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SUBJECT: Metallographic Examination of ORNL # 1, SHE # 2

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Metallography Report # 287

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Introduction:

Small Heat Exchanger ORNL # 1, type SHE # 2, was removed from test stand B after 2071 hours of operation; 1041 hours were under Δ T conditions. The heat exchanger, as shown in Fig. 1, contained 20 Inconel tubes having an outside diameter of 0.25 in. and a wall thickness of 0.025 in. The outside of these tubes was exposed to the fluoride mixture $NaF-ZrF_4-UF_4$ (50-46-4 mole %), while the inside of the tubes contained NaK (44% Na - 56% K). During Δ T conditions, the fluoride temperature entering the heat exchanger was 1310°F and on leaving was 1235°F. The temperature of the NaK entering the heat exchanger was 1050°F and at the exit was 1290°F. During isothermal operation, the temperature of both the NaK and fluoride circuits was 1300°F. Thirty-six temperature transitions from isothermal to Δ T conditions were made during the course of operation. An examination of the resistance heater used in conjunction with this heat exchanger also was made, the results of which are contained in Appendix A to this report.

Mass Transfer and Corrosion:

Thirty-five samples were removed from the entire heat exchanger; twenty-five of these were from the tube bundle itself as illustrated in Figure 2. Three samples, one each from the top, middle, and bottom of the tube bundle, were removed from sections 1 through 7, and two samples were removed from 1A and 3A as indicated. Figure 3 shows the method used for removing samples from each of the headers. All of the samples were mounted, ground, polished, and examined for evidence of mass transfer and corrosion.

The corrosion found on the outside of the tubes exposed to the fluoride mixture ranged to a maximum depth of .004 inches; however, the frequency of occurrence along the tube wall was heavier at the NaK outlet header, which was the hottest area in the heat exchanger. The maximum depth of fuel side corrosion did not change along the entire length of the heat exchanger, although the frequency of corroded grains increased with the fuel temperature from the cold to hot end. Figures 4 through 9 present a panorama of conditions encountered along the tube bundle. The locations of the samples are given in the caption with each photomicrograph.

In the examination of the headers it was noticed that one side of the tubes below each header was corroded to a much greater extent than the opposite side. The side of the tube which was more heavily corroded was the side which would be in tension while the heat exchanger was heating up.

Figure 10 shows the tension side of tube number 1 from the NaK inlet where one group of voids is found extending to a maximum depth of .004 inches. Compare Figure 10 to Figure 11 which shows the compression side of the same tube. The latter figure shows a very clean surface having only two small voids to a depth of .0005 in.

Discussion:

The depth of attack observed on the fluoride side of this heat exchanger was uniform from header to header and did not exceed .004 inches. This attack is, of course, substantially less than that which was found in the examination of intermediate heat exchanger ORNL # 1[1], which operated for a period of time comparable to the subject heat exchanger. This difference in attack between the two test units is explained by considering the relative locations of the heat exchangers in the fluoride circuits of the small and intermediate heat exchanger tests. In the latter tests the number one heat exchanger serves as the hot leg of the fluoride circuit, where heat is transferred from NaK to salt. As a result fluoride attack in this circuit is most rapid in the hotter sections of this heat exchanger.

In the small heat exchanger experiments, however, the heat exchanger serves as the heat dump for the fluoride circuit, heat being supplied from a direct resistance heater. Thus, the heat exchanger must be considered as the cold leg of the circuit, and little attack would be expected. Fluoride corrosion along the resistance heater, on the other hand, was relatively high. As seen in Appendix A, attack in this section reached a maximum depth of .028 inches.

In addition to a higher level of attack, IHE-ORNL No. 1 also showed evidence of intergranular cracking below the NaK inlet header. Such cracking was entirely absent in the examination of SHE-ORNL # 1.

A gold colored film was formed around the outside of the tubes and spacer bar of the latter heat exchanger near the fluoride outlet; a picture of the deposit is presented in Figure 12. Similar deposits have been found in Δ T-V loops and have been identified as TiO_2. The origin of these deposits is presently unknown. While the source of titanium is most certainly the Inconel tubing, the mechanism by which this element is reacted with oxygen without drastically affecting the fuel is unexplained. No other deposits, metallic or nonmetallic, were seen in the fluoride circuit.

The inside surface of the tube, which was exposed to the NaK, was only slightly attacked. The attack found was intergranular to a maximum depth of .001 inches as shown in Figure 3.

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[1] CF 56-7-135 "Examination of ORNL # 1 and 2 Intermediate Heat Exchangers Type I.H.E. # 3", J. H. DeVan

SECRET

Examination of The Resistance Heater From SHE Stand B

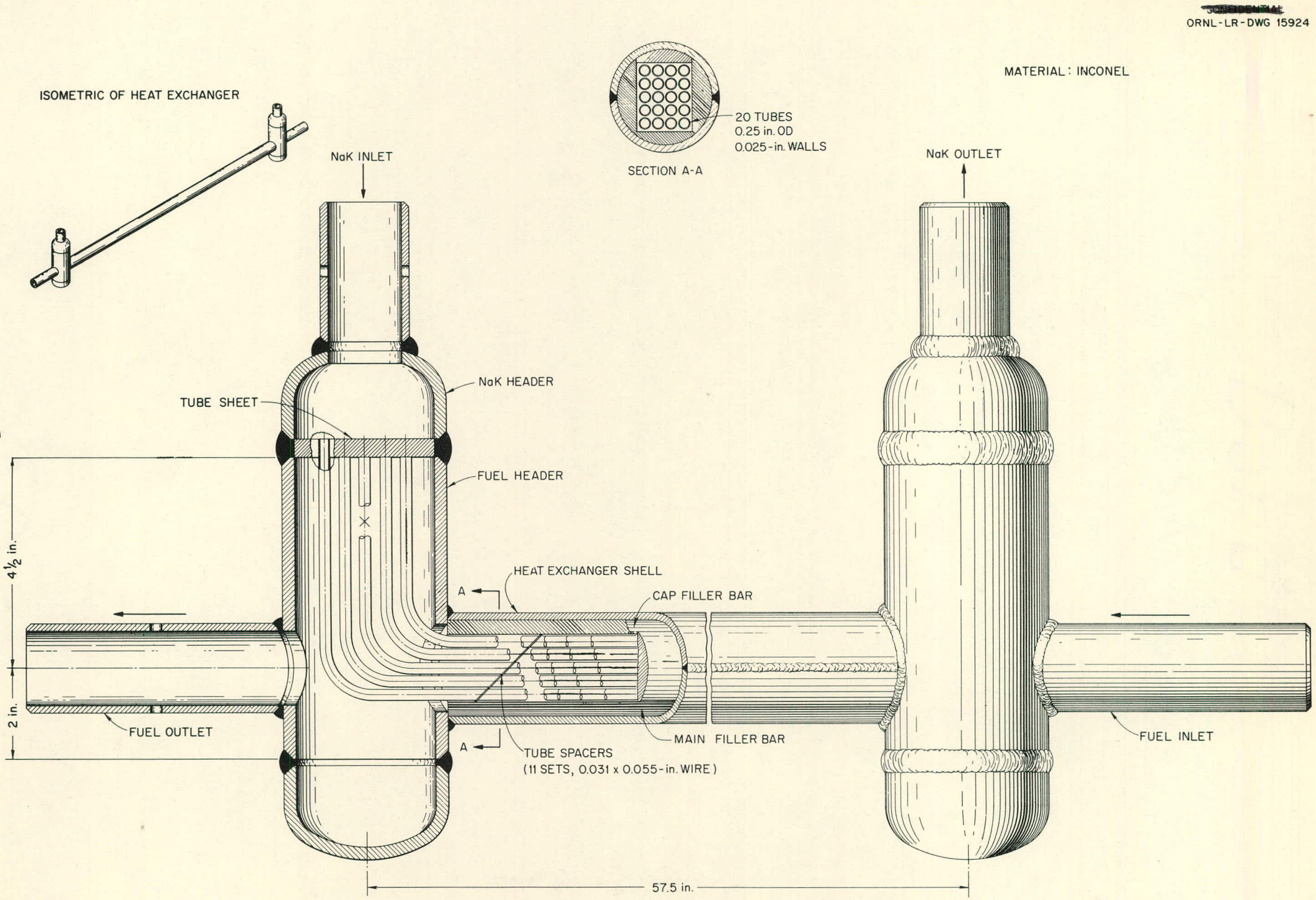
The subject heater was used in conjunction with the fluoride circuit of Small Heat Exchanger ORNL # 1, type SHE # 2, and was received for metallographic examination following the termination of the heat exchanger. The heater was constructed from 2 inch IPS Schedule 40 Inconel pipe in accordance with the diagram given in Fig. 12. During its operation the heater produced a fluoride outlet temperature of 1500°F for a total period of 2071 hours. During Δ T operation of the heat exchanger, heater wall temperatures near the outlet heater lug were in excess of this value, reaching a maximum of 1670°F.

The sections of the heater received for examination, which are designated in Fig. 13 were not marked as to the direction of flow, nor was it known from which half of the heater each section was taken. Consequently, metallographic samples, which were cut from the ends of the two sections received (Fig. 12), cannot be assigned specific locations with respect to their positions during test.

Metallographic results for the four samples examined are as follows:

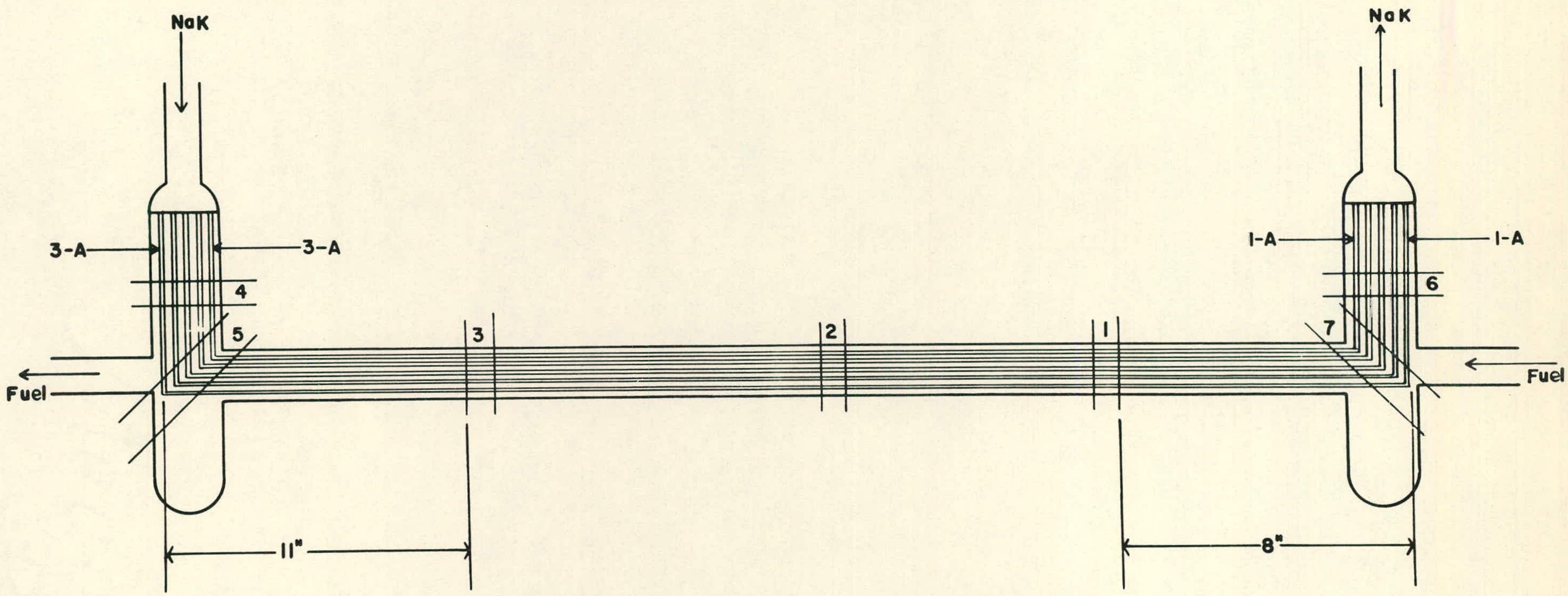
Sample No.	
X-10978	Heavy general and intergranular void formation to .015 inches.
X-10980	Heavy general and intergranular void formation to .015 inches. Heaviest attack does not occur generally but is concentrated on one side of the pipe.
X-10981	Attack varied from heavy general void formation .003 inches to heavy general and intergranular voids to .020 inches.
X-10979	The attack varied from heavy general void formation .006 inches on one side of the pipe to heavy general and intergranular voids .031 inches on the opposite side.

It will be noticed that the samples have been listed in order of increasing attack. It is probable that in this order the samples represent sections taken in sequence from the inlet to the outlet end of the heater, but, of course, this is not known. A photomicrograph showing the maximum attack recorded among the samples is given in Figure 14.



Small Heat Exchanger Type SHE-2

Fig. 1



HEAT EXCHANGER TYPE SHE-2, ORNL-1

Fig. 2 Sample Location and Nomenclature Y-21565

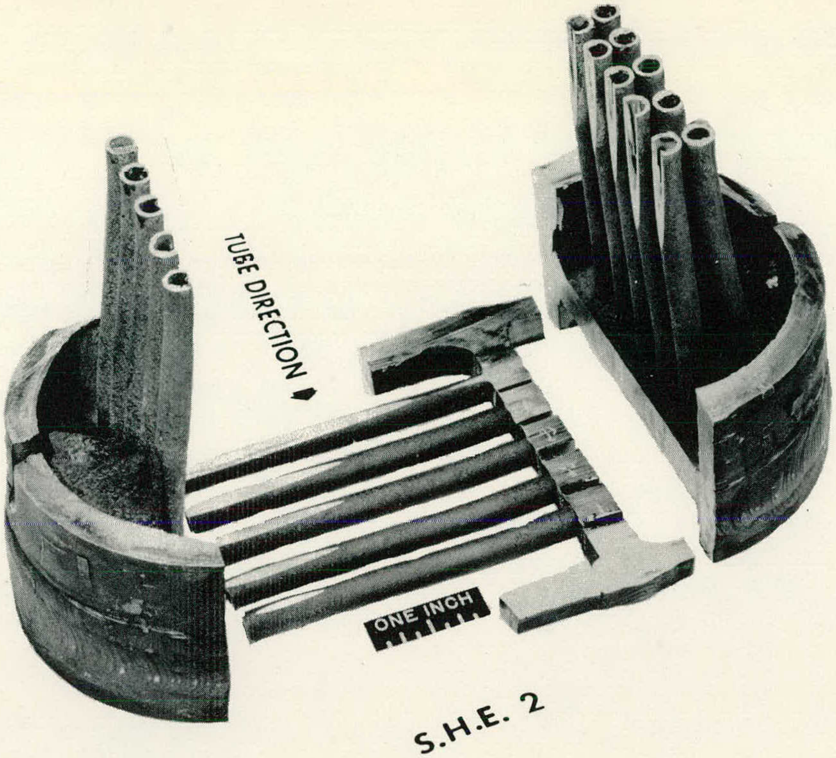


Fig. 3 Dissection method used for both headers. Y-18909

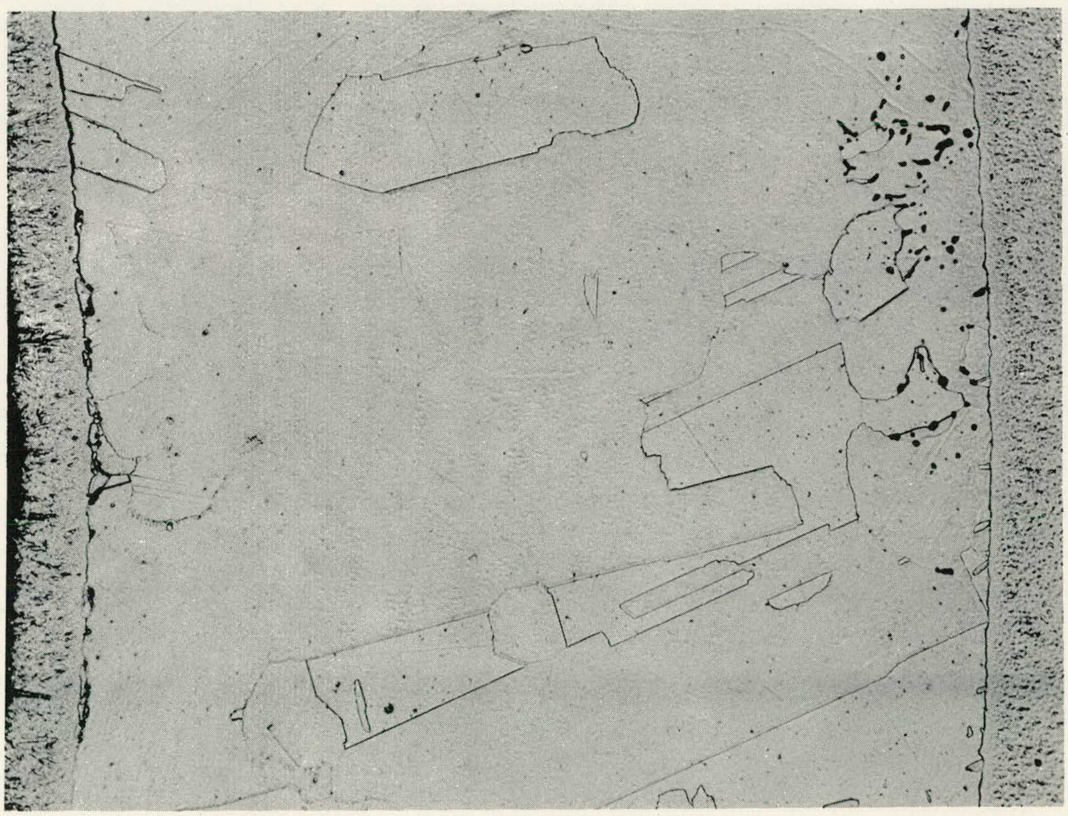


Fig. 4 Sample 1A (inside) Note the scattered voids .004 inches deep. Sample has been Ni plated. Etched with Mod. Aqua Regia T-11608 200 X

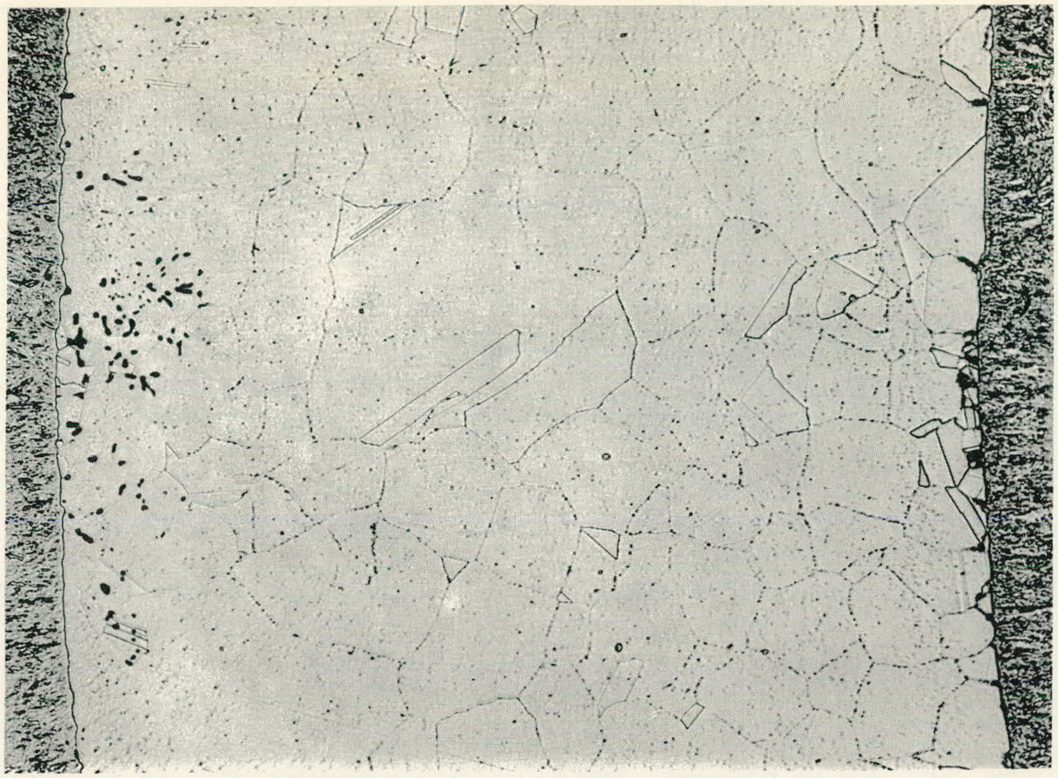


Fig. 5 T-11609 200 X

Sample 1 (top) Note the scattered voids .004 inches deep on the fluoride surface and regular grain boundary attack on the NaK surface. Sample has been Ni plated. Etched with Mod. Aqua Regia.

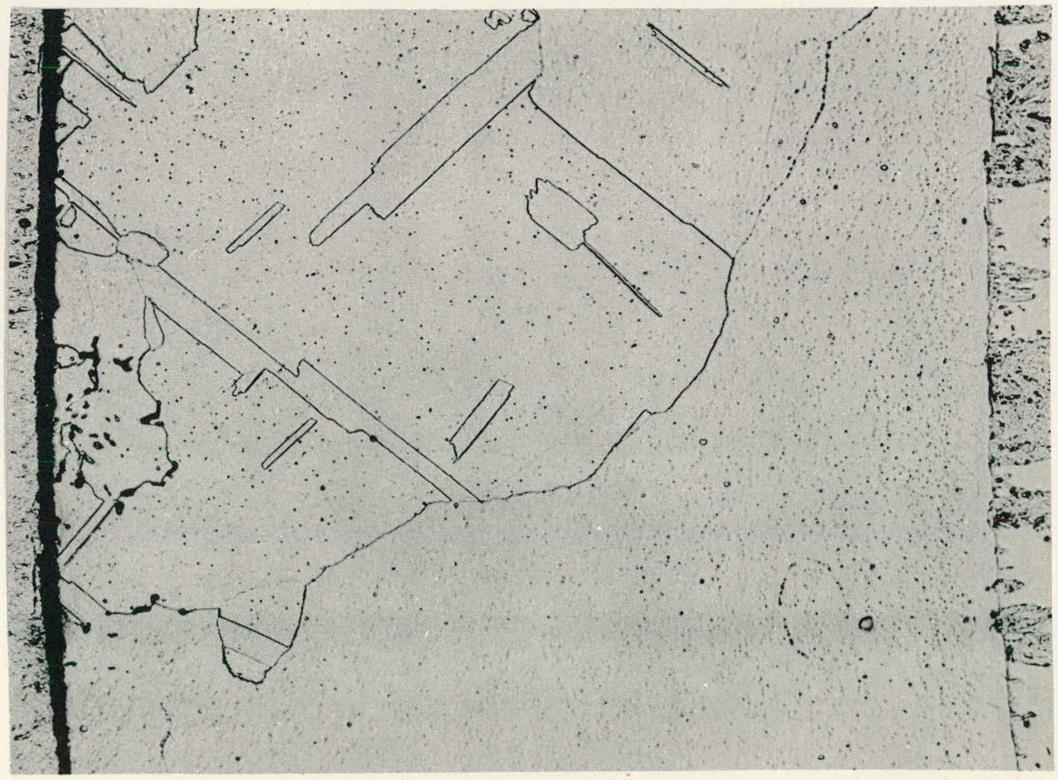


Fig. 6 T-11610 200 X

Sample 2 (middle) Note the scattered voids .004 inches deep on the NaK surface. Sample has been Ni plated. Etched with Mod. Aqua Regia

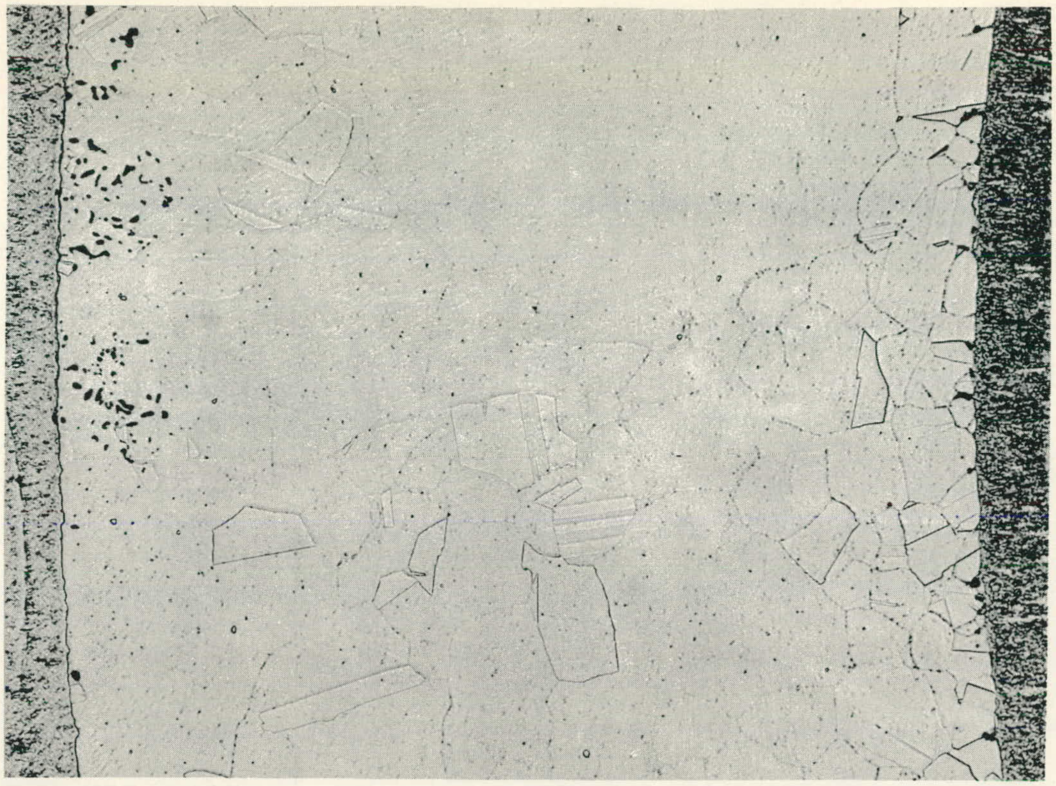


Fig. 7 T-11611 200 X

Sample 3 (top) Note the scattered void on the fluoride surface .005 inches deep and regular grain boundary attack on the NaK surface .001 inches deep; also note the variable grain size. Sample has been Ni plated. Etched with Mod. Aqua Regia.

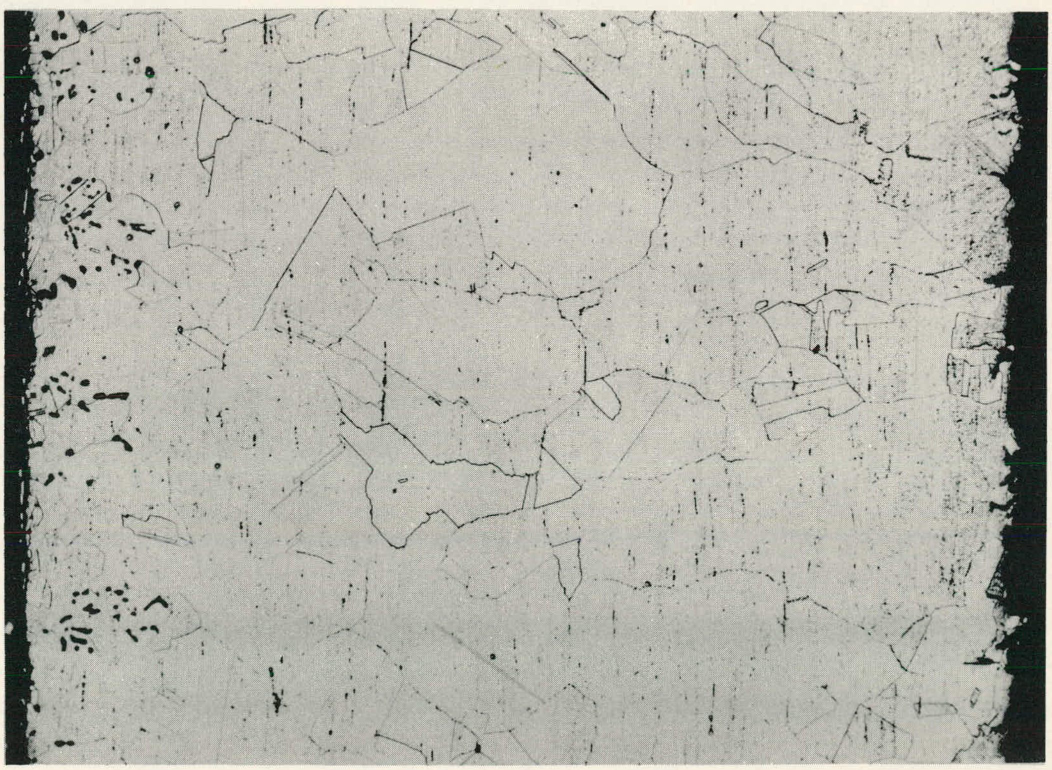


Fig. 8 Y-21264 200 X

Sample 4 (inside) Note the scattered voids on the fluoride surface .004 inches deep and the general roughening of the NaK surface; also note the more regular and smaller grain as compared with Fig. 7. Etched with Cu Regia.

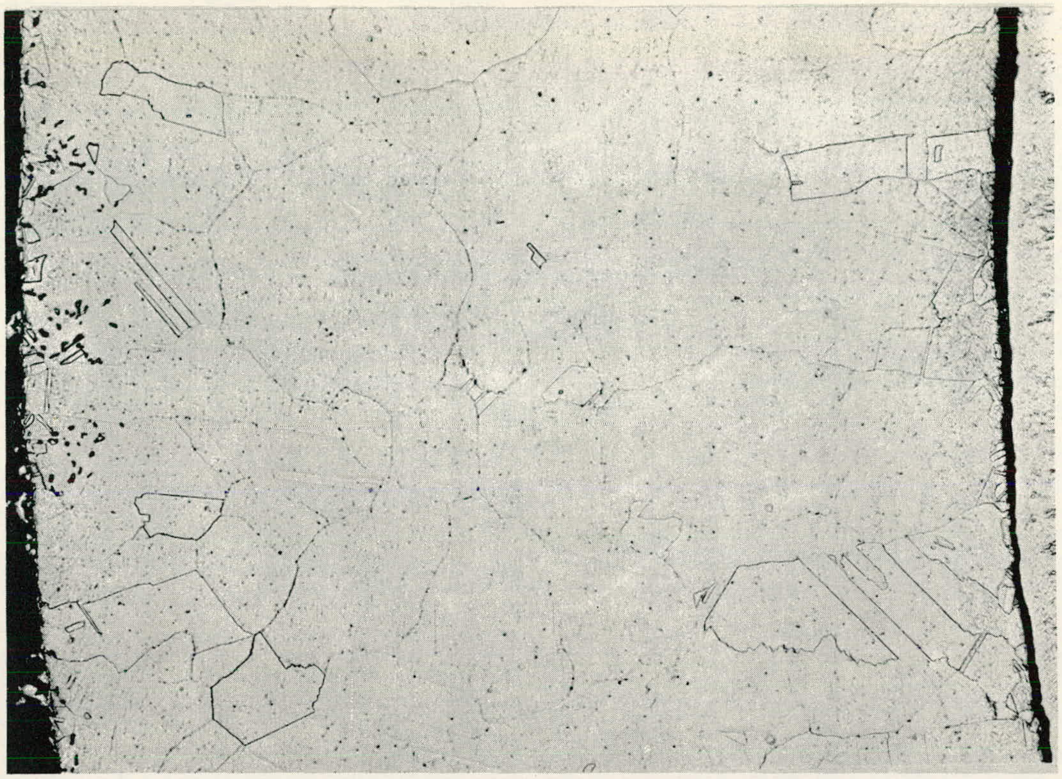


Fig. 9 T-11612 200 X

Sample 3A (inside) Note the scattered voids on the fluoride surface .004 inches deep and little or no attack on the NaK surface. Sample has been Ni plated. Etched with Mod. Aqua Regia.

Fig. 10 Y-19067 250 X

Tension side of tube number 1 from the NaK inlet header. Note the scattered voids .004 inches deep. Etched with electrolytic oxalic acid.

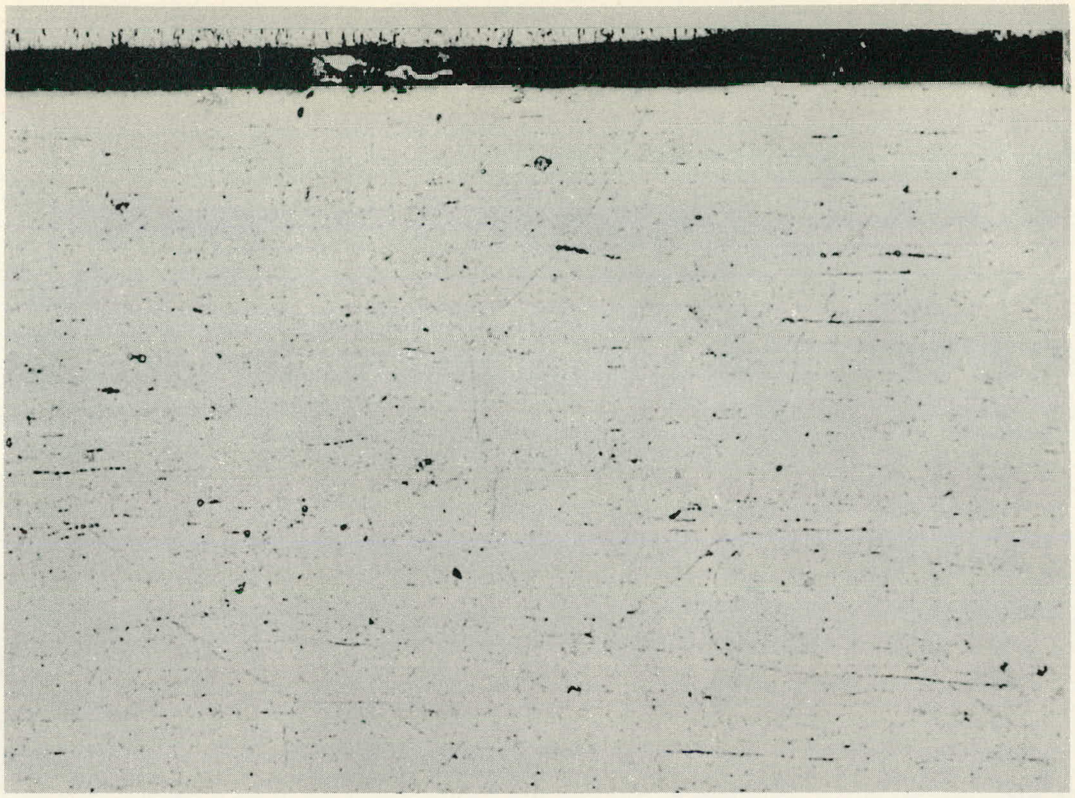


Fig. 11 Y-19068 250 X

Compression side of tube number 1 from the NaK inlet header. Note the absence of voids as compared with Figure 10. Etched with electrolytic oxalic acid.

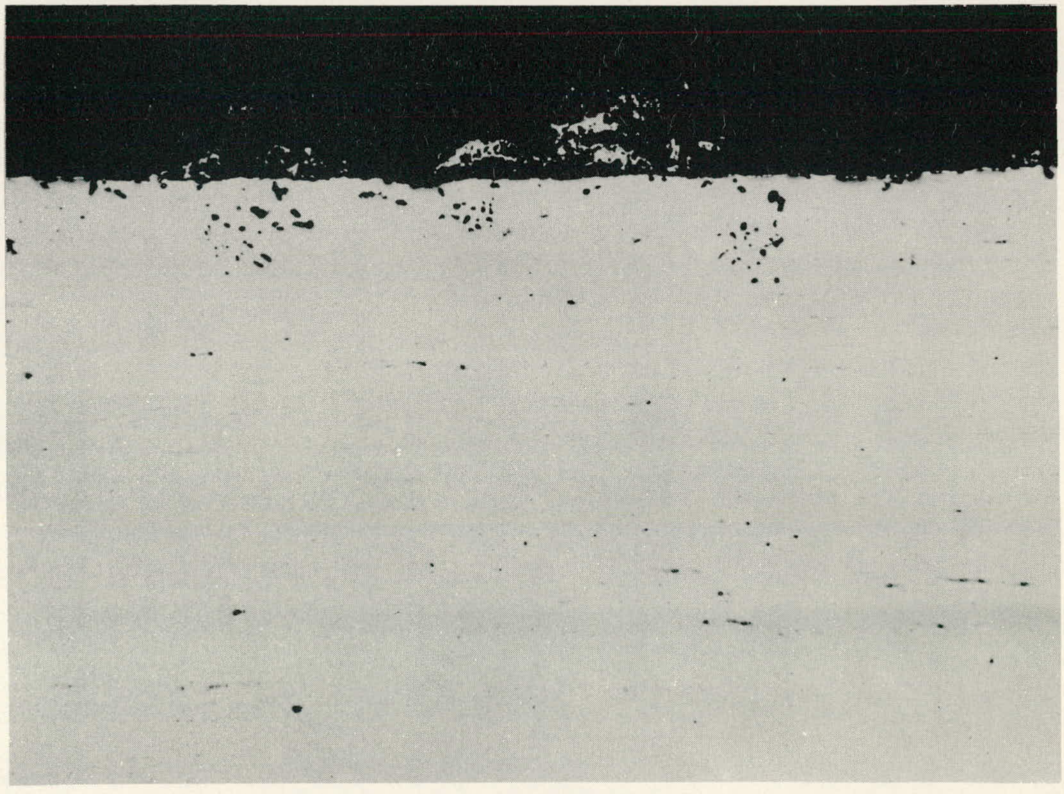


Fig. 12 Y-21263 200 X

Sample photographed in the as-polished condition. Note the deposit on the fluoride surface.

Y-21464

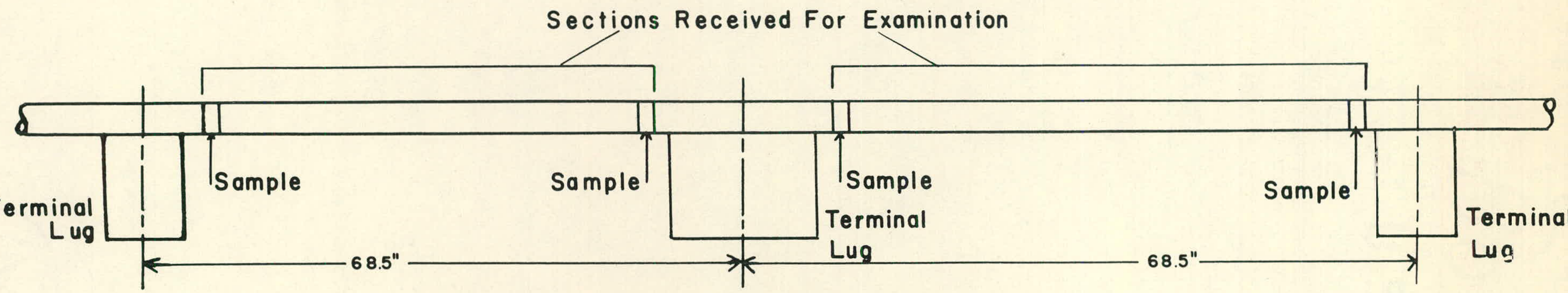


DIAGRAM OF SHE-B-RESISTANCE HEATER

Fig. 13 Sample location in the resistance heater section. Y-21464

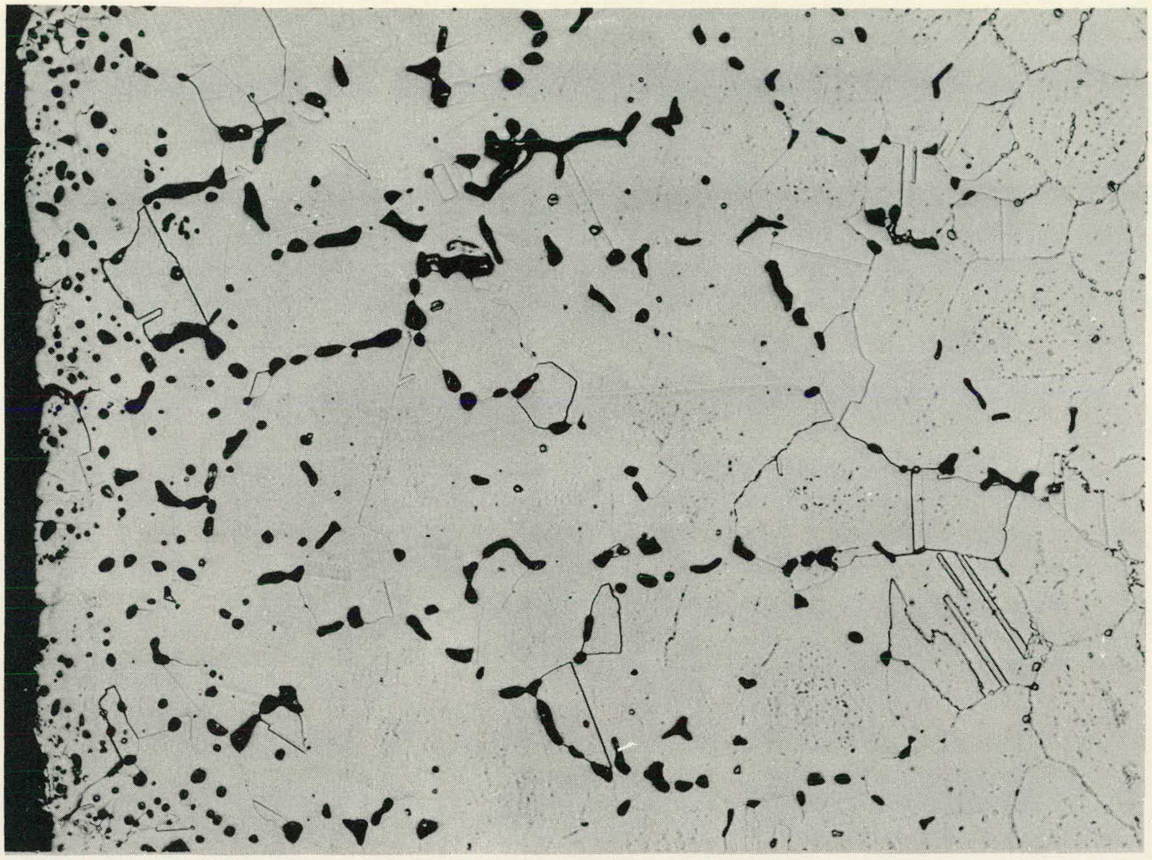


Fig. 14 T-11605 200 X

Sample from the heater section. Note the general and grain boundary attack to a depth of .031 inches. Etched with Mod. Aqua Regia