LILCO, January 15, 1985

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)	)	

ADDITIONAL CYLINDER BLOCK TESTIMONY OF DR. DUANE P. JOHNSON, DR. CHARLES A. RAU, JR., MILFORD H. SCHUSTER, DR. HARRY F. WACHOB AND EDWARD J. YOUNGLING ON BEHALF OF LONG ISLAND LIGHTING COMPANY

Testimony and Exhibits

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I. Introduction

1. Please state your names and summarize your professional qualifications.

A. (Johnson) My name is Dr. Duane P. Johnson. My professional qualifications are set forth in my previous testimony during this proceeding.

(Rau) My name is Dr. Charles A. Rau, Jr. My professional qualifications are set forth in my previous testimony during this proceeding.

(Schuster) My name is Milford H. Schuster. My professional qualifications are set forth in my previous testimony in this proceeding.

(Wachob) My name is Dr. Harry F. Wachob. My professional qualifications are set forth in my previous testimony in this proceeding.

(Youngling) My name is Edward J. Youngling. My professional qualifications are set forth in my previous testimony in this proceeding.

2. What issues are addressed by this testimony?

A. (All) Among the topics addressed are the EDG 103 endurance run, the results of inspections on the block following the endurance run, and the effect of these inspections on Lilco's previous evaluations and conclusions.

Also addressed are the effect of operating the EDGs at the qualified load of 3300 KW, including the margins between demonstrated performance and that cumulative damage which a postulated LOOP/LOCA might involve.

Finally, the County has stipulated that it does not seek to disqualify the blocks on the basis of the cam gallery cracks. However, it still contends that the cracks in the EDG 101 and 102 blocks should be monitored by placing wire strain gages across the cracks and by measuring the depths of the cracks before operation and at the first refueling outage. This testimony addresses whether there is any need to monitor the cam gallery cracks in the EDG 101 and 102 blocks in light of the high magnification photomicrographs, the x-ray crystallography and the strain gage test results.

3. Please briefly summarize the conclusions reached in your testimony.

A. (All) Our conclusions are as follows:

1. Fluorescent magnetic particle inspections of the block top and eddy current inspections of stud holes on the block top of the EDG 103 replacement block at the conclusion of the endurance run detected no reportable indications. The absence of ligament or stud-to-stud cracks in the block top confirms our opinion that the design enhancements introduced in the EDG 103 replacement block are beneficial and that they have reduced the possibility of fatigue crack initiation. Furthermore, the additional operation of the replacement block at 3300 KW for more than 500 hours during the endurance run confirms that the replacement block has been adequately designed and tested. Clearly, it has proven its capacity to perform its intended function of providing emergency power during postulated accident conditions at Shoreham.

2. Operating the EDGs at the qualified load of 3300 KW produces lower cyclic stress in the block top and in the cam gallery than at higher loads. This reduces the possibility of fatigue crack initiation in the block top, and reduces the rate of any crack propagation should crack initiation occur. Further, cumulative damage analysis shows that, if a postulated LOOP/LOCA occurs, the EDGs will perform their intended function with even greater margin at the qualified load than at the higher loads previously analyzed.

3. It is not necessary to monitor the cam gallery cracks in the EDG 101 and 102 blocks by placing wire strain gages across the repair welds or by measuring the depth of the cracks with the TSI depth gage at any time prior to the first refueling outage because:

a. The 550x magnification photomicrographs and the x-ray crystallography, combined with previous fractographic and metallographic examinations, demonstrate that cam gallery cracks up to 0.91 inch deep in the original EDG 103 block did not propagate in more than 1200 hours of operation, despite the severely degraded fatigue and fracture properties of that block material and the presence of cracked repair welds. Accordingly, the cracks in the EDG 101 and 102 blocks, which have superior fatigue and fracture properties and smaller repair welds, will not propagate.

b. Strain gage measurements made on the cam gallery of the EDG 103 replacement block prior to the endurance run demonstrate that the stresses perpendicular to the cam gallery crack indications (i.e., vertical) are fully compressive during EDG operation, including quick starts to 3300 KW and continuous operation at 3300 KW. Extrapolation of this data shows that the stresses remain fully compressive at 3500 and 3900 KW. Since fatigue cracks do not grow in fully compressive stress fields, the strain gage data confirms our prior opinion, based on physical examinations, calculations and fracture mechanics analyses, that regardless of the presence of any residual stresses, the cam gallery cracks in the EDGs have not propagated and will not propagate in the future.

c. Since the strain gage measurements on the replacement EDG 103 replacement block are directly applicable to fracture mechanics analyses of the cam gallery cracks in EDGs 101 and 102, they confirm that the cam gallery cracks in the EDG 101 and 102 blocks will not propagate even at loads up to and including 3900 KW. Further, the presence of any residual stresses will not affect the validity of the strain gage results. Residual stresses at the tip of any

cracks in the EDG 101 or 102 blocks which are assumed hypothetically for purposes of analysis to extend substantially below the repair welds would be very small and compressive.

II. Confirmatory Testing and Post Endurance Run Block Inspections

4. What is the operating history of the EDG 103 replacement block?

A. (Rau, Schuster, Wachob, Youngling) The EDG 103 replacement block was installed in June 1984. Since June, EDG 103 has been operated for more than 849 hours. Of these hours, 70 hours were at or above 3500 KW and more than 507 hours were at or about 3300 KW as indicated on the main control room kilowatt meter. A substantial portion of the hours placed on the EDG 103 replacement block occurred as a result of a 745 hour (10^7 loading cycles) confirmatory test. The endurance run portion of the confirmatory test was performed at the load level of 3300 KW, which is the qualified load for the Shoreham EDGs.

5. Was the EDG 103 replacement block inspected after the 745 hour confirmatory test?

A. (Johnson, Rau, Schuster, Wachob) Yes, the cam gallery area and the block top region of the EDG 103 replacement block were inspected at the conclusion of the endurance run portion of the 745 hour confirmatory test. In accordance with the program approved by the NRC Staff, which is outlined in SNRC 1094, the block top region was examined using fluorescent magnetic particle and eddy current inspection techniques. The

inspection showed no ligament or stud-to-stud cracks. In addition, eddy current examination of the four stud holes between cylinders no. 4 and 5 confirmed that neither ligament cracks nor stud-to-stud cracks initiated at the block top or at any location on the stud hole surface between the block top and the bottom thread in the stud hole.

The cam gallery area of the EDG 103 replacement block was inspected at cam bearing saddles no. 2 and 8 using visual, magnifying glass, liquid penetrant and magnetic particle examination techniques. Small, discontinuous linear indications detected by liquid penetrant examination were evaluated with the TSI crack depth gage to measure their depth. The deepest indication recorded after the endurance run was 0.010 inch deep. The remaining indications were all 0.004 inch deep or less.

6. Will any of the cam gallery indications impair the ability of the EDG 103 replacement block to perform its intended function?

A. (Rau, Wachob, Schuster, Youngling) Absolutely not. The indications evaluated after the completion of the endurance run showed no significant change from their condition at the time they were initially detected prior to the endurance run in October 1984. These indications are still not detectable visually without a magnifying glass, and they have been measured both before and after the endurance run to have no significant

depth. Furthermore, casting shrinkage cracks as deep as 0.91 inch in the original EDG 103 block did not propagate during more than 1200 hours of operation, including more than 400 hours of operation at or above 3500 KW, despite the severely degraded fatigue properties of the block material. Consequently, the very shallow indications in the EDG 103 replacement block, with its superior fracture and fatigue properties, will not impair the ability of EDG 103 to provide emergency power at Shoreham.

7. If the cam gallery indications in the EDG 103 replacement block have not changed, why are there some differences in the inspection reports before and after the endurance run?

A. (Johnson, Rau, Schuster, Wachob) None of the cam gallery inspection reports show significantly different indications after the endurance run. Minor differences in mapping of the surface indications revealed by magnetic particle and liquid penetrant techniques before and after the endurance run are not significant. The insignificant differences result from the very shallow nature of the indications, minor differences in surface cleaning and preparation, and test techniques.

Similarly, minor variations in the depth of indications measured by the TSI crack depth gage are not significant. Some slight variation is expected in reported depths because they are within the accuracy of the TSI crack depth gage. In our opinion, when the visual, magnetic particle, liquid penetrant

and TSI depth gage inspections are analyzed as a whole, they indicate that no propagation of these indications has occurred during more than 500 hours of endurance testing on the EDG 103 replacement block.

8. What effect, if any, do the results of the inspections of the EDG 103 replacement block following the endurance run have on your opinion regarding the adequacy of its design and testing?

A. (Rau, Wachob) The product enhancements incorporated into the EDG 103 replacement block have now been further tested by actual operation at Shoreham. The absence of any detectable ligament or stud-to-stud cracks in the block top after the endurance run confirms our opinion that the design enhancements introduced in the EDG 103 replacement block are beneficial. Since the EDG 101, 102 and original 103 blocks had initiated ligament cracks at approximately an equivalent number of operating hours as have now been placed on the EDG 103 replacement block without block top cracking, the design enhancements have reduced the possibility of fatigue crack initiation. Thus, the endurance run confirms our previous testimony, which was based on our review of the replacement block design and on our review of the R-5 test engine experience, that the replacement block has been adequately designed and tested.

9. Should the replacement block have been tested for 745 hours at or above 3300 KW to confirm its adequacy for nuclear service?

A. (Rau, Youngling) No. The 745 hour confirmatory test (10^7 loading cycles) was performed primarily to evaluate the adequacy of the modified crankshaft. The County's contention with regard to the replacement block, and our testimony with respect to the replacement block, addressed whether it was an unproven design that was inadequately tested. Operation of the engine since block replacement for more than 849 hours, of which more than 577 hours were at or above 3300 KW, further substantiates the extensive R-5 test experience. This confirms our opinion that the design enhancements incorporated into the block are beneficial, and that the design is both proven and adequately tested.

Furthermore, testing the replacement EDG 103 replacement block for 10^7 loading cycles was not necessary in light of our cumulative damage analyses of the EDG 101 and 102 blocks. These prior analyses demonstrate that the blocks are capable of performing their intended function even though they have ligament cracks. Thus, testing the EDG 103 replacement block for more than 577 hours at or above 3300 KW without developing any detectable ligament or stud-to-stud cracks further demonstrates that the block is qualified for nuclear service.

10. Since the EDG 103 replacement block has no ligament cracks, does it need to be inspected on the same basis as the EDG 101 and 102 blocks for stud-to-stud cracks?

A. (Rau, Wachob) No. In our original testimony, we stated that the EDG 103 replacement block should be inspected on the same basis as the EDG 101 and 102 blocks until sufficient operating service without ligament cracks had been obtained to increase the inspection intervals. The endurance run has placed enough hours on the replacement block without the development of ligament cracks to justify extending the inspection interval for that block.

The EDG 103 replacement block can now be operated without additional inspections for stud-to-stud cracks for combinations of load and time that produce less than the allowable fatigue damage index. In other words, operation may continue without further block top inspections until the fatigue damage index accrued is equal to one-third of the fatigue damage index demonstrated for the original EDG 103 benchmark period minus the fatigue damage index that would be required for one postulated LOOP/LOCA. Since it is anticipated that the EDG 103 replacement block will experience less than 100 hours of further operation before the end of the first fuel cycle, no additional block top inspections are necessary until the refueling outage.

III. Effect of the 3300 KW Qualified Load

11. What is the effect on the EDG blocks of operation at up to the qualified load of 3300 KW?

A. (Rau, Wachob) Operation of the EDGs at a maximum

load of 3300 KW rather than a maximum load of 3500 or 3900 KW will produce lower cyclic stresses in the block top and in the cam gallery. Specifically, operation of the engine at the lower load levels reduces the cylinder firing pressures, thermal strains, and vertical loads imposed on the head during cylinder firing. This results in a corresponding reduction in the loads transmitted to the block through the head studs and through contact with the liner and block top. As a result, the possibility of fatigue crack initiation in the block top is reduced, and, should crack initiation occur, the rate of any crack propagation will be slower.

12. The County contends that the qualified load might be exceeded for brief periods of time during EDG operation. If brief load excursions occur over 3300 KW, what effect, if any, will they have on the blocks?

A. (Rau) We have previously testified about the effect of engine operation at 3500 and 3900 KW. Our cumulative damage analysis of the block tops demonstrated that the blocks would withstand with sufficient margin a LOOP/LOCA with a postulated load profile that included 0.2 hours at 3900 KW and 0.8 hours at 3500 KW.

Further, stresses in the cam gallery area will not increase significantly at power levels above 3300 KW. These stresses have been verified by the strain gage testing, which demonstrates that the vertical stresses remain fully compressive even when extrapolated to loading as high as 3900 KW.

Reliable operation at loads in excess of 3300 KW has also been verified by the operating experience of the EDGs. Despite hundreds of hours of operation above 3500 KW, including more than 25 hours each at or above 110% of nameplate load, EDG 101 and 102 have not developed stud-to-stud cracks. The original EDG 103 block experience, which included 30 hours at or above 110% of nameplate load, demonstrated that cam gallery cracks will not propagate. In addition, the EDG 103 replacement block has already experienced 70 hours of operation at or above 3500 KW. These are direct demonstrations of the blocks' ability to perform reliably at loads up to and including their overload rating for brief periods of time. Thus, both the analytical and the empirical evidence demonstrates that brief excursions over 3300 KW, should any occur, will not impair the ability of the EDGs to perform their intended function.

13. What is the load profile that the EDGs at Shoreham will experience should a LOOP/LOCA occur?

A. (Youngling) The maximum emergency service load on any EDG is bounded by 3300 KW. A conservative LOOP/LOCA load profile would be 0.2 hours at 3300 KW, 0.8 hours at 3200 KW, and up to 167 hours at 2617 KW.

14. What effect, if any, does the reduced load profile have on the results or the conclusions of the cumulative damage analysis?

A. (Rau) A postulated LOOP/LOCA resulting in a load profile of 0.2 hours at 3300 KW, 0.8 hours at 3200 KW and 167

hours at 2617 KW will produce less fatigue damage than the LOOP/LOCA load profile previously analyzed. Analyses of the damage accumulated by the original EDG 103 block during the test period from March 11 through April 14, 1984 demonstrates that at the actual load profile of the EDG 101, 102 and 103 engines, the blocks will withstand a postulated LOOP/LOCA with even greater margin.

15. Has FaAA performed additional cumulative damage analyses of the block top since the conclusion of the previous hearings?

A. (Rau) Yes. As part of the preparation of the final generic block report, which was issued in December 1984, cumulative damage calculations were performed employing a refined determination of stresses from the strain gage testing. The additional cumulative damage calculations set forth in the final block report confirm our conclusion that the Shoreham blocks will perform their intended function with sufficient margin during a postulated LOOP/LOCA.

IV. Monitoring of the Cam Gallery Cracks in the EDG 101 and 102 Blocks is Unnecessary

16. Is monitoring of the cam gallery cracks in the EDG 101 and 102 blocks necessary or justified?

A. (Rau, Wachob) No. There is no need to monitor the cam gallery cracks prior to the scheduled maintenance interval at the first refueling outage. In addition to our previous calculations, and fractographic and metallographic

examinations, we now have additional data which establishes that monitoring is not necessary or justified. First, photomicrographs taken of the weld shrinkage crack at 550x confirmed Lilco's previous testimony that the cam gallery cracks in the original EDG 103 block were fabrication cracks that had not propagated during EDG operation. Second, x-ray crystallographic analyses were performed on the oxide present on the cam gallery cracks in the original EDG 103 block which established that the oxide was primarily (85 percent) magnetite. As a result of these tests, the County has stipulated that the cracks in the EDG 101, 102 and original EDG 103 blocks have not propagated during or as a result of EDG operation. Finally, strain gage measurements made on the EDG 103 replacement block, which are applicable to fracture mechanics analyses of cracks in the EDG 101 and 102 blocks, establish that the cam gallery cracks will not propagate beneath the repair weld depth even considering the presence of residual stresses.

A. <u>High Magnification Photomicrographs</u>

17. Please explain in greater detail how the high magnification photomicrographs support your conclusion that monitoring is unnecessary.

A. (Rau, Wachob) In our previous testimony, at Tr. 26525-26, we discussed a series of photomicrographs taken from a metallographic cross-section of cam gallery bearing support no. 7 of the original EDG 103 block. Two of these

photomicrographs, which are shown in Lilco Exhibit B-63, depict what we have called the casting shrinkage crack. As shown in Exhibit B-63, these photomicrographs were taken at 100x and 500x magnification. Two more photomicrographs, depicted in County Exhibit S-4, were taken at 50x and 100x magnification of what we have called the weld shrinkage crack, which, as shown in Lilco Exhibit B-61, is directly adjacent to the casting shrinkage crack. However, as was discussed at Tr. 26525-26, no 500x photomicrograph was originally taken of the weld shrinkage crack.

At the meeting of the parties on November 20, 1984, Lilco agreed to take additional photomicrographs of the weld shrinkage crack at 500x magnification. (See Tr. 26990-91). Accordingly, two additional photomicrographs at 550x were taken of representative areas of the weld shrinkage crack in cam gallery bearing support no. 7. These photomicrographs are attached as Exhibit B-65. The locations where these photomicrographs were taken are shown in Lilco Exhibit B-66, which is a marked-up version of County Exhibit S-4.

The 550x photomicrographs confirm what the 100x photomicrograph in County Exhibit S-4 depicted, namely that the weld shrinkage crack surface has a very thin oxide which is markedly different from the uniformly thick (0.2 to 0.5 mils), dark oxide on the contiguous casting shrinkage crack depicted

in Lilco Exhibit B-63. Comparison of the 500x photomicrograph of the casting shrinkage crack in Lilco Exhibit B-63 with the 550x photomicrographs in Lilco Exhibit B-65 shows the difference between the oxides present on the casting shrinkage crack and the weld shrinkage crack. The light gray appearance of the crack surface on the casting shrinkage crack is due to the presence of the thick oxide. The absence of a light gray layer on the weld shrinkage crack reveals that no thick oxide is present.

The significant differences between the photomicrographs confirms the opinion we expressed at Tr. 26469 that the casting shrinkage crack must have been formed before the weld shrinkage crack formed. The clear and pronounced difference between the thick, dark oxide on the casting shrinkage crack and the very thin oxide layer on the weld shrinkage crack indicates that the casting shrinkage crack formed during the fabrication process and did not propagate during EDG operation.

B. <u>The Stipulation</u>

18. Please describe in greater detail how the x-ray crystallography and the Stipulation support your conclusion that monitoring is unnecessary.

A. (Rau, Wachob, Youngling) As a result of the x-ray crystallography performed on a section of the cam gallery crack from bearing support no. 7 of the original EDG 103 block, which determined that the oxide layer on the crack was primarily (85

percent) magnetite, the parties have stipulated that the oxide layer was formed at high temperatures at the time of the casting process and that the layer was not due to fretting corrosion or graphitic corrosion. The parties have also stipulated that this evidence supports the conclusion that the cam gallery cracks in the original EDG 103 block did not propagate during or as a result of EDG operation. Further, the parties have stipulated that the evidence justifies the conclusion that the cracks in the cam gallery areas of EDGs 101 and 102 formed during the casting process, and that this supports the conclusion that the cam gallery cracks in EDGs 101 and 102 did not propagate during or as a result of EDG operation. A copy of the Stipulation stating that Suffolk County and the State of New York do not seek to disqualify the use of the EDG 101, 102 or replacement EDG 103 blocks on the basis of the cam gallery cracks is attached as Exhibit B-67.

The Stipulation, which was based on the results of the x-ray crystallography, establishes that the cam gallery cracks in the EDG 101, 102 and original EDG 103 blocks have not propagated during more than a thousand hours of operation on each engine, including hundreds of hours of operation at or above 3500 KW. Specifically, with respect to the original EDG 103 block, the x-ray crystallography and the Stipulation establishes that more than 1200 hours of operation, including more

than 400 hours of operation over 3500 KW, did not cause crack propagation despite the severely degraded material of that block and the presence of large weld repairs with weld shrinkage cracks.

Based on this extensive operating experience, there is no reasonable engineering basis for concluding that cracks measured to be much smaller and shallower in the EDG 101 and 102 blocks will ever propagate, let alone propagate during the 100 hours or less of operation that the EDGs are anticipated to experience prior to the first refueling outage. Accordingly, there is no need to perform any monitoring or measuring of the cam gallery cracks prior to the first refueling outage. Mapping of the cracks at the maintenance interval scheduled during the first refueling outage is more than sufficient to confirm that there is no crack growth.

C. Strain Gage Measurements

19. Please describe the strain gage testing that was performed on the cam gallery of the EDG 103 replacement block.

A. (Rau, Wachob, Schuster) Prior to the endurance run, strain gage measurements were made on the cam gallery of the EDG 103 replacement block at locations where cracks had been observed on the EDG 101, 102 and the original EDG 103 blocks. Prior to the installation of the strain gages on the EDG 103 replacement block, magnetic particle and liquid penetrant

examinations were performed. These inspections revealed the fine, discontinuous linear indications that were reported by Lilco during its oral testimony.

Before installing the strain gages, through-bolts numbered 1, 2, 3, 7, 8 and 9, which are in the vicinity of cam bearing support saddles no. 2 and 8, were loosened. Then, strain gages, which included four full rectangular rosettes and two biaxial gages, were attached at six block locations as shown in Exhibit B-68, pages 1 and 5. After calibrating and zeroing the gages, the strain data were recorded as the through-bolts were tightened (torqued) in five increments up to the specified torque.

The strain gage data were recorded while the engine was brought to hot standby condition and quick started to 3300 KW. The EDG was run continuously at 3300 KW for approximately one hour, and then at lower load levels which were subsequently achieved by unloading the engine incrementally. At each power level, strain gage data was recorded after allowing a steady state operation.

20. Please describe the results of the strain gage testing.

A. (Rau, Wachob) The strain gage measurements demonstrate that the stresses perpendicular to the crack indications (i.e., vertical) remain fully compressive at all operating conditions, including both fast starts to 3300 KW and steady state

operation at 3300 KW. This results from the large steady compressive stress that is introduced due to tightening of the through-bolts. Engine operation at load superimposes cyclic stresses on this steady compressive stress. However, the magnitudes of the cyclic stresses are less than the steady compressive stress. Therefore, the stresses remain fully compressive, thereby preventing crack propagation. The measured stresses perpendicular to the cam gallery indications are shown as a function of bolt torque and engine load in Exhibit B-68, pages 2-4 and 6-8.

21. Do the test results indicate whether the stresses perpendicular to the crack indications would remain compressive at higher engine loads?

A. (Rau, Wachob) Yes. The test results have been extrapolated conservatively to engine operation at 3500 and at 3900 KW. The results indicate that the stresses remain fully compressive even at these loads.

22. Would the stresses remain fully compressive even during fast starts to 3900 KW?

A. (Rau, Wachob) Yes. Fast starts do not introduce a significantly higher transient stress into the cam gallery as compared to steady operation at the same power levels. This is consistent with engineering analyses which indicate that transient thermal stresses introduced during fast starts will be insignificant in this region.

23. Are the strain gage tests performed on the EDG 103 replacement block applicable to the cam gallery regions of the EDG 101 and 102 blocks?

A. (Rau, Wachob) Yes. The geometry of the cam gallery is identical for each of the EDGs. Similarly, the compressive load imposed by the through-bolts is the same for each of the EDGs since the bolt torque specified is the same for each engine. Accordingly, in the absence of the repair welds and shrinkage cracks, strain gage measurements on the EDG 101 and 102 blocks would have been virtually identical to the measurements on the EDG 103 replacement block.

Although the EDG 101 and 102 blocks have repair welds and weld shrinkage cracks, the results of the strain gage measurements on the replacement block of EDG 103 are directly applicable to fracture mechanics analyses of cracks in the cam gallery regions of EDG 101 and 102. There is no indication that casting shrinkage cracks extend below the depth of the weld repairs in the EDG 101 or 102 blocks. Indeed, the evidence from the TSI depth gage is that no crack extends below the weld shrinkage crack. But if a casting shrinkage crack were present below the repair welds in the EDG 101 or 102 blocks, the strain gage measurements made on the replacement block of EDG 103 are directly applicable to the fracture mechanics analyses which show that such cracks would not propagate in operation. Accordingly, the conclusion drawn from the EDG 103 strain gage data that

the cam gallery cracks are nonpropagating applies to the EDG 101 and 102 blocks.

24. Based on the strain gage test results, would the presence of residual stresses affect your conclusion that cam gallery cracks will not propagate?

A. (Rau, Wachob) No. Before the crack formed, any residual stresses that were present would have been tensile stresses at the cam gallery surface. These tensile stresses would have been balanced by compressive residual stresses beneath the cam gallery surface. The repair welding process and the formation of weld shrinkage cracks has eliminated or reduced markedly the magnitude of any tensile residual stresses near the cam gallery surface. Correspondingly, it has reduced the magnitude of the balancing, subsurface compressive residual stresses. Consequently, if a crack was hypothetically assumed to be present to a depth beyond the repair weld, the residual stresses near the crack tip would be negligibly small and compressive. Thus, any residual stresses existing at the present time will not enable crack extension during operation.

This analysis has been confirmed by physical observations of the original EDG 103 block after extensive operation. In the original EDG 103 block cam gallery, casting shrinkage cracks extended substantially beyond the repair weld depth. They did not propagate, however, during more than 1200 hours of operation, including more than 400 hours at or above 3500 KW,

despite the degraded fatigue and fracture properties of that block material and the presence of even larger repair welds.

25. Can tightening and loosening of the through-bolts cause sudden crack extension?

A. (Rau, Wachob) No. During the course of the strain gage testing, the through-bolts in the vicinity of cam bearing supports no. 2 and 8 were fully loosened and subsequently retightened to the specified torque. No significant change in the surface crack indications resulted. In addition, the through-bolts on the EDG 101, 102 and the original EDG 103 blocks have also been loosened and retightened several times for required maintenance, with no indication of cam gallery crack extension. Since each of the existing Shoreham EDG blocks has already experienced through-bolt loosening and retightening, subsequent loosening and retightening will not produce crack extension, including "pop-in," of any cam gallery cracks.

26. The County contends that the EDG 101 and 102 cam gallery cracks should be monitored with wire gages because there is no reliable depth measurements of the cracks in these blocks. Do you agree?

A. (Rau, Wachob) No. Cam gallery cracks in the EDG 101 and 102 blocks have been inspected visually and with fluorescent magnetic particle and liquid penetrant. These inspections revealed that the repair welds are smaller and the weld shrinkage cracks shorter and tighter on the surface than in the

original EDG 103 block. This observation is consistent with the metallurgical analysis and mechanical testing which have shown superior mechanical properties in the EDG 101 and 102 blocks compared with the original EDG 103 block. Thus, all other factors being equal, both casting shrinkage and weld shrinkage cracks, if they form, will be shallower in the EDG 101 and 102 blocks than in the original EDG 103 block.

Crack depth measurements using the TSI depth gage have also indicated that the cracks in the EDG 101 block are much shallower than in the original EDG 103 block. The deepest crack in the EDG 101 block was measured to be 0.164 inch as compared to 0.91 inch in the original EDG 103 block. Thus, it is our opinion that the original casting shrinkage cracks were much shallower in the EDG 101 and 102 blocks and were completely ground out at the time of the repair weld.

Nevertheless, even if it is unrealistically assumed that casting shrinkage cracks in the EDG 101 and 102 blocks are as deep as those in the original EDG 103 block, there is no necessity to monitor the cracks because they will not grow. The evidence demonstrates clearly that the relatively large cracks in the original EDG 103 block with severely degraded material did not propagate. Similar cracks in the EDG 101 and 102 blocks, if they existed, would not propagate in the superior material of those blocks.

27. The County also contends that the cracks in the cam galleries of EDG 101 and 102 should be monitored because the repair welds are inadequate. Do you agree?

A. (Rau, Wachob) No. The operating experience of the original EDG 103 block makes clear that the cracked weld repairs do not cause cam gallery crack propagation even in material with severely degraded fatigue resistance. Thus, the operating experience of the original EDG 103 block for over 1200 hours with cracked welds and without any cam gallery crack propagation shows that the presence of weld shrinkage cracks in the cam galleries of the EDG 101 and 102 blocks will not cause crack propagation.

Furthermore, since the strain gage measurements establish that the stresses in the cam gallery area of the EDGs remain fully compressive under load conditions up to the EDGs' overload design rating, it is clear that no crack propagation will occur in the future as a result of any anticipated operation regardless of the presence of cracked repair welds. Consequently, it is not necessary to conduct wire gage monitoring of the repair welds on the EDG 101 and 102 blocks or to measure the depth of the cracks in the EDG 101 and 102 blocks prior to the scheduled maintenance interval at the first refueling outage.

LILCO, January 15, 1985

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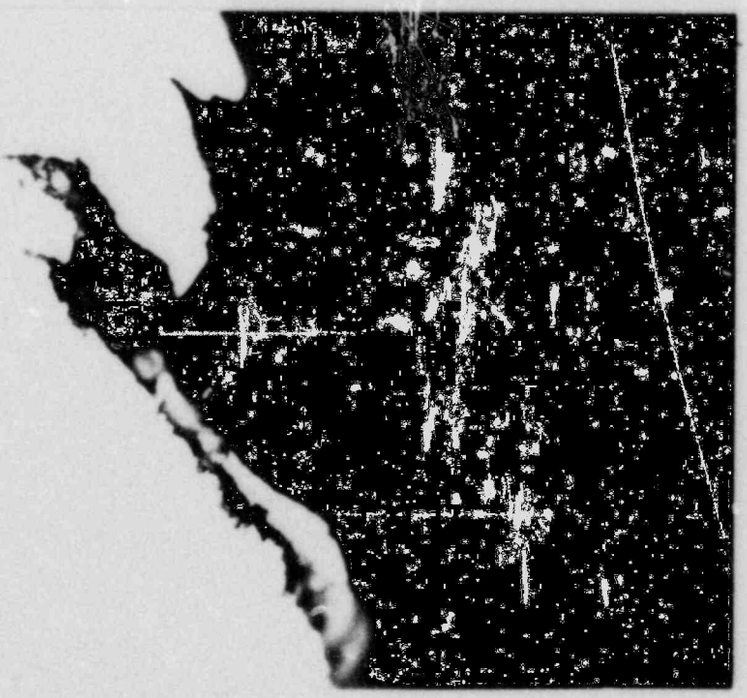
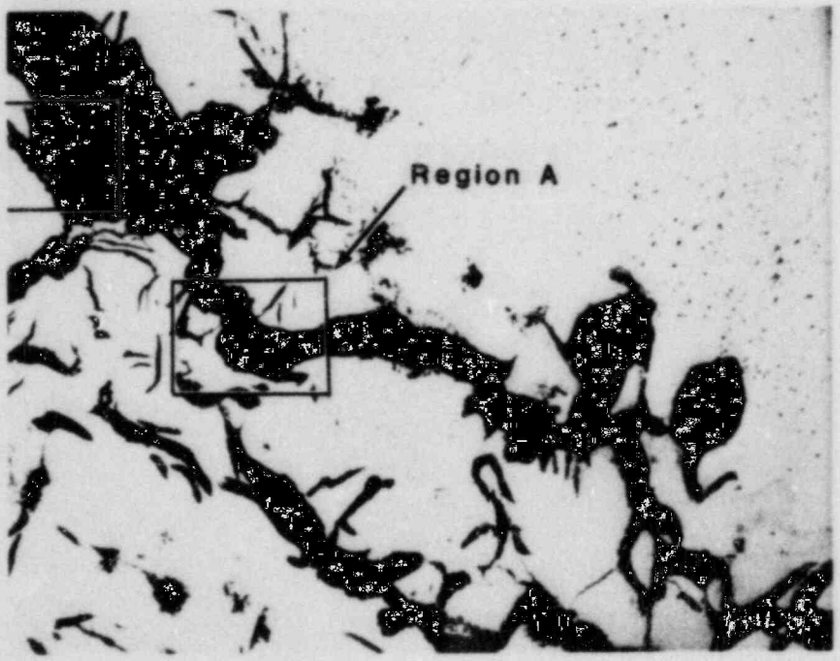
B-65	550x magnification photomicrographs of the weld shrinkage crack at face 1 of cam saddle no. 7 of the original EDG 103 block.
B-66	Mark-up of 100x magnification photomicrograph of the weld shrinkage crack at face 1 of cam saddle no. 7 of the original EDG 103 block.
B-67	Stipulation of the parties regarding cam gallery crack contention.
B-68	Strain gage measurements on cam gallery of replacement EDG 103 block.

Region A. 550X. Mount I613. Photo ID #PA07396-DP1-11/27/84.



Region B. 550X. Mount I613. Photo ID #PA07396-DP1-11/27/84.

Exhibit High magnification photomicrographs of the weld shrinkage crack at face 1 of cam saddle No. 7 of the original DG103.



Exhibit

Photomicrograph of the weld shrinkage crack at face 1 of cam saddle No. 7 of the original DG103. 100X. Mount I613. Photo ID #PA07396-DW7-9/4/84.