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NUCLEAR REGULATORY COMMISSION

IN THE MATTER OF:

LONG ISLAND LIGHTING COMPANY

(Shoreham Nuclear Power Station)

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UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

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In the matter of: :

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

(Shoreham Nuclear Power Station): :

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State Office Building,

Veterans Memorial Highway,

Hauppauge, New York.

Wednesday, October 31, 1984.

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

BEFORE:

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

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

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

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APPEARANCES:

On behalf of the Applicant:

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On behalf of the Nuclear Regulatory Commission Staff:

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Office of the Executive Legal Director

On behalf of the Intervenor, Suffolk County:

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C O N T E N T S

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C O N T E N T S (Continued)

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P R O C E E D I N G S

JUDGE BRENNER: Good morning. Back on the record.

Whereupon,

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

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

JUDGE BRENNER: Is the Staff prepared to answer our questions about that October 10th letter regarding its request for further information on the crankshafts?

MR. GODDARD: Yes, Judge Brenner, we are.

JUDGE BRENNER: All right.

MR. GODDARD: The letter of October 10th documents questions which were prepared by a Staff witness stemming from testimony which was given on the crankshafts during this proceeding. The Staff did not file direct testimony on Figure 3.13, which was referenced in that

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letter. Staff witnesses were questioned on this topic during cross-examination, and heard witnesses of other parties questioned on this topic.

The answers to those questions, as far as we can tell at this time, would not affect the Staff's recommendations for resolution of questions regarding the adequacy of the Shoreham crankshafts at any specified power level. The Staff will make the responses available to the Licensing Board and to the parties to this hearing immediately upon their receipt.

I will state that those questions were in fact framed after the record on crankshafts had been closed in this proceeding. They were transmitted to Mr. Clarence Ray with the request that those be responded to as quickly as reasonably possible.

JUDGE BRENNER: I'm a little confused. Why are you asking the questions if you also say they are immaterial to an assessment of the crankshafts?

MR. GODDARD: The Staff is not certain at this time whether any of the answers produced thereto would have a bearing on matters within the scope of this hearing. Obviously the subject matter is generally the same.

I might point out that the Staff is currently reviewing four separate designs of TDI crankshafts, or crankshafts in TDI diesel engines for nuclear standby

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service. This was prepared outside of the-- There was no intention to use this matter during the hearings or as a basis for further proceedings with regard to the crankshafts in this case.

JUDGE BRENNER: I'm sorry, I am still confused, and maybe you can help me out.

The letter references the assessment of the Shoreham crankshafts, so it includes that. The Shoreham crankshaft is squarely within a contested issue before us. And in your initial statement this morning you said that the information would not affect an assessment of the adequacy of the Shoreham crankshafts.

And then I asked you why are you asking the questions then, and then you changed what you said I believe to saying well, at this time you couldn't say whether it would affect it. Which is it?

If you want to talk about it some more and get back to us you can, but I'm just trying to show you why I'm still confused by your statement.

Why don't you think about it and come back to us with it.

MR. GODDARD: Well, at this point I think perhaps Dr. Berlinger, the author of that letter,--

JUDGE BRENNER: I want you to think about it, too, and put it together, because I want it to be

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considered by Counsel who is in a better position to understand considerations of scope of litigation versus scope of review outside of litigation. So I don't want to get it piecemeal. You put your act together, and see if you can straighten out my confusion.

Maybe there's a simple answer that I'm just not understanding, but I hope this further expression of my confusion might help you phrase your explanation to us.

We will take it up again later today. Right after the lunch break might be a good time.

MR. GODDARD: Fine.

JUDGE BRENNER: Did any of the other parties want to comment so far? It might be well to wait until we take it up again after the lunch break.

All right, let's do that. And if the parties want to confer further on it, I think that might be good also.

That will give me an opportunity to go back and look again at Figure 3.13, so I can see exactly what it is in light of its being referenced in the caption and also in your remarks this morning, Mr. Goddard.

All right. Mr. Farley, a minor housekeeping matter.

To my knowledge, I have not yet received the adjusted cross-examination plan from LILCO for the County's

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witnesses. Am I right?

MR. FARLEY: Yes. It should be here this morning.

JUDGE BRENNER: All right. I just wanted to make sure I didn't misplace it.

All right, we are ready for you to proceed with your redirect examination of these witnesses.

MR. FARLEY: Thank you, sir.

REDIRECT EXAMINATION

BY MR. FARLEY:

Q Dr. McCarthy, last week you testified, in answer to a question, that you would be -- quote -- "mildly flabbergasted" -- close quote -- if there were not additives in the lubricating oil used in the Shoreham EDGs.

Have you ascertained what type of lubricating oil was used in the Shoreham EDGs prior to April 14, 1984?

A (Witness McCarthy) Yes.

Q What type of oil was it?

A It's Mobil--

Q What type of additives?

A Well, it's a Mobil Delvac 1240 oil, which is an SAE-40 diesel service grade oil.

Q Do you know what the additives were?

A Yes. I have ascertained what those were. Specifically it contains, as I indicated last week, an

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anti-oxidant, an anti-sludge additive. It also contains an extreme pressure zinc diphosphate additive.

It also has anti-acid additives in the form of reserve alkalinity. The pH is kept elevated above neutral to counteract engine acids developed during the service.

It also has, as I indicated, a detergent and an anti-foaming additive.

Q Was this particular type of lubricating oil that you ascertained was used in the Shoreham EDGS prior to April 14, 1984, suitable for use in an emergency diesel engine such as those located at Shoreham?

A Most definitely.

Q Would the use of the Delvac 1240 in the Shoreham EDG engines promote or increase oxidation of the internal engine parts, in your opinion?

A No, definitely not.

Q You also testified that you predicted little operational impact on the Shoreham engines from any water leakage at the ligament cracks. Do you recall that?

A Yes.

Q How much-- Strike that.

Do you have an opinion as to how much leakage would have to occur at the ligament cracks that you're familiar with on the Shoreham EDGs before the operator at that station would become aware of a low load -- a low-level

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coolant alarm?

A Yes. The low-level coolant alarm on the Shoreham engines is set at 20 gallons, so after 20 gallons of coolant have leaked out of the system, the low-level alarm comes on.

Q Now referring to the same Shoreham EDGs and the surface indications or cracks that you're familiar with in the cam gallery areas, would your answer be the same for a leak in that area?

A Yes. The coolant alarm is not sensitive to where the leak is. It is just after a 20-gallon loss of coolant, the low-level alarm comes on.

Q Do you know whether or not there is any way to add coolant to the Shoreham EDGs while they are operating, assuming a coolant leak either from a ligament crack or a surface indication or crack in the cam gallery areas?

A Yes, I do. I have inspected those engines and to each is connected an inch-and-a-half water supply line that can be operated independent of the engine's operation to add up to 70 gallons a minute of makeup water to the cooling system of the engine.

Q Is that 70 gallons per minute the capacity of the system at Shoreham?

A Oh, no. Obviously-- The water supply system of Shoreham is huge. That is the capacity of just the makeup system to the diesel engine coolant.

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Q Do you know what the total water capacity of the system at Shoreham is?

A No, I do not-- Oh, excuse me.

In terms of total capacity makeup it is 70 gallons a minute, but for all intents and purposes, unlimited quantity. I mean--

Q I understand.

A No limit to the water main it is connected to.

Q Would the addition, in your opinion, of 20 gallons of water to the engine lubricating oil, assuming a leakage from either a ligament crack or a crack in the cam gallery area, compromise the lubrication system that you have testified to of the engines at Shoreham?

A No, it definitely would not.

Q Why is that?

A Well, basically the lubrication system in these engines has about 700 gallons of lubricating oil. Now this type of engine during normal full-power operation new is going to blow by -- in other words from the combustion products, which water is a component, is going to to blow into the crankcase I estimate four gallons an hour of water. TDI has indicated that they believe the number is nine gallons an hour.

But regardless, you have somewhere between five -- four and nine gallons an hour of water coming from the

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combustion crankcase -- from the combustion chambers into the crankcase all the time as part of the operating characteristics of this engine. This is true of most every internal combustion engine. In fact, when this engine was built, the best rings would probably give you one percent blowby. Now we can get this number down a little lower.

But the bottom line is the crankcase is regularly receiving four to nine gallons of water an hour anyway, and that's just a normal combustion operation. To have a leak that introduced 20 gallons into a 700-gallon lubricating system just is not going to cause a significant problem. It would add to the normal water load there but this water load is normally dissipated just by the hot oil agitation in the crankcase and evaporation of water at that temperature.

Q Dr. Rau, you have testified on cross-examination and in response to questions I believe from members of the Board about the thick oxide present on the shrinkage cracks with which you are familiar in the cam gallery areas of the EDGs at Shoreham.

Has FaAA measured this oxide thickness?

A (Witness Rau) Yes, Mr. Farley, we have.

Q What are the results of those measurements?

A The thick dark oxide on the shrinkage crack in the cam gallery areas is relatively uniform in thickness ranging between, as I recall, .2 to .5 of one-thousandths

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of an inch; in other words, .2 to .5 of one mill.

Q Would you describe very briefly how these measurements were made to determine the thickness of this oxide?

A Yes, sir.

On the profile view, that is, the metallographic cross-section which is prepared by cutting perpendicular to the shrinkage crack, mounting that piece of metal in plastic or bakelite, then progressively polishing through the metallographic procedures and then examining that piece of polished metal in the microscope, the measurements of the thickness are made, either from photographs taken at known magnifications on the microscope or directly with a calibrated eyepiece with cross-hairs directly in the microscope. They produce the same results.

Q You have also made reference on this same subject, the oxide, to oxidation taking place at temperatures between 100 degrees Fahrenheit and room temperature.

Have you estimated the time and temperature conditions under which the thick oxide was formed?

A Mr. Farley, I think what I said was the oxidation I believe took place between 1,000 degrees Fahrenheit and room temperature as the casting was cooling down from the solidification process.

WRBeb

I have lost the rest of your question now.

Q Have you estimated the time and temperature conditions under which the thick oxide was formed? You've given me the temperature. I'm looking for the time.

A Yes, Mr. Farley, Dr. Wachob and I did a series of calculations based on the general principles of oxidation in air at various temperatures. We knew the approximate times from the general times involved in the solidification or the cooling process associated with the blocks. We know that to be of the order of four or five days from the pour until the time it is knocked out of the sand and still too hot to touch.

Perhaps Dr. Wachob could describe in more detail the precise calculations, but generally speaking, from these known laws we could compute the rate at which the oxide would grow and increase in thickness as a function of time at various temperatures.

And we made various sensitivity kind of calculations where we would assume a linear temperature cooling from the pour on down to room temperature, and then we made various other assumptions.

But generally speaking, we know roughly the amount of time as the block cools continuously through the temperatures from the melting temperature of up around 2300 degrees Fahrenheit on down to room temperature.

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And to make a long story short, the thicknesses of the oxides which were measured, those .2 to .5 mill, are consistent with the shrinkage crack forming in the vicinity of 1,000 degrees Fahrenheit, and the oxidation occurring most rapidly at that temperature and progressively less rapidly as the temperatures cool.

And the summation of the times and temperatures between 1,000 and room temperature adds up to approximately the .2 to .5 of a mill in oxide thickness.

Again, Dr. Wachob assisted me in these calculations and may want to add something to it.

Q Dr. Wachob, are you familiar with the calculations that Dr. Rau has testified to about the calculations that were made to determine the thickness of this oxide?

A (Witness Wachob) Yes, I am, sir.

Q Would you please tell the Board what those calculations were?

A Again, as Dr. Rau has stated, the general principles of oxidation of iron from the literature were used. There were empirical relationships between the time and temperature and film thickness. As he has said, we have just estimated the cooling rate, knowing what the end conditions were, and then finally estimated what the thickness of that oxide would be during that cooling rate

WRBeb

at those temperatures. And again, it is very consistent with the thickness of oxide that we did measure.

Q Dr. Wachob, have you estimated how long it would take to form a comparable oxide thickness that you observed at Shoreham blocks on cast iron at engine operating temperature, even assuming no oil protection?

A We have made estimates of the oxidation rate that could occur in air assuming no oil was present. We used some conservative assumptions of assuming that the cam gallery area happened to be at 200 degrees F., which is greater than the water cooling jacket temperature behind, which is something like 160 or so, so we're above there.

Secondly, we used an estimated time of formation of about 1500 hours and the engine is actually operated at 1200 hours, so we're a little bit over on the engine operating condition.

Assuming those three bases for making that calculation, we have estimated that in that time frame you will get an oxide that is about 2,000 times too thin in comparison to what we've measured, so it is substantially less than that.

If you try and go back and calculate what the oxide thickness would be then for an equivalent thickness to what we have actually measured, how long would it take to produce that, it is a very, very long time.

WRBeb

Q Can you give us an approximation of what you mean by "very, very long time"?

A The calculation would show that to produce an oxide thickness of the .2 mill that we're talking about, over 30 million years.

Q In your calculations in arriving at this result of the oxidation estimate, did you do that at the operating temperature of the Shoreham EDGs?

A That calculation was based on a temperature that we think is in excess of the Shoreham EDGs in that area.

Q And what was it?

A 200 degrees F., sir.

Q Dr. Rau, do you have an opinion as to whether or not in the presence of continuous lubrication oil, would the oxidation rates in these shrinkage cracks or shrinkage indictions in the cam gallery area of the Shoreham EDGs be slower or faster than has just been indicated by Dr. Wachob?

A (Witness Rau) Well, what he has just indicated is so slow that it is pretty difficult to be much slower.

I think qualitatively though that everything else being equal, I think it would be even slower in the presence of the lubricating oil with the additives Dr. McCarthy has described than it would be in air at the same temperatures, again everything else being equal.

Q I meant whether or not it would be faster.

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A No, I don't think it would be faster.

Q Dr. Rau, do you have an opinion as to whether or not the thick oxide that you have described and observed on the shrinkage cracks in the cam gallery areas of the Shoreham EDGs -- strike -- in the Shoreham original 103 EDG could have been formed during the engine operation of that particular block and engine?

A Yes, I have an opinion, Mr. Farley. The opinion is it could not.

Q And why is that?

A The reason is based on a number of considerations.

The calculations which I just described and Dr. Wachob just described are one of them, indicating that the temperatures and times and environment are just not consistent with the formation of that thickness of oxide over the time of operation that that engine was in service.

Furthermore, as I testified yesterday, the uniformity in thickness of that oxide is inconsistent with progressive growth of the crack and the formation of oxide for different periods of times on different portions of that crack as it extends.

In addition, the differences in the thickness of oxide on the portion of the fracture surface between the repair weld and the adjacent cast iron compared to that

WRBeb

portion of the shrinkage crack that was not repair weld, that tremendous difference in thickness is completely inconsistent with formation during operation.

If they had been formed during operation, even if it had been pre-existing, I would have expected comparable oxide thicknesses on the cast iron at distances all along the crack depth, and that is definitely not the case.

Q Turing to another subject, you have previously testified that the original 103 block at Shoreham had a tensile strength which was degraded by the presence of degenerate Widmanstaetten graphite to well below that of typical Class 40 gray cast iron.

Did such a lower tensile strength affect, in your opinion, the extent of the cam gallery cracking or surface indications that you observed on the Shoreham EDGs?

A Yes, sir, it did.

Q Would you describe in what way?

A Yes, sir.

The shrinkage cracks which we've talked at some length about in the cam gallery area of the original 103 block were, in my opinion, formed as a result of the stresses introduced into that region by the -- during the cooling process. Those are stresses that are introduced by the differences in section size which result in a gradual increase in stresses as the material cools down.

WRBeb

In addition to the stresses introduced, the size of the crack, its depth, also depends upon the strength of the metal at that location as it responds to the stresses that are introduced into that region.

So clearly how big or how deep the shrinkage crack extends depends upon both the extent and magnitude of the stresses generated in that region, and also the strength of the metal, the cast iron, as in fact it is exposed to those stresses.

Given the very substantial degradation in the strength of the 103 block material due to the degenerate Widmanstaetten graphite, there is no question in my mind that the crack which forms in response to the stresses generated by the cooling process of the block will be substantially deeper than it would have been had the strength been typical of Class 40 gray cast iron in this section size.

And if you like, everything else being equal, if you were to compare the original 101 and 102 castings with nominally the same identical molds, pour conditions, and everything else, given the size, having in my opinion a virtually identical cooling rates and therefore stresses, but in fact having markedly different strengths of the cast iron exposed to those stresses, in my opinion you would end up with substantially deeper and more extensive indications

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in that material with the degenerate Widmanstaetten graphite.

Q Namely the original 103 block?

A Yes, sir.

Q Were you able-- Or I'm sure you were able. Did you have an opportunity to quantify this reduction in the -- or this degradation of the tensile strength in the original 103 block due to the presence of the Widmanstaetten graphite as compared to the typical Class 40 gray cast iron?

A Yes, sir, I have. And we reported those differences I think yesterday, if not previously, too.

Q Are you referring to an exhibit?

A Yes, sir. The tensile strengths of the original 103 block were summarized in Exhibit B-40.

Q Is that exhibit self-explanatory, or is any further explanation necessary to show that?

A I think we covered the majority of it previously, but the ultimate tensile strength of the original 103 was measured to be between 14.9 and 19.9 Ksi, thousands of pounds per square inch, as contrasted to a minimum expected ultimate tensile strength in these thicknesses of greater than 25 Ksi for a typical Class 40 gray iron.

I think that is all need be said.

Q Do you have an opinion, Dr. Rau, based on a reasonable degree of engineering certainty, as to whether

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or not this degradation in the ultimate tensile strength or tensile strength of the original 103 block due to the presence of the degenerate Widmanstaetten graphite, whether or not that explains why the cam gallery crack depth indications are much shallower in EDG 101 and the original EDG 103 blocks?

A Yes, sir.

As I have just indicated, I believe the size and similarity of the molds would have produced very similar stresses in the original 103 block casting as it did in the 101 block casting. And given the substantially different tensile strength, I would expect significantly different depths to the cam gallery shrinkage cracks. And in fact that is what was measured by the crack depth gages.

Q And the magnitude of the differences in this ultimate tensile strength is the figure you have just given in connection with that exhibit. Is that right?

A That's correct, Mr. Farley. Perhaps I should elaborate a little bit.

The differences in the tensile strengths I have discussed are indicative of a substantial difference in the point at which the crack would occur and the depths to which it would extend, given the stresses introduced by the solidification process.

In point of fact the differences between the

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original 103 block casting and the 101 and 102 block casting I believe are even larger than those reflected by the differences in tensile strength.

And let me simply say that that's -- without going into great detail, that that results because it is really the tensile strains at which failure occur that will govern the extent or the depth of the shrinkage crack formed in solidification.

And the stress-strain plot or the tensile stress-strain plot for these cast irons is not a straight line which goes up to the tensile strength and then breaks, but it bends over so that at the tensile strength of the degenerate Widmanstaetten graphite in the original 103, the strain is almost linear with stress whereas in a typical Class 40 gray iron, the strains are much larger than the proportional stress.

So, for example, if you were to compare 14.5 Ksi, the tensile strength for the degenerate Widmanstaetten graphite, with, say, a 27 Ksi for a typical Class 40 you have got a ratio of something close to 2.

The comparable ratio of the strain at which fracture occurs in these two materials would be much larger than that. I don't have the number at the tip of my tongue but I previously looked at it and it is a factor of 3, and perhaps larger than that.

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Therefore, I would expect an even greater difference between the performance of a typical Class 40 gray iron and the degenerate Widmanstaetten graphite that was present in the original 103. And therefore, I would expect very substantial differences in the crack depths of those cam gallery indications formed under identical solidification conditions.

JUDGE BRENNER: Excuse me, Dr. Rau.

I heard what you just said but nevertheless, to clarify in my own mind, returning to some of your previous answers to Mr. Farley where you were talking about the comparison of just the ultimate tensile strength, you report some figures from B-40 which confused me as to why they are pertinent to the cam gallery area because I thought those were from the block top of the old 103 block.

Can you help me out and tell me why those figures should be related to the cam gallery area?

WITNESS RAU: Yes, sir.

Although we did not cut mechanical test bars from the cam gallery area, we examined the metallurgical structure in the cam gallery area, and the metallurgical structure is virtually identical to that which is present in the block top, if anything, perhaps a little bit even more severe in the relative amounts of degenerate Widmanstaetten graphite.

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Therefore, in my opinion the tensile strengths which have been measured in samples cut from the block top are representative of the tensile strengths that would be present in the cam gallery region, perhaps even a little bit of an overestimate of what is there, based on the metallurgical structure I observed there.

BY MR. FARLEY:

Q Dr. Rau, for the uninitiated such as myself, is there a difference between strain and stress?

A (Witness Rau) Yes, sir.

Q Will you describe briefly what that is?

A I'm sorry, I thought twice about bringing that up but I couldn't avoid it.

JUDGE BRENNER: I think it is already on the record, but go ahead and bring it up again -- in the context of the crankshafts or the pistons, I'm not sure which off-hand, I think the crankshafts. But we can get it again in this context through this witness if you want, Mr. Farley.

WITNESS RAU: I will attempt to be brief.

This strain which is imposed on a metal is the amount of stretch, and the stress which is imposed on a metal is the average load divided by the area. So if you like, one is related to load and the other is related to how much it stretches.

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And my point was that because there is not a proportional linear relationship between the amount of pull and the amount of stretch, there is not a proportional or a linear relationship between the amount of stress and the amount of strain.

And therefore, the tensile stress at which the material breaks may have a ratio of a factor of two difference but the corresponding stretch at which the same two materials break can have a different ratio and in fact does between the degenerate Widmanstaetten graphite and conventional Class 40.

And the difference between the stretch at which they break is larger proportionally than the difference between the strength or the stress at which they break.

BY MR. FARLEY:

Q I think during a series of questions addressed to Dr. Wells which he answered, on page 24838, lines 6 to 8 of the transcript, did you wish to add something to the series of questions regarding residual stress which was addressed to Dr. Wells, starting on page 24835 through 24838?

A (Witness Rau) Yes, Mr. Farley, I did.

At that time Dr. Wells was talking about what calculations he had made or had not made with regard to the residual stresses that might be present in the cam gallery area, the area where the cam gallery cracks had been

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located and confirmed in the original 103 block.

I wanted to add at that time and will do so now that I had in fact done some evaluations or analyses concerning the residual stresses in this area. These were not sophisticated, detailed mathematical calculations but they were evaluations of the qualitative distribution of residual stresses that would be present due to the repair welding in this region.

In particular, there were some concerns or some comments made by the Staff in their direct testimony indicating uncertainty about the residual stresses in this location and what impact, if any, those residual stresses might have on our conclusions that the stresses always remain compressive in the cam gallery area and therefore, those cracks cannnot propagate.

What I wanted to add is that in our calculations we have made the conservative assumption that the residual stresses are zero; that is, not positive nor negative. In reality, the residual stresses introduced by the repair weld will be compressive at all locations beneath the repair weld, as you go from the deepest portions of the repair weld towards the back side, the water jacket side of the cam gallery.

Now the reasons for that are that when the repair weld is made you puddle in with your stick, the weld

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material, and the material of the cast iron surrounding that puddle is cooler than -- considerably cooler than the weld metal.

As the weld metal then starts to cool down, it solidifies and continues to cool from the melting point. It tries to shrink as all -- most materials do when they cool down. And as it attempts to shrink, however, it is attached to the cast iron in the vicinity of the cam gallery, and that massive amount of cast iron hangs onto the edges of it, at least initially.

And therefore, as the weld material tries to shrink, it goes into ever-increasingly higher tensile stresses in the weld bead as it tries to shrink but the cast iron around it won't let it shrink, so it goes into tension.

But by the very nature of residual stresses, there must be a compensating compressive stress somewhere else to hold the weld material which is in tension initially in place. Otherwise, the laws of physics cause the block to start spinning around in circles and obviously that can't happen.

So what happens is the weld metal goes into tensile stress until such time perhaps that it cracks, and I'll get to that in a minute. But the adjacent material beneath the weld, that position where the shrinkage crack

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extends beneath the weld, that portion must go into compression in order to compensate for the tensile stress that it is in the weld bead.

Or to state it another way, it is in fact the material down where the shrinkage crack is beneath the weld which is holding the weld bead from shrinking. So as the weld bead goes into tension it will necessarily be holding it, be squashed into compression.

And this kind of analysis clearly indicates to me that the residual stresses beneath the weld bead, to the extent they are there, will actually introduce additional compressive stresses which will tend to add to the compressive stresses due to the through-bolts that are already present, and tend to maintain even a larger margin between zero and the compressive stresses that are present in the cam gallery region.

I will just add one quick other point to this residual stress argument, and that is in the case of the original 103 block in the cam gallery areas, the procedure I was describing for you started to happen, and it continued for a while to happen, but eventually the tensile stresses being generated in the weld bead and across the interface, the heat-affected zone between the weld bead and the adjacent cast iron, reached a point where it exceeded the strength of that degenerate Widmanstaetten graphite.

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And that is in fact when the fine cracks between the weld bead and the graphite formed and led to this finer crack which we actually see along the surface in the cam gallery regions.

When that crack occurs of course we no longer continue to build up tensile residual stresses in the weld bead, nor do we continue to build up additional compressive residual stresses beneath the weld bead along the shrinkage crack. And therefore, in the case where the crack has formed between the weld bead and the heated -- excuse me -- and the adjacent cast iron, I believe the magnitude of the residual stresses will in fact be closer to zero than they would have been had that crack not formed.

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Q Turning to you, Dr. Johnson -- and Mr. Schuster can add anything he wants -- during your cross-examination I believe by Mr. Dynner you were asked several questions concerning TSI defect depth measurements.

First of all, will you describe what a TSI defect depth measurement is, how it works?

A (Witness Johnson) The principle upon which that particular device works is called a current injection method where a constant current is injected on one side of the indication and picked up on the other side of the indication and the voltage required to maintain this constant current is monitored. The deeper the indication, the greater the current path distance is, the greater the distance the current must travel in the material and thus the greater the voltage required to maintain the constant current.

Q Now can you describe for the Board the areas on which -- the areas and on which particular Shoreham EDG's were measured with TSI defect depth measurements?

A On the old DG 103 cam gallery areas No. 6 and 7, 2, 4, 8 and 9 were measured. On the DG 101, cam galleries 2, 3, 4, 5, 6, 7 and 8 were measured, the depth of the indications were measured. And on the new 103, the depth of indications on cam galleries 2 and 8 were measured.

MR. DYNNER: Objection. There was no cross-

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examination concerning the depth of any of the cracks on any of the EDGs, Judge Brenner. I think that we are going into an area that, if LILCO wanted to put in evidence testimony of this nature, they would have and should have done it in their prefiled direct testimony or by supplementary testimony. This is all new testimony.

JUDGE BRENNER: Well I'm not sure about the new 103, and I will hear from Mr. Farley about that, but as to the others there is all kinds of testimony as to the cam gallery cracks and different views of what they mean, both in the original testimony and then in the cross-examination. And just because a particular question as to the depth wasn't asked doesn't mean it is beyond the scope of redirect, because a lot of people certainly asked these witnesses as to what they think about these cracks and the depth. To get some testimony on where they are measured is certainly pertinent.

I do recall questions on -- I believe I recall questions on that TSI, if that's the right term, I don't recall the term but something like that, defect depth measurement.

MR. DYNNER: I do specifically recall I asked a question and only one question which is how accurate is a TSI depth probe and I got an answer to that.

But as I recall, sir, there was no general

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questions at all about the depths of the cracks and that is the basis -- during cross-examination and that is the basis for my objection.

JUDGE BRENNER: I am going to overrule it as to the old 103 and 101 because we've got testimony, direct testimony put in by LILCO as to those cracks. We've got testimony by other witnesses on it and the information is certainly pertinent and is within the scope of the questions that were asked of these witnesses, even though not that particular one.

Mr. Farley, I have had a minor continuing problem with the fact, for a reason I have never been able to figure out, LILCO never put any testimony in on something that certainly appears material to me, and that is that cracks in the cam gallery -- crack indications in the cam gallery region were discovered in the new 103 block and we don't have -- we did not have word one in testimony from LILCO on that, and now we have got an objection to any questions by you orally about those cracks, and how do you respond to both my comment and to the objection?

MR. FARLEY: Well the scope of the redirect was -- as you have first ruled, the inquiry in connection with the replacement 103 cam gallery areas are, in my opinion, areas that Mr. Dynner has covered in his cross-examination and therefore I should be permitted to redirect or, if

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Mr. Dynner didn't do it, certainly Mr. Goddard did it.

Thirdly, if the Board does consider that that is not appropriate, then to the extent that any of this inquiry deals with the replacement 103 block beyond the extent of the prefiled testimony, the latest of which was September 24, 1984, I ask that it be treated as an offer of proof.

JUDGE BRENNER: Now look, back up: the problem is, I do consider it material, but for some strange reason, LILCO apparently didn't consider it material because during the time we gave LILCO the opportunity to put in supplemental testimony it did not. And now I've got testimony from the Staff that is going to come in and I've got testimony from the County that is going to come in talking about the crack indications in the camshaft gallery of the new 103 block but there is no written testimony by LILCO.

And although there may have been some questions that strayed into the area by the other parties, I think they were very few and far between and I think Mr. Dynner was careful not to ask about it for his own strategic reasons. But I'm not interested in his strategy, I'm interested in getting the facts in the record and why LILCO didn't think the facts were pertinent to put in the record during the time we gave LILCO an opportunity to do so. And yet now you want to get it in.

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MR. FARLEY: I can't add anything more to what we included in our motion, what we argued and what has been already said.

Excuse me, just a minute.

(Pause.)

Judge, I would add that the stresses, in our opinion, in the 101, 102 and the replacement 103 blocks are the same, they are addressed in our testimony and we think that is an additional ground to permit this line of inquiry.

JUDGE BRENNER: The question you asked him is where did you take depth measurements through your TSI defect depth probe and he said, among other things, I measured the new 103 block cracks in the camshaft gallery with that device. I'm telling you from all I know from LILCO I wouldn't even know there were crack indications there, let along that they were measured and I'm not sure how far you want to pursue this, that's part of my problem.

Let me try to make it a little easier. What we've got so far I don't think presents any problem of prejudice to any party, I'm not going to strike it. But how far do you plan to go with this line of inquiry?

MR. FARLEY: I just had one or two other subsidiary questions on the deepest of the indications.

JUDGE BRENNER: Mr. Dynner, the County, in its supplemental testimony, discusses the camshaft gallery

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cracks in the new 103 block and the Staff discusses it also. You had access -- I am inferring from the fact that there is testimony on it that you had access to information, a, that these indications had been found and, b, what they are in terms of how deep and where they are.

And my problem here is we have to make findings of fact in a complex area and I am going to allow these witnesses to be asked about it now because we are going to have to get the views of these witnesses in order to evaluate the testimony of the County and also the Staff on the same subject, but more particularly from your point of view of the County witnesses. And I am just not going to allow the Board and the record to persist.

I don't understand why LILCO in the first instance proceeded such that that void in the record would exist and I don't -- as I say, I just don't see any prejudice to the County based on the fact that the County has had knowledge of these same things. But if something turns out where you can later point to a specific thing and say there is prejudice in terms of this is a great surprise to the County and not only is it a surprise but it is the kind of thing that requires inquiry in order to be prepared for it, I will hear you as applied to this specific item and then I will decide whether to strike this specific item or allow you that further inquiry if we agree that the inquiry

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is -- your argument that such inquiry is needed is correct. And that is the best I am going to do at this point because I don't want to leave myself and my fellow Board members blind to ascertaining certain facts. I want to be able to be in the best position to evaluate what the County is saying about those same cracks.

MR. DYNNER: Judge Brenner, if I may just clarify our position, I objected to questions concerning the depth of the cracks in the cam gallery areas of the original 103 block and of 101 and 102 on the grounds that no questions were asked during cross-examination concerning the depths of those cracks and that objection was overruled by the Board.

JUDGE BRENNER: Correct.

MR. DYNNER: My objection encompassed -- and in fact was not made but I think was treated as encompassing an objection of a question which I don't believe had yet been asked but perceived to be asked soon, and I was going to object to that and that was the depth of the cam gallery cracks in the replacement 103 block. The basis for that objection yet to be made but encompassed, I think, in your response --

JUDGE BRENNER: Well I handled it because I didn't want to stop after the very next question which we all guessed was coming.

MR. DYNNER: Yes, and all I wanted to point out

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was that my objection to be made in the case of the depths of the cracks in the replacement 103 block was on the basis that if you overrule that objection it would, in our view, be totally inconsistent with the Board's ruling yesterday that LILCO's motion for supplementary testimony which, in fact, did include in that supplementary testimony the crack depth measurement allusions to the new replacement 103 block, that that ruling by the Board would be, in our view, be inconsistent with your ruling to deny LILCO's motion.

And I thought for the reasons that the Board expressed yesterday that indeed that supplementary testimony is and would be prejudicial to the County. And it was really a different basis for the objection that I was going to make than for the objection that I made and was overruled, sir.

JUDGE BRENNER: Our ruling yesterday was that we could not state that it would be prejudicial to the County and therefore, given the equities of the situation and the timing controlled by LILCO, we denied -- we accepted the County's result of denying the motion. It wasn't that we agreed with each and every detail of the County's argument, but I did summarize in the ruling yesterday those aspects of the County's argument that we did agree with.

And I think I phrased it, or should have phrased it that we could not at that point state that the County

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would not be prejudiced.

And that was a distinction, if you want to talk about consistency, with a ruling we had earlier made that day as to the probe that was used to check whether there was an oxide present that you had also objected to. You may not see the connection but I do -- that is, you said this is the first time you were hearing that and my view there was it didn't seem like that big a deal and we'll let it in -- and the same relief I am giving you now as to this, we afforded you as to that also; I think after we got the testimony inmy judgment was correct that it was not that big a deal in terms of surprise to the County of not being able to ask questions about it, it was a simple measurement that was made.

But let's not get too diverted. That ruling exists, the ruling yesterday exists, and the ruling today is as to what he has done so far and what he is going to do in terms of the crack depth measurements, we will allow that in because the County testimony talks about it and the Staff testimony talks about it.

I think LILCO made a mistake in not putting testimony in on the camshaft gallery cracks, I have made that clear many times. I think LILCO defaulted on our explicit order to either put testimony in or file a Board notification on it and defaulted by silence instead of

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filing something expressing reasons why they felt they could not comply. And I consider that a serious matter.

Nevertheless, we want to get all of the facts in that are pertinent. Letting this in now is not the same as letting in all of that testimony which would have led to the whole subject of what strain measurements were made, the fact that we recognize that's only the first part of an on-going program, the timing of which LILCO has controlled in relation to the timing of this proceeding, and we are going to take that -- we discussed that yesterday, and we are going to take that into account in how we credit things.

But we do have to be able to evaluate the County and Staff testimony on this very same subject and we realize that in order to do it fairly we need to know what these witnesses think of it also. And if you want to consider it almost a brief oral rebuttal to some things in the County's testimony or the Staff's testimony, you can look at it in that light also. Although I say again, LILCO should have known that that kind of information should have been put in on the initial schedule.

If it becomes extensive -- and I don't think it is going to -- you come back to us again for whatever relief you think is appropriate this week or next week and point out where you think you were prejudiced because the information is necessarily based on underlying data which

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you have not had or something of that nature. And then if we agree with you we will either agree not to give any weight to the testimony or we will agree to give you some additional time to adjust, or we may disagree with you.

But I am having difficulty dealing with in in the abstract because I think all we are going to get here is how deep the cracks are. And I don't know what I am going to do with that information but I want it on the record from the witnesses who have measured it, because then the County witnesses are going to be talking about the same cracks and Staff witnesses also.

MR. DYNNER: I have no further argument on your ruling but I do want to make one observation --

JUDGE BRENNER: These are difficult rulings and I am going to be candid with you that they may not be fully consistent in the abstract. I think I have some consistency in my mind in that it is a matter of degree. But LILCO has taken a big chance, putting itself in the position it has by not filing -- by defaulting on its obligations that we had previously laid out.

MR. DYNNER: My observation is, as I say -- not by reason of further argument with your ruling -- I would like to point out that, as Mr. Farley had said, that the County did receive the measurements from the depth probe on, I think it was, October 21 or 22 and that we have -- since

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none of that information was in evidence, we had not done anything in terms of -- and would not have been able to do anything in terms of discovery or further probing as to what exactly was done, how the measurements were taken, et cetera.

I take it that what you are saying now --

JUDGE BRENNER: My feeling is --

MR. DYNNER: -- if you will give us the opportunity to question this panel about those matters in some depth if we feel it is appropriate to do so.

JUDGE BRENNER: I thought we may be talking about two different things but I don't want to prolong this discussion and when you look at the material you may be -- which you had received or now have received, you may be in a better position to sort it out in your own mind and come back to us.

But I thought the underlying data that may be more complicated were the strain gage readings and whether or not the stresses are compressive or not and not the simple fact as to what the depth of the cracks are, although I recognize it may turn out not to be a simple fact. But when I am talking about a matter of degree, that is one of the distinctions I am bearing in my own mind.

But it gets complicated. We can talk about it for ten more minutes -- I don't want to. Let me add one

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other point: You asked some questions yesterday that necessarily -- or at least fairly, if not necessarily, elicited from the witnesses some of the same information that LILCO had sought to put in through the written testimony that we did not let in.

And that gets into the problem that I also mentioned yesterday of it is not possible for a professional witness, an expert witness, to separate out what he learned on day three from what he learned on day one when he is putting it all together in his analyses. And some of that came in and you didn't object to it until about the third time it came around. And that's part of the problem also.

MR. DYNNER: I want to state, only in defense of my professional reputation, that the reason why I initially refrained from objecting was in part because there was not specific data given and because I thought the Board was going to step in and say something about that being inconsistent with the Board's own ruling that the supplementary testimony would not be admitted and I will now drop any further comments and hope that you will forgive me for this colloquy.

JUDGE BRENNER: Well I do forgive you because it is complicated procedurally and substantively. But I want to resolve it in favor of the Board and not being blinded to important facts.

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And, as I say, we still have the further distinction in mind that LILCO had this on-going program on, the schedule of which LILCO controlled in relation to the schedule of this proceeding, I have said that many times in different contexts. And we are not going to have information dribbling in day after day, and we are attempting to control that also.

MR. FARLEY: Judge Brenner, I believe, as you obviously noted, that one or more of the panel members may be ill.

May I have a short recess and inquire?

JUDGE BRENNER: Certainly. Why don't we take a recess until 10:20? And remember that -- Well your last question was what areas of the cam gallery did you measure, and we've got the areas down but nothing further.

MR. FARLEY: I know exactly where I am, Judge.

JUDGE BRENNER: All right. If you need more time at 10:20, notify us, please.

MR. FARLEY: I will. Thank you, sir.

(Recess.)

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JUDGE BRENNER: Back on the record.

Mr. Dynner informed me, I believe, what I think you're going to say, but you may say it for the record.

MR. FARLEY: Dr. Wells has some undefined problem that is very serious and at least he needs to go to a hospital or a doctor in this area right now. What he really wants to do is to go to Stanford Medical Center.

JUDGE BRENNER: Well, you don't have to give me -- we could go off the record if any personal details are necessary. I don't think they are. Just tell me what you want to do in terms of presence or absence.

MR. FARLEY: We are prepared to proceed with the redirect without Dr. Wells and whatever questions we have for him we can decide at lunch, I guess, whether or not they could be handled by some other witness and then -- I don't know what, if any, recross Mr. Dynner expected to conduct of --

JUDGE BRENNER: Obviously it would be good if we could make a decision now to avoid the possibility of having -- assuming he's okay but still wants to go to Stanford to make sure I'd like to avoid the situation where he has to wait to find out whether he needs to come back or not.

MR. FARLEY: Yes, sir.

JUDGE BRENNER: You know my perception is from

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the Board's point of view, and it's only the Board's point of view, is that it's highly likely that we can proceed with out him, not because he wasn't an important contributor to the Panel, but because he has been asked so many questions already it seems to me that any of the followup clarifying-type questions probably could be asked by a combination -- could be answered by a combination of the remaining Panel.

My suggestion is to proceed on that basis, rather than require Dr. Wells after all the testimony we've had -- assuming he's okay, of course, if it is more serious than that there is no question that he wouldn't be here -- proceed on that basis and if there is some problem we can try to adjust after. But my guess is it not highly likely that the problem will occur.

Mr. Dynner, do you have any specifics that would contradict what I admit is just a feeling on my part and not necessarily based on any great analysis by me?

MR. DYNNER: While you've been talking I've been going through my recross examination notes so far. I think there are about three or four questions that were specifically addressed to testimony by Dr. Wells. I would be happy to address those questions to FaAA in general. If they're able to answer them that will be fine. If they can't we perhaps can work out some mechanism by which the

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answers can be received at a later date.

JUDGE BRENNER: All right. I appreciate that flexibility. I'm sure Mr. Farley does, too.

MR. FARLEY: As I say, we're not talking about a witness who was only here for a short period of time. He's been here for a long time and we do have his views to a great extent already.

MR. GODDARD: The Staff has similarily reviewed its recross and has no questions for Dr. Wells and we are not opposed to his being excused.

JUDGE BRENNER: All right. Why don't we excuse Dr. Wells now subject to the possible need to recall if anything comes up justifying that recalling. But the recalling would not be this week. If he wants to leave the area let's give him the opportunity to do that. Of course, if he chooses to stay, that's okay also. Normally I think the witnesses when we dismiss the Panel, and I will do that, but you can tell Dr. Wells that we do thank him very much now for his efforts in answering the many questions that many different people asked of him.

I guess we can proceed with the rest of the Panel right now.

MR. FARLEY: May I be excused to do that and to collect the Panel?

JUDGE BRENNER: Surely.

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(Witness Wells excused.)

(Whereupon, the Panel, less Dr. Wells, resumed the stand.)

JUDGE BRENNER: Back on the record. While the witnesses are getting themselves seated, do you know how much more time you'll require, Mr. Farley?

MR. FARLEY: Judge, I had estimated originally approximately two hours but with all this I forget how much time has actually gone by.

JUDGE BRENNER: I'm just asking how much time you think you have left.

MR. FARLEY: I would think an hour and a half.

JUDGE BRENNER: All right. We mentioned going over some things over the lunch break and that's why I asked.

MR. FARLEY: That would be to accomodate the absence of Dr. Wells.

JUDGE BRENNER: All right.

Why don't you proceed and if you think you're finished but it's very close to the lunch break, we can adjust and take the break a little earlier and give you that opportunity also.

MR. FARLEY: Thank you very much.

For the record, Dr. McCarthy is going to remain with Dr. Wells until someone can accompany him to the emergency room or to a doctor.

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JUDGE BRENNER: Off the record.

(Discussion off the record.)

JUDGE BRENNER: Back on the record.

BY MR. FARLEY:

Q Dr. Johnson, what was the deepest TSI defect depth measurement indication in the old or the original EDG 103 at Shoreham, or Mr. Schuster?

A (Witness Schuster) .83 inches, sir.

Q And Mr. Schuster, what was the deepest TSI defect depth measurement indication in the EDG 101 at Shoreham?

A It was .164 inches, sir.

Q Finally, what was the deepest TSI defect depth measurement indication in the replacement 103 EDG at Shoreham?

A .014 inches, sir.

Q Dr. Rau, you have previously expressed your opinion relating the strength properties of cast iron to the size of shrinkage cracks. Do you have an opinion relating such strength properties of cast iron to the size of shrinkage cracks, if any, in the replacement EDG 103 block?

A (Witness Rau) Yes, I do, Mr. Farley.

Q All right; what are they?

A That the shallower or the very shallow depth indicated by the depth gauge in the replacement 103 is consistent with the higher class designation and the higher actually measured tensile strength and corresponding tensile

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failure strain of the original -- excuse me, of the replacement 103 block material as compared with the typical class 40 gray iron in the original 101 and as contrasted with the degenerate Widmanstaetten cast iron structure in the original 103 block.

Q Now, Dr. Rau, Mr. Dynner asked you a number of questions about your cumulative damage analysis. Specifically I want you to focus on the effect of initial and file crack sizes between cylinders four and five on the exhaust side in the stud-to-stud region on the original 103 block during the test period March 11 through April 14, which Mr. Dynner has called the baseline for the cumulative damage, and you have characterized as the demonstration period.

Did you previously perform cumulative damage analysis assuming a final crack depth of 5.5 inches at that location?

A Yes, sir, I did.

Q All right, and what were the results?

A The results were reported or summarized in the originally filed direct testimony in mid-August. There were several different results but the one which was reported was the margin between the cumulative damage that had been demonstrated by the test period March 11 through April 14, 1984 by the running of the original EDG 103 block over that

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period compared with the requirements, that is, that amount of cumulative damage that would be required by a postulated loop LOCA as specified in LILCO's Exhibit 51. And that original calculation indicated that the demonstrated margin was such that 100 continuous loop LOCAs could occur in the 101 or 102 or replacement 103 block without producing the same amount of damage that had already been demonstrated by the test period between March 11 and April 14, 1984 by the performance of the original 103 block during that test period.

Q Have you performed cumulative damage calculations for the crack depth of approximately 3 inches in that region?

A Yes, I have, Mr. Farley.

Q And what did that indicate?

A The analogous calculation, that cumulative damage calculation, again using the performance, the demonstrated performance of the original 103 block with the degenerate Widmanstaetten graphite over this test period between March 11 and April 14, 1984 has demonstrated that with the measured 3. -- excuse me, the measured 3-inch deep final crack size between cylinders four and five in the stud-to-stud region of the original 103 block, at the end of that test period that the 101, the 102, and the replacement 103 blocks can withstand more than 50 continuous loop LOCAs,

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one after the other, without generating the same amount of damage that was accrued by the original 103 block during that test period. In other words, there's a margin of -- as I said in my testimony -- 2 percent would be utilized or one over 2 percent more than a factor of 50 loop LOCAs could be tolerated without generating the same amount of damage that has been demonstrated not to effect the operation of the original 103 EDG during that test period.

Q I was going to ask you, did your conclusions regarding the margin between the requirements of a loop LOCA and the cumulative damage that had been demonstrated or successfully withstood by the original EDG 103, change as a result of the smaller file crack, and that's the 2 percent figure you just gave.

A Yes, Mr. Farley, the results changed slightly in numerical value. As I've indicated, the amount of damage that would be required changed from less than 1 percent to less than 2 percent of that which had been demonstrated by the test period between March 11 and April 14, 1984 by the performance of the original EDG 103 engine block.

Q Dr. Rau, Dr. Johnson has testified that the crack depth of the stud-to-stud crack between cylinders numbers four and five of the original EDG 103 block was no greater than 1.6 inches on March 11, 1984. He's also testified that due to the Widmanstaetten graphite structure of EDG 103,

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that the 1.6 crack depth is a maximum but it could have been shallower at that date.

Assuming the crack depth was less than 1.6 inches on March 11, 1984 would your conclusions change regarding the adequacy of the EDGs 101 and 102 at the Shoreham Nuclear Power Station for nuclear standby service?

A No, sir, my conclusion would not change.

Q And why is that?

A As I indicated, due to the change in the final crack size that is the original calculations assuming the 5.5 inch final crack size at the end of the test period compared to the recomputation of the analysis using the actually measured 3-inch maximum crack size, the demonstrated margin between the requirements during the loop LOCA and that which had been demonstrated are very large. A change in the initial crack size at the start of that test period, would similarly have only an effect on the details of the computation.

The margin demonstrated by the performance of the original 103 block by this test period would still remain very large. In other words, a very large number of loop LOCAs could be tolerated consecutively without accruing the same amount of damage that was demonstrated by the test period.

And whether or not, for example, the original

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calculation proceeded considering that the crack grew from an initial crack depth of 1.5 inches to a final crack depth of 5.5 inches or approximately 4 inches. Obviously in the subsequent calculation, assuming a final crack size of 3 inch whether it started at 1.6 or 1.4 or 1.0, the conclusions are not going to change significantly; I mean, the conclusions won't change and the numbers will not change significantly.

Q Also, Dr. Rau, you testified in response to various questions by Mr. Dynner, that your -- or the FaAA -- cumulative damage analysis, with respect to the EDGs 101, 102, and 103 at Shoreham, was conservative. In what ways -- or, please describe generally the essential conservative factors that you refer to?

A Okay, Mr. Farley, let me attempt to do so.

The cumulative damage analysis is conservative in a number of ways. The first conservatism is that in the existing EDGs, that is 101, 102, and replacement 103 block, there are at present no indications of stud-to-stud cracking on the block top. The cumulative damage analysis is conservative in that it assumes the presence of a crack, in fact, assumes the presence of a crack of 1.6 inches deep. To the extent there are no cracks there, there is a finite amount of time, which will be required for the crack to actually get started and that additional amount of time

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would be, in fact, additional margin between what which has been demonstrated by the calculation performed to date and that amount of time would be required to introduce damage into 101, 102, or the replacement 103 block during a loop LOCA, should it occur.

Secondly, the markedly superior fatigue properties, fatigue and fracture properties of the 101, 102, and replacement 103 blocks compared to the degenerate Widmanstaetten structure of the original 103 block were out of additional conservatism. In other words, it'll be even more difficult to initiate fatigue cracks or even overload cracks because of the superior properties of those blocks compared to the original 103 which is the baseline or the demonstration block on which the cumulative damage is computed. That's an additional conservatism which is not explicitely calculated but would add additional margin over and above that calculated.

In addition, any amount of time required to grow the crack from initiation up until it reaches a depth of 1.6 inches, has not been explicitely included in the calculation. That takes time also. And that addition time would add additional margin between that which has been demonstrated by the original 103 block and that which would be required by the 101, 102, or replacement 103 block should a loop LOCA event occur.

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A fourth conservatism intrinsic in the analysis done is that there is additional margin or life even beyond 3 inches in depth. The original 103 block did develop a 3-inch deep stud-to-stud crack as we've confirmed by destructive examination. That block was still performing without any operational effect whatsoever at the time it was removed from service. Given the markedly inferior fatigue and fracture properties of the original 103 block material suggests that even in 103 there was additional life, if you like, left in that block. And certainly in more typical gray irons, which have markedly superior strength and fatigue resistance and fatigue crack propagation resistance, there will be even additional margin and, if you like, that additional time or crack propagation beyond 3 inches has also not been quantitatively accounted for, and that additional time and that additional margin over and above the conservative cumulative damage calculations which I reported upon and which demonstrate the factor of 50 margin.

There are various other degrees of conservatism, for example, we have assumed for the purpose of our -- let me just stop there. There are other ways but I think they are of less importance than the ones I have already listed.

Q Dr. Rau, specifically in your cumulative damage

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analysis, is the load event or the load excursion which was the subject of various questions by Mr. Dynner experienced by the original 103 during the, again, test period March 11 through April 14, 1984 considered in your cumulative damage analysis?

A This was the next conservatism I was going to talk about and didn't.

It's not quantified explicitly in the numbers which I compute in our cumulative damage analysis. However, it is obviously considered in the cumulative damage analysis because that particular abnormal event, the one that occurred at an hour and three quarters before the removal of the original 103 block from service, that particular event was in fact included in the baseline or the demonstration test period upon which the cumulative damage analysis is performed.

For that reason, the analysis performed is conservative for another factor, and that is to the extent there was any crack extension during that abnormal event beyond the fatigue crack extension you would expect due to running at what I assumed to be 3900 Kw -- realizing it was less than that but I conservatively assumed it was 3900 Kw during that event -- to the extent there was any additional extension beyond that, that was not explicitly calculated.

And therefore, in computing the margin between

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that which was demonstrated by that testing in which that event occurred and that amount of damage that would be required in a loop LOCA where that event does not occur, there is additional margin. In other words, any growth, any portion of the growth between 1.6 inch and 3 inch which might have been ascribed as something other than the fatigue upon which the calculation was addressed would be that there would be even less amount of crack extension in 101, 102 and replacement 103 than that which has been -- on which the cumulative damage analysis has been based, and therefore there is an additional margin of conservatism.

JUDGE BRENNER: Mr. Farley, I wonder if I might interject.

Dr. Rau, I am a little confused on one point which I don't think was the main point of your answer. In passing you mentioned that it was conservative to assume that the diesel engine was operating at 3900 Kw during the event you discussed, even though it wasn't operating at that load. I take it is correct it was actually operating at a lower load, right?

WITNESS RAU: Again Mr. Youngling I think is in a better position to answer that than I, but it is my understanding that given the fuel rack stop positioning that certainly over the full duration of the event that the kilowatts could not be significantly in excess of 3500 Kw,

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which is where we set. But again Mr. Youngling may want to add to that.

JUDGE BRENNER: Well we have that testimony, I was just trying to bring it back as foundation, Mr. Youngling testified to that last week.

If that's right that in actuality part of the baseline during that event was at a lower load, why is it conservative for you to assume that it was operating at a higher load in your cumulative damage analysis. To someone unskilled, such as myself, it would seem to me to cut the other way. That is, it would be -- Well, I'll stop there.

My question was stimulated by your comment that you conservatively assumed 3900 Kw, I understand the other part of that conservatism of including --

WITNESS RAU: I understand, your Honor.

I think perhaps you are correct. Again we are dealing with a very short time period here, it is going to have no significant quantitative effect on the cumulative damage, if you like, total over the test period from March 11 through April 14. But I think you are correct in that regard.

JUDGE BRENNER: I asked mainly to see if I was misunderstanding the use of the so-called baseline which was a term you disagreed with last week but then used today.

But in any event, go ahead, Mr. Farley.

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BY MR. FARLEY:

Q Dr. Rau, how does the cumulative damage analysis that you performed and have testified about account for the difference between operation for various periods of time and at different load levels?

A (Witness Rau) It does so, Mr. Farley, in a very straightforward way. The computation of cumulative damage is based, in fact, as I have testified, on fatigue crack propagation. And fatigue crack propagation rate, that is, how fast the crack grows when exposed to pulsating or cyclic stresses is dependent upon the amplitude of the cyclic stresses and also the amplitude of the steady or the mean stresses. At each different power level there are correspondingly different ranges in stress or cyclic stresses and correspondingly different steady or mean stresses. The measured values for both of these are determined from the measured strain as the strain gage 13, located between the heads on the block top of the original EDG 103.

And it is in fact these different measured cyclic stresses and steady stresses which are incorporated into the cumulative damage analysis using the well-known relationship between the rate at which a fatigue crack grows and the range of the cyclic stress and the magnitude of the steady stress.

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Q Does that mean that --

JUDGE BRENNER: Mr. Farley, excuse me. I just want to note for the record that Dr. McCarthy has returned to the panel, I think, just before this question or in that time frame.

MR. FARLEY: Thank you, Judge Brenner.

BY MR. FARLEY:

Q Does what you have just stated, Dr. Rau, mean that your cumulative damage model is linear or non-linear in its computation of damages?

A (Witness Rau) Well that particular choice of words, I think, is one of semantics. In my opinion it is non-linear.

Q And why is that?

A It is non-linear because it is not proportional to the magnitude of the cyclic stress nor is it proportional to the magnitude of the mean stress, but, rather, it is proportional to a power of both of those. And when you raise something to a power other than unity, it becomes non-linear; if you like, the cracks grow more than twice as fast if you double the cyclic stresses. It grows-- If you double the cyclic stresses depending on whether it is degenerate Widmanstaetten graphite or conventional gray cast iron class 40, the rate of fatigue crack growth will increase by a factor of two raised to either the 5.83 for

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typical gray cast iron or to a factor of 9.58 as measured for the degenerate Widmanstaetten structure of the original 103 block.

So, it's very non-linear in the sense that as stresses go up the rates of crack progression, and, therefore, the rates of cumulative damage accumulation go up very non-linearly.

Q According to my recollection, Dr. Rau, somewhere in this record somebody has testified or is sponsoring the suggestion that it is necessary to "limit" the cumulative damage model. Do you have an opinion on that subject?

A Yes, Mr. Farley, I read that testimony. I believe it is in the County's Supplementary testimony, maybe in their original; I can't recall. My opinion is that it's not necessary to limit the cumulative damage calculations. You certainly can do so if, in fact, you know in what way to limit it. The limitations which are normally imposed on analyses like these are the imposition of the fatigue endurance limit if you're doing an initiation calculation of cumulative damage, or the imposition of a threshhold level below which cracks don't propagate into your cumulative damage algorithm.

I would simply indicate that by not limiting it, which is the way in which I have done it, it becomes conservative because the assumption is made that stress

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levels at all levels contribute to the damage, even though those at the lowest levels of load might not, in reality, contribute to the damage.

Again, if you know exactly how and in what way to limit you certainly could do so but it would become less conservative than the analysis I've already performed.

Q Mr. Youngling, focusing on the FSAR that we are litigating in this proceeding only are the maximum loads that each EDG at Shoreham, especially 101 and 102, will they experience the same loads at that particular FSAR?

A (Witness Youngling) No, they will not.

Q Would you please describe to the Board what those loads are?

A The FSAR provides a conservative estimate of the maximum loads that each diesel generator will see in response to a loop LOCA event. These maximum loads are conservatively estimated against nameplate values or nameplate ratings of the equipment on the diesels and that approach is consistent with the design phase of the plant.

For diesel engine 101 the maximum load is 3,409 kilowatts. For diesel engine 102 the maximum load is 3,365 kilowatts. For diesel engine 103 the maximum load is 3,881 kilowatts.

MR. DYNNER: I'm going to object at this point. The basis for my objection is there was absolutely no cross

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examination on any of these points. This is, again, another opportunity that LILCO is seizing upon to, in effect, put in supplementary direct testimony. There is testimony on this on page 54 of their prefiled testimony and nobody asked any questions about this matter on the cross examination and it's my understanding that redirect is supposed to be limited to matters raised during the cross examination.

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JUDGE BRENNER: Mr. Farley.

MR. FARLEY: Obviously, your Honor, I don't agree. In connection with the questions that have been asked on cross-examination by Mr. Dynner and especially by the Board and throughout the proceeding as well as in the prefiled testimony we certainly have not gotten -- there is a reference in the testimony to Exhibit 51.

JUDGE BRENNER: The objection is these witnesses were never asked about this and therefore it is improper redirect.

MR. FARLEY: I don't think that is a correct characterization.

JUDGE BRENNER: Okay. Will you remind me of where the witnesses were asked about these loads?

MR. FARLEY: I'm sorry, I don't have the transcript.

JUDGE BRENNER: All right. But just remind me in some other way, if you can. I don't remember. I'm not being coy with you, I don't remember any questions of this panel on that subject.

MR. FARLEY: May I ask Mr. Youngling if he recalls, sir?

JUDGE BRENNER: No, and I will give you -- well.... No, but I'll tell you what I will do. I will let you come back to it after lunch and you can talk to him

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then.

MR. FARLEY: Thank you.

JUDGE BRENNER: And when you ask Mr. Youngling during lunch, ask him to distinguish between the questions on the blocks, which is the subject here, and any questions he might have been asked about loads when he was a member of the panel on other subjects. And we will give you that opportunity because I understand that your motivation in asking the questions is redirect, you are claiming that this is proper redirect because you are, you believe, following up on questions that were asked of this panel.

MR. FARLEY: Yes, sir.

JUDGE BRENNER: All right. You are going to have to show me those questions, if not by a transcript page, at least by something that stimulates my memory.

MR. FARLEY: Yes, sir.

WITNESS YOUNGLING: Mr. Farley, I would like to finish my answer.

JUDGE BRENNER: No.

MR. FARLEY: May he?

JUDGE BRENNER: No, I thought he had finished.

And I do apologize to you, Mr. Youngling, I thought you were finished. But in any event at this point there is no sense in going back to it, because we may sustain the objection, in which case we would only have to

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go back -- I thought we had either -- I guess I don't remember what stage of the answer we were in, but -- no, we won't let you complete it if, in fact, you have not completed now. And if Mr. Farley shows me certain things, we'll let you go over it again.

BY MR. FARLEY:

Q Dr. Rau, what effect would incorporation of the specific current FSAR load profiles for EDG 101 and 102 have on your cumulative damage analysis?

MR. DYNNER: Same objection.

JUDGE BRENNER: Could I get the question again? Can you repeat it, Mr. Farley?

MR. FARLEY: Yes, sir.

JUDGE BRENNER: All right.

BY MR. FARLEY:

Q Dr. Rau, what effect would incorporation of the specific current FSAR load profiles for EDG 101 and 102 have on your cumulative damage analysis?

JUDGE BRENNER: I don't know what you mean by "specific current load profiles."

MR. FARLEY: It is tied into the last question as to what we are litigating.

JUDGE BRENNER: When you say "tied into the last question," you are asking him what if you varied the assumption -- which the answer on page 54 of the testimony

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states was made to take into account some different loads?

MR. FARLEY: No, sir.

JUDGE BRENNER: Well I'm sorry, I still don't understand what you are asking him.

Take a look at the testimony on page 54. Do you have that?

MR. FARLEY: Yes, sir.

JUDGE BRENNER: All right.

He testifies what power levels he assumed based on the FSAR which is attached as an exhibit. All right.

Now I don't understand what you are asking him when you say current loads because, as I understand it, those are the current loads.

MR. FARLEY: In the prior question I was asking --

JUDGE BRENNER: There was an objection to the prior question which I may well sustain.

MR. FARLEY: I wanted to give you the reason.

JUDGE BRENNER: Just answer my question: what loads are you asking him to assume when you say current loads, if it is something other than the loads reported in answer 73 because I thought those were the current loads?

MR. FARLEY: The answer on page 54 is the current load for one engine. And the question that I now have for Dr. Rau is the load profiles for EDG 101 and 102.

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JUDGE BRENNER: Okay.

Now that I understand that, why isn't the same objection pertinent? I asked you, you know, where indeed these witnesses have been asked anything about this subject and you are going to take some time to think about whether you can show me that. And we talked about that in the previous question and then you asked the very next question which you know is objectionable for the same reason if in fact the first objection is correct.

MR. FARLEY: I understand that that is the Board's position. I did indicate that I felt this question was tied to the last question in response to the objection, and I would ask leave to do the same thing that you permitted --

JUDGE BRENNER: All right. If you show me that the subject had come up, then I will let you ask questions on it. And if I knew where it came up I would volunteer the information. I am not sticking it to you because you don't remember, I don't remember either.

Okay.

BY MR. FARLEY:

Q Dr. Rau, were the number of hours on Exhibit B-15 between 100 percent and 110 percent load treated the same way as hours in the column entitled "Loads greater than 110 percent" for the purpose of your cumulative damage analysis?

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MR. FARLEY: I can tell you, Judge, this is specifically page 24,674, lines 16 to 18, October 23rd, 1984.

JUDGE BRENNER: Nobody had an objection, Mr. Farley.

MR. DYNNER: I didn't object.

JUDGE BRENNER: So let's not be cute.

MR. FARLEY: I wasn't trying to be cute, your Honor. If it was construed that way, I apologize.

WITNESS RAU: I need the question again.

BY MR. FARLEY:

Q Were the number of hours on Exhibit B-15 between 100 percent and 110 percent load treated the same way as the hours in the column entitled "Loads greater than 110 percent" for the purpose of your cumulative damage analysis?

A (Witness Rau) Mr. Farley, the answer is yes; in the cumulative damage analysis results which were used and reported in the testimony. We had in fact done other analyses which did more explicit breakdowns of the power levels. But in the conservative analysis which I reported leads to the fact of 50 in margin between the damage demonstrated and that which would be required for a loop LOCA, the assumption was made that all loads in excess of 100 percent -- that is, 3500 Kw -- were assumed to take place at 3900, and, therefore, the precise definition of

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110 percent would not have had any effect on the quantitative numbers -- the quantitative computations in the cumulative damage analysis.

MR. FARLEY: My next question was for Dr. Wells, which I will have to confer about.

BY MR. FARLEY:

Q Now, Dr. Rau, is there any other information than direct measurements of cracks on the original EDG 103 block at Shoreham that would indicate the relative amount of crack growth on such original 103 block prior to, or subsequent to, the load excursion?

A (Witness Rau) Could I have that one more time, please?

Q Yes, sir.

Is there any other information than direct measurements of cracks on the original 103 block that would indicate the relative amount of crack growth on the original 103 block prior to, or subsequent to, the load excursion?

A Yes, Mr. Farley, there are other ways that are evidence for the relative differences in the amount of crack extension prior to, and subsequent to, the abnormal load excursion.

Q Please describe those.

A The cumulative damage analysis, as I've described it, takes into account the number of hours, the power

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levels, and the corresponding cyclic and mean or steady stresses that correspond to those power levels. And the relative cumulative number of hours and power levels, and corresponding cyclic and mean stresses prior to the abnormal event, as compared to the total number of hours -- as a matter of fact, only 1.75; an hour and three-quarters -- after the event, can be compared. And clearly there was much more cumulative damage, or much more crack extension prior to the event, based on this calculation, than there would have been after the event.

It comes right out of the cumulative damage calculations.

Q Dr. Johnson, during your cross-examination, you responded to a number of questions relating to the procedures and criteria for detecting and sizing cracks by eddy current inspections, and the results of such inspections.

Were the eddy current tests performed on the EDGs 101 and 102 at Shoreham reliable at both detecting and sizing cracks?

MR. DYNNER: Could I ask for a clarification as to which eddy current tests the question is referring to, because there was testimony that there were a number of them.

MR. FARLEY: All of them.

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JUDGE BRENNER: All of them.

WITNESS JOHNSON: Yes; it is my opinion that the eddy current tests used on DG-101 and 102 are reliable at both detecting and sizing cracks in the block top area and stud holes in DG 101 and 102.

BY MR. FARLEY:

Q Further, Dr. Johnson, on some occasions during your cross-examination I understood you to refer -- or you used the term "unreliable" in the context of eddy current tests conducted prior to the September 1984 time frame on the original 103 block. Do you recall that?.

A (Witness Johnson) Yes.

Q What did you mean, or intend, by the use of the term "unreliable?"

A The eddy current test procedures used prior to the September time frame reliably detected cracks in the original DG 103. However, these tests may overestimate the size of the cracks in the original DG 103.

The reason for this overestimation of the crack size in the original DG 103 is that the high background signals caused by the degenerate Widmanstaetten graphite can be mistaken for continuation of the crack.

MR. FARLEY: Judge Brenner, I then have another series of questions for Dr. Wells which I'll have to check on.

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BY MR. FARLEY:

Q Dr. Rau, you made reference in your cross-examination to 2-D and 3-D finite element analysis of the block top. Would you please describe for the Board the differences between the 2-D and the 3-D analyses?

JUDGE BRENNER: I take it you mean two-dimension and three-dimension?

MR. FARLEY: Yes, sir.

WITNESS RAU: Yes, Mr. Farley.

In LILCO Exhibits B-45 and B-47 there are illustrations of one of the two-dimensional finite element models which was utilized to analyze the stresses in the block top region.

The two-dimensional models are simply that, they model the block top in the shape as shown on both of these figures, but make the assumption that the block top maintains that shape indefinitely as you move away from the block top down toward the base. Therefore they are appropriate only for analyzing the block top stresses and strains, and don't as accurately model the effects of differences in shape beneath the block top, for example, as we have stud bosses and we have webs and channels and things like that.

By contrast, the three-dimensional analysis of the block top region is illustrated by LILCO's Exhibit B-46.

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This exhibit shows a quarter section through the entire circumference of a single cylinder, and you can note on Exhibit B-46 that the three-dimensional model incorporates the study holes, the liner, and models the thicker boss regions and the changes in section between the bosses, and also includes the gusset which extends from the bottom of the bosses down and intersects the side walls of the block and the web between cylinders.

This three-dimensional model, therefore, is able to incorporate and to compute the effects of the geometrical changes on the stresses that are generated in and around the block top region.

The evolution, or incorporation of the three-dimensional analysis is, again, a logical extension and refinement of the two-dimensional approach, and enabled us to more accurately predict the stresses and strains, and, in particular, to more accurately model the effects of the ligament crack, should one occur.

Q Now, will you explain whether or not the ligament cracks were incorporated into your two-dimensional and three-dimensional models?

MR. DYNNER: Objection. We're getting into another area in which there were absolutely no questions asked during cross-examination about the 2-D or the 3-D finite element analysis; in fact, it's an area that was left

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I think there is no basis for it for redirect.

JUDGE BRENNER: You did ask questions, however, about the effect of the assumption of the ligament cracks on the analyses of what would happen in the stud-to-stud cracks, and although not squarely in the three-dimensional and two-dimensional analyses, at least some of the conclusions of Dr. Rau and other witnesses depended on those analyses.

And in fact, in the answers to some of those questions, he expressly referenced those analyses for support. And particularly you asked him questions about Exhibit B-49 and B-50, and I think it is closely enough related to this area to overrule your objection, so we will allow the question.

BY MR. FARLEY:

Q Do you recall the question, Dr. Rau?

A (Witness Rau) Would you repeat it, please?

Q Yes, sir.

Will you explain how the ligament crack was incorporated into your two-dimensional and three-dimensional models?

A Yes, sir. It is relatively straightforward.

If you examine Exhibit B-45, the way in which a ligament crack is modeled is a very physical way. Each of these elements is joined to each other at the little points

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which are called nodes, and to represent a crack in the ligament region, all that is done is to unbutton or disconnect the nodes along a line which runs radially from the stud hole out toward the intersection of the counterbore of the block and the liner.

So if you look at the symmetric radial line of nodes emanating radially from the stud hole, those points are simply unjoined and then, when the model is loaded in the computer, the ligament can open to the extent that the loads cause it to do so.

In the two-dimensional model shown in B-45, because the model is two-dimensional, when you unbutton that node it is equivalent to producing a ligament crack which is extremely deep, infinitely deep, if you like, running through the entire model.

By contrast, in Exhibit B-46, which is the three-dimensional finite element model, the ligament crack is introduced in precisely the same way. That is, along the line of nodes radially emanating from the stud hole out toward the intersection of the counterbore and the block with the cylinder liner, those nodes are released or unbuttoned.

They are only, however, unbuttoned down to a depth of 1.5 inch, which is the level of the counterbore landing and the observed depth of the maximum ligament

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cracks. Then the analysis is done in exactly the same way.

And of course the finite model, when loaded in the computer, opens or responds in the way in which the loads imposed upon it cause it to do so, given the totality of the effects of the shapes and sizes of all the components including the boss, the gussets and the liner.

Q Dr. Rau, did you also include in your finite element analyses stud-to-stud cracks as well as ligament cracks?

A I have no recollection now of having done tha Certainly I did not rely upon having done so.

We may have, in the early stages, attempted that in the two-dimensional model. I'm sure we did not do it in the three-dimensional model.

We have, rather, relied upon, as I have indicated, the initial stresses and the presence of a ligament crack and the cumulative damage analysis of the crack extension from that block top surface down in the stud-to-stud regions.

Q Did your finite element analyses include the, or was it used to analyze the circumferential cracks?

A Yes, Mr. Farley, finite element analyses were used to analyze to determine the stresses in the vicinity of the liner land intersection with the counterbore where circumferential cracks had been observed in the original

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103 block.

I should add, however, that the analyses used are not in all respect identical to those finite element analyses which were used to analyze the stud-to-stud and ligament cracks in the block top.

The three-dimensional analyses were in fact identical analyses. There was, however, an additional two-dimensional run -- excuse me -- an additional two-dimensional model which was axi-symmetric in nature and it was designed to get a very finite element breakup of the region in the vicinity of the sharp fillet radius between the liner land and the cylinder counterbore of the block.

So the combination of the axi-symmetric two-dimensional model and the three-dimensional model was used to analyze in detail the location where the circumferential cracks were detected in the original 103 block.

JUDGE BRENNER: Excuse me, Mr. Farley.

One thing confused me in your answer, Dr. Rau. You said that the finite element analyses used for the circumferential cracks were different in ways you highlighted from the finite element analyses used for the ligament and stud-to-stud cracks.

But I thought in the earlier answer, the answer to the previous -- to the question prior to that you said

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that you had no recollection of using the finite element analysis for the stud-to-stud cracks. So have I missed something somewhere?

WITNESS RAU: No, that's correct. If I said that I didn't mean to say that.

The finite element analysis was used to analyze ligament cracks and the locations where the stud-to-stud cracks occurred, not that they were actually in the models.

JUDGE BRENNER: Okay. I think that clarifies it. Thank you.

BY MR. FARLEY:

Q What were the results of your finite element analyses of the circumferential cracks?

A (Witness Rau) There are a lot of results, Mr. Farley. Let me attempt to just summarize the highlights.

The results of the finite element analyses, focusing on the liner land to counterbore area where circumferential cracks were detected in the original 103, showed that as a result of the preload, the thermally-inducted stresses, the stud forces, the pressure loads, the stresses generated at the sharp fillet radius between the liner land and the counterbore are very large in that concentrated region.

That is both the cyclic stresses and the steady

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stress or mean stress are very large right at that sharp fillet radius.

However, both the steady stress and the cyclic stress decrease very rapidly with distance away from that sharp fillet radius along the path or paths that a circumferential crack is predicted to extend. And in fact, the maximum stresses, that is, both the mean stress and the maximum extent of the mean stress plus the cyclic stress, becomes fully compressive at some distance beyond that corner.

Perhaps I should give those specific numbers. At least generally along the 45-degree direction which the stress analyses results indicate is the most highly stressed and the direction along which circumferential cracks are most likely to extend, if in fact they are going to extend at all, will become fully compressive at approximately .4 of an inch from the corner.

If the crack were to initiate in the sharp corner and attempt to extend either horizontally or vertically as opposed to 45 degrees, the position at which the stresses would turn fully compressive and prevent -- slow down and prevent subsequent crack propagation would occur even closer to the original fillet radius.

For example, for a horizontal crack it would be less than .3 of an inch where the stresses become fully

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compressive. For a vertical crack, that is, one running down from the land corner directly vertically downward, the stresses turn fully compressive at less than 40 thousandths of an inch, very soon after they start, even though they are very high initially right at the corner.

I think those are the major results of the finite element analysis, that is, very high stresses right at the corner, decreasing very rapidly with distance away from the corner, becoming fully compressive as you move away from that sharp corner.

Q Dr. Rau, you used the term -- quote -- "clobbered" -- close quote -- in answer to one of your questions by Mr. Dynner, referring to the fatigue behavior and Widmanstaetten graphite.

What did you mean by the use of the term "clobbered"?

MR. DYNNER: Asked and answered.

JUDGE BRENNER: I don't remember him being asked. I mean I knew what he meant but I don't remember him being asked specifically.

MR. DYNNER: I specifically asked him what he meant by "clobbered" and he specifically answered.

JUDGE BRENNER: What did he say?

MR. DYNNER: Well, I can find it in the transcript, but he basically said it was detrimental and

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had an impact. And I think Judge Morris remember, too,because he is looking at me and nodding.

JUDGE BRENNER: Fine. I don't remember. If you can find it in ten seconds, I will grant the objection. Otherwise, let's spend the ten seconds letting him repeat it. Either way.

MR. DYNNER: You are putting an impossible burden on me because it is clear I won't be able to find the specific transcript in ten seconds. Now you gave him--

JUDGE BRENNER: Now wait a minute. That's not clear.

MR. DYNNER: You gave him until lunch.

(Laughter.)

JUDGE BRENNER: It wasn't clear to me because I thought maybe you had the reference there.

MR. DYNNER: It is clear in my mind, and I remember it, and I think Judge Morris did, too.

JUDGE BRENNER: I don't remember it.

Let him answer it.

It would have been better, Mr. Farley, if you had read the sentence so when he gives the definition we know exactly.

But tell us what you meant by it, and then we'll pass on to something that is important.

WITNESS RAU: What I meant, your Honor, was that

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the fatigue and fracture and fatigue crack propagation resistance properties of the gray cast iron were very substantially reduced by the presence of the Widmanstaetten graphite structure.

I think Exhibit B-42 shows graphically the magnitude of the reduction in the fatigue properties. Perhaps-- I don't know whether you want any more details than that, Mr. Farley.

JUDGE BRENNER: Next question, Mr. Farley.

MR. FARLEY: Yes, sir.

WITNESS RAU: Mr. Farley, maybe I can add one last thing.

I don't think I have stated this directly before, but by comparing the -- by drawing a horizontal line in any strain range, which is the vertical axis of that graph, Exhibit B-42, the precise number of cycles required to cause fatigue failure of the test specimen can be ascertained. And it is in fact the difference between the dotted line which runs from upper left to lower right, and the cross-hatched region further to the right which indicates the difference between the degenerate Widmanstaetten graphite structure of the original 103 block and conventional gray cast iron.

And those differences range from factors of over 10 to 1,000 reduction in the fatigue life.

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BY MR. FARLEY:

Q Dr. Rau, in your opinion-- Strike that.

Dr. Rau, do you have an opinion as to whether or not a stud-to-stud crack would initiate below the block top at the first thread of the stud?

A (Witness Rau) Yes, sir.

Q What is it?

A I do not believe a crack will initiate at that location.

Q Why not?

A Based upon the results of my finite element analyses of the block top region, I have compared the stresses computed to exist in the block top compared to those stresses computed under the same loading conditions that exist at the first thread. The magnitude of the stresses is substantially reduced as you move down below the block top.

In particular, the analyses show that the stresses are more than a factor of two and a half times lower at the first thread than they are at the block top.

Because, as I've testified previously, fatigue cracking is very sensitive to the magnitude of the stress amplitude or cyclic stresses as well as the steady stresses, this more than a factor of two and a half times lower stress at the first thread will mean that it's more than five --

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well, on the order of five hundred times less likely to initiate a fatigue crack there than it would be to initiate a fatigue crack at the top of the block.

That calculation, in conjunction with the observations that have been made on the original 103 block, that in fact all the indictions are of a block top initiation, lead to my opinion that it is not going to occur down there.

JUDGE BRENNER: Dr. Rau, the figure you gave in your answer, do you have in mind the first thread of the stud or the first thread of the stud hole, or does it not matter because your answer would be the same for both?

WITNESS RAU: It would matter, your Honor. I'm sorry I didn't clarify that.

JUDGE BRENNER: Well, the question was the first thread of the stud, and I just wanted to know whether you had in mind what the question expressly stated.

WITNESS RAU: I did, your Honor. It is in fact the first thread of the stud where the load is transferred from the stud into the block.

The block of course, as you have indicated, has threads which extend slightly higher, up to one and a half inches. But it is in fact the position where the stresses are highest, where the stud imparts the load to the block, that I was making my comparison for.

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JUDGE BRENNER: Thank you.

BY MR. FARLEY:

Q Dr. Rau, do the fatigue and fracture properties of cast iron affect crack size in the location where circumferential cracks have been detected in the original EDG 103 block at Shoreham?

A (Witness Rau) Very definitely.

Q In what way?

A Well, the fatigue properties, Mr. Farley, to the extent they are different, would affect whether or not a crack is even initiated at the high stress locations where circumferential cracks have been seen to initiate, if in fact they do.

By that I mean if you compare, for example, the markedly reduced fatigue initiation resistance of the degenerate graphite structure with the conventional Class 40 gray iron, you may initiate circumferential cracks in a degenerate Widmanstaetten structure which is ten to a thousand times weaker in fatigue than conventional. You might not even initiate such cracks in a conventional, typical cast iron.

In addition, the differences in fatigue crack propagation behavior or resistance of degenerate microstructure compared to a typical one would also affect the extent to which a circumferential crack grew, if in

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fact it initiated to begin with.

Clearly the rate at which it grows would be substantially accelerated in the degenerate Widmanstaetten structure or, conversely, if you compared that which had been observed in the original 103 block which had degenerate Widmanstaetten structure with that crack depth you might expect after a comparable amount of service in a block top which did not have degenerate Widmanstaetten structure, if it initiated at all you would expect it to be very substantially shallower.

In addition to that, there is a threshold level below which fatigure cracks don't grow. If that threshold level is dropped below, the cracks will arrest and stop, and all subsequent cycling will have no effect on their continued propagation.

To the extent that the fatigue threshold is reduced by the degenerate Widmanstaetten structure, -- and that is my opinion -- the maximum depth, the depth at which the cracks might arrest would also be substantially shallower in a typical Class 40 gray iron than it would be in one which has degenerate Widmanstaetten graphite.

So for all these reasons, the mechanical properties of the cast iron affect the initiation, the extent, and the rate of growth in the circumferential crack location.

WRBeb

Q Thank you.

Mr. Youngling, yesterday you were asked about why LILCO did not specify.... I'm sorry.

Yesterday you were asked why LILCO had not specified--

JUDGE BRENNER: Hold it. I don't mind people coming in and going out but I want it noted for the record so we'll know who is here.

Off the record.

(Discussion off the record.)

JUDGE BRENNER: Back on the record.

Let us note that Dr. McCarthy is leaving the panel temporarily and when he comes back, whoever is questioning at the time should note his return.

Why don't you start your question again, Mr. Farley.

BY MR. FARLEY:

Q Mr. Youngling, yesterday, I believe in answer to questions by the Board, you were asked why you did not specify inspections other than visual inspections in connection with the LILCO purchase of replacement block 103.

WRBpp

Will you please explain to the Board why you only specified visual inspections?

A (Witness Youngling) Yes. Based on the analysis performed by all of our consultants, the field experience gained through our inspections performed in early 1983, the specific Shoreham operating experience a the recommendations of the TDI owners' group and FaAA, it was LILCO's conclusion that any significant concerns in the cam gallery area would be seen by visual examination of the block in that area in the unpainted condition.

MR. FARLEY: For the record, Judge, Dr. McCarthy has returned to the panel.

BY MR. FARLEY:

Q Dr. Rau, one final minor matter. At page 24,695 of the transcript, lines 17 and 18, you were giving an example and response to a question for the loop LOCA load profile specified in Exhibit 51 engine and you referred to blocks 101 and 103.

Did you also intend to include block 102?

MR. DYNNER: May I have just a moment to get that transcript reference, please?

WITNESS RAU: Can I look at it, too, Mr. Farley?

MR. FARLEY: May I hand this to Dr. Rau?

JUDGE BRENNER: Surely.

(Document handed to the witness.)

WRBpp

JUDGE BRENNER: The comma is in a different place that's why when Mr. Farley read it it sounded confusing. When you look at line 18, move the comma after 51 instead of after engine.

Look at the paragraph starting on line on 17 on that page. And that's -- what Mr. Farley was asking about. And the question is did you also mean to refer to the engine block for the 102 engine; correct?

MR. FARLEY: Yes, sir.

WITNESS RAU: Yes, I did, Mr. Farley. I just omitted that.

MR. FARLEY: Judge Brenner, I have no further redirect subject to the permission that you have granted me to confer with this panel about questions I had proposed to ask Dr. Wells and the permission you have granted me to return to the two questions that I had proposed to Mr. Youngling and Dr. Rau about the FSAR load profiles.

JUDGE BRENNER: All right. Just give me one moment.

(Pause.)

Let's recess for lunch at this point.

When do the parties want to take up LILCO's motion to strike a portion of the Staff's supplemental block testimony? Could we do it after we complete LILCO's witness panel?

WRBpp

MR. FARLEY: I think you ought to hear from Mr. Goddard, your Honor. The parties have discussed it in advance.

MR. GODDARD: Judge Brenner, this was discussed yesterday. The Staff would prefer to hold off on any discussion or argument on that motion until such time as Dr. Bush, who's testimony is the subject of that motion, could be present here. I would like an opportunity to discuss that with Dr. Bush.j

JUDGE BRENNER: Well, talk to him on the telephone because I don't want to wait until the moment he takes the stand. That's the whole idea of having --

MR. GODDARD: As of yesterday, your Honor, I was informed that Dr. Bush is ill. I don't know whether -- I can, nevertheless, speak him to him by phone or not. I could check on that later today.

JUDGE BRENNER: Well, I would prefer very much to take it up in advance of the time the witnesses take the stand. So I don't want to wait for his presence if we can at all avoid it. So see what you can work out and let us konw.

MR. GODDARD: I will report back to the board sometime this afternoon.

JUDGE BRENNER: Well, whenever you find out. It doesn't have to be this afternoon. If you cannot, we will

WRBpp

adjust. I've given you my preference, not a requirement.

All right, let's recess until 1:20 and then we'll come back and take whatever additional questions you have, Mr. Farley, if any, and then go to the followup.

Do you have an estimate of your followup, Mr. Dynner?

MR. DYNNER: About two hours, sir.

JUDGE BRENNER: Don't ask any questions that were already asked.

MR. DYNNER: I can assure you I won't be guilty of that.

JUDGE BRENNER: All right; you're a brave man for stating that.

We'll be back at 1:20.

Whereupon, at 11:50 a.m., the hearing was recessed for lunch, to reconvene at 1:20 p.m., this same day.)

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AFTERNOON SESSION

(1:20 p.m.)

JUDGE BRENNER: Back on the record.

Whereupon,

ROGER LEE MC CARTHY,

HARRY FRANK WACHOB,

CHARLES A. RAU,

EDWARD J. YOUNGLING,

CRAIG K. SEAMAN,

DUANE P. JOHNSON,

and

MILFORD H. SCHUSTER

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

JUDGE BRENNER: All right, Mr. Goddard, back to the crankshaft letter.

MR. GODDARD: I was expecting that, Judge Brenner.

JUDGE BRENNER: Deservedly so, since we said we would take it up at this very time.

MR. GODDARD: I would like to begin by giving a little more of the background for this letter of October 10th.

These are questions, as I stated earlier, which were developed by Dr. Bush, an NRC Staff witness, after the

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record in this proceeding on crankshafts was closed and in fact after Dr. Bush had returned to Richland.

These questions were forwarded to the Staff and at that time, the questions were sent out by letter. It was the intent of the Staff that they be sent out seeking generic information with regard to crankshafts insofar as the material produced would be applicable to all of the TDI engine applications for nuclear standby service.

It was the Staff's opinion at that time that the questions provided by Dr. Bush, sent out in a generic format, would be appropriate to the generic review for the TDI Owners' Group program plan review, Phase I, and that they should be addressed by the Owners' Group as appropriate to all of the engines.

It is obvious from a review of this letter that the appropriate editing of Dr. Bush's input was not made and that in fact the questions as they were sent out do relate to the Shoreham docket.

As a matter of fact, the NRC Staff I am told received a communication from the addressee of the letter, Mr. Clarence Ray, with regard to this, informing us that much of the information that we were apparently seeking by the letter would be available on the record of the Shoreham licensing proceeding, and he was told that in fact the intent of this letter was to obtain the benefit of input

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from all TDI owners in order that it could be considered within the broad scope of the TDI program plan review.

At this point the Staff has, on the record, indicated it will make all responses available at once to the parties and the Board.

Other than that, we welcome any specific guidance.

The letter has been sent in its form. It should have been edited to indicate that it was seeking a much broader generic form of information.

JUDGE BRENNER: I'm afraid I still haven't heard the answer to our questions of yesterday when we raised the letter, which is why is not the information being sought in this letter material to the contested crankshaft issue before us?

And then I gave you the benefit of some of our other thinking, that to our knowledge, nothing was said in the Staff testimony that there was further information needed, in the Staff's view, for the Staff to testify on the subject of the Shoreham crankshafts.

And I also added the fact that certainly this letter was not brought to our attention in terms of any formal notification. And I also commented on the curious timing of the letter, both given the date of the FaAA report and the schedule of this proceeding.

AGBeb

I'm afraid I haven't heard any information from you to assist me on those questions.

MR. GODDARD: Well, as stated, the letter was not sent out seeking Shoreham-specific information. It does read as specific to Shoreham. In fact, Figure 3.13 is an analysis of the Shoreham replacement crankshafts.

JUDGE BRENNER: This morning one thing you said I believe was that the information was not material to the contested issue before us, in the Staff's view. Then I thought you later softened it to say you didn't know whether it would be material.

And I guess I want to know whether this information is material or not to the Staff's assessment of the contested issue before us, and if not, why not.

MR. GODDARD: The Staff does not feel that the information which is sought, which is namely generic information as to all of the engines, would be in any way -- would in any way affect the Staff's conclusions insofar as we can expect at this time.

We do recognize that material obtained as a result of this letter and the follow-up telecommunications would possibly provide information which would be relevant to other parties in this proceeding or in other dockets and, accordingly, we have committed to making this information available as soon as it is received.

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Again, the Staff feels that it cannot do anything further at this time.

JUDGE BRENNER: Does any other party which to comment on any of this?

MR. FARLEY: LILCO does not.

MR. DYNNER: I'm not quite sure that I fully understand the Staff's position on this.

It seems to us from a reading of the letter that there does seem to be some concern regarding the safety factors of the crankshafts based upon the types of questions that have been asked by the Staff. And to the extent that there is in their mind information that would bear upon the safety factors for the crankshafts, it would seem to us that such information may well be relevant to the ability of the crankshafts to withstand the stresses to which they are going to be subjected.

Beyond that, I really don't have any comment.

MR. GODDARD: I would only point out briefly that at this time the Staff has no information. We have only sent out questions which were intended for all of the owners, based upon material which was developed within the confines of the Shoreham docket.

JUDGE BRENNER: As far as we knew on the record of this proceeding, the Staff had no remaining substantive review left of the Shoreham crankshafts other than what was

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expressly indicated in the testimony, which is limited to certain things, which is the Staff's position that there be confirmatory test runs of the diesel engines.

I didn't think about it at the time but I guess if somebody had -- if something had stimulated my thinking at the time I would have realized that procedurally the Staff's Safety Evaluation Report on Crankshafts was not issued. However, I say again I would have considered that just a procedural matter in that no substantive information would be in there as related to Shoreham beyond what we already had in the record.

This letter is apparently inconsistent with that view because it appears that indeed there is further substantive work being done by the Staff on the analysis of the crankshafts. You may say it is generic, but that includes Shoreham. That is not to the exclusion of Shoreham, and none of your comments this morning would exclude Shoreham from the review. In fact that would include Shoreham.

So I don't understand why this letter could go out and just by the happenstance of my noticing it in a pile of -- in a very large pile of routine correspondence, the subject comes up as opposed to the Staff, in some more appropriate fashion, informing us that some further substantive consideration is being given. Whether to call

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it analysis or not I don't know.

At this point, you are going to get the answers I assume-- I should also say that the schedule for the Staff's Safety Evaluation Report, if there is further substantive work being done beyond what the Staff has told us in testimony, is inconsistent with the schedule we set for this proceeding. It is inconsistent with what we told the Staff back in July about prioritizing its review. And it is inconsistent with the Staff's -- I'm repeating myself now -- inconsistent with the Staff's silence during the hearing that it was-- There was no word from the Staff that there would be any further substantive work applicable to the Shoreham crankshafts.

At this point the way we will leave it is you are going to get the information, presumably by November 2nd, which is only two days from now. In the findings, we want a discussion of what is in the record and what else is being done by the Staff. And that is the only way we can evaluate the significance or lack thereof of these questions in the particular context of the points that the Staff believes are material in their findings.

The other parties of course will-- Well, we will just deal with it on that basis.

MR. GODDARD: If I may, Judge Brenner, Dr. Berlinger, the author of that letter is here, and he has

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informed me that the Staff has no outstanding substantive considerations with regard to the Shoreham crankshafts.

JUDGE BRENNER: That is inconsistent with the letter and it is inconsistent-- It is not fully consistent with what you said.

Now if you can tell me expressly, which you have not -- and I don't want you to tell me if it is not true, of course -- that this is immaterial to the review of the Shoreham crankshafts, and why, that is the question I asked at the outset and I haven't had that answered. So I don't know how you can tell me there are no substantive questions pending on the Shoreham crankshafts when you cannot tell me that these questions are immaterial to any consideration of the Shoreham crankshafts because....

If you want another try at it, I will give it to you, but if you want to remain silent that's okay also.

MR. GODDARD: I will only state, Judge Brenner, that these questions were generated based upon what developed during the Shoreham hearing, and they were an attempt to obtain generic information as to the other crankshafts.

The letter does not read in that fashion. The Staff--

JUDGE BRENNER: I'm not worried about how the letter reads. You still haven't answered my question in the

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terms that I suggest you would have to be able to answer it in order to come to the conclusion that there is no outstanding review.

Why don't you put it together with the findings unless you have something you can tell me now about it?

MR. GODDARD: Dr. Berlinger would like to address the Board on this matter inasmuch as he is the project manager for the TDI Owners' Group.

JUDGE BRENNER: That's okay with me, but I think Judge Morris has a question.

JUDGE MORRIS: Let me ask one question.

MR. GODDARD: Yes, Judge Morris.

JUDGE MORRIS: Is Staff able to say at this time that all the information that is requested by that letter is available as it applies to Shoreham?

MR. GODDARD: If I may defer to Dr. Berlinger, please?

DR. BERLINGER: Judge Morris, the information that is requested and the questions as they are formulated were generated as a result of the discussions that took place here at this hearing. The information as it was forwarded is appropriate for a response from the Owners' Group as it applies to Shoreham and all of the other TDI owners.

The TDI Owners' Group, Mr. Ray, contacted me

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with regard to this letter and asked why he had to respond to this letter, all of the information he felt was contained in the transcript, in the record of this hearing.

And I indicated to him that I wanted all of the information pertinent to these questions submitted as part of the TDI Owners' Group program review so that we didn't have to go through the entire transcript and have all of our reviewers go through the transcript to get all the information needed to summarize their findings in a review of the crankshaft report.

As you are aware, the crankshaft report reference applies not only to Shoreham but it applies to other straight-8 engines such at River Bend, and it also applies to V-16 engines such as the Grand Gulf and others. Those reviews have not been completed yet, and what we wanted to do was to make sure that the pertinent information that was requested to be supplied as part of this hearing was also added to the permanent record relative to our Owners' Group review.

And therefore, the questions were sent out. Unfortunately, we did not appropriately revise the question format or make it clear in our letter that we were seeking generic information, and unfortunately the letter does read as if it is appropriate only to Shoreham.

JUDGE MORRIS: Let me ask my question one more

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time.

Is it the Staff's position that all of the information requested in that letter is available in the record of this proceeding as it applies to Shoreham?

DR. BERLINGER: No. I.... The direct answer to your very direct question is No.

The questions were formulated to provide a complete record of information. We don't expect to get any additional information relative to the Shoreham case that would add to what we have already gotten, but it would make for a complete record of both questions and answers to address the issue of ultimate tensile stress and how it affects fatigue life of these crankshafts.

JUDGE MORRIS: Well, I read that to imply that you don't know yet whether or not the information you get will be pertinent and germane to this particular proceeding.

DR. BERLINGER: At this point we would not anticipate that it would be. However, when we get the information, if there are any surprises, the appropriate people and parties will be informed. But we would not anticipate any at this time. That was not the intent.

JUDGE MORRIS: Unfortunately a Board can't operate on anticipations.

JUDGE BRENNER: All right.

Treat it very expressly in your findings,

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Mr. Goddard, under a category that very clearly addresses some of the things that we have talked about here, and then we will be able to deal with it in the context of the proceeding, and you can match it up with what is in the record expressly, and then point out anything you want to point out about the further information.

And as a general matter, the next time you hear something of substance going on that affects a contested issue in this proceeding, we want a direct notification about it. And it doesn't matter whether or not you have certain anticipations as to whether it might change your mind. The point is that there is something substantive going on, as distinguished from the mere procedure of pulling together the information that is already in the record to a further report.

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I think we are ready, if there is nothing further, ready to go back to any-- Do you have further questions, Mr. Farley?

MR. FARLEY: During the luncheon recess I resolved two matters that I mentioned to the Board before the recess.

The transcript references to the foundation that I rely on for the question I posed to Mr. Youngling about the maximum loads that each EDG would experience under the current FSAR, and to Dr. Rau, are pages 24,459 through 24,461. And I would respectfully request that I be permitted to put those questions to those two witnesses.

(Pause.)

JUDGE BRENNER: I think you've done it, Mr. Farley, but we will wait for Mr. Dynner to read it.

(Pause.)

JUDGE BRENNER: I'm about ready to let Mr. Farley ask his questions, Mr. Dynner, unless you've got some further argument?

MR. DYNNER: I will withdraw the objection.

BY MR. FARLEY:

Q Mr. Youngling, are the maximum loads that each EDG will experience the same under the current FSAR?

A (Witness Youngling) No, they are not.

Q What are they?

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A As I previously testified this morning, the maximum load on each of the engines is different. I will just repeat a portion of that testimony from this morning: the maximum load on the 101 engine is 3,409 kilowatts. The maximum load on the 102 engine is 3,365 kilowatts. And the maximum load on the 103 engine is 3,881 kilowatts.

I should also point out that in response to a loop LOCA event these maximum loads only occur for a conservatively estimated period of up to about 12 minutes, as we discuss in our Exhibit 51, and from the start of the response the loads continually decrease to a level of about 75 percent load.

Q Dr. Rau, what effect ford incorporation of these specific current FSAR load profiles of EDG 101 and 102 have on your cumulative damage analysis?

A (Witness Rau) The incorporation of the actual FSAR load profiles for 101 and 102 would increase the demonstrated margin between the test period demonstrated with the original 103 block and the requirements as so specified during a postulated loop LOCA for engines 101 or 102, and those margins would increase from the demonstrated 50 continuous loop LOCAs to something larger than that for engines 101 and 102. The calculations would still be conservative and appropriate for 103 because that's the conservative basis on which the calculation was done

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initially.

MR. FARLEY: I have determined that-- It is my understanding the FaAA Panel can address the three or four questions I have for Dr. Wells, if that's permitted.

JUDGE BRENNER: Okay. Yes, certainly. Give us one moment, though.

(The Board conferring.)

JUDGE MORRIS: Mr. Farley, I would like to ask a couple of questions before you move off the subject, if I may?

MR. FARLEY: Yes, sir.

JUDGE MORRIS: Dr. Rau, in doing your cumulative damage analysis, did you use the load profile for the engine 103 for all three?

WITNESS RAU: Yes, your Honor. I used a conservative estimate or bound on the load profile for EDG 103, in particular, using the power levels of 3935 and 2625 to bound the actual load profiles which are 3881, 3409, and 2617, respectively, as shown in our Exhibit 51.

JUDGE MORRIS: In some other analyses you have made on fatigue life or margin you have used the concept of endurance limit. Why did you not use that approach here?

WITNESS RAU: Well, your Honor, the concept of endurance limit, quite frankly, is only appropriate for the initiation of the cracks. Once, in fact, the crack is

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initiated, you have clearly exceeded the endurance limit and -- not that it is not a good concept, but it is not appropriate for addressing how fast and to what extent cracks might extend, and that is why we resorted to the fracture mechanics analysis which is the basis for the cumulative damage calculation.

JUDGE MORRIS: Thank you.

(The Board conferring.)

JUDGE BRENNER: All right. Why don't you proceed, Mr. Farley?

MR. FARLEY: I address this question to the FaAA Panel.

BY MR. FARLEY:

Q Initially, I would inquire of Dr. Johnson. Dr. Johnson, in response to a question of Judge Brenner on why you could not conduct the dye penetrant test in the stud hole, you responded in part that "It is heavily corroded." Would you please describe for the Board the specific characteristics that you considered in that term?

A (Witness Johnson) I don't feel I properly answered your question and I would like to answer it now. The general reason why penetrant tests were not performed in the stud holes are, first of all, it is difficult to clean out of the hole all of the lubricants used on the studs, residual lubricant oil, locktight and other residual

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materials that are trapped or are there. The second reason is it is difficult to properly apply the developer to the ID of the stud holes.

No corrosion was observed in the stud holes of any of the EDG ones except in the old EDG 103 after it was removed from service and stored outside. Now, for the original EDG 103 block as it stands now, the heavily corroded surfaces further preclude penetrant inspection of the stud holes.

Q I want to address this question to the FaAA Panel, probably initially to Dr. Wachob.

In reference to the FaAA evaluation of the operating experience with the TDI R-5 test engine, it was testified that FaAA believed, but could not be sure, that Dr. Swanger had observed the block tops of that engine with the heads off. Has FaAA confirmed whether or not Dr. Swanger observed those tops with the heads off?

A (Witness Wachob) Yes, we have confirmed that Dr. Swanger had examined the engine blocks, both blocks, with the heads off.

Q What were the results of that?

A Dr. Swanger did not witness a detailed inspection of that block top, and as a reconfirming independent review, we have gone back and confirmed that, indeed, there is only one ligament crack associated with the block top. That

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ligament crack is associated with cylinder number 4 of the right bank at the number 7 stud hole position, and this is the location of the inappropriate cylinder liner. And that was the only indication that was found to be associated with either a ligament crack or a stud-to-stud crack.

Q Do any other FaAA representatives wish to add to that?

(No response.)

Q Seeing no indication I will move to, I believe, the final question.

MR. DYNNER: I will continue my objection which was made earlier to the testimony concerning the block top of the R5 which, as you know, I objected to on the basis that I did not have an opportunity to cross-examine the witness with this experience, and I still don't have that, notwithstanding this additional testimony.

JUDGE BRENNER: Well, I'd like to hear a little more if you're going to pursue the objection -- and you just indicated you will -- of the bases for the testimony they just gave us now, and you can ask about it or Mr. Farley can develop it a little more now. I suggest some combination of the two might be appropriate, and then we'll put it together. You may recall last time that I spent some time attempting to elicit what the bases might be. You can infer from that that it is not a prerequisite that these witnesses

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actually have direct observation themselves of the inspection. We're willing to consider giving some weight to their reports of it as experts gathering the information up, depending on what the bases is. And that weight would depend on what the bases is for the testimony they're able to give. So far, we don't have any bases on the record.

If nobody pursues it, that might be okay. But you want to pursue it, at least, and given that indication I think it might be most efficient, Mr. Farley, if you attempt to elicit a little more information and then the subject will be open for Mr. Dynner to follow up on. And then we'll see what we have when we're done.

BY MR. FARLEY:

Q Dr. Wachob, would you please elaborate -- following up the Board's suggestion -- on the basis for the testimony you've just given with respect to the 4-5 engine block?

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A (Witness Wachob) I believe Dr. Wells made a comment that he thought that TDI had repaired an LP report of the block top inspection. He was incorrect in that it was a magnetic particle report and in that report TDI does state that there is a one ligament crack. With the concerns of the Board last week, I witnessed a mag particle inspection of both block tops and observed myself both visually and both the mag particle test that was performed and only one crack was found and, again, that was at the number 4 cylinder, number 7 stud position of the right bank.

Q All right, sir. Dr. Rau, on October 23, Dr. Wells had testified that FaAA had recommended increasing the radial gap between the liner and the block on the types of EDGs at Shoreham other than the replacement block. And to reduce the thermal and pressure loading on the EDG 101 and 102 liner landings. Did FaAA recommend to LILCO that these changes be incorporated in EDG 101 and 102 prior to fuel load?

A (Witness Rau) No, he did not, Mr. Farley.

Q Why not?

A Failure Analysis Associates did not believe it was necessary to do so, that the demonstrated margin in reliability to meet their intended purpose was demonstrated in the current configuration. In way of additional

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background, also, the proposed modification in the liner to reduce -- to expand the gap radially and to modify the proudness had their primary effect on the conditions for the ligament crack initiation. Since, in fact, there are ligament cracks in the block tops for EDG 101 and 102 already, it was not felt that these modifications would have a major effect on the reliability which is already demonstrated. We did, however, make a long-term recommendation that at some subsequent convenient time certain benefits with regard to stud-to-stud crack progression or, if you like, slowing the rate at which that might occur if, in fact, they were to initiate would be worthwhile making that change at that time.

Q Thank you, Farley, that completes LILCO's redirect.

JUDGE BRENNER: Mr. Dynner?

RECROSS EXAMINATION

BY MR. DYNNER:

Q While it is fresh in your mind, Dr. Wachob, you testified initially about Dr. Swanger's observations considering the block top of the R-5 engine. When did you talk to Dr. Swanger about this matter, approximately?

JUDGE BRENNER: Can I suggest something, Mr. Dynner, for you to consider and then if you have a reason I'll give you leeway to pursue the question anyway.

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As I understand the testimony now, it is not material what Dr. Swanger saw because Dr. Wachob witnessed the mag particle test and the basis for the conclusion being put forward by these witnesses now is not Dr. Swanger but, rather what Dr. Wachob observed.

MR. DYNNER: I will start at that point then, sir.

BY MR. DYNNER:

Q Dr. Wachob, when did you observe the mag particle test?

A (Witness Wachob) It would have been last Friday, October 26 -- pardon me. Thursday, October 25.

Q And how do you know that was the same block that was earlier referred to by Dr. Wells -- without Dr. Rau's consultation, Dr. Wachob?

A The knowledge of that was via Mr. Morris Lowrey and Mr. Greg Veshouri of TDI. This was a test engine that had been disassembled and the serial number was there to verify that.

Q Did you personally check the serial numbers of the engine on October 25 and at the earlier date that Dr. Wells was talking about?

A I did see the serial number and the serial number was recorded by the technicians that were involved.

Q At both dates? Is it your testimony you saw it

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at both dates?

A The testimony is that I saw it on October 25th.

Q Did you see the serial number of the block that Dr. Wells was referring to earlier?

A It has been put to me that Dr. Wells was talking about the R-5 test engine and that this is the R-5 test engine.

Q How many blocks were involved in the R-5 test series during the past three years?

A My knowledge is that since it is a "V" engine that the only two blocks are the two block tops that I observed.

Q Now, how do you know whether or not any alterations were made to the block tops of the R-5 engine during the span between when Dr. Wells said he thinks Dr. Swanger knew something about the liquid penetrant or mag particle test and Thursday, October 25?

Without consultation from Dr. McCarthy, I'm exploring what you know, Dr. Wachob. I don't think you need help.

A The visual examination of the block top did not show that there had been excavations, weld repairs, associated with any of those ligament cracks, ligament positions, and stud-to-stud positions.

Q Do you have with you the magnetic particle test

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report that was performed by TDI?

A I don't have it in the room with me.

Q Do you have it here in Hauppauge with you?

A Yes, I do.

Q Were there any indications on the rest of the block top besides the one ligament crack that you refer to?

A The ligament crack I refer to was the only indication in either the ligament position or the stud-to-stud position.

Q And which areas of the block top were tested with the magnetic particle examination, specifically?

A The specific areas that were evaluated was the ligament position off of the bolt hole in the stud-to-stud location.

Q Which bolt hole?

A The center two bolt holes to the cylinders.

Q Without Dr. McCarthy; if you know.

A Every bolt hole, every ligament position was examined.

Q All right. To make it easy for you, is your testimony that the area surrounding every stud hole of every cylinder of the block top that you're referring to, was subjected to mag particle test?

A Every ligament position that exists in the block top in every stud-to-stud location was examined as well as

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what would be the equivalent to the end position where there's a stud hole at the end and then there is no other cylinder. That position was also evaluated.

Q So is your answer yes?

A Every position was evaluated that is associated with a stud hole.

Q On every cylinder?

A On every cylinder on each block.

Q Mr. Youngling, is your testimony concerning the load levels of EDGs 101 and 102, or the load profiles during a loop LOCA, consistent with LILCO's Exhibit B-51?

I refer specifically -- the pages are unmarked on mine, but it's the -- it would be pages 7 and 8 labeled, respectively, Diesel 102 and Diesel 101.

JUDGE BRENNER: Except the other way around, right?

MR. DYNNER: My copies are labeled -- the sixth page in is labeled Diesel 102 and the seventh page is labeled Diesel 101.

BY MR. DYNNER:

Q Is your testimony a few minutes ago consistent with those load profiles for those two engines?

(Pause.)

A (Witness Youngling) Mr. Dynner, the numbers that I read before are in error. I made an error and I will have

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to correct that, yes.

Q Are the numbers on the pages that I have cited to you, that is to say as I read page 6 from Exhibit B-61 for Diesel 102, it looks as though the highest number there is 3,382.9 kilowatts; is that the correct number for Diesel 102, maximum?

A Yes, it is. I misread the number when I was looking at the chart and I read the number 3364 or 65 rounded off, which occurs after 60 seconds. So therefore, the maximum load on EDG 102 is 3,383 kilowatts.

Q And on Diesel 101 then, the maximum load would be 3,429, rounded off; is that right?

A Yes.

Q Thank you.

Dr. Rau, you referred earlier in your testimony the residual stress evaluation in the cam gallery area. Did you reduce that evaluation to writing?

A (Witness Rau) No, sir.

Q You testified in your deposition on October 11th that FaAA had not measured the residual stress in the cam gallery or cam saddle areas and that it didn't intend to do so; isn't that correct?

A That's correct, Mr. Dynner. I also testified in that deposition about the evaluation and analysis which I described for the Board.

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Q Well, can you explain to me -- do you regard your residual stress evaluation that you testified about this morning as in any way being a residual stress measurement or analysis of the cam saddle area?

A It is definitely not a measurement. It definitely is an evaluation of the cam saddle area.

Q It is true, isn't it, that your evaluation was done not based upon any residual stress measurements taken in the cam gallery area; is that right?

A That's correct.

Q Now, you also testified, Dr. Rau, that in the cam gallery crack --

JUDGE BRENNER: Mr. Dynner, are you going to leave the subject -- you started out asking about what he had said at the deposition on October 11th and you have asked those questions. I had a similar question although keyed to a different timeframe. I wonder if I could -- based on testimony of last week before us and I was going to save it for later. But I wonder if since you've raised it -- .

MR. DYNNER: Go ahead, sir.

JUDGE BRENNER: I have the transcript of October 24, 1984 and as I read the testimony on page 24,837, the first question and answer -- I recognize there are questions before and after that relate to the subject but the first

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question and answer -- do you have that transcript with you?

WITNESS RAU: No, I do not.

JUDGE BRENNER: Can somebody lend him a copy? It is October 24. I want you to be able to see the whole question and answer but while you are doing that I will tell you that my reading of that testimony by Dr. Wells on October 24 is that he says, even as of that date, FaAA performed no analysis of residual stress in the cam gallery area.

WITNESS RAU: Yes, your Honor. You might recall that I was attempting at that time on the subsequent page of the transcript to make a comment that I have made some evaluations and you asked us to bring it up on redirect. That was, in fact, what I was attempting to do at that time.

JUDGE BRENNER: Okay, thank you. I'm sorry, Mr. Dynner, go ahead.

BY MR. DYNNER:

Q Can you tell me when you made your evaluation that you testified about this morning?

A (Witness Rau) I considered on several occasions -- I finalized it prior to my deposition which I gave, I think, on the 11th. I don't recall; it would have been in the month before that.

Q When we were talking about the chemical composition of the crack in the cam gallery saddle of EDG

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original 103 block you testified, Dr. Rau, that the percentage of sulphur that you saw on the crack surface was very low, less than 1 percent. In fact, it is true isn't it, by atomic weight the amount of sulphur is much greater than that and, in fact, often in the range of 3 to 4 percent; isn't that right?

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A I was talking about weight percent, Mr. Dynner. Certainly the percentages by volume and weight are slightly different, depending upon the weight of the atom.

Q Well, even by weight percent, most of those percentages are around 2 percent, 2-1/2 percent, 3.43 percent, 1.6 percent, 2.05 percent; in that range. Isn't that right? And they are not less than 1 percent. Isn't that right?

A I don't know whether it is right or not, Mr. Dynner. The results which we provided to you stand on their own basis. Whatever they say is correct.

Q Let's take a look then.

MR. DYNNER: Judge Morris, if you can help me out, I am going to distribute it and ask that it be marked for identification.

(Documents distributed.)

JUDGE MORRIS: It will be Diesel Exhibit 76.

WITNESS RAU: Mr. Dynner, can I have the references you are referring to in my testimony?

MR. DYNNER: You will get them in a moment.

JUDGE BRENNER: He is getting that for you now.

MR. DYNNER: I'm sorry, did you say 76, sir?

JUDGE BRENNER: Now, Dr. Rau, you are asking for the reference to your testimony on the record as to the less than 1 percent?

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purposes of the transcript.

MR. DYNNER: Thank you.

(Whereupon, EDX analysis of EDG 103 cam gallery crack sample was marked as Suffolk County Diesel 76 for identification.)

MR. DYNNER: I regret to say that due to the fact that we have acted very swiftly, I have not numbered the pages of the exhibit.

BY MR. DYNNER:

Q Dr. Wachob, would you please identify if you can the contents of Suffolk County Diesel Exhibit 76 that I have just distributed?

A (Witness Wachob) These are EDX results that were provided in a request from you. They were associated with analyses of a piece removed from cam saddle No. 7 on the original 103 engine.

EDX is energy dispursive X-ray analysis.

Q And do these sheets represent the EDX analysis performed by FaAA of a variety of the areas of the crack surface which had the so-called thick dark oxide in this case from sample D-1?

A Several of the sheets are EDX results taken from sample D-1 in the fracture surface.

Several of them, however, are of the weld area

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which is not associated with the fracture surface directly.

Q And the sheets are so identified in the upper left-hand corner. Isn't that correct?

A I'm sorry. Pardon me.

Q The sheets that represent the analysis of the weld material are so identified in the upper left-hand corner under the heading, "Shoreham Nuclear Power Station." Isn't that right?

(Pause.)

JUDGE BRENNER: While he is doing that, why don't we note it is an eight-page exhibit, and I suppose we can call it EDX analysis of EDG 103 cam gallery. Is that acceptable?

MR. DYNNER: I would say it is a cam gallery crack sample.

JUDGE BRENNER: Fine.

WITNESS WACHOB: The specimens that are associated with the weld chemistry are marked "Weld."

BY MR. DYNNER:

Q Now it is true, isn't it, Dr. Rau, that the figure "S" is the chemical element indication for sulfur, isn't it?

A (Witness Rau) Yes.

Q And if you look at the sheets that are entitled "Sample D-1" and then various areas, A-3, A-1, A-2, A-5, and

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A-6, ignoring if you will the sheets that are marked "Welds," there is a column giving the weight percent following the symbol "S," and a column giving the atomic percent following the symbol "S."

And those would represent the percentage of sulfur found in the crack surface of those particular samples. Isn't that right?

A (Witness Rau) Those are the percentages by weight and volume of sulfur found in that particular location where the beam was interrogating the oxide on the fracture surface. That's correct.

Q And it is true, isn't it, that those numbers as a weight percentage range as follows:

2.05 percent, 2.50 percent, 3.43 percent, 1.6 percent.

Isn't that right?

A You have read the correct weight percentages, yes, sir.

Q Dr. Wachob, you testified earlier concerning your belief-- I think at one point you didn't think that there was a correlation between the sulfur content and the calcium content of the crack surface, and at another time, as I recall, you indicated that they were present, as you put it, in roughly comparable amounts.

Looking at this data, can you tell me whether you

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see any correlation between the presence of sulfur and the presence of calcium?

And before you do that, would you confirm to me that the chemical symbol for calcium is Ca?

(Pause.)

Can you confirm for me that the chemical symbol for calcium is Ca?

A (Witness Wachob) Yes, that is the symbol for calcium. Sorry.

Q Thank you.

Dr. Rau, I am going to ask you the same question so maybe Dr. Wachob can tell me whether he has seen any correlation, now that he has looked at this material, between the presence of sulfur and the presence of calcium.

A The ratio of sulfur and calcium varies on each one of those EDX spectra.

Q Let me put it this way:

Is sulfur ever present when calcium isn't, and is calcium ever present when sulfur isn't?

A In the spectra that we're discussing, that is true, sulfur and calcium occur in the same spectra.

Q And if we were to look at the atomic weight or atomic percent column, I should say, it is true that just trying to take a ballpark figure that overall you would say that there is roughly about a three to two relationship of

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sulfur to calcium, just roughly? Isn't that about right, except with respect to the sample from Area A-6?

JUDGE BRENNER: He is probably going to ask you how rough you want it to be because I think you can find a couple of other pages where three to two doesn't fit. But I'm not sure what your point is. In other words do you need to put it that way, because we are going to get back in glorious detail as to whether it is not true on some of these pages.

MR. DYNNER: I will strike that question then.

BY MR. DYNNER:

Q Did you answer my question, by the way -- I think you did.

There is no place where you see sulfur where calcium is not present, and in fact there is always at least a relationship of about one to one. Isn't that right?

A (Witness Wachob) These vary from ratios of about one to one to about three to one.

Q Now can you tell me whether you think that these EDX analyses are roughly representative of the other chemical EDX analyses that were taken from the sample area D-2, Dr. Wachob?

You might want to take a minute to take a look.

MR. DYNNER: I am trying to avoid putting more of these into the record, Judge.

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BY MR. DYNNER:

Q Let me make it easy for you, Dr. Wachob.

It is true, isn't it, that in all of the other EDX analyses sheets that were taken, including those from sample D-2, that you always have sulfur where you have calcium, and you always have calcium where you have sulfur. Isn't that right?

A (Witness Wachob) Would you repeat the question again? I'm sorry.

Q Sure.

In fact in all the EDX analyses wherever you have calcium you've got sulfur, and wherever you see sulfur you've got calcium present. Isn't that right?

JUDGE BRENNER: I want you to know you are providing ammunition for some of my colleagues who go after lawyers' redundancies.

WITNESS WACHOB: There is the presence of sulfur and calcium. However, their ratios vary considerably.

BY MR. DYNNER:

Q They are always about one to one or more. Isn't that right?

A (Witness Wachob) One to one, three to one, two to one.

Q Now can you tell me, Dr. Rau or Dr. Wachob, if you know, where do you think that sulfur came from?

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A (Witness Rau) I think previously, Mr. Dynner, I have indicated I thought that in part the sulfur came from the sulfur contained in the gray cast iron itself. Sulfur is a tramp element which is virtually impossible to get out of steel and cast irons. It is present as manganese sulfide and in other ways in cast iron. That is certainly one source.

There certainly are certain sulfur compounds which accumulate in the lubrication oil, and that is a possible source.

There may be others from the welding, repair welding process, but I have no first-hand evidence of that.

Q Well, can you tell me, it is true, isn't it, that this volume of sulfur would be unusual to find in the cast iron -- from the cast iron diffused, if you will, or present only on the surface and only on the very thin surface of the dark oxide if it came from the cast iron? Isn't that right?

A If it appeared only on the surface and not in the cast iron, if it was only at the top of the oxide, that would be unusual, but that is not our testimony and nobody has measured that, to my knowledge.

Q You testified, didn't you, that the calcium was present only in a very thin layer on the outside surface, didn't you?

A No, sir, that is not what I said, I don't think.

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What I meant to say was that as to certain things here that the measurement, the EDX measurement is made on the fracture surface. It does not interrogate any significant difference below the surface, nor into the bulk of the cast iron.

So the only portion you are interrogating is in fact the surface of the oxide.

Q All right. Let me put it to you this way:

Did you conduct any analysis, aside from the very thin surface of what you call the dark oxide layer, to find the presence of sulfur in the samples that you analyzed?

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A Which samples do you mean, Mr. Dynner?

Q The samples that we are talking about that you did the EDX analysis of.

A You mean did I do a chemical analysis on the metal directly below the oxide?

Q Did you do any analysis in order to determine whether or not there was sulfur present in the material beneath the thin layer of the surface of the dark oxide as you refer to it.

JUDGE BRENNER: I thought you wanted to know about calcium, or both maybe.

MR. DYNNER: Calcium or sulfur. He talked about sulfur in his answer.

JUDGE BRENNER: Why don't you ask him about both in one question?

Apply the question to calcium or sulfur.

WITNESS RAU: We have performed a chemical analysis of the bulk cast iron. I'm looking for those results right now so I can discuss them more fully.

BY MR. DYNNER:

Q It's true, isn't it, Dr. Rau, that calcium is not a common element to be associated with cast iron materials, so that when you found that that was unusual, wasn't it?

I am asking you a question, Dr. Rau, can you please pay attention? Did you hear the question?

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A (Witness Rau) Yes, sir.

Q Can you answer it?

A There are trace elements of calcium in cast iron. There are trace elements certainly in welded, repair welded cast iron. It --

Q Now wasn't --

A -- wasn't a shock to see it.

MR. FARLEY: Excuse me, your Honor. Let him finish, please.

JUDGE BRENNER: Yes. Go ahead, Dr. Rau.

WITNESS RAU: So in the context you asked the question it wasn't a shock or a surprise.

BY MR. DYNNER:

Q Well let me refer you, please, to page 103 of your deposition in which you testified in line 20:

> "The calcium that was seen on the fracture surface and measured is not a common element to be associated with the cast iron material, so therefore we found this to be unusual."

And then you go on to say "...the calcium was associated only with the areas of the pre-existing crack and our belief is that the calcium was incorporated in the surface during the casting and/or repair weld process, more likely in the

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casting process."

I'm sorry, that was Dr. Wachob.

A (Witness Rau) I was going to correct that. It's not me.

Q Do you disagree with Dr. Wachob's testimony, Dr. Rau?

A Well it is a matter of degree. As I mentioned, the calcium is not an uncommon tramp element but in the percentages we measured on the surface, that would not be expected in the cast iron.

Q Now Doctors Rau and Wachob, you have testified that what you have referred to as the high concentrations of calcium that appear on the surface of this crack indicate that the entire surface of the crack was introduced during casting and exposed to elevated temperature at that time.

Now if we assume for a moment -- please postulate with me for a moment that Dr. Anderson is correct and that perhaps the source of the calcium was from lubricating oil or from penetrant and therefore could have entered the crack subsequent to the cooling of the casting or the welding and, in fact, during the operation of the engine, it is true, isn't it, that the presence of calcium would not prove that the oxide was introduced during -- or that the crack was introduced during casting at exposed elevated temperatures at that time.

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MR. FARLEY: Objection. Improper redirect, speculative and compound.

JUDGE BRENNER: Well it is overruled. I can go through the reasons but I don't want to belabor it.

WITNESS RAU: Well if I am asked to hypothetically assume all of those things -- most of which I don't agree with -- surely if we make the statement that you can get calcium afterwards from those sources then it's presence would not be indicative that it was there before.

JUDGE BRENNER: Dr. Rau, I am a little confused on one point. I thought you, yourself, testified that calcium could have -- that the source of the calcium could have been the lubricating oil.

WITNESS RAU: I don't know whether I did but there is no question, Judge Brenner, that there is calcium in the lubricating oil, so it is a possible source of calcium. However the magnitudes of calcium which were measured on the fracture surface are much higher than the percentages of calcium in the oil.

I think it was Dr. McCarthy who talked about the absence of any concentrating mechanism at least that he could think of whereby the percentages would increase from that which was in the oil to that which was measured on the fracture surface. But certainly there is some calcium in the oil.

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BY MR. DYNNER:

Q And it is also true, isn't it, that given -- at least Dr. Wachob, isn't it, that given the fact that calcium would be highly unusual to find in cast iron, as you have testified, that if there were calcium you wouldn't expect to find the high concentrations of calcium, as you put it, have been placed on the crack surface from the cast iron material itself, would you?

A (Witness Wachob) I'm not sure I understand your question.

Q Okay. I'll try it again.

Based upon your testimony that you would find it unusual if there were calcium present in the cast iron, it would also be very unusual if the high concentrations of calcium you say appeared on the fracture surface came from the cast iron material itself, isn't that right?

A Yes, that's right, and that's one of the reasons why we believed it was an external source such as our welding or potentially some of the calcium coming from the oil. But again it takes a concentrating mechanism and that is lacking.

A (Witness Rau) I just might add for clarity, I'm not sure it came out the way I would have answered it anyway, it's true that you wouldn't expect that percentage of calcium in a cast iron, in the center of the cast iron

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after it was cast. So if you find it on the surface then it has come from an external source such as the mold wall or from the weld repair or something else at the surface.

Q Dr. Rau, now you have testified this morning that the thick oxide layer that you referred to is "relatively uniform in thickness." and then you said that it was .2 to .5 of one mil.

Now even by my rudimentary grasp of arithmetic, that is about a 2-1/2 to 1 ratio. How can you say that is relatively uniform?

A Well in the context, Mr. Dynner, of the enormous differences in oxide thickness you would predict between an oxide formed at 1000 degrees or 800 degrees on the cooling down and the thickness of oxide you would expect to be formed at less than 200 degrees in lube oil, the difference between 2- and 5/10ths of a mil varying, you know, from spot to spot, if you like, on that shrinkage crack is virtually insignificant compared to those kind of differences. That's what I meant.

Q Tell me, if you would, what you mean by "varying from spot to spot" in the thickness.

A Well in the metallographic cross-section, the section you take through and look at the crack in profile from the surface down towards the tip of it, if you examined it in the microscope and measured the thicknesses at various

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locations along the depth, you will find that it is not precisely constant and it doesn't necessarily gradually decrease with increasing depth, it jumps around from spot to spot within that range.

Q You didn't do a depth profile of the oxide layer, did you?

A I don't know what that means, Mr. Dynner.

Q You don't know what a depth profile means?

A No, sir, what do you mean by --

Q Well you knew it on October 11th. Have you fo~gotten?

A Well tell me what you want and I will try to answer it. What do you mean?

Q I am going to find the page in a minute, but you testified --

A Give me some context, Mr. Dynner, and I will answer your question.

JUDGE BRENNER: All right. He'll give you the question. You have told him why you can't answer. He just asked a few subsidiary questions while he was looking for the page. If you had realized that was going on you would have known you didn't have to answer.

Go ahead, Mr. Dynner.

BY MR. DYNNER:

Q The depth profile would be the profile of the

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oxide layer looking at it in cross-section so that you could determine the depth along all of the profile of that oxide layer.

And you didn't do a depth profile measurement of that so-called oxide layer -- and I am not going to keep saying "so-called" for brevity, I am just going to keep calling it the oxide layer from now on -- you didn't do a depth profile analysis of that oxide layer, Dr. Rau, did you?

(Pause.)

Do you need Dr. Wachob to remind you or can you testify on your own to that simple question?

A I can testify on my own to almost anything, Mr. Dynner.

Q Go ahead. I recognize that. I noticed it.

JUDGE BRENNER: I am going to comment right here, and I am going to do it lightly but next time it is not going to be so light. You two are living up to my favorite definition of an administrative proceeding as a place where the lawyers testify and the witnesses argue and I want it stopped right now and I want to get back to question and answer.

The examination, first of all, is going to take too long if you digress into things that are not going to develop any facts, let alone materials facts, and number

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two, keep in mind, Mr. Dynner, where you need to head for material facts because we are getting a lot of detail and maybe you think it is important in which case that's all right. But I want you to stop and think whether it is important before you ask the question.

You have been cross-examining -- you have been asking your follow-up questions now since 2:00 and that's 45 minutes and you were interrupted briefly by one or two questions by me but they were brief interruptions I believe. Let's pick up the pace and let's get back into a mode of questions and answers to develop information that is going to help the Board decide the merits of this case. And anything else that you want to do, each of you, you can do elsewhere.

All right. Ask your question.

BY MR. DYNNER:

Q You didn't do a depth profile analysis to determine the thickness of the oxide layer along its length in entirety, did you?

A (Witness Rau) Yes, I did, Mr. Dynner. I did not report specific numbers as we went down the depth but I very definitely did examine the thickness of the oxide as a function of depth from the surface of the cam gallery down towards the crack tip, and that is the basis for the testimony we have given and the thicknesses we have been

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talking about.

Q When did you do that, Mr. Rau?

A Those measurements were made at the time the metallographic cross-sections were made through cam galleries No.7 and 6 of the original 103 block and they would have been done late-August and early-September after those samples were cut from the scrapped 103 block.

Q Isn't it true that those measurements were made only by measuring a number of sections that were cut from the length of the crack surface?

A Yes, sir, that is exactly how I said I did it.

Q And you did that by taking a number of three or four slices, isn't that right?

A I don't recall the precise number but something like that.

Q Dr. Rau, can you tell me whether there was any correlation to the thickness of .5 or the thicker area of the -- .5 of one mil or the thicker area of the oxide layer to the bottom of the crack or the top of the crack?

A Well there was some variability from one section to another and from one position to another even in a given cross-section. Generally speaking there is a slight trend toward the thicker oxide being closer to the surface of the cam gallery and the thinner portion of the oxide tending to be towards the deeper portion, which is more restrictive and

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further away from the source of oxygen.

Q Now Doctors Rau and Wachob, you have testified this morning that you have done a calculation concerning the oxidation that formed this oxide layer, how quickly it would form and at what temperatures. Have you reduced that -- When did you make that calculation approximately?

A There were several iterations, but the bulk of the calculations were done last week.

Q Is any part of those calculations in writing?

A Dr. Wachob may want to add. I have nothing in my notes in writing, but I believe he does have some summaries of those calculations in his files.

A (Witness Wachob) I have some hand calculations and a table.

Q Now you stated this morning, at least in one case, that you made one assumption in these calculations.

I would like you, if you will, to give me all of the major factors that you use or assumptions that you used in making the calculation first for your calculation about the formation of the oxide at 1000 degrees downward in four to five days.

Can you do that?

A I don't understand the question. Can you --

Q What assumptions did you make in making your calculations?

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A I think Dr. Wachob should describe the details. Generally speaking we considered the range of temperatures, so it is not really an assumption. The only assumption involved is for the general qualitative constraints on the time of the cooling of the casting. We made the assumption that it cools down -- based on our knowledge and what we have learned from talking to TDI people -- on the order of 4 to 5 days. And beyond that we just relied upon conventional theories of oxide formation and growth and Dr. Wachob can tell you the details if you are interested.

MR. DYNNER: We are very interested. And I am not sure, Judge -- again we feel that this is another calculation, another study, that we have been blind-sided with that we knew nothing about, that one would have thought if it was going to be put into this litigation that it would have been put in at least in the form of supplementary testimony or at least we would have had a chance to see the calculations.

Now I'm not asking -- I am not going to ask that all of this be stricken because I think it may be important. I would like to ask two things: I would like to ask if we can get it so that Dr. Anderson can have a chance to examine a copy of the calculations; I would like to ask some questions about some of the factors that they used.

And then I think it would be appropriate in this

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particular case because of the timing of this thing just coming up this morning, that if Dr. Anderson feels it is proper it seems to us that this would be an appropriate time to request the Board to allow Dr. Anderson to have a short opportunity for some rebuttal testimony before the cross-examination begins. I think based upon the Board's past practices that this would precisely fall into the kind of situation in which direct rebuttal testimony would be appropriate.

JUDGE BRENNER: We have permitted that kind of procedure in the past and right now I agree with you it sounds like an appropriate matter to apply that procedure to -- that's just to the second request you have made -- and of course as we get questions and answers we can deal with any problems that come up. You let us know if you are going to do that, of course, before you do it.

MR. DYNNER: Would it be appropriate to request --

JUDGE BRENNER: Well you have made the request.

MR. DYNNER: -- a copy of the calculations?

JUDGE BRENNER: Mr. Farley.

MR. FARLEY: Object, your Honor, I do not think it is appropriate in response to cross-examination that a witness in preparing for redirect does something to rebut it and therefore that becomes a calculation or data that

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the opposing party is entitled to.

JUDGE BRENNER: Well why not? He went back after last week -- commendably so, I suppose, from the point of view of filling out the record, there is no criticism being made by me at least of going back and doing that further work -- but further work was done and in order to pursue it along the lines that Mr. Dynner said he would like to have an opportunity to consider pursuing it, why is the request unreasonable? You have brought it out for the first time in your redirect this morning. We have been here all week and no previous mention was made of it.

MR. FARLEY: Yes, sir. But we have been here longer than that and the difference between the direct testimony by LILCO and the direct testimony by the County has been known for a long time.

JUDGE BRENNER: I don't see how that is material to the fact that you have done some further work, it might have been appropriate to bring it out as -- well.... We are going to grant Mr. Dynner's request.

I inferred that the material is here. Isn't that correct, Mr. Farley?

MR. FARLEY: I don't know, your Honor.

JUDGE BRENNER: Dr. Wachob?

WITNESS RAU: Judge Brenner, I would just like to add that the calculations we are talking about are somewhat

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quantitative, I mean, they were done on the basis -- to provide some quantitative basis for the opinions which we had expressed. The calculations do exist -- and tables do exist, but these have not been thoroughly reviewed and they are not in a report format which is neat. We are pleased -- I mean, they do exist and they can be look at but I want you to understand this is not a report or something which is pretty.

JUDGE BRENNER: Well I understand you used it as a basis for testimony that you gave in response to your counsel's questions on redirect and we will draw inferences from what you thought of the accuracy of it given that use and the immediate question is though are those calculations in the table here?

WITNESS WACHOB: They are not in the building, sir, they are at the hotel.

JUDGE BRENNER: I meant -- all right. That answers the question.

Mr. Farley, make it available to Mr. Dynner as soon as feasible, which I assume will be some time today.

MR. FARLEY: All right, sir.

BY MR. DYNNER:

Q Dr. Rau, you testified that in making this calculation you assumed a linear cooling temperature.

Why did you make that assumption?

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A (Witness Rau) I'm not sure I said exactly that. I certainly did use the word "linear" as one of the assumptions you could make.

What we did was to compute or calculate the oxidation rates at a series of temperatures, even-numbered temperatures: 1000, 800, 600, and again to get a qualitative estimate of the oxide thickness we then would estimate the -- you know, assume one day at 1000, one day at 800, one day at 600 just to get a rough idea of the thicknesses. So one of the things we did was just to assume a linear cooling rate. You could, of couse, assume something else.

And Dr. Wachob can tell you how it is tabulated. I don't even know that we ever added it up in a linear way but I was just saying that is one of the ways you could do it.

A (Witness Wachob) The temperatures that were chosen were in a linear fashion in that we said in four days it cools between two points and just drew a linear line between and then took points off of that.

Q Did you have any basis for knowing in actuality how quickly the block really cools?

A We know when it is poured and you know when it comes out that is approximately a four-day period and when the molds come out general information is they are too hot

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to touch. So you can pick some temperature above too hot to touch, and that is what we've done. It is an approximation for that cooling rate.

Q Did you ask for any information from TDI on any measurements that they might make of the progression of cooling of the block in actuality?

A We asked for no numbers concerning the cooling rate, we did pose the question as to approximate temperature of the block when it was removed.

Q And that was your 1000 degree temperature?

A No, sir.

Q What was that temperature?

A That was the temperature as way too hot to touch.

A (Witness Rau) Let me just add to that, Mr. Dynner, that I did ask the TDI staff how long the solidification process took and that's where the four to five day estimate comes from. I have no firsthand knowledge of five days except by review of records and what they have told us.

Q Where did your 1000 degree figure come from?

A The 1000 degree figure, Mr. Dynner, comes from -- that is not an assumption, that is a result of the calculation. If you, as we did, go through the oxidation rates at a range of temperatures starting from 1300 degrees

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Fahrenheit on down, that upper temperature being set by the metallurgical reactions which occur in the steel, you will find that the oxidation rates at temperatures above 1000 are predicted to be so rapid as to produce an oxide much thicker than the one which has been measured in the shrinkage cracks and, by the same token, if you look at the oxidation rates down at 200 or even 600 you find that the oxidation rates are too slow to have produced the thickness of oxide on the shrinkage crack that was observed.

It turns out that if you assume -- or let's say if you calculate or postulate that the crack starts at approximately 1000 degress and then is in existence between the 1000 degrees and room temperature, you will estimate from this computation an oxide thickness which is approximately equal to that which was observed, that is, the 2/10ths to 5/10ths of a mil thickness. So it is a result of rather than an assumption in the analysis.

Q As I understand it then what you did was to take the 4 or 5 days it takes to cool down and then you know what the thickness was of the oxide layer and by that divide -- by knowing those two factors you could then pick the 1000-degree number, is that right?

A Yes, the 1000 degrees comes out of the computation, yes, sir.

Q So that's not proof of anything, is it, that just

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presupposes your conclusion, that is, that the oxide layer was all formed during the 4 or 5 days that the casting was cooling down, isn't that right?

A No, sir, Mr. Dynner, I don't think that's right at all. The observations we have made and talked about indicate for a lot of reasons that this is a shrinkage crack.

The issue we were attempting to address with this calculation are the conditions and the temperatures under which the shrinkage crack might have formed, and one of the bases for assessing that is the thickness of the oxide that was observed on that crack.

And it doesn't presuppose the answer. I mean, obviously the calculation is based upon postulating that the crack forms at various initial temperatures during the cooldown. But then looking at what oxide thickness would result if exposed to air during the cooldown from whatever temperature it forms at. It doesn't presume anything, you just would get a different thickness of oxide if in fact the crack formed at 1200 degrees Fahrenheit than you would if the crack first formed at 800 degrees. And of course you get a much thinner oxide if it first formed at 200 degrees.

Q If it first formed at 400 degrees you would get a much thinner layer and then that might tell you that some of the oxide formed after the block had completely cooled,

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isn't that right?

A No, sir, that's not right. If that were the case the block material would have to be heated up or in some other way the oxidation accelerated in order to grow to the thickness which has been observed.

Q Gentlemen, was this oxide layer, was this a wustite type of oxide?

Do you know, Dr. Wachob?

Do you know what a wustite is? Maybe I should ask you that question first.

A (Witness Wachob) Yes, I know what a wustite is.

Q Was this a wustite oxide?

A I don't know.

Q Do you know whether it was a hematite oxide?

(Pause.)

A It is possible that it is partly hematite, yes.

Q Why do you say that?

A Because the temperature at which wustite forms is slightly above where we think the crack formed, so it has to be a lower oxidation than the wustite.

Q Let me try it a different way:

Did you conduct any analyses to determine whether the oxide was a wustite, a hematite or a magnatite oxide?

A No, sir.

Q Why didn't you conduct an analysis to determine

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that, either of you?

A (Witness Rau) Mr. Dynner, the purpose and use we intended for those calculations was to provide an order of magnitude or relative measure of the oxide thicknesses and the precise oxide form was not relevant to that particular consideration.

Q I'm not talking now just about the calculation.

It is true, isn't it, that the precise type of oxide would shed light upon the temperature levels at which the oxide was formed, isn't that right?

A In a very general sense, I would just say it is correct, Mr. Dynner. We have in the past performed such detailed evaluations of the specific type of oxide in an attempt to ascertain the precise conditions under which it formed, but that is a very complicated analysis and fraught with difficulties of interpretation which we didn't believe justified doing it in this particular situation.

Q Did you carry out any analyses to determine whether or not carbon was present on the crack surface that you did fractography on?

A (Witness Wachob) No chemical analyses were performed to determine if carbon was on the surface. It was a visual appearance that we were looking at.

Q Did you see anything that you thought looked like carbon?

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A Do you mean graphite?

Q Carbon. Graphite. Graphite is carbon; isn't it? So you know what I mean?

A It is a form of, yes.

Q Yes.

A The gray cast iron on which the oxide is formed is made up of graphite, a network of graphite, which is surrounded by a perlitic matrix. In the case of the original 103 block itself it's also got the degenerate Widmanstaetten graphite in addition to the conventional flake graphite. The oxide was relatively uniform on this surface. It lay on top, if you like, of the perlite, that is, the steel portion in between the graphite flakes. Certainly where graphite flakes emerge on the surface there is graphite in those locations, but there is no graphite continuously on the fracturous surface.

Q Getting back, for a moment, to your analysis of the formation of the oxide layer, did you take any measurements to determine how much oxygen was present in the mold during the cooldown between the thousand degrees and when it became too hot to touch?

A Mr. Dynner, we did not make any measurements. We didn't have any probes in the molds at the time of the cooldown. But we did consider the situation that would exist during the solidification and snrinkage of the large

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casting of this type and reached a conclusion that there would be very large gaps produced between the mold wall and the casting during the cooldown, which would provide access to air, that one atmosphere of pressure and the corresponding partial pressure of oxygen.

Q Did you make any quantification of the assumption of the presence of the quantity of air you are talking about? Did you quantify your assumption of the presence of air in your calculation?

A I'm not quite sure I understand your question. Let me give it a try. If you as me --

Q I'll be glad to try to rephrase the question if it confuses you.

A Okay, please.

Q You've testified in your calculation that you were covering the period from when the block was 1,000 degrees down to the time when it was too hot to touch, in terms of when the oxide layer formed; isn't that right?

A That's correct. I said more than that, too. I said the result of the calculation was that 1,000 appeared to be approximately the temperature at which, if the crack formed at that temperature, the resultant oxide would be comparable to that which was measured. We did, in fact, do the computations for higher temperatures for postulated cracks forming at higher temperatures.

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Q All right. Now, in that calculation did you assume any particular amount of air that was present during that period, oxygen?

A Yes, Mr. Dynner. We assumed several different things, but one of the things we assumed was the -- there was one atmosphere of air and, of course, the corresponding partial pressure of oxygen which represents approximately 20 percent of the air.

Q I'm smiling because I didn't know that it was 20 percent.

Okay, now did you make any assumptions concerning the quantity of water or moisture that might be present during that time, if any? Vapor, if you will.

A The answer to your question is we made no measurements. The assumptions were that, given the temperatures of the pore except for the very, very early stages, the molds we try out at the humidity would be relatively low during the cooldown process.

Q Could you quantify for us what you mean by your assumption that the humidity would be low?

A (Witness McCarthy) If you had air as you would once the shrinking iron pulled away and left gaps with the mold sides, you would start to have an air ingestion and cycling process due to the fact that a complex casting will form what could be best termed as thermal siphons. That is,

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vertical legs of the casting will have slightly different temperature differences in different places and air will begin to circulate in currents. At this temperature, somewhere between 600 to 1,000 degrees, the relative humidity of air drawn in from atmosphere drops off the charts. So, whatever assumption you made about the relative humidity of -- take room temperature air, heat it to 600 degrees, now measure its new relative humidity which is extremely small, that's why I do condenses and it evaporates when the air heats up. At 600 degrees the relative humidity is very small and, in fact, it's so small that it really is not utilizable in any conventional corrosion calculation. You've dropped off the standard tables and rates.

Q Has Dr. McCarthy explained the assumptions that you made, Drs. Rau and Wachob, in your calculation?

A (Witness Rau) Yes, basically, we assume the oxidation of rates in air with extremely low negligible water vapor content.

Q Did you assume that there were any other chemicals present in the environment during this period from 1,000 degrees to the time it became too hot to touch?

A Only those that are in air and, again, they don't enter directly into the calculation.

JUDGE BRENNER: Mr. Dynner, is this a convenient

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time to take the break?

MR. DYNNER: Yes, sir.

JUDGE BRENNER: How much more do you have?

MR. DYNNER: I have a lot. I'm going to ask these questions because from what the witnesses have testified about their calculations being in form of some numbers and perhaps difficult to understand, while I have the opportunity I'm trying to get as much of this type of information as I can so that Dr. Anderson will have something to go on. And that is taking a bit longer than I thought.

What I intended to do, and the only thing I intended to do following up on the calculations, was to ask them -- and gentlemen if you'll listen for a minute, it might be something you can think about during the break -- I'm going to ask you the same kinds of questions concerning your calculation for the amount of time, the 30 million years that it would take for oxide to form at 200 degrees fahrenheit. I'm going to ask you about your assumptions concerning the presence of chemicals, the amount of air, the amount of water, that would be present in that environment that you assumed.

JUDGE BRENNER: In case it turns out to be 3 million years instead of 30 million years, let's not spend a lot of time on it.

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MR. DYNNER: I agree with you -- I would say even 100 years would satisfy me.

JUDGE BRENNER: You're very flexible today. How much do you have besides that?

(Pause.)

MR. DYNNER: If you will give me the break to go through this again I could have a more accurate estimate because I can try to cut down the things that I think would not have been as important given the fact that I've already been going for the length of time I have.

JUDGE BRENNER: I think we have enough testimony of this Panel such that it is feasible to expect that we should be able to complete this panel today.

MR. DYNNER: I agree with you, sir.

JUDGE BRENNER: But if you take all day we may not be able to do that because there are other parties and perhaps the Board might have some questions.

MR. DYNNER: I think looking at my sheets that I do have another hour and I think I will, as I say, pare it down to what I think is the most significant stuff and put my best stuff first.

JUDGE BRENNER: Mr. Goddard, how much do you have?

MR. GODDARD: Probably half an hour to an hour. My questions are much shorter than the answers I have been

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receiving.

JUDGE BRENNER: All right. We'll come back at 3:35.

(Recess.)

WRBeb

JUDGE BRENNER: All right.

Mr. Dynner, you may proceed.

MR. DYNNER: Thank you, your Honor.

BY MR. DYNNER:

Q Now, gentlemen, I gave you a series of questions that I was going to ask you, and I ask you now for the answers.

In the calculations that you made assuming oxidation in the area of those cam gallery cracks at 200 degrees Fahrenheit, how much oxygen did you assume would be present?

A (Witness Rau) Mr. Dynner, the same-- Again the calculations I think were done for a range of different oxygens but the ones which we prepared the table for were for again one atmosphere of air, which is the equivalent of .2 partial pressure of oxygen. And that particular assumption was made for a conservative bound on operating conditions in the presence of the lubricating oil.

Perhaps Dr. McCarthy would like to add something about the reasonableness of that assumption, given the characteristics of the oil.

Q I just want to follow up for a minute because I understood your testimony on that calculation to be that it was a calculation of oxidation of the area in the air at 200 degrees Fahrenheit. Was I mistaken?

WRBeb

A No, sir, that's correct, one atmosphere of air, .2 partial pressure of oxygen.

Q All right.

Did you also assume that the crack area would be bathed in oil?

A For that calculation, that's a conservative calculation assuming you have one atmosphere of air. In the case it is being bathed in an oil, I testified that the oxidation rates would be even less. I said it was virtually nothing. It is almost meaningless to talk about it.

It is not going to oxidize in either circumstance, if you have dry atmosphere at one atmosphere or whether you have the diesel lubricating oil bathing that area.

Q Okay.

Now is it your testimony-- I think you said that your calculation was made over a period of -- assuming 1500 hours of operation. Is that correct?

A (Witness Wachob) The time frame was assumed to be 1500 hours.

Q In fact, wouldn't the oxidation continue whether or not the engine were operating?

A Yes, the oxidation rate would continue after it's operating. However, the engine is now at a much lower temperature so therefore, the oxidation rate drops off. So

WRBeb

I have conservatively assumed more hours than actually it operated and calculated the oxide that is produced at the higher temperature.

There will be even less oxidation occurring at lower temperatures as it sits there in the dry air.

Q What's the temperature approximately of the cam gallery area when the engine is not in operation?

A (Witness Rau) I think Mr. Youngling may want to follow up on this, but it runs at approximately 160. That's the water jacket temperature immediately adjacent, and when you shut it down it is going to start to cool down, and it is a matter of how long you wait. Eventually it will cool down to room temperature.

Q Mr. Youngling, can you add to that?

A (Witness Youngling) In the standby condition, the engine is maintained at approximately 140 degrees Fahrenheit. Now that's the jacket water circulated through the engine. The room temperature is maintained at approximately 70 degrees Fahrenheit.

Q And it is true, isn't it, that right behind the cam gallery area there is jacket water. Isn't that right?

A Yes, there is.

Q And did you make any assumptions about whether -- in your calculations about whether oxidation would continue if the temperature were around 140 degrees?

WRBeb

A (Witness Rau) Mr. Dynner, I think we indicated that we didn't do any calculations below 200. I mean the numbers are getting ridiculously small for the amount of oxide. And for all intents and purposes there is no oxidation in dry air or in oil environments at temperatures below 200 degrees Fahrenheit.

And when you open up and look at the metal components in this engine, even though it has been run only periodically over a period of years, the metal parts in oil regions are bright and shiny.

Q Now explain something to me if you would.... Oh, I meant to ask one last questions and that is:

Did you assume the presence of any particular amount of water or water vapor or other chemicals in your calculation regarding the 1500 hours?

A Again, Mr. Dynner, the calculation was done assuming negligibly small water vapor in air, if you like. And given this oil with additives present, there will not be any oxidation even if you have modest amounts of moisture.

Q I thought you said your calculation was done assuming that there wasn't any oil there.

A Yes, Mr. Dynner, I've said it and I'll say it again. The calculation was done assuming one atmosphere of air dry, 20 percent partial pressure of oxygen.

Q That's what I'm asking you about.

WRBeb

A That's correct.

Q Okay.

A That's a conservative bound on what would happen if you had oil there because the oil has additives in it which are going to prevent the corrosion and make it -- retard it and make it even less than those negligibly small numbers.

Q I'm just trying to question you now about your calculations for the area in air alone, without the oil.

JUDGE BRENNER: That's about the fifth time we've gotten this now.

BY MR. DYNNER:

Q And there were no chemicals that you've assumed to be present in that area. Is that right -- other than air?

A (Witness Rau) For the air calculation that's right, Mr. Dynner. In the oil for which it is, you know, a conservative representation of, of course there are chemicals.

Q Now can you tell me what fretting corrosion is, Dr. Rau?

A Yes.

Q What is it?

A Well, it is corrosion which takes place in the presence of reciprocating metal contact. "Fretting" is a

WRBeb

word for reciprocating metal contact, if you like, rubbing.

Fretting corrosion is a combination of corrosion which takes place in coincidence with fretting.

Q And have you considered the possibility of fretting corrosion having occurred in the cam gallery cracks?

A The physical observations, Mr. Dynner, are inconsistent with fretting corrosion. To the extent we've observed that we have considered it.

Q Can you tell me in what ways you feel that what you saw was inconsistent with fretting corrosion?

A Well, Dr. Wachob may want to add, but there is just no evidence of fretting on the adjacent fracture surfaces of the shrinkage crack. There is no fracture breaking up of the brittle graphite flakes or Widmanstaetten graphite in the original 103 block. There's just none of those characteristics you'd expect to see if you have fretting corrosion.

A (Witness Wachob) In addition, the fractography of the fracture surface has details associated with it that are totally inconsistent with fretting corrosion.

Q And can you tell me what those details are, Dr. Wachob?

A The fact that you have a surface fracture that has occurred and has fractographic features associated with it

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that are fine and not striated, no rubbing indications on that surface, no linear indications where you have taken one metal surface, rubbed it back and forth on one another. You don't see those details with this fractography.

Q And is it your testimony that you would see those details even in the case of fretting corrosion of cast iron?

A Yes, sir.

Q Did you discover in your examination of any of the EDG blocks a thick dark oxide similar to the thick dark oxide that you testified was found in the cam gallery cracks?

A (Witness Rau) You mean anywhere else on the engine?

Q Yes.

A Yes, Mr. Dynner. We have not observed black thick oxides on the, say, the surface of the block top or on the surface of the cam gallery or on the fracture surface of the weld metal, in the shrinkage cracks or the repair weld portion of the shrinkage crack.

I must exclude of course the cylinder liners and those portions adjacent to the high temperatures associated with the cylinder firing. I haven't examined those in detail. There might be some evidence of thicker oxides in those regions, but nothing on the block in the areas we have been talking about.

WRBeb

Q And nothing on the block in the areas in which you looked. Is that right?

A I'm not quite sure what you're getting at here, Mr. Dynner. I thought I did, but Mr. Wachob has interpreted it a different way.

You mean any oxide on the mold, on the cast iron cooling down from the mold? Or are you talking about--

Q Let me repeat the question, and maybe you will understand what I am asking rather than what I'm getting at.

MR. DYNNER: And I say that not in a nasty way, Judge Brenner.

BY MR. DYNNER:

Q The question is:

Did you find any thick dark oxide which was similar in appearance to that that you found in the cam gallery cracks anywhere else on the block, in any area that you looked at on the blocks?

A (Witness Rau) As I understand your question, Mr. Dynner, no.

Q Thank you.

Now if the thick dark oxide were in fact formed at the time of the casting, that is to say during the period the block was cooling down from 1,000 degrees down to when it became too hot to touch, wouldn't you expect to find that

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this thick dark oxide was in other portions of the block, particularly in portions where there are crevices or notches, places where an oxide that would be formed under the same conditions that you say the oxides were formed in the cam gallery would also tend to form?

A Yes, that's a true statement.

You must recall of course that the block is cleaned off after it comes out of the mold. And I have made no attempts to examine crevices which might not have been cleaned off.

Q Well, have you made any investigation or made any inquiries to TDI once you came to your conclusions about the way in which you say the formation of the oxide occurred in the cam gallery cracks to discern or to determine whether TDI is familiar with such oxides forming in other parts of the block during casting?

The question is just whether you made any inquiries about it.

A Well, not explicitly the way you put it, but we did talk to TDI and their consultants about the presence of oxides on in fact the cam gallery shrinkage crack, and they confirmed that that kind of oxide was consistent with it being a shrinkage crack.

Q That wasn't my question.

Did you ask TDI whether in fact they found this

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thick dark oxide, which I think you testified was very hard and difficult to remove, occurred in any other areas of the block, whether they are familiar with this phenomenon? Did you make any of those inquiries?

A Only with regard to whether this thickness of oxide was typical of the surface of shrinkage cracks in their large castings, and they answered yes, it was.

Q Who was that that answered yes, it was, by the way?

A It was certainly Professor Wallace. It may also have been some of the other TDI representatives.

Q Dr. Rau, I wonder if you could help me out. I became confused a bit over some of your testimony concerning the profile or nature of the cam gallery cracks when you talked about it at one point, saying that there were other cracks or secondary cracks or something between the weld material and the cast iron as opposed to the profile that I had thought existed of the actual crack.

MR. DYNNER: With the Board's indulgence, I wonder whether it would be possible to have Dr. Rau, if he is willing, to use that blackboard back there to show us what the profile of that crack looks like, and maybe describe it as he shows it with the weld material in it and the locations of this other crack that he spoke of.

JUDGE BRENNER: You know the blackboard is

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difficult to pack with the record.

MR. DYNNER: Yes. That's why I suggested perhaps if he could describe what he's drawing the record might be reasonably clear, and I know that it would be very helpful to me, and I think to the Board.

JUDGE BRENNER: I would rather that you try it without it, and if we get bogged down, we can retreat to your suggestion. But I'm concerned that the record be as descriptive as possible, and I think human nature is if he doesn't have the blackboard, he'll tend to be more descriptive than if he does.

Is there some exhibit somewhere that could be referred to? I don't know of any, but....

MR. DYNNER: I don't know.

Maybe a compromise would be if he could draw it on a piece of paper or hold it up and then we could xerox that and make it part of the record, if you wouldn't mind, sir.

JUDGE BRENNER: I don't mind, but I would rather try it without it first. I'm not sure what your confusion is yet. Let's see if you can ask him questions about it, or have him describe it again, and then ask some follow-up questions. And if that doesn't work and you are still honestly concerned that there is confusion, we'll try whatever else need be done in order to clarify things for

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you and for the record.

BY MR. DYNNER:

Q If you were to describe the profile of the cam gallery crack with the weld material present, how would you describe it in a representational way so that sitting here with my pad of paper in front of me, I might be able to draw what you are describing so I can see, Dr. Rau?

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A (Witness Rau.) Okay. Let me again make reference to a sketch which was in the Staff testimony perhaps to get started, I've forgotten the number, but perhaps the Staff could help me out. Page 2, supplementary testimony.

Q I just wanted to be clear, Dr. Rau, what I'm talking about is the side view, the profile if you will, of the crack upon which a fractograph analysis was prepared. I'm not asking you to locate the location of the crack on the cam gallery.

A I understand. I'm trying to do this in order to make sense for the record. You have to start somewhere.

JUDGE BRENNER: I don't know B-24, even if it's only a schematic, might not help.

MR. DYNNER: B-24 would be a good place to start, thank you, Judge Brenner.

JUDGE BRENNER: I'm not sure what you're asking either, because if you want to know where he took the slide for the profile; we may need both.

MR. DYNNER: That would be good in terms of describing the type of profile I'm asking him about and he can show me how he altered it.

WITNESS RAU: Let me start with Staff Exhibit 2 which shows the sketch at the bottom of the cam saddle area, showing the bearing support, the bearing, the web, and then

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schematically, the location of the crack.

If you took a cross section, just make a cut right down through the web, which goes right through that bearing and right through the crack and everything, and then viewed that cut edge-on so you are viewing the crack in profile, what you would see is a thick section at the top where the fuel pump bracket is located. You would then see what looks like a notch on one side of the plate, the minimum section or the deepest part of the notch would be almost exactly where the crack is located or sketched on page 2 of the Staff's supplementary testimony. And then as you proceeded lower down in this cross section the section would again get thicker as it moved out toward where the bearing is.

The shrinkage crack, as indicated in this sketch, runs from left to right in the section we've just made. The repair weld occupies a position right at the tip or the root of the smooth notch, right in the location where the shrinkage crack emerges at the surface. So in this profile, what we would see is a thick section at the top, reducing to to a thin section and at the minimum portion of that thin section, there would be a horizontal crack, shrinkage crack, which in the case of the largest crack that was seen in the original 103 block would extend approximately 3/4 of the way through that minimum thickness. On the edge of that reduced

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section would be a semi-circular region of weld repair where the original metal had been removed and replaced by the repair weld material. And the crack which originally extended all the way out to the edge of the surface would no longer be there but would be replaced by the weld material.

However, along this semi-circular glob of weld metal, there would be another crack which ran from the surface where the glob was in contact with the cast iron, along the interface between the weld and the adjacent cast iron all the way up until the time this secondary crack reached the original shrinkage crack.

So, in profile, we see a crack which is horizontal from over the center portion of this minimum section of web and then it bends and runs along the edge of the repair weld and eventually emerges at the surface where the repair weld ends or terminates at the edge of the cast iron.

I think that's about the best I can do, your Honor.

BY MR. DYNNER:

Q Now, can you take Exhibit B-24 and, looking at that and assuming and understanding that that's a very schematic and representational view, as you've said, of a typical cross section of a V shaped crack, can you show us in this representational figure approximately where the weld

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material would be that you found in the crack upon which you performed a fractographic analysis?

A (Witness Rau) Generally I can, yes, Mr. Dynner.

If we envision Exhibit B-24 instead of holding it the normal way, if you rotate it 90 degrees clockwise so that the opening, the most open portion of the crack resides on the righthand side, and the crack runs horizontally in this view, we now have the same orientation as the profile I just attempted to describe.

In this orientation the repair weld would be located at the far right where, again, schematically this crack is shown to be very open. In reality, of course, it is much more like a line running all the way along to the surface. And the repair weld would then run in a semi-circular shape, roughly speaking, from above the top of the widest portion of the crack semi-circularly, say, approximately through half of the crack depth or one-quarter of the total width of that piece of metal, and then emerge as the bottom of the semi-circular below the lower portion of the most wide open portion of the crack.

I then indicated, you can see, when you do that the outermost portion of the crack has been replaced by intact weld material. The interior portions of the shrinkage crack are still there, but during the solidification and cooling of the weld repair, there's an

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additional crack formed between the edge of that weld bead, the semi-circular bead we just considered around the largest portion of the opening, and it would run continuously from the inner section of the weld bead with the internal portion of the crack right along the interface between weld and cast iron until it emerges out at the far righthand surface.

So when you get all done you end up with a crack which, starting on the righthand side, starts at the edge of the weld, swings up in an arc along the innerface between the weld and the cast iron, and then the crack progresses horizontally to the left along the original shrinkage path.

Q I think you said, Dr. Rau, or someone testified that the crack was ground before the weld material was placed in it. Could you show us again, using Exhibit B-24, would the weld material end where that -- in the V portions of that part of the crack that has weld material, or would it extend in a semi-circular fashion into the cast iron material where it would have been ground.

A I don't understand what you're asking, Mr. Dynner.

Q All right. What you have done, as I look at my Exhibit B-24, is I now have a semi-circular line running along the -- what I would call the crack mouth, because that's what it's called on this drawing -- and then roughly halfway down in this case, I have another semi-circular line

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so that what I get looks like a partial view of two sides of a circle.

And what I'm wondering now is whether the cast iron material, which appears as part of this cross hatching here, whether the weld would extend into that material where it was ground prior to the weld material being put in.

Where does the grinding occur, in other words, to prepare the crack for the weld?

A Okay. That one I can answer.

The shape of the weld, which we have now said is roughly semi-circular, and occupying the rightmost portion when you turn Exhibit B-24 on its side clockwise, the grinding would have occurred over the entirety of the size of the weld pool, if you like. In other words, the cavity into which the weld material was puddled was, in fact, the whole which it may have been arked out and subsequently ground or it may have been ground in total. But that would have been the grind and what you see as weld in the profile or cross section except for the material immediately adjacent to where the weld has bonded to the cast iron would have been the ground surface.

But of course the actual surface itself of the ground surface is consumed by the melting and fusion with the weld metal.

MR. DYNNER: Judge Brenner, I'm sorry. I don't

WRBpp

know whether the Board is having a hard time, but I'm having a hard time drawing this strictly from a verbal picture and I think it would be very helpful if the witness could draw what the thing looks like on B-24. We would then have it right there. We can Xerox it and put it in as an exhibit and I can ask some more questions. But he's having trouble understanding me and I sure am having trouble understanding him.

JUDGE BRENNER: Can you represent what you're trying to describe, Dr. Rau, by using that B-24 and drawing in any appropriate things. I'm the one who mentioned that exhibit and for all I know it's not very good for that purpose.

WITNESS RAU: It's not very good for that purpose, your Honor, if you really believe the record requires a sketch, I have one that I'd be pleased to make available that I think is representative of the cross section to the actual cam gallery region and reflects the point we've been talking about.

JUDGE BRENNER: All right. I suppose you only have one copy?

WITNESS RAU: I have four copies, your Honor.

JUDGE BRENNER: Why don't you people communicate with each other, especially off the record. If you knew you were going to do something like this, Mr. Dynner, at the

WRBpp

break would have an appropriate time to do it. I'm somewhat surprised that it's coming out after a week and a half of testimony on this subject in the final followup round.

Can you give us those? Do you need them all?

WITNESS RAU: Whatever you like, your Honor.

JUDGE BRENNER: All right. Why don't you keep one, give him one, give us one, and give the other parties one.

JUDGE BRENNER: Off the record.

(Discussion off the record.)

JUDGE BRENNER: Back on the record.

BY MR. DYNNER:

Q Dr. Wachob, am I correct, that is, you were describing a cam saddle area. You described it i a manner which indicated that, in effect, it has a curve to it. It sort of curves inward and then out again, doesn't it, right where the cam saddle is?

A (Witness Rau) Well, generally speaking, yes. I don't mean to imply that it's a continuous curve. It curves and is straight for a little bit and then it curves some more. But generally speaking, it's thicker at the fuel pump bracket area it reduces down in thickness at the location where the shrinkage cracks are located, and then it increases again in thickness as you move down towards the actual bearing support.

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MR. DYNNER: I'm going to distribute and ask to be marked for identification Suffolk County Diesel Exhibit, I hope it is 77. Is my memory right, Judge Morris?

JUDGE MORRIS: Correct.

MR. DYNNER: Thank you.

JUDGE BRENNER: Somebody is going to tell us what this is, right?

MR. DYNNER: Yes, sir.

JUDGE BRENNER: All right. Are you sure you need this, Mr. Dynner, given the other sketches we have and the one we're going to have?

MR. DYNNER: I think it's going to be helpful.

JUDGE BRENNER: All right. We'll mark it for identification but somebody's going to have to tell us what it is. Suffolk County Exhibit 77 for identification. It's a one-page sketch -- not a sketch -- well, I'll let somebody else describe it. It's a mechanical drawing.

(Whereupon, the document was marked as Suffolk County Exhibit Number 77, for identification.)

BY MR. DYNNER:

Q Dr. Rau, why don't you take a crack at telling us what this is. I think you know what it is.

A (Witness Rau) I can't be completely sure what it

WRBpp

is. It looks like a copy of portion of a drawing and it appears to be a geometry which is very much like the cam saddle -- the cam gallery saddle area.

Q Can anyone else on the Panel who is familiar with the blueprints of the TDI engine components identify with more precision what this document is?

MR. FARLEY: Judge Brenner, for the record I suspect that this is part of a TDI drawing which the County and LILCO have a protective agreement.

MR. DYNNER: I signed an agreement on that but my agreement says I can use it in this litigation.

JUDGE BRENNER: Not without discussing it with the other parties and letting us know when you're using one of the subjects of that agreement, Mr. Dynner. You know better than that.

MR. DYNNER: Well, I don't because my agreement says I can use this in the litigation before the Board.

JUDGE BRENNER: Well, we're in open session now and I've never reached any determination one way or another whether anything is entitled to proprietary treatment but you can't suddenly introduce something without prior discussion with the other parties and certainly telling us is one of the subjects of that agreement. And especially since I have expressed doubt before I even knew that it was necessary.

WRBpp

MR. DYNNER: All right. Well, we'll pull it back then. If it's your ruling, we'll collect it.

JUDGE BRENNER: I didn't say you can't use it, I just said you're not proceeding in the appropriate way.

MR. DYNNER: I'm sorry, I thought it was appropriate for the limited use that I'm going to make of it.

JUDGE BRENNER: It's in the public record. That's where we're going to put it. What do you need it for that you can't accomplish through some other means?

MR. DYNNER: Well, maybe I can accomplish it through some other means. I thought this would be a simple way of accomplishing it.

JUDGE BRENNER: It may well be. But now you have the proprietary problem which you should have anticipated.

Is Mr. Farley correct that --

MR. DYNNER: Mr. Smith has informed my co-counsel that he has no objection to this if this exhibit is sealed.

JUDGE BRENNER: I don't want to seal exhibits unless I first make the determination that it's necessary for the record --

MR. DYNNER: Okay.

JUDGE BRENNER: -- that we use the exhibit.

Remember, we never agreed with the fact that it

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was proprietary. We never disagreed.

MR. DYNNER: We'll just take it back.

JUDGE BRENNER: Come on. We're wasting a lot of time unnecessarily in my view.

Let's note for the record, in fact, the exhibit is being withdrawn by Suffolk County, and so we have no Suffolk County Exhibit 77 at this time.

(Whereupon, Suffolk County Exhibit 77 is withdrawn.)

JUDGE BRENNER: If you find you need it you'll have to provide a bases as to why you need it just in order for us to trigger going through the effort of deciding how we should make use of it. But I want to try to avoid even having to get to that point if you can adduce whatever you need to adduce without the use of that.

BY MR. DYNNER:

Q Dr. Rau, isn't it true that the curve, if you wall, in the wall supporting the cam saddle area would, by its geometry, result in the likelihood of tensile strain, tensile stresses in the curved area?

A (Witness Rau) That's definitely not true, Mr. Dynner. And also you misstated -- or incorrectly stated -- in your question that even this region supports the cam saddle; that's not a true statement, either.

Q All right, is it your testimony that the curved

WRBpp

region is associated, let's put it that way, that the curved region which is associated with the cam saddle is curved, that is, it forms a sort of semi-circle, as you described; isn't that right?

A Yes.

Q All right.

JUDGE BRENNER: Do you want to use that sketch now that we have copies? It sounds like the question you asked.

MR. DYNNER: I guess not.

JUDGE BRENNER: All right. Go ahead.

BY MR. DYNNER:

Q Do I understand your testimony to be that the fact that that area is curved, as you have been describing, would not result in tensile stresses in that area?

A (Witness Rau) Of course not, Mr. Dynner. You can make it about any shape you want and you don't get tensile stress unless you put some tensile load on it.

Q All right. Now, in that area that we're talking about, is there a load put on it by the through bolt that's adjacent to that area?

A Yes.

Q And is it your testimony that that load would not result in tensile stress in the curved area?

A Very definitely. It results in compressive stress in the curved area.

WRBagb

Q Dr. Rau, concerning the cumulative damage analysis that you did, you testified that it made no difference to your conclusion that the stud-to-stud crack between cylinders 4 and 5 on the exhaust side of the original EDG 103 -- that it would make no difference to your conclusion whether the depth of that stud-to-stud crack was 3 inches or 5.5 inches as finally measured, isn't that correct?

A That's correct, Mr. Dynner, it would not make any difference to the conclusion, it would only change the margin, the very large margin which we have already demonstrated by a small amount.

Q Well you said with a final crack of a 3 inch depth that would show that the EDGs can withstand 50 consecutive loop LOCAs.

Am I correct that if the crack had been 5.5 inches deep that would show that the EDGs could withstand about 100 consecutive loop LOCAs?

A Well it is a very conservative analysis but at least that much, yes.

Q And we also have testimony that the initial crack depth which was measured with the eddy current device in the block that you say contained Widmanstaetten graphite was not accurate would it make any difference to the conclusions of your cumulative damage analysis if the initial crack depth

WRBagb

of the 3 inch crack had been 2.5 inches in depth?

A Well that is a hypothetical because I don't believe that to be the case. Our inspection is conservative and I don't believe it could be larger.

But if you ask me to assume that in fact it was, I do not believe it would change my conclusions; I believe if anything it might even increase the margin a little bit. Because what it would mean is that given the same amount of cumulative damage on Engine 103 with the original block during the test period from March 11 through April 14 that there had been even less crack extension -- that is, as you asked me to assume 2.5 to 3 inches -- than what I based the conservative calculation upon presently which is 1.6 inches growing to 3 inches.

Q Well the reason I am confused a little bit, Dr. Rau, is that by reducing the final crack size from 5.5 inches to 3 inches you obviously have reduced what you perceive to be the amount that the crack grew, you have reduced the amount that the crack grew and you have gotten therefore a result that says that based on that analysis the EDGs can withstand 50 loop LOCAs instead of 100.

Now in the hypothetical I have given you you now have only a half-inch extension and you seem to be -- Does that mean it would -- it could withstand more loop LOCAs or fewer loop LOCAs with less crack depth extension?

WRBagb

A Mr. Dynner, I think there is some confusion. When you added the last phrase "with less crack extension" therein lies the difficult.

Recall that the cumulative damage analysis is comparing that amount of damage accumulated during the test period of the old 103 with that amount of crack extension which occurred during that same test period. And to the extent that you changed the amount of crack extension during the test period, you are changing what happens during the test period but the comparison for computing the margin is simply based on other engines, other EDGs withstanding the cumulative damage requirements of the loop LOCA without accruing any more damage than that which the original 103 accrued during the test period.

So the question can't really be answered the exact way you asked it.

Q So as I understand what you are really saying is it is that no matter what kind of crack extension or crack growth assumptions that you made, given the fact that your analysis was based upon, as you stated, the number of hours, the loads and the stresses associated with those loads, you would never get to the point where you would show that the EDGs 101 and 102 could not withstand a loop LOCA, isn't that right; no matter what crack growth assumptions that you made you would never get to the point where EDGs 101 and 102

WRBagb

would be shown not to be capable of withstanding a loop LOCA, isn't that right?

A No, Mr. Dynner, that's not right. Surely you can postulate some physically unrealistic relationship between the cyclic and the mean stress and the rate at which a fatigue crack propagates which would predict much more severe conditions under a loop LOCA load profile than that which was experienced in the test period.

But in point of fact the test period between March 11 and April 14, 1984 was a rather severe duty compared to the duty that is required of any of the EDGs during the loop LOCA. And given the performance of the original 103 with the degenerate graphite structure, it certainly is true that you are not going to predict with any rational analysis more severe damage under a loop LOCA load profile which is less severe than the test period. Now generally speaking that's true.

Q If you don't know the exact depth -- the exact depth -- of the crack that we are talking about as of March 11, 1984 then you can't possibly know how long it took that crack to grow to 3 inch depth, can you?

A I certainly do. Whatever length it was at the beginning of the test period, it took the amount of duty which the original 103 saw during the test period to grow to the 3 inch length. So assume it is all the way to a limit

WRBagb

of zero if you want. In any case, we have demonstrated -- or the original 103 engine demonstrated by its performance during the test period -- that with a very large margin, 50 loop LOCAs, the existing 101, 102 or the replacement 103 will not accrue that amount of crack extension with that degree of margin, even if a loop LOCA should occur.

Q Dr. Rau, supposing that you used for your cumulative damage analysis the 4.5 inch crack that developed from the stud hole at cylinder No. 1 and ran down the front of EDG 103 and supposing that you assume with me that that crack grew its 4.5 inch amount in one hour and 20 minutes.

If you had that data and put it into your analysis, would you still come out with a conclusion that all of the EDGs could survive a loop LOCA without experiencing the damage of a 4.5 inch crack running down the front of the engine that is the same crack I'm talking about?

A Mr. Dynner, you haven't given me enough complete information in your hypothetical for me to answer the question.

Q Well I am assuming a damage period now that the crack extension took place in one hour and 20 minutes, rather than the crack extension took place from March 11 to April 14.

A I understand that, Mr. Dynner, but you must also

WRBagb

describe the loading conditions which exist during that time period. Otherwise you cannot perform the cumulative damage calculation because, as I indicated, it is based upon the hours, the power levels and the corresponding stress ranges, that is, cyclic stresses and mean stresses that go with the time frame.

Q That is easy. I will assume 3900 Kw for the hour and 20 minutes because that is what we think we know it is. 3900 Kw was the load. One hour and 20 minutes was the time. Factoring that into your cumulative damage analysis, would that still predict that the EDGs would survive a loop LOCA without experiencing that type of crack, that is, EDGs 101 and 102?

A Well that is an incredibly unrealistic hypothetical, Mr. Dynner. But if you ask me to assume that hypothetical, am I to assume that the crack occurred in the degenerate Widmanstaetten graphite structure in the original 103?

Q Exactly the same assumptions that you made with the 3 inch crack, stud-to-stud, and I think you do make that assumption.

A I have not made that calculation because I believe it to be completely ridiculous, but I will try to answer your question.

Mr. Dynner, I think it is too close to call,

WRBagb

quite frankly. I am trying to do a very qualitative calculation in my head, knowing how the calculation is done, given these very extraordinary conditions and all I can indicate is surely the margin demonstrated would be reduced dramatically given the assumptions you have asked me to hypothetically assume. I cannot tell you whether you would eat up the entire factor of 50 margin that is demonstrated.

Even if you did, however, I don't believe that could occur. The only way in which you could have that kind of an extension in that period of time would not be by fatigue, it would have to be by overload rupture, basically just a pop. I don't even believe it is even realistic.

Let me just add the pop I am talking about is in the degenerate Widmanstaetten structure which has some incredible weakness that would just cause it to pop under the load conditions you have asked me to assume.

MR. DYNNER: I would like to make sure that everybody has this schematic drawing that has been circulated.

JUDGE BRENNER: All right. Let's mark -- this is the drawing that Dr. Rau had made available earlier and copies have since been made and we can call it Suffolk County Exhibit 77 for identification. And it is a drawing showing, among other features, the labeled features "cam saddle, cam shaft, and fuel pump bracket," and it is an

WRBagb

apparent depiction of some crack area in the upper cam saddle curve region.

(Whereupon, the schematic furnished by Dr. Rau was marked as Suffolk County Diesel Exhibit 77 for identification.)

BY MR. DYNNER:

Q Looking at Suffolk County Diesel Exhibit 77, Dr. Rau, can you identify on that drawing which portion represents the crack or a similar crack to that which occurred in the cam saddle on which fractographic analysis was performed?

A (Witness Rau) Yes, this is a schematic representation again of a cross-section made right through the cam saddle.

The far left-hand side of the exhibit would be where the water is, that is the water jacket side. On the right-hand side of the curved portion you are in the cam gallery region, which is the oil region. The location of the camshaft is shown in the buried location on the right lower portion and the cam saddle, which is the web or the stiffener which supports the cam bearing is shown in the middle.

In the upper left there is a shaded region which is adjacent to the schematic representation of the shrinkage

WRBagb

cracks. That shaded region is intended to represent the repair weld present at this particular cam saddle location.

The cracks to the left of the shaded region are the original shrinkage cracks. The dark line which runs between the shaded region and the light region below the horizontal cracks is a schematic representation of the crack between the repair weld and the adjacent cast iron.

Q Can you estimate for us, Dr. Rau, approximately -- in the real crack approximately how -- what is the width of that weld material which would be the height as shown in this schematic drawing?

A Well the height of the weld in this drawing from top to bottom would be on the order of 3/4 to 1 inch. The total thickness or width of the region across which the crack plane is located is 1-1/4 at this section.

Q Now can you show me in this drawing where would be the portion that was ground out prior to the weld material being put in?

A The entire shaded region, in my opinion, would have been arced and perhaps subsequently ground out and that the weld metal is basically puddled in. The amount of melting between the weld metal and the adjacent cast iron is very limited in this particular weld repair, done without preheat, or with very little preheat.

Q Now Mr. Schuster, can you tell me, does the type

WRBagb

of weld material we are talking about here adhere well to an oxide surface, a surface that had an oxide coating on it?

MR. FARLEY: Objection, I don't think this witness is qualified.

MR. DYNNER: He is a qualified welding specialist, according to his resume.

JUDGE BRENNER: I recall that also. Let's see what the answer is; although I don't know why you're not addressing the panel generally, but if you have a reason I will let you restrict it.

MR. DYNNER: Only because he is a qualified welding specialist according to his resume.

JUDGE BRENNER: I know, but you have other witnesses with related areas of expertise on the panel, or potentially so.

Why don't you just --

MR. DYNNER: If there is no objection to getting Mr. Schuster's response --

JUDGE BRENNER: The objection is overruled if you want to limit it to Mr. Schuster for now.

MR. DYNNER: And anyone who wants to add can.

JUDGE BRENNER: All right.

WITNESS SCHUSTER: Based on all of the conversation I have heard about the area, the question isn't proper, if I can say that, because it was indicated that the

WRBagb

area was ground. And in the grinding operation you have got to remove the oxide, if there was any oxide on that surface.

So with the conditions given, the surface is going to have -- it is going to be ground, you know, fairly clean.

Oxides generally are cleaned off before a part is welded.

BY MR. DYNNER:

Q Dr. Johnson, you testified that TSI probe depth measurements were made on several of the blocks and you didn't tell us what the deepest measurement was for Block 102. Can you give us that information?

A (Witness Johnson) The measurements were not performed on 102.

WRBeb

MR. DYNNER: I'm going to address this question to anyone on the panel from LILCO.

BY MR. DYNNER:

Q As I remember your testimony it was that you did not discover that the cam gallery cracks contained weld until August of 1984. Is that correct?

A (Witness Schuster) That's correct, sir.

Q Now it is true, isn't it, that you were informed by Delaval--

JUDGE BRENNER: I'm confused. I'm sorry. Maybe my memory of the record is wrong.

I thought that the cam gallery crack welds were discovered in the spring of 1983.

WITNESS SCHUSTER: No, sir, the welds were discovered in 1984, in August. Remember, we went through all the discussion about the paint being removed by FaAA when they did their examination on the block after it was replaced.

WITNESS RAU: The cracks had been discovered earlier, your Honor.

WITNESS SCHUSTER: Not the welds.

JUDGE BRENNER: All right, I'm with you now. Thank you.

BY MR. DYNNER:

Q It is true, isn't it, gentlemen, that Delaval

WRBeb

informed you as early as April of 1983 that they performed weld repairs on the blocks in areas of compression? Isn't that right?

A (Witness Schuster) They informed us that if they were to perform weld repair -- and I testified to this, I believe it was yesterday -- it would be in an area of low stress.

Q And they told you that in April of 1983. Isn't that right?

A I think you're referring to the Isleib report. Isn't that correct?

Q Will you just answer the question, please?

A (Witness Youngling) Mr. Dynner,--

Q No, there's a question pending and I would like Mr. Schuster to answer it. He started to answer it,

A I think--

JUDGE BRENNER: I thought you said anybody from LILCO.

MR. DYNNER: Yes. Mr. Schuster started to answer the question and I wonder if I could get his response to the question.

JUDGE BRENNER: Well, he didn't exactly start to answer it. He expressed some confusion.

Let's let anybody from LILCO answer, and then you can follow up.

WRBeb

MR. DYNNER: All right, fine.

WITNESS YOUNGLING: I see you referencing a document. Perhaps if you can key to a document that may help us.

BY MR. DYNNER:

Q Right now I have a question:

It is true, isn't it, Mr. Youngling, that as early as April of 1983, Delaval told LILCO that they made weld repairs on blocks only in areas of compression. Isn't that true?

A (Witness Youngling) I am going to have to defer to the other LILCO people. I am not aware of that.

Q Do any of you know about that?

WITNESS SCHUSTER: Judge Brenner, I had indicated yesterday when we had the discussion about Delaval and weld repairs that if they were to do a weld repair -- and we had the question we had asked, and we referenced it to the time frame during the Isleib report which was in 1983 -- that if they were to do a repair, it would be in an area of low stress.

And we went into some discussion about the areas that might be considered to repair, and we talked about a flange area, et cetera.

That's true, I did, you know, reference the report that I believe Mr. Dynner has in front of him right

WRBeb

now.

MR. DYNNER: We will try to get better copies. I notice -- it's the first time I'm looking at the xeroxed copies -- that they are not all as legible as they might be, but I think for purposes of this examination they will be okay, especially since the witness had indicated he is familiar with the document.

JUDGE BRENNER: Well, he didn't indicate that. You will have to ask him.

MR. DYNNER: I'm about to do that.

Could I have this please marked for identification as Suffolk County Diesel Exhibit 78? I will, if you would like, describe the document and then get the witness to identify it.

The document consists of seven pages. The first page has the date in the upper left-hand corner of April 14, 1983. In the right-hand corner it says "NSD83-190."

The addressee or the name that appears under the date in the left-hand corner is Mr. A. W. Zeuthen, and the title is "Trip Report - Diesel Generators at Kansas and Delaval, California."

My pages of this document appear to be out of sequence, but this is the way that we received them on discovery so I did not try to alter the page sequence.

The third page is labeled "2" at the top, and it

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is signed by J. J. Cirilli. It shows there are attachments, and a copy to Mr. R. M. Kascsak.

The fifth page in says at the top "Transamerica Delaval, Inc." The first line from the margin says "Thurs. 4/7/83 Dick Pratt."

JUDGE BRENNER: That's not legible on my copy, but all right, go ahead.

(Whereupon, Cirilli trip report w/attachments was marked as Suffolk County Diesel Exhibit 78 for identification.)

BY MR. DYNNER:

Q Anyone from LILCO on the panel, have you seen this document before, and can you identify it?

A (Witness Schuster) It's a trip report from Mr. Jim Cirilli, who I had indicated in my earlier testimony was a participant in the trip to Kansas and to Delaval.

Q Is Mr. Cirilli an employee of LILCO?

A Yes, sir, he is.

Q Who is Mr. Zeuthen?

A That's the corporate metallurgist, sir.

Q For LILCO?

A Yes, for LILCO.

Q And who is Mr. Kascsak who has a copy shown to him on page 2, which is the third page of this document?

WRBeb

A That's Mr. Kascsak, who is an employee of LILCO also, sir.

Q Now if you will turn for a minute to the fifth page -- and again I apologize for the fact that time constraints did not permit me to number them, but we will number them if the Board wishes later on when we give you better copies.

On the fifth page in you see in the left-hand column under the three little ooo's there is a dash, and it says:

"Weld repair blocks only in areas of compression (cosmetic)."

And I was referring and asking you, anyone from LILCO, as to whether or not, now looking at this document, do you recall whether or not in April of 1983 you were informed by Transamerica that weld repair on the blocks was made only in areas of compression?

Can you answer that question now?

A Obviously this is the report from Mr. Cirilli. I don't recall the compression.

I did indicate that flange areas and areas of low stress would be repaired by welding. I indicated that the other day. That doesn't change anything I've said.

Q Did anyone from LILCO, when you received this information, ask Delaval whether in fact weld repairs had

WRBeb

been made in the EDG blocks at Shoreham?

A We didn't have any reason at that point in time to, you know, question whether there was a weld repair in the area of the cam saddle fillet, as I have indicated earlier.

Q Well, in fact isn't it true -- anyone from LILCO -- that the reason for the trip to Delaval had to do with the fact that you had just discovered that there were linear indications in the cam gallery area of your EDGs? Isn't that right?

A The trip to Delaval was-- You know, there were several reasons, as the report outlines. One of those reasons was to determine whether the indications that were in the cam saddle area were process-induced.

The second portion of that trip was to, if we in fact found process-induced indications, could we acquire any knowledge of an operating history related to that.

And that was the reason why we went to Kansas and subsequently found the same indications in the saddle on the 9, as I have indicated, and was told that the engine had some 50,000 hours on it.

Q Well, subsequent to April 7th, 1983, -- anyone from LILCO -- did you ever ask Delaval whether there was weld repairs in the cam gallery areas of the EDGs at Shoreham?

WRBeb

JUDGE BRENNER: Your question is did LILCO ever ask TDI?

MR. DYNNER: Yes, sir.

BY MR. DYNNER:

Q Do you recall now, gentlemen, that you have had your conference?

A (Witness Schuster) I think I may be able to help, to give a little more background as to--

JUDGE BRENNER: Just answer the question. I don't want any more background. And then if you need background after you answer it, I'll let you.

WITNESS SCHUSTER: Could you repeat the question? I'm not so sure I know what it is any more.

BY MR. DYNNER:

Q Did you ever ask-- Subsequent to April of '83, did you ever ask Delaval whether there were weld repairs in the EDG blocks at Shoreham in the cam gallery areas?

A (Witness Schuster) Subsequent to?

Q Yes. That means after.

A After. In 1984 we asked Delaval whether there was weld repairs in the cam gallery. I think Dr. Rau can help in that area because FaAA was involved in those discussions.

Q Just tell me what month in 1984, if you will, was the first time you asked.

WRBeb

A Again I've indicated that I think Dr. Rau would be more -- it would be more appropriate for him to answer the question because--

Q My question is when LILCO first asked.

A (Witness Youngling) FaAA is our agent, and they asked.

Q So is it your testimony that LILCO never asked except through FaAA?

A Yes.

Q All right.

Now when did FaAA first ask Delaval as to whether there was weld material in the cracks in the cam gallery areas of the EDGs?

A (Witness Rau) I cannot answer that question for everybody at FaAA, Mr. Dynner. I know that from the time of my intense involvement in the analyses, we certainly met-- I recall meeting with TDI representatives in July where we had -- I think it was July -- where we had detailed discussions requesting all kinds of information about the cam gallery. And there was no information or no indication that there were weld repairs in the cam gallery at that time.

We subsequently-- I mean after we had actually discovered the welds by our detailed personal inspections in August, we asked again, very explicitly again. And even at

WRBeb

that time -- I don't know how to describe it -- TDI didn't say that they were aware of them, they simply acknowledged that they were in fact there.

That's about all I can say.

Q Now it is true, isn't it, Mr. Schuster, you testified earlier about this engine block from a DSR 48 engine in Lincoln -- I'm sorry, in Lincoln, Kansas, which you said had run 50,000 hours with cam gallery cracks. Is that right?

A (Witness Schuster) I said that that block had the same indications that the Shoreham block had and that it had 50,000 hours of operation, yes, sir.

Q And it is true, isn't it, that that engine was operated at 85 percent of load to run a generator that was rated at 2550 Kw?

And that information in fact is on the second page of the County's Diesel Exhibit 78, which you have before you. Isn't that right?

A That's correct.

Q And it is true, isn't it, that the rated horsepower of the Lincoln, Kansas, engine at full load is only about 450 horsepower per cylinder versus about 610 horsepower per cylinder for the full load rating of the EDGs at Shoreham. Isn't that right?

A I would like to defer that question to Mr. Rau.

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Q Well, let's make it easy for you, and look up in the same page, the second page of this document where it shows, under the heading "Engine" that the horsepower is 3,588.

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So the answer to my question is yes, isn't it, Mr. Schuster?

A It says at 400 rpm.

Q So the answer to the question is yes, isn't it?

A Yes.

Q Thank you.

JUDGE BRENNER: You know if that is important to you, Mr. Dynner -- I hate to encourage additional questions -- but the witness suggest you ask somebody else who he apparently believed knew and all the witness gave you is he read the page with you.

MR. DYNNER: Yes.

BY MR. DYNNER:

Q Does anyone else have any information that in any way conflicts with the information on this page? Anyone on the -- Nobody has any information that conflicts?

MR. FARLEY: Object, that was not the form of the question, Judge, that it conflicts. It was a question of whether or not -- what is the horsepower and the rpm of the engines at Shoreham.

JUDGE BRENNER: What?

You lost me, Mr. Farley.

MR. DYNNER: We are talking about the engine in Lincoln, Kansas.

JUDGE BRENNER: Mr. Dynner, we have discussed

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this before.

MR. DYNNER: All right. I'm sorry.

JUDGE BRENNER: But Mr. Farley I thought did have a point until he lost me on his second phrase.

Why don't you ask the same question you asked of Mr. Schuster of the panel, because it may not conflict but....

BY MR. DYNNER:

Q Gentlemen, it is true, isn't it, that the engine that we are talking about in Lincoln, Kansas has a rated horsepower at full load of about 450 horsepower per cylinder as opposed to the approximately 610 horsepower per cylinder rating of the EDGs at Shoreham, isn't that right?

A (Witness Youngling) Yes, sir.

Q Did you -- this is to the whole panel -- did you measure the depth and length of the cam gallery cracks in the engine in Lincoln, Kansas?

A (Witness Schuster) We did not measure the depth of the indication in the Lincoln, Kansas engine. We did measure the length of the indication.

Q How many indications were there?

A I would have to look at the record to refresh my memory, but I believe it was a single one.

And -- No, I won't guess at the length of it but it was a single indication if I remember correctly.

WRBagb

Q Mr. Rau, I believe that you -- and please correct me if I'm wrong -- I believe you testified earlier that the indications or cracks in the cam gallery saddles of the replacement block for EDG 103 could not even be seen by visual inspection currently, is that your testimony?

A (Witness Rau) I don't think that is a precise reflection. I think what I said is that there were no reportable indications by visual inspection under LILCO's visual inspection standard that was in effect at the time the replacement 103 block was purchased and inspected in the unpainted condition.

Q And what's the size of a reportable indication that you are referring to?

A You'll have to ask the detail inspectors. I think Mr. Schuster or Mr. Johnson are in a better position to answer that question.

A (Witness Schuster) Could you repeat the question, please?

Q Yes. What I was asking is what is the size of the reportable indications that Dr. Rau was referring to?

A A reportable indication based on the criteria that was use for linear indications would be an indication that is three times the width. That's the definition of a linear indication, if I have answered your question.

Q It is true, isn't it, that the crack indications

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on the cam gallery areas of cam saddles 2 and 8 of the replacement block EDG are at least -- the length is at least three times their width, isn't that right?

A The criteria that I was discussing with you was not a visual criteria.

Q Would you answer my question?

A The criteria that I gave you was not a visual criteria.

Q No, my question is: it's true, isn't it, that the cracks in the cam saddle areas No. 2 and 8 of the replacement EDG block are in fact in length more than three times their width, isn't that right?

A That's correct.

Q -- anyone on the panel?

A By magnetic particle inspection and liquid penetrant inspection.

A (Witness Youngling) Mr. Dynner, I would like to add to that. You refer to these as cracks. These are not cracks, these are indications.

Q Well I am not going to rise to the bait and try to get into a philosophical discussion of the difference between a crack or an indication because I have been there. At the record will speak for itself as to the inspection reports in the record.

Now Dr. Rau, what were the visual --

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WITNESS RAU: Excuse me, are we permitted to talk about the depth of these -- quote -- indications as he is talking about the length or not?

I mean it is not a philosophical discussion between an indication and a crack, your Honor.

JUDGE BRENNER: Let him ask his questions.

Although you shifted gears, Mr. Dynner, at one point after Mr. Schuster misunderstood your question, you never got back to that.

MR. DYNNER: I am about to.

BY MR. DYNNER:

Q Dr. Rau, could you tell me what is the visual reportable indication criterion that you were referring to?

A (Witness Rau) There is a specific procedure, I believe, defined by LILCO and that is the one I am referring to. I have forgotten the number. Mr. Schuster has testified about it several times before, that's the one.

A (Witness Schuster) NSSP 55.

Q Tell me what the standard is for that, if you would, anyone.

A (Witness Seaman) Mr. Dynner, maybe it would pay to explain a little bit about what the standard is. It contains as part of it a series of photographs which would indicate as-cast surfaces and on the tops of the photographs it indicates what types of surface conditions and what types

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are not acceptable.

Q Is it your testimony that none of the crack indications in the replacement EDG block cam saddles would be reportable under that criterion?

A (Witness Schuster) That's correct, sir.

JUDGE BRENNER: Mr. Dynner, how many more questions do you have?

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Dr. Rau, while he's doing that, I'll tell you that your concern, in my recollection, you can talk to your own Counsel but we had testimony at approximately 10:35 a.m. this morning as to the depth of that crack. You work it out with your attorney. Or indication or whatever you want to call it.

MR. DYNNER: I've got him on another 45 minutes is my guess, although it's hard to tell because the pace has been very slow.

JUDGE BRENNER: Well, I don't understand that based on earlier estimates and then revised estimates and then as recently as 3:30 at the break or, until approximately 3:30, you said you had about an hour. And I can tell you, although I haven't interjected on my own, many of your questions could have been asked initially and I don't think that they are all legitimate followup questions. Sure, they touch on subjects that were touched on in the followup examination but they don't meet the other requirement of whether they could have been asked originally. I viewed that requirement very liberally because I understand questions could stimulate new thoughts and with hindsight you now know you want to ask those questions.

But even a liberal application is such that I'm afraid what you're doing to some extent is we set what I

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thought was a reasonable time limit for your original cross examination and I think you're now using the followup to fill in that which you couldn't ask in the original time limit and limit is almost a misnomer considering the number of days involved.

MR. DYNNER: Well, I want to assure you, Judge, that not only was that my intention but I could absolutely assure you that every single one of these questions is based upon my notes of answers that were given during cross examination. That's the way I do my recross.

JUDGE BRENNER: You heard what I said. If you didn't hear it, read the transcript. Because what you have just said is not inconsistent with what I said.

MR. DYNNER: Yes, sir, I just wanted to be sure that you understand that I was not trying to use this as a device to increase my cross examination.

JUDGE BRENNER: All right. I will accept that. Nevertheless, the effect is that I think the followup is taking longer than is reasonable given the state of the record and the evidence.

(Board conferring.)

MR. DYNNER: Well, I see that it's now -- oh, I'm sorry.

(Board continuing to confer.)

JUDGE BRENNER: You were going to say something,

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Mr. Dynner?

MR. DYNNER: I was going to say two things. First of all, I was going to say that seeing what the time is now I can assure the Board that I will further strip down whatever remaining questions I have and try to reduce them to the absolute minimum because I hear exactly what you're saying and I have no desire to ask superfluous questions or to extend the time of this hearing. And I will definitely do that this evening.

The second matter I wanted to get to was to move into evidence the County's Diesel Exhibit 76, which were the EDX chemical analysis reports; Exhibit 77, which is the schematic drawing of the cam gallery crack; and Exhibit 78, which is the trip report that has been identified.

JUDGE BRENNER: Mr. Farley, any objection?

MR. FARLEY: I have no objection.

MR. GODDARD: No objection from the Staff.

JUDGE BRENNER: All right. Due to the absence of any objections we'll admit them into evidence with the overall caution that we have expressed as to admitting exhibits which may have a lot of things in them beyond what was attached on in the written or oral testimony still applies. And I'm thinking particularly of Exhibit 78, but we always have that control and we will admit those three exhibits as requested.

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(Whereupon, Suffolk County Diesel Exhibits Nos. 76, 77, and 78, having been previously marked for identification, were received into evidence.)

JUDGE BRENNER: All right. We'll give you more time tomorrow morning, Mr. Dynner, but not much more time and what we have in mind is approximately 45 minutes which, combined with the total time you spent, I think has been a long time. But the fact that you have overnight to put it together and become efficient should assist you and also the record and, thereby, assist us.

I think that, certainly this is hindsight, just because of the chronology, but some of the lines of questioning you pursued are such that you could have asked the fourth question first and cut out the first three. The chronology of when they asked about the welds -- TDI put the welds -- is a recent example of that, in my opinion. And I know what you wanted to get at and the importance was relative to other events. And you could have more directly asked it that way, I think. But it's late in the day for all of us and that effects the questioners as well as the witnesses.

I do want to remind the parties, as we've expressed in our prehearing scheduling order that we will be

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proceeding as a quorum after today for, at least, the timeframe contemplated in our prehearing order, within which we expect to complete this evidentiary proceeding. So, Judge Ferguson may not be present again at this hearing, as also indicated in that order he will, of course, read the transcripts and thereby be cognizant with that which is occurring.

And with that, we'll recess at this point until 9:00 tomorrow morning.

(Whereupon, at 5:09 p.m., the hearing was recessed, to reconvene at 9:00 a.m., Thursday, November 1, 1984.)

CERTIFICATE OF OFFICIAL REPORTER

This is to certify that the attached proceedings before the UNITED STATES NUCLEAR REGULATORY COMMISSION in the matter of:

NAME OF PROCEEDING:
LONG ISLAND LIGHTING COMPANY
(Shoreham Nuclear Power Station)

DOCKET NO.: 50-322-OL

PLACE: Hauppauge, New York

DATE: October 31, 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

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