particles in the plus-4-mesh fraction. However, the percentage retained on the 8-mesh sieve increased from 21.9 to 34.2 percent with a decrease in gasification from 77.5 to 53.1 percent.

TABLE 16. - Size consist of residue at various percentages of carbon gasified during run 13

Run and period		13-M	13-E	13-F
Carbon gasified, percent		77.5	65.8	53.1
U. S. mesh No.1/	Opening, inch2/	Percent retained on screen		
	0.742	0.0	1.5	0.0
	.525	.3	.0	.2
	.371	.14	.7	1.2
4	.185	15.1	19.2	17.8
8	.093	21.9	33.0	34.2
16	.046	17.3	17.8	21.0
30	.0232	15.6	11.3	10.4
50	.0116	13.2	8.7	7.5
100	.0058	7.4	4.1	4.1
200	.0029	3.9	1.9	2.0
Minus-200	-.0029	3.9	1.8	1.6
Average size, inch		0.101	0.134	0.124

1/ No. 1 U. S. Standard service.
2/ Standard square-mesh screen openings.

Experiments using the location and amount of steam admitted as variables while maintaining a constant combustion space temperature and feed rate, indicated that:

1. With equal amounts of water available per ton of moisture- and ash-free lignite, the gas yield per ton and the percentage of carbon gasified is higher when at least part of the live steam was admitted to the upper reaction zone.

2. With equal amounts of water available per ton of moisture- and ash-free lignite, the hydrogen-carbon monoxide ratio of the product gas is not influenced greatly by the location of steam introduction except at very high steam rates to the char zone.

3. Equal increments of live steam increase the percentage of gasification and gas yield per ton more when admitted to the upper reaction zone.

4. Extrapolation of the experimental data indicates that, without addition of steam, 1 ton of Dakota Star lignite of 37 percent moisture and 5.5 percent ash would have approximately 53 percent of the available carbon gasified in the production of 32,000 cubic feet of gas at a 2.0-2.1 hydrogen-carbon monoxide ratio under the experimental conditions used for run 13.

5. The lower reaction zone produces only a relatively small percentage of the total product gas, except at very high steam additions to that zone.

MATERIAL AND HEAT BALANCES

Material and heat balances were completed for runs 11, 12, and 13 and are shown in tables 24 and 25 of the appendix.

Figure 17 presents in graphic form selected balances of the material entering and leaving the annular space for each of the three runs. Three balances were taken from each run and represent the highest and lowest percentage recovery, as well as the balance nearest 100 percent. This graphic presentation illustrates visually that satisfactory measurement of both entering-and leaving-material streams were obtained because 94.7 to 103.0 percent of the material entering was accounted for. The variation in the percentage of each component was a function of the operating conditions that were changed for the individual periods.

Heat balances for hydrogen-carbon monoxide ratios of 1.8, 2.3, 3.0, and 4.0 are shown in figure 18. Except for the 1.8 ratio, a period from each of runs 11, 12, and 13 is shown at the respective ratios. These bar graphs were constructed from the heat balances tabulated in the appendix.

The diagrams show that the heat requirements to carry out the gasification process varied from 24.6 to 32.4 percent of the total heat in the entering materials with the actual percentage used, depending on H_2-CO ratio and the moisture content of the lignite gasified. Steam-dried lignite (periods 12-C, 12-F, 12-H, and 12-A) required less heat than the natural lignite.

The potential heat in the product gas, depending upon the percent gasification and the ratio, was between 49.1 and 65.5 percent of the total heat input. Adding potential heat in the char and dust to that in the gas increased the percentage of the total input found in the products of gasification to between 71.8 and 83.6 percent. The actual percentage of heat input recovered in the gasification products depends upon the type of material gasified, the resultant ratio of the gas, and the percentage of carbon gasified. The highest recovery of 83.6 percent of the total heat input as potential heat in the product gas and char was obtained at the lowest ratio (1.8) and with steam-dried lignite. In all cases the percentage of heat input present as potential heat in the char and gas was greater when dried lignite was gasified. As the overall gasification reactions are endothermic, more potential heat is present in the sum of product gas and char at a higher percentage carbon gasified.

More heat was lost as sensible and latent heat in the undecomposed steam at the higher ratios. At a hydrogen to carbon monoxide ratio of 2.3, using natural lignite as feed, 2.7 to 2.9 percent of the total heat input was in the undecomposed steam, whereas this amounted to 6.7 to 8.8 percent at a ratio of 4. The percentage of the total heat input in the undecomposed steam at the same ratio was slightly higher when the dried lignite was used because the product gas and water vapor mixture left the retort at higher temperatures. If dried lignite is to be gasified, design changes consisting of a heat exchanger to recover the sensible heat in the product gas and undecomposed steam leaving the retort would result in a slightly higher thermal efficiency for the process.

Radiation, convection, and unaccounted for losses were 5 to 13 percent of the total heat input. At nearly equal heat loss, considerably different percentages of loss were obtained due to variations in the heat input. During period 11-J, the losses amounted to 364,000 B.t.u. per hour or 10.0 percent of the total input. The losses for period 12-A were nearly the same, 332,000 B.t.u. per hour, but the percentage loss was only 5.0 percent of the total input. Actual losses were 332,000 to 760,000 B.t.u. per hour. The higher values are greater than those previously reported (4), owing to installation of a large exhaust fan in the roof of the retort building. The fan, operating intermittently, discharged quantities of warm air from the retort building into the atmosphere, and this warm air was replaced by cold air. Fluctuations in heat losses were caused by the intermittent operation of this fan.

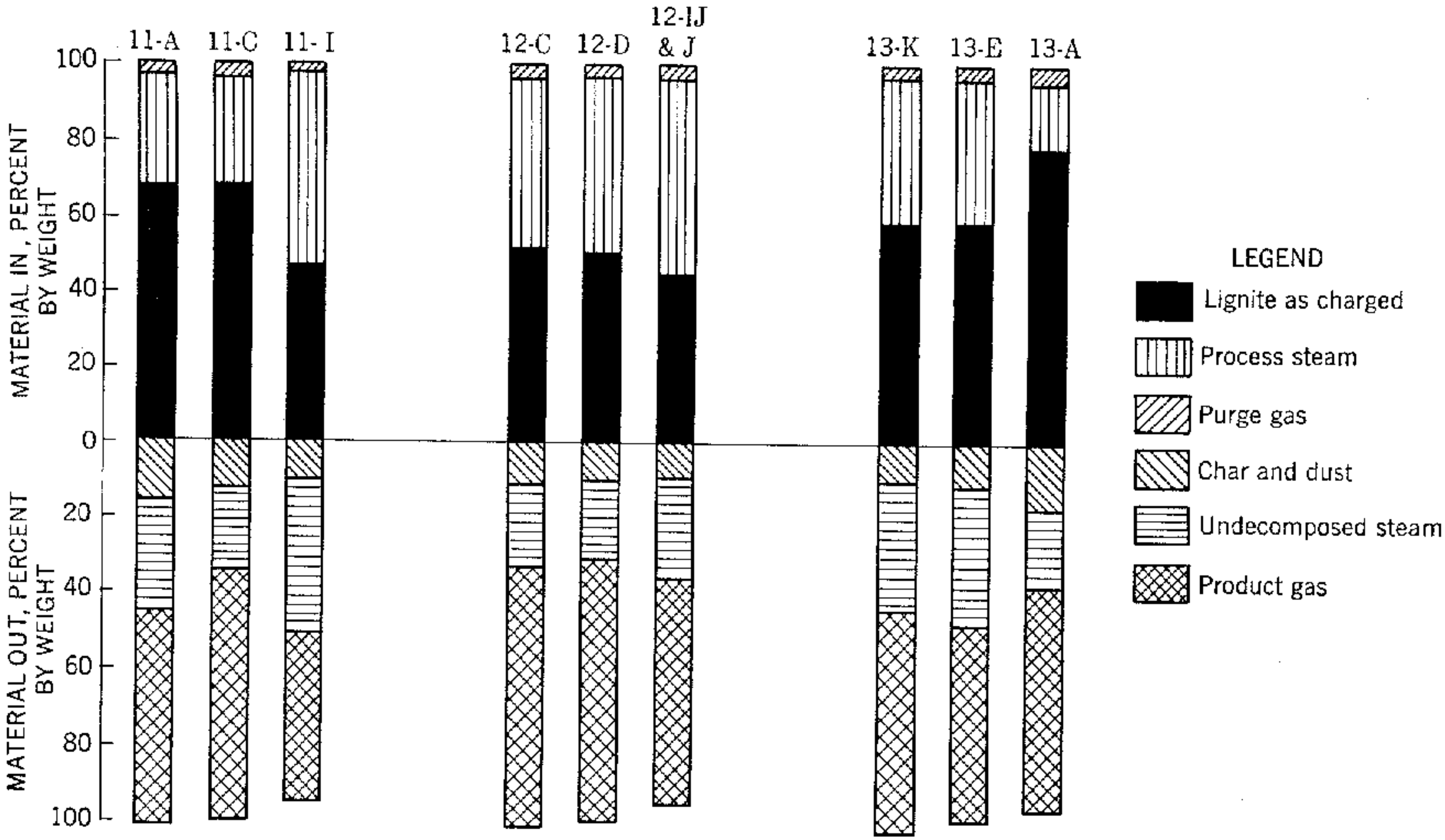

Figure 17. - Material entering and leaving annulus during gasification process.

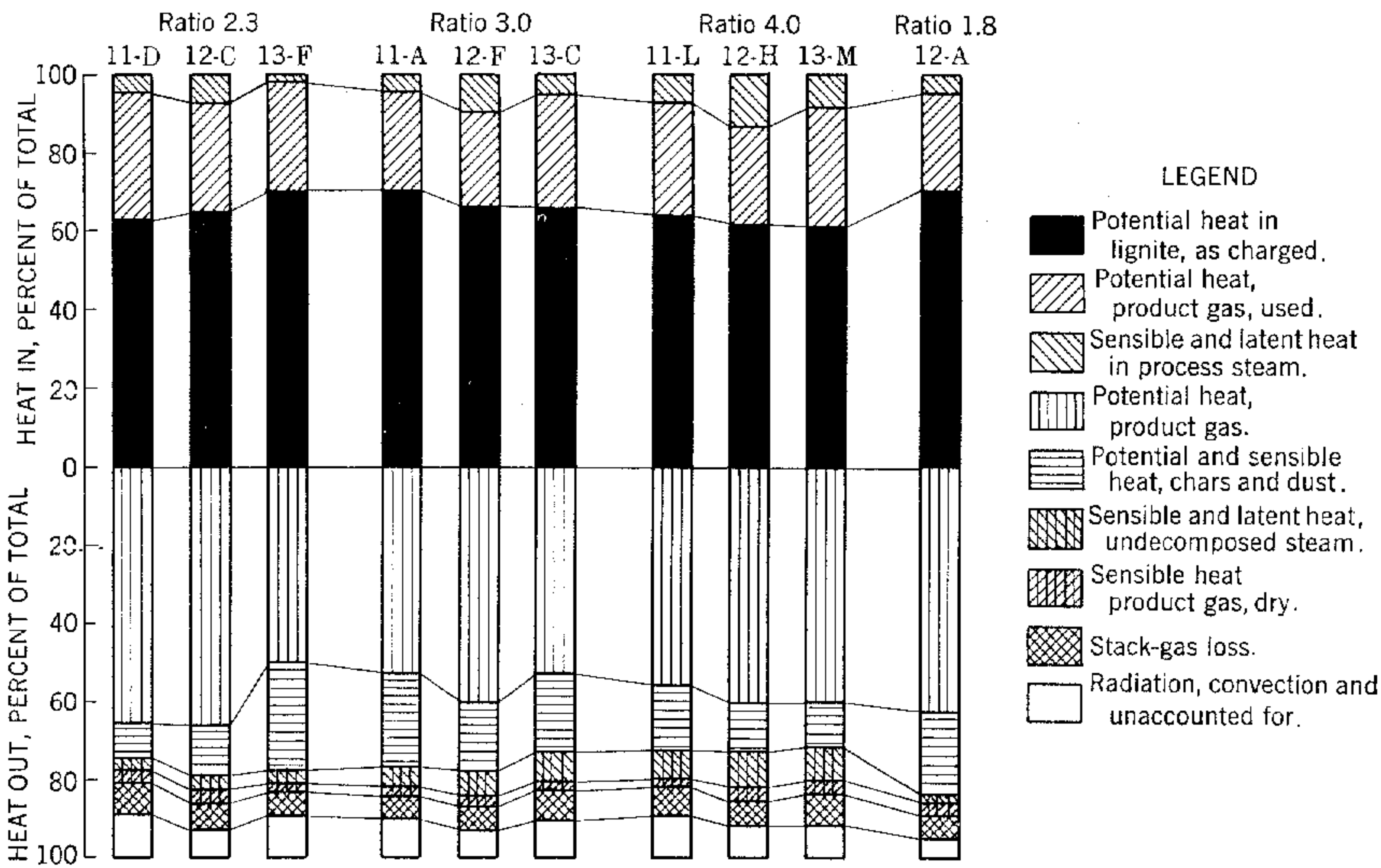

Figure 18. - Heat distribution during gasification at various hydrogen-carbon monoxide ratios of product gas.

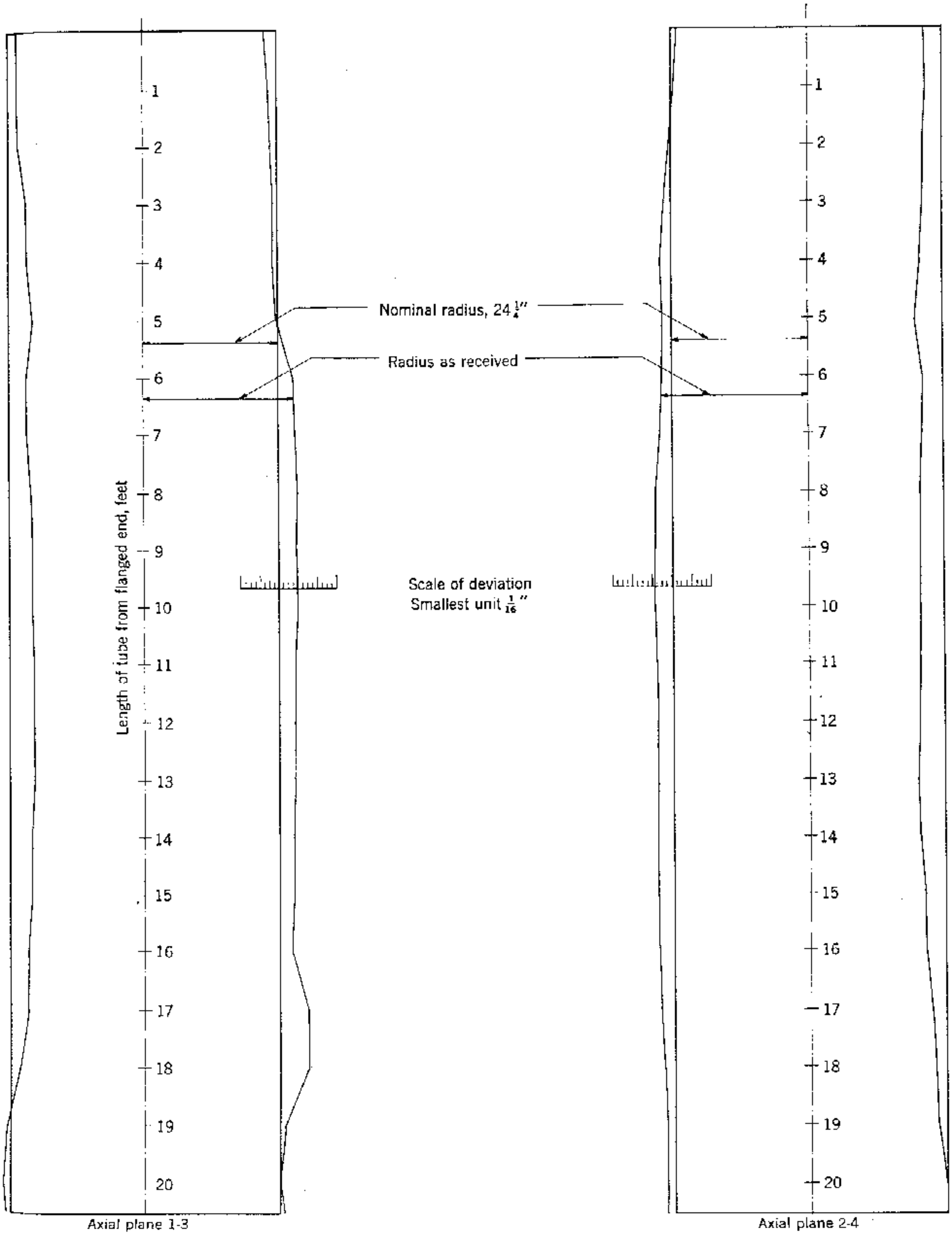

Figure 19. - Radial dimensions of HK alloy retort tube as received.

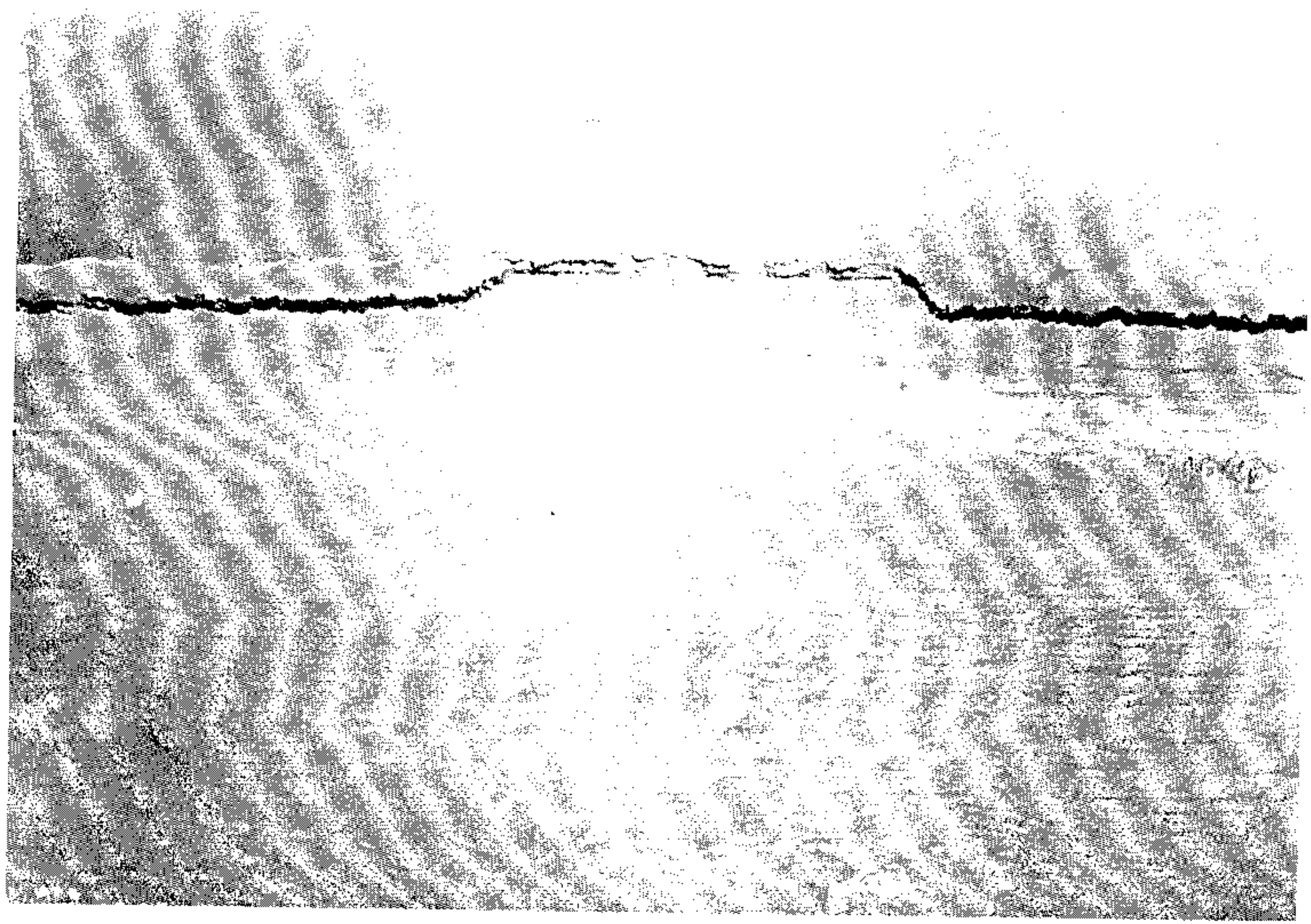

Figure 20a. - Exterior view of broken weld of HK cast-alloy tube.

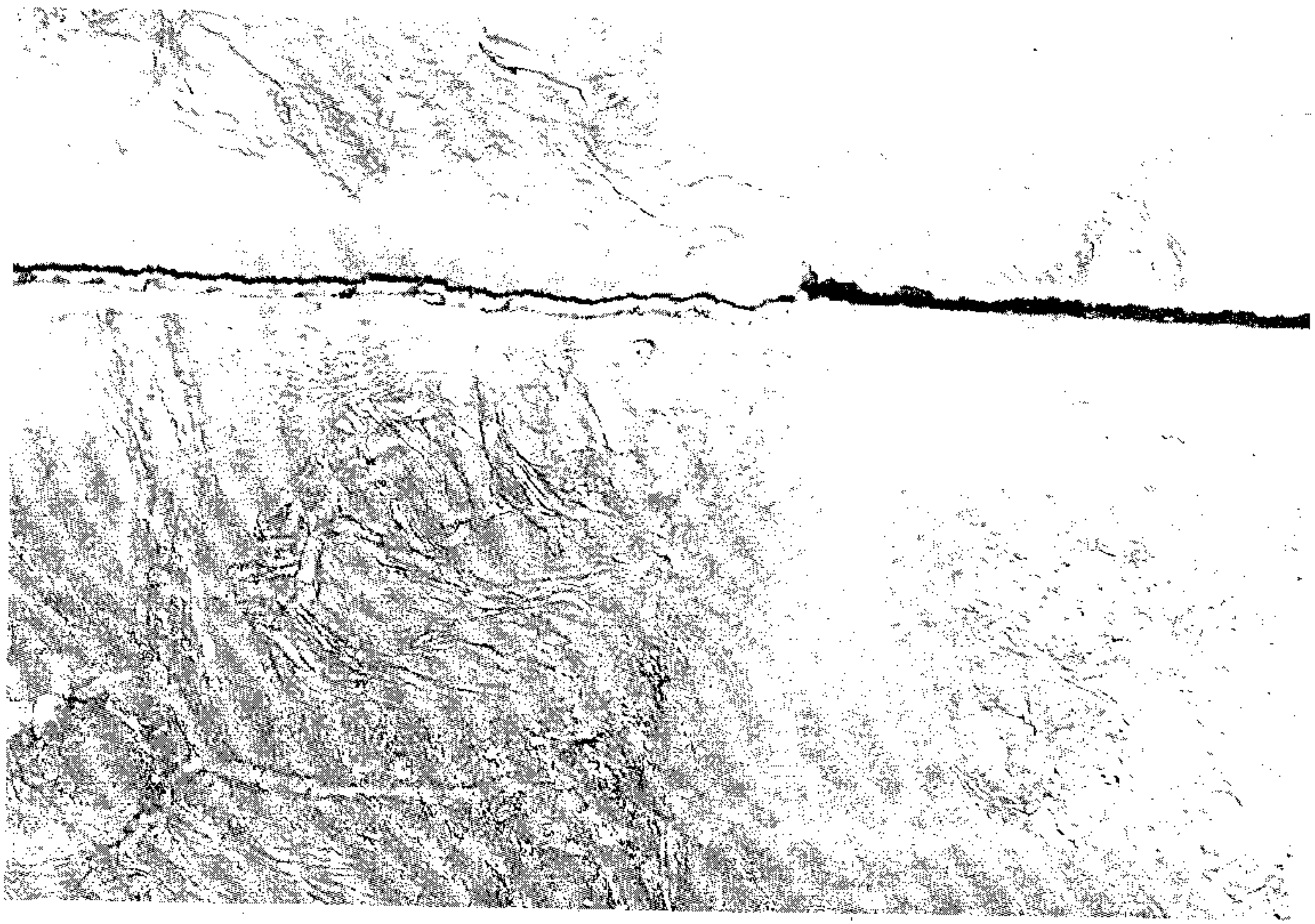

Figure 20b. - Interior view of broken weld of HK cast-alloy tube.

The rate of heat transfer ranged from 2,100 to 4,400 B.t.u. per square foot an hour, the average heat transfer being 3,000. Although no attempt was made to determine the actual maximum possible heat transfer, the highest rate obtained in these experiments is in the same range as that previously reached (2).

BEHAVIOR OF RETORT TUBES

The performance of the metal reaction tube is of primary importance in this investigation of the gasification of lignite, as the operating conditions are unusually severe and are unique for a commercial gasification process. Owing to the initial cost of a metal-alloy tube of the size used in the demonstration plant, it was previously assumed that a minimum tube life of 10,000 hours would be required to avoid an unfavorably high unit production cost (2).

In a previous publication, the history and performance of the metcolized and alloy-clad retort tubes were covered in detail (4). This report gives additional information concerning the HK-cast alloy tube and the performance of the 310-alloy, rolled-plate tube to date.

Table 17 summarizes the entire operation of the commercial scale demonstration plant from February 1945 to July 1950. During a total of 5,772 hours of operation with 4 different reaction tubes there has been produced 53,269 M c.f. of product gas in partly gasifying 1,178 tons of lignite.

The HK cast alloy[11/] tube was 20 feet, 6 inches in length, had an internal diameter of 48.5 inches, and a wall thickness of 0.75 inch. It was fabricated by welding together 2 centrifugally cast sections with a single circumferential weld of 310 alloy 68 inches from the flanged end of the tube. The entire inner surface of the tube was exceedingly rough, with channels and pits varying in depth to 7/16 inch. In addition, the 2 sections of the tube were offset at the weld seam by as much as 1/8 inch. Detailed radial measurements were made at 45° intervals on the circumference and at 1-foot intervals along the vertical axis. The results of these measurements, shown on an exaggerated scale in figure 19, indicate the irregularity of the radii. Using these radial measurements and a 22-inch nominal radius (outside measurement) of the inner tube, the actual width of the annulus as used during run 9 was calculated. The nominal width of the annulus was supposed to be 2.5 inches, but the actual width varied between 1-31/32 inches and 3-13/32 inches. This indicates that the observed hangup of the charge during run 9 (4) could have been caused by both unequal width of the annulus and the roughness of the inner surface of the HK-cast tube.

Run 10 was begun with a nominal 3-1/4-inch annular space to insure a satisfactory width despite the radial variation in the outer tube. The unit operated erratically, and the run was terminated after 53 hours of operation when the cast tube cracked at the weld seam. Approximately 128 inches of the 150-inch weld had separated, leaving the 2 sections held together by only 22 inches of the intact weld.

Figure 20 shows two pictures of the cracked seam before the sections were completely separated. Photograph (a) gives an outside view and photograph (b) an inside view of the broken weld, illustrating the nature of the break. Also, in photograph (b) the rough inner surface of the cast tube should be noticed. No evidence of corrosion was visible after a total of 151 hours of operation.

11/ HK alloy had a nominal composition of 25 percent chromium and 20 percent nickel with small amounts of carbon, manganese, and silicon.

TABLE 17. - Summary of operation of commercial-scale pilot plant, February 1945 to July 1950

Run No.	Retort 1/ tube	Date From-	Date To-	Time operated, hours 2/	Lignite processed, tons	Gas made, M c.f. 3/
Preliminary	1	2-27-45	3-7-45	192	4/ 22.5	731
1	1	6-13-45	6-24-45	257	55.4	1,626
Subtotal	1			(449)	(77.9)	(2,357)
2	2	12-6-45	12-16-45	258	56.0	2,569
3	2	3-6-46	3-25-46	418	94.4	4,121
4	2	4-16-46	5-16-46	5/ 736	5/ 187.9	8,690
5	2	12-13-46	12-28-46	369	54.1	2,300
Subtotal	2			(1,781)	(392.4)	(17,680)
6	3	9-8-47	10-4-47	625	118.4	5,680
7	3	12-1-47	12-23-47	475	74.1	3,273
8	3	1-26-48	2-13-48	429	78.9	3,586
Subtotal	3			(1,529)	(271.4)	(12,298)
9	4	4-30-48	5-4-48	98	14.2	640
10	4	1-17-49	1-21-49	53	4/ 6.0	4/ 253
Subtotal	4			(151)	(20.2)	(893)
11	5	5-4-49	6-2-49	694	172.4	7,304
12	5	9-8-49	9-26-49	6/ 438	6/ 85.1	5,759
13	5	11-18-49	12-18-49	730	164.3	6,979
Subtotal	5			(1,862)	(421.8)	(20,042)
Grand total	All types			5,772	1,183.7	53,270

1/ 1, spray-coated (metallized) tube; 2, alloy-clad tube; 3, reconditioned alloy-clad tube; 4, cast HK alloy tube; 5, 310-rolled plate alloy tube.
2/ Time to the nearest hour from lighting burners until turned off.
3/ Up to and including run 6 gas production was measured with an orifice meter; a positive displacement meter was used in all succeeding runs.
4/ Estimated values.
5/ Includes 72 hours when 7.6 tons of char was charged.
6/ Steam-dried Dakota Star lignite used for run 12.

Figure 21 shows selected portions of the weld after the two sections had been completely detached. Photograph (a) shows a section of the weld that had not separated during the run. Three distinct layers are evident, with no fusion apparent between the middle and lower layer. Photograph (b) shows a section of the weld that had separated during the test. Distinct layers are again visible with poor fusion apparent. The differently shaded portions of the cross section indicate that the failure had occurred in stages.

After the failure of the cast tube, a reaction tube fabricated from four 5-foot 1-1/2-inch-wide rolled-alloy plates joined by 3 circumferential horizontal welds was procured. The vertical seam in each section was displaced 180 from the adjoining vertical weld. All welds were x-rayed and were found acceptable under the provisions of the applicable ASME code. The alloy used was a AISI 310 type with a small percentage of columbium added. The actual composition as determined by analysis was: Cr, 24.4-24.5 percent; C, 0.03-0.06; Ni, 20.8,;Mn, 1.8-2.0; P, 0.018-0.020; Si, 0.50-0.74; and Cb, 0.69-0.75. All welds were made with 310-type rod with columbium added in the

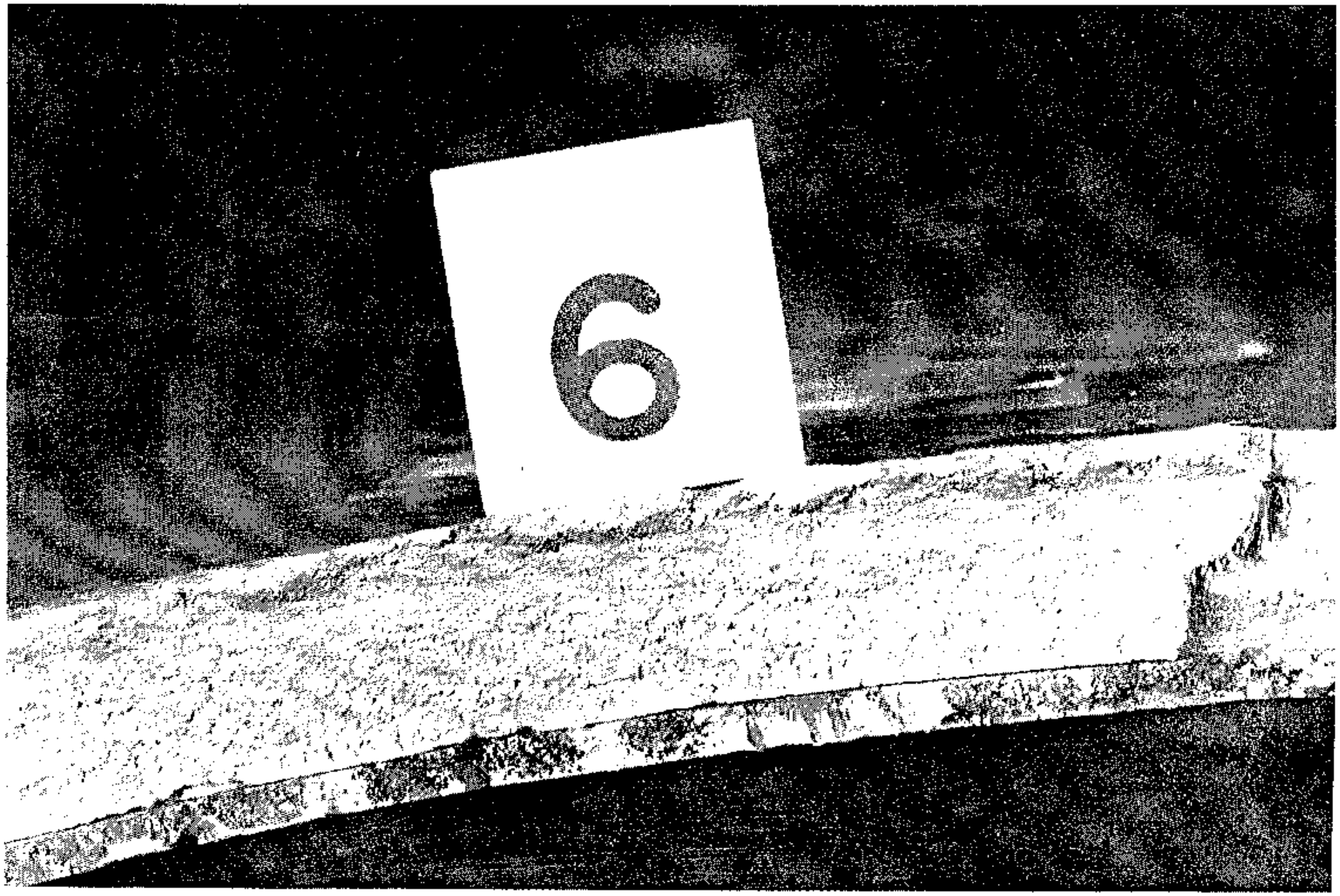

Figure 21a. - Cross section of broken weld of HK cast-alloy tube.

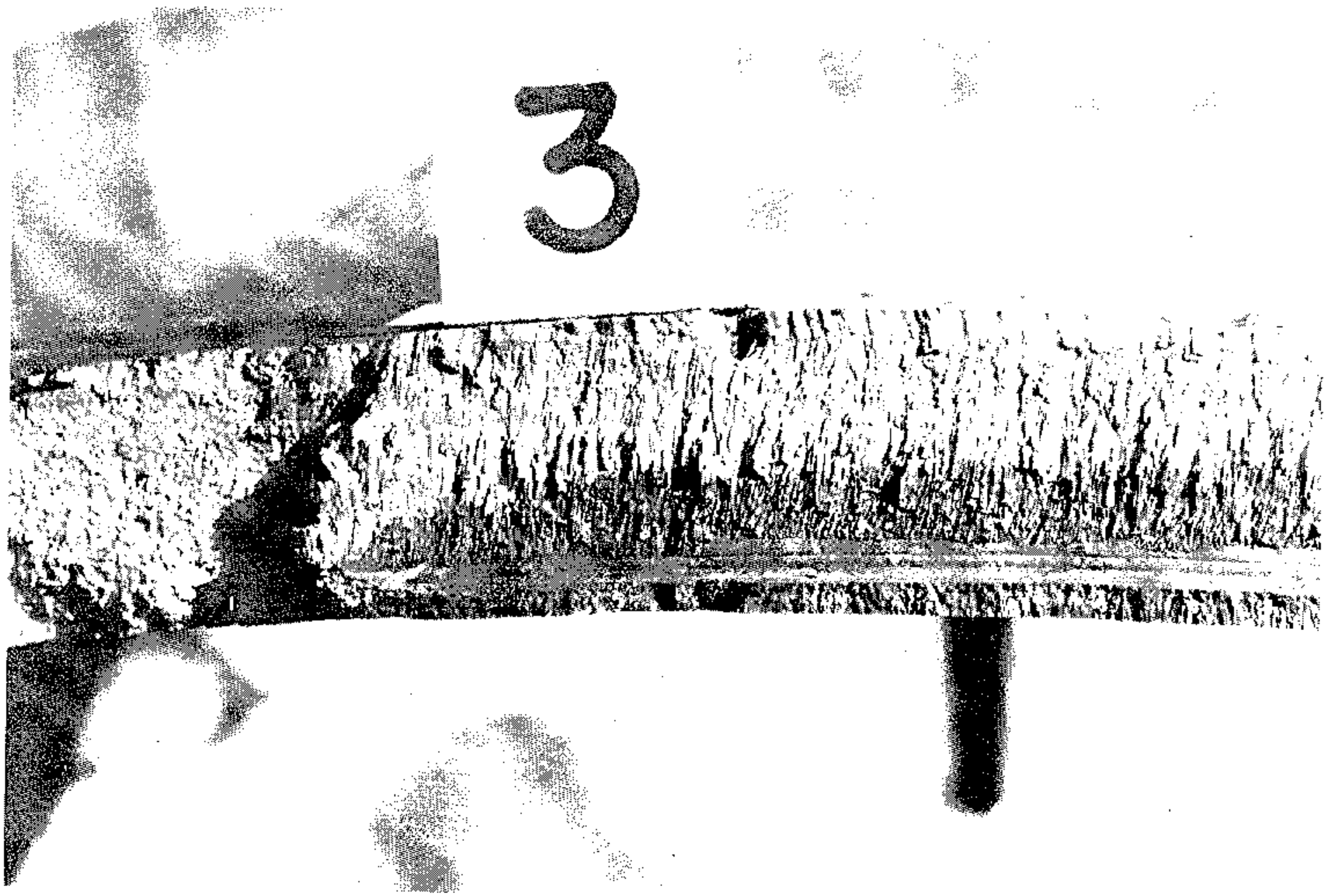

Figure 21b. - Cross section of broken weld of HK cast-alloy tube.

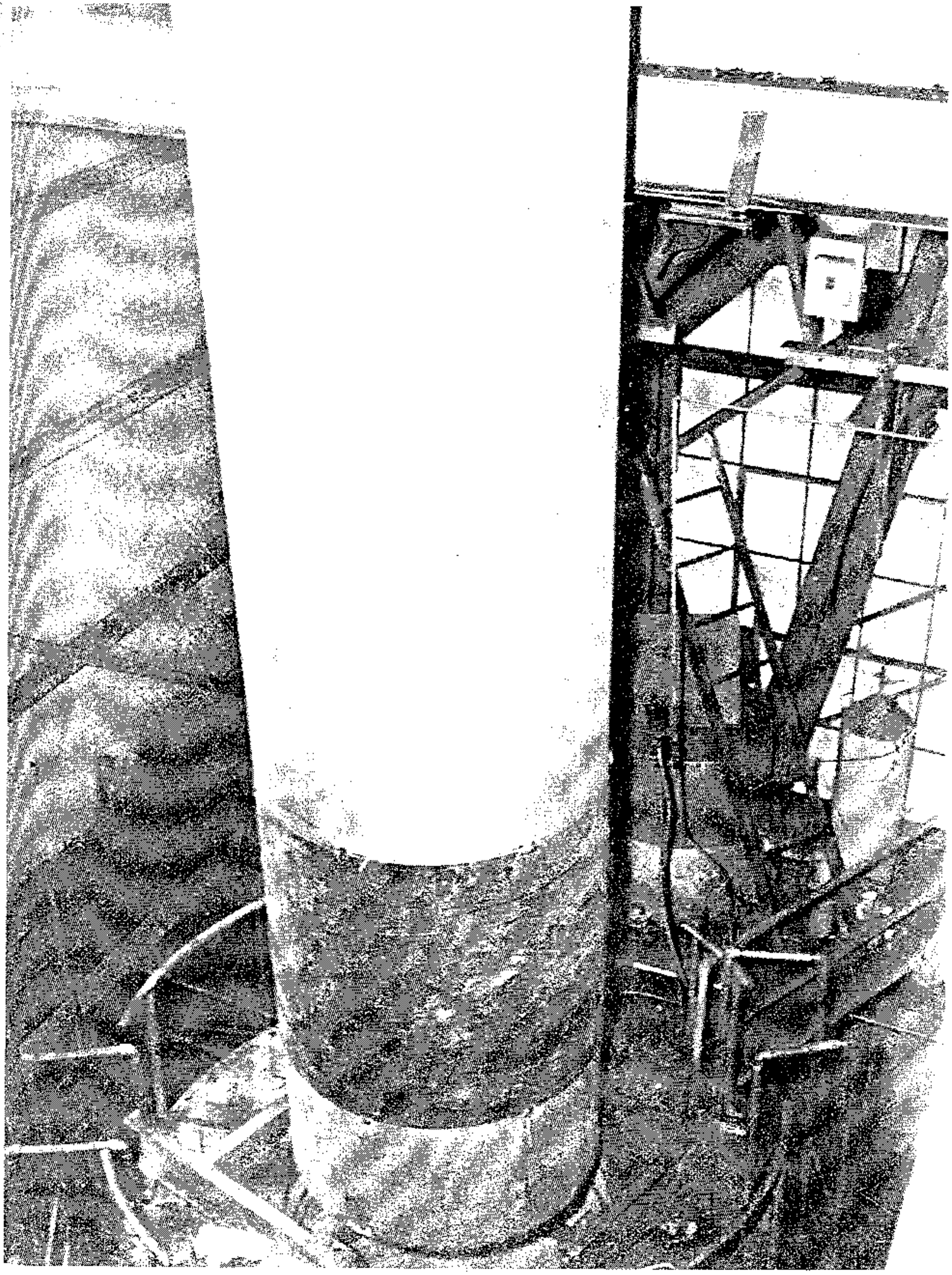

Figure 22. - 310-alloy tube being lowered into the retort for first test.

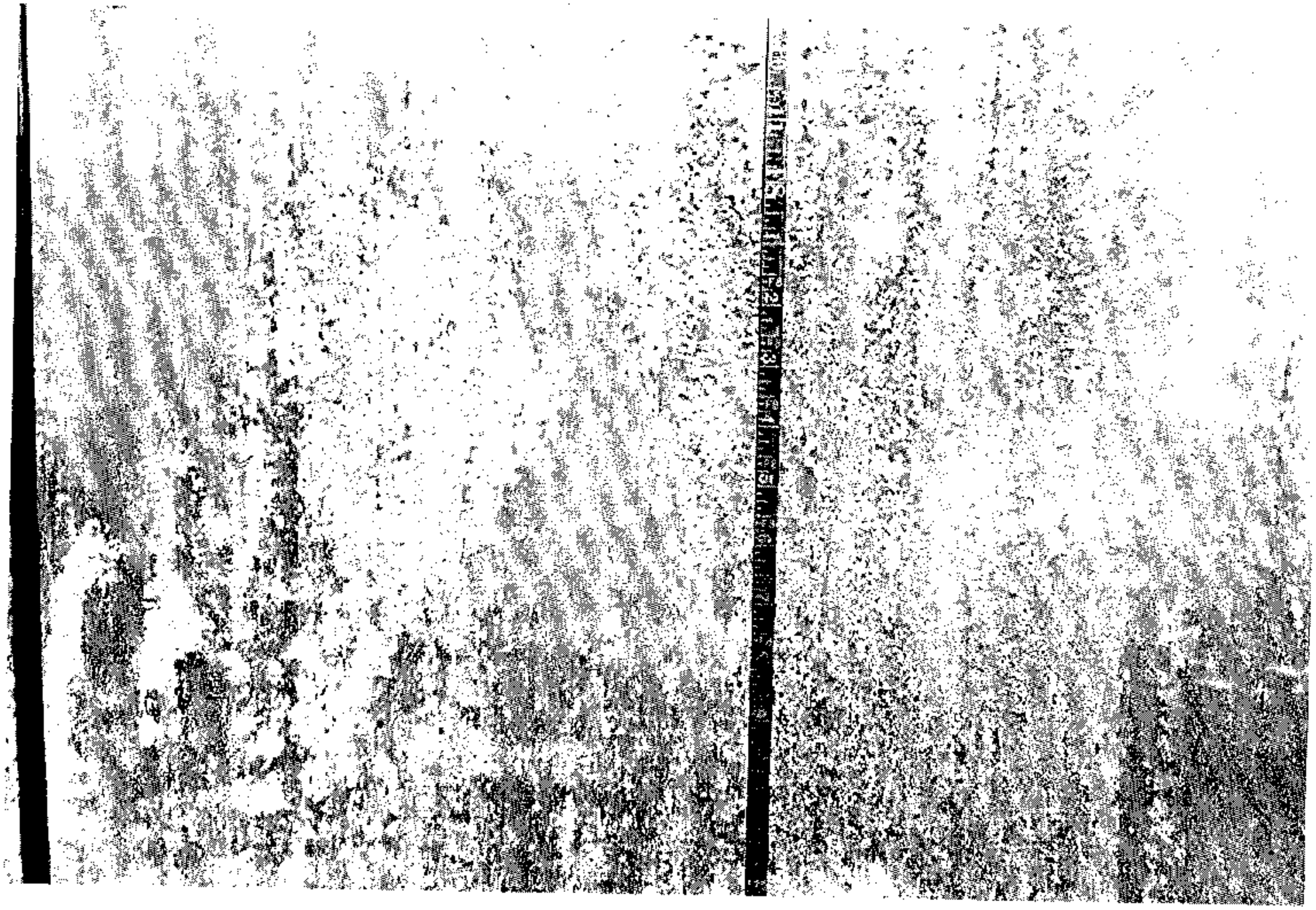

Figure 23a. - Corrosion of inner surface of 310-alloy tube before run 13.

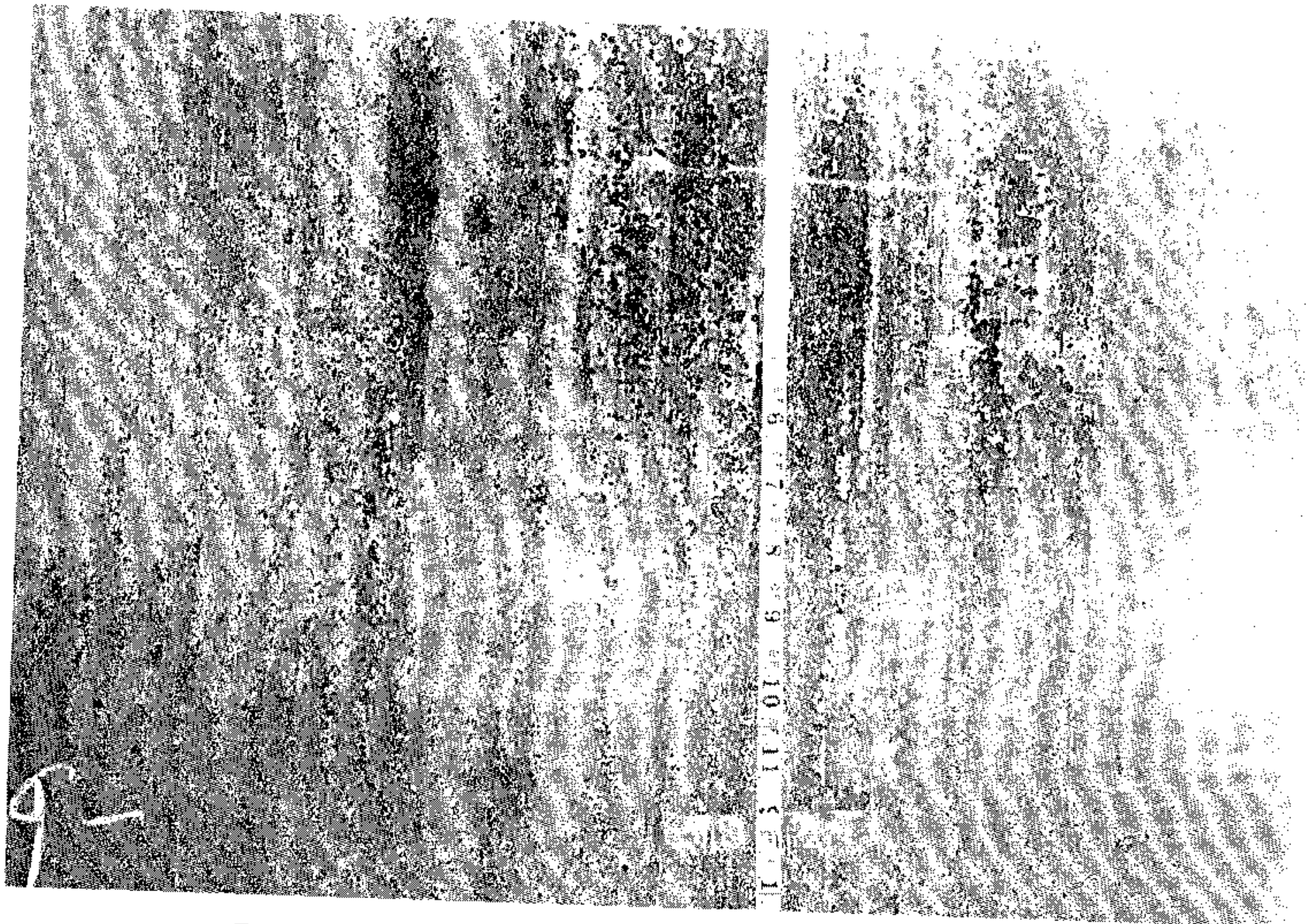

Figure 23b. - Corrosion of inner surface of 310-alloy tube after run 13.

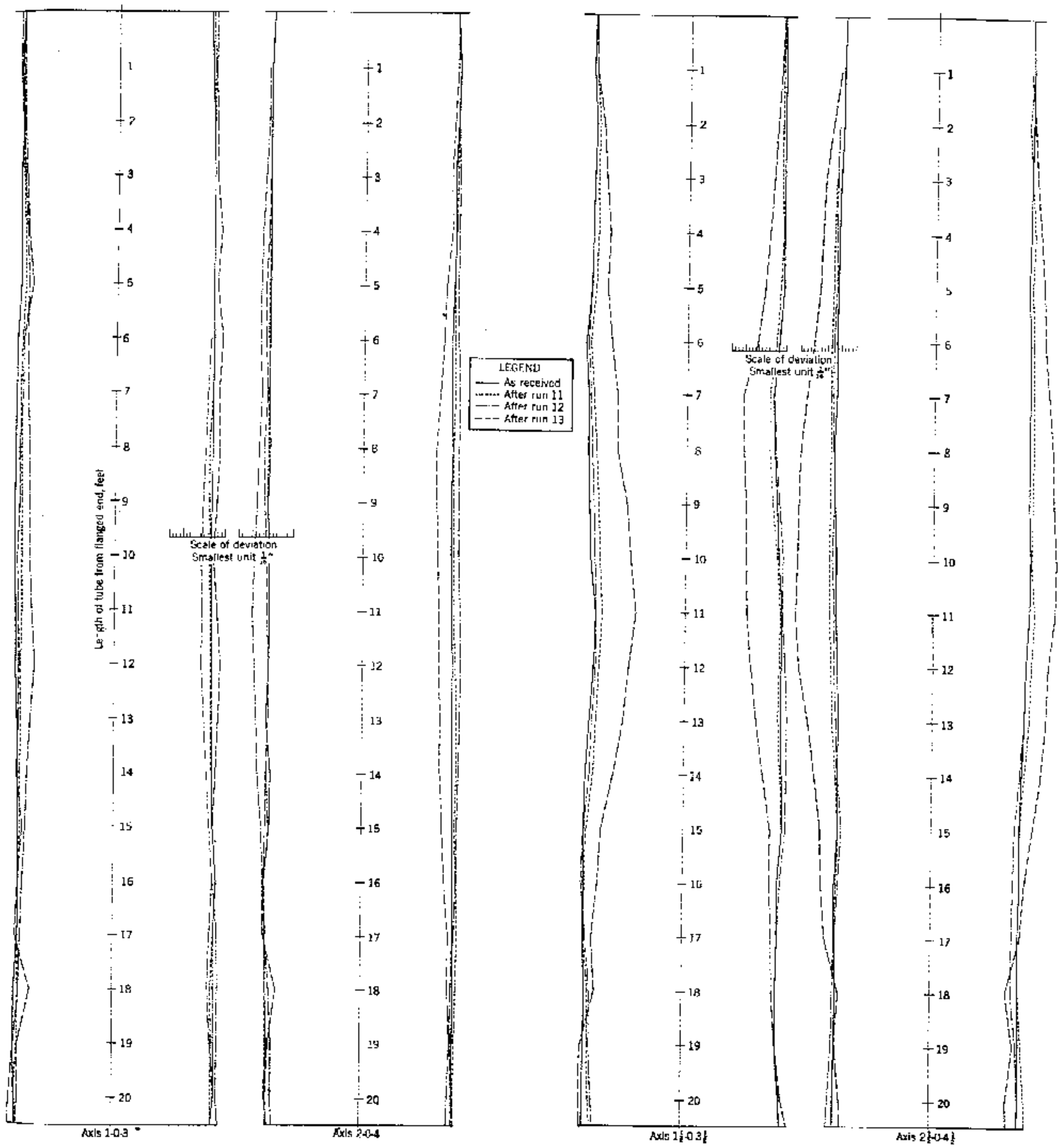

Figure 24. - Variation in length of radii of 310-alloy retort tube.