LILCO, AUGUST 14, 1984

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

Before the Atomic Safety and Licensing Board

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

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

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I. INTRODUCTION OF WITNESSES

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

II. BACKGROUND

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

A. (Wells, Seaman) The original 13" x 11" crankshaft failed due to a fatigue crack which initiated at the surface of the machined fillet radius where the crankpin blends into the web. FaAA's analyses show that the fatigue crack which resulted in the failure of the EDG #101 crankshaft began at a score mark on the crankpin fillet. The transitional area from crankpin to web and web to main journal is an area where the highest applied surface tensile stress range occurs in the crankshaft. The 13" x 11" crankshaft that failed and the other two that had fatigue cracks in a similar location were not shotpeened. It was FaAA's and LILCO's opinion that shotpeening the fillet areas of the replacement crankshafts would reduce mean surface tensile stresses in the fillet area of the crankshaft by placing the fillet surfaces in compression. Shotpeening renders the surface less susceptible to handling damage such as the score mark where cracking initiated on the original EDG #102 crankshaft. In addition, shotpeening eliminates machine imperfections by blending, as a result of plastic flow of the metal, and prevents initiation of cracks on the machined fillet surface thus providing a higher endurance limit for this area and correspondingly for the crankshaft. While TDI, the manufacturer of the Shoreham diesel generators did not believe that the replacement crankshafts required shotpeening, it did concur in the view that this was an acceptable application for shotpeening. It should be noted also that TDI normally shotpeens crankshaft fillet regions for its "V" configuration engines.

5. What exactly is shotpeening?

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

A. No.

13. Why not?

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

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

A. (Wells, Seaman) Yes.

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

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

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

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

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

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

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

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

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

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

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

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

Do you agree?

A. (Burrell, Wells, Wachob) We agree that shotpeening does increase the residual tensile stress in the area below the compressed or shotpeened area. However, this residual tensile stress is additive only to the mean value of the operating stress and not to the range of dynamic stress. Additionally, fatigue cracks such as occurred in the failure of the original 13" x 11" crankshaft, in almost all instances, initiate at external surface areas. Subsurface fatigue cracking is very unusual and requires the presence of a significant void or inclusion and a given stress state, for initiation of a fatigue crack. There is always a possibility that any cast or forged piece of metal may contain a subsurface inclusion or void. The only protection against this risk or possibility are the manufacturer's quality control procedures for the melting, casting and forging processes and its quality assurance procedures during and after the manufacturing process. The replacement crankshafts for the EDGs were manufactured by the West German firm of Krupp Stahl, A. G. Krupp is a reputable manufacturer or forger of large metal parts such as these crankshafts, whose forging and machining of these crankshafts was certified by the American Bureau of Shipping as evidenced by its stamp on the Krupp certificates. See Exhibit #C-31 and Exhibit #C-37. Additionally, Krupp's quality assurance in the form of ultrasonic testing and magnetic particle testing of these crankshafts revealed no relevant inclusions or voids. Exhibit #C-33. All of this provides as much reasonable assurance as is possible, that no subsurface voids or inclusions of sufficient size to initiate a subsurface fatigue crack are present in these crankshafts. Therefore, we conclude that the possibility of this type of fatigue crack initiating in the subsurface area is indeed quite remote.

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

A. (Wells, Seaman) No.

20. Why not?

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

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

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

A. No.

22. Why not?

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

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

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

A. No.

24. Why not?

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

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

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

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

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

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

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

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

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

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

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

29. Why not?

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

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

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

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

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

IV. CONCLUSION

31. Please summarize your conclusions.

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

1) The original shotpeening of the replacement crankshafts by TDI while not adding the full beneficial effect did no harm to the crankshaft.
2) The re-peening by MIC corrected any "alleged" problems that could have existed as a result of the TDI peening.
3) The compressive stresses in the fillet regions of all three replacement crankshafts have been increased, as was intended.
4) The fatigue or endurance limit of the replacement crankshafts has been significantly increased as a result of shotpeening.
5) There is no basis for the County's contention 1(b).

Attachment 1

Failure Analysis Associates

CLIFFORD H. WELLS

Specialized Professional Competence

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

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

Background and Professional Honors

B.S. (Mechanical Engineering), Yale University
M.S. (Civil Engineering), Yale University
Ph.D. (Applied Mechanics), Yale University
Oak Ridge School of Reactor Technology

Vice-President, Research and Development,
Failure Analysis Associates
Assistant to President and Director of Engineering Mechanics,
Southwest Research Institute
Assistant Manager, Materials Engineering and Research,
Pratt & Whitney Aircraft
Structural Engineer,
Oak Ridge National Laboratory
Research Assistant,
Yale University

Fellow, ASME
President-elect, Federation of Materials Societies
Chairman, Air Force Studies Board Panel on NDE, National Research Council
Chairman, National Materials Advisory Board Committee on Fatigue at Elevated Temperature
Member, National Materials Advisory Board Committee on Fretting Initiated Fatigue
Chairman, Executive Committee, Materials Division of ASME
EPRI Materials and Corrosion Committee
Metal Properties Council Subcommittee on Materials for Coal Conversion
Editor, Fatigue of Engineering Materials and Structures
Editor, Journal of Nondestructive Evaluation

Selected Publications

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

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

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

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

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

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

"Fundamental Mechanisms," Control of Fretting-Initiated Fatigue, National Materials Advisory Board Report NMAB-333, National Academy of Sciences (1977).
"Fatigue at Elevated Temperature," edited by C. H. Wells, A. E. Carden and A. J. McEvily, ASTM Special Technical Publication No. 520 (1973).
"Quantitative Lifetime Assurance of Turbine Rotors," Fatigue Life Technology edited by T. A. Cruse and J. P. Gallagher, ASME, pp. 37-51 (1977).
"Uniaxial Creep Behavior of Metals Under Cyclic Temperature and Stress or Strain Variations, Journal of Applied Mechanics, Vol. 98, pp. 445-449 (1976) (with P. R. Paslay).
"Mechanisms of Dynamic Degradation of Surface Oxides," Proceedings of Symposium on Mechanical Properties of Surface Oxides, Metallurgical Society of AIME (1975) (with P. S. Follansbee and R. R. Dils).
"Prospects of Lifetime Prediction in Creep and Fatigue," NSF Workshop on Inelastic Constitutive Equations for Metals-Experimentation-Computation-Representation, edited by E. Krempl, C. H. Wells and Z. Zudans (1975).
"Design Procedures for Elevated Temperature Low-Cycle Fatigue," Proceedings of the 38th Meeting of the Structures and Materials Panel, Advisory Group for Aerospace Research and Development, NATO, AGARD-CP-155.
"On the Applicability of Fracture Mechanics to Elevated Temperature Design," International Conference on Creep and Fatigue in Elevated Temperature Applications, Institution of Mechanical Engineers, London, England (with A. J. McEvily).
"Electrochemical Grinding of Cylindrical Test Specimens," Journal of Engineering for Industry, ASME Transactions, Vol. 93, pp. 1090-1092 (1971) (with T. W. Knight, R. B. Barrow and L. A. Williams, III).
"Creep of Single Crystal Nickel-Base Superalloy Tubes under Biaxial Tension," Journal of Applied Mechanics, ASME Transactions, Vol. 38, pp. 623-626 (1971) (with P. R. Paslay, G. R. Leverant and L. H. Burck).
"Mechanisms of Fatigue in the Creep Range," Metal Fatigue Damage Mechanism, Detection, Avoidance and Repair, ASTM Special Technical Publication No. 495, pp. 61-127 (1971) (with M. Gell and C. P. Sullivan).
"Fatigue of a Glass-Bead Blasted Nickel-Base Superalloy," Metallurgical Transactions, Vol. 1 (6), p. 1595 (1970) (with L. H. Burck and C. P. Sullivan).
"The Fatigue Strength of Nickel-Base Superalloys," The Achievement of High Fatigue Resistance in Metals and Alloys, ASTM Special Technical Publication No. 467, p. 113 (1970) (with M. Gell and G. R. Leverant).
"An Analysis of Primary Creep of Face-Centered Cubic Crystals," Journal of Applied Mechanics, ASME Transactions, Vol. 37 (3), p. 759 (1970) (with P. R. Paslay and G. R. Leverant).
"Elevated Temperature Testing Methods," Manual on Low-Cycle Fatigue Testing, ASTM Special Technical Publication No. 465, p. 87 (1969).
"Interactions Between Creep and Low-Cycle Fatigue in Udimet 700 at 1400°F," Fatigue at High Temperature, ASTM Special Technical Publication No. 459, p. 59 (1969) (with C. P. Sullivan).
"Low-Cycle Fatigue of Ti-6AL-4V," ASM Transactions Quarterly, Vol. 62, p. 263 (1969) (with C. P. Sullivan).
"An Analysis of the Effect of Slip Character on Cyclic Deformation and Fatigue," Acta Metallurgica, Vol. 17, p. 443 (1969).
"A Small-Strain Plasticity Theory for Planar Slip Materials," Journal of Applied Mechanics, ASME Transactions, Vol. 36 (1), p. 15 (1969) (with P. R. Paslay).
"The Control of Build-up and Diametral Growth in Shear Forming," Journal of Engineering for Industry, ASME Transactions, Vol. 90 (1), p. 63 (1968).
"Low Cycle Fatigue of Udimet 700 at 1700°F," ASM Transactions Quarterly, Vol. 61 (1), p. 149 (1968) (with C. P. Sullivan).
"An Analysis of the Bauschinger Effect in Some Engineering Alloys," Journal of Basic Engineering, ASME Transactions, Vol. 89 (4), p. 893 (1967).
"The Elastic Constants of a Directionally-Solidified, Nickel-Base Superalloy, Mar M-200," ASM Transactions Quarterly, Vol. 60 (2), p. 270 (1967).
"The Effect of Temperature on the Low-Cycle Fatigue Behavior of Udimet 700," ASM Transactions Quarterly, Vol. 60, p. 217 (1967) (with C. P. Sullivan).
"An Improved High-Temperature Extensometer," Materials Research and Standards, Vol. 6 (1), p. 20 (1966) (with D. N. Tishler).
"Low-Cycle Fatigue Damage of Udimet 700 at 1400°F," ASM Transactions Quarterly, Vol. 58 (3), p. 391 (1965) (with C. P. Sullivan).
"The Low-Cycle Fatigue Characteristics of a Nickel-Base Superalloy at Room Temperature," ASM Transactions Quarterly, Vol. 57 (4), p. 841 (1964) (with C. P. Sullivan).
"The Latent Strain Hardening of Aluminum Alloy in Monotonic and Cyclic Loading," Applied Materials Research, Vol. 2 (4), p. 193 (1963).

Attachment 2

Failure Analysis Associates

DUANE P. JOHNSON

Specialized Professional Competence

Nondestructive evaluation and structural monitoring methods; production line inspection system development, field inspection and monitoring services, inspection and monitoring reliability analysis, nondestructive inspection procedure development and review, inspection level and interval optimization, eddy current instrument development, advanced electromagnetic sensor development, advanced signal processing, R&D on advanced nondestructive inspection and monitoring methods.

Background and Professional Honors

B.S. (Electrical Engineering), University of Minnesota, with High Distinction
M.S. (Physics), University of Washington
Ph.D. (Physics), University of Washington

Manager, Nondestructive Evaluation and Monitoring,
Failure Analysis Associates
President and Co-Founder,
Reluxtrol, Inc.
Supervisor, Nondestructive Inspection,
Pratt & Whitney Aircraft
Associate Professor of Physics,
American University, Cairo, Egypt

Member, American Society for Nondestructive Testing
Member, American Physical Society
Member, Institute of Electrical and Electronics Engineers

Selected Publications

"Review of State of the Art Inspections of Steam Turbine Blades," EPRI Steam Turbine Blade Reliability Workshop (1982) (with E. K. Kietzman).

"Electromagnetic Testing of Ceramic Materials," EPRI Report (1981) (with L. Y. L. Shen).

"Controlled Reluctance Eddy Current Inspection of Steam Turbine Components," EPRI Workshop on NDE of Steam Turbine and Electrical Generator Components (1980) (with S. Sarian and E. K. Kietzman).

"Assessment of Current NDI Techniques for Determining the Type, Location and Extent of Fossil-Fired Boiler Tube Damage," EPRI Report (1980) (with E. R. Reinhart and S. Sarian).

"Production Line Nondestructive Evaluation of Continuous Formed Metal Parts Using Controlled Reluctance Eddy Current Probes," ASNT Spring Conference (1979) (with S. Sarian).

"Reliability of Flaw Detection by Nondestructive Inspection," Metals Handbook, Vol. 11 (with several authors).

"Economics and Managerial Aspects of Nondestructive Testing Evaluation and Inspection in Aerospace Manufacture," Appendix C, National Academy of Science Publication NRAB-337 (with T. L. Toomay).

"Determination of Nondestructive Inspection Reliability Using Field or Production Data," Materials Evaluation, Vol. 36 (1978).

"Estimation of Defect Detection Probability Using ASME Section XI UT Tests on Thick Section Steel Weldments," ASM/ASTM/ASNT/ANS International Conference NDE in Nuclear Industry (1978) (with T. L. Toomay and C. S. Davis).

"A Workable Approach for Extending the Life of Turbine Rotors," Fatigue Life Technology, ASME Symposium (1977) (with P. M. Besuner).

"Optimizing NDI Sensitivity," Metals Progress, Vol. 112 (1977).

"Inspection Uncertainty: The Key Element in Nondestructive Inspection," Materials Evaluation, Vol. 39 (1976).

Attachment 3

Failure Analysis Associates

HARRY F. WACHOB

Specialized Professional Competence

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

Background and Professional Honors

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

Senior Metallurgical Engineer,
Failure Analysis Associates

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

Selected Publications

"Very High Cycle Fatigue of a Forged Aluminum Alloy," Fatigue and Corrosion Fatigue up to Ultrasonic Frequency (October 1981) (with H. Nelson).

"Influence of Microstructure on the Fatigue Crack Growth of A516 in Hydrogen," Third International Conference on Effect of Hydrogen on Behavior of Materials, p. 703 (August 1980) (with H. Nelson).

"Effect of Strain Rate and Depressed Temperature on the Low Cycle Deformation Behavior of Alpha Iron," Metallurgical Transactions, Vol. 10 (3), p. 305 (1979) (with H. H. Johnson).

"Halogen Stress Corrosion Cracking of Zircaloy-4," Symposium on Environment-Sensitive Fracture of Engineering Materials (1979) (with H. G. Nelson).

"Effect of Alloying Elements on the Equilibrium Partition of Nitrogen or Carbon in Ternary Iron-Base Alloys," ARMCO Final Report (December 1979) (with A. J. Heckler and J. A. Peterson).

"A Stress Corrosion Cracking Model for Pellet-Cladding Interaction Failures in Light-Water Reactor Fuel Rods," ASTM STP 681, Zirconium in the Nuclear Industry (1978) (with J. T. A. Roberts, R. L. Jones, E. Smith, D. Cubicciotti, A. K. Miller and F. L. Yaggee).

"EPRI-NASA Cooperative Project on Stress Corrosion Cracking of Zircaloys," EPRI NP 717 Project 455-1, Final Report (March 1978) (with R. L. Jones, D. Cubicciotti and H. G. Nelson).

"Kinetics of Hydrogen Entry from $TiFe_{0.86}Mn_{0.11}H_x$," Proceedings of the DOE Chemical/Hydrogen Energy Systems Review, p. 409 (1978) (with H. G. Nelson).

Attachment 4

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

LONG ISLAND LIGHTING COMPANY
SHOREHAM NUCLEAR POWER STATION
(1979 - PRESENT)

AS PROGRAM MANAGER

- Established a program to provide an in-depth design review and quality revalidation of Transamerica Delaval diesel generators to qualify these units for nuclear emergency standby power. This program was required as a result of numerous engine failures and negative NRC audits of the vendor.
- Responsible for presentations to utility executives to enlist participation in the program - results: 11 of 11 utilities with operating licenses or active construction programs are contributing and participating.
- Managed the program utilizing a team concept involving over 150 personnel including engineers, scientists, diesel consultants, quality control inspectors and clerical support.

AS SENIOR PROJECT ENGINEER

- Managed an on-time and budget Pre-Service Inspection Program including providing expert testimony for the Atomic Safety and Licensing Board.
- Responsible for coordination of utility/architect engineer response to an Independent Design Review resulting in a clean bill of health for Shoreham.
- Supervised an engineering section responsible for all mechanical engineering, power systems, structural engineering, piping (including ASME) and pipe supports engineering.

AS ASSISTANT PROJECT ENGINEER

- Responsible for plant betterment program - one example is a radwaste system modification to back flushable etched disc filters which resulted in an over $200,000 savings.
- Assisted in development of the first domestic Induction Heating Stress Improvement Program for mitigation of stress corrosion cracking in Reactor Recirc System piping including coordination with NRC, G.E. and international firms.
- Engineering responsibilities included NSSS systems, radwaste systems, ASME piping and supports, and structural disciplines.

DANIEL INTERNATIONAL CORPORATION
ENRICO FERMI UNIT II
(1978 - 1979)

AS PROJECT ENGINEER

. Assigned to the Walbridge Aldinger Company (WACo) to establish the firm's ability to perform piping and mechanical installations. As a direct result, the WACo contract was increased 100% to $40,000,000.

. Supervised an engineering office responsible for ANSI B31.1 piping, fire protection piping, the biological shield wall and temporary facilities.

AS CONSTRUCTION ENGINEER

. Assigned to a task force established to review three quality assurance manuals and 40 construction procedures for effectiveness and efficiency - this effort resulted in a 20% increase in productivity in the field.

. Responsible for drywell piping including planning, engineering, materials procurement, and management of offsite programs in Michigan and California.

LONG ISLAND LIGHTING COMPANY
SHOREHAM NUCLEAR POWER STATION
(1975 - 1978)

AS CONSTRUCTION SUPERVISOR

. Responsible for the first on-time completion of a mechanical system at Shoreham - the Reactor Recirculation System in the Primary Containment.

. Established a coordinated construction team for piping and mechanical equipment installation in the Primary Containment including - contractor supervision, labor, quality control, cost engineering and scheduling.

. Assigned to a task force established to evaluate the construction program - the result was a major construction reorganization with significant improvements in progress, scheduling and cost control.

AS CONSTRUCTION COORDINATOR

. Provided a recommendation to purchase previously rented heavy construction equipment which resulted in a savings of over $500,000.

. Monitored civil/structural construction and field engineering activities including detailed reporting to management.

EDUCATION

Cornell University	B.S. Engineering
Brocklyn Polytechnic	18 Credits toward M.S. in Nuclear Engineering

Attachment 5

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

EDUCATION

Stevens Institute of Technology,
Hoboken, New Jersey
B.E. Mechnical Engineering, 1975

WORK EXPERIENCE

Springfield Industries (1976 - 1980)
Administrative and Technical Sales
of Steel Wire Products

Metal Improvements Company, Inc.
472 Barell Avenue, Carlstadt, New Jersey
(1980 - Present)
Responsible for plant operation and administration of programs including wingskin forming as well as other experimental programs.

Responsible for small satellite plant.

Temporary Division Manager responsible for complete metal improvement company for three months.

Attachment 6

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

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

RESUME

N. K. BURRELL

EDUCATION: BSME UNIVERSITY OF ILLINOIS 1950

SHOT PEENING EXPERIENCE:

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

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