

To: K. E. Moore, NPGD

From: L. W. Sarver & J. S. Rovder, ARC

September 12, 1977

PRELIMINARY REPORT ON EXAMINATION
OF CR-3 DECAY HEAT PUMP SHAFT

Statement of Findings

This report covers preliminary results of metallurgical evaluation of a broken CR-3 decay heat pump shaft (Florida Power Corporation). Results were obtained via visual and optical microscopy examination, micro-sectioning and optical metallography, hardness testing on shaft cross sections, and by scanning electron microscope examination of the fracture surfaces.

The results of examinations to date suggest that fracture may have originated in the root of the shaft keyway (on a lineal locus along the shaft axis) then subsequently propagated from several secondary initiation sites on several planes inclined to the shaft axis. Fracture initiated roughly at the point of coincidence of an over sleeve on the shaft. The shaft appeared to be tightly-fit into the sleeve.

The initial crack area was crystallographic in appearance and thus differed significantly from subsequent beach-marked crack surface areas; the latter appeared to be representative of a progressive (fatigue) crack propagation process but the original crack process which produced the crystallographic surface is not known.

No geometric or material abnormalities were observed at the crack origin site.

1491 195

2910300 596

Fractographic analysis showed cracking to be predominantly transgranular in character but showed also some mixed intergranular and transgranular fractures; some of the latter mixed character was observed near beach markings. Intergranular fracture character did not appear to be associated with the origin of cracking. The significance of the intergranular fracture mode is not known.

Substantial damage was sustained along some portions of the locus of the crack origin, so complete fractographic analysis was precluded.

Hardness was not found to vary substantially through the shaft cross section (Rockwell C 31.5 to 35). Lowest values were recorded near the keyway. Hardness values appeared to be generally consistent with an H 1150 heat treatment (which produces Rockwell C 33 hardness) for 17-4 PH alloy - the shaft material.

Metallographic analysis revealed a microstructure containing essentially tempered martensite - as expected for H 1150 heat treatment of 17-4 PH alloy (i.e., the result of the solution heat treatment, air cool, and tempering heat treatment). Longitudinal microsections revealed what appeared to be some residual elongated ferrite grains; the significance of this characteristic is not known.

The results and findings stated are preliminary. It should be kept in mind that limited time was available to do this work. Virtually no background information was supplied, so we have no case history upon which to build a failure analysis. We will continue to complete the program set out by J. A. Gorman but more information is needed for us to do an adequate analysis.

1491 196

Preliminary Results: Documentation

- Appearance of Broken Shaft -

Figures 1-4 depict the broken shaft as observed at 90° rotations about its own axis.

Figures 5-7 illustrate the crack origin area at the keyway root. A subsurface crack, hidden from view in figures 5 (left) is exposed in Figure 7.

Figures 8-10 and 11-13 illustrate various aspects of both sides of the totally through-wall crack.

Figures 14-15 illustrate both sides of one of the nearly - through - wall crack surfaces which was forced open for viewing.

- Fractography -

Figure 16 illustrates a portion of the locus of crack initiation at the root of the keyway. Figures 17 and 18 illustrate details near the origin. Figure 19 shows the crystallographic character which generally typifies the fracture surface at the origin (Refer also to Figure 7).

Figures 20 and 21 show two different beach-markings from a secondary propagation system, as for example indicated by arrow in Figure 9 or Figure 15. Figures 22-24 illustrate growth character proceeding the last beach mark while figure 25 illustrates growth character beyond the last beach mark (fast growth). The mixed-mode conditions shown in Figure 24 occurred near a beach mark.

- Metallography -

Microstructure of the shaft is shown in Figures 26-29 (Transverse section) and in Figures 30-33 (longitudinal section). Microstructure close to the keyway is illustrated in Figures 34-37.

1491 197

- Hardness -

Rockwell C hardness surveys from transverse and longitudinal sections of the shaft are reported in Figure 38.

1491 198

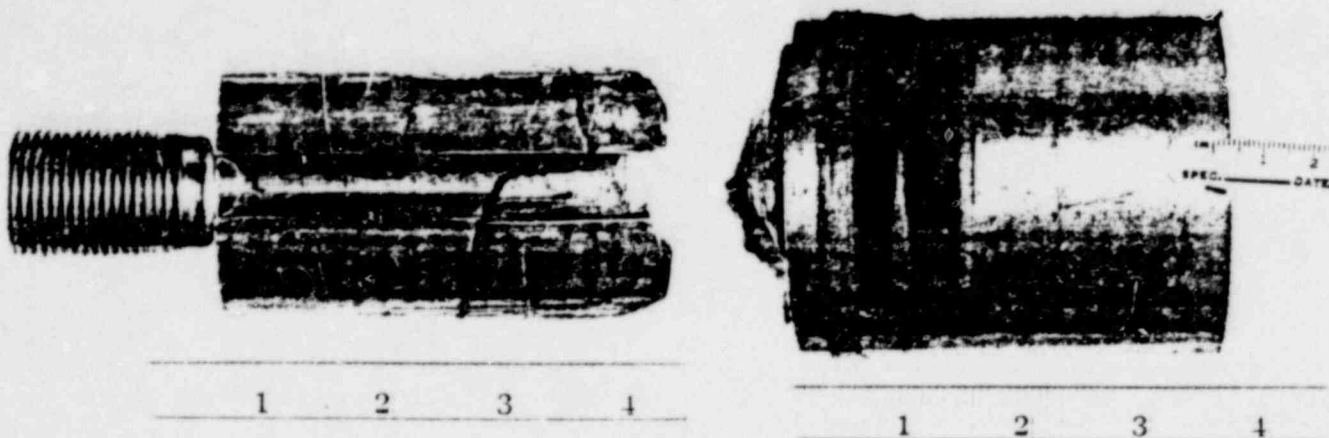


FIGURE 1 CR-3 SHAFT

POOR ORIGINAL



FIGURE 2 CR-3 SHAFT

1491 199

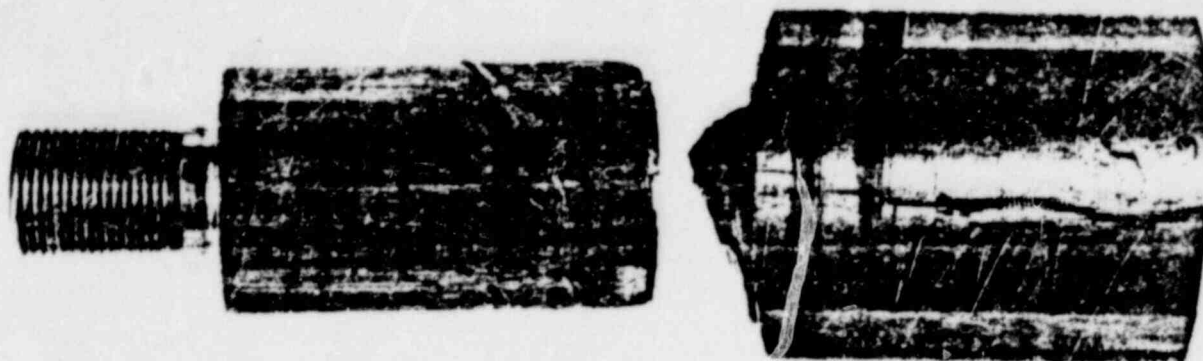


FIGURE 3 CR-3 SHAFT

POOR ORIGINAL

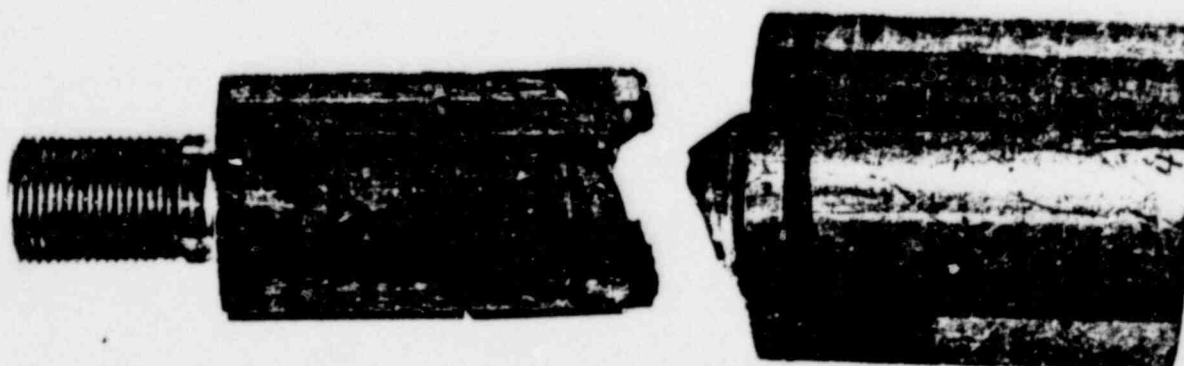


FIGURE 4 CR-3 SHAFT

1491 200

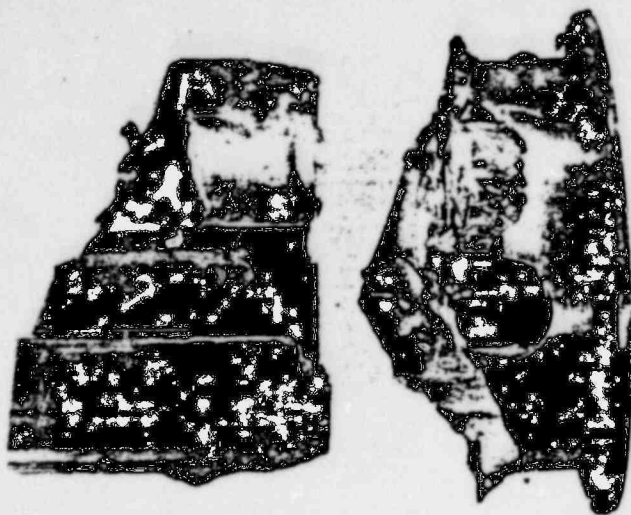


FIGURE 5 CR-3 SHAFT



FIGURE 6 CR-3 SHAFT



FIGURE 7 CR-3 SHAFT
CRACK ORIGIN

1491 201

POOR ORIGINAL



FIGURE 8



FIGURE 9

POOR ORIGINAL

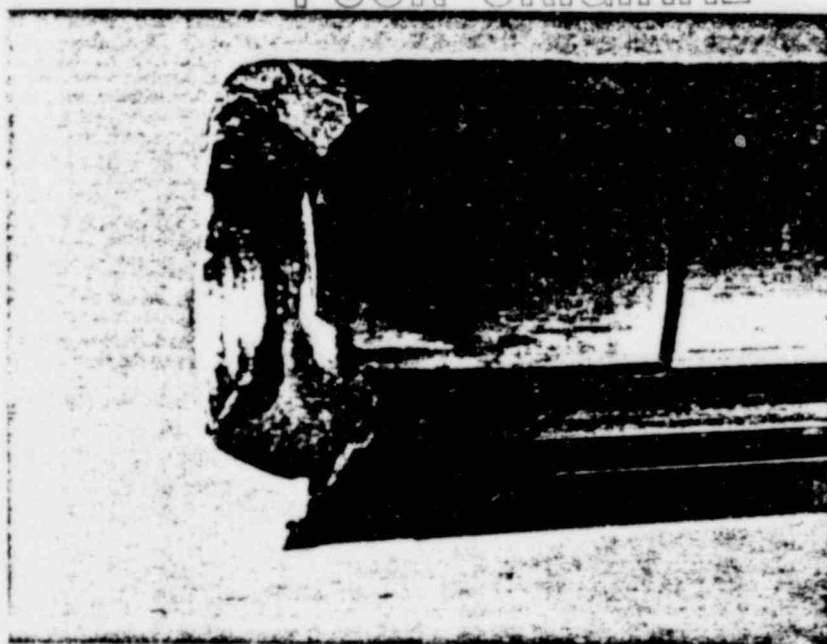


FIGURE 10

1491 202



FIGURE 11



FIGURE 12



FIGURE 13

1491 203

POOR ORIGINAL



FIGURE 14

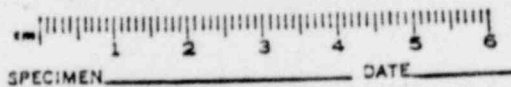


FIGURE 15

POOR ORIGINAL

1491 204

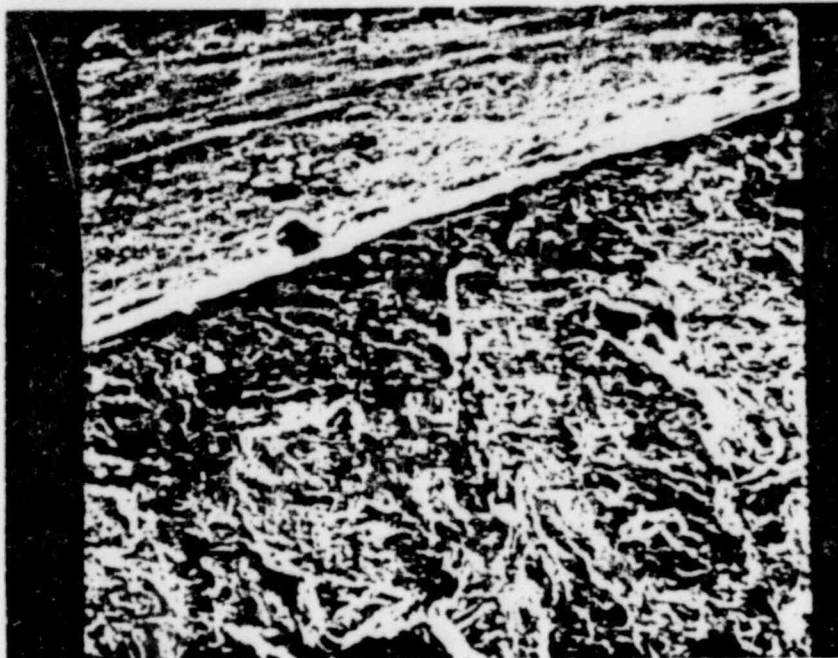


FIGURE 16

ORIGIN AREA

190X

POOR ORIGINAL

1491 205

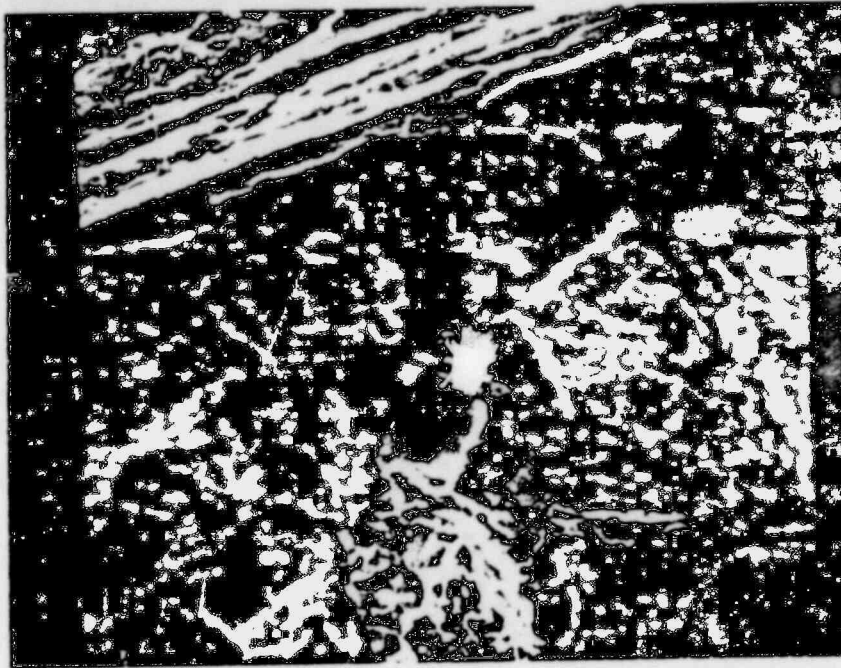


FIGURE 17

620x

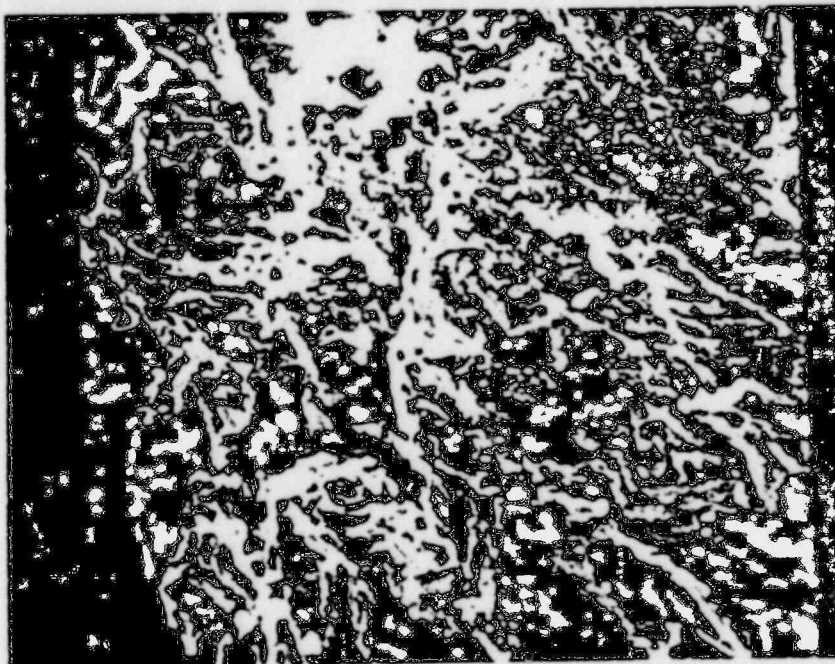


FIGURE 18

620x

POOR ORIGINAL

1491 206



FIGURE 19

1400x

POOR ORIGINAL

1491 207

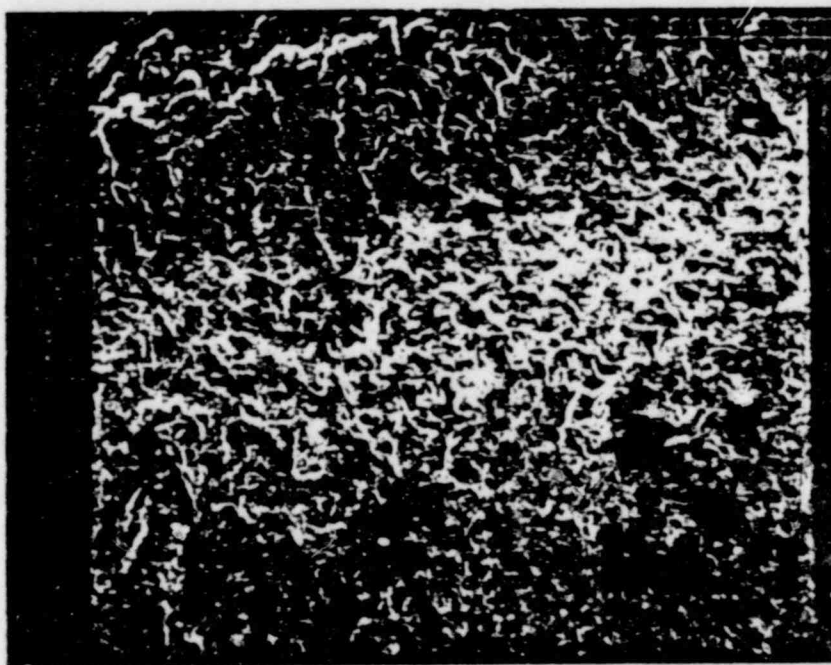
1st Surface →



FIGURE 20

50x

1st Surface →



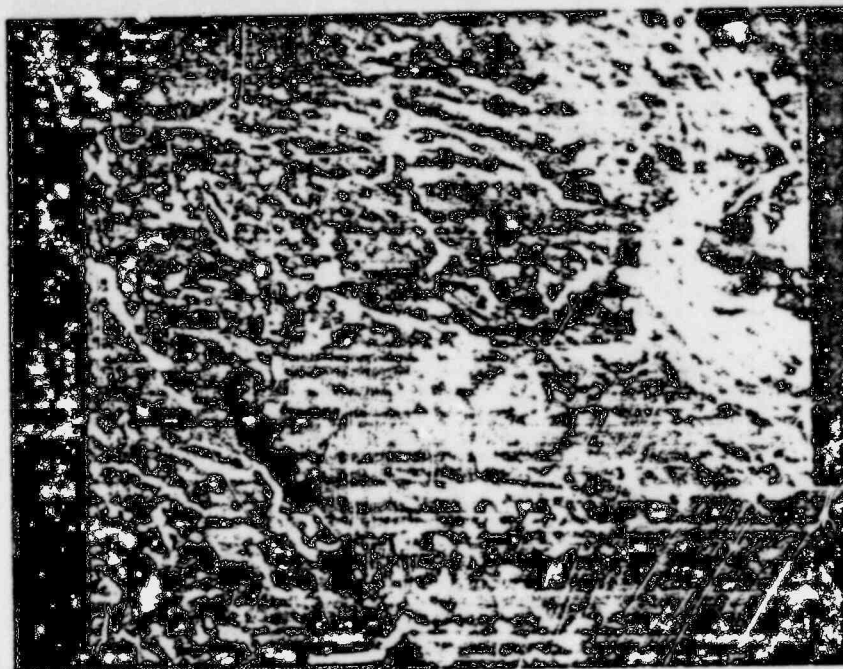
MIXED MODE ↑

FIGURE 21

1491 208

50x

POOR ORIGINAL

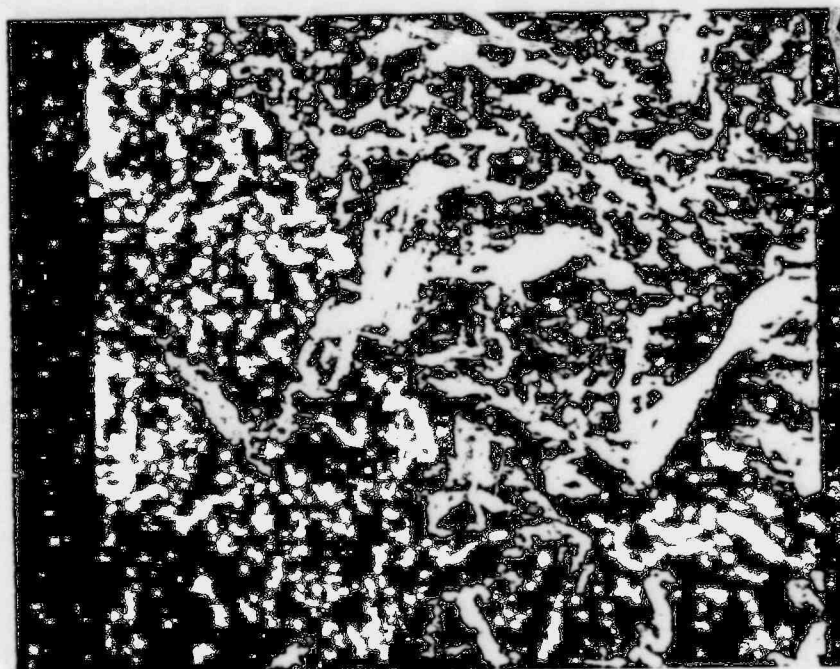


150x

3

FIGURE 22

500x



150x Surface →

FIGURE 23

1491 209

POOR ORIGINAL

500x

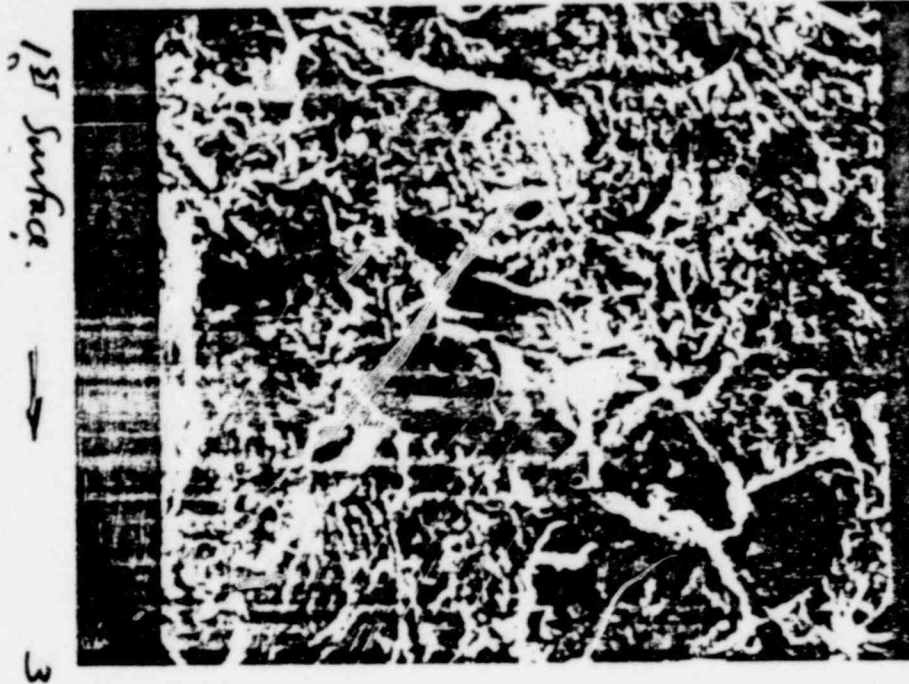


FIGURE 24

500x

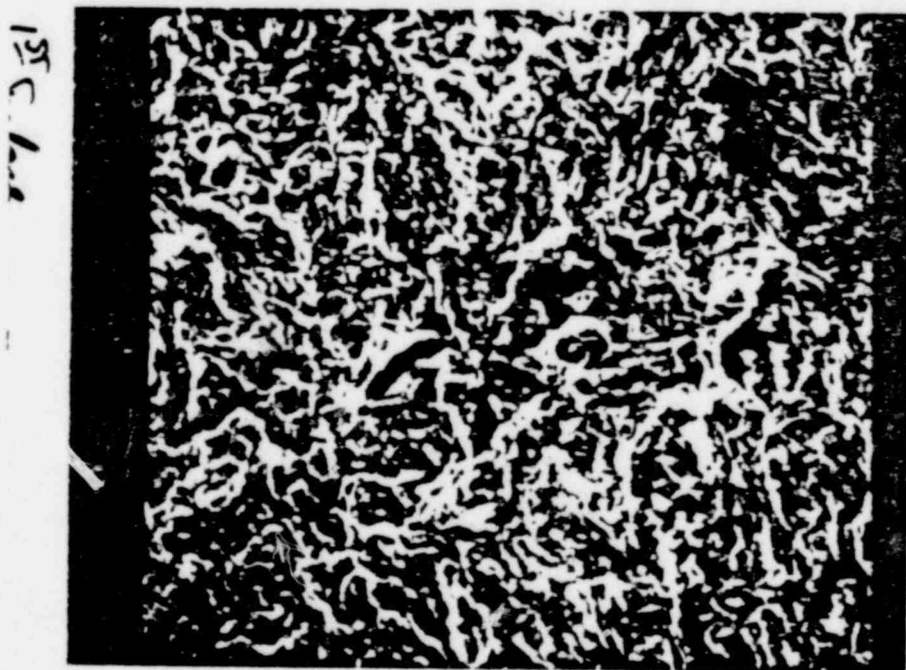
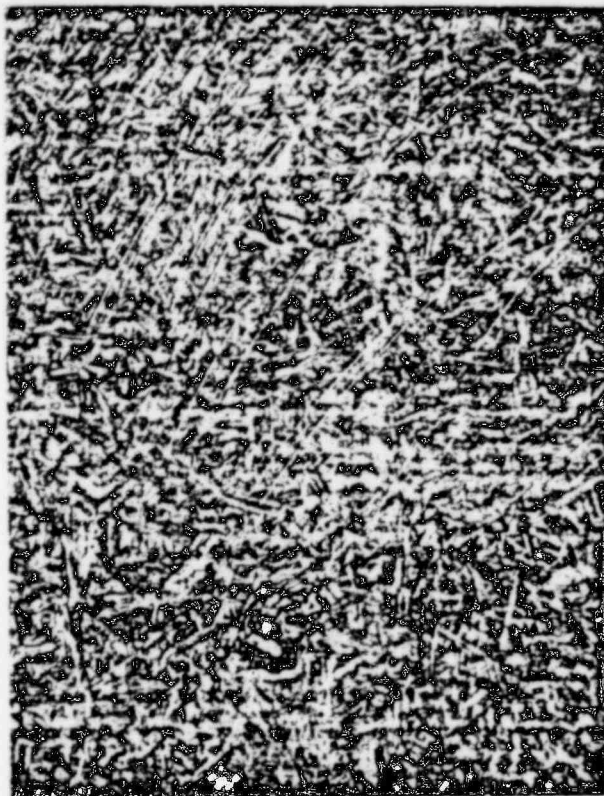


FIGURE 25

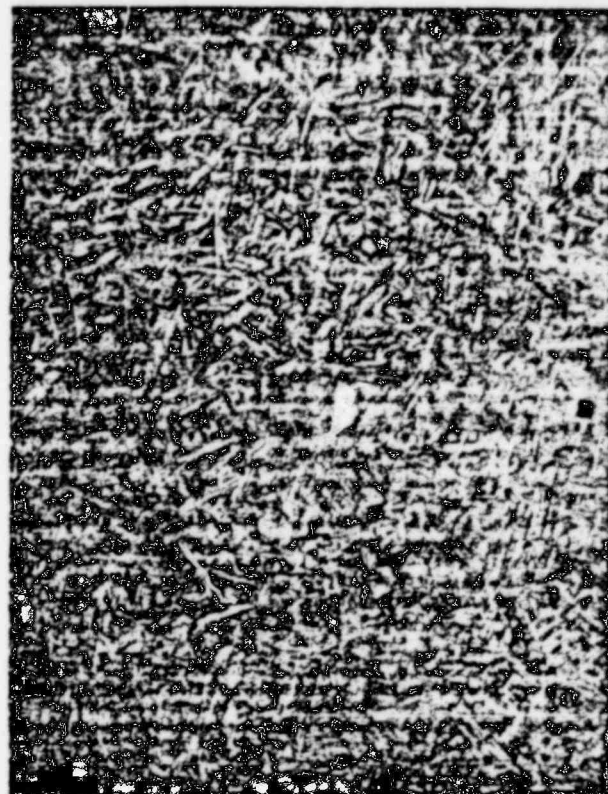
1491 210

500x

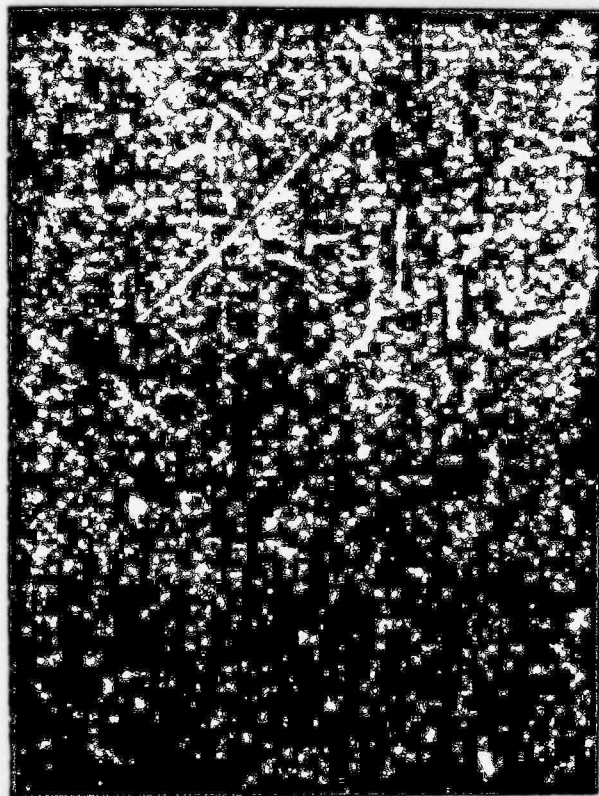
POOR ORIGINAL



SHAFT O.D TRANS. 100X



SHAFT CENTER TRANS. 100X



SHAFT O.D TRANS. 400X

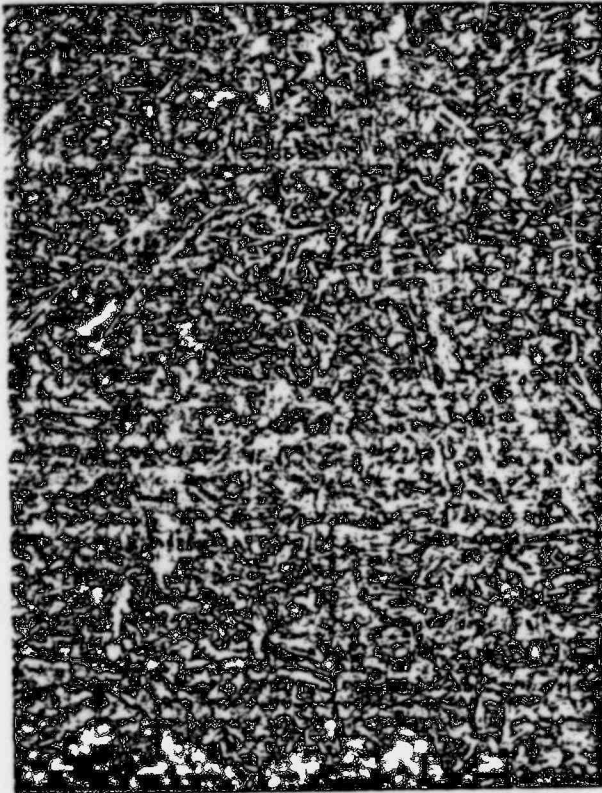


SHAFT CENTER TRANS. 400X

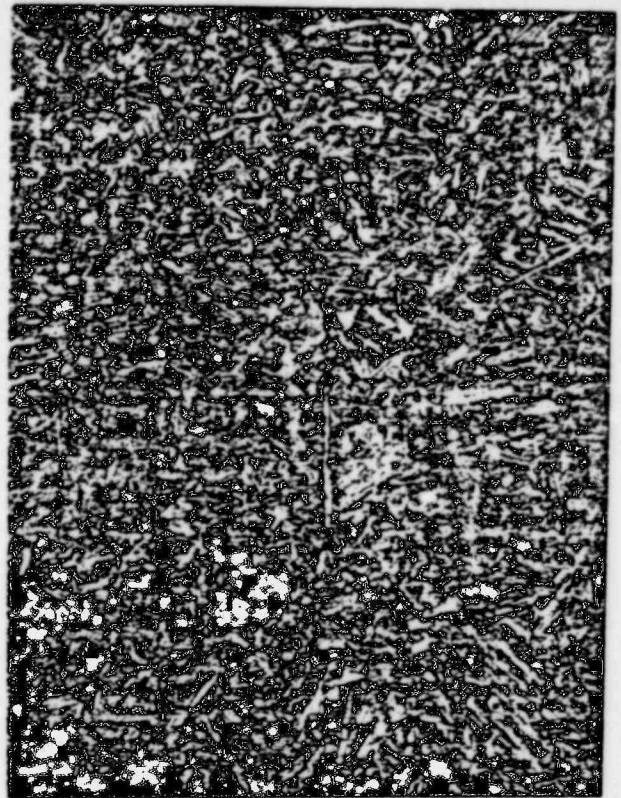
1491 211

FIGURES 26-29

POOR ORIGINAL



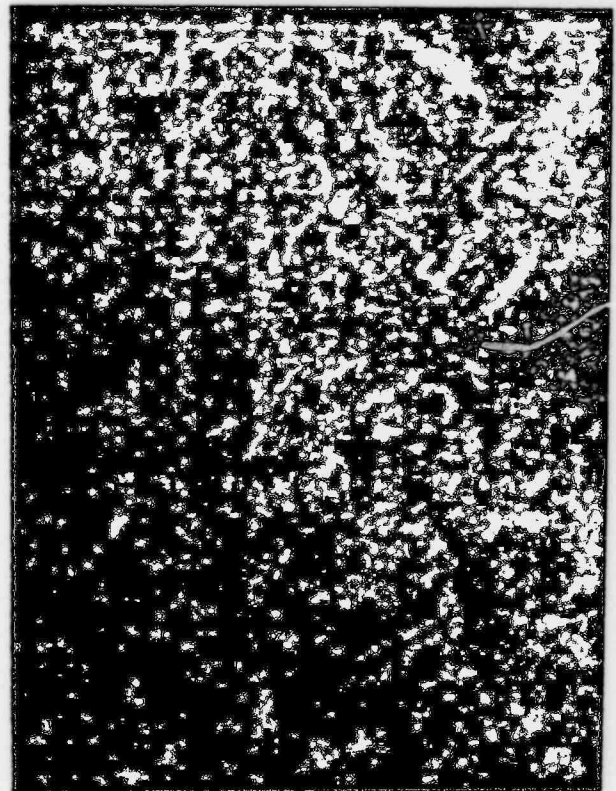
SHAFT O.D. 100X
LONGITUDINAL



SHAFT CENTER 100X
LONGITUDINAL



SHAFT O.D. 400X
LONGITUDINAL



SHAFT CENTER 400X
LONGITUDINAL

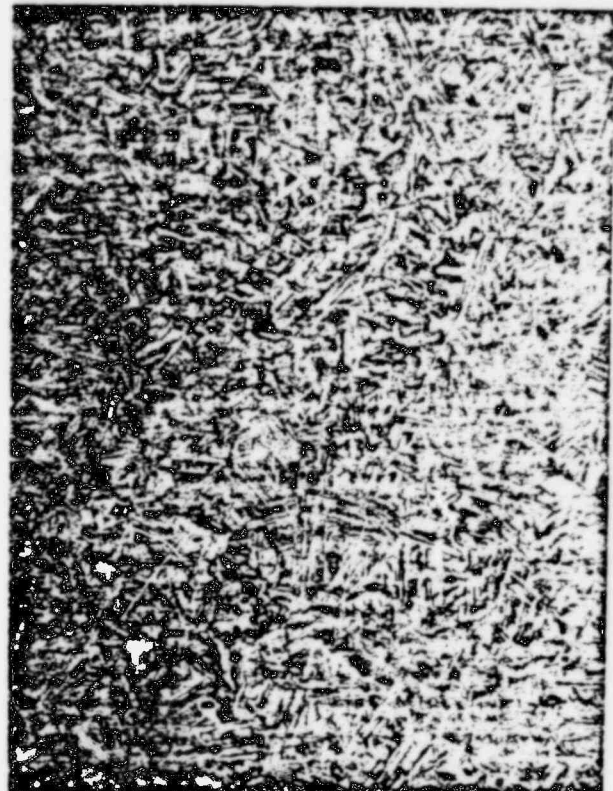
FIGURES 30-33

POOR ORIGINAL

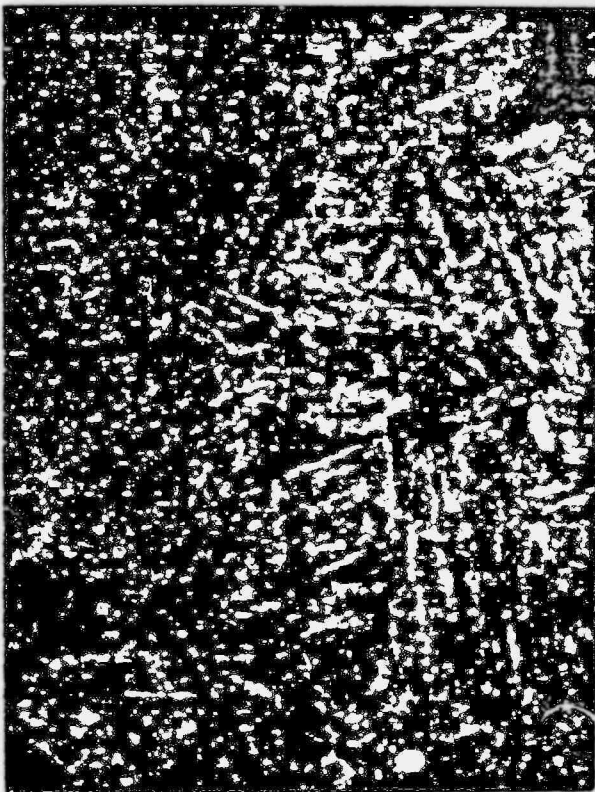
1491 212



KEYWAY CORNER 100X
TRANSVERSE



KEYWAY BASE 100X
TRANSVERSE



KEYWAY CORNER 400X
TRANSVERSE



KEYWAY BASE 400X
TRANSVERSE

1491 213

FIGURES 34-37

POOR ORIGINAL

