50-322 OL

I-S-1 through I-S-10 11/1/84

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

Before the Atomic Safety and Licensing Board

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

SUPPLEMENTAL TESTIMONY OF DR. ROBERT N. ANDERSON,
PROFESSOR STANLEY CHRISTENSEN, G. DENNIS ELEY,
AND RICHARD B. HUBBARD
REGARDING SUFFOLK COUNTY'S EMERGENCY DIESEL
GENERATOR CONTENTION CONCERNING CYLINDER BLOCKS

SUFFOLK COUNTY
October 18, 1984

TABLE OF CONTENTS

SUFFOLK COUNTY 10/18/84

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

Before the Atomic Safety and Licensing Board

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

SUPPLEMENTAL TESTIMONY OF DR. ROBERT N. ANDERSON, PROFESSOR STANLEY CHRISTENSEN, G. DENNIS ELEY, AND RICHARD B. HUBBARD REGARDING SUFFOLK COUNTY'S EMERGENCY DIESEL GENERATOR CONTENTION CONCERNING CYLINDER BLOCKS

I. INTRODUCTION

1.Q. What is the purpose of this testimony?

A. (All). This testimony addresses new information on cylinder blocks disclosed by Supplemental Testimony filed on September 20, 1984, on behalf of LILCO's witness panel and by subsequent discovery. That information concerns: (1) cracks in the cam gallery area of all EDG cylinder blocks, including the replacement block for EDG 103; (2) circumferential cracks around the cylinder counterbore landing; and (3) changes in LILCO's measurements of cracks in the blocks.

2.Q. What conclusions have you reached as to these matters?

A. (All). Our conclusions may be summarized as follows:

(1)(a) Cracks in the camshaft gallery area of the original EDG 103 cylinder block have been found to be far more extensive and more than twice as deep than first represented by LILCO and FaAA. Analysis of fractography and metallography of crack samples shows that these cracks were originally formed as hot tears during the casting process, were unsuccessfully attempted to be repaired with welding, and have since propagated.

(b) Similar cracks are in the cam gallery areas of the blocks of EDGs 101 and 102. These cracks will continue to propagate, and those blocks are therefore unsuitable for nuclear service.

(c) Cam gallery cracks have been found in the replacement block for EDG 103 after operation of that engine during testing. Inspection records show that no such cracks were present before the replacement block was placed into operation. Accordingly, these cracks occurred due to operating stresses.

(2) Circumferential cracks were recently discovered during destructive examination of the original EDG 103 block. LILCO and FaAA did not thereafter reinspect EDGs 101 and 102 for circumferential cracks, but assume they are present extending continuously 360 degrees around the circumference of the liner landing of each cylinder. Examination of sections of the original EDG 103 block shows the circumferential crack to be relatively deep and propagating. Circumferential cracks in EDGs 101 and 102 may cause EDG failure.

(3) Sectioning of the original EDG 103 block disclosed that the large stud-to-stud crack between cylinder numbers 4 and 5, which LILCO and FaAA had represented to be 5-1/2 inches deep, was really 3 inches deep. The erroneous measurement of this crack suggests other crack measurements may be wrong. Further, the inability of LILCO, FaAA, and TDI Owners Group inspections to discover the circumferential cracks or the nature and extent of the cam gallery cracks casts considerable doubt on the reliability of those inspections.

II. CAM GALLERY CRACKS

3.Q. What cracks were found by FaAA and/or LILCO in the camshaft gallery area of the original EDG 103 block?

A. (Hubbard, Anderson). The FaAA Block Report issued in June 1984 and LILCO's cylinder block testimony stated that there were "crack indications" in the cam galleries of all three EDGs, with the longest measuring 4-1/2 inches long and 0.375 inch deep in EDG 103.[1/] This information proved to be erroneous when, in late August, FaAA sectioned portions of the original EDG 103 block. Inspections showed cracks in all nine camshaft gallery saddle areas; there was a single 3 inch long crack, while the other eight cracks ranged in length from 4-1/4 inches to 5-3/8

1/ See Exhibit 7 to Suffolk County EDG testimony at 4-6; see also Testimony of Roger L. McCarthy, et al., August 14, 1984, at 62-63, and Exhibit B-52 (since deleted by LILCO).

inches.[2/] Some of these cracks were measured by FaAA after sectioning and found to be from 0.5 inch to 0.906 inch deep in a block wall only 1.25 inches thick.[3/] FaAA found that all of these cracks had been ground and welded. Some representative photographs of these cracks are shown in Exhibit S-3.

4.Q. What do you believe initially caused the cam gallery cracks in the original EDG 103 block to form?

A. (Anderson). Based upon my examination of the sections removed by FaAA from the block and of numerous photographs of these cracks, they appear to be hot tears formed initially during fabrication of the block. This theory is supported by the fact that the cracks were filled with welding material in an apparent effort to repair them.

5.Q. Do you agree with FaAA's conclusion that these cam gallery cracks did not propagate after their formation during the casting process?

A. (Anderson). No. That conclusion is based upon FaAA's erroneous interpretations of a "dark oxide" on the surface of a crack sectioned from cam gallery No. 7, the presence of high concentrations of calcium on the surface of that crack, the absence of a "rust-colored oxide," and the appearance of the crack surface.

6.Q. Was the sectioned crack surface covered with a thick dark oxide?

2/ FaAA Liquid Penetrant Examination Report, 8/24/84 (Exhibit S-1).

3/ Exhibit S-2.

A. (Anderson). FaAA did not analyze the crack surface to determine the presence of oxygen, so the substance is not necessarily an oxide. Although it is possible that all or part of the coating is an oxide, I believe the darkness of its color is attributable to graphite from "graphitization" or graphitic corrosion of the surface of the crack, and not to oxidation at extremely high temperatures as hypothesized by FaAA. Graphitic corrosion occurs in gray cast iron in relatively mild (low temperature) environments.[4/] The graphite would have the effect of darkening a rust-colored oxide on the crack surface. The presence of minute particles of dirt and the oil to which the crack would be exposed could contribute to the darkness of the surface. The EDX chemical analysis of the surface performed by FaAA would not detect the presence of carbon (and hence, graphite).

7.Q. If most of the substance covering the crack surface is an oxide, is FaAA correct that the oxide could only have formed in high temperatures and in the presence of air during cooling at the time of the casting process?

A. (Anderson). No. First, I believe FaAA's conclusion is based in part on their misinterpretation of the cause of the "dark" color of the surface substance. As indicated above, I believe that the darkness of the color is attributable to the surface presence of carbon due to graphitization, and does not indicate that the substance was the product of oxidation at ex-

---

4/ Fontana and Greene, Corrosion Engineering (McGraw-Hill, 1978) at 70-71.

tremely high temperatures. Red or rust-colored oxides, unlike dark oxides, are formed in low and moderate temperature environments and would have the dark appearance of the surfaces I examined if graphitization had taken place.

Second, the block casting is formed under strong reducing conditions where air cannot enter. Initially, the block casting mold is literally burning. If air did enter the cam gallery area, it could do so only by diffusion in small amounts over a short period before the surface metal cools to the point where any hot tears present would not form oxides. If this had occurred, there would only be a small amount of oxide with uneven distribution over the crack surface. Thicker layers of oxide would occur at the mouth of the crack than lower down, because the mouth would have been exposed to more oxygen during the cooling period than the bottom of the crack. However, the substance covering the crack appeared fairly uniform in thickness.

Third, the cracks in the sections I examined appear to have been ground and widened in preparation for the welding repairs, because they narrow abruptly below the weld material; a normal hot tear configuration would have a more uniformly V-shaped configuration. Thus, in the ordinary course of events, an oxide formed during the cooling process would have been removed in the upper area of the crack where the grinding took place; but the crack surface from which the weld had separated had a uniform layer of the dark substance from the top to the bottom of the crack.

Alternatively, if the oxide layer postulated by FaAA formed at the time of the casting process was not all removed by the pre-welding grinding, then the oxide should have been present on the side of the crack to which the weld material was still adhered. I examined cross sections of the crack under a microscope and observed no sign of the so-called dark oxide in the area of the crack to which weld material was still adhering.

8.Q. Does the presence of high concentrations of calcium on the crack surface support FaAA's conclusion that the "oxide" covering that surface was introduced during casting while the crack was exposed to high temperatures?

A. (Anderson). No. FaAA's chemical analysis disclosed the presence of calcium in some, but not all, areas which were tested. In all samples where calcium was detected, sulfur was also detected in proportionate amounts. Therefore, I believe that the presence of concentrations of calcium resulted from exposure of the crack surfaces to calcium sulfide, which is often present in diesel oil lubricants and dye penetrants. Thus, the calcium was introduced after the block had been cast and cooled completely.

9.Q. Do you agree with FaAA's conclusion that the relative uniformity of the "oxide" layer on the entire crack surface shows that no crack propagation has occurred?

A. (Anderson). No. A relatively uniform layer throughout the crack's surface is consistent with graphitic corrosion. While the ferritic material corrodes or rusts at different points in time as the crack propagates, the graphitic corrosion leaves a surface layer of graphite. This graphite forms a protective layer so that the corrosion stops and the surface becomes relatively uniform over time.

10.Q. Does the absence of any beach marks in the crack suggest that there was no propagation of the crack after it was initially formed?

A. (Anderson). No. Because of its brittle nature, cast iron does not form beach marks during the process of crack propagation.

11.Q. Is there additional evidence that the cam gallery cracks are propagating?

A. (Anderson). Yes. Exhibit S-4 is two photographs showing the magnified surface of a portion of a cam gallery crack that was sectioned by FaAA. The photographs show that the weld material (the white area in the upper left) has pulled loose from the cast iron surface of the crack, but that some cast iron was still adhering to the weld material. This shows that the weld material pulled free from the crack surface due to operating stresses, as opposed to heat shrinkage.

12.Q. Are there cracks in the cam gallery areas of the blocks of EDG 101 and 102?

A. (Hubbard, Anderson). Yes. LILCO has reported the presence of these cracks in all of the EDG blocks. The cam gallery area of the EDG 101 block was subjected to magnetic particle ("MP") examination on September 20, 1984 and to liquid penetrant ("LP") examination the following day. The inspection reports (attached respectively as Exhibits S-5 and S-6) disclosed cracks in the cam gallery areas of all eight cylinders, ranging up to 2-3/4 inches long. Mr. Rau of FaAA examined the cam gallery bearing saddles Nos. 8 and 9 on the block of EDG 102 and found welded crack indications about 2-1/2 inches long in both areas.

(Anderson). Based upon photographs of the cracks in the camshaft gallery areas of the blocks of EDGs 101 and 102, the descriptions of those cracks by FaAA personnel, and LILCO inspection reports, I believe these cracks are similar to those found in the original block of EDG 103. While the lengths of the cracks in the EDG 101 block may be somewhat shorter than those in the original EDG 103 block, they are, like those in the latter block, propagating cracks. Hence, I believe the blocks of EDGs 101 and 102 are unsuitable for nuclear service.

14.Q. Were cracks found in the cam gallery area of the replacement block for EDG 103?

A. (Hubbard, Anderson). Yes. The areas of cam bearing saddles numbers 2 and 8 were inspected by LILCO both before and after grinding (on September 30 and October 1, 1984) while preparing EDG 103 for additional testing. The test reports show cracks in both of these areas, ranging up to 2 inches long.[5/]

15.Q. Were these cracks present in the block before it was used during operation of EDG 103?

5/ Exhibit S-7.

A. (Hubbard, Anderson). No. LILCO has supplied us with copies of reports of all inspections of the replacement block by or on behalf of TDI, LILCO, Stone & Webster, FaAA, and the TDI Owners Group, or any agent of LILCO, pertaining to the cam gallery area. None of these reports disclosed any indications in that area. Moreover, LILCO retained an expert, Mr. C. R. Isleib, to observe the casting of the replacement block and conduct a detailed inspection of it after cleaning and before it was painted. The Isleib inspection report concluded:

> Careful inspection revealed no cold or hot cracks or tears, nor any cold shuts visible to my naked eye, nor under the 5x glass I used. Special attention was paid to internal fillets such as in the camshaft bearing saddle areas.6/

We therefore conclude that the cracks in the camshaft gallery area of the replacement block initiated, or propagated from sub-surface defects, during and as a result of the operation of EDG 103.

III. CIRCUMFERENTIAL CRACKS

16.Q. Are there circumferential cracks in the original block of EDG 103?

A. (Hubbard, Anderson). Yes. The FaAA Block Report erroneously stated that none of the EDG blocks had circumferential cracks. Circumferential cracks are cracks at the corner formed by the cylinder liner counterbore and the cylinder liner landing; a representational drawing of a circumferential crack is shown in

6/ The Isleib report is attached as Exhibit S-8.

Exhibit S-9.[7/] After August 14, FaAA found "some" circumferential cracks when it sectioned portions of two cylinders of the original EDG 103 block, according to LILCO's Supplemental Testimony. Actually, the LILCO report of magnetic particle inspections conducted on September 19, 1984[8/] shows circumferential cracks extending 100 percent around the circumference of all eight cylinders.

17.Q. Are there circumferential cracks in the blocks of EDGs 101 and 102?

A. (Hubbard, Anderson). Apparently LILCO and its agents have conducted no inspections since September to determine this. They claim that it is difficult to inspect for circumferential cracks, and simply assume that they are present in the EDG 101 and 102 blocks, running continuously 360 degrees around the circumference of each cylinder.[9/]

18.Q. Do you agree with FaAA's testimony that circumferential cracks in the EDG blocks are "shallow"?

A. (Anderson). No. FaAA's statement that the cracks are "shallow" is based upon examination of sections of portions of only two cylinders from EDG 103, with a maximum depth which FaAA says is 3/8 inch. There is no data to determine whether circumferential cracks in other cylinders may be deeper. I have made an

---

7/ Exhibit S-9 is Figure 1-1 of the FaAA Block Report.

8/ The Magnetic Particle Examination Report is attached as Exhibit S-10.

9/ Deposition of Charles A. Rau, Harry F. Wachob, and Robert K. Taylor, October 11, 1984, at 20.

examination of circumferential cracks in the sections analyzed by FaAA, and I observed that below the tip of the 3/8-inch crack are multiple small disconnected cracks branching out into the cast iron material. The linking up of the main crack with the branch cracks would in my estimation extend the crack to over one inch in depth. This would extend about 2/3 completely through the block material thickness running at a 45 degree angle from the corner of the counterbore landing to the cylinder between the stud bosses.[10/]

FaAA speculates that circumferential cracks in the blocks of EDGs 101 and 102 would be smaller than those in the original 103 block, because of the allegedly inferior mechanical properties of that block. I conducted a microscopic examination of a specimen of the liner landing ledge from the original EDG 103 block, and observed that it contained appreciably less amounts of Widmanstaetton graphite than appeared in other portions of the block as shown by LILCO's block exhibit B-33. Therefore, I do not believe one can validly predict that circumferential cracks are smaller in the blocks of EDGs 101 and 102.

19.Q. Do you agree with FaAA's conclusion that circumferential cracks will "grow slowly, arrest, and will not cause any operational problems"?

A. (Anderson). No. The fact that the original EDG 103 block did not fail due to the circumferential cracks by the time it failed and was scrapped for other reasons, does not support

---

10/ FaAA estimates that the thickness is 1-1/2 inches at that point. Deposition of Rau, et al., at 14.

FaAA's conclusion that the circumferential cracks will not propagate to the point of impairing EDG operation. As described above, the circumferential crack I examined had numerous branches below its tip and appeared to be propagating. The operating history of EDG 103 is therefore cause for concern with EDGs 101 and 102 rather than evidence of their reliability.

20.Q. Can circumferential cracks cause operation of an EDG to fail?

A. (Christensen, Eley). Yes. A circumferential crack could permit some up and down movement of the cylinder liner relative to its position against the gasket sealing the liner to the cylinder head. Such movement could cause leakage of combustion gases, requiring premature shutdown of the engine. In the event the crack propagates through the counterbore, the cylinder liner landing would separate from the block, causing the cylinder liner to fall into the crankcase. This would cause serious damage to the EDG and probable catastrophic failure.

IV. CRACK INSPECTIONS

21.Q. What changes in crack depth measurements has LILCO made as a result of FaAA's sectioning of portions of the original block of EDG 103?

A. (Hubbard). LILCO sectioned the large stud-to-stud crack between cylinder numbers 4 and 5 of the original block of EDG 103 and found it had a depth of 3 inches, rather than 5-1/2 inches as previously reported in the FaAA Block Report and LILCO's written testimony.

22.Q. Is there any basis for LILCO's Supplemental Testimony that "the actual depth of the cracks in the original EDG block are shallower than previously thought"?

A. (Hubbard). No. The depth of only one single crack was revised by the Supplemental Testimony. The Supplemental Testimony does, however, cast considerable doubt upon the reliability of inspections for cracks in the EDG cylinder blocks carried out by LILCO, FaAA and the TDI Owners' Group. First, the erroneous measurement of the crack in the original EDG 103 block suggests that other crack measurements may also be wrong, whether over-stating or under-stating crack depths. Second, before last month neither LILCO, FaAA nor the TDI Owners' Group had discovered the existence of circumferential cracks in the EDGs, despite numerous inspections. Third, before last month none of those organizations had discovered that the camshaft gallery cracks were twice the assumed depth and had been welded. The final DR/QR Report for Shoreham was issued and LILCO's testimony was filed in this case in reliance upon faulty inspection data.

Associates

LIQUID PENETRANT EXAMINATION REPORT

A. Material	Type: GRAY CAST IRON	Fabricated Process:	[ ] Welded [X] Cast [ ] Worked
	Geometry: [ ] Pipe [ ] Plate [ ] Rod [X] Other:		
Cross Section Thickness: Max 2" Inch	Min 1 1/4" Inch	Surface Condition:	[ ] Machined [ ] As Fabricated [X] Ground [ ] Other:

B. NDE Procedure No. 6.2	Surface/Mat'l. Temp. 68°F	M & TE. No. N/A	MWR/RR. No. N/A
Inspection Materials	Brand	Designation	Batch No.
1. Pre-Cleaner	MAGNA FLUX	SKC-NF/ZC-7B	84A028
2. Penetrant	MAGNA FLUX SPOTCHECK	SKL-HF/SKL-S	70073
3. Emulsifier and/or Remover	Magna Flux	SKC-NF/ZC-7B	84A028
4. Developer	MAGNA FLUX SPOTCHECK	SKD-NF Formula B	816092
5. Post Examination Cleaner	Magna Flux	SKC-NF/ZC-7B	84A028

Sketch or other detail (use other side if necessary):

SEE PHOTOGRAPHS

C. Evaluation — Report below those indications observed and the pertinent information required. Where additional space is required, use other side.

Location	Size (Inches)	Description	Action (Accept/Reject, and comment as necessary)
1. #1	3"	FINE	[illegible]
2. #2	5 3/8"		
3. #3	4 3/4	FINE with PITS	
4. #4	5"	Fine and open with Pits	heat cracks

D. Acceptance Criteria	NONE MAPPING areas ONLY	Operator: [illegible] Level: II Date: 8-24-84

E. Attest

Analysis Associates

LIQUID PENETRANT EXAMINATION REPORT

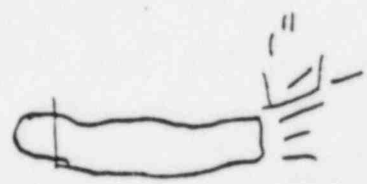
PT 010 DG103 BLOCK

A. Material	Type: GRAY CAST IRON	Fabricated Process:	[ ] Welded [X] Cast [ ] Worked
	Geometry: [ ] Pipe [ ] Plate [ ] Rod [X] Other:		
Cross Section Thickness: Max 2" Inch	Min 1 1/4" Inch	Surface Condition:	[ ] Machined [X] Ground [ ] As Fabricated [ ] Other:

B. NDE Procedure No. 62	Surface/Mat'l. Temp. 68°F	M & TE. No. N/A	MWR/RR. No. N/A
Inspection Materials	Brand	Designation	Batch No.
1. Pre-Cleaner	MAGNAFLUX	SKC-NF/ZC-7B	84A028
2. Penetrant	" "	SKL-HF/SKL-S	7D023
3. Emulsifier and/or Remover	" "	SKC NF/ZC-7B	84A028
4. Developer	" "	SKD-NF Formula B	81G092
5. Post Examination Cleaner	" "	SKC-NF/ZC-7B	84A028

Sketch or other detail (use other side if necessary):

#9 4 1/4"



N/A

C. Evaluation	Report below those indications observed and the pertinent information required. Where additional space is required, use other side.		
Location	Size (Inches)	Description	Action (Accept/Reject, and comment as necessary)
1. #5	4 3/4	Fine-open pitts & Porosity	
2. #6	5 1/8"	open	 ← welded area
3. #7	4 1/2	Fine open with Porosity	
4. #8	5 1/4	open Fine with Large Porosity	
D. Acceptance Criteria			Operator: [signature] Level: II Date: 8-24-84
E. Attest			Responsible Certifying Inspector ____ Level ____ Date ____

N/A