Docket Nos.: 50-445
and 50-446

DEC 3 1984

Mr. M. D. Spence
President
Texas Utilities Generating Company
400 N. Olive Street
Lock Box 81
Dallas, Texas 75201

Dear Mr. Spence:

Subject: NRC Staff Position Regarding Detection of Linear Indication on the Multi-Vane Diffuser Shroud in Safety Injection Pumps Installed in Comanche Peak Steam Electric Station (Units 1 and 2)

By letter dated February 1, 1983, TUGCO submitted for review a report prepared by the Pacific Pump Company, which presented the results of an evaluation of the significance of linear indications found on the diffuser shrouds of the Pacific Pump supplied safety injection pumps installed in Comanche Peak. The enclosed evaluation report contains the staff's findings and position based on its review of that report.

In summary, the staff is in general agreement with the analysis performed as well as the conclusion and recommendation made by Pacific Pumps and endorsed by TUGCO. However, it is the staff's position that the periodic inspection of the safety injection pump include surface inspections (e.g. penetrant, magnetic particles), and not be limited solely to visual inspection. It is requested that TUGCO formally notify the NRC of its intent to comply with the staff's position for additional inspection, and provide for such inspection in the Comanche Peak ISI program.

Sincerely,

/s/

B. J. Youngblood, Chief
Licensing Branch No. 1
Division of Licensing

Enclosure:
As stated

cc: See next page

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12/3/84	12/3/84

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UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

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COMANCHE PEAK

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Texas Utilities Company
Comanche Peak Units 1 and 2
Docket Nos. 50-445/446

I. INTRODUCTION

In February 1983 Texas Utilities submitted the subject report presenting the results of an evaluation performed by Pacific Pumps on the significance of linear indications found on diffuser shrouds of the safety injection pumps installed at Comanche Peak.

Visible linear indications on the shroud that separates and supports the diffuser vanes and return guide vanes have been found in the JHF type pumps supplied to Texas Utilities - Comanche Peak Station. These indications exceeded the designer-permitted maximum of 1/16 inch (in.) and ranged in surface size from 1/8 in. to over 1.0 in. It is Pacific Pumps' opinion that these indications resulted from casting processes and have been present since casting. The manufacturer believes that linear indications are merely more visible now due to the operational testing and subsequent cleaning operations of the pumps and do not affect the operability of the pumps.

II. DISCUSSION/EVALUATION

The pump manufacturer, Pacific Pumps, has given the engineering disposition "USE AS IS." The purpose of the report submitted by the applicant is to support that disposition and show that these indications do not affect the operation of the pumps. The specific considerations stated by the manufacturer are as follows:

- The cause of the indications is well understood;
- the stress levels in the part are relatively low;
- these parts are designed and manufactured in the same manner as thousands of nearly identical parts used in similar pumps without failure; and

- The arrangement of the pump is such that even if a shroud were broken in two, the pieces would be constrained to an extent that the pump would continue to function in channeling the fluid flow and would not interfere with the operation of the pump.

The indications seen on these intercovers are examples of casting process effects which are associated with the original solidification and cooling of the casting. The pump manufacturer states that his experience in the use of castings of these alloys is that such indications are common and are quite often seen during receiving inspection of raw castings. Once the parts have cooled and are properly heat treated, no driving force remains to cause new cracks or extend the existing indications. Included in the submittal is a report by a metallurgical consultant which presents evidence to support the conclusion drawn above.

The complex geometry in the region of the part where the indications are found necessitated the use of the finite element method to calculate the stresses. A discussion of this analysis and the results are presented in the report. It is the manufacturer's opinion that these low stresses cannot cause crack initiation or propagation in these parts. The metallurgical consultant's report uses the stresses calculated along with load history data obtained from the N.S.S.S. supplier to analyze crack propagation and life projections using the methods of fracture mechanics. This analysis supports the opinion expressed above and the resulting conclusion that the integrity of these parts is not affected by the presence of the indications. An additional consideration is that the primary stress causing load, the hydrostatic end force, varies from a minimum at the 11th stage and is maximum at the 1st stage. Assuming that the indications are caused or made worse by operating stress, then the parts having the greatest number of indications would be in the first few stages. This is not the case. Instead, the indications reported show a random distribution.

Pacific Pumps has designed and built pumps having essentially identical diffuser/intercover design for more than 30 years. The materials used for these pump parts have included cast iron, bronze, and various steels including the martensitic stainless steel used for the subject parts. No failure has occurred in the subject pumps due to material failure in the diffuser intercover shroud. The manufacturer's report lists operating pumps with similar internal construction.

The stress calculations show that, during operation, these parts are pressed together by hydrostatic forces so that the end face of each diffuser blade is loaded in compression. Fractures in the shrouds yielding pieces that included diffuser vanes would be held in place by these compressive loads and the return passage vane, which is integrally cast between the shroud and the thick section of the intercover. A shroud failure between blades is not plausible since the shroud is lightly loaded.

The manufacturer's opinion is that the above discussion and associated attachments are sufficient to justify the use of these parts "as is" and recommends that these elements be used. In addition, the manufacturer's report presents recommendations for field inspection and criteria for further action.

Analysis

The stresses carried by the pump intermediate cover (see Figure 1) were analyzed by the finite element method to show the generally low stress condition in the area of indication and to provide data for use in a fracture mechanic analysis. The cover shown in Figure 1 is one of a number of static members assembled at the same time as the impellers and alternate with the impellers. Each cover serves to guide the water from the outlet of a previous impeller to the inlet of a subsequent impeller where the water is pumped to a higher pressure. As a result each "cover" has one stage of differential pressure across it. It becomes, in effect, a piston hydrostatically loaded by the pressure buildup of the pump. This load is carried by the return guide vane, shroud, and diffuser vane into the next lower stage cover or into the case at the first stage. Although this is the only significant source of load on these parts, the manufacturer has considered this load to be made up of two superimposed components. The first component is a "static" component represented by the required design pressure increase of approximately 145 psi in each stage. The second component is a high frequency dynamic component caused by the blade passage of the impeller. Experience shows that the second component is typically 1% of the developed pressure but for calculation of stress an upper bound of 3% is used. Since the loads accumulate from stage to stage the finite element analysis was performed assuming that the full pump differential pressure of 1590 psi acts across one cover. Other sources of stress such as hydrodynamic forces or thermal cycling have been considered to be much less than the pressure forces discussed above. The possiblity of significant thermal stresses and thermal fatigue are precluded by the fact that the section is flooded on all sides and is relatively thin. In addition, the pump is subjected to very few significant thermal cycles.

For the actual analysis, the equivalent pressure load was applied to the cover end of the part with the diffuser vane end fixed in the axial direction. Three models were run to determine if any significant redistribution of local stresses occur due to the presence of the indication in the part. The indication was simulated by removing thin elements to create a notch-type void in two of the models. The third model includes the complete section. The finite element analysis showed that the stress distribution in the shroud is mostly due to a bending load acting across the section. This agrees with expected behavior since the load path is predominantly from the return vane to the diffuser vane and is introduced into the shroud as bending from the forces applied by adjacent vanes. In addition, the analysis shows that the absence or presence of the indication does not significantly alter the stresses. The magnitude of the stresses are quite small especially when considering that the cover is cast from an alloy (CA6NM) having a minimum yield strength of 80,000 psi and minimum ultimate tensile of 110,000 psi. For reference, the ASME B&PV allowable for this alloy is 27,500 psi.

In summary, the calculated stresses are approximately 2,000 psi. For purpose of further analytic conservatism 3,000 psi will be used for the "static" component and 100 psi (approximately 3% of 3,000) for the "dynamic" component. The "static" component is really not static since it is applied many times over the life of the plant; specifically, each time the pump is started. The N.S.S.S. vendor (Westinghouse) has provided data that indicate that a reasonable upper bound for the starts and stops is 2,500 cycles. The cycles for the "dynamic" component has been similarly determined by considering the expected maximum operating time of the pump and the total number of blade passings that would occur and is 2×10^{10} cycles. The above data was provided to Mettek, Pacific Pumps consultant, and was used in the fracture mechanics analysis to show that the presence of the indication will not lead to part failure.

Mettek prepared two reports for Pacific Pumps; one, a failure investigation on the shroud section of an intermediate cover and the other, a fracture mechanics analysis of the cover with the observed indications. The Mettek failure analysis consisted of preparation of tensile and impact specimens from the cover and a metallurgical analysis of the indications observed. The tensile test exceeded the specification requirements for yield and tensile strength but five of the six specimens tested were below specification minimum requirements for elongation and one of the six did not meet specification minimum requirements for reduction of area.

There are no specified impact test requirements in ASTM A296 and the four specimens tested exhibited absorbed energy of 20, 26, 16 and 18 ft-lbs and lateral expansion of 17, 18, 11 and 12 mils respectively. Additionally, two Charpy specimens were fatigue precracked and used to measure fracture toughness (K_{Ic}) per ASTM E399. The test was invalid per E399; therefore, equivalent energy estimate of fracture toughness (K_{eq}) based on assumption of crack initiation at maximum load. The results of the two tests provided K_{eq} of 140 and 146 Ksi-in^{½}.

The specification to which the diffuser castings were ordered requires only visual examination of the surface to locate adhering sand, scale, cracks and hot tears. Magnetic particle inspection is performed only upon agreement between manufacturer and purchaser. During the original manufacture of the intermediate pump covers, only visual examination was required. The hot tear indications that initiated the investigation were identified by visual inspection. The metallurgical analysis showed that the cracks existed prior to heat treatment and are typical of all phenomenon described as hot tears which are commonly observed in the 400 series of casting alloys. No opening or closing of the initial saw cut was observed, which indicates that residual stresses are quite low, as would be expected for a casting with a subsequent heat treatment.

METTEK performed a second analysis on an actual cracked cover casting to develop acceptance criteria. For the intermediate covers found to contain the linear surface indications, the additional work performed was as follows:

o characterize the CA-6NM casting alloy with regard to the size, shape and location of the hot tears found in the intermediate covers, specifically in the shroud section;

o characterize the CA-6NM casting alloy from an intermediate cover by selectively sectioning an actual cover and machining test specimens to determine the yield strength (YS), tensile strength (UTS), fracture toughness (K_{Ic}), fatigue crack growth rate (da/dN) in air and a boric acid solution (corrosion fatigue), and the threshold stress intensity for sustained load crack growth rate in a boric acid solution (K_{Iscc});

- o determine the load history profile for start-up and on-line pressure pulses for a projected 40-year life; and

- o analyze for the safe design life employing fracture mechanics.

The approach throughout this program was to take a "worst case" approach in the analysis. All values selected in the safe-life design analysis were selected to provide an extremely conservative analysis; i.e., maximum anticipated stresses, lowest fracture toughness, highest crack growth rates, largest possible size and shape of the hot tear, located radially to the circularly shaped shroud section.

Determination of Dynamic Fracture Toughness

Instrumented impact tests per ASTM STD E812-81 and conventional Charpy Impact Tests per ASTM STD E23-81 were conducted to determine the effects of strain or loading rate. The samples were all machined from the cover section. From the results of the plotted data the minimum value of toughness at the upper shelf was conservatively estimated to be 75 Ksi-in$^{1/2}$ and the minimum fracture toughness on the lower shelf was 45 Ksi in with a transition temperature at about 100F. These minimum values were used in all subsequent analysis.

The standard Charpy impact tests were correlated to the fatigue-precracked, dynamic fracture toughness tests by using a correlation described by Barsom and Rolfe in "Fracture and Fatigue Control in Structures", Prentice-Hall, Englewood Cliffs, N. J., 1977 where:

$$K_{Id}^2 = 5E \cdot CVN$$

where E=30 Msi and CVN (Charpy V notch energy) is in units of ft-lbs; then, K_{Id} (dynamic fracture toughness) is in units of Ksi-in$^{1/2}$

Determination of Fatigue Crack Growth Rate

Fatigue testing for crack growth rates as a function of the crack-tip stress intensity range (ΔK) was done according to ASTM STD E647-81 using a compact type specimen with the thickness (B) of 0.5 in. and the width (W) of 1.5 in. During tests the crack length was measured optically from both sides with a travelling microscope. The average crack length (a) was used in calculating the rates. Testing was at a frequency range of 10 to 60 Hz depending on the applied stress intensity range. The stress ratio (R) was 0.1 and the temperature was ambient or about 80F.

Fatigue crack extension was monitored as a function of the number of fatigue cycles (N). The incremental polynomial method, a recommended curve smoothing technique described in the Appendix of ASTM E647-81 was used to analyze the data and calculate the slope or rate of crack extension.

In addition to conducting the test in air, a corrosion-fatigue study in a boric acid solution representing the refueling water in the storage tank. The purity of the water was maintained by using distilled water and adding boric acid to provide 2000 to 4000 ppm of boron. The pH of the solution was between 4.0 and 4.7 as called for in the specification supplied by Westinghouse. The oxygen was not controlled during the test representing again worst-case condition by using a system that was not de-oxygenated. The test results of the corrosion fatigue test overlays the test results in air. Therefore, it can be concluded that the boric acid refueling water solution does not represent a more aggressive corrosion-fatigue environment. Both sets of data are represented by a conservative upper-limit curve given by:

$$da/dN \text{ (Micro-inches)} = 2.57 \times 10^{-4} (\Delta K)^{3.0}$$

with ΔK in units of $Ksi\text{-}in^{\frac{1}{2}}$

Stress Corrosion Testing in Boric Acid

An accelerated stress corrosion testing method developed at METTEK (Ref. "Accelerated, Low-Cost Test Method for Measuring the Susceptibility of HY-Steel to Hydrogen Embrittlement." By L. Raymond, ASM Conference, Washington, D.C. November 1982) was used to determine the threshold stress intensity for sustained load crack growth in a boric acid solution. Again, the system was not de-oxygenated, representing the most agressive environment. One test specimen was broken in air for comparison. The results showed no environmentally assisted crack growth; i.e., $K_{Iscc}/K_{Ic} > 0.9$.

The test method employs a Charpy-sized specimen, loaded by a rising step method. A potential @ -1.2V vs SCE is used to generate an aggressive hydrogen environment that has been shown to induce stress corrosion cracking in high toughness HY-140 ship steels. This same method of testing did not produce any environmentally assisted cracking in the CA-6NM casting alloy.

Safe Life Analysis & Hot Tear Characterization

A conservative analysis for safe life operating cycles of the intermediate cover of the Safety Injection Pump requires knowledge of the largest possible size of hot tear and the operational stresses in addition to the data obtained in this test program.

The size and shape of the hot tears were identified. Consistent with the worst case analysis, the largest anticipated tear would be represented by a

0.5 in. deep, through the thickness (13/16 in.) radially oriented edge crack. Because of the geometry of the diffuser vanes in the shroud section, whereby they cross at about 1.0 in. from the edge of the shroud. The extension of the hot-tear would not be expected to exceed this value. These observations are consistent with the stress analysis. Therefore, for the safe-life analysis, the hot tear was analyzed in fracture mechanics characterization as a single edge notch specimen with the initial depth of crack not exceeding 0.5 in.

Critical Stress Calculations

Based on the conservative estimates of fracture toughness on both the upper and lower shelves, the fracture strength curves of the CA-6NM alloy were plotted. The curves were derived from a fracture mechanics relationship for a single edge notch specimen.

The curve shows the critical stress to be 31.8 Ksi and 53 Ksi for the lower and upper shelf, respectively. If the tear were to extend to one-inch, the critical stresses would then be lowered to 22.5 and 37.5 Ksi, respectively.

Determination of Fatigue Threshold

The actual stresses the shroud experiences under operating conditions have been detailed in another section of this report. Finite element analysis has shown that the stress history profiles can be characterized. Two aspects of the analysis are considered, start-up and on-line pressure pulses. Conservatively, the start-up stresses can be described as $\Delta\sigma = 3$ Ksi and $R = 0$; whereas the on-line stresses are $\Delta\sigma = 0.1$ Ksi and $R = 0.97$. In essence, a tensile stress component of 3 Ksi is never exceeded. It should be noted that this stress level is far below the critical stresses described in the previous section; i.e., for the worst case the critical stress exceeds the operating stress by a factor of seven.

Determination of Fatigue Threshold

From the fatigue crack growth rate data in both air and primary coolant, a fatigue-crack growth threshold stress intensity $K_{threshold}$ for crack growth is suggested to be about 8 Ksi-in$^{1/2}$. Comparison of this threshold with data from other steels supports the conclusion that the value of 8 Ksi-in$^{1/2}$ is reasonable for casting alloy, and the data with which it was compared is for both low-strength and high-strength low alloy carbon steels. Further leads to the conclusion that the maximum operational driving force or stress intensity of 4.2 Ksi-in$^{1/2}$ for fatigue-crack extension of the largest possible hot-tear is below the threshold stress intensity for fatigue-crack extension. This means that no crack extension of the hot tear will occur in fatigue because the driving force is too low, similar to operating below the endurance limit in a classical fatigue S-N curve analysis.

Determination of Safe-Life Cycle

If it is assumed that a threshold stress intensity range does not exist, but instead the measured crack growth rate of the fatigue crack growth rate tests can be extrapolated along the straight line on the log (da/dN) vs log (Δ K) plot, i.e., then the conditions for safe-life cycles can be calculated.

Using the safe-life cycle or requirement specified by the contractor,

$$N_{(start\text{-}up)} = 2500 \text{ cycles/40 yrs}$$
$$N_{(operational)} = 2 \times 10^{10} \text{ cycles/40 yrs}$$

and calculating the number of cycles for a hot-tear to extend to 1-inch, the number of cycles to extend the hot tear to 1.0 in. is shown on Figure 2. As noted, over 100 yrs of projected on-line pressure pulses would be required. Similarly, over 40,000 years of projected start-up cycles would be required to extend the hot tear to 1.0 in. radial length.

A design envelope similar to the modified Goodman diagram can also be calculated, although further modified to incorporate initial size of the hot tear. The Goodman diagram is essentially a constant finite-life diagram, plotting the stress range ($\Delta\sigma$) vs. σ mean. If values of 1×10^4 or a factor of safety of four is used on the start-up cycles over the 40 yr period and 2×10^{10} cycles are used for the on-line pressure pulses, then the σ may be calculated.

The stress range $\Delta\sigma$ and σ mean can be delineated as shown in the fracture mechanics modified Goodman diagrams of Figures 3 and 4.

As observed on studying Figures 3 and 4, the operational stresses are far below any combination of mean and alternating stress range that would exceed the safe-life zone delineated by the lines for a_o = 0.25, 0.50, or 1.0 in. Obviously these zones decrease in size as the assumed initial size of the hot tear increases.

Applicant's Conclusions

1. Under the worst possible operating conditions, the largest observed hot tear would not extend to near critical values within the projected 40 year operational conditions of the intermediate pump cover.

2. Because of the low projected operating stresses, the operating stress intensity range is below threshold for fatigue-crack extension. Even assuming no threshold exists, extension from 0.5 in. to 1.0 in. would take over 100 years for on-line pressure pulse conditions and even longer for the other considerations.

3. The storage tank refueling water would not aggravate the conditions by causing accelerated conditions of corrosion-fatigue or stress corrosion crack, even without de-oxygenation of the boric acid solution.

4. The minimum conceivable fracture toughness under low-temperature, high-loading rate conditions would not produce fracture unless the tear extended radially to 1.0 in. and the operating stresses exceeded 20 Ksi; whereas it is calculated that the actual operating stresses do not exceed 3 Ksi.

Applicant's Field Recommendations

The pump manufacturer feels that the various analyses performed clearly demonstrate the suitability of these parts "as is." It is their opinion that the following field program would be prudent:

Whenever the pump casings are opened due to operating problem or normal maintenance, the intermediate cover in the shroud section should be visually inspected to determine the extent of the indications. A special scheduled disassembly for the purpose of inspecting these parts is not recommended. The reason for this is that the analyses indicates that failure is not reasonable and that the cost and risk of doing damage to a good pump during disassembly and reassembly cannot be justified. However, the manufacturer recommends that intermediate covers be inspected on at least a ten-year cycle. Since this is generally advisable for plant reasons other than these intercover indications, they feel this is a prudent maximum inspection cycle.

The actual visual inspection should be made to a controlled procedure since individual interpretation can be very misleading when dealing with this type of indication. Pacific Pumps suggests that Article 9 of Section 5 of the ASME Boiler & Pressure Vessel Code would serve as a good guide in this area. Other non-destructive methods such as Magnetic Particle (MT) or Dye Penetrant or radiographic examination are not recommended since they require special preparation of the part or technique to be used and would probably not be useful. Pacific Pumps' factory trials using MT on these parts shows that good visual inspection is more than adequate to detect significant indications of the type observed.

A log should be kept of the findings. This should include at least the quantity and size of indications found on each intermediate cover. In addition, it is recommended that all indications that extend more than 1 inch radially towards the center of the part be referred to Pacific Pumps for possible further analysis. This is nearly double the depth of any indications seen so far. The actual length of 1.0 in. is based upon the depth of the shroud in a radial direction before a vane is encountered and approximately the same as the notch depth introduced into the finite element model. A higher level of complexity in the stress field is introduced if the indication extends into or along a vane. However, even in this case, the applicant believes the stress levels to not be significantly increased in the plane causing opening of any crack.

The applicant's recommendations can be summarized as follows:

1) Visually inspect the shroud section of the intermediate cover during normal or emergency maintenance or every 10 years (but do not open pump only for intercover inspection).

2) Log all indications found in the shroud for each part. A map is not recommended. Overall statistics are the key.

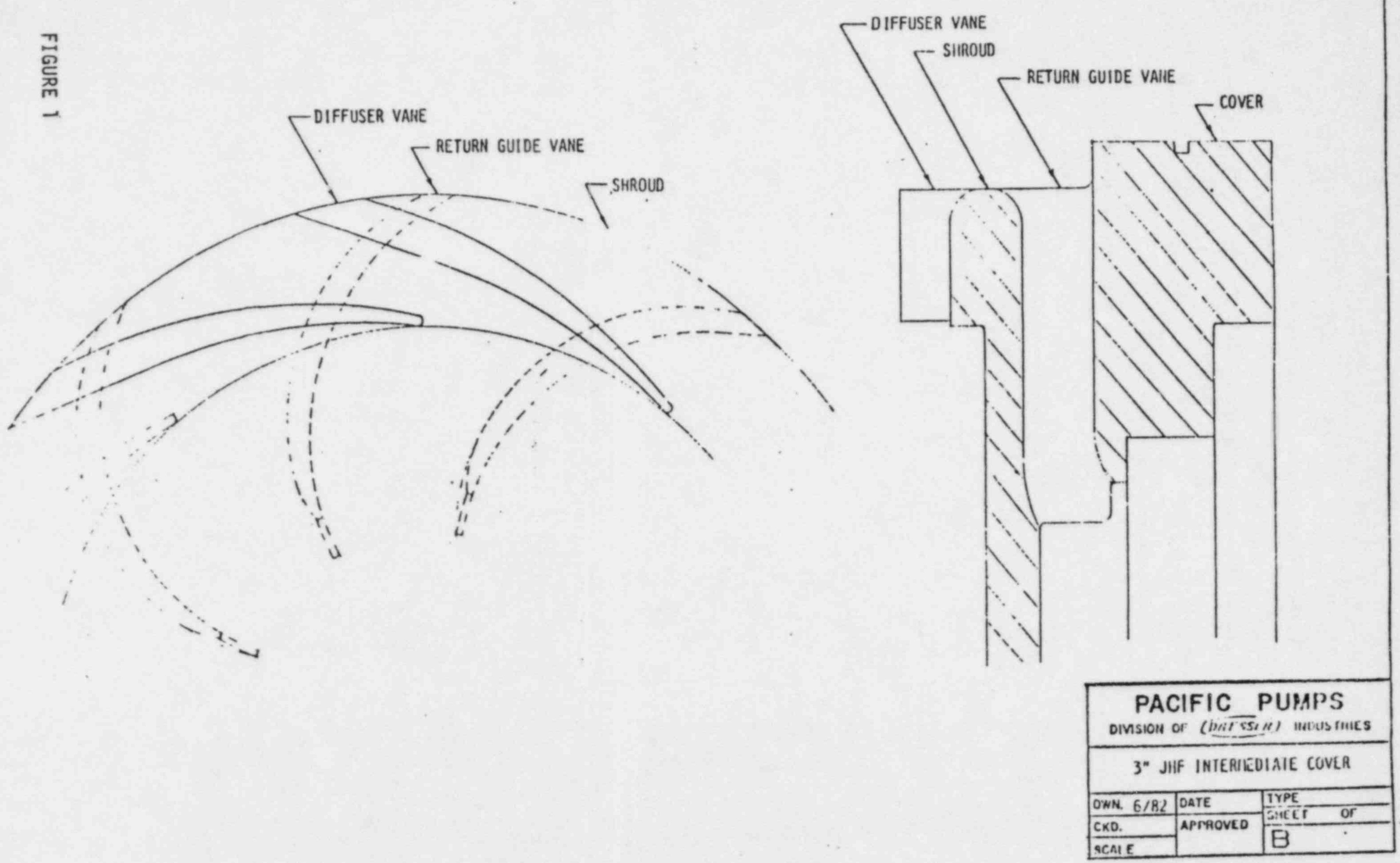
3) Report to Pacific all indications having a depth greater than 1.0 in. in the radial direction.

   Pacific emphasizes that they suggest the above program even though they are convinced that the indications pose no threat to the integrity of the intercover or operability of the pump.

III. CONCLUSIONS

The staff concurs with the field recommendation of Pacific Pumps on the basis of the analyses performed by that vendor's contractor for the applicant of

Comanche Peak. The staff further agrees that performance of a tear down of these pumps for the sole purpose of inspection is contraindicated by the information provided. The current ISI requirement of inspection at the 10 year interval appears to be justified. The staff is not in agreement with the use of visual inspection solely and requires that surface inspection (either penetrant or magnetic particle) should be added.


DIFFUSER VANE
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3" JHF INTERMEDIATE COVER
DWN. 6/82
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FIGURE 1

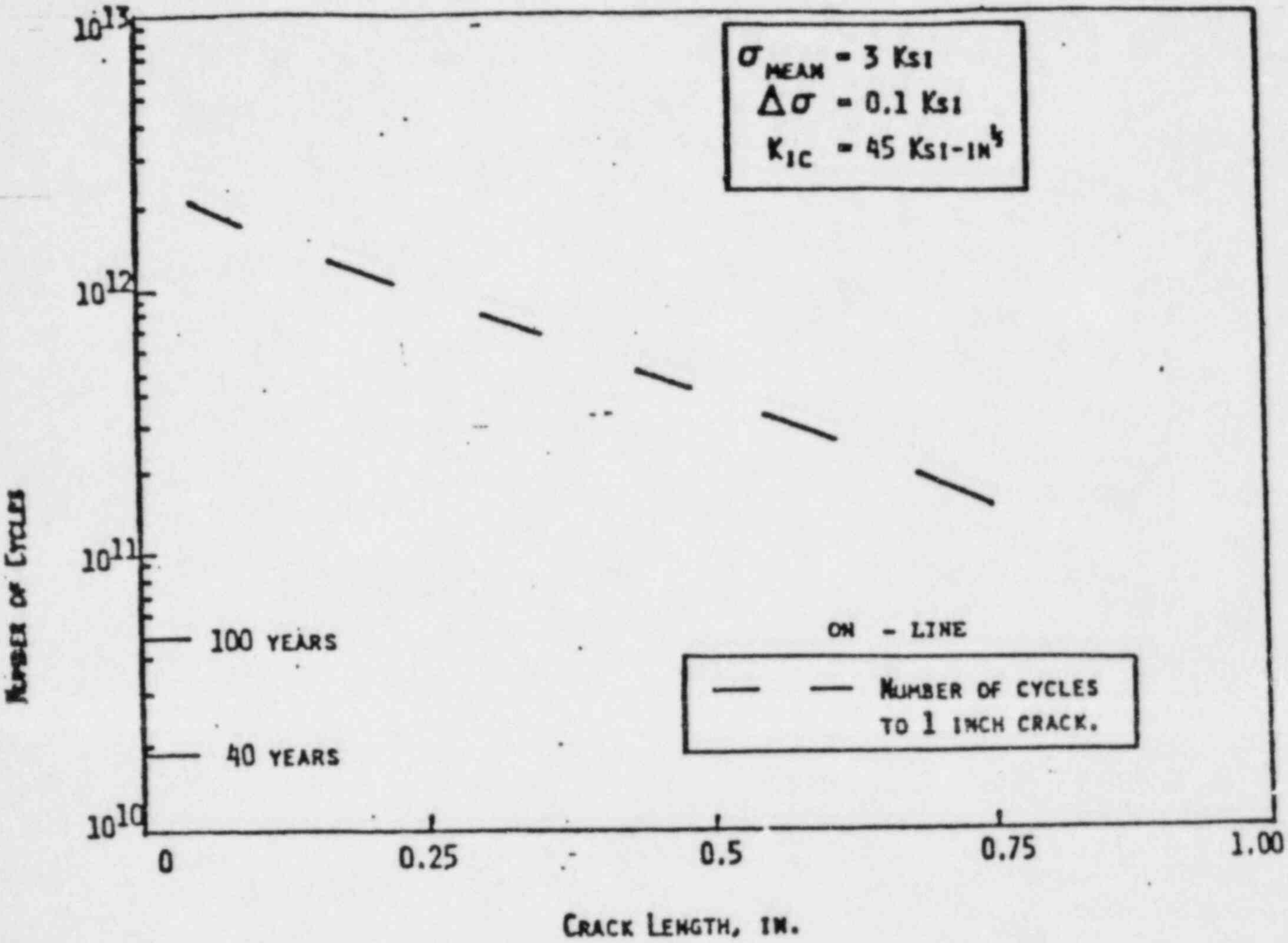

FIGURE 2. Predicted number of on-line fatigue cycles required to extend a radially oriented edge crack to 1-inch in length. Initial size or depth of hot tear is indicated on horizontal axis.

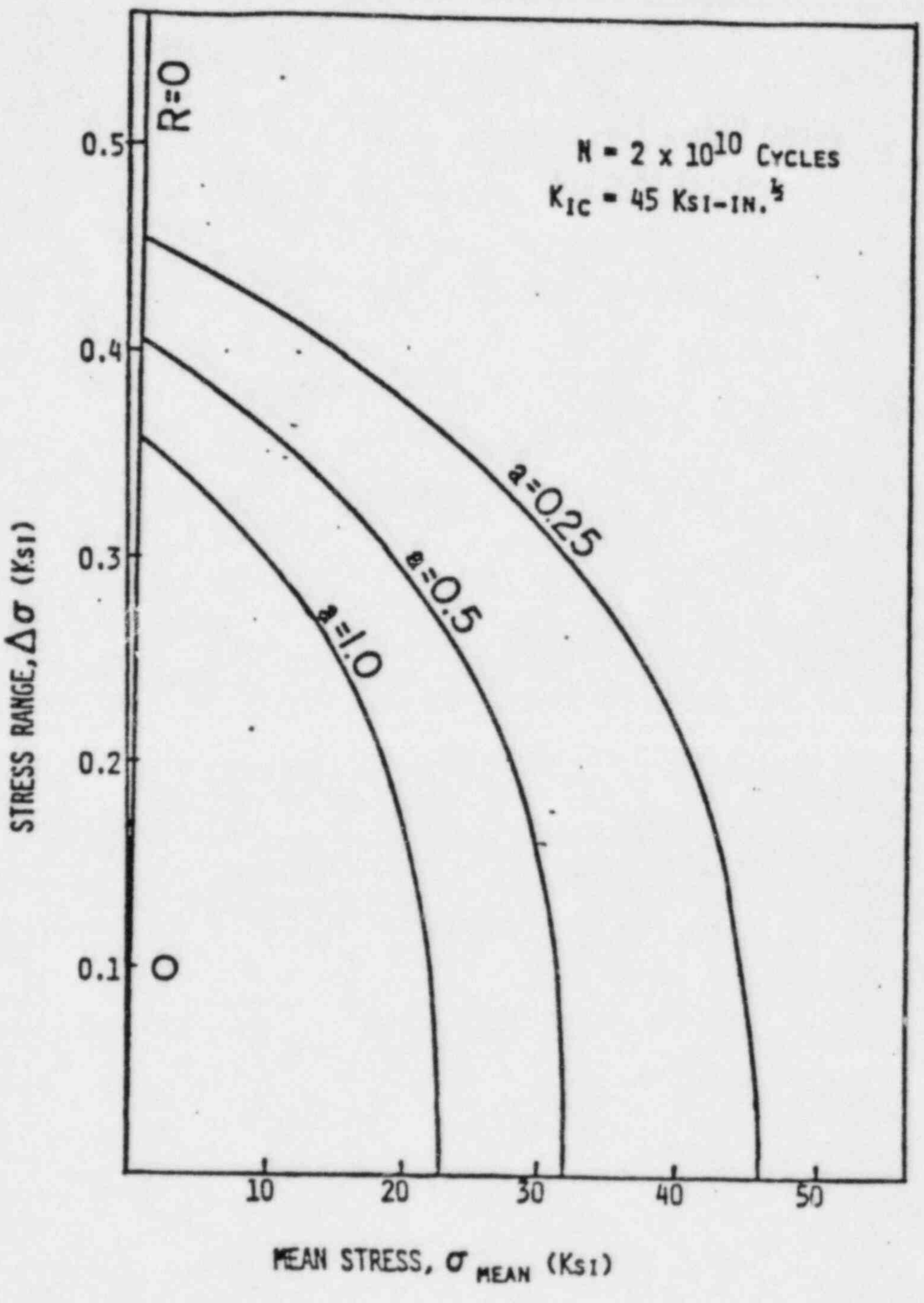

FIGURE -3. Safe-life design envelope for a projected 20,000 million cycles of on-line pressure pulses. Circle indicates actual operating conditions.

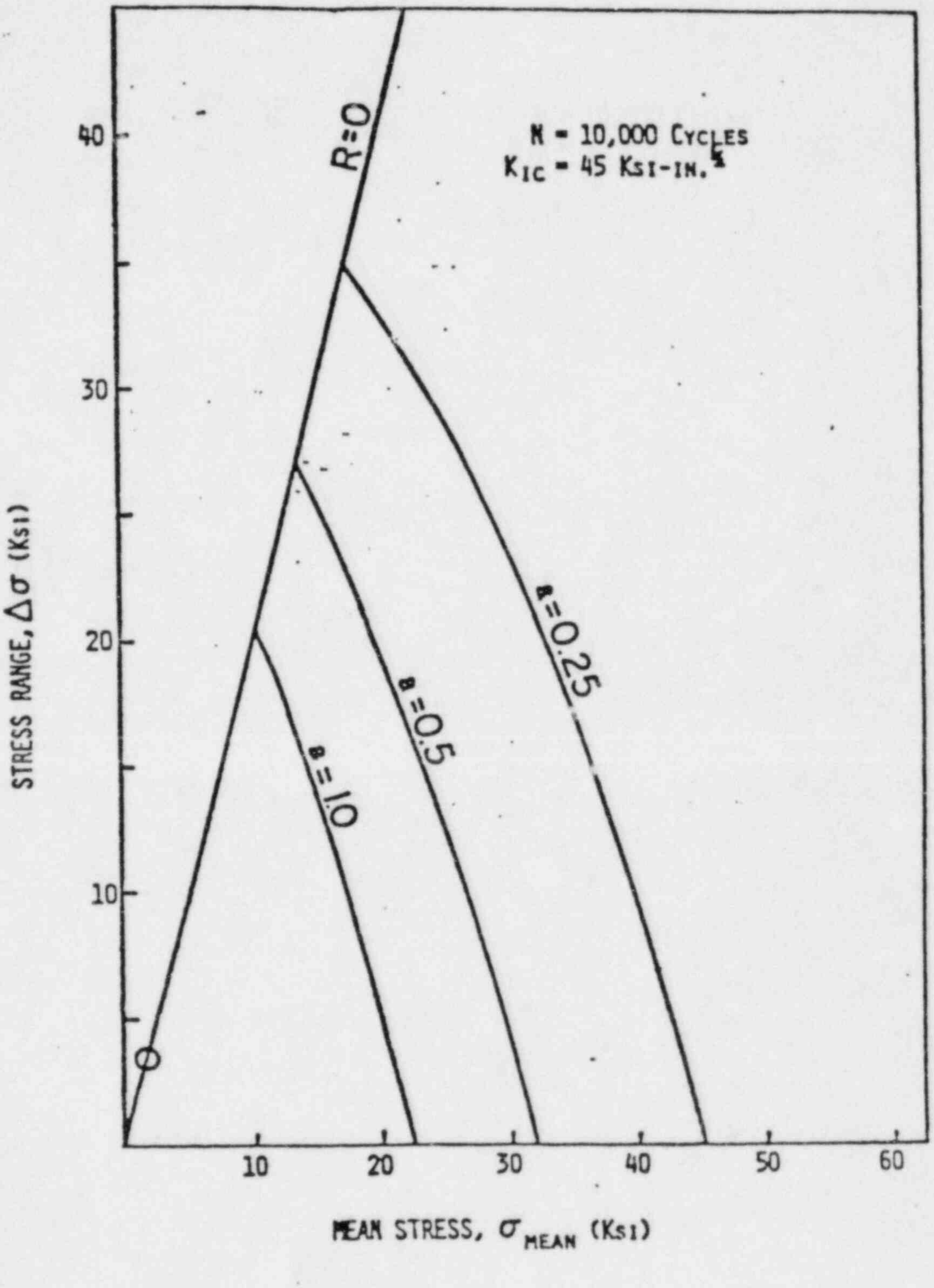

FIGURE 4. Safe-life design envelope for a projected 10,000 start-up cycles. Circle indicates actual operating conditions.