.

Q Dr. Bush, in response to one of Judge Brenner's questions, you used the term fold over, I believe?

A Yes.

Q Did you see anything in the documents or evidence in this proceeding, the testimony that you've seen, that would indicate to you that the original TDI shot-peening on the 102 and 103 shafts contained any foldovers?

A No. I was simply using an analogy in response to the question. Quite often, particularly if you have mill scale or something of that nature, and you don't appropriatly clean a surface and then you further work it, particularly, if you're forming it and not simply rolling it, you can achieve what I was defining as a foldover or lap. In this instance, because of the fabrication process, I would not anticipate such a mechanism. As I say, I was using it solely as an analogy of how one could achieve the condition, the hypothetical condition.

Q Dr. Bush, is your expressed view in your testimony that the crankshafts should be tested to 10 to the 7th cycles, based on Professor Sarsten's calculations, as to the torsional stresses these crankshafts might see?

A In part, and the bending stresses also. I think the basic reason, of course, is that in any instance where one has had failures in a given class of components, the ultimate test is to take them to the point where they either have failed before they reached that point or they achieve that value, say, 10 to the 7th, and haven't failed, at which time you can infer that further operation under similar conditions should not result in failure.

Q Is that view of yours based at all on any concern that you have with the reshot-peening by Metal Improvement Company?

A No. It is based -- As I indicated earlier, if you exceed certain stress levels, regardless of the shot-peening, you may achieve failure. All that does is delay the onset of failure. If you are in the median range where shot-peening has a real advantage, conceivably you can have a failure in a nonshot-peened object, whereas you would not fail when it was shot-peened. I have not convinced myself that shot-peening is necessary for this particular geometry. This gets back to Dr. Well's -- I think -- last comment. I generally think of these in terms of fracture mechanics, and if I have relatively low stress concentration factors then I'm less concerned. I recognize any time I put a surface in compression I would achieve a net gain. Unfortunately, I don't like to operate at stresses close enough to the line that I would have to depend on shot-peening. That's really my concern there.

Q Thank you, Dr. Bush.

MR. STROUPE: Judge Brenner, LILCO has no further questions.

JUDGE BRENNER: The Staff.

RECROSS-EXAMINATION

BY MR. GODDARD:

Q Dr. Bush, other than testing, are you aware of any means which might quantify with confidence the effect of shot-penning on the fatigue life of a crankshaft of the approximate size and geometry of those used in the Shoreham EDGs?

A (Witness Bush) Yes, I think so. I guess if I were doing it -- Dale Rudd at Pennsylvania, has developed a very excellent device; in fact, I was just reviewing papers by him for publication in the last few weeks -- where he can go on almost any geometry or configuration and establish the residual stresses in an given location, recognizing that, for obvious reasons, you essentially are not measuring point stresses, you have to measure them over a finite depth. It is an outfit or a piece of equipment that is quite portable and would be relatively simple to conduct such a measurement. The other way -- I would not suggest that, that generally depends on destructive testing. You remove -- you peel off layers and observe the behavior, and I wouldn't suggest that on a piece of equipment that you're going to use.

A (Witness Wachob) Could I comment?

He had performed some of the residual stress analysis. for us on the original 13" x 11" crankshaft, and even in that instance where you had smaller pieces that we were able to give him, there is still a geometry problem of getting it in there and making the measurement in a really critical area. You can get in and make a measurement in dead center, but you're not necessarily going to get it out on the ends. So it's a good tool, but it's not as convenient to do every area, and therefore, you may not be able to do it in this instance.

Q That would bring us back to the area of testing, wouldn't it, Dr Wachob?

A Yes.

Q Thank you.

MR. GODDARD: No further questions.

JUDGE BRENNER: I think we have exhausted even the follow-up now; am I correct, if not the witnesses?

Actually, these witnesses are luckier than those who have been here for a full day.

We certainly appreciate the presence of all of you here to assist us in this endeavor, and I'm pleased that the time schedule was able to work out, since it is the end of a week, and that we finished, and you don't have to fly back here unnecessarily, or otherwise get back here.

For those of you who were not asked questions, don't feel badly, consider yourself for the better.

(Laughter)

But we appreciate your presence here and, of course, we, along with all the parties, have gone through the written testimony, and sometimes that's the reason why not all questions need be asked. And I encourage that in this hearing. People remember a lot of this information is already in writing. And I think that was done in this instance. And we note that and appreciate that also.

Thank you very much for your time. You're excused.

(Panel excused.)

JUDGE BRENNER: If we have nothing further for the week, we can adjourn. But Mr. Goddard doesn't want us to, apparently.

MR. GODDARD: I don't know if I would go that far, Judge Brenner. The Staff has one matter.

JUDGE BRENNER: I said that smilingly, I should note.

Go ahead.

MR. GODDARD: Earlier in the week the Staff indicated that they would make available to the parties the professional qualifications of Dr. John Tobin who may, if Dr. Bush is unavailable to testify on the subject of cylinder blocks, be called as an expert witness on that subject matter.

The Staff has been unable to obtain Dr. Tobin's qualifications from Richland, Washington, but hopes to have them available to the parties early next week. We have, however, been able to obtain Dr. Tobin.

That's all I have, Judge Brenner.

JUDGE BRENNER: Give us one moment.

(The Board conferred.)

JUDGE BRENNER: Mr. Stroupe, you had something.

MR. STROUPE: Judge Brenner, I have one thing. We have just learned from TDI that one of the panelists scheduled for the Block panel, Professor Wallace, apparently is not available on Monday, Tuesday or Wednesday of next week. He is available Wednesday, not available Monday and Tuesday. I understand the previous admonition that you have given to me. I just wanted to make that information public to the Board and to the parties, for whatever reason.

JUDGE BRENNER: All right. I appreciate that and appreciate your position in terms of the particular timing, which you have the right to emphasize, since you just learned.

I don't know, offhand, what that means. You'll have between now and Monday to figure it out from your point of view, and there is no point in my pursuing the question of why is he unavailable, and so. Whether or not that becomes pertinent, we can deal with on Monday, but beginning Monday, we will take up the LILCO testimony on blocks -- I'm sorry, we will take up the Staff's testimony on crankshaft, and I'm hopeful we will get to blocks sooner rather than later.

Are the settlement papers ready to give to us after we adjourn?

MR. STROUPE: My understanding is, Mr. Goddard signed one copy.

JUDGE BRENNER: I don't need them signed. I just need them to read, so I know what's going on.

MR. STROUPE: I believe it is.

JUDGE BRENNER: All right.

Let me say one other thing on the record. We expect, and if it has not occurred yet, I hope the parties begin doing the following, and that is, considering, as the proceeding unfolds, and as the evidence is being heard, whether or not there are areas within issues susceptible of further narrowing, in terms of what is in controversy. You certainly have done that with respect to the cylinder heads, so it's likely that my comment is totally unnecessary.

Also, we certainly observed in the earlier part of this proceeding that those types of ongoing conversations did occur, at least after we started encouraging them, although our encouragement was only necessary in the beginning.

And the parties, I think, deserve a lot of credit for the hard work that was done outside the hearing

4 WRBbw

room, as we endeavored to make clear in our orders and decisions from time to time.

We think that there may be areas, as we hear the testimony, susceptible of such narrowing, if not settlement, but certainly, at least narrowing. There are sub- within the issues, and we hope the parties will be discussing those.

We understand that we are only hearing part of the case at any given point, and we have the written testimony of all parties, and as the testimony unfolds, we get more information through the cross-examination. We know that much, but the parties know that, plus what they think will be coming in later through cross-examination. And I think there are some areas that may be susceptible of narrowing. I may be wrong, and I'm certainly not prepared to go into detail, at this time, at least, but I want the parties to be actively considering it among themselves and with their clients, and then with each other, as the parties have apparently done with respect to the heads. And I will leave you with that word.

All right, we can adjourn for the week, and we will be back here at 10:30 on Monday morning.

Have a good weekend.

(Whereupon, at 12 noon, the hearing was adjourned, to reconvene at 10:30 a.m., Monday, September 24, 1984.)

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 PROCEEDINGS: Long Island Lighting Company
Shoreham Nuclear Power Station

DOCKET NO.: 50-322-OL

PLACE: Hauppauge, New York

DATE: Thursday, September 20, 1984

were held as herein appears, and that this is the original transcript thereof for the file of the United States Nuclear Regulatory Commission.

William R. Bloom /sg

WILLIAM R. BLOOM
Official Reporter
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