ORIGINAL

UNITED STATES
NUCLEAR REGULATORY COMMISSION

IN THE MATTER OF:

DOCKET NO: 50-322-OL

LONG ISLAND LIGHTING COMPANY
(Shoreham Nuclear Power Station)

LOCATION: HAUPPAUGE, NEW YORK

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UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

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In the matter of: :

LONG ISLAND LIGHTING COMPANY : Docket No. 50-322-01

(Shoreham Nuclear Unit : (OL)

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State Office Building,

Veterans Memorial Highway,

Hauppauge, New York

Tuesday, 23 October 1984

The hearing in the above-entitled matter was convened, pursuant to adjournment, at 9:00 a.m.

BEFORE:

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

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

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

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APPEARANCES:

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On behalf of the Intervenor, Suffolk County:

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C O N T E N T S

Witnesses	Cross
Roger Lee McCarthy)	24,525
Harry Frank Wachob)	
Charles A. Rau)	
Clifford H. Wells)	
Edward J. Youngling)	
Craig K. Seaman)	
Duane P. Johnson)	
Milford H. Schuster)	

Exhibits	Identified	Received
75 Suffolk County Pages 11, 12, 21, 23, 27 and 39 of FaAA eddy current exam report	24,598	24,600

Morning Recess	24,577
Luncheon Recess	24, 616
Afternoon Recess	24,678

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PROCEEDINGS

JUDGE BRENNER: Good morning.

If there are no preliminary matters, you can continue your cross-examination, Mr. Dynner.

MR. DYNNER: Thank you, your Honor.

Whereupon,

ROGER LEE MC CARTHY,
HARRY FRANK WACHOB,
CHARLES A. RAU,
CLIFFORD H. WELLS,
EDWARD J. YOUNGLING,
CRAIG K. SEAMAN,
DUANE P. JOHNSON,
and
MILFORD H. SCHUSTER

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

CROSS-EXAMINATION (Continued)

BY MR. DYNNER:

Q Gentlemen, yesterday I asked you, and I think I asked you specifically, Dr. Wells, to please confirm to me whether or not Table 3-2 on page 3-9 of the FaAA block report is true and correct but for the information regarding the TDI gages.

You have now had an opportunity to review that

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information. Do you have an answer?

A (Witness Wells) Yes, Mr. Dynner.

It cannot be stated categorically either Yes or No for the following reason, that the numbers in that table were in fact not subject to our QA program. And while at the time of the draft report they did represent our best calculations and interpretations of the block top situation, those particular results and those models have been replaced by models with greater resolution and greater accuracy.

The reason for such replacements, as you noted yesterday, the fact that TDI strain gage data was used in preparing Table 3-2 of the draft report. In addition to the use of the TDI data, we had other developments subsequent to that report that resulted in our changing the models.

For one thing, after we had investigated the properties of the old EDG-103 block we found that our assumption of the mechanical properties, namely that the modulus should be 16 million pounds per square inch, Young's modulus of elasticity, was not correct, that for the degraded material, the proper value of Young's modulus by test should have been 12.8 million pounds per square inch.

We also refined models for the reason that we were not content with the overly conservative estimates in our client's work; that is, the diesel generators' owners group were not content with the degree of overconservatism

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that was inherent in our early simplified models.

As you are aware I believe, the normal approach in the design review of a component is to start with the simplest, what we feel are the most cost-effective conservative analyses. After going through such conservative analyses, where we find that the degree of conservatism is excessive and the calculations place an onerous burden either on maintenance or on operation of the particular component, then it is of course necessary to go into greater detail to develop models that are of course more complete, more complex necessarily, in order to obtain the accuracy in the prediction of structural integrity.

Specifically we decided that we had to perform a number of calculations that would allow us to vary parameters such as gaps, clearances, and material properties to scope the cause-and-effect relationships between the various loading conditions and the block top stresses. These conditions of course comprise the thermal mismatch between the liner and the block, the internal pressure in the cylinders and the pre-load effect on the torquing of cylinder head nuts.

This required us to look at a variety of boundary conditions in combinations on these loads so that we more thoroughly understood the effect of such conditions on the block top stresses.

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We also realized at that time that some of the assumptions, particularly involving the presence of cracks in our two-dimensional models, were grossly overconservative, and we were obliged to develop three-dimensional finite-element models. And in some cases we added additional elements to our existing models to make them more complete and more accurate.

Thank you.

Q All right.

I would like to back up a minute, Dr. Wells, so I could have a better understanding of the specifics of that answer.

First of all I'm curious. You keep referring to this as a draft report. The first page of the report says that it is final pending confirmatory reviews required by FaAA's QA operating procedures.

Isn't it a fact that this June 1984 block report was issued and circulated by FaAA to the parties, to the NRC, as a final report pending these confirmatory QA procedure reviews, and that it was not a draft?

A No, sir, that's incorrect. The purpose of that report was to provide information to the best of our ability at that particular date. And as you know, under the rules of quality assurance, a report cannot be final, cannot be anything more than a draft, until it has been reviewed and

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signed off.

We did not and could not in that particular time period complete the review of all the calculations and assumptions and therefore, that report was issued to the TDI diesel generator owners group merely as a summry of the best of our knowledge and conclusions at that time.

Now the objective of that report, which was the final contribution to the DR/QR report on the Shoreham engines, was to provide a conservative estimate that at least would substantiate some amount of safe operation of those engines. If we had not been able to conclude that there was some period of safe operation, of course that report would never have been issued.

So the purpose of the report was to summarize our conclusions as to the best period of safe operation, together with restrictions as to operation and maintenance procedures in order to give Long Island Lighting Company some idea of the maximum life which at the time we were comfortable with and could stand behind.

Q Why does the cover page say the report is final? If it was a draft why doesn't the page say draft?

A At that time the report represented the conclusions as of the date of the issuance of that report which we had intended to make a final report, subject to our QA procedures.

WRBeb

Now in going through those QA procedures over the intervening weeks and months now admittedly we have found it necessary in some cases, appropriate in most cases, to make a number of changes. We found it necessary to make changes in the material properties because we had found that the material of the 103 block, as I stated, that was employed for the strain gage measurements had a different stiffness, and it was necessary to change those numbers.

It was necessary to remove any reference to the TDI strain gage measurements because they could not be independently confirmed and documented.

And it was desirable in a number of cases to achieve this additional completeness and accuracy so that we could offer the owners of these engines a much less restrictive maintenance and operating program. By that I mean add additional periods of operation without the necessity to perform intermittent inspections.

Q Have you now at FaAA completed your quality assurance review of this June 1984 block report?

A We have concluded the quality assurance review of the material that you have today in testimony, and that will be issued forthwith as a final report--

Q That is not the question, Dr. Wells. I am going to interrupt you because you didn't answer the question.

I said have you now completed your quality

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assurance review of the June 1984 block report?

A The draft report has been subjected to our QA program, and those portions of that draft report issued in June that we have maintained to this date have in fact been reviewed and approved by our QA program.

All of the additional information, all of the additional tests and the models' material data, fracture mechanics calculations, whatever they may be, have also been subjected to our QA program, have been approved, reviewed and are final as of this time.

Q And is there some final report now that we can all have the benefit of so that we know what you have now concluded after these months of quality assurance review and changes?

A There certainly will be. The information that you have before you in our testimony represents these final conclusions and recommendations. And these final conclusions and recommendations and the bases for them will be issued as a final report.

Q But the parties, including Suffolk County and presumably the NRC Staff, have not been give the benefit of your final report which presumably sets forth the bases for your conclusionary statements in your testimony. Isn't that true?

MR. FARLEY: Objection, your Honor. He has

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stated twice that it is in the testimony and the supplemental testimony.

JUDGE BRENNER: It is sustained. It's argumentative to the point of not being conducive to developing any facts before us.

BY MR. DYNNER:

Q When is this final report going to be issued, Dr. Wells?

A (Witness Wells) The material has all been prepared. It is merely a matter now of our having the time to put together the editorial work, to conclude the drawings, to put the report into hard covers or final covers, and issue it.

May I have a moment, please?

(Pause.)

Mr. Dynner, the best answer I can give to your question is that as soon as these proceedings terminate, it will take us about ten days to two weeks to complete the final preparation of the report and make it available to everybody.

Q Let's take a look at Table 3-2 for a moment, Dr. Wells. Do you see the portion of that table which, on the left-hand margin, says "Between studs," and then "(for cracked ligament)" and then it says "FaAA gage No. 13" and under the column entitled "Stress in Ksi" it shows

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"Preload experimental 4.3."

Now assume with me for a moment that you still are talking about a table that would be applicable to normal Class 40 gray iron, cast iron. Have you changed the number 4.3 Ksi for the preload experimental figure?

A The strain measurement is correct. The gage readings themselves, the recording data reduction have been approved by the QA procedure--

Q Dr. Wells, it would be very helpful to me if you would answer Yes or No and then give your explanation.

Have you changed the number 4.3 in that column?

A We have changed the number 4.3 for the following reason, that in reducing strain readings to stress readings it is necessary to use material properties, specifically Young's modulus of elasticity.

Now that we know that Young's modulus of elasticity is different for the degenerate structure of the original DG-103--

Q Let me interrupt. I have told you to assume--

MR. FARLEY: I would request the witness be permitted to answer. It's responsive.

MR. DYNNER: There is no point in wasting time. I have told him to assume this was normal Class 40 gray cast iron.

JUDGE BRENNER: Let him finish the answer

WRBeb

nevertheless, Mr. Dynner,--

MR. DYNNER: All right. I am trying to speed things up.

JUDGE BRENNER: I know, and I'm going to speed things up soon enough, too, if this keeps up.

But putting that aside for now, I don't know at that point in his answer whether or not he needs to give that explanation or not.

MR. DYNNER: I'm sorry.

JUDGE BRENNER: I recall that limitation in your question, but he might still need that explanation, notwithstanding your limitation.

Dr. Wells.

WITNESS WELLS: Thank you, Judge Brenner.

I find it difficult to make categorical Yes or No answers to such a question without the proper context.

The number 4.3 is appropriate to normal gray cast iron, gray 40 cast iron with a modulus of 16 million pounds per square inch. However, I must also emphasize that the strain gage measurements were not made for such material.

WITNESS RAU: Mr. Dynner, if I might add something, it is even more complex than Dr. Wells, in trying to give a brief answer, has indicated.

Not only must the numbers change somewhat because the modulus of the original 103 block with the degenerate

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microstructure is lower than normal but in addition to that, in the old 103 block with the degenerate graphite structure, there was a difference between the elastic modulus, the stiffness of the liner which is typical gray iron, and the block.

Now that difference had to be accounted for also, once it was determined to be in existence, by additional analyses, and that has been done. So that it is not just the fact that the modulus of the block changed, it's the fact that on the original block we had a difference between the modulus of the block and the liner.

There is a lot of reasons why you can't-- The numbers were correct for the conditions analyzed at the time the table was produced, but they are not appropriate now having the realization that in fact we had degenerate Widmanstatten structure with lower elastic constants.

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Q Let me see whether I understand, Dr. Wells, with Dr. Rau's explanation.

Table 3-2 is based upon strain gage readings which were taken from the original EDG 103 block; is that correct?

A (Witness Wells) That's correct.

Q Your position is that the original 103 block contained excessive amounts of Widmanstaetten graphite such that it did not represent normal mechanical properties of class 40 gray cast iron; is that correct?

A It's correct. It is not a position, really. It's a simple test measurement.

Q And as a result then, the strain gage readings which were taken from the original EDG 103 block are no longer considered valid as applicable to the blocks of EDGs 101, 102, and the replacement 103 block; is that correct?

A The numbers in the table are appropriate only to the combination of modulus values, namely 16 million for the liner and 12.8 million for the block itself. Because this is a composite structure, it is not possible to make a ratio between the modulus values to covert from strain to stress. One has to go through a structural model of some sort in order to determine the relative stiffnesses of the liner and block and their interaction.

Q Is the answer to my question, then, yes?

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A Would you repeat your question, please?

Q Isn't it true that because the strain gage tests were performed on the original EDG 103 block with, what you claim to be, a degenerate Widmanstaetten graphite that reduces or changes the mechanical properties of that block material, that those strain gage data are not applicable directly to the EDG 101 and 102 blocks and the replacement blocks for EDG 103, which have different properties?

A Yes. As I stated earlier, I believe the numbers do not apply to the different modulus blocks like EDG 101 and 102. The numbers have to be modified by calculation and they are not directly interpretable but must go through this intermediate calculation.

A (Witness Rau) Let me add something to that. We have to be careful we understand what we mean by directly here. Certainly the strain gage measurements at gage position are appropriate for analyzing 101, 102, and the new 103. It's just that you've got to take the number precisely which is measured from the strain gage, multiply by one number, and then draw conclusions about 101, 102, and the new 103. But you can, through the finite element analysis which we have performed, make an additional calculation which enables you to utilize that measurement to predict what is going to happen in 101, 102, and the new 103.

Q And where does that additional calculation appear

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in your testimony or the block report, if it does?

A It does, Mr. Dynner. If you look at Exhibit 48, we have presented in the testimony scale factors which used in conjunction with the strain gage measurements reported in the testimony and also included in this table, enable you to calculate the appropriate stresses at different locations and the 101, 102, and the new 103 block. And, in fact, enable you to generate the results you're asking about.

Q Where are those scale factors? Can you identify them in this exhibit that you're talking about?

A Yes. The entire exhibit are scale factors for different conditions. If you look at the -- there are three columns, the center column and the right column labeled "Uncracked ligament" in the center and "Cracked ligament" on the right are both -- are all scale factors as are the numbers down below those two columns. Various combinations of these scale factors are used to compute from the strain gage measurement at position 13 between the heads on the block top what the stresses would be in the ligament area, between the stud and the counterbore, or what they would be at the location between studs.

If you look at the lefthand column you see "ligament" noted at the top left and "stud to stud" noted in the middle. So those scale factors in the upper portion of the table, in that region demarked by the horizontal lines

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with the ligament in the upper left, are appropriate to the ligament region of the block top, that is, between the stud hole and the counterbore. And those scale factors below that horizontal line in the region noted "stud to stud" in the upper left, are appropriate scale factors to obtain the stresses at the edge of the studhole, between the studs, from the strain measurements at gage position 13 that were made on the original 103 block.

Q Now, Dr. Rau, as you well know Exhibit B 48 is another one of these exhibits that was originally submitted with your August 14 testimony and was later revised. And I have the revised version as well as the original version. And I'm going to explore with you the revisions that were made and ask you why they were made.

The original Exhibit B 48 is identical to the revised Exhibit B 48 with the following exceptions: First, in the column entitled "Uncracked ligament" opposite the words, "100 percent on liner 321" the original exhibit showed a number of 1.08. The revised exhibit shows a number of 1.21. Why was that change made?

A The change you're referring to was made because of the quality assurance review at failure analysis which, in fact, had indicated a transcription error. More precisely, in fact, the quality assurance was done at the time the exhibit was filed with the testimony but,

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unfortunately, the uncorrected table got included with the exhibits not the corrected one and we merely replaced, for both this one and the other change -- which you're going to get to I'm sure, if I might just shortcircuit it -- the number at the far right, the 4.29 which was originally 4.22 was a transcription, just a, you know, a numerical error which had been corrected and just swapped, if you like, in the exhibits.

Q The other changes are that in the bottom portion where it says "additional relationships" where it says, "cracked block/uncracked block" originally it said, "equals" in the second line, "1.3442 thermal end pressure." The revised version now says "equals 1.26 thermal."

Why was that change made?

A Mr. Dynner, the reason the single line in the original exhibit was replaced by two separate ones, in particular, your question asked why it changed from a single number related to thermal end pressure to a number with only the word thermal, you have to also add that on the fourth line there's an addition to Exhibit B 48, which includes a new number for pressure alone.

Now the reason that there's now two numbers rather than one is a separation of the scale factors associated with the thermally induced stresses, that is, due to the expansion of the liner against the block as opposed

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to the scale factor associated with the pressurization of the cylinder during the firing. In the original exhibit, which was prepared when the pressure analyses were being performed in the same way as the termal analysis, we had identical scale factors. As part of our improvement and refining of the analyses, we refined the pressure portion of the analysis to consider the fact that the cylinders were not being pressurized simultaneously -- adjacent cylinders were not being pressurized simultaneously. That refinement lead to slight changes in the scale factors for pressure and thermal. And because they were no longer considered to be identical they were separated into two separate factors and those are, in fact, included in these figures you made reference to.

Q And the figures are different also, aren't they? The original gives a figure of 1.342 for thermal end pressure and your revise says 1.26 for thermal and 1.28 for pressure. Why are those numbers now different?

A Again, I don't recall the precise reasons for that number change except what I have already indicated to you. We refined the analysis for the pressure and we refined the analysis for the thermal also. My recollection is that we produced additional -- one minute, please.

(Pause.)

Mr. Dynner, in refining the models, which we did

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between the preparation of the draft report and the finalization of our testimony and exhibits, as Dr. Wells indicated, we expanded the modeling to include three dimensional finite element models, which included the ligament crack in the three-dimensional model.

Because we changed from a two-dimensional finite element model to a three-dimensional finite element model, the rations or the scale factors changed when we were dealing with cracked versus uncracked. In other words, the uncracked results were less effected by a refinement than were the cracked models. Perhaps to make this understandable, the two-dimensional model, when you put a crack between the stud hole and the counterbore, in a two-dimensional model, that crack effectively runs all the way from the block top, all the way down to infinity or all the way through the entire block at that location.

That, of course, is not representative of physical reality. Physical reality is that the ligament crack extends from the block top down to something less than about an inch and a half. And the material below that is still there in the block top and is resisting opening and loading of the balance of the block top.

For that reason when you go from a two-dimensional to a three-dimensional model, there's a considerable difference in the stresses generated between

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the stud-to-stud locations when there's a crack an inch and a half deep compared to what was, effectively, a crack which was very, very deep. And those changes have lead to modifications in these scale factors.

Q Now, when did you make the changes, specifically that are reflected in this revised exhibit? What date was this revised exhibit prepared?

A Mr. Dynner, I don't have a specific date. I can tell you, though, at the time that the testimony was filed, this revised exhibit was in existance. And it was just, as I've mentioned to you, it was flopped with the pre-existing one in the submittal. So it's some time prior to August 14.

Q Now, would you tell me where in your testimony there is a description of the meaning and/or significance of the revised Exhibit B 48?

A Mr. Dynner, I mean, I'll attempt to answer that if you like, but I'll have to read through the entire testimony to attempt to locate all those locations where there might be some reference made to this.

Q Well, maybe some of your colleagues can assist you who are more familiar with the testimony than you may be.

A I'm completely familiar with it, Mr. Dynner. There are various places where it comes into fact.

Q All right. Why don't you tell me some of them,

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if any? Anyone from FaAA can answer.

JUDGE BRENNER: How about if Mr. Farley has reference. Is that all right with you, Mr. Dynner?

MR. DYNNER: If he can give me a reference to it, sure, that would be helpful.

WITNESS FARLEY: Why don't you start with page 44?

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WITNESS RAU: Mr. Dynner, there is no question that many of the questions and responses, number 59 starting on page 42 and continuing through question 64 at page 48, make use of the results of these scale factors and calculations to various degrees and in various ways. As I stated previously there are no doubt other areas throughout the testimony which also make reference.

BY MR. DYNNER:

Q Now this statement in your testimony on page 44 says that the additional analyses were performed to study the effect of preload distribution on stud-to-stud stresses.

Going back for a moment to table --

A (Witness Rau) Excuse me, where are you reading from?

Q I am reading from page 44, the last sentence of the first paragraph.

JUDGE BRENNER: It is the paragraph that continues over.

WITNESS RAU: I've found it. Thank you.

BY MR. DYNNER:

Q Now going back to Table 3-2, the Block Report, for a moment, using the scale factors that you have referred to in the revised Exhibit 48, can you tell me now what would be the preload stress number which used to be 4.3?

A (Witness Rau) Mr. Dynner, you haven't given me

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enough information to give you an answer.

Q Well I am trying to get the information from you, I'm not trying to give you information, sir. I'm trying to understand from you gentlemen how the additional analyses that you performed with the 3-D finite analysis and the application of Exhibit B-48 would affect or change the stress figures that are given in Table 3-2, so that I can figure out and the Board can figure out how the information concerning the stress on the block top has been changed. And we can do that in a numerical form that is convenient for us to understand if you will cooperate and try to giveme the information as it is now modified.

I would like to know how the figures on Table 3-2 where it says between studs for cracked ligaments and it gives numbers for prenode experiemental, thermal experimental, pressure range experimental and analytical at various load levels for FaAA gage number 13 and for the block top at stud hole location two. I would like to know whether you can tell us what those numbers are now that you have done these additional analyses.

A Mr. Dynner, as I mentioned, this is a complex issue because there is not a single answer to your question. It depends on specifically what conditions you want the answer for.

For the particular -- Let me take an example and

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try to give you what I think you are asking for.

The 4.3 you are referring to in the draft report, Table 3.2, is the strain gage reading at gage position 13 modified or scaled, if you like, for the position between the studs with a cracked ligament already in place. Okay?

For that condition -- and clearly with the -- assuming typical gray cast iron material at the time those numbers were taken, to get the corresponding number from Exhibit B-48 and the testimony you would take the original strain gage measurement, which is not shown in this particular table, and you would multiply it by the factor sho n at the bottom of Exhibit B-48, that is, the ratio, the number 1.1 which corresponds to good material to bore material to reflect the difference between the old 103 block and typical cast iron. And to get to the stud-to-stud location, you would then divide by, for the preload conditions, the third of those three factors listed below which is cracked block/uncracked block, the 1.06 factor for preload conditions.

And those two factors together, in conjunction with the original strain gage measurements would give you the appropriate preload stresses, taking into account the preload stresses and taking into account the difference in the materials, properties that was present in the original 103 when these strain gage measurements were made.

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Let me go one step further and perhaps I can shorten --

Q That number would be practically unchanged then, isn't that right?

A In fact it does not change very much, that's correct. But you can't -- the number is in the high 3's, that's my recollection, something like that, when you go through that process.

But let me try to short-circuit this if I can, Mr. Dynner. This Exhibit B-48 is an intermediate exhibit which goes from, if you like, the strain gage measurement at gage position 13 which are presented in the testimony. It enables you to calculate -- enabled us to calculate a conservative bound on what the block top stresses might have been in order to consider whether or not fatigue crack initiation was possible.

We have utilized Exhibit B-48 in order to go from the strain gage measurements at position 13 and to compute a conservative bound on the stresses at the ligament location and the stud-to-stud location at the stud hole edge. And those specific numbers, the results of going through this intermediate step at B-48, result in Exhibits B-49 and B-50. Those two are Goodman diagrams on which are plotted the results of going from the strain gage through these factors and generating the alternating stresses, that is,

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the cyclic stresses which are associated with cylinder firing and the mean stresses which are the result of both preload and thermal conditions.

So the results are there presented in Exhibits 49 and 50.

Q Looking at Table 3.2 for a moment, assume with me for a moment that -- or let me ask you this:

If one were to add the preload experimental stress figure plus the thermal experimental stress figure plus the pressure range experimental stress figure, that would give one the total stress at that point on the block top, wouldn't it?

A Mr. Dynner, it depends on what point in the firing cycle you are talking about. Certainly if you add -- for the conditions which were analyzed and reproduced in Table 3.2, which is a hypothetical situation, these numbers were created assuming we had uniform typical gray cast iron properties in a strain gauge test which didn't exist. But if you make that assumption then what you said is generally true: if you took the preload stress, added to that the thermal stress, you would have the steady stress and the pressure stresses would then be cyclic, if you like, producing a cyclic stress over and above that superimposed upon it, if you like.

Q All right.

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If you then compared that total stress number with the tensile strength, the UTS of the material, that would tell you, wouldn't it, whether the material was going to crack or not, isn't that right, because that would tell you whether the total stress at some point exceeded the UTS, is that right, Dr. Rau?

A Well that is not completely correct. The second part of your question is correct: that is, if you add the numbers together and that number exceeds the ultimate -- the tensile strength of the material, then that is a statement of fact that it exceeds the tensile strength of the material.

But in point of fact, you have to have the stresses exceeding the tensile strength of the material over a significant volume of material in order for the material to break, you can't just have it at one point. So it is not necessarily correct that you will get failure of the material whenever the stresses at one point exceed the measured tensile strength or the tensile bar because of the tensile bar, that stress is applied uniformly over the entirety of your test bar whereas in this case we have much higher stresses localized at the very edge of the stud hole, for example, and those stresses decrease and are very much lower both as you move away from the stud hole toward the stud-to-stud region and they also become much lower as you

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move down from the top of the block toward the bottom of the block.

Q To clarify: I am talking about precise positioning of the FaAA gage Number 13 and of the block top at stud hole location number two, which is what your table refers to. And I think you testified you thought that placement of those points was the most significant in order to conduct your analyses.

So at those points it's true, isn't it, that if you added those numbers together and if they came up with a stress number that was higher than the UTS of the material at that point, you might expect that a crack would initiate, isn't that right, at that point, which is your point, not mine?

A I tried -- on that last question and perhaps you didn't understand me.

If in fact the numbers which were present at gage 13 were the same magnitude, if they did not decrease with depth away from the block top and if in fact the numbers were not conservative and if in fact they were appropriate for the correct mix of the lineup modulus and the block top modulus -- in other words, if you had a big region where the stresses in fact exceeded the tensile strength of the material, surely it would crack.

But in point of fact, just because the stresses

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at the block top where they are high exceed a conservative estimate of what the ultimate tensile strength might be doesn't necessarily mean that you are going to get cracking.

Q Well it would be more likely that it would crack than not, wouldn't it?

A No, you can't even say that. Because again you can't compare conservative estimates of stress, upper bounds on stress, if you like, with lower bounds on material properties and say you will get failure. What you can say is you can compare upper bounds on stress and lower bounds on property and say you might get failure.

Q I said more likely than not. I didn't say you will.

A I agree and I listened very carefully and you cannot say that. You can't say it is more likely than not. I would just state again that you can only say it might happen.

Q Isn't it true that the strain gage readings did show that the stresses at full load and at 110 percent of load exceeded the tensile strength of the material at the point of those readings?

Dr. Wells, can you answer that, since you are giving this testimony on the strain gage now that Mr. Taylor is not with us?

A (Witness Wells) Yes, I can, Mr. Dynner.

WRBeb

Could I ask you to refer to our Exhibit B-30? Or I can explain the readings of the particular gage No. 13. For the benefit of the Board, may I just explain what this figure shows?

On the left side you see the effect of preload as the cylinder head nuts are torqued first on the cylinder that is on one side of the gage location and then -- This would be No. 5 first -- and then the cylinder head nuts on the adjacent cylinder on the opposite side of the gage are torqued.

And you can see both the transverse -- and transverse in this case means perpendicular to the line between the center of the stud holes, and that is the stress component that would tend to produce this crack that we looked at yesterday afternoon. And longitudinal, of course, gage 11, means the stress in the direction along the line which is not the crack direction.

You can see that as load is applied, the gage reading which is now properly corrected for the material properties in order to convert the strain readings of the gage to the local stress reach a certain value after torquing, followed by the heating of the engine.

The heating of the engine itself will tend to redistribute the stresses and in particular, when the load is applied and the temperature in the cylinders continues

WRBeb

to increase, you see a gradual increase with load after the engine is stabilized, shown on the right-hand side of this figure, where we have indicated both the maximum of the range of the stress cycle as the engine fires, and the minimum value.

The sigma one max means essentially the maximum value of the tensile stress perpendicular to the line connecting stud holes where cracking is observed in this specimen that we have looked at. The sigma one minimum means that corresponding stress when the firing pressure has been removed and the only pressure acting on the cylinders is the turbocharger discharge pressure.

You can see that that minimum stress gradually increases with load. The reason for that is that the liners are all being heated to some average temperature depending on the peak firing temperature of the gas. This is what we call the thermal stress.

The base line, if you will, from which the pressure stress is exerted represents the essentially steady state expansion of the liner along with other temperature gradients that are introduced in that vicinity.

So if one were interested in calculating the stress at any location other than the gage reading, one would select the load level from this figure in B-30, would take that stress value and scale it by the appropriate

WRBeb

factors in Exhibit B-48 in order to go from the gage location to the edge of the stud hole or anywhere else throughout the block top region.

Dr. Rau wants to amplify that.

Q I don't know whether you've answered my question yet. I don't think you have.

JUDGE BRENNER: I guess you had better repeat it.

WITNESS WELLS: Perhaps if you would....

BY MR. DYNNER:

Q Isn't it true that the strain gage readings show that the stress at full load and at overload exceeded the tensile strength of the material at that point?

A (Witness Wells) At the location of the--

Q At the location of the gage, yes, sir.

WRBpp

A In answer to your question, the tensile strength measured by test bars minimum tensile strength, is exceeded by the maximum stress shown for gage 13.

Q And the test bar is not representative of the UTS of the block material, is it, Dr. Rau?

A (Witness Rau) The test bar is very definitely representative of the block material. I wanted to add something to the previous question, though.

Q Well, let me followup with this one first.

A Can I just answer or is that not appropriate?

Q I'd like to followup with a question.

JUDGE BRENNER: Frankly, I think the last few answers were not as directly responsive to the question as they could have been or, to state it more precisely, they seemed to wander beyond what was necessary to answer.

So let's stay with Mr. Dynner's points. I'll try to let you explain what you need to and we have been doing that but you tell your Counsel if something got misrepresented in the last series of questions, then he'll straighten it out. I'm concerned about the pace of the examination. Part and parcel with our concern with the pace is I want to allow the cross examiner to have better control on setting the pace and so that if I'm critical of it, it will be his problem and nobody else's.

Go ahead, Mr. Dynner.

WRBpp

BY MR. DYNNER:

Q Dr. Rau, what's the thickness of the test bar?

A (Witness Rau) The thickness of the test bar -- you mean the thickness in the gage section. I mean it varies in thickness from where you hang on to the specimen to where the center of the bar is.

Q Now Dr. Rau, you're testifying what the UTS of the test bar is. What's the thickness at the point where the UTS was determined?

A A quarter inch in diameter. That's the test bar itself. Of course, it is machined from the block, which is much thicker.

Q Well, it's not machined from tne block is it? It's cast separately from the block, isn't it?

A No, sir. The ultimate tensile strength which you asked Dr. Wells whether the minimum values were exceeded by the strain gages were, in fact, cut from the block tops of the old 103 block with the degenerate microstructure present between cylinders 6 and 7. They were cut from various positions starting at the top of the block and down through the first two and a half inches of the block top. And a large number of tensile specimens were presented and you've seen the results of those.

Those are the measurements. The minimum of which was exceeded by the numbers shown on Exhibit B 30. Clearly

WRBpp

those stresses at the position of gage 13 were not sufficient to crack that location during the tests, because there was no crack observed at that location after this stress was, in fact, seen by the material during our test.

Q Now, I'd like you to explain one more thing to me.

Would you please turn to figure 3-6 in the block report? Figure 3-6 in the block report is entitled "Principal stresses versus load for gages 11, 12, and 13, located between studs." It is the same title as is borne by Exhibit B 30.

Now, figure 3-6 was compiled from the actual strain gage measurements taken on EDG 103 according to the block report; isn't that right, Dr. Wells?

A (Witness Wells) Yes, that's correct, Mr. Dynner.

Q Dr. Wells, could you explain to me why the maximum stress -- that's the line going up the highest as I understand it on the righthand side at 35 to 4000 KW -- shows that it exceeds 20,000 psi in figure 3-6, but in Exhibit B 30 that same line shows that it is only somewhat in excess of 1600 psi. In other words, there's a -- your B 30 Exhibit shows a maximum stress of some 4000 psi less than is shown on figure 3-6. Why is that?

A Certainly I may have given you an incomplete answer to your previous question. The stress that is

WRBpp

represented in the figure 3-6 of the block report you referred to is, of course, calcuted assuming the modulus values and, at the risk of being repetitious, the strains are correct. The gage only measures the unit extension of the block top and it is necessary to calculate the stresses from those measurements.

Now, in this case because of the difference in physical properties of the material, the correct numbers for the old 103 block, which is the one the gages are on, of course, are different. Therefore, there is this difference between our Exhibit B 30 and figure 3-6 of the draft block report.

Q Do you know, Dr. Wells --

A (Witness Rau) If I might add, I could very simply resolve the issue I think, sir. If you simply take the stresses you're referring to in 3-6, realizing that the -- and this is approximate -- that the modulus of the degenerate graphite material is about 12.8 million. Divide 12.8 million by 16 million for typical graphite. You get a ratio. It's about .8. You multiply 20 by that ratio of .8, you'll get about 16. Now, it's a little more complicated than that but very simplistically, that's all we're talking about here. The strains are correct but because the material -- degenerate material properties -- the stiffness is different and therefore the stresses are different.

WRBpp

And the only difference between these numbers is, in fact, that the knowledge in the definitive measurements of the elastic constants and mechanical properties of the degenerative graphite which were made between the time these two exhibits were produced.

Q Does the presence of degenerative graphite change the UTS of the block material?

A Yes.

Q Would you have been able -- or were you able to determine by looking at the representative test bar taken from the original EDG 103 block that, in fact, it had a lower UTS than present in normal cast 40 gray iron?

A You misspoke I believe, Mr. Dynner. There was no test bar ever cut originally from the block top of EDG 103. There was, in fact, a separate B-bar -- test bar -- cast separately at the time of manufacturer, which was measured by TDI and the results of which have been reported. And we have subsequently actually cut specimens from the block top of the original 103 after it was removed from service. So we have direct measurements in the block top. Prior to those measurements that were never any mechanical tests done directly on the block top. You can't get the material without destroying the block top.

Q Are you saying that the test bar for the original 103 block would not have shown the different UTS than the

WRBpp

block itself, or it would have shown a different UTS, which is it?

A It definitely would have shown a difference. If, in fact, you had measured the ultimate tensile strength by cutting a sample from the EDG 103 block at the time of manufacture, you would have measured virtually identically to the numbers we subsequently measured after the block was scrapped, and is markedly different from the measurements of the tensile strength in the B bar, that is the 1.2 inch diameter separate casting, which is done routinely in the casting and verification of the class of the gray cast iron.

Q Well, which test bar were you talking about when you testified about five minutes ago that this test bar with a half inch diameter was representative of the material in the block in the UTS of it?

A Our direct measurements of what the block top tensile strength was. Our measurement.

Q Which test bar are you talking about? The one you said was representative, which one were you talking about?

A The ones that are representative, Mr. Dynner, are the ones which we cut from various locations in the block top, the original 103 block top. We cut a number of specimens -- I've forgotten the exact number, Dr. Wachob would tell us -- but five to ten specimens from different

WRBpp

locations and measured what the strength was. This is in the actual two and a half inch thick machine block top, which was originally cast as three and a half inches. Our samples are cut from that and are representative of the mechanical properties of the block top. They are the mechanical properties of the block top.

A (Witness Wells) May I suggest that reference to our Exhibit B 39 will indicate the locations of these test bars relative to the between-stud regions.

A (Witness Rau) Excuse me, it's B 38.

JUDGE BRENNER: No, it's B 39 that shows the specimen location.

BY MR. DYNNER:

Q Mr. Seaman and Dr. Johnson, you have now had an opportunity to review the eddy current test documents, which were furnished to you yesterday; is that right?

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

Q Now, is it true that these documents were taken from TER Q-465, which was part of the DR/QR review package?

A The document that you handed us yesterday is not the same as the record copy in our quality files of TER Q-465. The document we have found as a result of our review is actually from the support package in the engineering files back in FaAA's offices.

There are a number of differences between the two

WRBpp

documents. In summary, the document that you handed us contained some notes that the engineers had put on the document as well as pages 33 through 47, which are some engineer's sketches that were prepared to summarize the inspection results and to develop the original B 25 exhibit from the testimony that was filed on August 14.

Perhaps Dr. Johnson could add a little bit more.

MR. FARLEY: Judge Brenner, before I would do that, for the record, it should show that the document Mr. Seaman was referring to was the one that Counsel for the County asked to be marked for identification, Suffolk County Exhibit 75, which in fact, was not marked Exhibit 75.

JUDGE BRENNER: We know that. And you've got it again now.

BY MR. DYNNER: Now, looking for a moment at these documents which were in the support package as you have testified --

JUDGE BRENNER: We're going to hold off a further explanation because instead of getting abstract explanations and differences and similarities, you focus on the part you want to focus on. I'm explaining that for the witnesses.

BY MR. DYNNER:

Q Would you look for a moment at page 11, and I'm talking about the page references in the lower righthand corner of this document.

WRBpp

Now it's true, isn't it, that the document at page 11 with the attachment at page 12 constitute an eddy current examination report dated in the lower righthand corner 4-18-84 and signed by Don Johnson, is that right?

A (Witness Johnson) Yes.

Q Now, could you please -- one of you can answer, that would be fine. If the other person disagrees you can add. If you agree, you don't have to say anything. That's the general rules we follow in order to have some exedition here.

Take a look, will you, at Exhibit B 25 which again is the map of the cracks on the top of EDG 103's original block after the block failure in April of 1984.

Now it's true, isn't it, that this eddy current examination report shows that the depth of the stud number 3 on cylinder number 5 which, in the revised crack map, is shown as 0.85 inches in depth, is really 3 7/8 inches in depth at the outside of the stud hole running into the stud to stud crack?

A The 3.7/8 inch depth noted on the eddy current examination is also noted on the original Exhibit 25 as 3.9 inches.

Q So your answer to the question is yes? You meant 3 7/8, didn't you?

A 3 7/8 is 3. -- rounded is 3.9 inches.

WRBpp

Q So your answer to my question is yes, is that right?

I'm going to ask you again. It's very easy. If you'll just say yes or no and then you want to add an explanation, we'll all understand your answer.

The answer to the question is yes, is that correct?

A It is not the depth of the crack.

Q All right. What is it, then?

A Our estimate of the depth of the crack is 0.85 inches.

Q No, I didn't ask you that. I asked you what this report shows. I didn't ask you what your estimate is.

Would you please listen to the question and try to answer it yes or no and then you can give your explanation.

JUDGE BRENNER: That one was ambiguous, Mr. Dynner, because you said what is it and he was confused as to what "it" was a pronoun for. Why don't you ask it again?

BY MR. DYNNER:

Q What does the figure 3 7/8 as it appears on this report, both on the first and second pages of the report, indicate with respect to stud number 3 on cylinder number 5?

A (Witness Johnson) It indicates the eddy current

WRBpp

indication is 3 7/8 inches deep which is rounded to 3.9 inches.

Q Thank you.

Now, would you please turn -- and Dr. Johnson, to your knowledge, these copies that I have are correct copies of the original documents, aren't they?

A There are some notes that have been added to it by the engineer.

Q I'm talking about the original block support package that you identified this as coming from, pages 11 and 12 that we're talking about.

A They were in the draft -- the support package for the draft report, yes.

Q Okay.

Now, I would like you to turn for a moment to page 39. In the lower righthand corner it says page 39. Now, can you identify what this document represents?

A This is an engineering summary of the cross section showing the interpretation of the eddy current inspection records particularly directed at the region between cylinder 4 and cylinder 5 and stud 3 -- well, cylinder 5, stud 3, and cylinder 4, stud 6.

Q And do you see the line running down vertically along the representation of stud 3 of cylinder number 5 that is labeled 3 7/8? What is that line referring to?

WRBpp

A The 3 7/8 is representing the depth of the eddy current indication on cylinder number 5 studhole number 3 on the outside of it which means it would correspond to the location of the stud to stud crack.

Q It would be the greatest depth of that stud to stud crack at this point?

A That is the greatest eddy current measure of the eddy current indication of the stud to stud crack.

Q Now, could you tell me on the left of this drawing, there is a line with arrows that says two and a half inches and is sort of a crossed hatch -- I shouldn't say crossed hatch -- an area on the lefthand side of that stud number 3 that has horizontal lines across it. What does that two and a half inch measurement represent?

WRBeb

A That represents the results of the eddy current inspection conducted right after the overload incident in the field which indicates the eddy current indication at that time indicated -- the indication depth was 2-1/2 inches.

Q And that's a depth indication of the ligament crack running from stud No. 3 of cylinder No. 5. Isn't that right?

A Yes.

Q And on the right-hand side of the drawing--

A (Witnes Rau) Could I add something here?

It is my understanding that that measurement is a measurement of the depth of the ligament crack along the stud as measured by the eddy current as contrasted to any penetrant inspections that might have been done on the counter bore, that is, over on the cylinder side, and it is only representative of the depth as indicated by the eddy current along the stud side.

Q Yes, that's what Dr. Johnson testified to.

Now on the right-hand side of that joint, Dr. Johnson, there is another similar 2-1/2 inch measurement with horizontal lines.

Does that measurement represent eddy current measurement of the depth of the ligament crack at that point running from cylinder No. 4, stud No. 6?

WRBeb

A (Witness Johnson) This is the depth of the eddy current indication.

Q Is your answer to that question Yes or No, and then you can give an explanation if you would like.

Mr. Seaman, please don't interfere with this examination. You held up your hand. You stopped him from answering. And you're trying to converse with him.

MR. FARLEY: Judge, many of these questions cannot be answered Yes or No.

MR. DYNNER: I have already suggested to you that--

JUDGE BRENNER: Wiat a minute. Hold it, Mr. Dynner.

The problem wasn't Yes or No, Mr. Farley. The problem was he was directing it to a particular witness, so Yes or No is immaterial to the immediate question.

If you have something you want to add, Mr. Seaman, you can add it out loud after the answer, because Mr. Dynner wants to restrict it to Dr. Johnson at this point, which we will allow him to do, within reason. But if you have information you want to add, you can do so after, but tell us all about it.

Okay.

WITNESS JOHNSON: Will you please repeat your question?

WRBeb

MR. DYNNER: Yes.

BY MR. DYNNER:

Q Is it true that on the right-hand side of this drawing when there is a measurement showing 2-1/2 inches and horizontal lines across the outer portion on the right-hand side that that represents the eddy current measurement of the depth of the ligament crack at that point running from cylinder No. 4, stud No. 6?

A (Witness Johnson) Yes, that is the depth of the eddy current indication corresponding to the crack, the ligament crack in that location.

Q Now if you will turn for a moment to page 21 of this document,--

A (Witness Seaman) I would like to add one thing to that answer.

The use of the terms "cracks" and "indications" is being interchanged here a little bit, and I think it may be a little bit misleading.

Yesterday I believe Dr. Johnson talked about whether or not he felt the eddy current inspections in fact in the old DDG-103 with the degenerate structure represented the depth of the crack, or whether it did not represent the depth of the crack in the old or original 103 block.

So what we are really talking about here are the indications from the eddy current inspections, and we don't

WRBeb

believe that that is representative of the cracks in this area. And I believe that that's a distinction that is important to make.

Q Is what you are referring to, Mr. Seaman, the fact that when later on eddy current examinations were made of these cracks there was a difference in the standards for the recording of values? Is that correct, Mr. Seaman?

Mr. Seaman, I don't want you-- We've been through this so many times.

Mr. Schuster, please don't converse when I ask a particular witness a question.

A What I'm referring to is our opinion with respect to whether or not these indications are in fact as deep as recorded by the original eddy current inspections.

Q Now would you answer my question? Is that based upon the fact that later on you took eddy current readings and you used a different standard for recording the values of those readings, as you testified yesterday on this panel?

A No.

Q All right.

If it is not based on that, what is it based on?

A What I just answered in the previous answer, sir.

Q Repeat it for me, please.

A What I testified was it was based on our opinion regarding the original inspections that were done using

WRBeb

eddy current on the original 103 block, which we feel didn't accurately represent the depths of the cracks in those areas.

Q What is the basis for that opinion, Mr. Seaman?

A The basis of that opinion is the subsequent work that was done that has been reported regarding the destructive sectioning of the original 103 block which indicates that the depths of the cracks, the actual depths of the cracks were less than what were reported by the original eddy current examinations.

When we re-performed the eddy current examnations with a refined procedure we were able to get good correlation with the crack depths that we had recorded during the destructive examination, and we feel that those results are more appropriate to use when defining the depth of the cracks.

Q There was only one crack that was sectioned. Isn't that right?

A There was one crack that was sectioned. That's right.

Q So you are basing your opinion on a single crack, and that crack that was sectioned was not the cracks that we've been talking about this morning, is it?

A Well, we-- While it is true that there was only one crack that was sectioned, we also did subsequent

WRBeb

examinations on other cracks that were in the lab, and the depths of those indications were confirmed by other methods, and we got good correlation between those other methods and the eddy current tests. And it is based on those other inspections as well as the destructive testing.

A (Witness McCarthy) I would also like to add to that that typically the eddy current inspection program is calibrated with a single standard. There is nothing unusual about using a single crack to calibrate for this degenerate material.

Q Was a separate examination made of this crack, the ligament crack on cylinder No. 4, stud No. 6, that is shown in this page 39 as having a depth of 2-1/2 inches, Mr. Seaman?

A (Witness Seaman) You're referring to the 2-1/2 inch crack?

Q That's right.

A Yes, there were LP inspections done on the cylinder liner landing area which we feel more accurately represent the depth of the indication in the ligament crack area.

Q The cylinder liner landing area is a different portion of that crack than the depth of the crack at the stud hole, isn't it?

A Yes.

WRBeb

Q So the answer--

A However, we feel that those cracks -- we feel that we have evidence that those cracks basically extend horizontally, not as depicted, for example, on the stud-to-stud region. We feel that's a more accurate representation of the depth of the crack.

Q But this crack you didn't measure on both sides with dye penetrant, did you, Mr. Seaman? Do you know?

Did you do a dye penetrant test on the stud side of that crack?

A If I could, I would like to consult with Mr. Johnson. I believe that he could shed some light on this.

Q You can answer that question, Dr. Johnson, if you know.

So this conference doesn't continue too long, let me refresh your recollection, Dr. Johnson, that as I recall yesterday you testified that subsequent to these eddy current examinations that you did not conduct any dye penetrant examinations of the cracks -- of these ligament cracks on the stud hole side. Do you recall that testimony?

A (Witness Johnson) I was just looking at the inspection report for this area, and the inspection which-- There was not a penetrant inspection conducted down the stud holes.

WRBeb

Q Now would you please take a look at page 21 again? That's the page number in the lower right-hand corner.

JUDGE BRENNER: Could I back up for a second? I'm confused.

Dr. Johnson, my recollection -- and it is only a recollection of yesterday's testimony -- is in accordance with Mr. Dynner's; that is, that you testified that there were no dye penetrant tests in the stud hole. Is that correct?

WITNESS JOHNSON: Yes. Didn't I say that?

JUDGE BRENNER: All right.

So I don't understand why you've had to examined the particular inspection report to answer that, and that is why I'm concerned that maybe I've got your testimony of yesterday incorrect.

BY MR. DYNNER:

Q Before we go to--

JUDGE BRENNER: Wait just a minute. He looks like he's thinking about it.

WITNESS JOHNSON: I just wanted to check again that indeed that what we had done in that area was an eddy current test.

JUDGE BRENNER: All right.

I want you to understand that I accepted your

WRBeb

testimony yesterday as a universal fact without having to examine each and every inspection report as to each and every crack that might come up.

WITNESS JOHNSON: Well, I checked it yesterday and I checked it again today.

JUDGE BRENNER: Okay.

We can take a break at this point if it is acceptable.

MR. DYNNER: If I could ask one more question?

JUDGE BRENNER: Fine.

BY MR. DYNNER:

Q Mr. Seaman, at page 39 -- or Dr. Johnson, or anybody, who prepared this document at page 39?

A (Witness Johnson) My understanding is several engineers were involved in the preparation of page 39, but I do not know the list of engineers that were involved.

Q The outline of the schematic drawing of the stud holes appears to be a printed document, and at the bottom right-hand corner it says "FaAA M84-5-5."

Was that drawing, the printed portion, prepared by FaAA?

A The schematic representation, the cross-section --Yes -- was prepared by FaAA as were-- The FaAA engineers were involved in the production of this total document.

MR. DYNNER: Thank you.

WRBeb

We can take a break now, Judge Brenner.

JUDGE BRENNER: We will take a break until 10:50. Could we borrow the section of the block during the break if it is available?

(Recess.)

WRBpp

BY MR. DYNNER:

Q Gentlemen, please turn to page 21 numbered in the lower righthand corner of the document we have been discussing.

Dr. Johnson, would you please identify this document?

A (Witness Johnson) This is an eddy current examination report by Don Johnson who works for me. He did the inspection on 4-18-84.

Q And in this document it shows under the column indication numbers there is reference to certain numbers. Could you identify what locations they refer to?

(Pause.)

A Indications number 1 and number 2. We don't have a drawing for where they're located, except that it is in cylinder number 4. Stud number 6 is indication number 1, and in stud number 7 is indication number 2.

Q Dr. Johnson, you said the second one was cylinder number 7, did you say?

A No. If you can look to the previous page which is the calibration report --

Q That's page 20.

A Your page 20.

Q Yes.

A And it identifies that we're dealing here with

WRBpp

cylinder number 4 and then we're talking about stud number -- indication number 1 is in stud number 6 and indication number 2 is in stud number 7.

Q Thank you. And where it indicates in the column "Length of Indication," two and a half, does that mean that the eddy current measurement was made along the length of those studholes, which would really be the depth of the crack at that point?

A These are measures of the depth of the ligament crack.

Q And those are indicated as two and a half inches; isn't that right, both of them?

A Yes. These are indicated as two and a half inches.

Let's remember that we are talking about a procedure which we described before, leads to overestimation of the depth of defect, because as you try to trace it down to 25 percent of the threshold you can confuse Widmanstatten with the extension of the crack.

Q Yes, we all have that in mind, Dr. Johnson.

And the "Remarks" shows that this is -- that those cracks extend from the surface past liner landing to rough cast surface; is my reading of that correct, in the column under "Remarks?"

A These measurements--

WRBpp

Q Is my reading correct of those remarks?

A --extends from surface past liner landing to rough cast surface.

Q Thank you very much.

And, in fact, looking at the revised crack map which is Exhibit B 25, we see that those two cracks have been revised on the crack map to show a depth of less than two and a half inches in each case; isn't that right?

A That is correct.

Q Now, if you will turn for a moment to the numbered page 23 in this document, you will see -- could you identify this document for me, please?

A This is another sheet which has an examination report. Don Johnson was the inspector. The inspection was performed on 4-19-84.

Q The indication numbers shown in the lefthand column refer to the sketch on the document -- the numbers on the sketch; don't they?

A Yes.

Q And you'll see on this document, it's true isn't it, that indication number 2A appears to be the ligament crack running in the 8 o'clock position on cylinder number 7; is that right? That would be the number 6 stud?

A Yes.

Q And looking at the revised crack map, that number

WRBpp

of two and a half inches in depth was changed; wasn't it?

A Yes, that number was changed based on -- once again, we concluded that the eddy current tests were not reliable at sizing the depth of the crack and in that case we relied on the penetrant results in that area which indicate that the crack initiates on the stud side on the stud and actually never reaches the liner landing.

Q Now, if you see on the drawing, also, there is a reference to number 4, indication number 4, and that is at stud hole number 2 on cylinder 7; isn't that right?

A Yes.

Q And that shows a depth of one and a half inches; isn't that correct?

A Yes.

Q And that depth was not changed on the revised crack map; isn't that correct?

A That's correct because that is consistent with the penetrant results on the liner landing area.

Q Is that measurement of the depth of the crack in the stud hole or on the counterbore?

A There are two measurements reported there. One down to the liner landing area, it's an inch and a half, and then there's a second one an inch and a half to the threads. That would be in the stud hole. The penetrant inspection was done on the liner landing area.

WRBpp

Q But there was no penetrant inspection done in the stud hole, so that eddy current reading of one and a half would not change; isn't that true?

A That's right.

Q Thank you. Did you do a new eddy current examination of that particular crack in the stud hole?

A No, we did not.

Q Why not?

A I didn't feel it was necessary.

Q How did you decide which ones to do a new eddy current on and which ones not to do a new eddy current on?

A We did new eddy currents on all of the pieces which we had in our laboratory at Failure Analysis Associates. We do not have the rest of the block at Failure Analysis Associates. The numbers that are changed are based on penetrant results that were done during the time same timeframe 4-18-84, either a day before or a day after.

Q You didn't have cylinder number 7 samples in the laboratory, did you?

A No.

Q So you're telling me -- tell me, are you telling me on the stud on cylinder number 7 which is in the 8 o'clock position and is indication to A on page 23 that you changed that even though you didn't do a new eddy current on it and you didn't have it in the laboratory?

WRBpp

A The changes that you will see here are when you --

Q Please try to answer my question. I am talking specifically about a specific indication, a specific stud hole and a specific cylinder. And I asked you, you didn't have on cylinder number 7, the indications shown at number 2A on page 23. You didn't have that cylinder in the lab and you didn't do an eddy current examination on it after this one and you didn't do an analysis of it in the lab; isn't that right?

A We did not. The answer to your question is yes. The reason the number is changed is because we have a penetrant test conducted in that area which indicates that the crack initiates on the stud -- at the stud -- and runs only 2/10ths of an inch towards the liner landing.

And as I said before, we do not have confidence, in fact, we have demonstrated that the eddy current test that was performed in the field on degenerate Widmanstatten overestimates the depth of cracks, in fact, interprets the Widmanstatten as the extension of a crack when, in fact, it isn't the extension of a crack.

Therefore, we do not believe that the eddy current tests performed in the field on the original 103 material is reliable. So if we have in the data that are represented at revised crack map is whenever we had a

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conflict between eddy current results which we demonstrated are not reliable and penetrant results which we know to be reliable, we used the penetrant results.

Q Dr. Johnson, if you look carefully, you will see that indication number 2A on page 23 clearly shows -- there is an arrow pointing to it. It is a crack that is running down inside of this stud hole. You did not have any conflicting inspection reports to this one on the depth of that crack, did you?

A 2A clearly shows that it is pointing to -- not the stud hole but the liner landing area and we have penetrant results on that liner landing area. And the penetrant results say that there is no crack extending down the liner landing area.

Q When did you do the penetrant examination of that if you didn't have this in the laboratory?

A As I said before the penetrant -- there was a complete penetrant test done of all the total top of the block.

Q When?

A In the timeframe of 4-18-84, give or take a day. The bulk penetrant and eddy current tests were being performed at that time.

Q I thought you had said that in order to be conservative that you always showed the greater depth of any

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crack where there was a conflict, didn't you say that yesterday in your testimony?

A Any that I have confidence in. I don't have confidence in the eddy current test on the Widmanstatten for reasons which have been clearly demonstrated. If you want to know what the unreliable eddy current test measurements concluded, then you can look at the original Exhibit 25. We dc not believe that is an accurate representation of the cracks which exist in the block. What we feel is an accurate representation as we can get of the cracks which is in the block is the new Exhibit 25, and that's why we have presented the new Exhibit 25.

Q And it's true, isn't it, that on the revised Exhibit B 25 you still do show some crack depths based upon your original eddy current examination, where you had no other later eddy current or later dye penenetrant examinations; isn't that right?

A That's not correct.

Q You're telling me now that the crack map on B 25 does not contain a single measurement based upon the original eddy current examination reports; is that right?

A Would you repeat the question, please?

Q Yes. Are you telling me that there is not a single measurement shown on the revised Exhibit B 25 that is based upon the original eddy current examination reports?

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A We have some measurements that are on this crack map which are not in conflict with the penetrant measurement but we don't have a corresponding measure from penetrant, and that those would be stud to stud cracks except where we have done destructive tests. That is, those blocks which have been removed to the laboratory which are in the region between 4 and 5. There are some additional stud to stud cracks which we have no alternative number to use because penetrant was not done down the studs. So in those instances you will see numbers which still depend upon the old or the unreliable eddy current tests. Which means that those cracks are not greater than those numbers which still remain. They may be less.

Q Is an example of those stud to stud cracks which depend on the eddy current crack test the stud to stud crack on the intake side between cylinder number 1 and cylinder number 2?

A Yes.

Q And that shows the depth of 1.5 inches on the revised crack map; isn't that right?

A Yes, on the revised one and also on the original one. Now, that crack may be less than 1.5.

Q Take a look, will you, at page 27 of this document?

JUDGE BRENNER: Mr. Dynner, are you going to be leaving this cylinder number 7 that we have been talking

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A Yes, on the revised one and also on the original one. Now, that crack may be less than 1.5.

Q Take a look, will you, at page 27 of this document?

JUDGE BRENNER: Mr. Dynner, are you going to be

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leaving this cylinder number 7 that we have been talking about?

MR. DYNNER: I'm going to leave it for the moment because it is important that I follow up on this one question.

JUDGE BRENNER: All right. I have a question about it when you are done. Go ahead.

BY MR. DYNNER:

Q Now, if you look at the drawing -- this is an eddy current examination report dated April 18, 1984 signed by Don Johnson from FaAA, isn't it?

A (Witness Johnson) Yes, it is.

Q And if you look at the location numbers you will see that the stud to stud crack on the intake side between cylinders number 1 and 2 on this document is identified by indication number 4; isn't that right?

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Location 4; isn't that right?

A Indication or location 4 is part of the stud-to-stud crack, yes.

Q And if you look at that reading you will see that it shows the depth of that stud-to-stud crack to be 1-3/4 inches. Isn't that right?

A No, that is not the depth of the crack. That is the distance the crack is traveling across from stud to stud. Indications 5 and 6 indicate the distance down the thread-- excuse me -- down each of the stud holes, and it says to the threads which is 1.5 inches. And that's where the 1.5 inches comes from on the original and current crack maps.

Q Everything else in your testimony so far says that wherever it says length of indication it refers to the depth of the crack except this one case. Is that your testimony?

A No, there are other instances. If you look at the diagram, that would be the interpretation. That's how the engineers interpreted it, and they were conferring with Don Johnson at that time. I don't think it's-- It's very clear.

You must read the "Remarks" for the interpretation of this.

Q Dr. Johnson, could you explain something for us?

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Where is says "magnitude of indication" why is it that in one case you show 125 percent equals 1-1/2 inches and in another place 100 percent equals 1-1/2 inches and your double-reading the magnitude of 200 percent shows only 1-3/4 inches?

A The magnitude of the indication is not associated with the length of the defect. To determine the length of the defect you scan along the length of the defect. That represents the maximum amplitude of signal obtained anywhere as you scan along the length of the defect. And as you can see, it is well above the 50 percent recording threshold.

JUDGE BRENNER: Dr. Johnson, while Mr. Dynner is considering his next question, I am looking at your Exhibit B-25 for the ligament indication at cylinder 7, stud 6, which is the same indication that Mr. Dynner was asking you about earlier.

There is a figure of 0.2 inches and an asterisk and the explanation of the asterisk at the bottom of that crack map is "Top surface indication - no depth to crack measurable down stud hole."

I am a little confused because I thought I heard the testimony being that there was no further measurement down that stud hole since the mid-April eddy current measurement which you believe to be not reliable. Could you explain what that notation meaning for the asterisk means in

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light of that?

WITNESS JOHNSON: The asterisk? I would have to say in that case there was no-- The penetrant test did not measure any indication of length -- excuse me -- of depth. The reason it didn't measure any measure of depth if because the penetrant indication has not be used down the stud hole and since it didn't get to the liner landing there was no measurable depth down the liner landing which you would obtain from penetrant.

Now as I said before, we did have eddy current measurements of those depths which we consider unreliable and were of course reported on the original Exhibit 25 crack map.

JUDGE BRENNER: Would the explanation you just gave me apply to all the other asterisks on this Exhibit B-25?

WITNESS JOHNSON: There are some asterisks where there was an indication on the top surface and there was also no -- even the eddy current measurement done originally indicated no depth down the hole.

For example, there are stud-to-stud cracks between cylinders 3 and 4 which we had eddy current indications on the top surface but no measure -- we had no indication running down the stud holes.

JUDGE BRENNER: Even with the eddy current test?

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WITNESS JOHNSON: In that case even with the eddy current test.

JUDGE BRENNER: Well why not, if the degenerate block would give you what you would consider to be those unreliable indications even in the absence of a crack?

WITNESS JOHNSON: It doesn't always. Every place you scan you see a threshold above 25 percent threshold; it's just that in certain areas you do. When you are trying to trace a crack if you are so unfortunate to hit one of those -- at the end of the crack if you are so unfortunate to hit one of those areas where it is a little more noisy than normal, the inspector interprets that to be a crack.

JUDGE BRENNER: If you have already given this testimony, forgive me, but I just don't recall. Can you tell me why you cannot conduct that dye penetrant test down the stud hole?

WITNESS JOHNSON: It is a difficult geometry. You cannot properly clean it, it is heavily corroded. The top of the block is clean; down the hole is heavily -- well it is corroded. You can't properly get the developer in there. And of course when you get down to the threads it becomes a very difficult problem.

JUDGE BRENNER: Mr. Dynner.

BY MR. DYNNER:

Q Just to follow up on what Judge Brenner was

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asking you, these eddy current examinations really do depend a lot on the interpretations given to them by the operator of the equipment, don't they?

A (Witness Johnson) In terms of detecting cracks, it is very straightforward. When you are measuring the length of the crack, you must scan along the crack and you scan back and forth across the crack, moving along the crack, and you look for an indication as we have described. And if you see those indications you say Yes, the crack is still there and move on further and continue.

And the criteria that we have set up is very objective, so I wouldn't call it a subjective test.

Q What is the objective criteria to help the inspector determine when he hears what you call a noise whether the noise is caused by Widmanstatten graphite or whether that noise is caused by a real crack?

A In the original test --

Q Could you just answer that question? What is the objective standard that you use so that the inspector can differentiate between noise caused by degenerate graphite and noise caused by a crack?

JUDGE BRENNER: Wait a minute. Mr. Dynner, you probably are much quicker than me, but I could tell from his first four words that he was not going to answer your question. And while in general your comments have been

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consistent with our Board comments from time to time to witnesses and have aided efficiency, once in a while I think you are a little too quick with it. And that was one time.

Dr. Johnson?

WITNESS JOHNSON: Could you repeat your question please?

JUDGE BRENNER: I'm sorry.

BY MR. DYNNER:

Q What is the objective criteria that you use for the inspector to determine whether the noise he hears is from the degenerate graphite or whether it is from the crack?

A (Witness Johnson) The objective criteria for calling out a crack is 50 percent of the signal obtained from an EDM notch in a standard that we have in normal cast iron. We did not at this time have a procedure for distinguishing normal cast iron from Widmanstatten cast iron because we didn't think we were dealing with Widmanstatten cast iron.

A (Witness McCarthy) Let me add a little --

Q I would like to follow up on that.

Do you have a standard now, an objective criteria now for distinguishing the noise generated by Widmanstatten graphite and the noise generated by a crack?

A (Witness Johnson) Well cracks don't generate

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what we consider noise. That is the relevant signal.

And the criteria we have now, we do depend upon the inspector -- well for detection of the crack the criteria is the same. For determining the extent of the crack -- now the problem with determining the exact end of the crack is that as you get to the end of the crack the signal starts dropping.

So currently we do depend on the judgment of our qualified inspectors to disguish what is the normal noise level in the Widmanstatten material and when we have a signal which exceeds that normal or drops below that normal noise level in that material. The detection criteria is very specific, it is still 50 percent, it's just that we no longer, when we are attempting to trace the end of the crack we no longer go down to 25 percent of the standard signal but we now permit the inspector to use his judgment as to where the noise level is in that area.

Q And am I correct, Dr. Johnson, that in the eddy current inspections that were done in September -- not the original ones -- that what you have done is to say that if the noise level or the signal reading, whatever you want to call it, is below 50 percent that there is an assumption made that that noise level or magnitude is caused by degenerate graphite and not by a crack, isn't that correct?

A I don't think that's correct, and let me explain.

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When we are fully on one of these cracks, our signals are well above noise level, even in Widmanstatten graphite, as you can tell by the levels which are recorded. The only time the crack signal drops significantly below that level is very near the edge, like within a tenth of an inch of the edge or so.

So we make make an error of a tenth of an inch or so in the total extent of the crack, but not more than that with the procedure we are currently using.

Q Doesn't that mean that the largest variation you could find between the original eddy current examination and the new eddy current examination would be a tenth of an inch?

A No, that is not what that means. As I told you before, by the previous procedure he needed it to drop below 25 percent before he stopped and called it the end of the crack. It dropped below 50 percent but not below 25 percent and he kept tracing that and at that time based on if it would have been normal material, he would have thought there was some light crack in there.

So you -- No.

A (Witness McCarthy) If I could just add a little to the testimony of Dr. Johnson at this point: I have this fear that everybody has got this image of an inspector with earphones on listening to an acoustic signal --

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JUDGE BRENNER: Don't worry about that fear, although Mr. Dynner did refer to it as hearing noise at one point.

WITNESS MC CARTHY: Okay.

JUDGE BRENNER: So I will help you out and we can get to the next question.

WITNESS MC CARTHY: This is a very straightforward judgment to make in that this is a threshold signal on an oscilloscope that can be seen visually and noise is a very continuous and more or less rough background trace and a crack or flaw indication is a very discrete part of that trace and this is not a judgment call that an operator has to spend years discerning it or something of that nature, it is a very straightforward visual observation.

(Counsel conferring.)

MR. DYNNER: Judge Brenner, I would ask that this document I have been asking questions from, that the pages numbered 11, 12, 21, 23, 27 and 39 be marked for identification as Suffolk County Exhibit 74 and be admitted into evidence.

JUDGE BRENNER: I think we would be up to 75.

MR. DYNNER: Are we at 75 now? I'm sorry. 75, I stand corrected.

JUDGE BRENNER: All right.

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(Whereupon, pages 11, 12, 21, 23, 27 and 39 from FaAA eddy current examination reports were marked as Suffolk County Exhibit 75 identification.)

JUDGE BRENNER: Any objection?

MR. FARLEY: Yes, your Honor. I object because the proper foundation has not been laid for the introduction of this document into evidence. Of course, it could be used in cross-examination in the way Mr. Dynner has used it, but based on the testimony of Mr. Seaman, it is not the final document showing all of the inspections that were made and that were quality-controlled.

You may think that that goes to the weight and not the admissibility --

JUDGE BRENNER: Go ahead.

MR. FARLEY: -- and I would respectfully suggest to you that if that is the way the Board is inclining that I think it is Federal Rule 703 that the prejudice to LILCO far outweighs the relevancy of the document on the basis of the foundation that has been laid.

JUDGE BRENNER: You may have the wrong rule.

MR. FARLEY: I may have the wrong number, your Honor. I am doing it from memory.

JUDGE BRENNER: 703 in fact is usually cited by

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those wh' want to get everything into evidence including the kitchen sink as opposed to arguing that something stay out of evidence.

(The Board conferring.)

JUDGE BRENNER: We are going to admit those pages into evidence. Strictly speaking, I must tell you my candid view that we could have treated this one just as we treated Exhibit 73 and leave it marked for identification and at the present time I don't think it would matter whatsoever for any findings that the County would want to base on the documents given the existence of the documents for identification and the oral testimony on it.

But I guess out of an abundance of caution I want to allow the County to be able to write what findings they want to from this exhibit. I don't think it is going to matter but nevertheless we will admit it.

The other thing I should point out is that we obviously disagree with your reasons for keeping it out, Mr. Farley. Enough questions were asked about it so that there is a proper foundation for admitting these documents. We understand what they represent and if there is any -- and Mr. Dynner brought out the witnesses' views and the witnesses were well able to add their views as to what the context is of these pages, and if there is anything else you want to bring out with respect to it, we are not concerned

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about prejudice to LILCO because you are in control of the documents and the witnesses and it is not a collateral matter; it is certainly clearly within the subject of the litigation, so I am not concerned about getting on a digressive tract by requiring you to bring anything forward on redirect that you want to.

So for those reasons we will admit pages 11, 12, 21, 23, 27 and 39 -- Did I get that right, Mr. Dynner?

MR. DYNNER: Yes, sir.

JUDGE BRENNER: -- into evidence.

Can you give me a handy description of what these are excerpts from?

MR. DYNNER: Yes, sir, these are eddy current examination reports by FaAA, except for page 39, which as they testified, is a document which has been prepared by FaAA engineers and relates to the eddy current examination reports.

(Whereupon, the document previously marked for identification as Suffolk County Exhibit 75 was received into evidence.)

JUDGE BRENNER: All right.

Let me add that do not forget that we are capable and may, as appropriate, exercise that overall control that when we see findings for the first time based on material

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in documents which were not asked about at all, if it is on a controversial point, we may well not accept such findings if the point was not asked about or otherwise covered in the direct prepared testimony.

Off the record.

(Discussion off the record.)

JUDGE BRENNER: We'll go back on the record.

BY MR. DYNNER:

Q Gentlemen, before I resume with the general line of questioning, would you tell me on Exhibit B-30 that we had some discussion about previously -- and I am talking about the document entitled "Principle Stresses Versus Load for Gages 11, 12 and 13 Located Between Studs" -- is this document purported to show this information for a Shoreham EDG block having normal characteristics of Class 40 gray cast iron?

A (Witness Wells) No, Mr. Dynner, these are the stresses calculated for EDG 103 with the old block.

Q And am I correct that these are the stresses calculated and adjusted for the fact that you believe that EDG 103 in the original block contained excessive amounts of Widmanstatten graphite?

A This figure has been corrected for the measured physical properties of the block top.

Q Is the answer to my question yes.

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A (Witness Rau) The answer is no.

A (Witness Wells) I cannot answer that affirmatively, I cannot.

Q I am going to have to ask the question again. I just don't understand the answer.

Is the information shown in Exhibit B-30 adjusted from the prior Figure 3-6 of the Block Report in order to show that EDG 103's original block contained what you regard as excessive amounts of Widmanstatten graphite which affect its mechanical properties?

A No, sir, not at all. The purpose of this figure is to show the actual stresses in the block top based on known measured, documented physical properties.

Q That is the block top of EDG 103's original block top?

A Yes, that is correct.

A (Witness Rau) Mr. Dynner, I think the problem is you are saying it -- you are tying it into the microstructure and in point of fact that may be true also but it is based upon direct physical measurement of the mechanical properties of the block top of the original 103. It doesn't rely upon necessarily any interpretation of microstructure, even though that may in fact be responsible for the difference in the measured mechanical properties of the block top.

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Q All right.

But the reason, Dr. Rau, that Exhibit B-30 differs from Figure 3-6 in the Block Report is because Exhibit B-30 takes into consideration the actual measured properties of the original block, is that correct?

A That is correct.

Q And as I understand your testimony, and if I can just get a quick summary, the fact that those actual physical properties of the original EDG 103 block were different than the properties assumed when you did the original strain gage measurements and prepared Figure 3-6 would result in different stress calculations using the same strain gage readings, is that right?

A That is correct.

MR. DYNNER: Judge Brenner, I am going to proceed for a short while on page 21 of the cross plan and I will be moving along.

BY MR. DYNNER:

Q Gentlemen, please turn for a moment to page 13 of your prefiled testimony.

In your answer to question 12 you state that ligament cracks were discovered in all three engine blocks.

Please identify when those cracks were first discovered in each block.

A (Witness Schuster) The ligament cracks in the

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diesel generator blocks were first identified in February of 1984 for DG 102, that was the first block that we located these indications.

Subsequent to that examinations were performed in March on DG 103 and 101 and similar indications were noted in our examination reports.

Q How did the ligament cracks come to be discovered in EDG 102 in February?

A The ligament cracks were first determined by visual examination which was part of our requirement for the DR/QR program, sir.

(Pause.)

That inspection was documented on LDR 2083.

MR. DYNNER: Judge Brenner, page 22 of the cross plan, number eight.

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BY MR. DYNNER:

Q Dr. Wells, take a look, please, at Exhibit B-23. Why did you choose to place gage No. 3 at that location shown in Exhibit B-23?

A (Witness Wells) As I recall, Mr. Dynner, we picked that location because in our opinion it was the highest stress location near the edge of the block.

Q And how did you determine that it was the highest stress location?

A It was strictly a matter, as I recall, of the distance between the edge of the stud hole and the edge of the block top.

You will notice on that exhibit that there is a curvature of the block top that produces a smaller what would be stud-to-stud distance but in this case it is just a stud to the outside surface, then in the corresponding stud hole in the other side of the center line.

Q What was the strain gage reading for this particular gage?

I will add for you the reason why I am asking that question is that my own examination of the Block Report and of your testimony does not-- I couldn't find....

A The reading of gage 3, Mr. Dynner, is shown in our Exhibit B-31, and you will notice that is marked cylinder 1. It is essentially the same as the exhibit for

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gage 13 that we have previously described, so I won't, unless you think it is necessary, explain how the mean and the range and the pre-torque and so on are represented in this figure.

But you can see there that the peak stress at 100 percent load ranges up to something in excess of 12,800 psi.

Q On my copy of Exhibit B-31, it looks like the peak stress goes up to about-- It goes up to close to 14,000 at the overload condition of 3,900 Kw. Is that correct?

A That's correct, Mr. Dynner.

Q Does that stress in psi exceed the UTS of the block material?

A As we testified previously, the range of values measured from block top material does encompass some of these measurements. I would like to refer you to the specific test data if I may, which is Exhibit--

Q It's Exhibit 39, isn't it -- Exhibit 40?

A Exhibit B-40, Mr. Dynner, for the record.

Q Yes.

A The complete answer then to your question, Mr. Dynner, would be that that particular value does not exceed the measured ultimate tensile strengths.

Q And it is true, isn't it, that there -- unless I'm misreading this Exhibit B-39, which shows the

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locations from which specimens were taken, that there was no specimen taken from the location where gage 3 was placed. Isn't that right?

A That's correct, Mr. Dynner. We had no specimen. I believe, however, we checked the microstructure of the material in a similar position....

A (Witness Rau) That is true. We had no mechanical test bar cut from that particular location but we did in fact have material samples and polished replicas which revealed and confirmed that the microstructure contained degenerate Widmanstatten graphite in that location. It was consistent with the microstructure elsewhere in the block.

Q But you don't know what the UTS of the material was at the placement point of gage No. 3 was, do you?

A (Witness Wells) We do not know precisely.

A (Witness Rau) Again I would just add that it is certainly going to be in the same range, given the comparable microstructure of the ultimate tensile strength measured at various locations in the block top.

Q That is an assumption, isn't it?

A That's my opinion.

Q I mean the range-- If you look at the summary of tensile tests on Exhibit B-40, the range for the block top goes from 14.5 up to 21.9, doesn't it?

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A Those numbers are in fact correct as quoted off of B-40, but I would caution you that the higher numbers are in fact from the web portion that is well below the block top and the range in measured tensile strengths in the block top region itself range from 14.5 to 19.9 as shown in Exhibit B-40.

Q Now this Exhibit B-40 is a summary of tensile tests. It doesn't give us all of the UTS readings for the various locations shown on Exhibit B-39, does it?

A Could you repeat that? I didn't hear it all.

Q Yes.

Exhibit B-40 is a summary of the tensile tests. It does not give us all of the UTS numbers for each of the specimen locations shown in Exhibit B-39, does it?

I don't know whether that's a difficult question but it seems to me on its face that is correct, isn't it?

A (Witness Rau) The problem is, Mr. Dynner, that not all of the specimens are shown on Exhibit B-39 to be completely accurate.

Q I didn't ask you that. I asked you--

A I thought you did. I'm sorry.

Q No. My question is:

The summary of tensile tests does not in fact give you the UTS for all of the locations shown on Exhibit B-39, does it?

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A Clearly there has not a tensile specimen been cut from every square millimeter of the block top shown in Exhibit B-39. I don't understand your question.

Q Dr. Rau, look, your Exhibit B-39 says that it is a schematic drawing of specimen location from DG-103 segment removed between cylinders No. 6 and 7, and it shows a bunch of shaded areas and those are the areas from which specimens were taken. Isn't that right?

A They are illustrative of the areas, yes.

Q All right.

And those areas show, for example, if you look at one area that is marked TF, 3a and then there is an arrow to d, and that would indicate that specimens were taken from 3a, 3b, 3c and 3d from that shaded area. Isn't that right?

A That's a true statement. Specimens were taken at various elevations from the block top down towards the 2-1/2 inch distance below the block top.

Q All right.

Now you look over at Exhibit B-40 and that just gives you the UTS of specimens taken at, in this case, TF 3a. It doesn't tell you what the UTS was of the specimens at 3b, 3c and 3d, does it?

A No, Mr. Dynner, but you are making the assumption that it was a tensile specimen taken from each of those locations and that may not be the case. Some of these

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specimens are fatigue samples; in other words they were also round bars but they were not pulled all the way to failure in one continuous operation but rather, they were placed in the test machine and cycled between strain limits until a fatigue crack developed and caused failure.

Some of these locations were tensile samples, as noted in B-40. Others were fatigue samples which were not so noted on that exhibit, but the results of which are summarized on Exhibit B-42.

Q Now, Dr. Rau, is it your testimony that Exhibit B-40 shows all of the specimens which were subjected to tensile tests, or just some of them?

A Mr. Dynner, my recollection is that this is all of the pure tensile tests that were measured.

We did have some of the fatigue samples which were also broken and from which we have an estimate of the ultimate tensile strength. I can confirm that, but at this time that is my best recollection.

Q On any of the specimens taken from the original EDG-103 block, did you ever have any UTS less than 14.5 ksi?

A Again my recollection is no. The only-- My recollection is no. There certainly would have been no direct measure of it. The only thing there might be is some indication-- Certainly there is no indication of anything markedly different than that.

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Some of the fatigue samples where we attempted to run a fatigue test at a very high strain range, approaching the ultimate tensile stress, broke on the first quarter cycle, and we got a measurement -- an estimate of ultimate strength from that particular test, in other words, the first quarter cycle of a fatigue test. And my recollection is that those numbers were completely consistent with this range which was reported in B-40.

Q Did you get any for the block top that were higher than 19.9 ksi?

A Again I don't believe so.

Q What do the initials "TF" stand for in the specimen identifications?

A "TF" stands for tensile fatigue specimen.

Q What do the initials on Exhibit 39, "CT," stand for?

A Compact tension.

Q Looking for a moment at Exhibit B-39, you testified, Dr. Rau, that there were additional samples or specimens taken from the block top which are not shown in this Exhibit B-39.

Can you identify what those samples are?

A I was referring, Mr. Dynner, to the fact that you can't see some of the sample locations below the top.

Perhaps Dr. Wachob, who actually cut them out,

AGBeb

would like to add to that.

A (Witness Wachob) What is shown in this figure are the specimens that were taken out of the exact block top position of the segment between cylinders 6 and 7. The a through d or a through e notation is a notation from specimen a lies in the block top, specimen b lies below the block top, all the way down until specimen e would be at the very bottom of the block top.

So the letter notation, a through d, represents the specimen taken in the same position, just at a different depth to this position.

Q Are there any other locations that are not shown in Exhibit B-39 that were specimens taken from the block of EDG-103, the original block?

A The two tensile specimens which are listed as TF 8a, TF 9b were taken in the web -- that's Exhibit 40 -- were taken in the web portion of the block which is below the block top and it is the ligament basically that separates cylinder cavity to cylinder cavity.

Q What was the thickness of the material at those webs?

A 1-1/4 inches, approximately.

WRBpp

Q What was the thickness of the block top from which the specimens were taken?

A Two and a half inches.

Q Was that what it was supposed to be or what it actually was?

A (Witness Rau) Mr. Dynner, let me just clarify so we don't confuse you here. If you're asking about the thickness in the part when we machined it it was two and a half. I think you're aware that when it's cast, of course, it's thicker than that and there's certain material machined off.

A (Witness Wells) The two and a half inches is the correct dimension shown on the drawing, Mr. Dynner.

Q Is it the correct actual measurement of the block top of EDG 103 at the points at which the specimens were taken as shown on Exhibit B 39?

A (Witness Wachob) The nominal value is two and a half inches. The specific block top thickness at this location was approximately two and three-quarter inches.

JUDGE BRENNER: Dr. Wachob, I'm not sure if there is confusion. When you gave the dimension as to the web were you giving the dimension of the test specimen or of the web itself?

A (Witness Wachob) The dimension I provided before the one and a quarter inches is the thickness of the as-cast

WRBpp

web between cylinders.

BY MR. DYNNER:

Q Were there any other specimens taken besides those that you have not identified in your testimony today?

MR. FARLEY: Judge, I object, for the record. We're dealing with tensile tests at one point and now the question has gotten so broad that I think the record is going to be ambiguous because other specimens and replicas were taken.

JUDGE BRENNER: I will overrule the objection and we will see where it goes. We'll see whether there is confusion or not.

WITNESS RAU: I was about to ask for clarification. You are talking only about a mechanical test samples or about any material which was cut from the block for any purpose?

BY MR. DYNNER:

Q I'm talking about the specimens that were taken for mechanical tests. I'm not talking about the specimens which we all know were removed for examination of cracks such as the one you showed the Board yesterday.

A (Witness Rau) There are no other mechanical test samples that were cut from locations other than those which have been illustrated schematically in Exhibit 39.

Q And the ones in the web that you identified,

WRBpp

right?

A Yes, sir.

Q Now it's true, isn't it, Dr. Wells, that the place where strain gage 3 --

JUDGE BRENNER: Mr. Dynner, let me stop you for a minute. This is a good point to break for lunch. I was wondering if you were going to get back to the thrust of your plan 8 on the cross plan and you just did. But I think it's going to take more than just one or two questions.

MR. DYNNER: All right, sir.

JUDGE BRENNER: When we come back from lunch, I will ask you for an estimate, Mr. Dynner. How much further cross examination you have of these witnesses.

In addition on a related subject, we have decided to require revised cross examination plans for future witness panels. We won't put the Staff to the burden of giving me a cross plan for this Panel, but after this Panel is complete, I want revised cross plans for all future panels. So that would be of the County and Staff witnesses on blocks and of the County witnesses on pistons.

It is my guess that we won't get to those other witnesses this week but if that is incorrect I am not going to require it this week. But beyond this week you should have time to do it and to also try to accomodate your workload. We would like it as soon as it is available, but

AGBpp

it would be acceptable if we get it on the beginning of the day that the cross examination may be expected to begin.

We will come back at 1:35.

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

WRBagb

AFTERNOON SESSION

(1:35 p.m.)

JUDGE BRENNER: Good afternoon.

Mr. Dynner, you were going to give us an estimate -- or more precisely, I asked you to give us an estimate.

MR. DYNNER: Judge Brenner, I am going to have to make a very rough estimate for obvious reasons. And my estimate is going to be three days based upon the following factors.

In the first place, I have spent roughly a day and a half now unfortunately doing nothing more than attempting to ascertain explanations from these witnesses for the substantial revisions to their testimony which were contained in changes to exhibits and in their revisions by deletions to the testimony that were not explained otherwise.

At the time that the September 24 filing took place, I approached counsel for LILCO and I requested that LILCO consider having its panel file supplementary testimony explaining the reasons for the very substantial and significant changes to their testimony and exhibits.

In lieu of that I received a letter from counsel that I have already alluded to which gave a very short statement, part of which I read into the record, and did not explain in anywhere near meaningful detail the reasons for

WRBagb

those changes.

I asked that that supplemental testimony be considered to be filed solely for the purpose of saving time and I expressed that fact to counsel.

So I view what has happened so far as an unnecessary and unfortunate addition, and as you can see from looking at the cross-examination plan, we are now just beginning to get into that plan, although I have been able from time to time to cover certain questions that are dealt with later on as you are aware.

Secondly, I have been able, as a result of the withdrawal of all of the DeLaval witness panel, to of course eliminate pages 47 through 53 of the cross-examination plan. However I will of course have to conduct some cross-examination on the supplemental testimony which was filed by LILCO again late in September.

Third, I feel that despite my best efforts I am still not getting adequately short answers from the witnesses and I am still having to repeatedly request that they answer yes or no and then give an explanation if appropriate, and I feel as though we are getting a number of extraneous speeches, answers which instead of directing themselves to the questions are bringing in other material that is not necessarily related or that would be ordinarily given by either follow-up questions or in their redirect

WRBagb

examination of their counsel. And I say that not in a vein of being critical of these witnesses but just in terms of the time that the examination has taken.

So I am going to have to give a rough estimate based upon the fact that I am now, as you know, on page 22 of the cross plan and you know where it goes. I expect to be able to stick very, very close to the cross plan with one or two exceptions, and of course with respect to an exception for the supplemental testimony.

JUDGE BRENNER: Well the cross plan has been of minimal assistance to the Board so far because you have not followed it. I just wanted to state that for the record. You have given the reasons why not just now. So I don't know where you are going.

MR. DYNNER: If I can assist you: I am right now, as you know, on page 22, number eight. I will tell the Board each time -- if there is a shift where the cross plan does not follow in chronological order, I will tell you where I am going in the cross plan. But I expect to be able to, now that we have gotten I think most of the explanations for the revisions in testimony, to be able to stick to the cross plan.

JUDGE BRENNER: You are estimating three full days beginning from now?

MR. DYNNER: Yes, I have to give you a -- I mean,

WRB_gb

I would love to be able to do it in a day and a half but I have to give you what I think is a realistic estimate. I am trying to speed things along.

I think it is obvious to everybody that I have been doing my best to control the questions to keep them as short as possible and in trying to control the witness' answers so they are direct.

But I am going to be frank in my estimate and not -- I don't want to get into a situation that we have had sometimes in the past of underestimating grossly what the time is going to be. I think it is better to try to be realistic, although obviously I can't represent to you that it is going to be a shorter time or a longer time, it is my best guess at this time.

JUDGE BRENNER: Well I will say preliminarily -- and then the Board will talk about it and consider that time estimate -- that even three total days is on the long side of what we would have anticipated for the panel. And certainly a total of just about five days, not quite, but just about five days is far in excess, even allowing for time needed to get the explanations.

I don't think it is an accurate characterization of the time you spent so far to say that most of that time has been spent on the need to get explanation for the changes.

WRBagb

Some of it has been, but -- I'll stop there and we'll talk about it.

Don't assume from this moment that three days is acceptable to us and we will let you know.

Without taking up any more time, why don't you proceed now?

MR. DYNNER: Fine --

MR. FARLEY: Judge Brenner, may I respond?

JUDGE BRENNER: No, it is not necessary.

MR. FARLEY: I would like the record to show that I disagree with the substantial number of characterizations that Mr. Dynner made.

JUDGE BRENNER: It is not necessary.

We are going to judge the pace of the cross-examination based on its usefulness, not the representations of what he thought should have been accomplished before testimony.

If we see things being accomplished, that's one thing, but we are under the impression already that the past day and a half has not been as efficient as it should have been.

And part of that, in my view at least, are the nature of many of the questions that are being asked and not due to speeches by the witnesses.

Go ahead, Mr. Dynner.

WRBagb

Whereupon,

ROGER LEE MC CARTHY,
HARRY FRANK WACHOB,
CHARLES A. RAU,
CLIFFORD H. WELLS,
EDWARD J. YOUNGLING,
CRAIG K. SEAMAN,
DUANE P. JOHNSON,
and
MILFORD H. SCHUSTER

were recalled as witnesses and, having been previously duly sworn, testified further as follows.

BY MR. DYNNER:

Q Gentlemen, we are still on page 15. We have been talking about the answer to your question 18.

Now it is true, isn't it, Dr. Wells, that the spot where Gage No. 3 was placed is almost exactly, if not exactly, the place where the large crack extended out from Cylinder No. 1 and down the face of the block some 4-1/2 inches on EDG 103, isn't that right?

A (Witness Wells) Yes, sir, that's right.

Q Was it possible from the information you've got from the strain gage testing to have predicted that that kind of a crack would propagate or would initiate at that spot?

WRBagb

A No, it was not. We did not have the proper information to reduce the strain gage results at that time. I would have to say though, as I testified earlier, just from an engineering judgment standpoint one would predict that that particular location would be among the weakest areas on the engine.

Q Do you know, Dr. Wells, what was the placement of and reading for Strain Gage No. 1?

A Gage No. 1 is actually a crack mouth opening displacement gage and is not strictly speaking, Mr. Dynner, a measure of strain on the block top.

Q Does your testimony contain the readings from Gage No. 1?

A No, sir, we don't report those displacement readings.

Q Do you know what they were?

A To the best of my recollection the maximum displacement at the location of that compliance gage was approximately 14 thousandths of an inch -- excuse me, that is not the range, that is the maximum opening.

Q What was the placement and reading for Strain Gage No. 2?

A I believe, Mr. Dynner, No. 2, which actually refers to a Channel No. 2 and then a Gage No. 2, this is a channel on the instrumentation, is a thermocouple. We'll

WRBagb

check that, sir.

Q All right. While you are checking that, can you tell me what was the location cf Gage No. 4?

You realize while I am asking these questions that I am assuming, I think you testified before, you had gages all the way running up to No. 13 and we have already seen where 8, 9, 10, 11, 12, 13 are and where 3 is.

A Sure.

Again these are channel numbers, not necessarily gage numbers. We had three gages, as you know, diametrically across from the complicance gage between Cylinders 5 and 6 that I testified earlier failed and we got no readings from those three.

Q What numbers would they have been, the three that you didn't get readings from?

A In Exhibit B-22, I believe these are gages numbered 4, 5 and 6. They could be 5, 6 and 7, I just don't recall at the moment.

There were --

Q B-22, you say?

A Yes, sir.

Q Help me out, would you, because I don't see any numbers 4, 5, 6 on that exhibit.

A Excuse me, Mr. Dynner, I had some other information and I missed your question, I'm sorry.

WRBagb

We think two channels were used for the compliance gage. There was a compensating gage and an active gage employed in that particular electric connection that I believe was a bridge connection.

So in other words, Gages 1 and 2 were the compliance gage, we believe, 3 was the gage at the front end of the engine, Cylinder No. 1. The thermocouple used one other channel. Three gages were inactive, dead, positioned diametrically across from the compliance gage between the stud holes on the intake side of Cylinders 4 and 5. The remaining gages are as indicated in Exhibit B-22.

Q Does the compliance gage include the gage that measured the crack mouth opening displacement, is that what you meant by "compliance gage?"

A That's correct, sir.

Let me again clarify that these are strain gages. But the strain gage is attached to a hoop, a semi-circular hoop which is affixed to the block on either side of the crack.

Q On page 17 in Question 21 of your testimony, Dr. Wells, you state:

"No long-term increase was observed in crack mouth opening displacement during the test."

What did you mean when you used the term

WRBagb

"long term increase?"

A I am unsure of the purpose of that word "long-term." What we found was that over the duration of the test there was no increase which could be distinguished from any variability from cycle to cycle in the gage reading, therefore no indication that the average value of the crack opening increased exhibiting any increase in the depth of the crack.

Q What was the average opening?

A I do not recall the average at different power levels. But as I said a moment ago, my recollection is the maximum opening of that crack, which did not vary, at full load; and this actually was for the maximum load, as I recall, employed in that test series was 14 thousandths of an inch.

Q Now you testified that the maximum power that you ran the engine during this test was 3830 kilowatts, is that right?

A Yes, that is our testimony.

Q How long did you run it at that power level while you were testing for crack mouth opening displacement?

A May I defer to Mr. Youngling, please?

A (Witness Youngling) Mr. Dynner, I don't recall the exact time at each load level but I would say a half-hour to 45 minutes.

WRBagb

Q When you say in your testimony as you have explained it about "no long-term increase was observed," was in fact the crack mouth opening and then closing during the operation of the engine?

A (Witness Wells) Yes. The gage does measure both the minimum and the maximum and it is the range of that opening that is of direct concern from a crack growth standpoint. The only number that I recall though, Mr. Dynner, is the maximum value.

Q Was the mouth of the crack measured before the test began?

A The compliance gage was adjusted to read zero with no load applied to the engine.

Q Again my question was: was the crack mouth measured before the test began?

A If I understand your question there was zero crack mouth opening at the initiation of the test, it is nearly zero during operation as well. The minimum value is close to zero opening.

Now we did not apply replicas or high magnification microscopy or any of that sort of thing but there is no opening of the crack at the initial part of the test without load on the engine that would compare at all with the 14 thousandths

Q How do you know that?

WRBagb

A By visual observation, sir. These cracks are tight.

Q You can see visually whether that crack was or was not opened one thousandth of an inch, is that your testimony?

A May I have Dr. Rau comment on that?

Q Well I want to know first -- since this is your testimony, you and Mr. Taylor's, who is unfortunately not here -- I want to know whether you, you are the one who gave this testimony, I want to know whether you can tell by visually looking at that, the crack that was tested, whether or not it was opened a thousandth of an inch or not.

WRBeb

Dr. Rau, I don't really think that this question calls for you to have a conference with Dr. Wells.

A No, it is not necessary.

The crack opening that can be seen visually would be, in my professional judgment, a mill to two mills.

A (Witness Rau) May I add something?

Q Go ahead.

A The examination of this part, which of course has a much deeper crack in this location than it did at the time of the measurements, you can see by examining this that the amount of opening is very small.

The point I wanted to make is at the time of the testing it would have been even smaller than this. I would concur with what Dr. Wells has said but also point out that whatever opening is there, even the one to two mills that Dr. Wells is talking about, is in fact controlled really by the oxide thickness.

There is an oxide on the crack and so when you see a dark line there, it doesn't mean it's open.

Q How do you know that it would have been smaller than is seen now, Dr. Rau? Were you there during this test?

A No, I was not there during the test.

Q Well, how do you know it would have been smaller?

A From the inspection records we know that the crack was not a full three inches deep or anything like that

WRBeb

at the time.

Q I'm talking about the measurement of the crack mouth, and there was no measurement taken, according to Dr. Wells' testimony, so what inspection records are you talking about?

A I'm talking about the inspection records of crack depths, and my general knowledge of fracture mechanics which indicates the relationship between the amount of crack mouth opening you are going to have, the applied loads and the size of the cracks. There is a scientific relationship between them.

A (Witness Wells) If I may amplify, Mr. Dynner, there is no crack opening if there is no stress across the crack -- tensile stress, excuse me.

Q Dr. Rau, what would be the difference that you would expect to see in the crack mouth displacement if the crack had been four inches in depth instead of three inches in depth?

A (Witness Rau) You're asking before the test started?

Q Yes, sir.

A I wouldn't expect to see any opening in either case because there would be no tensile load before the test. Again, it would be controlled only by the thickness of the oxide.

WRBeb

Q I thought you testified that the reason you would know that the crack mouth would be smaller than it appears now was because of your knowledge about the depth of the crack. Did I misunderstand you?

A That is one of the reasons. I don't know the exact words but basically what I said was that whatever opening you observe now, which again is controlled by the oxide thickness and the general roughness of the fracture surface, would have been less when the crack were smaller.

Q That wouldn't depend upon the depth of the crack at any particular time. Is that true?

A No, that it not true at all. It very definitely depends on the depth of the crack because the deeper the crack is, the more open it will be under load, and the deeper it is, the more oxidation will have had time to develop and therefore, the thicker the oxide, and therefore, the more the crack will be held open by the thickness of the oxide on the fracture surfaces. And that is directly related to crack depth.

Q If the crack had gotten one inch deeper during the test, what would the size of the crack mouth displacement be that would be reflected by that one inch growth in depth?

A Again, you are asking before the test started, during the test?

WRBeb

Q During the test. During the test if the crack had grown by one inch, what size would you expect to see in the crack mouth displacement, Dr. Rau?

A Again, just a clarification. If it were an inch and a half to start and it grew from an inch and a half to two and a half?

Q Let's say it was three inches to start and it grew another inch.

A Okay.

Again there is a direct calculation of that. I can't do it in my head, but I can go-- There are scientific equations which relate the applied stresses to crack depth to the crack mouth opening displacement, and there would be a substantial increase in the crack mouth opening displacement measured at the block top if in fact the crack extended from three to four inches.

And that number can be computed but I can't do it in my head.

A (Witness Wells) May I add to that?

In a very approximate sense the crack opening displacement will be proportional to the depth of the crack, other things being equal, which I don't represent they are completely. But as a rough rule of thumb, if the crack were to grow from an inch and a half to three inches, and if the initial displacement under maximum load were 14 mills, then

WRBeb

if the crack were to grow to a three inch depth, then that displacement would be on the order of 28 mills.

MR. DYNNER: Judge Brenner, I am going temporarily to page 26 of the cross plan under "f."

Judge Brenner, I am sorry to have to do this again. I don't want to mislead you. I've covered most of this material, I see on reflection again. I will ask one or two questions in that area.

BY MR. DYNNER:

Q Gentlemen, earlier today you referred to the Goodman-Smith diagrams which are depicted at Exhibit B-49 and at B-50.

Now I would like you to clarify for me the fact that earlier today when we talked about the stresses, the principal stresses which you have read for the block as shown in Exhibit B-30, you testified that that document, Exhibit B-30, referred to the original EDG-103 block.

Is that right, Dr. Wells?

A (Witness Wells) Yes.

Q Now unless I misunderstood you, and I may have, I had thought you said that based on those stresses, you then calculated the Goodman-Smith diagram.

Was in fact the Goodman-Smith diagram that is Exhibit B-49 and B-50 calculated on the basis of the stresses depicted in Exhibit B-30, Dr. Wells?

WRBeb

A Mr. Dynner, I did not perform the analysis of the Goodman-Smith diagram, and I would like to defer to Dr. Rau.

Q Dr. Rau, did you conduct those analyses yourself?

A (Witness Rau) They were done under my supervision.

Q Who did them?

A There was a team of people who participated, and again it depends on where you draw the line between the stress analysis and the actual drawing of the Goodman-Smith diagram. But certainly Mr. Taylor participated, Scott Rau participated, I participated. There may have been others.

Q Mr. Taylor was the task leader, wasn't he?

A Excuse me. You asked a question. Do you want me to answer it or not?

Q Mr. Taylor was the task leader for the block analysis, wasn't he?

A Are you asking me?

Q Yes.

A Mr. Taylor was certainly the project engineer for the block analysis, yes.

Q No, my question was -- and you are going to have to listen to my questions. I said:

Was Mr. Taylor the task leader for the block analysis?

A I don't know what you mean by task leader.

WRBeb

Mr. Taylor may have called himself that, but....

Q Well, was he?

A He was the project engineer on the entire block project, block task.

I was the task leader. I was, say, the supervisor, if you like, of the fatigue analysis, the cumulative damage analysis, and the leader of the metallurgical and the mechanical testing aspects that were done.

And Dr. Wells had overall responsibility.

Q On page 4 of the testimony prefiled where Mr. Taylor testified, and his testimony was later deleted when he was dropped from the panel, he said that his role in the investigation of the Shoreham TDI R-r cylinder blocks was to act as task leader.

MR. FARLEY: Objection.

BY MR. DYNNER:

Q I wonder whether you agree with that or not?

JUDGE BRENNER: What is the basis of the objection?

MR. FARLEY: The testimony has been withdrawn, your Honor, the same category as all of his testimony on pistons.

JUDGE BRENNER: The objection is overruled.

WITNESS RAU: Well, perhaps Dr. Wells, who is

WRBeb

responsible for the entire project, can answer that. I have indicated to you my understanding of what the roles were, and certainly my direct knowledge of what my role was.

BY MR. DYNNER:

Q Dr. Wells?

A (Witness Wells) Yes.

Originally I assigned the responsibility of the component task review to Mr. Taylor as task leader. That was back at the beginning of the DR/QR program.

Subsequent to that, and this would go back to some time in the late spring, as I recall, I went to Dr. Rau and I asked Dr. Rau for his assistance in assuming or sharing the responsibility for both analysis and the crack growth and damage calculations for the block.

Q Well, do you agree with Mr. Taylor's withdrawn testimony that he in fact was the task leader as stated in the withdrawn portion at the bottom of page 4, Dr. Wells?

A I assigned him that responsiblity as task leader.

Q Do you agree with that testimony that he gave? Yes or No?

A Mr. Taylor did not have complete responsibility for all phases of this work, Mr. Dynner. I don't think I can answer that a simple Yes or No.

Q Was he--

A At one time he was the only person in

WRBeb

responsible charge under me.

Q Was Mr. Taylor's testimony, written testimony on the bottom of page 4, that his role in the investigation of the Shoreham TDI R-4 cylinder blocks was to act as task leader, is that testimony true or false, Dr. Wells?

A His testimony is true.

Q Thank you.

And is it true that as he testified that he directed the assignment of technical analyses?

A He did not do that exclusively, Mr. Dynner.

Q Is his testimony true or false?

A His testimony is true.

Q And is it true that he directed the cylinder block strain gage testing at Shoreham and Comanche Peak?

A Absolutely true.

Q And is his testimony true that he was the main interface in the block analysis for the preparation of FaAA's report?

A He was the main interface between the design review quality revalidation group and the block efforts at Failure Analysis Associates, with myself as the overall manager.

Q And Dr. Rau, is your testimony on page 3 that your role in the investigation of the blocks has been to plan and supervise the metallurgical evaluation, materials

WRBeb

testing, and cumulative fatigue damage analysis, is that true or false?

A (Witness Rau) It's true.

Q Did you leave anything out when you described your role at page 3?

A I mean it is not a detailed description of everything I did on every day from, you know, April, May through today. But these are the major areas for which I had a responsibility.

I certainly did consult on other areas for which I did not have direct responsibility.

Q Okay.

Now, Dr. Wells, can you help me out by telling me whether it is true that the information on stress shown on Exhibit B-30 was used in developing the Goodman-Smith diagrams which are Exhibits B-49 and B-50?

A (Witness Wells) Yes, indeed, it was used.

Q Now could you please explain for me in what manner it was used in the sense that the information on Exhibit B-30 is as you have testified for the original 103 block and the Goodman-Smith diagrams in Exhibits B-49 and B-50 are by their terms for the Shoreham EDG 101 and 102 blocks?

A Certainly, Mr. Dynner.

As we spent some time this morning I hope

WRBeb

explaining, we used the measurements from gage 13 and the scaled factors shown in Exhibit B-48 to arrive at conclusions of the mean ranges of stress for the 101 and 102 blocks as well as 103.

Q So you scaled-- Am I correct that when you used this scaled information that you scaled up -- scaled that stress information on the basis of your assumption that the blocks of EDG-101 and 102 are comprised of typical Class 40 cast gray iron? Is that right?

A In the analysis of DG-101 and 102 blocks, yes, we used the properties of normal grade 40 gray cast iron.

Q In looking at Exhibit B-49 for a minute, do I understand that that exhibit predicts that stud-to-stud cracks will initiate if ligament cracks are present in the blocks?

A The Goodman-Smith diagram does indicate that based on the analytical models that we feel are conservative of course, that the initiation of stud-to-stud cracks is certainly possible.

Q That is not my question. My question is:

Does it show that stud-to-stud cracks are predicted to initiate in a block that contains ligament cracks? It does predict that, doesn't it? Yes or No?

A There is no way to answer Yes or No. It predicts that under the analytical models that were used to develop

WRBeb

the scale factors and the properties we assumed that yes, there is some possibility but there is no definite prediction that such an area will fail on the 101 and 102 blocks.

In a sense this is Dr. Rau's testimony, and I would like to defer to him for additional clarification.

A (Witness Rau) Mr. Dynner, I think I said yesterday and maybe earlier this morning that the fact that the conservative analytical calculations scaled from the strain gage measurements at gage position are in excess or above the Goodman-Smith line simply is indicative that fatigue cracking may occur.

Both the analysis and also the material properties which are used to construct this diagram are conservative, and therefore, if the materials properties, for example, are slightly better than the minimum properties for chemical iron--

For example, look on the abscissa. That is the horizontal axis of Exhibit 49, where the mean stress if listed, and the lines come together at 25 ksi. That's the minimum tensile strength for typical Class 40 gray iron in the section thicknesses represented above the block top.

Clearly all of the typical gray irons will not have minimum tensile strength. Some will have 26, some will have 30, some will have 32. And the fact that the points

WRBeb

reside slightly above the line, given the fact also that the analyses are conservative, only suggests that the fatigue crack initiation is possible, not that it will occur.

Q Dr. Rau, let's now take what you just said and apply actual tensile strength properties of the 101 and the 102 blocks. What would they be?

You see my point, Dr. Rau? Instead of depending upon some kind of notion of a typical Class 40 gray iron which, as you just testified, would have a fairly significant range, let's use the actual figures for 101 and 102. Do you know what they are?

WRBpp

A Mr. Dynner, we know what the B bar test results reported by TDI at the time of fabrication of the 101, 102 blocks were. We know that those test results done on a separately cast bar of 1.2 inch diameter indicated strengths well in excess of the minimum tensile strength for class 40 gray iron in that particular size casting. We therefore have reason to believe, given the normal typical microstructure for 101 and 102 block tops, that we will have tensile strengths for the 101 and 102 block tops which are considerably in excess of the minimum expected properties for the thickness of the block top.

In other words, the 25 which is shown on the horizontal axis of Exhibit 49 would be exceeded, in my opinion, by the actual 101 and 102 blocks.

Q Dr. Rau, you testified this morning that those B bars or test bars on the EDGs at Shoreham had been cast separately from the blocks by Delaval and that they were not representative of the mechanical nature and strength of those blocks, didn't you?

A What I testified this morning was not that, Mr. Dynner. What I said was that the separately cast bars, because they are cast at the same time from the same pour by requirement but they are cast in a separate mold, thinner. And they're going to, therefore, cool at a different rate and they will, in fact, therefore have a higher tensile

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strength than the much thicker actual casting which cools at a much slower rate.

Now there is a relationship, however, between the strength which is measured in a 1.2 inch diameter separately cast bar and in the same pour of metal and that which you will get in the thicker block top from the same pour. And the fact that the B bar, the 1.2 inch diameter bar measured by TDI at the time of manufacture reported, is in excess of the minimum tensile properties in a 1.2 inch diameter bar.

And the fact that the microstructure is shown to be typical of class 40 gray cast iron suggests that in the 3 1/2 inch thickness, which is the thickness that the block top slab was when it was cast, that we would expect tensile strength in excess of the 25 ksi which is the minimum expected for a 3.5 inch thick block top.

Q Did you want to add something, Dr. McCarthy?

A (Witness McCarthy) Yes, I think where there might be an area of confusion here is, the 103 block top does not have the typical microstructure. And you need two pieces of information. One is the strength levels as measured in the B bar and then second, the assurance that the block top came out with a typical class 40 gray iron microstructure. What we have in the case of 103 is a microstructure that's very degenerate, whereas, in 101 and 102 we have a very different microstructure from 103, which

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allows us to make the normal predictions from the B bar which you can't do in the case of 101 because of the tramp elements in the casting and the resulting degenerate material that came about as a result of the tramp elements.

Q Dr. Rau, what is the relationship that you are talking about between knowing the tensile strength of the 1.2 inch separately cast B bar of EDG 101 and the 3 1/2 inch as-cast depth of the block top of EDG 101's block?

A (Witness Rau) Mr. Dynner, I think I understand that question but it was very long. You asked me what the relationship was between the different thicknesses.

Q You told me that there was a relationship that if you knew the UTS of the 1.2 inch separately cast B bar for the 101 block that you would be able to tell what the UTS was of the 3 1/2 inch as-cast thickness of the block top; and I'm asking you what that relationship is?

A Okay. Mr. Dynner, you did not accurately characterize my testimony. What I said was there was a relationship between the two and that relationship is shown quite clearly on Exhibit B 12.

This exhibit shows from very standard and well-done references the relationship between the thickness and the casting and the properties of the gray cast iron, the tensile properties that result. And you can clearly see that there is a decrease in the tensile strength with

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increasing thickness which is related to the cooling rate of the casting.

You can also see that the relationship, if you had a class 40 gray iron with minimal tensile strength of 40, would result in a 3 1/2 thick plate approximately a minimum tensile strength of 25. By the same token if you had a tensile strengh of, say, 50 in a 1.2 inch B bar you would expect a strength higher than 25 when you got down to a 3 1/2 inch thick block top casting.

Q You know, I was curious about this, Dr. Rau, in Exhibit B 12. Why is it that the original version of Exhibit B 12 had next to the circle in the upper righthand corner, the notation "Iron Castings Handbook B bar" and in the revised version the words "B bar" have been deleted?

A Mr. Dynner, this was done just for complete accuracy. Clearly, the B has a very specific meaning. It means that the bar diameter is 1.2 inches. And that's a true statement for those points where the thickness is -- where the bar diameter is 1.2 inches. But for your other data points shown on there, some which are thicker some which are thinner, it's not strictly correct to call it a B bar. It's a cast bar but the B means 1.2 inches.

Q What was the source of the information for this document?

A The references, Mr. Dynner, are listed in the

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upper right of the Exhibit B 12. They are the ASM Handbook, the American Society for Metals Handbook, the Iron Castings Handbook. There were also other related references which showed basically the same results. I don't have them listed here but there were others.

Q Well isn't it true that the Iron Castings Handbook that gave the information indicated by the circles was giving that information for a B bar and not for a general casting?

A No, sir, that is not true.

Q Do you have a page reference for that information in the Iron Castings Handbook?

A I don't have it here.

Q Does anybody else on the Panel know what that is?

A Mr. Dynner, let me just state again -- maybe you didn't understand me. Nobody who is familiar with the codes is going to suggest that all different thicknesses of bars are B bars. I mean a B bar means it's 1.2 inches diameter. There are other -- there's a C bar and an A bar. An A bar is thinner than 1.2 and a C bar is thicker and a D bar is thicker still. So it just has no meaning. It was taken out for clarity and accuracy.

Q Well, did the Iron Castings Handbook give that information for any particular thickness of a casting? Was it given for a 1.2 inch casting, or was it given for a

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different size?

A Mr. Dynner, the thicknesses we're talking about and the casting diameters are on the horizontal axis of Exhibit B 12, every place where there's a data point or a line the fitness is represented there. And the data point means that that particular reference provided information on a casting which was cast at that thickness.

MR. FARLEY: Judge Brenner, I have copies of the Iron Castings Handbook, if you would like to pass these to Dr. Rau.

JUDGE BRENNER: Why don't we see if anybody wants to come back to it after a break instead of pausing now?

Thank you, Mr. Farley.

BY MR. DYNNER:

Q Now, just so I can be sure that I understand it, it's true, isn't it, Dr. Wells, that there was no actual metallurgical test conducted to determine the actual UTS of the block top of EDG 101 or EDG 102?

A (Witness Wells) There was no direct mechanical test.

A (Witness Rau) There was in fact metallurgical tests, though, which is what your question stated, and the metallurgical tests were described yesterday having to do with replicas and pieces of the block tops cut from 101, 102, old 103, and new 103.

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Q Yes. We will get into that later on.

Is your testimony with respect to Exhibit B 50 about what it shows insofar as 101 and 102 as indicated the possibility of crack initiation of stud to stud cracks also true with respect to Exhibit B 50, which is the Goodman Smith diagram for high cycle fatigue at 100 percent of load?

A (Witness Rau) Yes, Mr. Dynner, as I understand your question. The fact that these points -- I mean, all the analogous statements made with regard to Exhibit B 49 are also appropriate here. The points in excess of the lines represent the possibility but not necessarily the fact that we will get fatigue crack initiation.

Q Now, would you look at B 50 for a minute, Dr. Rau? Do you see where there's an asterisk and it says "stud to stud crack"? What does that mean? Does that mean that the place where the stud to stud crack would initiate in the presence of a block -- are on a block with ligament cracks?

A I'm sorry. You're going to have to ask that again. I got confused.

Q What does it mean where it says "stud to stud crack?"

A That's a representation of a combination of alternating stress and steady stress which are predicted conservatively to exist in the block top at the stud in the

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stud to stud location if, in fact, there is already a ligament crack in the ligament adjacent to the region between the studs you're considering.

Q All right.

Now, where would that asterisk that is marked "stud to stud" crack, where would that be before you would say that you could really predict that the crack will initiate? Where will it be on this chart? I'm trying to get an idea, Dr. Rau, as to what location you'd be moving for a more highly -- a higher -- possibility or predictability of a crack initiating.

A Mr. Dynner, the Goodman Smith diagram as applied to the analysis of high cycle or high frequency fatigue cracking deals only with whether or not fatigue initiation can occur. It's typically designed to predict whether or not you're going to get cracking or whether or not -- it never -- in the case of the high frequency fatigue -- deals with precisely how long it will take. Nor does it deal with any quantitative fashion with regard to how far to the right or left of the line you must be before you can have a certiain level of confidence with regard to the statements that there might or might not be fatigue crack initiation.

Q You understand what I'm getting at, Dr. Rau, if you can help me out. You were careful in answer to my question about whether on B 49, about whether it predicted

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initiation of cracks to say, well it doesn't really predict it but in any case there's a possibility. I'm trying to figure out where that asterisk would have to be for you to be willing to cross the line of possibility into the line of predictability. In what direction will you move that asterisk to be able to make a prediction?

A Mr. Dynner, let me try to answer your question in this way. There is no quantitative way to do it. Clearly, as you get further up and further to the right the chances of getting fatigue crack initiation or moving from the possibility to more possible increases it's related also to the conservativism in the materials properties and the conservatisms in the analysis. If we had both of those which were very precisely known in all ramifications, then you wouldn't have to be as far above or to the right of the line in order to make a statement about a higher possibility of cracking.

But since there are considerable conservatisms in the analysis we've done to scale from the gage 13 measurements up to those maximum stresses around the stud holes and because there's -- again, we're plotting the minimum expected strength and fatigue properties for the typical gray cast iron -- it's very difficult to be more specific than I have been.

Let me just add one more thing.

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That's also completely consistent with the physical observations. I mean, these analyses predict the possibility of getting stud to stud crack initiation once you have a ligament crack and that has occurred under certain rather severe combinations of loading. It surely has not happened at every stud to stud location for which there has been a ligament crack and for which there's been significant operation. So, clearly there's conservatism built into the analysis of the materials properties.

And that's exactly what I would expect, given the way it's been done.

Q Did you do a Goodman Smith diagram for high cycle and low cycle fatigue at 3900 KW load rather than just the 3500 KW load that is indicated in these documents?

A Well, in the course of the entire examination, the entire project we have, in fact, plotted points which are representative of other power levels. It's a rather straightforward thing to do. You just move the stars to different locations.

Q Well, why don't you tell me on B 50 where you moved the stars for overload at 3900 KW, if you can?

A Well, yes I can. Let me tell you how to do it without, perhaps, taking the time to do it.

Q I would rather you do the opposite. Do it for me rather than tell me how. I want to see the results rather

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than the exercise you go through.

A Fine. If you'd like me to do it, I'd more than pleased to do it but I don't know if we should take the time to do it here in front of everybody while everybody sits around.

Q If it's going to take you a while I would be happy to defer that but I'd like to get that information for both because I noticed that in the equivalent Goodman Smith diagrams, which were figures 13 and 14 of the block report, there was, in fact, plotted on those Goodman Smith diagrams the stars, if you will, or asterisks, or dots, showing the low cycle and high cycle fatigue initiation points at 110 percent of load.

So I'd like to get the equivalent information and be more precise, do it for 3900, rather than 110 percent which is somewhat less than 3900.

A Mr. Dynner, again, I'd be pleased to do that given sufficient time. Let me just point out, it's a very straightforward thing. You can do it yourself at the break, if you like.

Q I can't do it, Dr. Rau, you overestimate my capabilities.

A Let me just tell you how you do it. If you don't care, then I'll just do it and give you the result later.

JUDGE BRENNER: Okay, tell us how you do it.

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BY MR. DYNNER:

Q If you want to tell us, go ahead.

A (Witness Rau) If you go to Exhibit B 30, which shows the results of gage 13, and the stud to stud location between the heads, you have both that maximum stress and minimum stress at gage 13 location as a function of engine power level. These are the results obtained by analyzing the strain gage results. The two uppermost and far right points seen in that exhibit for gage 13 are those max and min stresses that were generated at as close to 3900 as Mr. Youngling was able to get the engine during that testing, it was 38 and something else.

The next series of dots to the left, those two we were just talking about, indicate the corresponding max and minimum stress that were measured and then computed from the strain gage results at 3500 KW. The difference between those two suggests the differences in mean stress, which is the average between the minimum and the maximum as well as the difference between is, in fact, the range. And all you need do is take those two points or the percentage differences between those two and put them on Exhibits 49 and 50 and you have your answer.

Q Now I really need you to do it for me.

(Laughter.)

JUDGE BRENNER: Come back to it tomorrow,

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Mr. Dynner.

MR. DYNNER: Certainly.

WITNESS MC CARTHY: If I can add one thing to what Dr. Rau has indicated. You can get some feel of the conservatism shown in our figure of the authenticity stress and the Goodman diagram points by looking at the position of the asterisk for what we predicted stud to stud cracking with a cracked ligament, which is far to the right and far up on the line. If you look in Exhibit 16 and 17 you can see how many cracked ligaments there are and now many positions where there is a stud to stud piece of material which a cracked ligament already present. Both these blocks have had over a thousand hours in service. There are cracked ligaments in at least 14 of these locations and we don't have any stud to stud cracks.

MR. DYNNER: That's precisely the kind of speeches which I have stated that I'm trying to avoid in order to move this cross examination along, Judge Brenner. And I think it is totally unnecessary.

JUDGE BRENNER: I'll agree with you on that one. There is not a particular question for which that answer was directed.

Ask your next question.

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MR. DYNNER: Judge Brenner, I am going back now to page 23 of the cross plan.

BY MR. DYNNER:

Q Gentlemen, please look at page 17 of your testimony. Now in answer 22, Mr. Youngling, you refer to the fact that EDG 103 experienced an abnormal load excursion.

By "abnormal load excursion," do you mean an accidental overload condition?

A (Witness Youngling) No, I don't. Basically what I meant by that characterization was that the engine was in a position where it tried to pick up additional load in the system. However the engine had been placed in a fuel limiting condition which resulted in the engine bogging down, if you will, in speed.

Q So it was not overloaded, is that what your testimony is?

A Overloaded in what sense? I don't know what you mean.

Q Do you know what an overload condition is, Mr. Youngling, for the diesel engines?

A Yes, I know what I interpret an overload condition to be.

Q What is an overload condition?

A An overload condition is when I ask the engine to

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pick up additional load above its continuous rating.

Q Okay.

Did that condition occur during this abnormal load excursion?

Dr. Wells, do you have something to say? If so, just say it, you don't have to write notes for Mr. Youngling.

A The engine was capable of only putting out a fixed amount of torque because of the amount of fuel that it could --

Q I am going to cut you off because that is precisely the kind of answer that you can say yes or no and then give me your explanation. It confuses the record to do otherwise. And I am going to ask --

A Ask me the question again and I will try to answer for you.

Q During that abnormal load excursion that you talked about in your testimony, did in fact an overload condition occur?

A No, I don't feel that an overload condition occurred in the sense that I understand an overload condition.

Q Now it is true, isn't it, that this abnormal load excursion lasted for only approximately 23 seconds, isn't that right?

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A The excursion would have had to have lasted approximately 25 seconds at a minimum.

Q And is it your testimony that in fact it did last for 25 seconds?

A From the time that the incident occurred until the time that the engine was tripped was 25 seconds, yes.

Q I don't want to quibble, but, Dr. MrCarthy, on page 1-2 of the Block Report, you state that the abnormal load excursion occurred for 23 seconds.

Is that incorrect and Mr. Youngling is right?

A (Witness McCarthy) If Mr. Youngling has the documentation in front of him, I would have to defer to him. As we indicate and set off asterisks on the front of the preliminary June report, we haven't had a chance to compare all of the numbers with the underlying documents.

A (Witness Youngling) Let me add, Mr. Dynner, that the engine has to see less than 400 rpm in order for the trip mechanism to actuate and that has to be seen for 25 seconds.

Q So it takes 25 seconds for the engine to trip out, is that right?

A Yes.

Q Now Mr. Youngling, during this 25 seconds, what was the load that the engine was carrying, if you know?

A I do not know what load the engine was carrying.

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Q Mr. Seaman and Mr. Schuster, you are the co-sponsors of this testimony. Do either of you know what the load was on the engine during the 25 second period?

A (Witness Schuster) No, sir, I do not.

Q How about you, Mr. Seaman, do you know?

A (Witness Seaman) I believe it was operating at full load.

Q And full load is 3500 Kw, is that right?

A Yes, that's correct.

JUDGE BRENNER: I'm sorry, I'm confused. I thought the problem was that the diesel picked up the site load for some period of time, I don't know, can you help me out there?

WITNESS YOUNGLING: Yes, Judge. What happened is that the engine -- we lost off-site power and in that transient the engine tried to pick up the additional site buildings. However the fuel rack on the engine was fixed at a certain value such that a limited amount of fuel could go into the engine. Consequently the engine reduced in speed, it bogged down. It is almost like driving up a hill and keeping your foot on the gas pedal at a fixed level, if you will.

JUDGE BRENNER: All right. I think I understood that before but I am trying to put that together with Mr. Seaman's testimony that the load was a full load and

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no more, even for a brief period of time. Was the fuel rack set at full load and no more?

WITNESS YOUNGLING: Yes, the fuel rack had been set at full load, 3500, the continuous rating of the engine.

JUDGE BRENNER: Okay. Thank you.

BY MR. DYNNER:

Q I want to clarify this with you, Mr. Seaman.

My question to Mr. Youngling and to Mr. Schuster and to yourself was whether you know what load, in addition to the 3500 Kw the engine was operating at the time that this occurred, what was the load that was picked up by the engine during the 25 seconds? That was my question.

A (Witness Seaman) Okay. I don't know the answer to that.

Q All right.

Now you say at the top of page 18 that after the -- I am confused by this, and you can clarify this for me, Mr. Youngling.

After the engine tripped out it continued to run a low load for ten minutes before it was shut off, is that correct?

A (Witness Youngling) Yes.

Q What's the effect, if any, of an engine -- of the engine running at no load?

A None, not at all. Engines run at idle with no

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load quite frequently.

Q So that sentence doesn't have any significance to what went on; is that right?

A Which sentence? Where are you?

Q At the top of page 18 where you say "The diesel continued to run at no load for ten minutes before it was shut off."

A Yes; the significance of that condition was that we had lost the service water pump which was supplying cooling water to the engine. So in our attempts to put the engine back on, we had no cooling heat sink to the engine. We were cognizant of that, and after ten minutes we took the engine off, since we didn't have that cooling.

Q Then you say you finally restarted the engine. How long did it take you to restart the engine? What was the time period between when you shut the engine off and when you restarted it to continue the qualification testing?

A We shut the engine down after this 10-minute period. We then gave the engine a start signal again to ensure that we understood why it started, and we brought the engine back up to supply some loads. But we shut the engine right down again. So it didn't run very long at all, as I remember.

The engine was actually brought back for testing that evening.

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Now, the event occurred at approximately nine o'clock in the morning, and the engine was brought back that evening about 5:00 p.m. for continuation of pre-operational testing.

Q So you restarted it and continued the qualification testing at 3900 Kw at about what time in the evening?

A It was about five o'clock in the evening, as I remember.

MR. FARLEY: Judge Brenner, just for the record: all of these subjects were requested in Mr. Dynner's letter of September the 4th, and at your suggestion they were all produced by LILCO to the County on September the 25th.

PRESIDING JUDGE: So what? He has to build a record in front of us.

MR. FARLEY: I understand.

PRESIDING JUDGE: It's not in the record by virtue of what you gave him. He's trying to build a record here.

MR. FARLEY: I'm suggesting that he could be more specific in his questioning.

PRESIDING JUDGE: I can think of some points when I wanted to raise that criticism, but these last two or three questions were not one of them. I thought they were unusually concise and direct questions.

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Go ahead, Mr. Dynner.

A question like "What time was it?" "How long" are not subject to that kind of criticism, Mr. Farley. Save it for the next time.

Go ahead, Mr. Dynner.

BY MR. DYNNER:

Q When you started the engine up and you ran it at 3900 Kw, you say in your testimony a crack in Cylinder No. 1 was noticed.

At what point into this qualification test at 3900 Kw did you notice -- did you first notice this crack at Cylinder No. 1?

A (Witness Youngling) The engine was restarted to begin a 24-hour run. The first two hours of that run were to be done at 3900 Kw. The engine ran for one and three-quarter hours at 3900 before we took it off the line. Approximately twenty minutes prior to that time, the test engineers on shift noted on the front standard of the engine an oil seeping, and they investigated that, and within twenty minutes after first seeing the indication they took the engine off. That was at one and three-quarter hours, then, into a 3900 run.

Q Somebody first noticed-- At one hour and twenty-five minutes into the full power run, somebody noticed oil seepage, did you say? Or did they notice the

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crack?

A No, they noticed an oil stain running down the front of the engine. The test engineer thought that the oil was coming out from under the cylinder head. He wiped it clean, and, in the process of wiping it clean, he saw the outline of a crack. He then got his supervisor there and they made a decision to take the engine off and I was called.

Q Well, was it determined where this oil was coming out of?

A Yes. Where it was was, the oil was coming out of the stud hole for the cylinder heads. There is always a certain amount of oil up in there because there is an oil cooling and lubricating system in the cylinder head sump cover, which seeps down into the stud holes.

Q Are you the one who determined that the engine should be stopped after the initial twenty minutes?

A No. I was not on site when it was secured. That decision was made by the on-shift test engineers.

Q Was there any report about what the length of this crack at Cylinder No. 1 was at the time it was first noticed?

A When the test engineers called me at home, they told me that the crack came out from under the head and went down the front face of the block. And they said it went

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down for about three inches, as I remember.

Q And do you know whether that measurement, or that estimate of the length was made after the engine was stopped or before it was stopped?

A I can assure you it was made after the engine was stopped.

Q Did LILCO or FaAA or anybody--

A Mr. Dynner, let me also add here: I don't know whether the man took a ruler to it or not. He just called me and said it looked to be about a three-inch crack down the front end of the engine. He said, "We took it off," and I acknowledged that and told him I would report to the site.

Q Did FaAA or LILCO or anybody who were their agents notice whether or not that crack was present before the qualification testing was resumed at five o'clock?

A Let me speak for the start-up personnel. We did not see that crack.

Now, did we look in that area? No, we did not look in that area. So, could it have been there? Yes, it might have been there.

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Q Well, why did you shut down the engine, EDG-103? Why was it shut down after it developed this crack? Why didn't you just continue with the qualification testing?

A Well, first of all, let me say that from an operating standpoint the operating parameters on the engine were very satisfactory.

But let me put you in my shoes, or in the test engineer's shoes. If you saw that situation, if you understood the situation with these engines, and the scrutiny they had been under, wouldn't you have shut them engine down? I sure would have.

Q If I were in your shoes I would have gotten rid of them long before now.

MR. FARLEY: Objection. Move to strike.

PRESIDING JUDGE: We don't have to strike it, because, like most statements lawyers make in this hearing, it's meaningless.

(Laughter.)

MR. DYNNER: I object, Judge Brenner.

(Laughter.)

BY MR. DYNNER:

Q No; I want to ask that question to you seriously, because, Mr. Youngling, as you know, it wasn't just a question of the engine being shut down, in fact the engine was shut down and the block was scrapped. And I want to

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know whether this crack had anything to do with that decision.

A (Witness Youngling) Well, when we first saw the crack, sure, we were concerned about it, and that's why we shut the engine down.

We then had FaAA, we had other -- our own engineers look at the crack, and we made a determination, I believe the next day, that we should go ahead and strip the engine block down and have a look at the entire engine block. That resulted in the crack map at Exhibit 25 being developed.

We also contacted people and firm that are world-reknown in repair of cracks on cylinder blocks, and we contacted two firms. And there was very real confidence that they could repair that front crack.

However, when we found the one between 4 and 5, one of the firms was not confident that he could repair the crack, nor we were confident that we could sell ourselves and the NRC, and everyone else, that we had a sound condition there.

As a result, management, as a result of my recommendation to management, decided to replace the cylinder block.

Q Dr. Wells, it's true, isn't it, that FaAA also recommended that the 103 block should be scrapped as a

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result of these cracks?

A (Witness Wells) Yes, Mr. Dynner, for the same reason, that we could not support the integrity of the block, even with its repairs.

PRESIDING JUDGE: Could I get a clarification on the chronology of the decision, Mr. Youngling?

LILCO made a decision to replace the block before it was known that, at least in LILCO's view, the microstructure of the block was deficient compared to what it was expected to be?

WITNESS YOUNGLING: Judge, we had gotten a preliminary report back from FaAA that showed that there was about a 10 percent disparity in the block strength characteristics. Now, I don't remember whether I had that word before I made my recommendation to managment or not. I seem to think I did. But in light of having the feedback on where the cracks were, having the feedback from the repair people, and, I believe, having that feedback that it was a weaker block, I'm not sure whether-- It was right around that time we decided to make the recommendation to management to replace.

BY MR. DYNNER:

Q Dr. Wells--

A (Witness Rau) Can I add something for clarification, Mr. Dynner?

The report which Mr. Youngling is speaking about has nothing to do with the mechanical tests performed by FaAA on the material cut directly from the top of the original 103 block. He is not referring to our review of TDI's records of the original casting B bars.

That was just for clarity.

Q Dr. Wells, --

PRESIDING JUDGE: I'm confused again; I'm sorry.

I thought we had earlier testimony that the review of the TDI B bar for the 103 block would not have given you that information anyway.

WITNESS RAU: It certainly, your Honor, gives you no information with regard to the degenerate graphite and the dramatically lower strength and fatigue and fracture properties. But there was, in fact, a difference even in the B bar between the margin above the minimum specification of 40 in the 1.2-inch diameter bar.

In other words, the 103 original was measured to have a lower tensile strength than that 1.2-inch bar than were 101 and 102. And I believe that was the basis which was one of the contributing factors to Mr. Youngling's recommendation to his management.

PRESIDING JUDGE: Thank you.

BY MR. DYNNER:

Q Dr. Wells or Dr. Johnson, whoever ppropriate

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here: what was the depth of the-- Let me ask you: what were the dimensions of the crack that developed from the No. 1 cylinder stud hole and ran down the front of the block?

A (Witness Wells) Well, first, the crack was confined to the region from the stud hole outboard toward the front of the engine. In other words, it went first through the 2-1/2 inches of the nominal block top, it proceeded through the boss area to a depth below the block top, which -- I believe -- was 4.4 inches. 4.4 inches I'm told is correct.

Now, that indicates that the crack was still confined along the stud itself, in the stud hole. So it grew out from the stud hole through the side wall of the engine -- the front wall; pardon me -- down to a depth of 4.4 inches. It did not, of course, penetrate the coolant passage, because the hole itself is 5-1/2 inches deep from the block top.

Q Were any measurements made of the inside depth of the crack, as opposed to the depth of the crack as seen on the face of the front of the engine?

A I don't recall that.

May I ask Mr. Johnson or Mr. Schuster?

A (Witness Schuster) There were measurements taken in that stud hole on the end of the block at about 4/17/84. The specifics of what those measurements are I don't recall

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at this point.

Q You don't have a report with you of that measurement, Mr. Schuster?

A No, sir, I do not.

The 4.4 or 5-inch dimension that has been mentioned earlier -- and it's on the exhibit -- is accurate, to my recollection. You know, the dimension inside the bore of the stud hole, and the dimension that's given there, 1.5, on the liner landing phase is accurate.

But the problem I have is in the stud hole itself, and the measurements that were taken there I don't recall what those might be, sir.

Q Dr. Johnson, your silence indicates that you don't know either; is that right?

A (Witness Johnson) That's correct.

The measurement that is recorded on the crack map, of course, is the largest measurement we observed. And that was running down the outside.

Q Now, Dr. Wells, you have testified that in your opinion, in FaAA's opinion, a portion of the crack growth on EDG-103 was attributable to the unusual load excursion, and you base that on a number of factors, and I'd like you to explain them for me.

First of all, what is the relevance of the -- to your opinion of loads achieved during testing?

WRBwrb

This is at the top of page 20 of your testimony, for your convenience.

A (Witess Wells) Yes, sir. The loads achieved during testing, on page 20, refer to steady state operation, during which, as we have testified before, we could not observe any change in the displacement of the crack faces. And as I believe I testified earlier, had there been significant extension of the crack, certainly from an inch and a half, as the measurement was before the test, to three inches afterward, there would have been a large measurable change in the crack displacement. Therefore, at 3830 kilowatts we were not observing any crack growth at all, at least insofar as we could measure with the accuracy of this compliance gage.

Q In fact, the engine ran at 3830 kilowatts during that test, as you testified earlier today, for only about a half-hour; isn't that right?

A Yes. Mr. Youngling has testified that it was operating at 3830 kilowatts.

Q And the loads achieved during the prior testing, before the large crack was found at Cylinder No. 1, would be shown on Exhibit B-15, wouldn't they?

A Yes, that's correct.

Q Now, do you see where it says "block failure, 4/14/84"? Is that the date that the large crack came out of

WRBwrb

Cylinder No. 1 and the engine was shut down April 14th, '84?

A (Witness Youngling) Yes, that's the date that the engine was secured; yes.

Q And if you look before that you see "qualification testing: hours," and you show, if I'm not mistaken, one hour at 110 percent load; is that correct, Mr. Youngling?

A Yes.

Q That should really be one and three-quarter hours, given the fact that you just testified that the engine ran at 3900 kilowatts for about one and three-quarter hours between the time that it experienced the abnormal load excursion and the time that it was shut down after the 3900 kilowatt test; is that right?

A No, Mr. Dynner, that is not a correct characterization.

When we are operating at this 110 percent point, we are fluctuating around that point, and the hours sometimes were above and sometimes were below, because we are at that very high power level. So the hours where we were below were thrown into the 13 and where above thrown into the greater.

Q Now, wait a minute. Where you see that sign that says L, which stands for load; right? and then it looks like a V on its side, and it says "110," what does that mean?

WRBwrb

A It means that the load was greater than 100 and less than 110 percent.

Q Greater than 100. Now, 110 percent of the rated load for this engine is, what?

A Unfortunately I don't know if FaAA interprets it this way, but unfortunately we always get the 3900 2-hour rating of this engine confused with the so-called 110 percent rating of the engine.

Q Answer my question first, and then you can give your explanation.

PRESIDING JUDGE: Mr. Dynner, it takes a little explanation. And I don't know if you were present--

MR. DYNNER: I would just like to have him say yes or no and give me the answer, and then explain it, Judge Brenner.

PRESIDING JUDGE: This one isn't that easy. I've been through it before at a conference of parties, which seems like a long time ago now. So take my word for it.

Go ahead, Mr. Youngling.

WITNESS YOUNGLING: Unfortunately we have this misnomer of the 2-hour rating on the engine is 110 percent. It is not 110 percent. It's 111.4, I believe. The 2-hour rating on the engine and the loads, the hours at that rating, 3900 Kw, are the ones that are in this last column entitled "L greater than 110 percent."

WRBwrb

BY MR. DYNNER:

Q 110 percent by my rudimentary arithmetic, 110 percent of 3500 would be 3850. And, therefore, greater than 3850 would include all of your testing at 3900; is that right?

A (Witness Youngling) No, that isn't right.

As I have testified, we continue to have this misnomer of 110 percent is equal to the 2-hour rating of the engine. The 2-hour rating of the engine is 3900 Kw, which is 111 -- I believe -- point-4 percent.

When we in start-up who are tracking these hours, categorize the hours, when we talk about the overload rating, the 110 percent rating, we put hours that are at 3900 Kw in that pot, if you will.

Q I thought that's what my question said.

But, Mr. Youngling, did you prepare -- did LILCO prepare this Exhibit B-15?

A We were the source of the data on this exhibit, yes.

Q I asked whether you prepared it, not whether you were the source of the data.

A We gave the data, and the actual configuration of the chart was done by the FaAA people. But we provided them with the engine hour data.

Q Dr. Wells, the last column, where it says

WRBwrb

"L greater than 110 percent," is that supposed to show all of the testing at 3900 Kw, or all of the operation at 3900 Kw?

A (Witness Wells) I must confess, Mr. Dynner, I don't recall exactly what the boundary is between the 110 percent, whether that's 3850 or 3900. And I'd have to go back and check records.

Q Does anybody who belongs to FaAA know what this exhibit B-15 means? Can you tell us what-- Can anybody on the panel tell us what the numbers mean? And translate those numbers at the top to kilowatts, if you can, for us.

A (Witness Rau) Well, again, I don't have any first-hand knowledge of this definition. But certainly all 3900 hours would be included amongst those numbers at the right: there is no question about that.

The only question is whether there are any additional hours at 3875, if, in fact, there were any at 3875. That might also be included in those numbers.

Q I have a lot of other questions, so I accept what you say as the last column including all the testing at 3900.

And, Mr. Youngling, I'm going to come back to you, because you testified earlier that you tested the engine after the abnormal load excursion for one and three-quarter hours at 3900 kilowatts, and I'm confused as to why that

WRBwrb

isn't reflected on Exhibit B-15. It only says one hour, it doesn't say 1.75.

Why is that?

A (Witness Youngling) As I said earlier, when we operate at that high condition, we have a tolerance, and we take readings on those tolerances. And some of the time we are below, some of the time we're above. And when we're below we throw them in one side, and when we're above we throw them in the other side.

Q How do you know when you're above or below, if it's a tolerance?

A Whenever we run a test like this we have to maintain a certain tolerance on our instrumentation, or on the test. I have recording devices which permit me to read out the kilowatts being put out by the engine, so that I know exactly where the engine is being held. And I can maintain that engine within a certain band or tolerance. That tolerance is set up around 3900 Kw.

Q Dr. Wells, now returning for a moment to your testimony on page 20, if you look at the number of hours that this EDG-103 saw at greater than 110 percent of load, the total is 30, and of that 30 at least an hour was the last hour of testing before the block failure.

Isn't it on that basis just as reasonable to conclude that the crack growth that you saw in the block was

WRBwrb

the result of the additional hour and three-quarters of testing at 3900 Kw rather than the 25 seconds that the engine carried an unspecified and unquantitated additional load?. --unquantified.

A (Witness Wells) It certainly is reasonable to expect that part of the crack growth occurred in that period that you mentioned, and a portion also occurred at the time the engine attempted to pick up the plant load.

Q How do you know that? That's just speculation, isn't it?

A We have no quantitative information that would tell us whether the majority of crack growth occurred during this "abnormal event," prior to it or subsequent.

Q Now, Dr. Wells, you say in Answer 25 on page 20 that inspections were performed on some blocks at other nuclear power stations.

Were any of those inspections carried out by FaAA, the ones you're referring to there, of course?

The reason I'm asking that -- to clarify for the Board -- is that originally your testimony said that FaAA inspected the blocks, and is revised now to say inspections were performed.

A But that's in incorrect statement. FaAA has actually worked under the quality assurance program of the Diesel Generators Owners Group, and when in the plants, it

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has operated under the plant's program. Therefore, technically speaking, we do not perform inspections, certainly on the block top; all we did was witness the inspections of block tops and perform metallurgical examinations or checks of indications when asked to do so.

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Q So, as I understand it, there were FaAA personnel who observed the inspections that you're referring to in that answer; is that right?

A Yes, sir, that's correct.

Q Were you one of those people?

A No, I was not present during any of those inspections.

Q Was Mr. Taylor?

A I'm not positive, Mr. Dynner.

JUDGE BRENNER: Mr. Dynner, we have been running for a little over an hour and three-quarters ourselves. This might be a good time to take a break?

MR. DYNNER: Yes, sir.

JUDGE BRENNER: All right. Let's take a recess until 3:40.

(Recess.)

JUDGE BRENNER: We are back on the record. During the break, Mr. Dynner, we considered your time estimate and we recognize that you said it was just an estimate of three more days. Whether you end up believing you have underestimated or overestimated it, it is our view that the total time that would be spent on cross examination of this panel, if we permitted you all that time, let alone the possibility that you might say you wanted more, would be excessive if we set a limit of your time estimate that

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would get us until roughly the lunch break on Tuesday of next week. We're going to tell you that you should assume that we will require you to complete your cross examination of this panel by the noon lunch break on Monday. That, in our view, is even more time that we think would have been reasonably necessary, but we're giving you some leeway along the lines that our judgment is wrong -- just in case our judgement is wrong.

We base our judgment on the way you've spent your time so far as the most important factor. And we think you have not spent it wisely and efficiently in terms of information that is going directly to what we feel we need to know.

I recognize you have other things to cover in your cross plan and we think if you spend your time efficiently from here on in you can cover it in the time we've allowed.

As usual, we will certainly consider as a safety valve, a request when we get to noon on Monday that the total time you spent until that point has been very efficient and very useful and through no fault of your own you could not complete matters and you've still got very important matters left to cover. But, we're going to average in the time spent so far in that consideration and I've already given you our view that that time has not been

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efficiently spent. So assume that you'll be cut off at noon on Monday.

Frankly, one of the only reasons we've given you the additional hour and a half on Monday is you'll have the break to collect whatever remaining things you have. And so we've already given you a partial safety valve at this time.

And why don't you proceed now?

MR. DYNNER: I move to strike answer 25 and the information resulting from it on the grounds that the witness has no personal knowledge of that information and doesn't know who does. Also question 26 to the extent it talks about the blocks at other nuclear power stations. And the non-nuclear service information.

JUDGE BRENNER: Give me a moment to re-read those questions and answers and then we'll hear from you, Mr. Farley.

(Pause.)

JUDGE BRENNER: All right, Mr. Farley.

WITNESS FARLEY: If your Honor please, I understood Mr. -- Dr. Wells, Dr. Rau and Dr. McCarthy to have testified from the commencement of this cross examination but this entire testimony and exhibits and supplemental testimony was a team project and they not only personally did things themselves but there were a number of

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people that were operating under their supervision and direction. And simply because Mr. Dynner established before the break that Dr. Wells was not at one of these places does not mean that FaAA cannot sponsor testimony that it has independently verified. In fact, I think this has been the subject of a ruling by the Board on one of the other components. And we submit that we did have independent verification by FaAA on all of the testimony that we seek to sponsor on nuclear and non-nuclear operating experience.

JUDGE BRENNER: Does the Staff have a view one way or the other and anything to add to the reasons we have heard?

MR. GODDARD: No, the Staff would join the motion. I believe it only went to 25 and 26. It would seem from the flow of the questions that 27 would be lightly adjunct to the first two mentioned by Mr. Dynner.

MR. DYNNER: Judge Brenner, if I can add a point --

JUDGE BRENNER: The Staff would join the motion because the witnesses were not personally present at the inspection; is that right, Mr. Goddard?

MR. GODDARD: Because they were not personally present at the inspection and, I don't believe, from the answers given by Dr. Wells that effective cross examination on these particular answers could be had by virtue of that

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lack of firsthand knowledge.

(Board conferring.)

JUDGE BRENNER: Mr. Dynner, you wanted to add something, I believe.

MR. DYNNER: It may be unnecessary. I was simply going to point out that the sole sponsors of this testimony are Dr. Wells and Mr. Taylor. And Mr. Taylor was the task leader, of course, and he is no longer a witness. Therefore, it was irrelevant that there were other witnesses who have adopted the testimony. They didn't adopt testimony that they didn't sponsor I assume.

JUDGE BRENNER: We are going to deny the motion to strike. We do have some preliminary view that it is not going to be very weighty in any event. It is very general testimony in the first instance and it really doesn't, by virtue of the testimony, provide any details.

Also -- and you didn't point this out in your motion to strike -- it comes close to an area for which there were motions to strike other testimony, I believe, presented by the County based on other engines. Although, some of those were non-nuclear. But the analogy is still there that there are references between engines and unless you explain the differences in similarities, you have to make a judgment as to how much weight to give the data from other engines. And we've always had that in mind.

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You have not established the point, contrary to Mr. Goddard's view, that no effective cross examination whatsoever could be had of this testimony. As experts they are entitled to rely on information that might be gathered for them or even otherwise available if not originally gathered for them.

Of course, their knowledge or lack thereof of what was done in the gathering of that data would affect the weight. So we deny the motion to strike. Your motion has had the effect of alerting us early as to your view of the weight and besides that, as I said, even if no questions had been asked on these particular questions and answers, it is quite general and we think that any decision we reach on these issues as sub-issues is quite highly unlikely to turn on this particular portion of the testimony unless there is something else connected with it that we're not presently realizing.

MR. DYNNER: I would respectfully bring to the Board's attention the fact that the Board did strike the County's direct testimony on pages 157 through 159, concerning the County's testimony on the non-nuclear engines and I will assume that your ruling now is consistent with that ruling in view of your comments about weight that you would give to the LILCO testimony that I just moved to strike.

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JUDGE BRENNER: Not exactly. And I did try and indicate that we see something in the record by which we would dra a distinction between a reliance on the nuclear engines as opposed to the non-nuclear engines. I did go so far as to say it was certainly a very analogous consideration. And unless we find other evidence in the record as a reason why we should tie the conclusions from the non-Shoreham but nuclear engines to the Shoreham engines, we wouldn't credit it.

However, there is some testimony as I recall, in the block testimony, which is what we're concerned with now, as to similarities of the blocks between some of these differently configured engines, the V engines and the inline engines, and so on.

So that was the thrust of our granting the motion to strike the County testimony. In addition, as I stated at the time when we had particular motions before us, we acted on them, we did not go looking throughout the testimony to see if there was similar testimony which could have been the subject of motions to strike at that time.

But there are a number of things going on that we'd have to find in order to decide how to credit testimony along these lines. One of them, I just mentioned, would be the differences or similarities between the engines. But the other, and the focus of your motion to strike, would be

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the knowledge of the bases for the conclusion that no cracks were found or anything else on those other engines.

BY MR. DYNNER:

Q Dr. Wells, were any cracks found in the engine block at Catawba?

A (Witness Wells) The block top inspections at Catawba revealed no cracks. These inspections were witnessed by an engineer under our supervision, Dr. Lee Swanger.

Q Were any other cracks found in the block at Catawba beside the block top? My question was, any cracks at all in the engine block at Catawba?

A I am unaware of any records of cracks in the blocks at Catawba.

Q Were any cracks found in the blocks at River Bend?

A I'm aware of the inspection records on one block and no cracks have been found on that block.

Q Would you identify the document that you're reading from?

A I am reading the notes compiled for my benefit on the inspection summaries of River Bend, Shearon Harris, Catawba, Grand Gulf, Comanche Peak, Plant Vogtle, and San Onofre.

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Q Thank you, Dr. Wells.

Am I correct, Dr. Rau, that the analyses conducted by FaAA which conclude the finite element analysis in the block tops and the analyses that were done leading to the Goodman diagrams give you information about the predictability of crack initiation but do not enable you to predict the propagation behavior of the cracks; is that right?

A No, Mr. Dynner, that's not correct.

Q Would you explain how that information is useful in predicting the crack growth rate?

A Mr. Dynner, you started off indicating all analyses among which you talked about the block top. But you now wish me to talk about all analyses --

Q No, I didn't. You misunderstood my question. I said the finite element analyses and the analyses which were used for the purpose of developing the Goodman diagrams that we talked about this morning.

A Okay. And your question is?

Q My question is, does that data enable you to predict the crack growth rate for crack propagation for the cracks in the block top?

A Let me first indicate that we're dealing not strictly with only analyses as we went through it in some detail. We're dealing with the strain gage measurements and

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then the scaling of strain gage measurements to various locations on the block top. The combination of those two, can and has been used to analyze fatigue crack propagation. The general methodology whereby that's done is described in a series of questions and answers dealing with and entitled, "Cumulative fatigue damage analysis."

Again, it's a very general question. I could go on but I don't know exactly where you want me to go.

Q The Goodman-Smith diagrams don't have anything to do -- don't permit you to predict crack growth rates do they? Isn't that what Dr. Wells and you testified to earlier today?

A That is correct.

(Pause.)

Q Dr. Wells, would you look for a minute on page 7 in your conclusion number one. Am I correct in reading that conclusion that the observations of the various engines that you are referring to are the only support for your conclusion that the ligament cracks in EDGs 101 and 102 do not and will not impair the ability of the EDGs to perform their intended function?

A (Witness Wells) No, that is not the complete situation, Mr. Dynner. We have, of course, tried to obtain all information on engine blocks containing ligament cracks both within the DR/QR program and elsewhere. But the

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significance of ligament cracks has also been evaluated by FaAA not in ignorance of this information since, obviously we must take into account what the experience has been in these engines, but our knowledge of material properties and the stresses and the behavior of the cracks that we have observed at Shoreham.

Would Dr. Rau elaborate on that?

A (Witness Rau) Yes, I will. In addition to what Dr. Wells has just said, the cumulative fatigue damage analyses, which we've done, which I have not yet described in detail but which basically quantify the effects of engine operating conditions and the time at these various engine operating conditions on fatigue crack growth, in the various blocks, can be used in conjunction with the demonstrated test experience, which has been obtained through the inspections and the knowledge of the propagation or the non-propagation of cracks in the original 103 block, which contains the markedly inferior degenerative graphite microstructure.

In other words, the very fact that the old 103 block with that microstructure has been subjected to extensive amounts of operating experience at a range of load levels, many of which are quite high, has demonstrated an enormous amount of cumulative fatigue damage which, in conjunction with the lack of extension of the ligament

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cracks which Mr. Dynner asked about in the 103 old block with the degenerate graphite microstructure provides a strong basis for the conclusion that ligament cracks will not extend in typical gray cast iron, which has markedly superior resistance to fatigue crack initiation and fatigue crack growth.

In addition to that, the finite element stress analyses which have been performed indicate that the -- although they're conservative -- they indicate that the stresses are highest at the top of the block and they're highest adjacent to the stud hole.

And as the cracks progress, if you like, down from the block top and any position away from the highest stress location right at the stud hole, those lower stresses will cause the cracks to be driven less quickly. The driving force is lower and therefore the cracks will grow more slowly.

And this is consistent with the cumulative fatigue damage analysis and provides some of the bases for the opinion that these ligament cracks will not extend in blocks like 101 and 102, which have typical gray cast iron microstructure and material properties.

Q Dr. Wells, do you know what the marine engines that you refer to in your testimony were run at, what loads they were run at in each case?

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A (Witness Wells) I have some of that information, Mr. Dynner. I don't represent that I know 100 percent of the load levels. I can tell you what we do know of their operation.

Q Well, can you briefly tell me which marine engines that you refer to in your testimony operate at 100 percent of their rated load, if any?

A I'm trying to find this precise part of the testimony you're referring to, Mr. Dynner. Would you help me?

My problem is the context in which you are interested in our knowledge of these blocks. For instance, by category of stud to stud cracking, cracks down the walls of the engine, ligament cracks.

Q The question is simple. You've referred to some experience with marine engines. I'm asking you whether you can identify any of those marine engines which operate at 100 percent of load, of rated load?

(Pause.)

Q We have had many minutes go by. If you can't answer the question just say, Dr. Wells.

A I'm afraid I'm unable to answer the question as to the specific load levels of specific marine engines. The ones that I see here I find are stationary engines.

Q If you will turn for a moment to page 44 and 45

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of your testimony. Dr. Wells, you state there that there are three possible mechanisms of crack initiation acting separately or in combination and the block top. You mentioned first, low cycle fatigue, second, high frequency fatigue and third, overload rupture.

My question is, Dr. Wells, are these three mechanisms also mechanisms for crack propagation as well as crack initiation in the block top?

A Yes, in general they are.

Q Have you conducted analyses or measurements to determine the amount of high frequency fatigue and/or low cycle fatigue and/or overload rupture would be required in order to have a crack propagate at any given rate?

A Let me answer your question with the part that I can sponsor then refer, if I may, to Dr. Rau.

We have examined the relative damage -- relative stresses and the resulting damage from both cycle fatigue, high frequency fatigue, and overload in the following way. Our models have looked at, first, the high frequency fatigue loading which occurs at the firing frequency resulting from the application of test pressure which we have discussed, I think, in some length already. The low cycle fatigue damage that occurs results from the startup of the engine and the accompanying thermal strains primarily, we believe, between the liner and the block top. So each time the engine is

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started up the application of firing temperature and pressure increase the liner temperature relative to the block thereby adding to the kinds of stresses that result from firing pressure --

Q I'm going to interrupt, Dr. Wells, just to tell you that what you are doing is describing those three mechanisms. So far, you have described two of them. My question was, have you performed an analysis to determine the magnitude of all or any of those mechanisms that would be required in order to predict a crack growth rate in any of the block top cracks? Can you answer that and then maybe give your explanation?

A Yes, certainly. We have been able, through the analytical models and the results of strain gage testing, been to predict the relative amounts of the mean and ranges of stresses appropriate to these three mechanisms. The other way these relative values of stresses which we discussed this morning in conjunction with the scaling factors have been used could be best described by Dr. Rau, who performed most of this analysis.

A (Witness Rau) Let me attempt to respond to your question. I may have to describe a little bit of the cumulative fatigue damage approach because the answer to your question involves using not only the strain gage and the finite element analysis that have been performed but

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also using the test results from the known operation on the original 103 block with the degenerate graphite microstructure, and the general method of approach is to use the known or the bounds on crack extension in the original 103 block to make calculations of the amount of crack progression either in low cycle, high cycle, or overload, which could occur in 101 and 102 or the replacement 103 block.

Now, that has been done and the general way in which it is done is to -- number one, it is based on fatigue crack propagation or overload. Let me handle the fatigue crack propagation first and then try to indicate how the overload would be -- and is, in fact, incorporated.

The fatigue crack propagation in cast iron is known to obey a relationship to the applied stresses and the crack sizes which is described by the general fracture mechanics technology. Without going into the details, if the stress range which is applied to a part with a known crack it increases. The cracks grow more quickly. And in fact, they grow much more quickly as the stresses go up. It's not a linear relationship with a stress range, but it's a power law. As the stresses double, the crack progression increases as two raise to the 5.83 power for good material or raise to the 9.58 power for the degenerate Widmanstatten graphite microstructure.

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In addition to that, we know that as the steady stress which is applied to the cast iron increases. This is a multiple factor, that the cracks also grow faster. The rate at which they extend is not as sensitive to the steady stress as it is to the cyclic stress but there is a relationship and that's quantifiable.

What I have done is to quantify the amount of operation at various power levels, through the strain gage of measurements at strain gage 14 to estimate the different stress ranges at those power levels. And then through the amount of test operation which the original 103 block has experienced, to relate the cumulative damage resistance of the material that has been demonstrated for crack progression in the old 103 block material.

And then by comparing the requirements, say, for a loop LOCA event -- in other words those power levels and those amounts of time -- or that matter any other kind of operation which you may choose to analyze -- by knowing what the bounds on crack extension were in the old 103 block, by knowing what the materials properties were for the old 103 block -- and by knowing the differences in the loads and the times and therefore the stresses -- the relative stresses between those blocks, the amount of crack progression in fatigue can be quanitified for a loop LOCA or any other operating condition. And that's exactly what we have done.

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And we've also taken that analysis then and quantified the relative amounts of crack progression that would occur as a fraction of that which did occur and was demonstrated by the performance of the old 103 block. In other words, we measured that the crack between cylinders 4 and 5 extended during a known test period on the old 103 block from a depth of about 1.5 inch down to a depth of 3 inches, over a given amount of cumulative damage associated with the operation at that time. By making a computation of the amount of damage that would be required for a loop LOCA in a typical or good gray cast iron block, I was able to compute quantitatively what percentage of the damage would be generated by a loop LOCA in, say, 101 or 102, given that there is already the presence of a ligament crack adjacent to that stop. That is the general method and that, in fact, quantifies the results.

To give you an example, for the loop LOCA load profile specified in Exhibit 51 engine, blocks 101 and 103 have been demonstrated by the cumulative damage analysis to require less than 2 percent of that cumulative damage crack propagation resistance which has already been demonstrated by the testing and observations on the original 103 block.

That's how it works for fatigue.

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Let me secondly address the overload mechanism which Mr. Dynner asked about.

MR. DYNNER: I just wanted to jump in here for a minute because there has been a ten minute answer to a very short question. And that is:

Did you calculate the magnitude of the high frequency fatigue that would be necessary to predict a particular crack growth rate?

And what I have had here is a ten minute recital of the direct testimony which already is in the record. I have not asked any questions about the cumulative damage index, I have simply asked a straightforward question and I was just waiting to see how long this was going to go on. And when it became clear it was using up most of the rest of my remaining time this afternoon, I thought it was time to interject. Maybe I am wrong, but I don't think so.

JUDGE BRENNER: All right. You have interjected and slightly exaggerated the percentage of your time that would be used up.

Can you answer the question? He has repeated it now.

WITNESS RAU: Yes. Let me continue with how the overload, effects of overload --

MR. DYNNER: No --

JUDGE BRENNER: No --

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MR. DYNNER: -- because that is not responsive.

JUDGE BRENNER: He wants you to switch gears and answer his question.

WITNESS RAU: I did answer his question to the best of my ability, your Honor. I didn't think I could describe how you would quantify the rates of crack propagation without telling you how it is done.

JUDGE BRENNER: Well I would hope that you could answer the question without necessarily going into how it is done.

Why don't you repeat the question again?A'

MR. DYNNER: Yes.

BY MR. DYNNER:

Q Did you calculate the magnitude of high frequency fatigue necessary to predict a particular crack growth rate in the block top?

A (Witness Rau) Yes, the procedure I just described indicates how that would be done.

Q High frequency fatigue is the mechanism that appears when the engine is running at higher loads as opposed to the low cycle mechanism which is when the engine is starting up, isn't that right?

A No, Mr. Dynner, that's not correct.

Q Okay

Is it a fact that the mechanism that you were

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referring to of high frequency occurs in greater amounts the higher the load carried by the engine?

A Would you repeat that, please?

Q Is it correct that the high frequency HFF occurs in greater amounts the higher the loads at which the engine is being run?

A The question is ambiguous. But if you are asking me do cracks grow faster when the loads are higher everything else being equal, the answer is yes. But I can't answer it exactly the way you asked it.

I should add that the high frequency fatigue analysis incorporates the amount of crack propagation that would occur independent of the load level. All load levels which the engine experiences are not just those which are high.

Q Let me try it this way:

Have you calculated the crack growth rate of the cracks in the block top at operation of the engine at 3900 Kw?

In other words, how fast would a ligament crack grow if the engine were being operated at 3900 Kw?

A Again, Mr. Dynner, you haven't given me enough information to give you a specific answer, but let me say that yes, we have made calculations from which you can infer the average crack growth rate if you know the average crack

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size and whether or not there is a ligament crack or not a ligament crack and where it is and what the material properties are, whether you are dealing with the old 103 or a new engine.

Q Let's take 101, EDG 101. What is the rate of growth of a ligament crack in EDG 101 when that engine is operating at 3900 Kw?

A Again there is no unique answer to that, Mr. Dynner. The rate of the crack progression is going to change as the crack gets bigger, as it changes position. I can't give you a precise number. I could make a computation or extract it from computations that have already been done of what the average rate is over a given size of crack extension at 3900. Again it would be based upon the kind of analyses I have already done. It is basically in the numbers that have been computed and I can't just pull it out in 30 seconds, but it is there.

Q Let's try another one --

A Let me just say I have imported in the testimony the results of particular load profiles which includes a certain combination of hours at 39, a certain combination at 35, whatever load profiles were germane to the particular statement I was making.

And so we have done those calculations for 39 but I am not aware of any operating -- I didn't do any

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calculations for 3900 forever, so I don't have that particular number.

(Pause.)

Q It is true, isn't it, Dr. Wells, that in FaAA's analytical models you used a maximum combustion gas pressure of approximately 1670 psi, isn't that right?

A (Witness Wells) That is correct. That is the full load pressure that we have used in our analysis.

Q And you did not use the maximum firing pressure of -- resulting from the operation at 3900 Kw, did you?

A Not explicitly in our models. We have taken the results of strain gage testing on the 103 block and operation at that load range has been factored into Dr. Rau's cumulative damage analysis. So we have not neglected the 3900 kilowatt operation.

A (Witness Rau) Let me just add to that. The finite element calculations that are done are elastic calculations. And the calculation can be done at one pressure level and then the stresses for any other pressure level can be obtained by scaling them because they are linear calculations.

And what Dr. Wells' said is completely true. In addition to that, the Strain Gage 13, from which we scale stresses any other place in the block top, do in fact increase in magnitude as the pressures increase with

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increasing loads, so that is an integral part of the calculations which are done.

(Pause.)

Q Why was Exhibit B-41 deleted, original Exhibit B-41?

A Original B-41 was omitted because -- for several reasons. First of all, some of the information contained on it are incorporated as part of Exhibit B-42. In addition to that it contained the results for Class 50 gray cast iron which, at the time of the preliminary draft June report, was some of the first fatigue data we ascertained through our literature search. As we subsequently obtained information for Class 40 and as we subsequently did our own testing of the original 103 block material and typical Class 40 gray iron, it just became irrelevant.

Q Is the information on that original exhibit accurate or not?

A To my knowledge it is completely accurate, just irrelevant. Again so many portions of it have been incorporated into B-42 and some of those portions of it about Class 50 are just irrelevant.

Q Dr. Wells, is it true that once a ligament crack is present in the block top the transverse stress between the stud holes increases by a factor of two?

A (Witness Wells) There is an increase,

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Mr. Dynner. It is not precisely a factor of two and I have to derive that number for you.

A (Witness Rau) Mr. Dynner, there is no reason to derive it. You could obtain it directly from Exhibits B-49 and B-50 as we talked about this morning, depending on whether you want mean stress or cyclic stress.

The difference between the location of the stars on those exhibits suggests -- when it says "crack," that means there is a ligament crack in the stud and they are the corresponding stresses in the stud-to-stud location. That point which shows in parentheses after "stud-to-stud uncracked" is the one at the stud-to-stud location before there is any ligament crack located at that position.

And the difference between those points either on the mean stress axis or the alternating stress axes reflects the relative increase in either of those stress components when a ligament crack is formed adjacent to the stud-to-stud region.

Q You interpret these for me then, Dr. Rau. Is it in fact a factor of two roughly by your looking at these documents?

A No, sir.

Q All right.

What is the factor on Exhibit B-49?

A For which type of stress would you like the

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factor computed?

Q Either or both.

A Again I will have to take it approximately off of the graph.

Q Sure.

A The alternating stress -- Give me a minute and I will just measure it with a ruling and calculate it for you.

(Pause.)

JUDGE BRENNER: You don't have the data points that go directly, you are going to just rely on your ruler measurement of the graph?

WITNESS RAU: I could find them, your Honor. I don't have them right in front of me. In one minute perhaps I can locate them in my notes.

(Pause.)

JUDGE BRENNER: If you don't have them handy you can do it the way you were going to. It just occurred to me it would be more accurate and any of us could do it the way you were about to do it.

MR. DYNNER: You can do this overnight, too, along with the others and maybe that will save time.

WITNESS RAU: I would be pleased to do that --

MR. DYNNER: If I could have the information --

WITNESS RAU: -- I can find the numbers I'm sure.

MR. DYNNER: -- for both the low cycle fatigue,

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that is Exhibit B-49, as well as Exhibit B-50, the high cycle fatigue.

WITNESS RAU: Surely.

MR. DYNNER: Thank you.

BY MR. DYNNER:

Q You say in your testimony at the top of page 46 that the --

MR. DYNNER: Judge Brenner, I am on page 49 of the cross plan.

BY MR. DYNNER:

Q At the top of page 46 you say that the Goodman-Smith curve identifies the possibility that for either high frequency fatigue or low cycle fatigue cracking may initiate at a load level of 100 percent.

Isn't it also true that the data from those Goodman-Smith diagrams would indicate that cracks might initiate at a load level of 90 percent under certain conditions?

A (Witness Rau) Yes, given the conservatism in the analytics and also the materials data which goes into those diagrams, they would also indicate the possibility of fatigue crack initiation at loads below 100 percent.

Q Specifically at 90 percent?

A I believe so. Again I can check the numbers to see, but I believe so.

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Q How about at 80 percent?

A Again I would have to make a specific calculation. You can do it from the diagrams, Exhibits 49 and 50; in point of fact though keep in mind the conservatism again in both the materials properties and the analytics make that kind of exercise not fruitful.

Q Yes, you have testified many times that you are conservative and what I would like you to do, if you would, just to save time, as a third small task, so that you can give the Board and parties the information is to tell me by your reading of these Goodman-Smith diagrams, B-49 and B-50, what is the lowest load level at which those asterisks appear above the curved lines which as I understand is where the possibility of crack initiation occurs. I would like to have that information if you could do that for tomorrow and we will save time questioning today.

A Again that is not a trivial calculation, it is very straightforward but I don't know, if you keep giving me a list of things to do, that I am going to have time to do them all, or whether it is even appropriate to do them all. It is not part of my testimony.

Q Well I understand that you have said in your testimony it initiates at a load level of 100 percent, you have now testified that it would initiate -- it might initiate at 90 percent and it certainly is relevant given

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the fact that we are trying to determine whether these blocks are or are not suitable for use in nuclear installations to find out at just how low a level of operation you would predict from these Goodman-Smith diagrams that cracks would initiate.

So I would think it is relevant and I would respectfully request that you supply that information to the Board and the parties.

JUDGE BRENNER: Well let me explain for Dr. Rau's benefit, and as Mr. Farley certainly knows, he can come back tomorrow with any objections of a legal nature or any problems of a practical nature that he wants to raise tomorrow. Beyond that there will be another break, a longer break while these witnesses are still on the panel -- although to the extent it is feasible it would be helpful to get the information tomorrow, nobody has to work long hard hours after spending long hard hours in the hearing all day, and we have had people come back before and say -- with either a legal objection from counsel or with explanation that it was not practical.

So don't worry about it, just because Mr. Dynner leaves you with a request doesn't mean it is an enforced assignment and we will deal with the record as it develops.

MR. DYNNER: I certainly did not mean that to be anything other than a request and done within a time frame

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that allows the witness panel to have some time to eat and sleep.

JUDGE BRENNER: Nobody can accuse you of being unkind, Mr. Dynner.

MR. DYNNER: Thank you.

BY MR. DYNNER:

Q Dr. Wells, if you would look for a minute at page 46.

Can you tell me, in your answer to question 63, how many --

JUDGE BRENNER: Wait a minute.

Let me advise you that even though he is asking another witness, it may turn out that the other witness is going to volunteer you to assist and then we will have to repeat the question.

WITNESS MC CARTHY: If I may just make a remark about the last question -- which is what Dr. Rau and I were discussing -- and the last request made of Dr. Rau, the analysis presented and the figures B-49 and B-50 were not intended and are far too conservative of a toll to be used to predict the threshold of crack initiation at lower operating load levels.

And one of the reasons that it is going to be a difficult analytical task is that once the analysis shows that you are in a range where at 100 percent load you are

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going to have initiation, we didn't then spend time to refine the tool to go down to lower load levels. Instead we said All right, there are cracks there, we would have to assume they are going to initiate and let's go forward from this point.

To now turn around and attempt to use that threshold as a tool to say Okay how far back down the curve, the operation curve, can you go is not an appropriate exercise for those diagrams.

JUDGE BRENNER: All right.

Dr. McCarthy, I accept that even in the abstract without knowing that there might be some concerns either practical or legal or substantive in terms of the view of the witness panel of the use of the testimony for certain purposes, and I suggest that since we will have to come back to this tomorrow anyway you can consider further what you have just begun to tell us and we know you have some preliminary concerns and we can get it all in one place when you have all had a chance to discuss it and decide with your counsel what at least initially LILCO and its witnesses think is most appropriate.

WITNESS MC CARTHY: Thank you.

BY MR. DYNNER:

Q Dr. Wells, I was referring you to page 46.

Now if it is true that many DeLaval engines have

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been operated for a substantial number of hours at high loads without developing ligament cracks or stud-to-stud cracks, how do you account for the fact that all three of the EDG's at Shoreham have developed ligament cracks and at least one has developed stud-to-stud cracks?

A (Witness Wells) It is difficult for us to assess, Mr. Dynner, because the early history of the operation of these engines is not completely known.

Basically we feel that the Shoreham engines, especially in the case of 103, represent a rather extreme combination of material properties and loading. The ligament cracks that have been seen in 101 and 102 are, we think, probably quite widespread throughout the industry.

Ligament cracking is basically a type of crack that has to be looked for quite carefully; they are not at all easy to find without making a concerted effort to look for them. And it may well be that ligament cracks have been rather common throughout the industry; I am not terribly surprised, in other words, that ligament cracks have shown up in 101 and 102.

On the other hand, stud-to-stud cracks appear to be quite a rare event. And unfortunately at the moment I can only express a professional opinion, having looked at only two blocks with stud-to-stud cracking and examined the microstructure: one certainly could infer from that

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that the variation of material properties has a great deal to do with the existence of stud-to-stud cracking.

Q You don't know, do you, when the first stud-to-stud crack initiated in EDG 103?

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A We do not know precisely when that crack occurred. As I say, the first time we saw it it had developed as two separate cracks from the stud holes between cylinders 4 and 5. The best we could do at that particular time after the qualification run was attempt to measure its depth. And even now having broken it open, is not possible to trace its precise origin through time.

Q On page 47, Dr. Wells, you testified that it is clear that the other factors in addition to the state of stress, such as materials properties, play a major role in crack initiation and propagation. What other factors did you have in mind besides the materials properties, if any?

A There are several, Mr. Dynner. From our analyses of the block top stresses we know that certain assembly factors are important. We know, for example, that the fit of the liner in the block can be a significant factor. There are two aspects of that. The radial clearance, I think I mentioned before.

In addition to that, the height of the liner above the block top. And, of course, variations in torque that may occur. There have been changes throughout the history of the Delaval engines, as I understand it, in torque levels, and the preload does certainly contribute to block top cracking.

It's also clear from our observations that if

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scale builds up -- and it can build up definitely -- between the liner collar and the block that certainly the radial pressure between the liner collar and the block can increase. Heat transfer certainly would play a role.

There's not much one can do to predict quantitatively the effects of heat transfer, I think, other than to say that variations in the ratio of fuel to air and scale that inhibits heat transfer would influence the liner temperature and, thereby, the amount of stress in the block top.

Q You're aware, aren't you, Dr. Wells, that a number of other owners of Delaval engines have engaged in modifications of their blocks in order to reduce the likelihood of initiation of cracks in a block top including, for example, reducing the liner proudness or protrusion of the liner above the block top; isn't that right?

A Well, not precisely. As I understand, these modifications are to the liner but you are correct in that the clearance between the liner and the block has been increased and also there have been decreases in the so-called liner proudness, the height of the liner. These, I don't believe, have in any case involved machining the blocks.

But we have, in effect, recommended to LILCO that for the long term these changes are certainly desirable from

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the standpoint of reducing the effect of thermal and pressure stresses on the accumulation of damage.

And, in fact, on the new block for DG 103, LILCO has decided to take our recommendation on a somewhat increased radial clearance and decreased liner proudness.

As, I'm sure, you're aware other nuclear plants have been given the same recommendations by the diesel generator owner's group.

Q Mr. Youngling, do you know whether LILCO is going to take steps to make these block modifications in EDG's 101 and 102 before those blocks go into nuclear service if, indeed, they ever do?

A (Witness Youngling) We have taken FaAA's recommendations and, on the basis of their long term recommendation, we are considering those for future implementation after fuel load.

Q Is your answer to my question yes or no?

A They will not be implemented on 101 and 102 prior to fuel load.

Q Thank you.

JUDGE BRENNER: You can find a convenient stopping point in the next few minutes, Mr. Dynner, and then we'll recess for the night.

MR. DYNNER: I think this would be a good point, Judge Brenner.

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JUDGE BRENNER: Okay. We'll recess then until 9 o'clock tomorrow morning.

(Whereupon, at 4:57 p.m., the hearing was adjourned until 9:00 a.m., Wednesday, October 24, 1984, at this same place.)

CERTIFICATE OF OFFICIAL REPORTER

This is to certify that the attached proceedings before the UNITED STATES NUCLEAR REGULATORY COMMISSION in the matter of:

NAME OF PROCEEDING:

LONG ISLAND LIGHTING COMPANY
(Shoreham Nuclear Power Station)

DOCKET NO.: 50-322-OL

PLACE: Hauppauge, Long Island, N. Y.

DATE: October 23, 1984

were held as herein appears, and that this is the original transcript thereof for the file of the United States Nuclear Regulatory Commission.

(Sigt) William R. Bloom Anne G. Bloom
(TYPED)

William R. Bloom & Anne G. Bloom
Official Reporter

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