NRC Staff, October 12, 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)	)	

SUPPLEMENTAL TESTIMONY OF SPENCER H. BUSH AND ADAM J. HENRIKSEN CONCERNING CYLINDER BLOCKS OF THE TDI EMERGENCY DIESEL GENERATORS AT THE SHOREHAM NUCLEAR POWER STATION

Cam Gallery Cracks

Q. Have you reviewed the supplemental LILCO testimony dated September 20, 1984, concerning the significance of the cam gallery cracks?

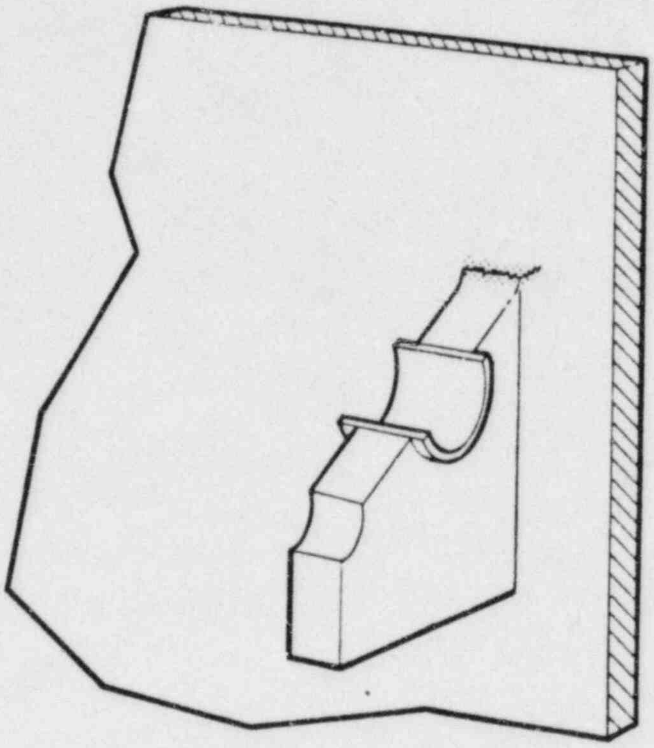
A. (Bush, Henriksen) Yes. Based on LILCO's supplemental testimony, our previous position should be modified as follows:

> Our perception of the geometry of the bearing saddles in the cam gallery was based on an examination of TDI engine drawings. An examination of the original EDG 103 block on Friday, September 21, revealed that our interpretation was incorrect. The attached figure presents the actual versus the perceived geometries. In the actual geometry, the high compressive stresses from bolt-up of the cylinder block to the engine base should neutralize or exceed the alternating tensile and/or bending stresses in the vicinity of the cracks. Our perceived geometry approximated a cantilever, so the vector of cam loads would always be positive. The latter geometry could result in continued growth of the existing cracks.

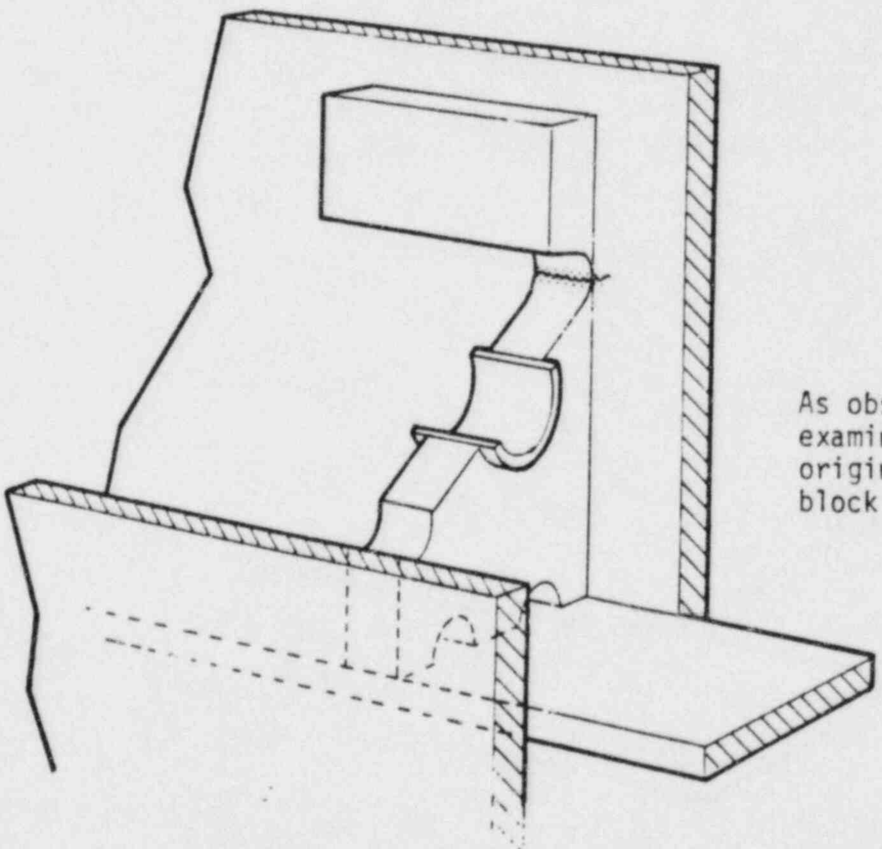
Q. Have you examined LILCO's supplemental testimony of September 20, 1984, concerning the origin of the cam gallery cracks in EDG 103?

A. (Bush) Yes. In addition, I have examined photographs of the fractography of cam gallery number 7, and metallographic specimens of cracks in two cross sections through the cam gallery. I agree that the metallographic evidence confirms that the cracks formed during initial cooling of the casting, based on the heavy oxide layer on the crack faces. Furthermore, there is no evidence of fatigue growth at the crack tip.

CAMSHAFT GALLERY SADDLE



As perceived in
preparation of
original testimony



As observed in
examination of
original EDG 103
block on 9/21/84

Q. Are you aware of the weld repairs in the cam galleries of both EDG 101 and 102?

A. (Bush) Yes. I believe that these weld repairs are cosmetic in that they probably did not improve the integrity of the cracked areas. Instead, the repairs may have further degraded the integrity of the metal in the vicinity of the welds because of residual stresses resulting from the welding process. I have several concerns and/or comments regarding these welds:

- FaAA's metallographic examination of cam gallery cracks in the original EDG 103 block showed that the cracks had not been completely removed before the weld repairs were performed. On the basis of this evidence, there is a question about whether the cam gallery cracks in EDG 101 and EDG 102 were completely removed prior to weld repair.

- In the absence of a definitive weld procedure, I have no basis for evaluating whether or not any of the following processes were adequately controlled during the weld repairs:

  1. complete removal of cracks
  2. appropriate design of the weld preparation
  3. use of techniques such as intermittent beads plus peening, limitation of weaving, etc., to minimize residual stresses
  4. adequate preheat during welding
  5. an appropriate post-weld heat treatment.

Inadequate control of these five processes would explain the cracking between weld "nugget" and surrounding base material.

One definite plus in the weld repairs was the use of nickel-iron electrodes, which minimize carbon interpenetration and degradation of the weld. Henry Wachob of FaAA reported orally on September 21 that the weld material was confirmed by chemical analysis to be a nickel-iron alloy.

Q. Do you concur that the cracks in the cam galleries of EDG 101 and 102 are less severe than those in the original EDG 103 cam gallery?

A. (Bush) Not necessarily. I am unaware of any definitive nondestructive examination data that validate this statement; therefore, I believe it is an assumption. In my opinion, the conservative position would be that cracks of depths similar to those observed in the cam gallery of the EDG 103 block could occur in the EDG 101 and 102 blocks. I suspect that local cooling rates during the casting process were more significant than metallurgical properties of the castings in determining the depth of shrinkage cracks in the cam galleries of the three blocks. Thus, even though the metallurgical properties (including microstructural morphology and mechanical properties) of the EDG 101 and 102 blocks are better than those of the original EDG 103 block, the local cooling rate could have led to deep cam gallery cracks in all three blocks.

Q. Do you believe the evidence permits a conclusion that the cam gallery cracks are resolved?

A. (Bush) Not necessarily. Under Section III of the ASME Code, such crack-like defects in safety-related components of nuclear power systems would by required to be removed. This applies to "active" nuclear components such as pumps, as well as to "passive" components such as piping. ASME Section III is not applicable to emergency diesel generators. However, because the cam gallery cracks in the EDG 101 and 102 blocks have not been removed, I recommend that they be monitored. This could be accomplished by installing wire strain gages across the repair welds of several representative cracks to evaluate crack behavior. While I believe the compressive loads introduced during assembly of the diesel generators should prevent growth of the cam gallery cracks during operation, I am less certain of the level of residual stresses and the consequences of these stresses when the compressive loads are removed. Conceivably they could be high enough to lead to crack "pop-in" (abrupt crack growth) when a block is unbolted. I believe this to be relatively improbable but feel that strain gaging is appropriate to monitor crack behavior in the absence of complete weld repairs.

Q. In the summary of your original testimony, you expressed the opinion that conclusive information about the cam gallery cracks could be obtained from an extended engine test. Would you concur in testing the EDG 103 engine rather than either EDG 101 or 102?

A. (Bush) Yes. My interest is in whether or not compressive stresses in the cam gallery always exceed alternating stresses under conditions of startup, steady-state operation, and shutdown. I understand that the cam gallery of the replacement block in EDG 103 may contain cracks, but that there are no weld repairs. In my opinion, appropriate strain gaging of this block would yield more definitive data concerning the compressive and alternating stresses in the cam gallery than could be obtained from either the EDG 101 or the EDG 102 blocks, where the strain gages would have to be installed over weldments. It would be preferable to locate the strain gages in regions where no cracks exist. However, if no cam gallery saddles are crack-free in EDG 103, those saddles are still preferable for strain gaging to the saddles with weld repairs in EDG 101 and 102.

Even if the stress field in the cam gallery is shown to be compressive through a test of EDG 103, I recommend monitoring existing cam gallery cracks in the EDG 101 and 102 blocks, as noted in my response to the preceding question.

Q. Despite the concerns cited in your previous questions related to cam gallery cracking, what is your engineering judgment concerning the significance of such cracks for engine reliability?

A. (Bush) It is my engineering judgment that the existing cracks in the cam gallery should undergo little or no growth, provided that the strain gage tests confirm that the cam gallery region remains under a sustained compressive load throughout operation. This presumes that the summation of compressive bolt loads on tensile alternating loads is always compressive.

Q. What examinations should be conducted in the cam gallery after completion of the engine test?

A. (Bush) Surface examination with either liquid penetrant (PT), magnetic particle (MT), or eddy current (ET) to determine if any new cracks have initiated in areas where baseline examinations have been performed. These examinations could be performed on some but not necessarily all of the saddles.

Q. Would a decision to test EDG 103 to 10^7 cycles resolve the questions concerning the ligament cracks in EDG 101 and 102, the potential for stud-to-stud cracks, and the circumferential cracks reported in the original EDG 103 block?

A. (Bush, Henriksen) No. The caveats in our original testimony still exist in the absence of confirmatory data on the EDG 101 and 102 blocks. The satisfactory operation of the new EDG 103 block will provide valuable information about whether or not cracks will be operationally induced. We suggest a technique such as ultrasonic crack-tip diffraction to establish the dimensions of any stud-to-liner ligament cracks and/or stud-to-stud cracks that might form, particularly to determine crack depth. The block should be inspected for cracks between studs of adjacent cylinders after each operation, as discussed in our original testimony.

Q. What should be done with regard to EDGs 101 and 102?

A. (Bush) I believe that plans should include appropriate nondestructive examinations such as proposed for EDG 103. In particular, the blocks should be monitored for the formation of cracks between studs of adjacent cylinders after each operation, as discussed above.

Circumferential Cracks in Cylinder Liner Counterbore

Q. Do you have an opinion on the circumferential cracks found by FaAA in the corner formed by the cylinder liner landing and the cylinder liner counterbore of the original EDG 103 block, as discussed in LILCO's supplemental testimony?

A. (Bush) Yes. I anticipate that similar cracks may occur in the EDG 101 and 102 blocks, because of the relatively high stress concentration associated with the geometry of this area. It is my opinion that such cracks will be self-limiting as they propagate away from the area of high stress concentration, and that they do not represent a hazard to EDG reliability.

The bases for my opinion concerning the initial growth, then cessation of growth, of circumferential cracks relate to the multiplicity of stress sources in the region of the cylinder liner landing. The relatively high stress concentration factor resulting from the very small radius fillet in the corner of the landing is a definite contributor to early crack initiation. Thermal loads resulting from heatup and cooldown of the engine will introduce high secondary stresses in the region of the landing. In addition, the ignition within the cylinder will lead to a pulsating secondary thermal stress. Both will influence crack initiation but have little or no effect on crack propagation, because such thermal stresses tend to maximize near the surface. The cylinder liner expands on heating and introduces a hoop stress that should drop off with distance. Additional stresses occur from the compression of the liner against the landing and various bolt loads.

An obvious method of determining the significance of the combined stresses would be to perform a three-dimensional finite element analysis of all relevant stresses. Neither LILCO nor the TDI Diesel Generator Owners' Group has provided a 3-D analysis for review. I have not recommended that such an analysis be required as a basis for resolution of this issue, because I believe that reasonably reliable inferences can be made using engineering judgment and the known behavior of analogous systems. Based on my engineering judgment, I conclude that tensile stresses in the corner formed by the cylinder liner landing and the cylinder liner counterbore will drop off rapidly with distance so that a crack will move into a compressive stress field resulting from bolt-up of the cylinder block and the cylinder head.

A worst case would be a crack that propagates a full 360° circumferentially around the landing. Even with such a crack, I anticipate no major failure so long as the crack depth remains shallow. The crack orientation may or may not be horizontal; quite often such cracks propagate at about a 45° angle.

Original testimony on cylinder block contentions, modified to delete Mr. A. J. Henriksen as a cosponsor of answers that pertain primarily to metallurgical considerations. Deletions have been made with strikeovers, and any changes and/or additions are shown in boldface.

Original testimony on cylinder block contentions, modified to delete Mr. A. J. Henriksen as a cosponsor of answers that pertain primarily to metallurgical considerations. Deletions have been made with strikeovers, and any changes and/or additions are shown in boldface.

CYLINDER BLOCKS

Contentions

The County contends that the emergency diesel generators (EDGs) are inadequate because:

> Cracks have occurred in the cylinder blocks of all EDGs and a large crack propagated through the front of EDG 103. Cracks have also been observed in the camshaft gallery area of the blocks. The replacement cylinder block for EDG 103 is a new design which is unproven in DSR-48 diesels and has been inadequately tested.

Q. Have you reviewed the testimony filed by the County on July 31, 1984, in support of its contentions regarding the cylinder blocks in these proceedings?

A. (Bush, Henriksen) Yes.

Q. Have you reviewed the testimony filed by LILCO[(a)] on August 14, 1984, which concludes that:

1. The ligament cracks present in EDG 101 and EDG 102 are benign. Observations of various engines indicate that the cracks will not propagate beyond a depth of 1-1/2 inches. Accordingly, the ligament cracks in EDG 101 and EDG 102 do not and will not impair the ability of the EDGs to perform their intended function.

2. The crack that propagated down the front of the old EDG 103 block and the cracks that developed between the stud holes of adjacent cylinders on the old EDG 103, do not threaten the integrity of EDG 101 or EDG 102. Metallurgical analysis of the existing blocks has established that EDG 101 and EDG 102 do not have the extensive degenerate graphite microstructure that produced markedly inferior fracture fatigue properties in the old EDG 103 block. Further, EDG 103 was subjected to an abnormal load excursion that contributed to further crack extension. A cumulative damage analysis predicts that the EDG 101 and EDG 102 blocks are substantially less likely to develop stud-to-stud cracking and that they will withstand a LOOP/LOCA with sufficient margins, even if they were to initiate stud-to-stud cracking during a LOOP/LOCA.

(a) Testimony of R. McCarty, C. Rau, C. Wells, H. Wachob, D. Johnson, R. Taylor, C. Seaman, E. Youngling and M. Schuster on Suffolk County Contention Regarding Cylinder Blocks.

3. The cam gallery cracks in the Shoreham EDGs, which were discovered more than 1-1/2 years ago, are not predicted to propagate significantly even after hundreds of hours of engine operation. In addition, there is no reported incident in which cam gallery cracks have caused a sudden engine failure. The cam gallery cracks are, therefore, not predicted to impair the ability of the EDGs to meet their intended function.

4. The replacement block for EDG 103 has been tested adequately. The replacement block is not a new design. It is simply a current production model that incorporates certain product enhancements, each of which has been shown to be beneficial by exhaustive testing in the R-5 engine.

and, further(a), that:

1. The ligament cracks present in EDG 101 and EDG 102 are benign. There is no evidence that the cracks will propagate beyond a depth of 1-1/2 inches. Accordingly, the ligament cracks in EDG 101 and EDG 102 do not and will not impair the ability of the EDGs to perform their intended function.

2. The crack that propagated down the front of the old EDG block and the large cracks that developed between the stud holes of adjacent cylinders on the old EDG 103, do not threaten the integrity of EDG 101 or EDG 102. TDI believes that EDG 103 was subjected to abnormal high stress as a result of an unusual load excursion and that this caused additional extensive cracking in EDG 103.

3. The cam gallery cracks in the Shoreham EDGs were discovered more than 1-1/2 years ago. These cracks have not propagated significantly despite hundreds of hours at full load and overload conditions. It is TDI's opinion that the cam gallery cracks will not propagate significantly and that they will not impair the ability of the EDGs to meet their intended function.

4. The replacement EDG 103 block has been adequately tested. The replacement block is not a new design. It is simply a current production model that incorporates a few product enhancements, each of which has been shown to be beneficial by exhaustive testing in the R-5 engine.

A. (Bush, Henriksen) Yes.

(a) Testimony of C. Mathews, M. Lowrey, and J. Wallace.

Q. Please summarize your conclusions regarding the cylinder blocks.

A. **(Bush, Henriksen)** In summary, we conclude that:

- Presently, the information regarding the cracks in the camshaft gallery on the cylinder blocks for EDG 101 and EDG 102 is incomplete. Consequently, no conclusion can be made as to the suitability of these two cylinder blocks for the operation stated.

- The replacement block for EDG 103 is not a new design; it has been proven. Further, if it is certified to be free of stud-to-stud cracks between adjacent cylinders and in the camshaft gallery and if it is inspected for cracks after each operation, it will be suitable for nuclear service for one refueling cycle.

Q. Do you know the material specifications for the cylinder blocks on the Shoreham TDI 101 and 102 engines?

A. (Bush~~,~~ ~~Henriksen~~) Yes. Drawing #03-315-03-AC of the cylinder blocks for the Shoreham TDI 101 and 102 engines ~~specify~~ **specifies** an ASTM-A48-64 class 40, gray-iron casting.

Q. Was the material specification for the original cylinder block on the Shoreham TDI 103 engine also ASTM-A48-64 class 40, gray-iron casting?

A. (Bush~~,~~ ~~Henriksen~~) Yes.

Q. What are the material specifications for the replacement cylinder block on the Shoreham TDI 103 engine?

A. (Bush~~, Henriksen~~) Drawing #03-315-05-AD of the cylinder block for the Shoreham TDI 103 engine specifies an ASTM-A48-76 class 45B, gray-iron casting.

Q. What is the significant difference between an ASTM-A48-64 class 40, gray-iron casting and an ASTM-A48-76 class 45B, gray-iron casting?

A. (Bush~~, Henriksen~~) The tensile and yield strengths of an ASTM-A48-76 class 45B, gray-iron casting are superior to those of an ASTM-A48-64 class 40, gray-iron casting.

Q. Have you reviewed the portion of the FaAA report that deals with the metallurgical analysis performed on cylinder blocks of the Shoreham TDI 101, 102, and 103 engines?

A. (Bush~~, Henriksen~~) Yes.

Q. Do you consider the quality of the gray iron in the original cylinder block of the Shoreham TDI 103 engine typical of standard casting practice?

A. (Bush) No. The morphology of the graphite flakes, as evidenced from the photomicrographs presented, was not typical. Such flakes would lead to degraded mechanical properties.

Q. Did you find the quality of graphite in the cylinder blocks from the TDI 101 and 102 engines similar to that in the original block from the 103 engine?

A. (Bush) No. The microstructure of the samples from the cylinder blocks of the 101 and 102 engines is typical for an ASTM class 40, gray-iron casting.

Q. Have you reviewed the portion of the FaAA report that deals with the physical tests that were performed on samples from the cylinder block of the Shoreham TDI 103 engine?

A. (Bush, ~~Henriksen~~) Yes.

Q. What did you conclude from your review?

A. (Bush, ~~Henriksen~~) That the results from the physical test confirm the conclusion drawn from the metallurgical analysis. The material in the original cylinder block from the Shoreham TDI 103 engine is substandard as compared to ASTM class 40, gray-iron castings.

Q. Can it be assumed that, since the photomicrographs indicate that the cylinder blocks from engines 101 and 102 indicate typical class 40, gray-iron castings, their physical properties such as tensile and yield stresses are, in fact, typical of class 40, gray-iron castings?

A. (Bush, ~~Henriksen~~) The assumption may certainly be made that the material in the cylinder blocks for engines 101 and 102 is superior to the material in the original 103 cylinder block. Whether or not the 101 and 102 blocks actually have the physical properties of class 40, gray-iron castings can be confirmed only by actual tests. ~~We~~ I have no knowledge that this testing was ever done.

Q. Assuming that the material in the cylinder blocks for engines 101 and 102 conforms to the specifications for ASTM class 40, gray-iron castings, would you consider the ligament cracks presently observed in the blocks between the cylinder liner counterbore and the cylinder head studs as benign?

A. (Bush) The empirical evidence would indicate that these cracks grow to the size cited, then arrest. This empirical evidence is based on repetitive examinations of cracks in both ship and stationary diesels. There is one substantial difference between such diesels and emergency diesels tested periodically. Basically, the first group operates at near steady-state conditions, whereas the emergency diesels will reach peak loads rapidly and operate with variable thermal gradients. Because of this difference, one cannot unequivocally state that the cracks will arrest. A definitive three-dimensional finite element analysis with valid load inputs through the thickness of the block, covering hoop stresses, thermal loads, bolting loads, etc., would confirm whether the crack has arrested because of a rapidly decreasing stress gradient.

Q. If the ligament cracks from cylinder liner to studs could be shown to have been arrested, what, in your opinion, would be the probability of a crack initiating between studs of adjacent cylinders?

A. (Bush) If the liner/stud crack can be shown to have arrested, the probability of a crack initiating between the two studs and then propagating into the block is very low because there is a limited driving force. The initial cracks in the 103 block are believed to be due to the degraded mechanical properties; the very severe overloads because of the load transient are believed to have caused rapid crack growth. In essence, this would correspond to a low-cycle fatigue problem where every cycle drives the crack a substantial distance.

Q. In your opinion, will the ligament cracks presently observed between the counterbore and the studs render the cylinder blocks on engines 101 and 102 unsuitable for nuclear service?

A. (Bush) The nature of the loss of power/loss of coolant accidents is such that demand for high diesel generator-related power is quite short-lived; thereafter, the power demands are much less. Even if the diesel generators were to be derated and it became necessary to meet LOOP/LOCA conditions above the derated rating but no higher than the nameplate rating, the limited duration at higher power should not pose a major problem.

Q. Do you consider checking for cracks between studs of adjacent cylinders after each operation above 50% load as adequate?

A. (Bush~~, Henriksen~~) No. As stated earlier, ~~We~~ I do not have an adequate basis for concluding that all present cracks are arrested. Therefore, ~~We~~ I feel this inspection should be performed after any operation.

Q. Do you consider the suggested eddy-current test as adequate to detect cracks of sufficient size to lead to detorquing of the studs?

A. (Bush) It must be recognized that the eddy-current test with ferritic materials is limited to the "skin" of the metal. All testing of the block surface must be done through the restricted access between cylinder heads. Although eddy-current testing will be difficult, it is not impossible, provided the surface between the two studs is sufficiently smooth (i.e., a machined surface).

The more fundamental issue is the initial locus of crack initiation. The most probable location would be between stud hole and cylinder, which is impossible to examine without disassembly. In my opinion, on the basis of a limited review, the most probable location for cracks to initiate would be at the corner of the counterbore at the start of the threads. Depending on the stress distribution, such a crack could progress down the threads or up to the surface. Based on LILCO testimony for blocks 101, 102, and the original 103 plus blocks for other TDI diesels, cracks exist at the surface and to depths of 1.5 inches. It is possible that the liner/stud cracks might grow down the threads under the start-stop loading typical of emergency diesels. If this occurred, there could be a redistribution of stresses so that cracks may initiate between the studs. We suspect that such cracks would initiate at the corner adjacent to the top thread. However, unless the cracks propagate to the surface, eddy-current testing will be useless. An alternative technique that might work is a zero degree ultrasonic wave commonly used in metals as a depth gage. If the external surface area and geometry are adequate to insert the ultrasonic transducers, cracks between the studs have the potential of detection. This technique has the advantage of measuring the depth dimension whether the crack reaches the surface or remains subsurface.

Q. Mr. Berlinger, do you agree with the previous response?

A. (Berlinger) Not completely. With regard to the issue of crack initiation sites, limited hard evidence has been submitted by LILCO in their exhibits B-16, B-17, B-18 and B-25. These crack maps indicate that some block cracks which extend down into the block from the block top surface had not been observed to the depth of the stud threads (1 1/2 inches). Conversely, no cracks have been observed at the depth of the threads which did not extend up to the block top surface.

FaAA and LILCO have stated during recent technical discussions that they have used eddy current probes to inspect stud counterbore and thread areas in stud holes in the 101, 102 and old 103 Shoreham blocks. In those cases for which no surface crack indications had been observed, these inspections did not find any subsurface cracks. These measurements/inspections would confirm that cracks which would initiate below the surface would propagate and be evidenced at the block top surface.

The Staff believes that it is difficult to predict the locations of crack initiation, and that the potential exists for crack initiation in the block stud area from subsurface initiation sites (e.g., stud threads). However, the evidence from previous inspections of the Shoreham cylinder blocks would indicate that crack initiation would not be subsurface. Therefore, monitoring of the block top surface for stud-to-stud cracks should be done using the most appropriate nondestructive examination technique which should not be limited to consideration of only ultrasonic techniques.

Q. Do you consider the position suggested by LILCO that stud-to-stud cracks to depths of 1.5 inches are acceptable as justified?

A. (Bush) No. The only basis for such a position is believed to be the existence of stud-to-stud cracks in the original 103 block. Cracks of unknown geometry were known to exist prior to the severe overload that drove a crack to a depth exceeding 5 inches. As noted previously, we believe the probability of stud-to-stud cracks is very low, assuming the cast iron is not atypical as was the case with the original 103 block.

The appearance of a stud-to-stud crack in normal quality cast iron would indicate that too little is known concerning the stresses and stress distributions leading to such a crack. A deliberate decision to continue operation without repair of such a crack is not justified because the presence of such a crack indicates that the current analytic techniques do not accurately model crack initiation and growth.

If a well designed three-dimensional finite element analysis using stresses validated by experimental methods were conducted, it might be possible to justify the conscious operation with stud-to-stud cracks. Personally, I doubt it, because of difficulty in establishing local stresses.

Q. Have you had occasion to review the LILCO testimony and exhibits referring to the cracks in the camshaft gallery?

A. (Bush, Henriksen) Yes.

Q. Based on this testimony and relevant exhibits, have you formed an opinion as to why these cracks initiated in the first place?

A. (Bush, Henriksen) No. We believe this point has not been addressed in the testimony or the exhibits.

Q. Have you formed an opinion as to crack growth rate in the camshaft gallery based on FaAA's analysis on this subject?

A. (Bush, Henriksen) No. The FaAA analysis approach probably is correct, provided the input data are correct. However, we have some reservations as to the correctness of the strain gage data supplied by TDI. These data constitute the main basis for the FaAA analysis.

Q. Is your concern regarding the TDI strain gage data related to the fact that the data were obtained from a 6-cylinder rather than an 8-cylinder engine, a slightly larger fuel injection pump, and a little faster rising fuel cam?

A. (Bush, Henriksen) No. Those are minor issues of no consequence.

Q. What is your concern then?

A. (Bush, Henriksen) First, referring to LILCO Exhibit B54, Gage #1 is not located in the area in question; yet the values obtained from Gage #1 are presented in the testimony as the stresses found in the cracked area.

Second, again referring to LILCO Exhibit B54, Gages #2 and 3 appear to be located in the same area. As can be noted in LILCO Exhibit B53, there is a difference of over 50% at 110% load, and over 100% at 100% load in mean stress between the two gages.

Third, and most important, we do not understand how, for the same mode of operation, the stresses can change from tension to compression as a function of engine load. The fuel injection pump is positively loaded every second revolution regardless of load. The vectors in the loading diagram do not change direction as a function of load. Thus, in our opinion, the stresses should not change direction as a function of load.

Q. In your opinion, do the cracks in the cam gallery pose a potentially serious problem?

A. (Bush, Henriksen) Yes. Depending upon the depth of the cracks and the anticipated growth pattern, the cracks may or may not pose future problems. Examination of TDI drawing #03-315-03-AC indicates that cracks may possibly propagate into the cylinder cooling water space, which could result in water entering into the camshaft housing. Lube oil in that housing drains into the engine crankcase. Leakage in this area is unlikely to be noticed during engine operation. Thus, enough water may mix with the lube oil in the crankcase to cause serious damage to bearings, shafting, etc.

Q. In your opinion, do the cracks in the camshaft gallery of the cylinder blocks for engines 101 and 102 render these engines unsuitable for nuclear service for one refueling cycle?

A. (Bush, Henriksen) Yes, until the questions raised regarding the TDI strain gage measurements and the reversal of direction of stresses are answered such that we have a reasonable assurance that the cracks in the cam gallery are benign or grow at such a slow rate that they are of no concern.

Q. Mr. Berlinger, does the Staff believe that the concerns, relative to the cracks in the camshaft gallery can be resolved?

A. (Berlinger) Yes, the Staff believes if an engine were tested as suggested to resolve the concerns regarding the crankshafts, that data obtained during that testing could provide information regarding the stresses and crack propagation in the cam gallery area. Assuming that either EDG 101 or 102 were to be tested, if the cam gallery area were thoroughly inspected to characterize the existing cracks by determining the length, depth and direction of existing cracks before and after the suggested 10^7 cycle test, and, if the crack area were instrumented with strain gages and measurements were taken during these tests, the Staff believes that conclusive information about the behavior of the cracks could be obtained which would resolve the existing concerns.

Q. In your opinion, is the replacement cylinder block for EDG 103 of a new design?

A. (Henriksen) No. Drawing #03-315-05-AD indicates that the replacement cylinder block is a modified version of the original cylinder block drawing #03-315-03-AC.

Q. Other than the change in material, which you have stated earlier was an improvement, have you reviewed LILCO's testimony with regard to the other changes to the replacement cylinder block?

A. (Henriksen) Yes.

Q. Do you consider any of these changes or modifications detrimental?

A. (Henriksen) No.

Q. Do you consider any of these changes or modifications beneficial?

A. (Henriksen) Yes. All changes to the replacement cylinder block, as listed in LILCO's testimony, are considered beneficial.

Q. Do you have any remarks regarding any of the changes or modifications?

A. (Henriksen) Yes. LILCO's testimony indicates that the replacement block has a greater cold clearance gap between the cylinder liner and the cylinder block. This change is not reflected in block drawing #03-315-05-AD. However, we understand from a TDI (R. Johnston) letter dated May 4, 1984, to Stone & Webster Engineering Corporation that TDI has recommended this change be made to the cylinder liners. (The TDI letter is Exhibit 6 of this testimony.)

Q. As a design, do you believe the EDG 103 replacement cylinder block inadequately proven?

A. (Henriksen) No. We have compared drawing #03-315-05-AD of the replacement cylinder block with drawing #02-315-05-AW, which depicts the cylinder block for the R-5 prototype test engine. We found that, in the area affected by the changes, with the exception of the dimension regarding the cold gap clearance as mentioned earlier, the two drawings indicate the two cylinder blocks appear to be exactly alike. The R-5 cylinder block has been extensively tested at a load level higher than the EDG 103 will ever experience. Thus, we believe that, provided the R-5 cylinder block did not develop cracks during its extensive testing, as a design the EDG 103 cylinder block has been proven.

Q. Does the fact that the R-5 is a V-engine and the EDG 103 is an inline engine in any way enter into your evaluation when comparing the two cylinder block designs?

A. (Henriksen) Yes. However, for the area of interest there is no difference in cylinder block design between a V-engine and an inline engine.

Q. Have you drawn any final conclusion regarding the EDG 103 replacement cylinder blocks?

A. (Henriksen) Yes. Provided preoperational inspection reveals no cracks between studs from adjacent cylinders or in the camshaft gallery, and provided inspections for cracks are conducted after each operation, the EDG 103 replacement cylinder block is considered suitable for operation through to shutdown for the first refueling.