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FURTHER CORROSION TESTS ON MATERIALS IN REGENERATIVE AIR PREHEATERS

By J. F. Barkley, Hilmer Karlsson, and C. F. Stark

United States Department of the Interior —— 1959

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FURTHER CORROSION TESTS ON MATERIALS IN REGENERATIVE AIR PREHEATERS[1]

by

J. F. Barkley,[2] Hilmer Karlsson,[3] and C. F. Stark[4]

SUMMARY

Field tests were made on the rate of corrosion of 30 materials used in air preheaters under regular operating conditions, and the buildup of deposits was observed. Twenty-three materials were tested with coal as the fuel on an underfeed stoker and seven with oil, including a short period with pulverized coal as fuel. The plant equipment is described, and pertinent plant operating data are tabulated. Figures 17 and 19 (pp. 24 and 27) give the results of corrosion tests on the uncoated metal test specimens.

The information obtained from these tests follows the general pattern described in Bureau of Mines Report of Investigations 4996, Corrosion and Deposits in Regenerative Air Preheaters. The deposits were similar, and the corrosion rates of Cor-Ten and Mayari-R steel (previously found to be essentially the same at the Harding Street Station using coal) continued to show little difference at the Marion Generating Station using principally oil. The one high-alloy steel tested, type 321, showed a much higher corrosion rate than the low-alloy steel, Cor-Ten.

No coatings used on test specimens resisted corrosion satisfactorily except the acid-resisting enamels, XR623A Ferro, Barrows, and Erie. These coatings were not attacked, but imperfections in their application resulted in destruction of metal underneath. Properly applied, one coat served as well as two.

The Pyrex-glass test specimens showed no evidence of corrosion but showed very small, inconsequential loss from breakage.

1/ Work on manuscript completed December 1958.
2/ Former chief coal technologist, Bureau of Mines, Washington, D. C.
3/ Assistant to president and consulting engineer, Air Preheater Corp., New York, N. Y.
4/ Research engineer, Air Preheater Corp., Wellsville, N. Y.

INTRODUCTION

In 1953 the Bureau of Mines published Report of Investigations 4996, covering extensive research to determine the resistance to corrosion of many materials and the nature of the deposits that accumulated on them. The present report gives information on corrosion tests, made later, of various materials not included in the original report. One series of tests was made at the Harding Street Station of the Indianapolis Power & Light Co., where the former tests were made. Another series was made at the Marion Generating Station of the Public Service Electric and Gas Co. of New Jersey.

This work, like that described in the previous report, was done as a cooperative project of the Air Preheater Corp. and the Federal Bureau of Mines.

ACKNOWLEDGMENTS

The series of tests at the Harding Street Station were made possible through the valuable cooperation, now extending over many years, of the Indianapolis Power & Light Co. Very helpful were R. H. Goodrich, assistant to vice president of operations; C. B. Vance, superintendent of production; R. W. Gausman, director of plant research; A. A. Benson, director mechanical-civil engineering; and G. F. Spangler, retired (former superintendent of Harding Street Station); and their assistants. The series of tests at the Marion Generating Station of the Public Service Electric and Gas Co. of New Jersey were made possible through the highly satisfactory cooperation of that company.

Figure 4 was supplied by the Public Service Electric and Gas Co. of New Jersey, and figures 16 and 17 were furnished by the Air Preheater Corp. Needed assistance was given by many members of the personnel, especially P. H. Hartung, general superintendent of generation, Electric Generation Department; John Allhusen, superintendent of the Marion Generating Station; W. W. Maull, chief engineer, and Frank K. Pierson, master mechanic. The continued help and encouragement of R. M. Gates, chairman of the board, and W. F. Jetter, president of Air Preheater Corp. were greatly appreciated. The valuable assistance in field and laboratory tests of Robert Dorsey, research technician, Air Preheater Corp., is also acknowledged.

DESCRIPTION OF FIELD TEST EQUIPMENT

Figure 1 shows the Harding Street Station of Indianapolis Power & Light Co., and figure 2 is a cross section of the boiler equipment used for the field tests. The boiler was a 21-section, water-tube type, manufactured by Springfield Boiler Co. and rated at 124,000 pounds of steam per hour at 450 p.s.i.g. and 725° F. It was fired by a Westinghouse underfeed coal stoker of 10 retorts. The air preheater (fig. 3), manufactured by Air Preheater Corp. was a Ljungstrom regenerative, vertical-type, size 18 preheater with about 13,830 square feet of heating surface, comprising a lower or hot-end layer of vertical plates 12 inches high and an upper or cold-end layer of vertical plates 6 inches high. A more complete description of this equipment is given in Bureau of Mines Report of Investigations 4996.

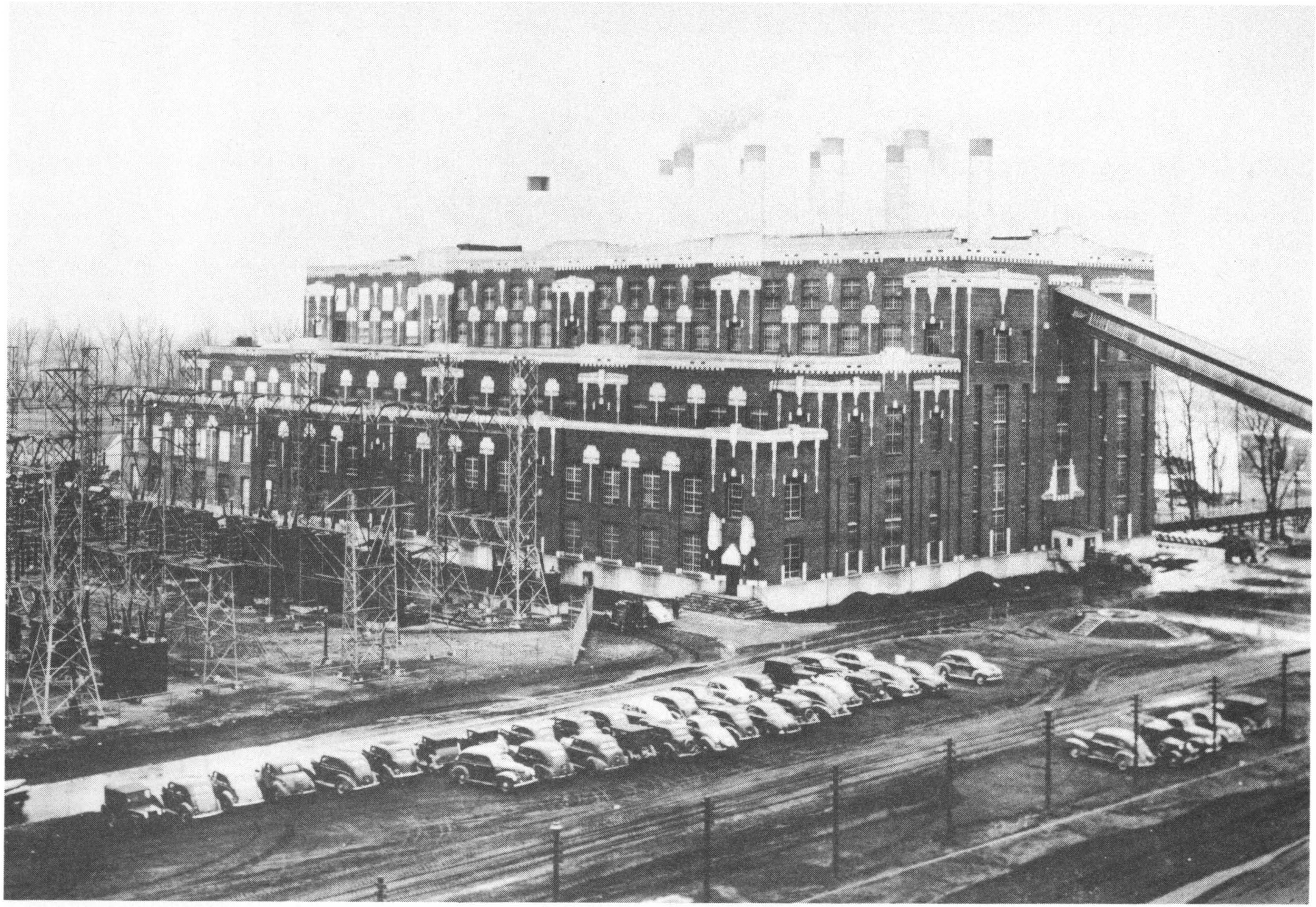

FIGURE 1. - Harding Street Station, Indianapolis, Ind., of Indianapolis Power & Light Co., Where Field Tests Were Made.

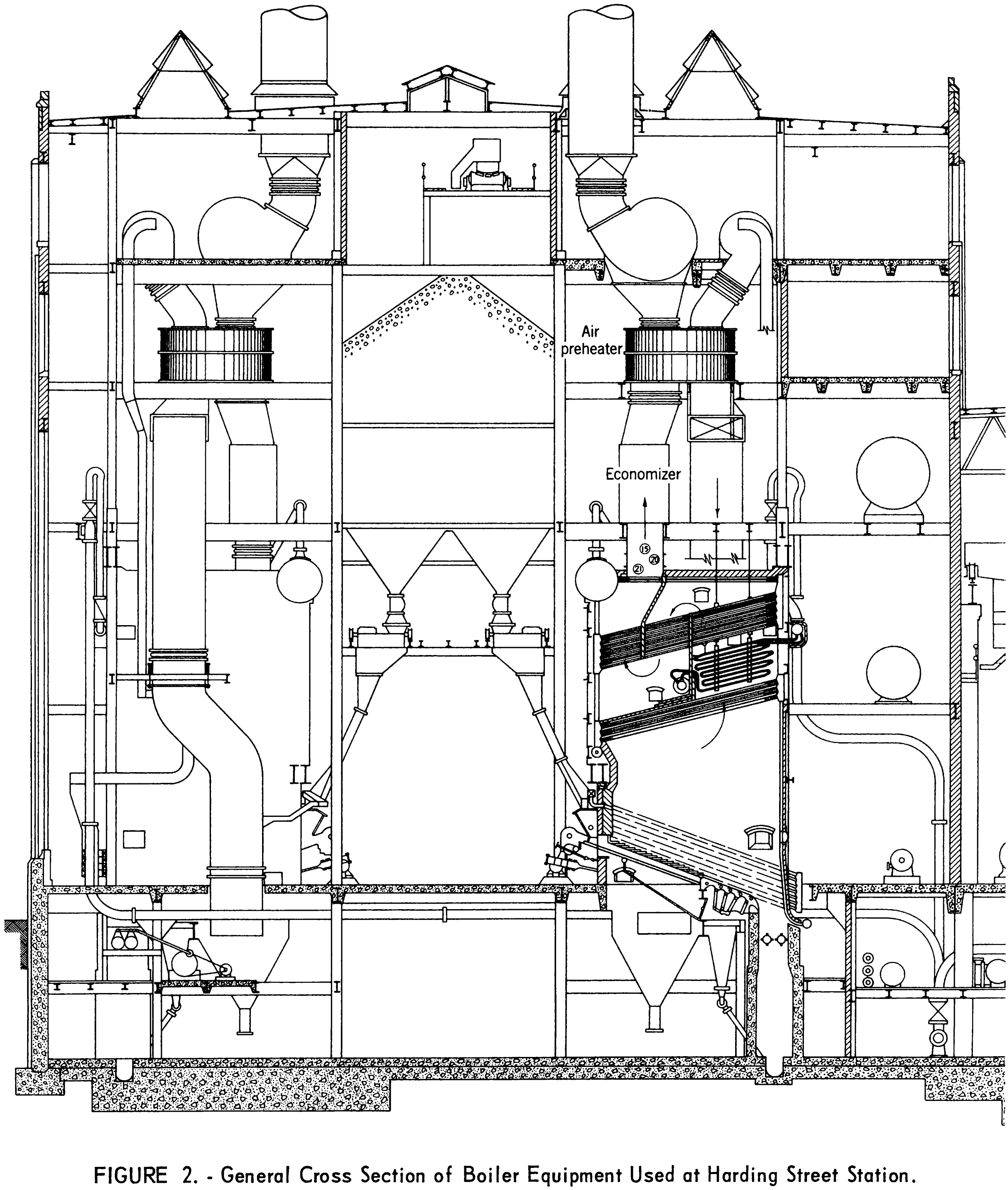

FIGURE 2. - General Cross Section of Boiler Equipment Used at Harding Street Station.

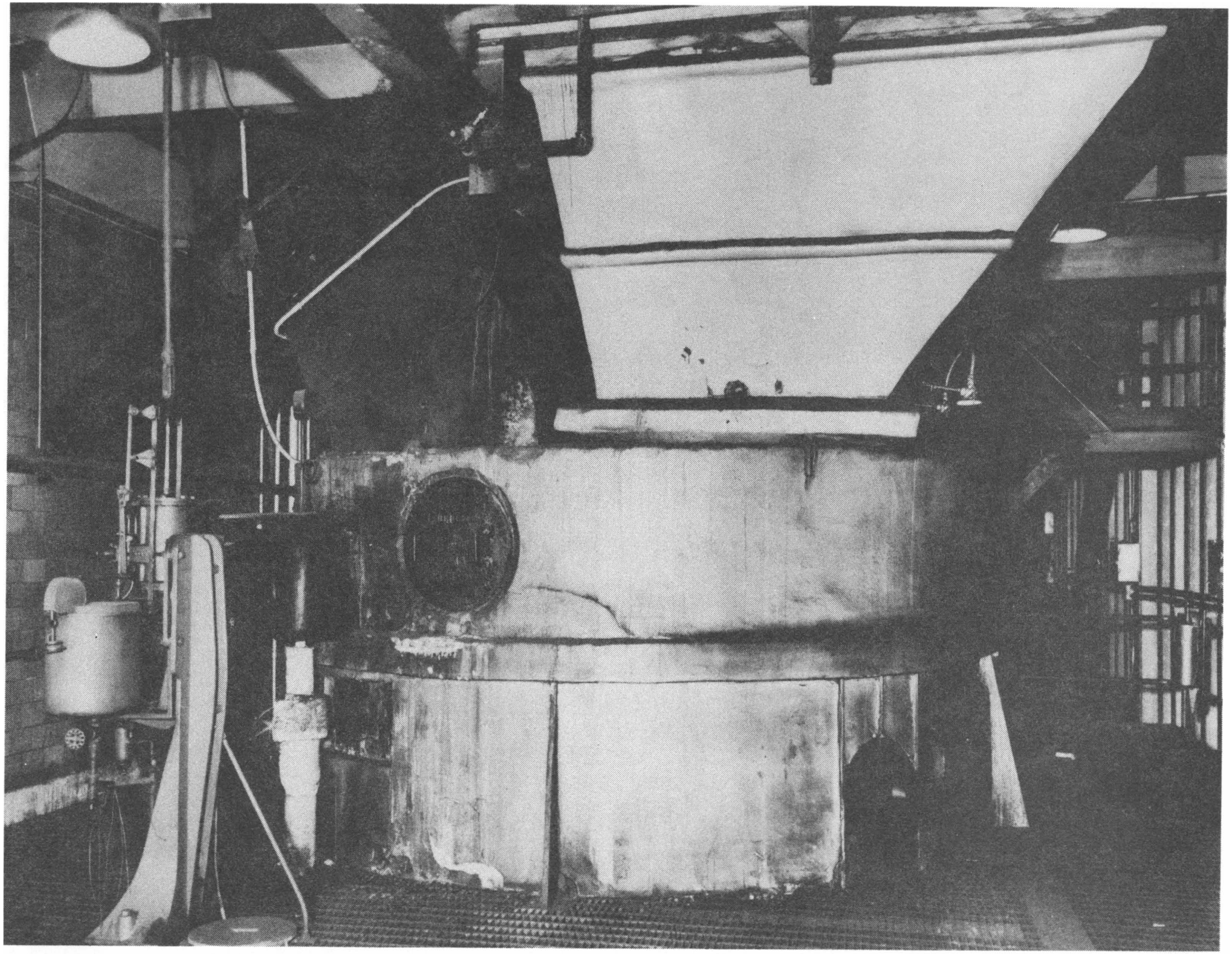

FIGURE 3. - Air Preheater Used for Field Tests at Harding Street Station.

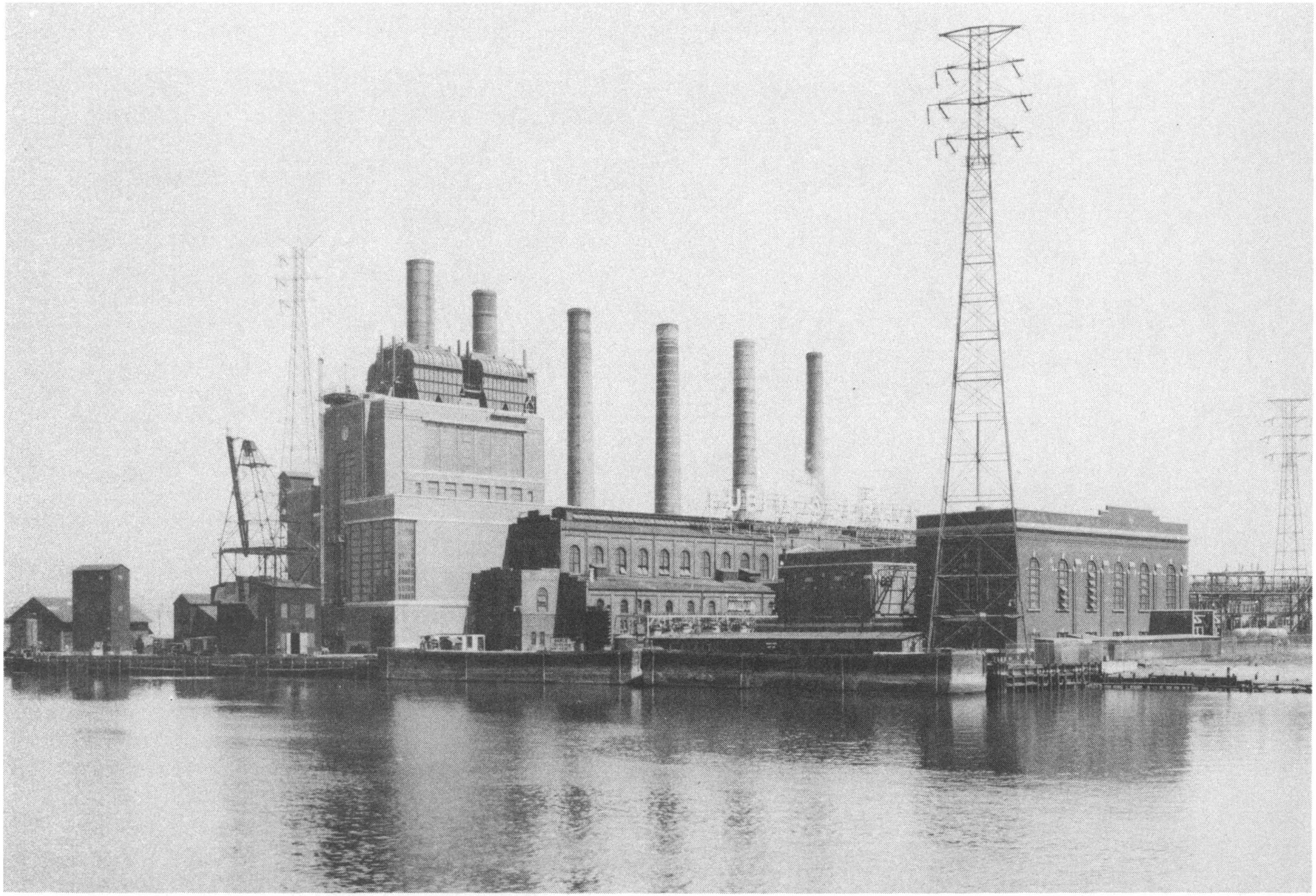

FIGURE 4. - Marion Generating Station, Jersey City, N. J., of Public Service Electric and Gas Co. Where Field Tests Were Made.

(Courtesy Public Service Electric and Gas Co. of New Jersey.)

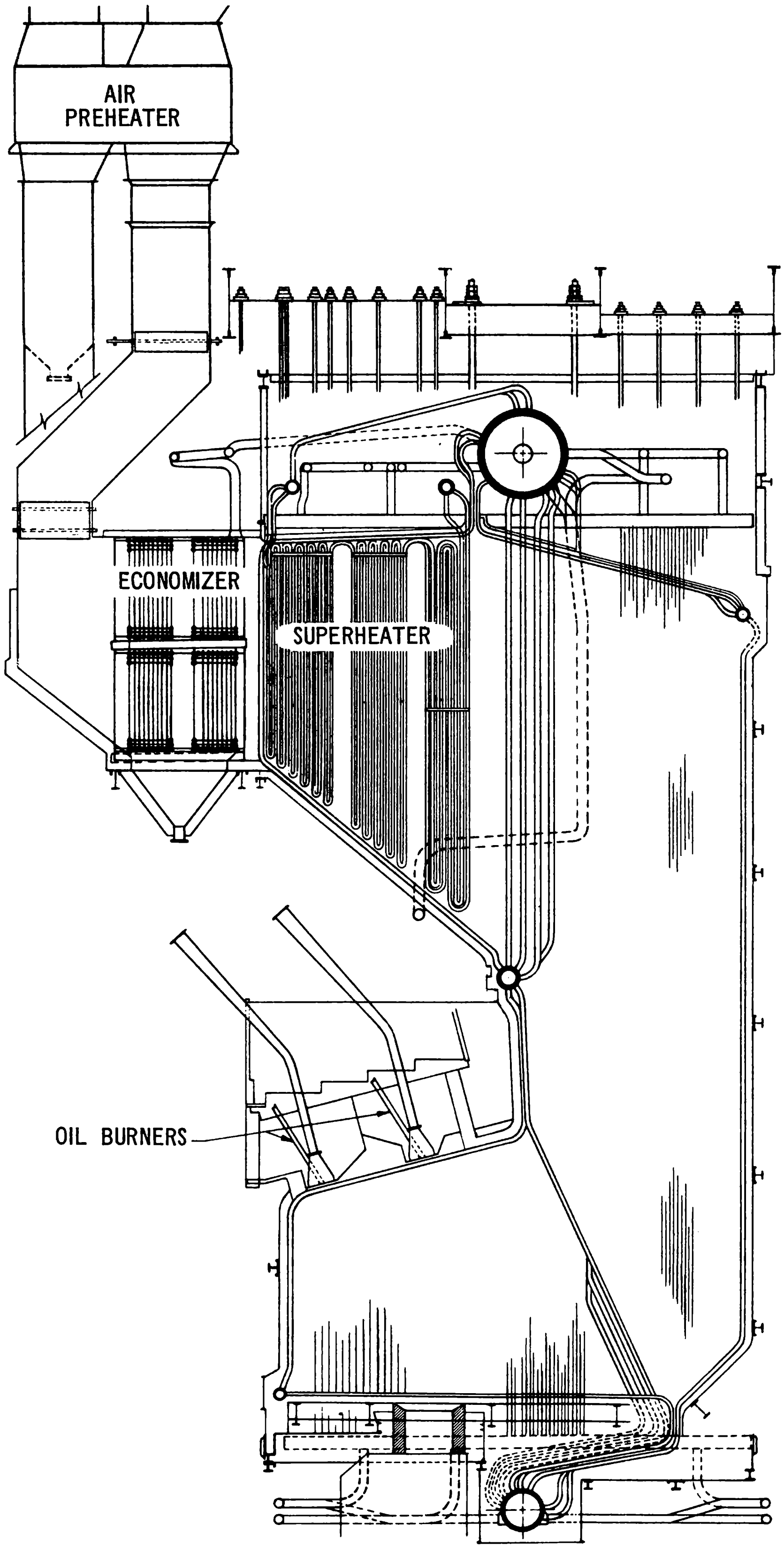

FIGURE 5. - General Cross Section of Boiler Equipment Used at Marion Generating Station.

Figure 4 is a view of the Marion Generating Station, Jersey City, N. J., of Public Service Electric and Gas Co., and figure 5 is a cross section of the boiler equipment used. Descriptions of the principal parts of the equipment follow:

Boiler: Babcock & Wilcox radiant boiler; capacity, 550,000 pounds steam per hour; working pressure, 1,475 p.s.i.g. Total furnace volume, 23,500 cubic feet; total heating surface, 7,929 square feet. Boiler is designed for pulverized coal and oil firing through burners in the roof of the primary furnace. With coal as fuel, the slag is tapped continuously through an opening in the furnace floor.

Superheater: Babcock & Wilcox continuous-type, tube-pendant superheater. Design pressure, 1,475 p.s.i.g.; operating pressure at superheater outlet, 1,350 p.s.i.g.; steam temperature at operating pressure, 950° F.

Burners: Oil: Twelve Babcock & Wilcox mechanical atomizing intertube oil burners; operating range 150 to 300 pounds pressure, oil heated to 220° F.

Coal: Six Babcock & Wilcox multiple intertube pulverized fuel burners.

Economizer: Babcock & Wilcox counterflow; 11,500 square feet of heating surface; 880 2-1/2-inch outside-diameter tubes arranged 44 tubes high, 20 tubes wide, and 20 feet long, continuous steel tube, which will heat 550,000 pounds of water per hour from 455° F. to 510° F. with 600,000 pounds of gas at 700° F. leaving the main economizer when the boiler is oil fired.

Forced-draft fan: American Blower Corp. No. 10 special high-speed fan, class III, double-inlet, double-width; constant speed 500-hp. Westinghouse motor, 1,188 r.p.m.; 160,000 c.f.m. of air at 120° F. with a static pressure of 13.9 inches water. An American Blower Corp. hydraulic coupling controls fan speed.

Induced-draft fan: American Blower Corp. size No. 12, Sirocco-type two-speed fan; high-speed 1,250-hp. Westinghouse motor, 716 r.p.m.; low-speed 750-hp. Westinghouse motor, 596 r.p.m.; 275,000 c.f.m. of gas at 350° F. and at a static pressure of 19.3 inches water. Control of the gas is maintained through louvre-type dampers at the fan-inlet boxes.

Air preheater: Ljungstrom regenerative, vertical-type, size 20; approximately 49,700 square feet of heating surface, comprising a lower or hot-end layer of vertical No. 24-US gage open-hearth steel plates, 42 inches high, of 3.5-mm. notched, 1.725-mm. undulation and a top or cold-end layer of vertical No. 18-US gage, low-alloy, corrosion-resistant steel plates, 12 inches high, alternating 6.00-mm. notched and flat sheets; rotor driven by 5-hp. motor, 1,200 r.p.m. through a spur-gear speed reducer to 2.5 r.p.m.

Figure 6 illustrates the principle of operation of the regenerative air preheater. The rotor carrying the heat-transfer elements rotates continuously at low speed; therefore, the elements pass alternately through the hot boiler flue gas and the relatively cold air to be used for combustion. As they pass through the hot boiler gas flowing to the induced-draft fan, heat is transferred to them, thus cooling the gas; as they pass through the cold air from the forced-draft fan, the stored heat is transferred from them to the air, thus heating the air.

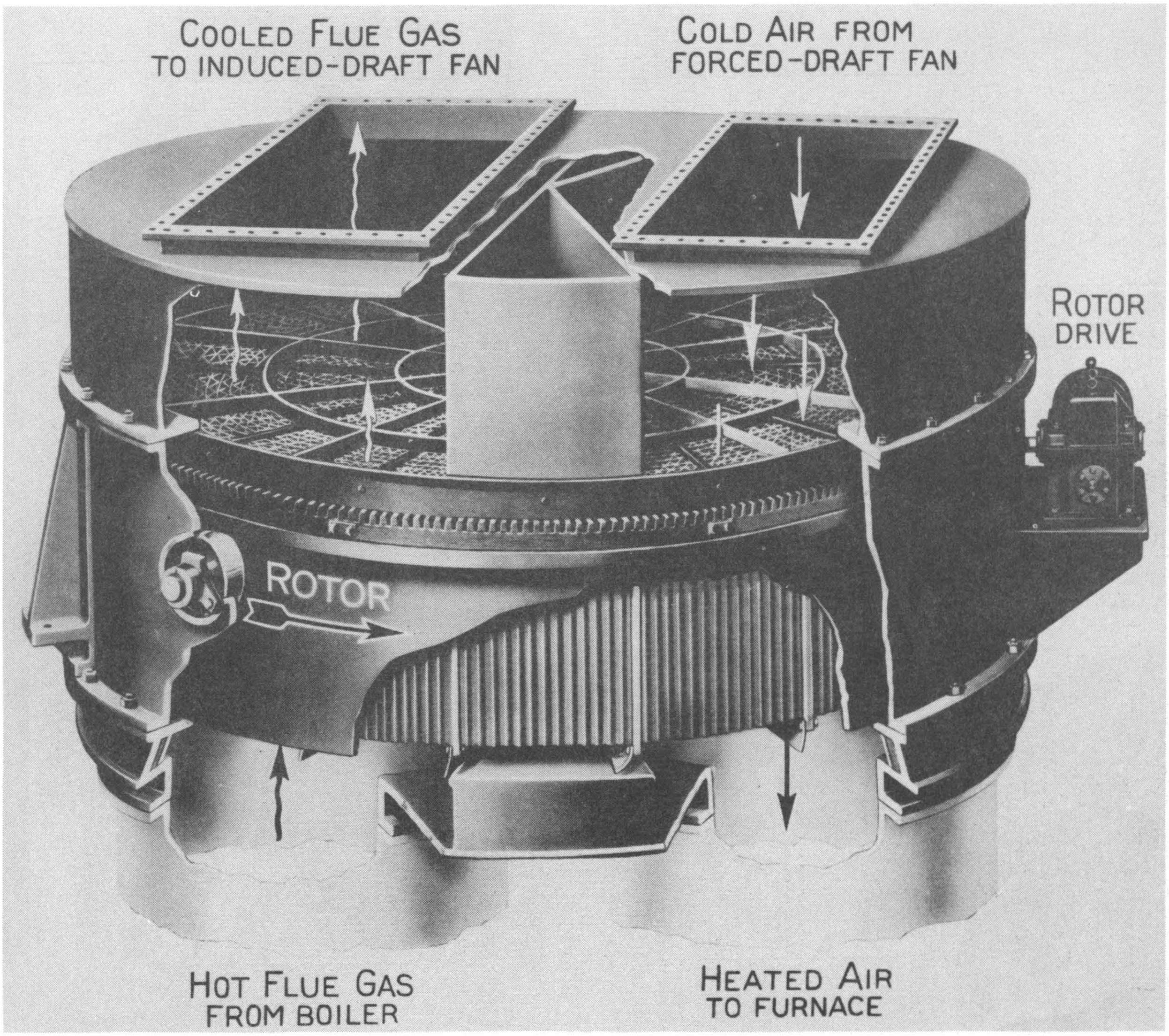

FIGURE 6. - Principle of Operation of Regenerative Air Preheater; Heating Elements Pass Alternately Through Hot Gas and Cold Air.

Figure 7 shows one type of installation of the heater elements; in this type, the elements are divided into shorter top or cold-end elements and longer bottom or hot-end elements. The elements can be shaped to form small passages for the gas and the air flow. Figure 8 illustrates the alternate flat and notched elements or plates. This type was used for the metal test plates.

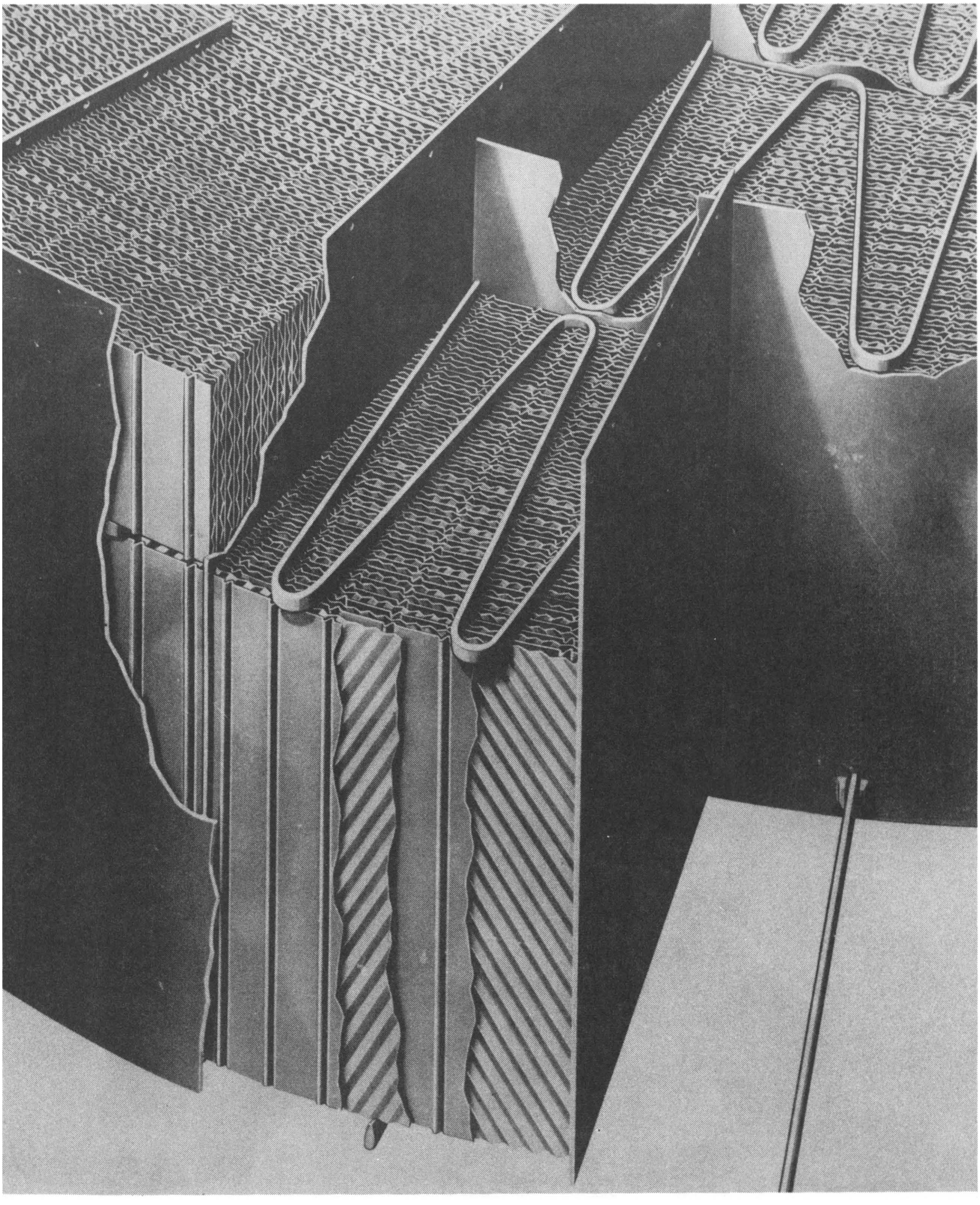

FIGURE 7. - Detail of One Type of Installation of Heater Elements—Shorter Top or Cold-End Elements and Longer Bottom or Hot-End Elements.

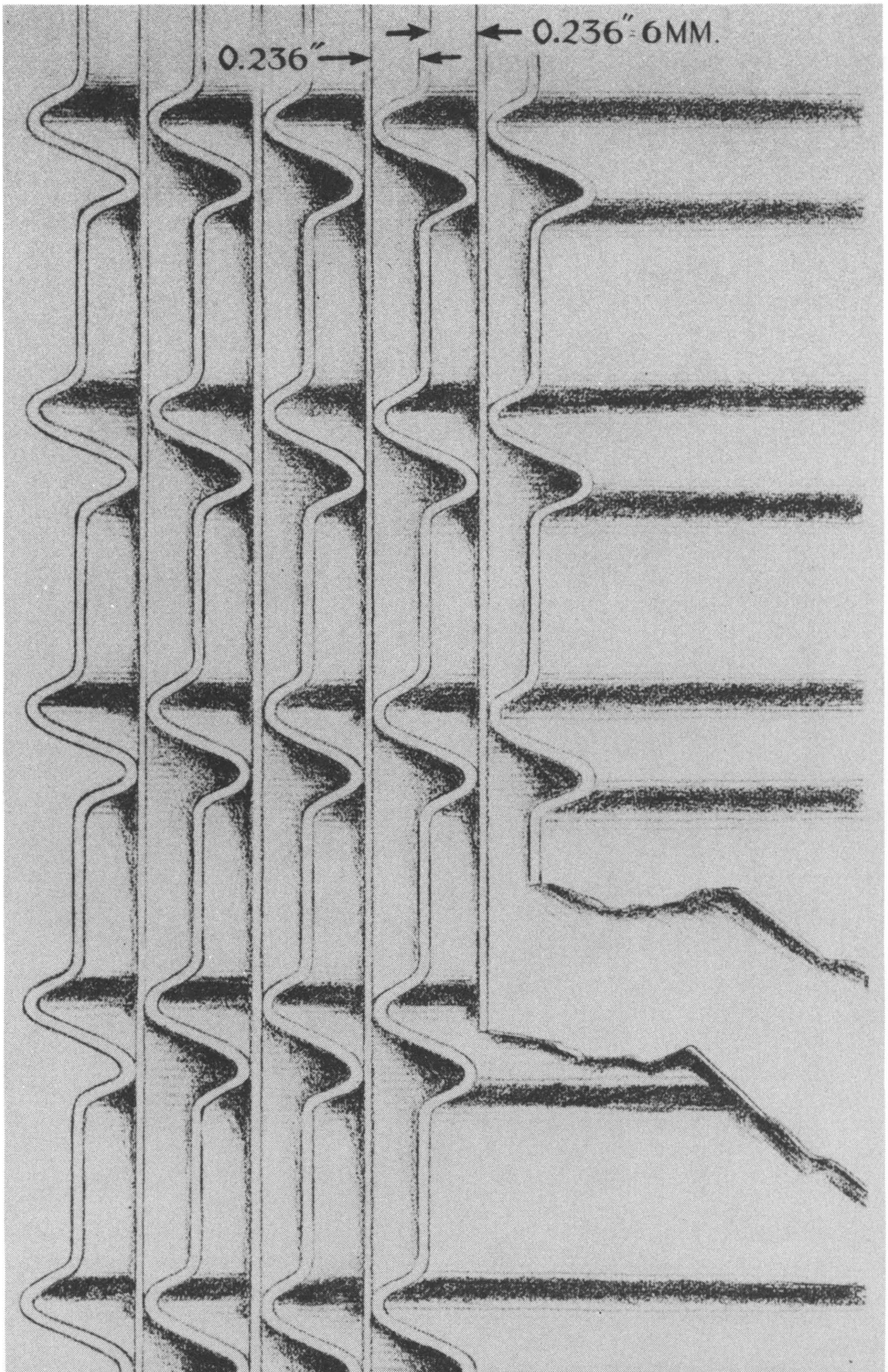

FIGURE 8. - Shape of Alternate Flat and Notched Plates Used for Metal Test Plates in This Work.

For convenience in handling, baskets (fig. 9) were used to hold the test specimens in the air preheater. Figure 10 shows the baskets installed at the top or cold end of the air preheater.

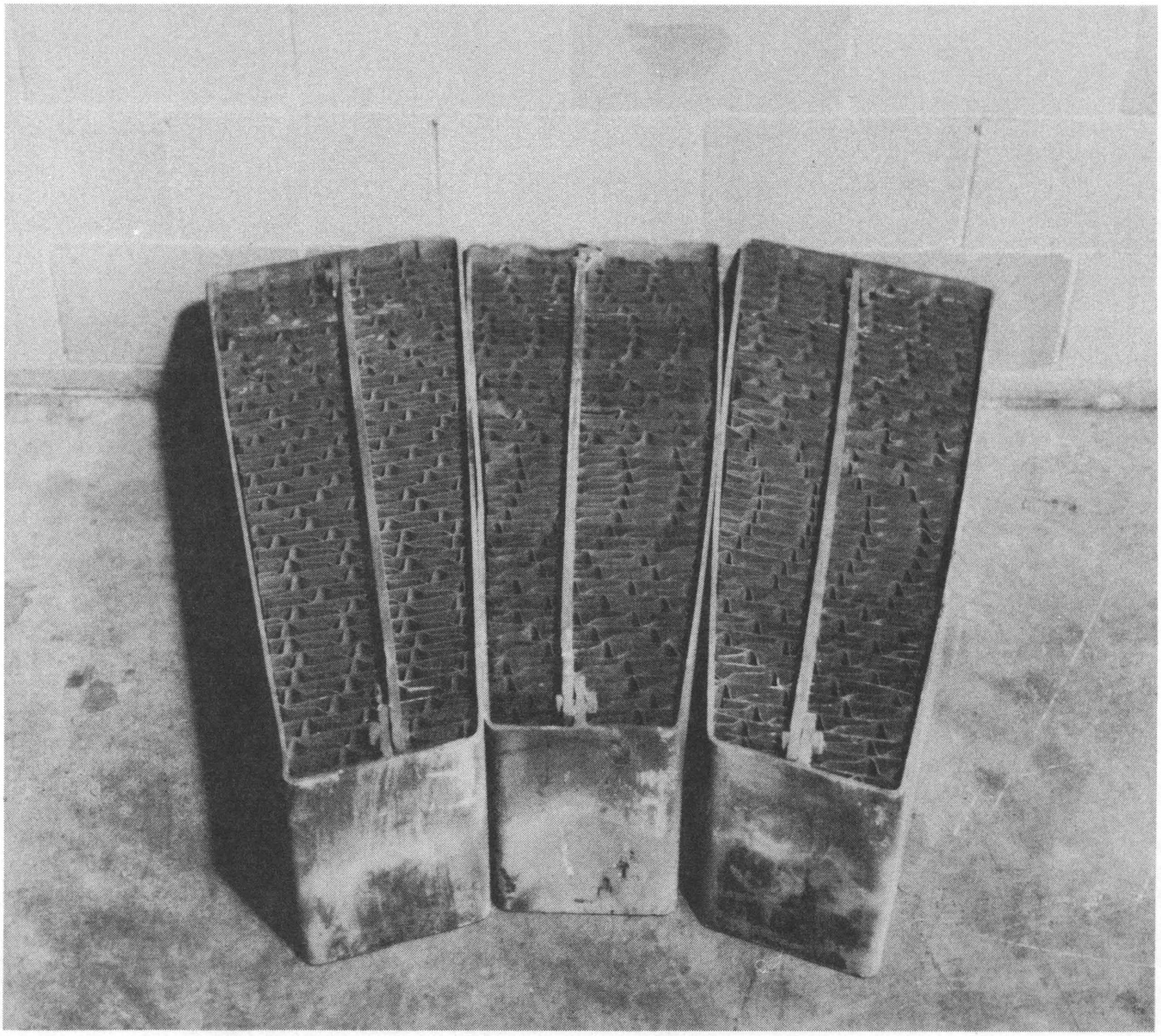

FIGURE 9. - Baskets Used to Hold Test Specimens of Heater Elements.

To remove the deposits that accumulated on the heater elements and keep the gas passages open, a standard-type air-preheater steam "soot" blower was used on each air preheater. (See fig. 11.) It was installed in the casing at the top of the air preheater to blow downward with the incoming air against the top or cold end of the heater. The steam nozzle was arranged to swing from center to perimeter, thus obtaining entire coverage.

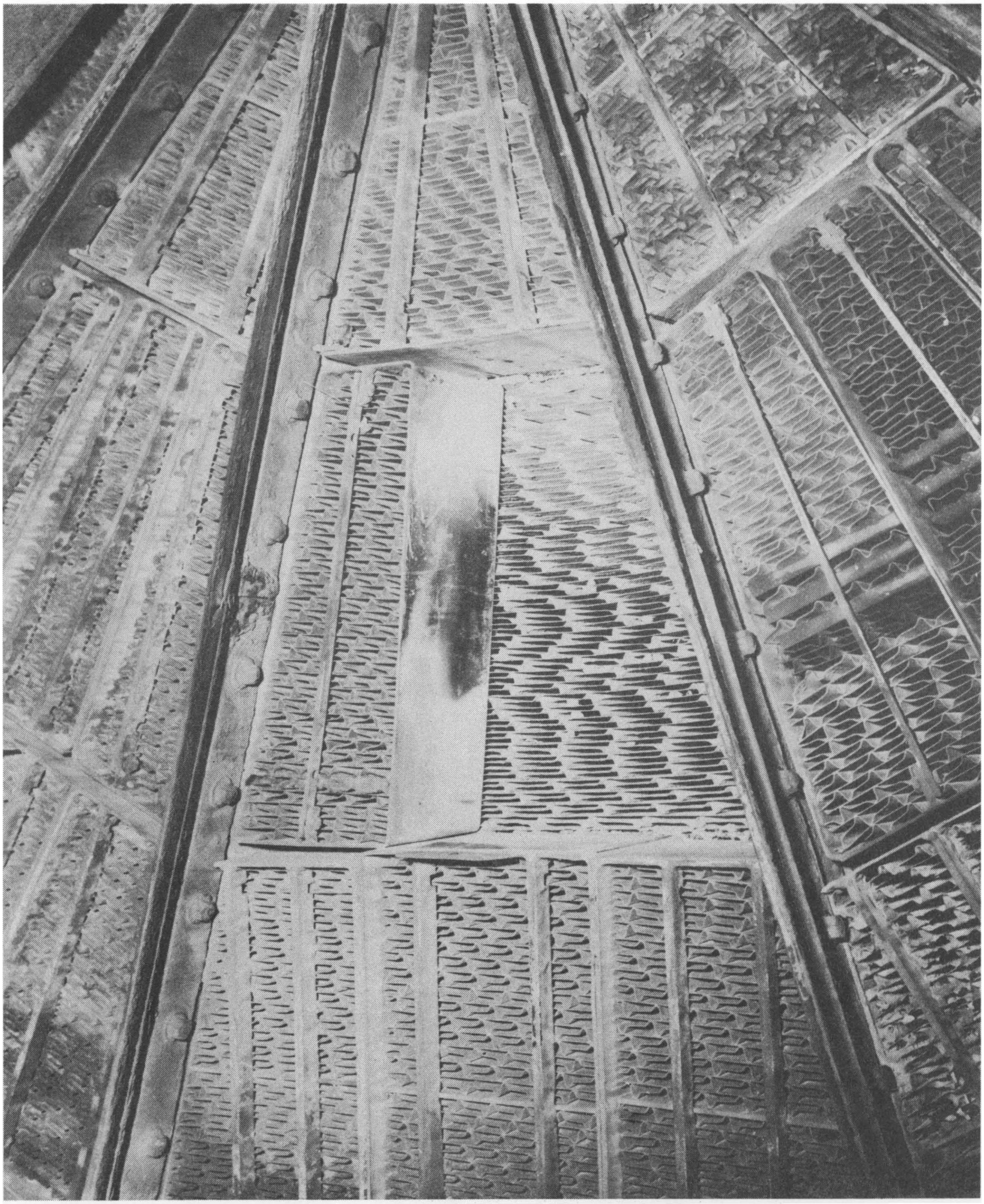

FIGURE 10. - Baskets of Test Specimens at Top or Cold End of Air Preheater.

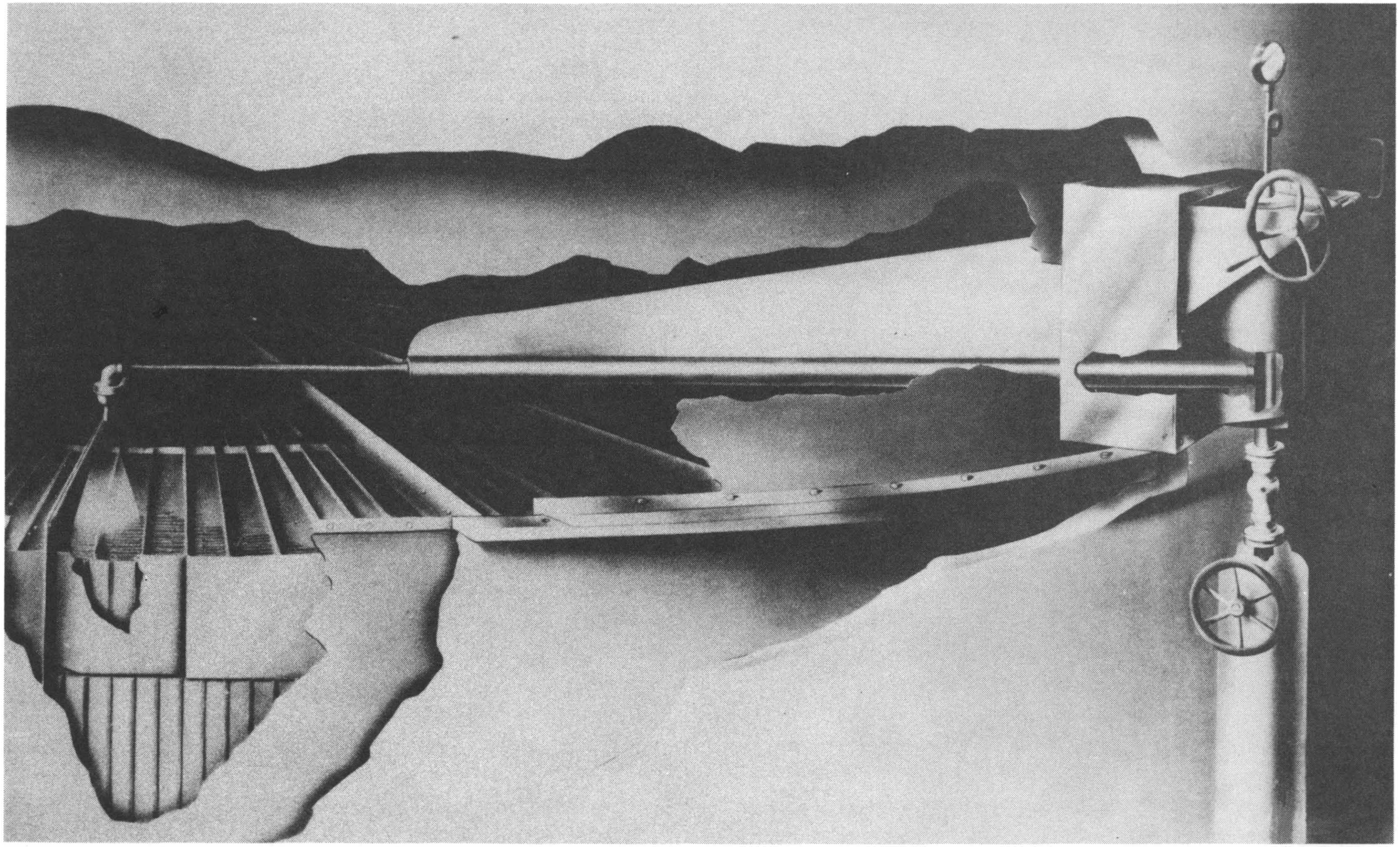

FIGURE 11. - Air-Preheater Steam "Soot" Blower Used for Removing Deposits Accumulating on Heater Elements.

PLANT DATA ON OPERATION OF FIELD TEST EQUIPMENT

Table 1 lists pertinent plant operating data taken by the plant operators during the test period at the Harding Street Station, and table 2 lists similar data taken at the Marion Generating Station. The last column of each table shows the average conditions of operation. Coal was used during the tests at the Harding Street Station and oil at the Marion Generating Station, except for a short period at the latter station when pulverized coal was used. Certain item numbers from table 1 are shown in figure 2 and certain items from table 2 in figure 5 to indicate the approximate position in the equipment where the data for the items were taken. The temperatures, from table 1, of gas and air entering and leaving the air preheater are plotted in figure 12; those from table 2 are plotted in figure 13. A curve is included on each figure showing the humidity of the entering air.

GENERAL DESCRIPTION OF FIELD TESTS

Rates of corrosion of regenerative air-preheater elements or plates were determined on 23 materials at the Harding Street Station and 7 materials at the Marion Generating Station. Table 3 lists the materials and gives information on analyses, grain structure, and coatings. The test specimens at the Harding Street Station were 6 inches high and 6 to 8 inches long; those at the Marion Generating Station were 12 inches high and 10 to 22 inches long. The rolled-metal plates ranged in thickness from about 0.022 to 0.062 inch. Each test specimen of rolled metal consisted of a flat sheet and a shop-cold-rolled notched sheet placed together (see fig. 8). Coated-metal specimens were similar, their thickness being increased by the coating. The Pyrex specimens were flat plates 5/32 inch thick. They were laid in the air-preheater basket between notched Cor-Ten plates. Ordinarily four test specimens of each material were placed vertically at the cold end of the air preheater, one or more specimens being withdrawn at time intervals determined by the extent of corrosion. Figures 14 to 17, inclusive, show typical accumulations of deposits and destruction of test specimens.

Before being placed in the air preheater, each specimen was weighed and its thickness determined by micrometer over its entire area. Upon its withdrawal from the air preheater, visual observations were made of the deposit accumulation and any corrosion. The specimen was then cleaned by washing it with water and weighed, and the contour of its thickness was determined by micrometer. The percentage loss in weight of each test piece expressed the average percentage loss for the length of time the specimen was in the preheater for a height of 6 inches at the Harding Street Station and for a height of 12 inches at the Marion Generating Station. Adjusting these percentage losses in weight to a common specimen thickness and to a common period of time in the air preheater at each station would give percentage weight losses that would be comparable if operating conditions were the same over the various periods of testing. As there was no assurance that operating conditions would be the same, standard specimens to which the materials could be compared were inserted with all test specimens. The standard specimen material chosen was Cor-Ten steel.

TABLE 1. - Plant data on operation of field test equipment during testing period at Harding Street Station

	1951								1952									1953				
1. Year	1951								1952									1953				
2. Month	May	June	July	Aug.	Sept.	Oct.	Nov.		Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May
3. Outdoor dry-bulb temperature, °F	64	70	74	72	63	57	36	No. 2 boiler down for general overhaul Nov. 29, 1951 - Mar. 31, 1952. All test elements withdrawn Dec. 5, 1951. New elements installed Apr. 5, 1952.	55	63	78	79	73	66	52	43	36	34	36	42	48	66
4. Outdoor relative humidity, percent	68	74	75	74	75	73	76		67	72	72	67	72	71	59	73	83	82	68	75	72	72
5. Hours steaming	52	354	365	351	368	483	366		414	434	344	582	482	487	524	510	490	506	239	271	426	68
5a. Percent of time steaming	36	49	49	47	51	65	51		66	58	48	78	65	67	70	71	66	68	36	36	59	9
6. Hours on bank	83	254	327	317	353	236	136		209	304	247	152	248	214	168	163	239	238	311	473	273	19
6a. Percent of time on bank	58	35	44	43	49	32	19		34	41	34	21	33	30	23	23	32	32	46	64	38	3
7. Hours off	9	112	52	76	0	25	218		0	6	129	10	14	20	52	47	15	0	122	0	20	657
7a. Percent of time off	6	16	7	10	0	3	30		0	1	18	1	2	3	7	6	2	0	18	0	3	88
Steaming conditions:																						
8. Steam rate, 1,000 lb. per hour	85	88	83	85	90	94	85		89	98	92	91	88	94	94	87	82	82	78	86	74	52
9. Minimum steam rate, 1,000 lb. per hour	22	63	31	68	67	79	70		60	60	62	63	64	64	60	61	63	59	60	59	54	36
10. Steam pressure, p.s.i.g.	440	438	438	439	438	438	439		445	445	444	446	446	446	446	440	441	441	438	438	437	437
11. Steam temperature, °F	707	724	738	727	719	722	722		716	731	720	723	710	715	706	712	725	721	729	739	726	695
12. Air temperature - heater inlet, °F	106	110	116	116	112	110	99		105	104	109	109	113	108	102	104	96	95	96	98	103	105
13. Relative humidity of air entering heater, percent	17	22	20	18	17	14	9		13	19	28	28	21	19	12	9	11	10	9	11	12	21
14. Air temperature - heater outlet, °F	243	254	268	251	252	259	250		230	235	223	224	227	232	235	235	231	233	223	224	227	233
15. Flue-gas temperature - boiler outlet, °F	742	735	705	730	748	804	777		687	679	666	653	666	710	744	766	747	754	710	708	666	566
16. Flue-gas temperature - heater inlet, °F	531	513	499	525	537	563	543		450	434	421	417	442	466	512	505	498	498	461	460	439	377
17. Flue-gas temperature - heater outlet, °F	390	393	382	394	410	421	403		348	337	333	331	341	363	384	388	374	377	355	351	344	320
18. Minimum flue-gas temperature - heater outlet, °F	315	329	340	358	362	351	345		280	275	299	293	308	315	325	324	323	324	312	298	295	300
19. Mean temperature of cold edge of heater elements, °F	248	252	249	255	261	266	251		227	221	221	220	227	236	243	246	235	236	226	225	224	213
20. CO_2 - boiler outlet, percent	7.9	-	-	-	-	-	-		12.9	12.9	11.1	12.5	11.8	11.1	10.4	10.2	10.2	12.5	11.6	13.4	12.0	8.2
21. Boiler outlet draft, inches water	1.3	1.7	1.7	1.7	1.9	2.0	1.8		1.4	1.4	1.6	1.5	1.8	1.8	1.8	1.8	1.9	1.5	1.6	1.3	1.3	1.2
22. Air-heater gas-inlet draft, inches water	3.4	4.4	4.6	4.7	5.1	5.3	5.0		2.7	2.7	2.9	2.8	3.3	3.4	3.4	3.5	4.6	3.0	3.0	2.6	2.5	2.2
23. Air-heater gas-outlet, draft, inches water	3.9	5.4	5.5	5.6	6.0	6.5	6.1		3.6	4.4	4.4	3.4	4.1	3.8	4.3	4.3	5.6	3.9	4.0	3.9	3.9	3.3
24. Draft loss through heater, inches water	.5	1.0	.9	.9	.9	1.2	1.1		.9	1.7	1.5	.6	.8	.4	.9	.8	1.0	.9	1.0	1.3	1.4	1.1
Banked-fire conditions:																						
25. Flue-gas temperature - boiler outlet, °F	483	458	460	460	453	462	463		445	458	457	453	461	449	451	472	457	454	451	451	441	498
26. Flue-gas temperature - heater inlet, °F	353	354	358	368	370	369	372		342	350	339	356	351	365	384	382	366	369	368	345	353	338
27. Flue-gas temperature - heater outlet, °F	323	348	343	351	353	356	350		324	325	313	336	324	335	361	354	335	352	345	324	337	300
28. Minimum flue-gas temperature - heater outlet, °F	303	317	316	316	324	327	319		280	296	279	289	289	309	311	324	305	310	310	288	294	282
29. CO_2 - boiler outlet, percent	2.1	-	-	-	-	-	-		4.8	4.6	4.4	5.4	4.1	3.9	2.1	1.7	2.9	3.0	3.4	3.7	3.3	2.7
30. Total coal consumption, tons	335	2,290	2,340	2,395	2,464	3,287	2,300		2,646	2,880	2,425	3,740	3,133	3,285	3,472	3,214	3,018	3,014	1,543	1,901	2,385	272
31. Coal analysis:																						
a. Total moisture - as received, percent	12.5	12.6	12.1	12.0	12.0	11.8	12.7		12.1	11.5	11.6	11.7	11.6	12.5	12.8	12.4	12.8	12.2	11.7	12.1	12.1	11.6
b. Ash, dry basis, percent	10.6	10.6	10.8	11.5	10.8	10.8	10.4		10.9	10.1	10.2	10.2	10.1	10.6	9.9	10.4	10.0	9.9	9.9	10.0	9.9	10.0
c. Sulfur, dry basis, percent	4.1	4.2	3.8	3.9	4.1	4.3	4.0		4.1	3.9	4.0	3.9	4.2	4.2	3.9	4.3	4.4	4.4	4.3	4.3	4.2	4.3
d. B.t.u. per pound - as received	11,241	11,227	11,207	11,326	11,281	11,342	11,279		11,351	11,316	11,456	11,389	11,410	11,191	11,245	11,326	11,316	11,377	11,477	11,413	11,384	11,422

	1953							1954												1955		
1. Year	1953							1954												1955		
2. Month	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Average
3. Outdoor dry-bulb temperature, °F	77	78	76	67	61	46	33	31	40	38	57	58	76	78	74	70	56	42	32	28	28	56
4. Outdoor relative humidity, percent	64	67	66	57	62	64	69	74	68	66	66	60	63	57	76	68	79	80	79	76	75	70
5. Hours steaming	452	488	443	561	550	481	294	256	108	138	158	140	287	140	192	63	137	75	33	103	187	-
5a. Percent of time steaming	63	66	60	78	74	67	40	34	16	19	22	19	40	19	26	9	18	10	4	14	43	45
6. Hours on bank	95	256	207	160	181	110	208	421	396	332	326	373	377	336	552	638	607	381	207	329	243	-
6a. Percent of time on bank	13	34	28	22	24	15	28	57	59	44	45	50	52	45	74	88	82	53	28	44	56	38
7. Hours off	173	0	94	0	13	129	242	67	168	274	235	231	56	268	0	20	0	264	504	312	2	-
7a. Percent of time off	24	0	12	0	2	18	32	9	25	37	33	31	8	36	0	3	0	37	68	42	1	15
Steaming conditions:																						
8. Steam rate, 1,000 lb. per hour	76	63	62	69	74	65	78	91	98	93	94	101	104	97	96	94	108	95	92	90	87	86
9. Minimum steam rate, 1,000 lb. per hour	58	58	52	55	61	66	62	63	64	65	68	68	70	72	64	58	79	64	63	66	65	61
10. Steam pressure, p.s.i.g.	439	436	437	437	437	438	438	439	439	438	441	442	442	437	439	439	438	437	435	436	438	440
11. Steam temperature, °F	717	705	716	698	701	692	677	771	825	725	723	718	729	757	738	751	741	675	639	747	752	722
12. Air temperature - heater inlet, °F	125	117	107	106	102	100	92	84	56	98	96	99	105	108	102	99	95	87	56	80	87	101
13. Relative humidity of air entering heater, percent	16	20	26	17	17	10	9	11	10	8	18	16	26	23	31	27	25	17	32	11	9	17
14. Air temperature - heater outlet, °F	242	217	244	248	250	251	241	242	255	226	229	226	241	246	235	234	234	197	108	212	223	233
15. Flue-gas temperature - boiler outlet, °F	637	620	626	653	675	706	714	788	814	691	691	681	702	708	655	656	675	599	523	659	656	692
16. Flue-gas temperature - heater inlet, °F	428	416	428	445	461	474	482	532	541	464	473	477	484	466	451	445	457	388	338	464	470	468
17. Flue-gas temperature - heater outlet, °F	358	349	346	356	360	369	369	411	376	339	356	342	345	340	321	326	336	288	205	333	349	355
18. Minimum flue-gas temperature - heater outlet, °F	307	311	315	325	334	342	340	350	344	304	310	312	318	318	311	316	327	281	183	309	329	316
19. Mean temperature of cold edge of heater elements, °F	242	233	227	231	231	235	231	248	236	219	226	221	225	224	212	213	216	188	131	207	218	228
20. CO_2 - boiler outlet, percent	12.4	10.5	10.9	11.5	9.7	10.2	12.5	13.2	12.9	12.0	11.7	12.8	12.3	12.3	12.3	12.2	12.3	10.9	11.5	-	-	11.6
21. Boiler outlet draft, inches water	1.9	1.8	2.0	1.8	1.9	2.0	2.1	2.2	2.2	2.1	2.3	2.2	2.4	2.3	2.5	2.5	2.5	2.4	2.1	2.4	2.2	1.9
22. Air-heater gas-inlet draft, inches water	3.4	3.2	3.5	3.1	3.5	3.6	3.8	4.0	4.3	3.9	4.5	4.5	4.8	4.6	5.4	5.4	5.4	4.7	5.1	5.2	5.1	4.0
23. Air-heater gas-outlet draft, inches water	3.7	3.8	4.1	3.7	4.1	4.1	4.3	4.5	4.9	4.5	5.1	5.1	5.4	5.1	6.0	6.0	6.0	5.3	5.7	5.8	4.6	4.7
24. Draft loss through heater, inches water	.3	.6	.6	.6	.6	.5	.5	.5	.6	.6	.6	.6	.6	.5	.6	.6	.6	.6	.6	.6	.5	.7
Banked-fire conditions:																						
25. Flue-gas temperature - boiler outlet, °F	453	445	439	450	444	442	443	467	479	431	423	425	438	452	409	391	372	300	248	355	390	437
26. Flue-gas temperature - heater inlet, °F	377	355	368	363	375	371	378	415	426	366	363	371	371	395	367	350	347	280	233	335	375	360
27. Flue-gas temperature - heater outlet, °F	355	348	344	343	352	358	366	375	379	337	343	336	326	339	324	318	316	253	199	310	348	335
28. Minimum flue-gas temperature - heater outlet, °F	321	303	309	311	318	322	321	327	331	295	292	290	294	298	281	276	264	198	145	252	296	296
29. CO_2 - boiler outlet, percent	3.2	3.6	3.6	3.8	2.7	3.2	2.8	3.3	3.2	4.1	2.8	3.8	3.0	3.1	3.0	2.6	2.0	2.1	2.2	1.8	-	3.2
30. Total coal consumption, tons	2,489	2,275	2,039	2,779	2,921	2,278	1,694	1,924	1,021	1,129	1,253	1,261	2,344	1,142	1,505	656	1,142	608	313	894	1,331	2,032
31. Coal analysis:																						
a. Total moisture - as received, percent	11.5	11.3	10.8	10.5	11.3	11.5	12.9	12.3	12.5	12.1	11.9	11.7	11.6	11.0	11.9	11.5	12.1	12.3	12.7	12.8	13.2	12.0
b. Ash, dry basis, percent	9.7	9.6	9.7	9.8	10.2	9.1	8.8	9.2	9.4	9.2	9.4	9.1	8.9	8.8	9.4	9.3	9.0	8.6	8.8	8.7	9.0	9.8
c. Sulfur, dry basis, percent	4.1	3.9	4.3	4.1	3.9	3.8	3.7	3.9	3.9	3.9	4.1	3.9	3.6	3.5	3.9	3.9	3.6	3.5	3.5	3.5	3.5	4.0
d. B.t.u. per pound - as received	11,414	11,517	11,567	11,598	11,371	11,585	11,463	11,449	11,414	11,504	11,472	11,543	11,572	11,689	11,466	11,522	11,546	11,564	11,476	11,435	11,389	11,417

TABLE 2. - Plant data on operation of field test equipment during testing period at Marion Generating Station

	1956						
1. Year							
2. Month	June	July	August	September	October	November	December
3. Outdoor dry-bulb temperature, °F	72	73	74	64	57	46	40
4. Outdoor relative humidity, percent	67	68	70	72	71	69	67
5. Hours steaming	702	744	699	720	700	720	696
5a. Percent of time steaming	98	100	94	100	94	100	94
6. Hours out of service	18	0	45	0	45	0	48
6a. Percent of time out of service	2	0	6	0	6	0	6
Steaming conditions:							
7. Steam rate, 1,000 lb. per day	7,806	4,983	6,720	6,715	10,473	8,898	9,395
8. Steam rate, 1,000 lb. per hour	325	208	287	280	436	371	391
9. Minimum steam rate, 1,000 lb. per hour	135	95	96	98	215	139	158
10. Steam pressure, p.s.i.g	1,272	1,279	1,291	1,291	1,305	1,298	1,299
11. Steam temperature, °F	925	918	917	923	928	923	923
12. Air temperature - heater inlet, °F	99	105	113	107	90	88	93
13. Relative humidity of air entering heater, percent	28	25	21	18	24	17	11
14. Air temperature - heater outlet, °F	496	524	554	556	596	583	587
15. Flue-gas temperature - heater inlet, °F	539	564	613	614	677	660	666
16. Flue-gas temperature - heater outlet, °F	316	323	328	325	337	331	337
17. Minimum flue-gas temperature - heater outlet, °F	285	302	295	301	305	300	306
18. Mean temperature of cold edge of heater elements, °F.	208	214	221	216	214	210	215
19. CO_2-economizer outlet, percent	9.8	7.9	8.8	8.6	12.1	11.1	11.2
20. Air-heater gas-inlet draft, inches water	4.2	3.0	4.3	3.7	5.8	4.6	4.6
21. Air-heater gas-outlet draft, inches water	6.2	4.6	6.8	5.6	9.2	6.9	7.2
22. Draft loss through heater, inches water	2.0	1.6	2.5	1.9	3.4	2.3	2.6
23. Total oil consumption, bbl	45,865	31,933	39,345	39,809	58,635	51,947	52,839
24. Total coal consumption, tons	-	-	-	-	-	-	-
25. Fuel analysis:							
a. Total moisture - as received, percent	.17	.23	.08	.14	.22	.33	.14
b. Ash, dry basis, percent	.43	.15	.61	.11	.11	.11	.22
c. Sulfur, dry basis, percent	3.26	3.44	3.39	3.58	3.03	3.58	3.16
d. B.t.u. per pound, as received	18,174	18,227	18,118	18,132	18,175	18,032	18,133

	1957							
1. Year								
2. Month	January	February		March		April	Average	
3. Outdoor dry-bulb temperature, °F	28	36		42		53	50	
4. Outdoor relative humidity, percent	67	43		42		43	62	
5. Hours steaming	700	490		694		624		
5a. Percent of time steaming	94	73		93		100	95	
6. Hours out of service	44	182		50		0		
6a. Percent of time out of service	6	27		7		0	5	
Steaming conditions:								
7. Steam rate, 1,000 lb. per day	9,913	9,328		9,133		9,031	8,400	
8. Steam rate, 1,000 lb. per hour	413	389		381		376	351	
9. Minimum steam rate, 1,000 lb. per hour	170	195		158		134	145	
10. Steam pressure, p.s.i.g	1,303	1,295		1,292		1,296	1,293	
11. Steam temperature, °F	925	918		918		917	921	
12. Air temperature - heater inlet, °F	89	99		96		95	98	
13. Relative humidity of air entering heater, percent	8	6		7		11	16	
14. Air temperature - heater outlet, °F	612	608		613		604	576	
15. Flue-gas temperature - heater inlet, °F	712	696		700		691	648	
16. Flue-gas temperature - heater outlet, °F	336	340		341		339	332	
17. Minimum flue-gas temperature - heater outlet, °F	306	299		305		300	300	
18. Mean temperature of cold edge of heater elements, °F.	213	220		219		217	215	
19. CO_2-economizer outlet, percent	11.8	12.8		12.8		12.2	10.8	
20. Air-heater gas-inlet draft, inches water	5.1	5.0		3.8		4.3	4.4	
21. Air-heater gas-outlet draft, inches water	8.3	7.3		5.9		6.9	6.8	
22. Draft loss through heater, inches water	3.2	2.3		2.1		2.6	2.4	
23. Total oil consumption, bbl	55,100	13,935		34,205		45,245	1/ 46,081	
24. Total coal consumption, tons	-	5,679		4,226		-		
25. Fuel analysis:		Oil	Coal	Oil	Coal		Oil	Coal
a. Total moisture - as received, percent	.55	.14	6.76	.56	6.04	.82	.31	6.40
b. Ash, dry basis, percent	.04	.03	8.68	.09	10.10	.13	.18	9.39
c. Sulfur, dry basis, percent	3.22	2.70	2.20	3.81	2.72	3.78	3.36	2.46
d. B.t.u. per pound, as received	18,248	18,326	12,565	17,974	12,374	18.017	18,141	12,470

1/ Includes equivalent conversion of 9,905 tons of coal.

TABLE 3. - List of materials and pertinent information

No.	Materials	Chemical analysis, percent: C	Mn	P	S	Si	Ni	Cr	Cu	Fe1/	Miscellaneous	Grain structure, ASTM No.
	Harding Street Station											
	Uncoated metal											
-	Cor-Ten steel2/	0.10	0.40	0.105	0.038	0.54	0.45	0.89	0.42	97.06	-	8
1	18% chrome, 8% nickel steel with titanium - type 3213/	4/.08	-	-	-	-	9.5	18.0	-	72.02	Ti, 0.40	-
2	Otiscoloy steel5/	.10	.98	.103	.028	.04	-	-	.37	98.38	-	8
3	Wrought iron3/	.08	.015	.062	.010	.158	-	-	-	98.48	Slag, 1.20	-
	Coated and plated											
4	Aluminum on Cor-Ten - mollerized	Plates dipped in electrically heated salt and aluminum bath held at 1,400° F.										
5	Aluminum silicone on Cor-Ten	Sicon aluminum 3X-222A applied by brushing and air dried.										
6	Barrows enamel (1 coat) on 22-USG Cor-Ten	A vitreous ceramic coating applied by dipping and fired at 1,520° F. for 5 minutes. Approximately 0.010 enamel thickness per side.										
7	Barrows enamel (2 coats) on 22-USG Cor-Ten	A vitreous ceramic coating. First coat applied by dipping and fired at 1,520° F. for 5 minutes. It was redipped and fired at 1,520° F. for 3 minutes. Approximately 0.014 enamel thickness per side.										
8	Barrows enamel (1 coat) on 24-USG open hearth	A vitreous ceramic coating applied by dipping and fired at 1,520° F. for 5 minutes. Approximately 0.008 enamel thickness per side.										
9	Barrows enamel (2 coats) on 24-USG open hearth	A vitreous ceramic coating. First coat applied by dipping and fired at 1,520° F. for 5 minutes. It was redipped and fired at 1,520° F. for 3 minutes. Approximately 0.012 enamel thickness per side.										
10	Carbon coating on Cor-Ten	A mixture of National Carbon Co. No. 140 coating compound with C_3 carbonaceous cement and an accelerator. Coating applied by brushing and air dried.										
11	Chemoxide on aluminum 2S	Applied by a 2-minute dip in an acid solution at room temperature.										
12	Dow Corning silicone on Cor-Ten (2 coats)	First coat sprayed with XP-4335 modified silicone aluminum and cured 16 hours at 800° F. Second coat sprayed with XP-4016 silicone primer and cured 3 hours at 482° F.										
13	Do	First coat sprayed with XP-4016 silicone primer and cured 1 hour at 302° F. Second coat sprayed with XP-4335 silicone gray and cured 3 hours at 482° F.										
14	Do	First coat sprayed with XP-214 silicone primer and air dried. Second coat sprayed with XP-4345 modified silicone gray and cured 4 hours at 392° F.										
15	EC anodized aluminum 2S	Anodized for 4 minutes in sulfuric acid electrolyte at 80° F.										
16	Do	Anodized for 20 minutes in sulfuric acid electrolyte at 80° F.										
17	EC coating on No. 7740 Pyrex brand clear borosilicate glass (5/32 in. thick)	A metallic oxide coating applied to one side of plate at high temperature.										
18	Erie enamel (1 coat) on 22- and 18-USG Cor-Ten	A coat applied by dipping entire unit and fired at 1,550° F. for 40 minutes. Approximately 0.005 enamel thickness per side.										
19	NBS-A19 ferroenamel on Cor-Ten	A coat applied by spraying 10 to 20 g. per sq. ft. of surface (dry weight) using regular ground coat and fired at 1,600° F.										
20	XR623A ferroenamel on Cor-Ten	A coat applied by spraying 15 to 18 g. per sq. ft. of surface (dry weight) using a high-temperature, acid-resisting ground coat and fired at 1,600° F.										
21	Solaramic enamel (1 coat) on 22-USG Cor-Ten	A coat applied by dipping the entire unit. Approximately 0.005 enamel thickness per side.										
22	Solaramic enamel (1 coat) on 22-USG Cor-Ten	A coat applied by spraying each sheet individually. Approximately 0.006 enamel thickness per side.										
	Ceramic and miscellaneous											
23	#7740 Pyrex flat plate (5/32 in. thick)	A clear, borosilicate, Pyrex-brand glass plate.										
	Marion Generating Station											
	Uncoated metal											
1	Aluminum alodized 3003-H143/	-	1.25	-	-	-	-	-	-	-	Al, 98+ {Fe, Si} 0.75	-
2	Hi-strength steel5/	.08	.32	.009	.023	-	.92		.70	97.87	Mo, 0.08	8
3	Jalten steel3/	4/.15	4/1.40	4/.14	4/.05	4/.10	-	-	6/.30	97.86	-	8
4	Mayari-R steel3/	.08	.50	.10	.03	.10	.28	.28	.27	98.36	-	8
5	NAX (CSX) steel5/	.14	.68	.018	.021	.77	-	.61	.27	97.4	Zr, 0.05	8
6	Yoloy (HSX) steel5/	.12	.52/.50	.061	.027	-	.56	.22	.39	98.11	-	8
	Coated											
7	Ferro enamel (1 coat) on 24-S aluminum	Sheets were first alkaline cleaned, put through the Du Pont pretreatment, and prefired at 1,000° F. for 7 minutes. The plates were then sprayed with a coat of low-temperature acid-resisting enamel, approximately 0.002 in.2/ per side. The enameled sheets were then fired at 1,000° F.										

1/ Approximate. 2/ As determined from test plate. 3/ Typical. 4/ Maximum. 5/ As determined at rolling mill. 6/ Minimum.

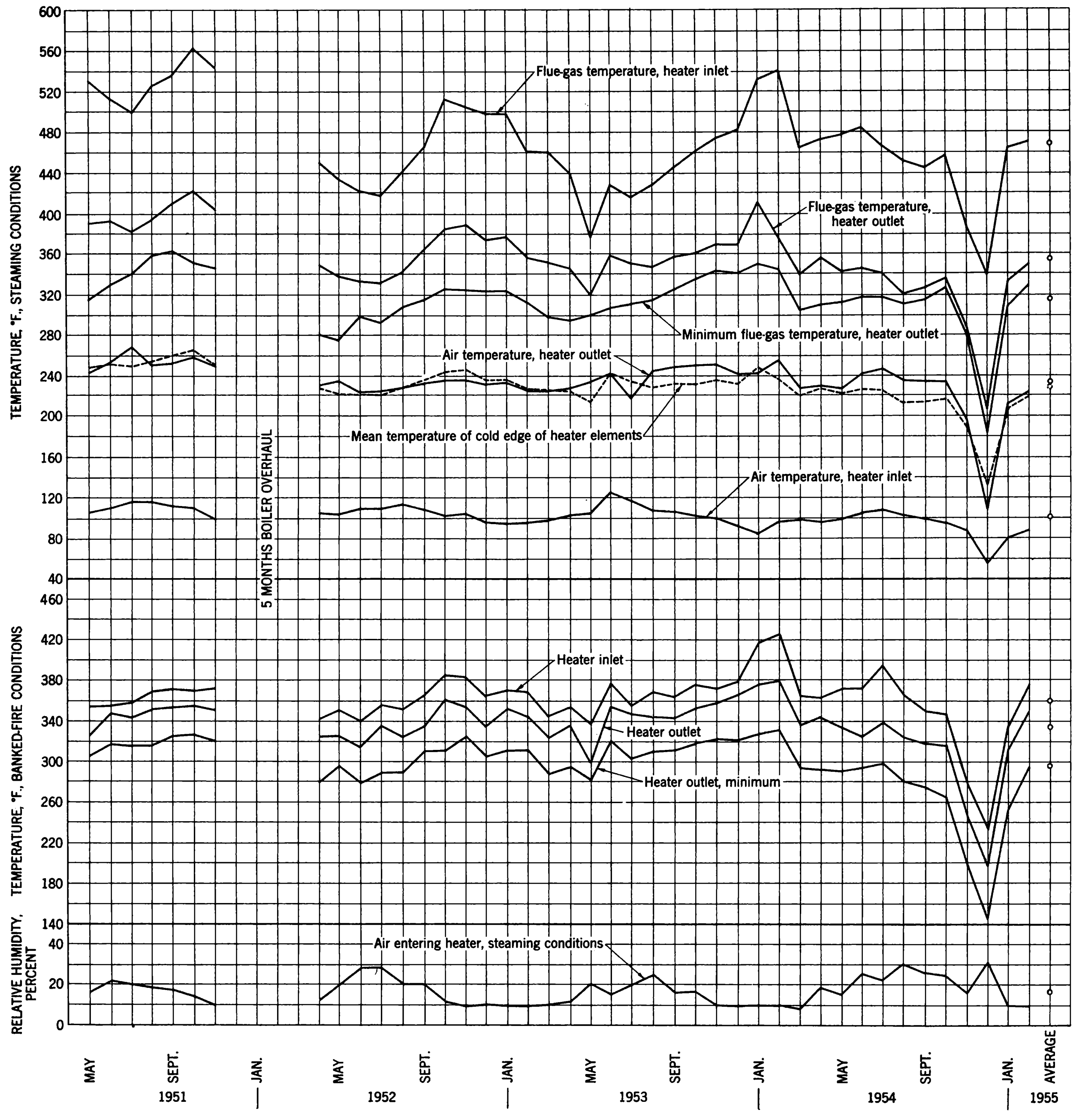

FIGURE 12. - Temperature of Gas and Air Entering and Leaving Air Preheater at Harding Street Station and Relative Humidity of Entering Air.

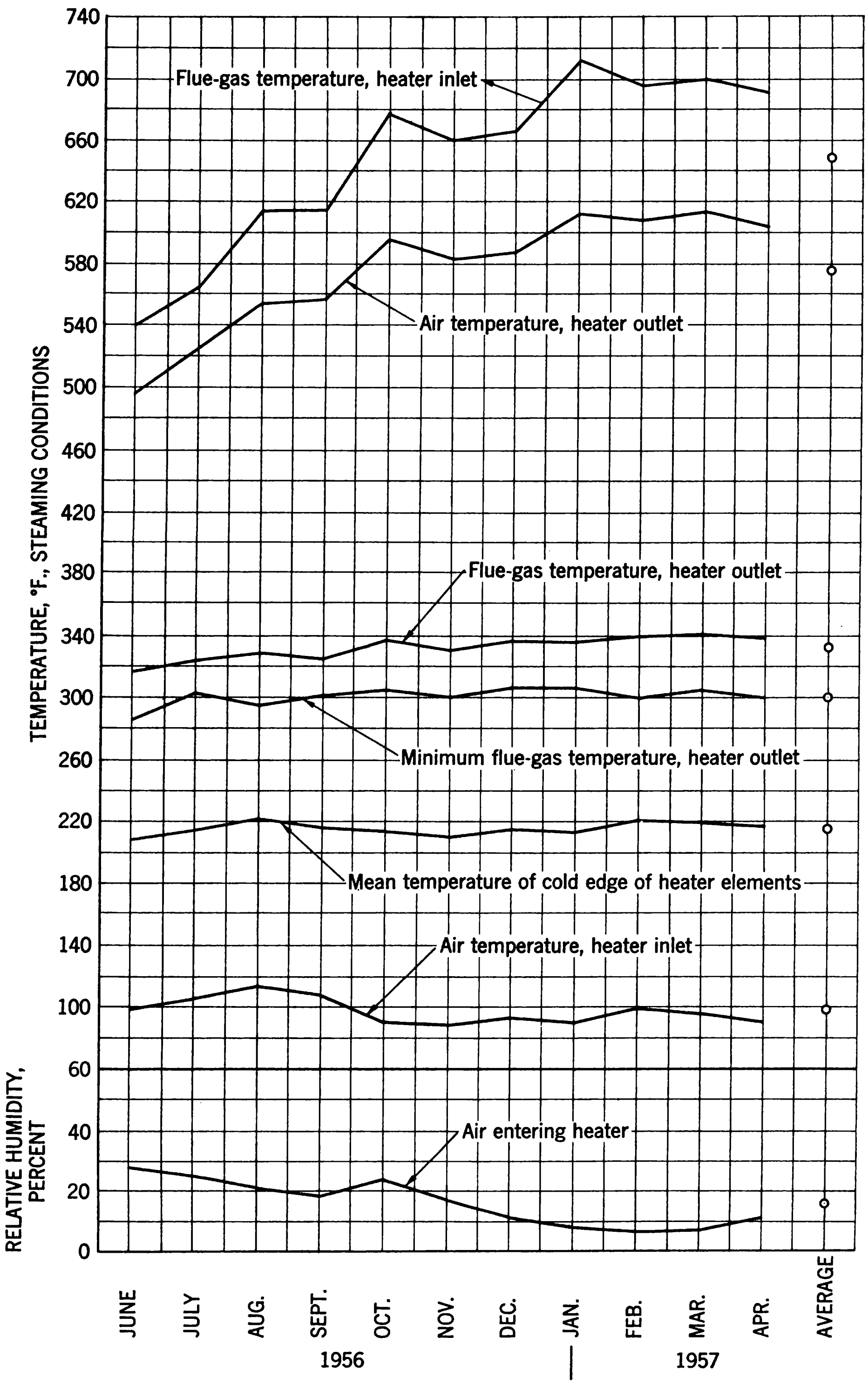

FIGURE 13. - Temperature of Gas and Air Entering and Leaving Air Preheater at Marion Generating Station and Relative Humidity of Entering Air.

DEPOSITS

The deposits that formed on the test specimens in this series of tests were similar to those that formed in the previous tests, being composed of numerous chemical elements and having the three predominant characteristics of partial solubility in water, presence of sulfates, and acidity. A general discussion of deposits and their formation, accumulation, composition, and characteristics is given in Bureau of Mines Report of Investigations 4996.

Descriptions of individual deposits that accumulated on some test materials listed in table 3, from visual examination after removal from the air preheater, follow:

Harding Street Station:

Otiscoloy. - Deposit formations were rough and brittle between 1-1/2 and 5 inches from the cold end and smoother at

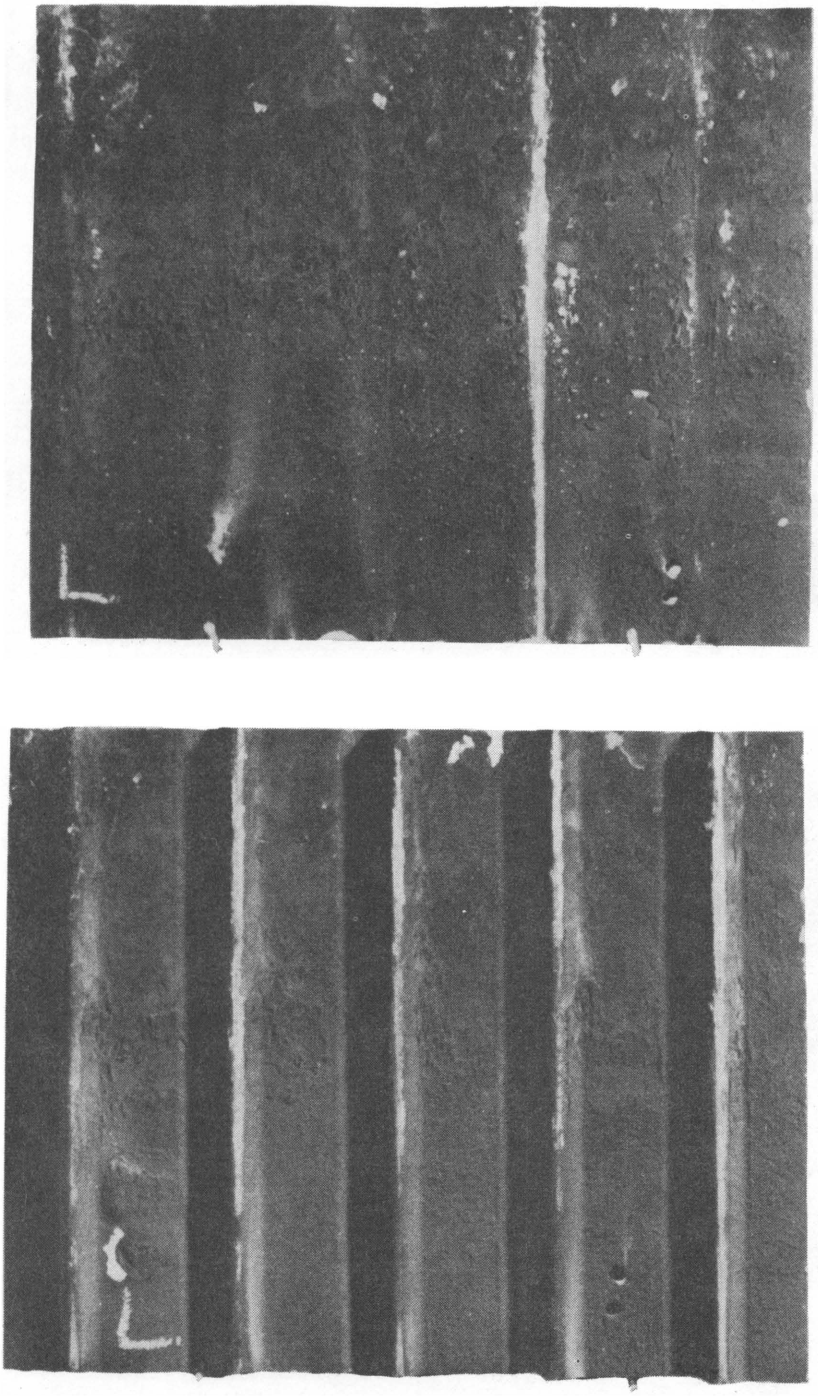

FIGURE 14. - Typical Deposits and Corrosion: 22-US Gage Cor-Ten, 261 Days Service, Harding Street Station.

the upper and lower edges. Heavy, creamy white sulfate deposits were formed along the ribs and points of contact.

<u>18% chrome, 8% nickel steel with titanium - Type 321</u>. - Heavy black deposits were present from the cold end to within 2 inches of the hot end. The notches were filled and contained a greenish white deposit extending to within 2 inches of the hot end.

<u>Wrought iron</u>. - Moderately heavy deposits were scattered over the plates; most of the deposits formed 2 inches from the cold end and in the notches.

<u>EC coating on No. 7740 Pyrex</u>. - A two-banded deposit was formed. The top 4 inches were covered with a grayish black teardrop formation, which blended into a smoother grayish black deposit covering the rest of the sheet.

<u>EC anodized aluminum 2S, 4 minutes</u>. - The entire plate was covered with a very light coating of black, powdery deposit.

<u>EC anodized aluminum 2S, 20 minutes</u>. - Same as above.

<u>Chemoxide on aluminium 2S, 2 minutes</u>. - Same as above.

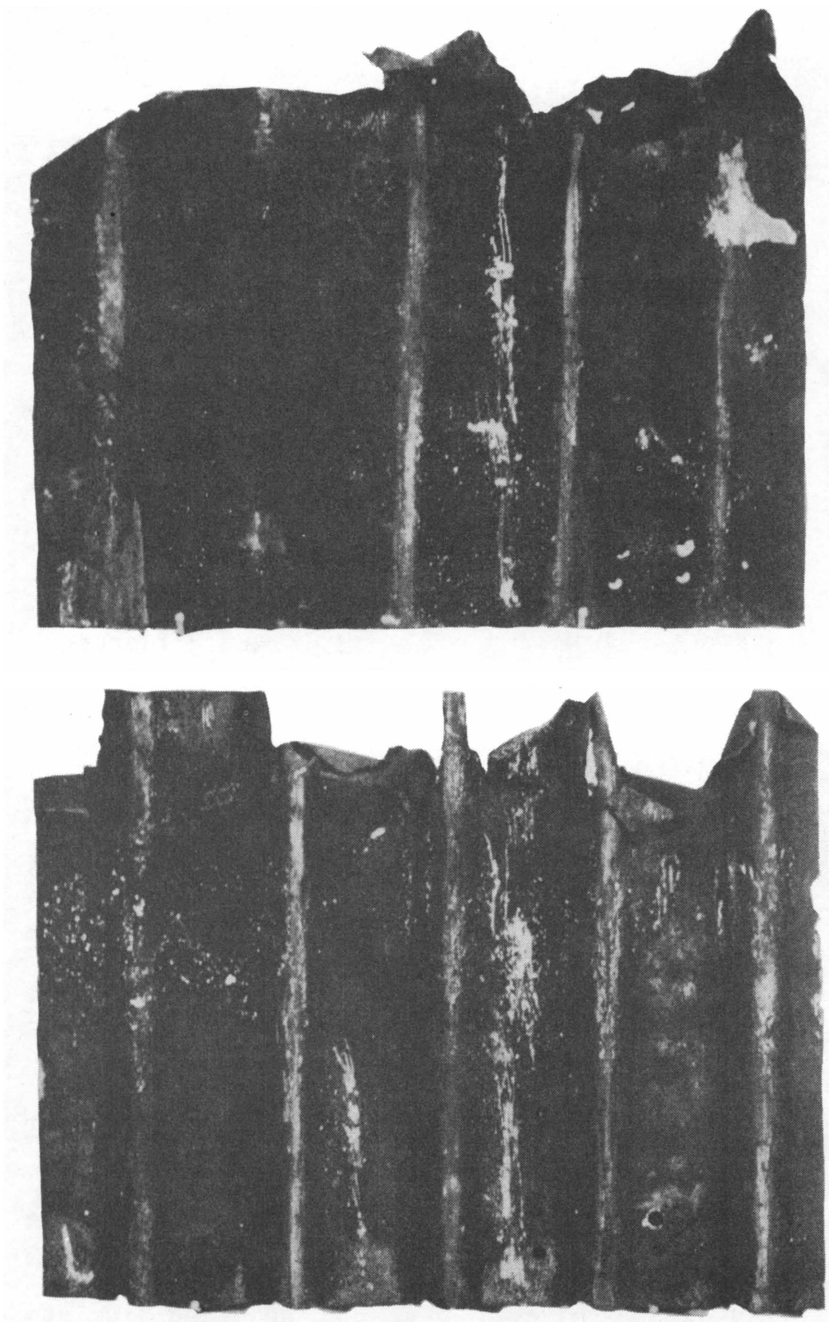

FIGURE 15. - Typical Deposits and Corrosion: 22-US Gage Cor-Ten, 449 Days Service, Harding Street Station.

Carbon coating on Cor-Ten. - A two-banded deposit was formed. The top 4 inches was covered with a rough, hard, brittle formation which blended into a thin, smooth deposit covering the rest of the plate.

Aluminum Sicon silicone on Cor-Ten. - The entire sheet was covered with a rough, brittle deposit. The deposits were heavier 3 inches from the top on the ribs, and traces of white sulfates were visible along the notches and points of contact.

NBS-A19 ferroenamel on Cor-Ten. - A moderately heavy, irregular coating of hard, brittle deposits over a creamy white sulfate undercoating extended 4 inches from the cold-end edge. Bridging occurred at a depth of 2 inches between the ribs of the notched plate.

XR623A ferroenamel on Cor-Ten. - A two-banded deposit was formed. The top 4 inches was covered with a soft, rough deposit, which blended into a thin, smooth deposit covering the rest of the plate. The notches contained a slightly greater buildup than usual.

Barrows enamel (one coat) on 24-USG open hearth. - Deposits were exceptionally light. A light filling of the notch occurred at the cold end.

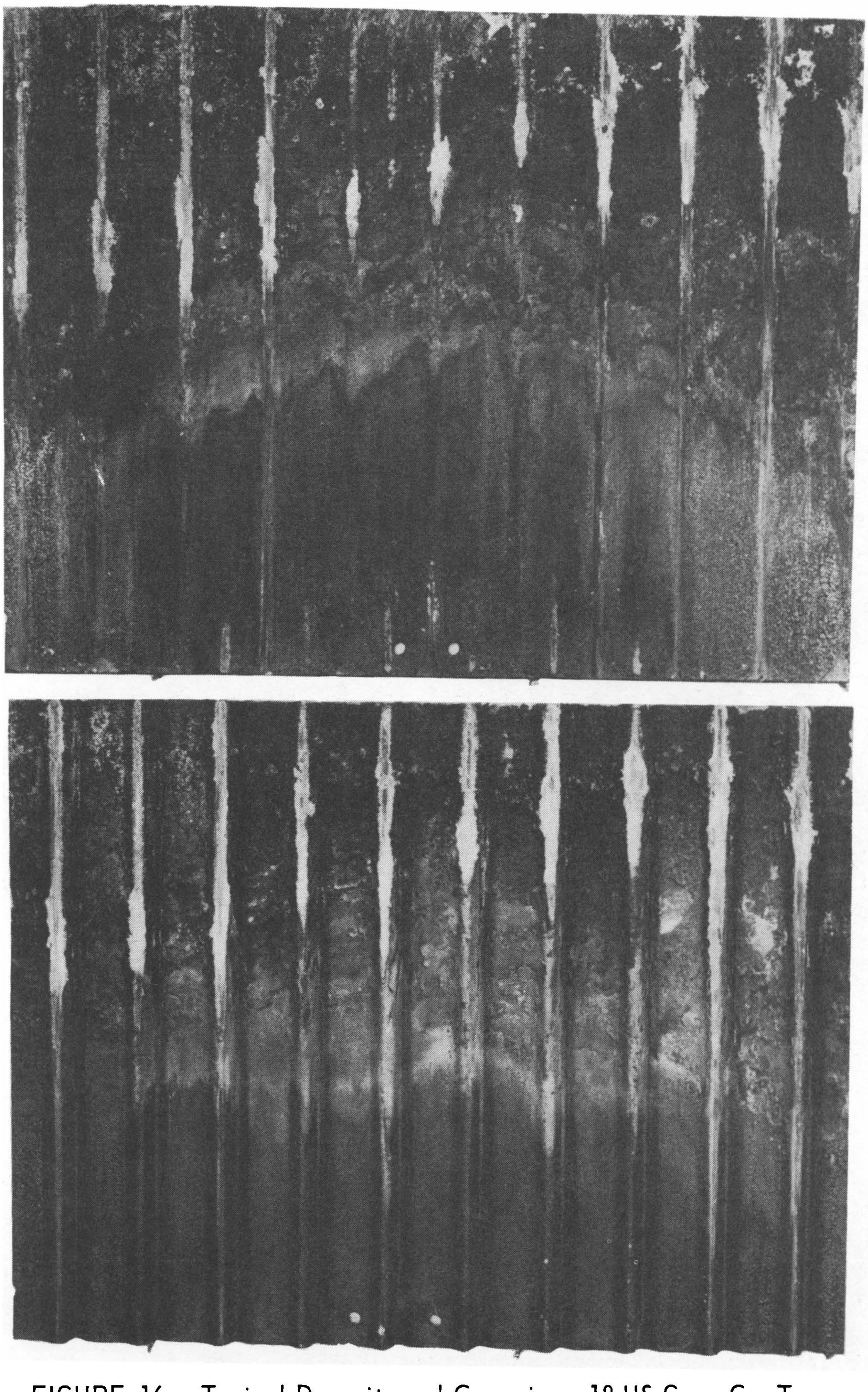

FIGURE 16. - Typical Deposits and Corrosion: 18-US Gage Cor-Ten, 141 Days Service, Marion Generating Station.

(Courtesy Air Preheater Corp.)

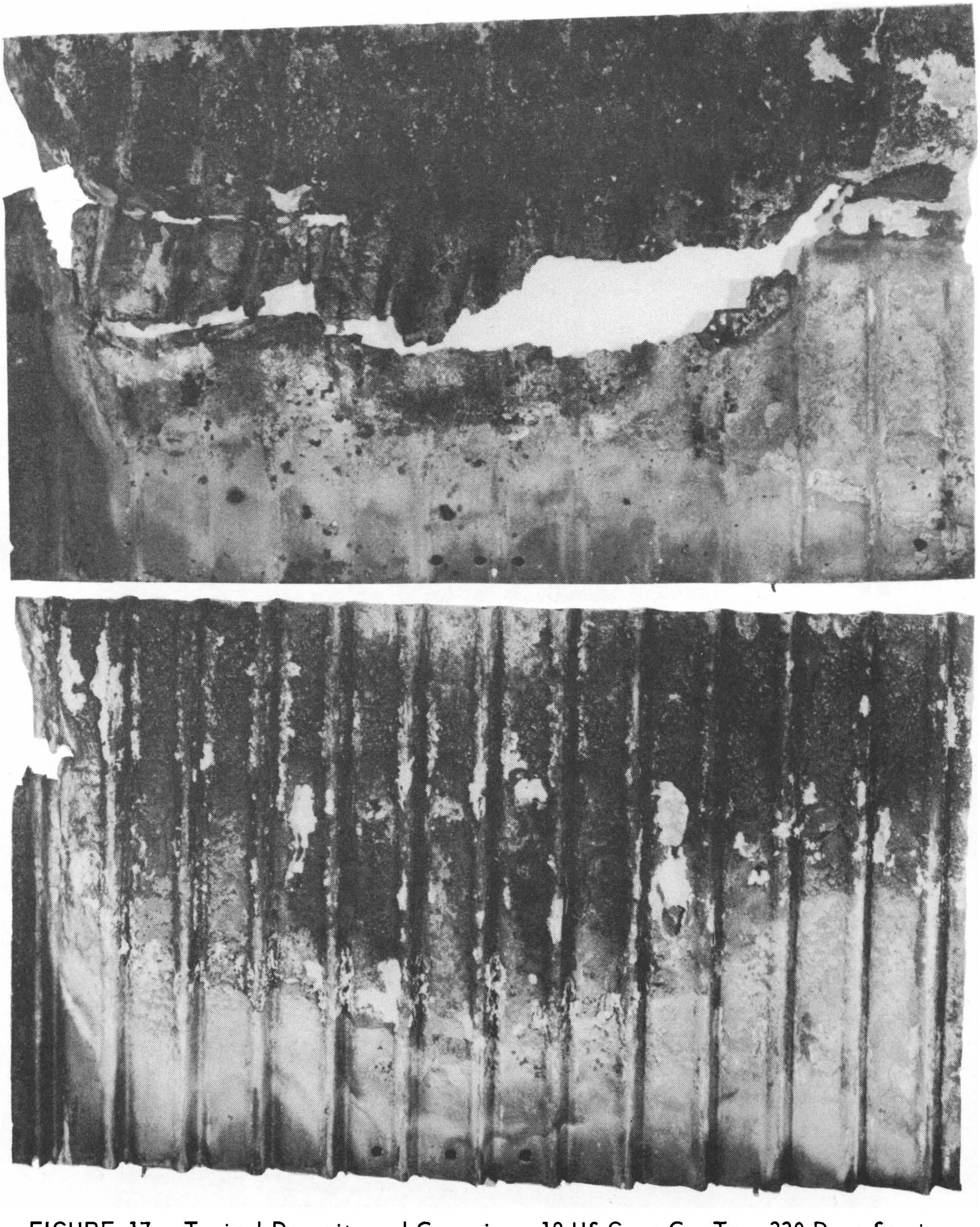

FIGURE 17. - Typical Deposits and Corrosion: 18-US Gage Cor-Ten, 330 Days Service, Marion Generating Station. *(Courtesy Air Preheater Corp.)*

Barrows enamel (two coats) on 24-USG open hearth. - The deposit formation was heavy, and the notched sheet 3 inches below the cold end was bridged over with deposits.

Barrows enamel (one coat) on 22-USG Cor-Ten. - Moderate deposits covered the entire plate, except at a depth of 3 inches where the deposits were heavier.

Barrows enamel (two coats) on 22-USG Cor-Ten. - A heavy deposit formed over the entire plate with some bridging of the notches.

No. 7740 Pyrex flat plate (5/32 inch thick). - The deposit formed was grayish black and hardened along the cold end but was brittle and flaky at the hot end. Parts of the bare glass were visible at the points of contact.

Marion Generating Station:

NAX (CSX) high tensile. - A two-banded pattern of deposits was formed on the sheets. The upper one-third had a slight accumulation of soft, black deposit; the lower two-thirds of the plates had a soft, heavy, greenish black deposit.

Jalten steel. - A two-banded deposit was formed. The upper one-fourth of the plates had a heavy grayish black deposit; the lower three-fourths had a very thin, uniform coating of black deposit.

High strength. - A three-banded deposit was formed. The upper 2 to 3 inches had a heavy, coarse, grayish black deposit; the middle 4 inches a moderately small, black formation; and the remaining 5 inches a uniform, light, powdery deposit.

Yoloy. - A two-banded, moderately heavy, greenish black deposit was formed at the upper half of the plates and a fairly uniform, relatively light, smooth deposit at the lower half.

Aluminum alodized 3003-H-14. - Deposits formed two bands; the upper half was a moderately light, powdery coating which tapered off to a very thin film.

Cor-Ten. - A three-banded deposit was formed. The upper band, which was approximately 5 inches wide, was heavy, soft, and brittle. Below this band for about 3 inches was a moderately heavy, thin, gray deposit. The bottom 4 inches had a uniform covering of light, smooth, blackish deposit.

Mayari-R. - A two-banded deposit was formed. The upper band was 4 inches wide, rough, brittle, and moderately heavy. The rest of the plate was covered with a light, fairly smooth coating.

Ferroenamel on 24S aluminum. - Three bands of deposits were formed. The upper 1 inch and the lower 7 inches were moderately heavy, smooth, and black. The middle band, which was about 3 inches wide, was a thin, grayish white sulfate covering.

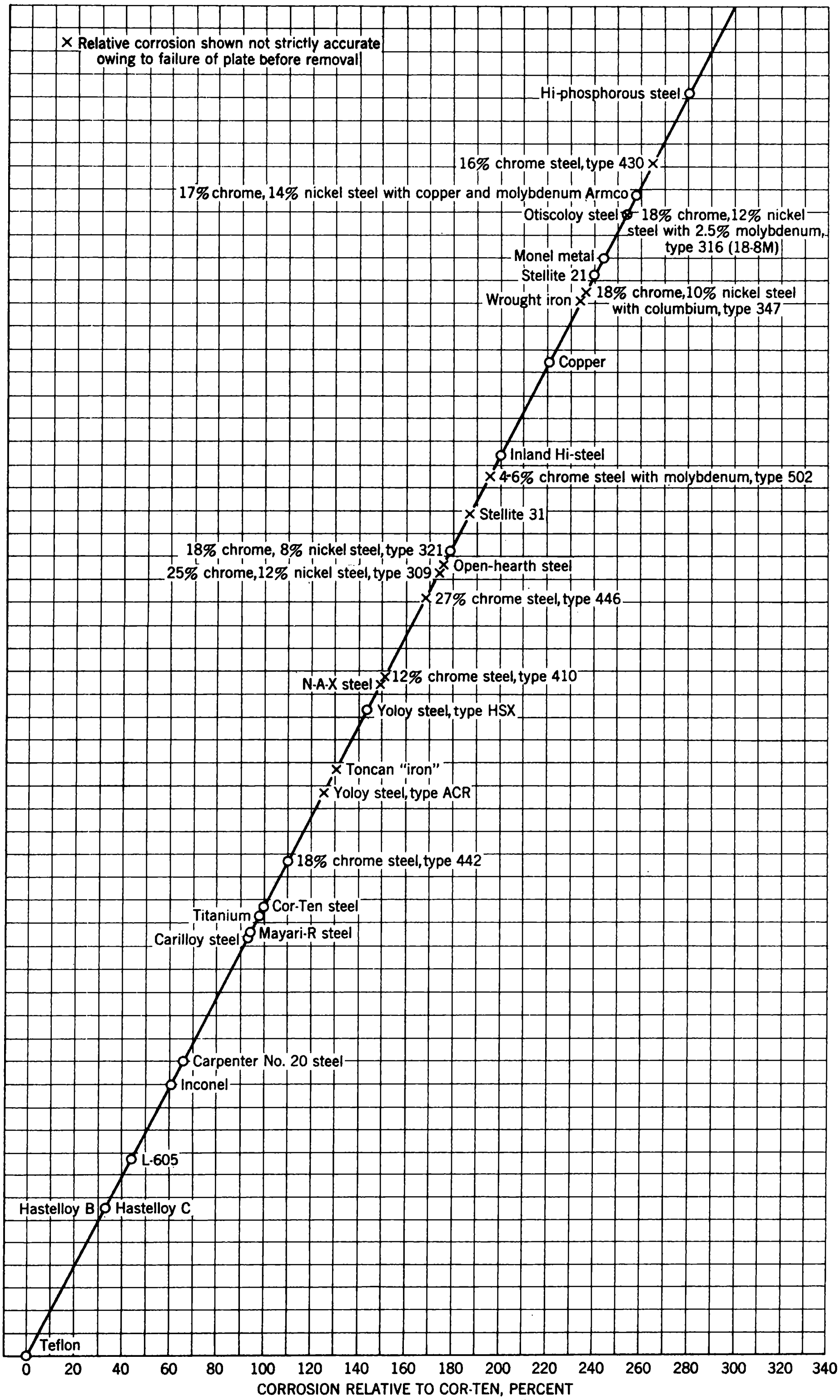

FIGURE 18. - Relative Corrosion Rates, in Harding Street Station Air Preheater, of Various Materials to That of Cor-Ten Steel.

CORROSION

Figures 18 and 19 are figures 42 and 43 of Bureau of Mines Report of Investigations 4996, with added data on figure 18 for the three metals listed in table 3 under the Harding Street Station. Figure 20 gives data for the metals listed in table 3 under the Marion Generating Station. These figures show the percentage loss in weight of test plates relative to that of the standard Cor-Ten plate material. This standard material was given a rating of 100. For example, a rating of 200 for a material, would mean that its corrosion rate, as percentage loss in weight for the same height and thickness of plate and under the same operating conditions, would be twice that of the standard Cor-Ten. The thinning or corrosion of a test plate was due principally to chemical reactions resulting in the formation of sulfates and to a very slight extent to the abrasive action of the dust. When a plate

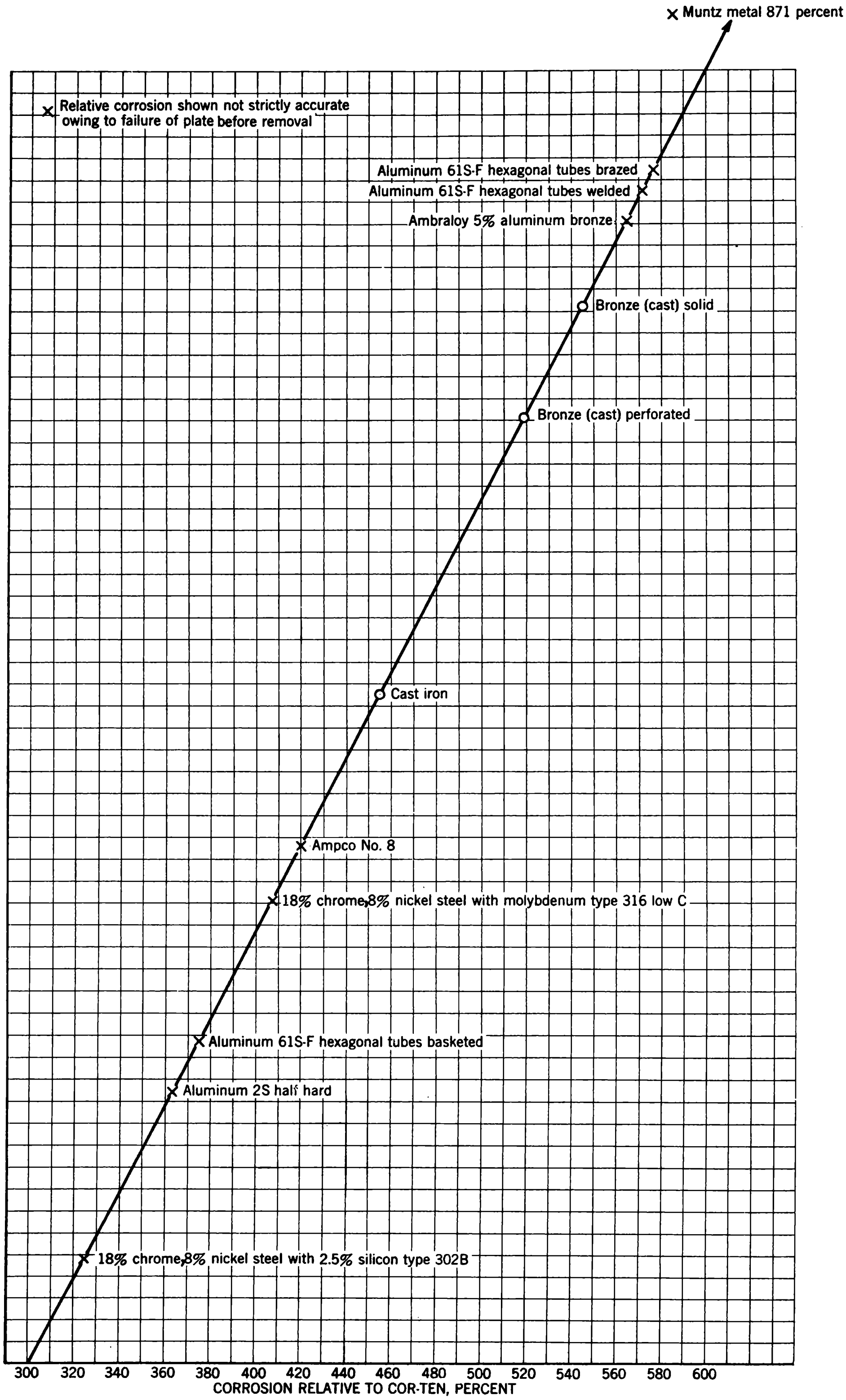

FIGURE 19. - Relative Corrosion Rates, in Harding Street Station Air Preheater, of Various Materials to That of Cor-Ten Steel.

reached a certain thickness near its cold edge, the action of the soot blower would tear and bend it, as shown in figure 15, p. 22. For example, a Cor-Ten flat plate would bend or tear at a thickness of about 0.008 inch. An attempt was made to establish the loss of weight of each plate before it was torn or bent by the soot blower; however, as shown on the curves, some materials thinned so rapidly that the plate tore before it could be removed.

The accuracy of the values of the curves in figures 18, 19, and 20 is subject to various field factors affecting corrosion of the plates. These corrosion-causing factors do not have the same values over the entire cross-sectional area of the preheater. Although the standard Cor-Ten plate was placed close to the test plate, the factors affecting both may not have been precisely the same. Probably, the plotted values

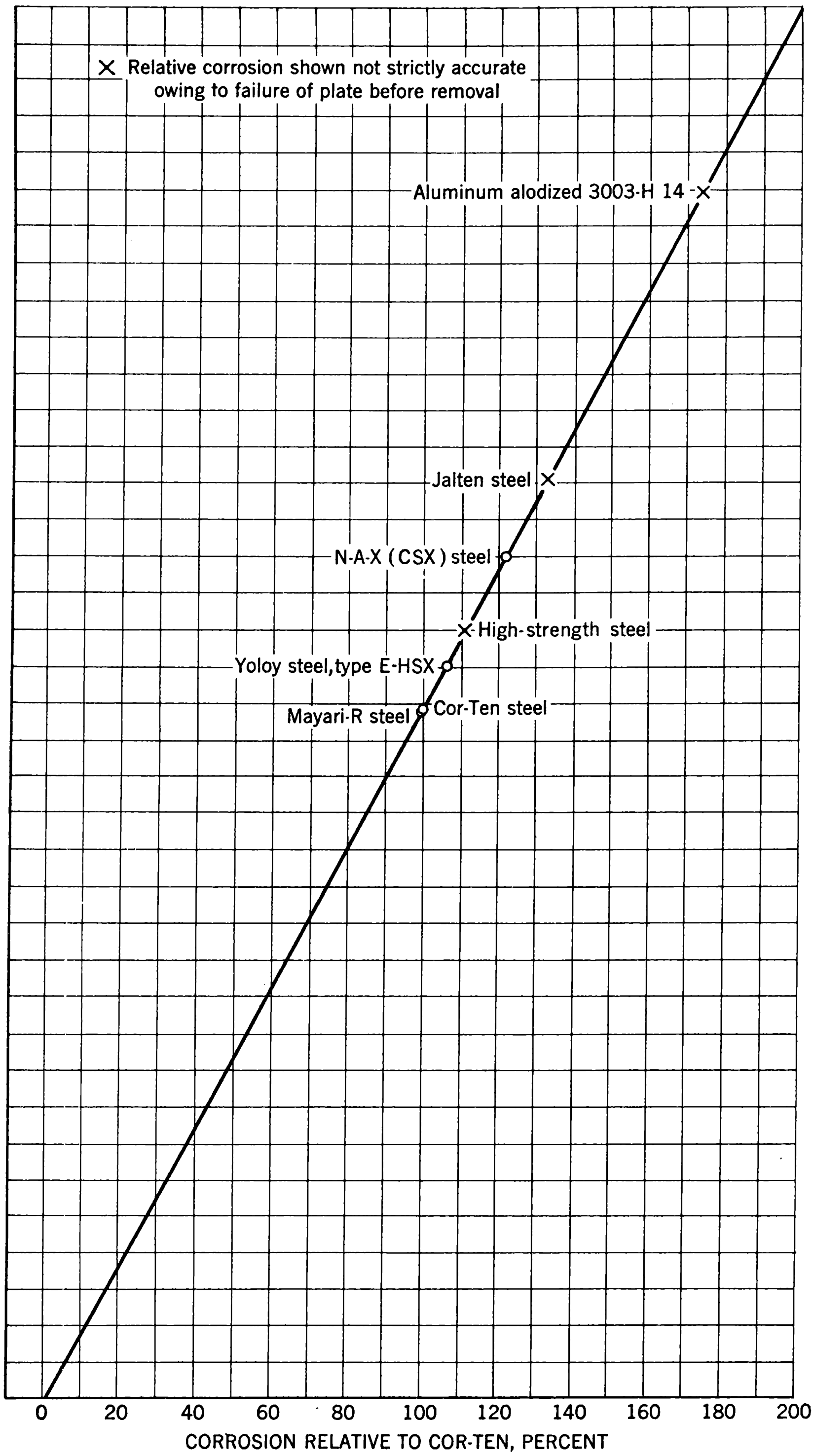

FIGURE 20. - Relative Corrosion Rates, in Marion Generating Station Air Preheater, of Various Materials to That of Cor-Ten Steel.

are correct to within plus or minus 5 percent.

The actual loss of weight of the 6-inch Cor-Ten plate, as determined by previous tests at the Harding Street Station, averaged 2.28 grams (0.00503 pound) per inch of length in 100 days of service. This loss is 12.3 percent of the original weight for a plate 0.024 inch thick. The actual loss of weight of the 12-inch Cor-Ten plate at the Marion Generating Station averaged 5.15 grams (0.01135 pound) per inch of length in 100 days of service, or 12.6 percent of the original weight for a plate 0.024 inch thick.

No coatings used on test specimens resisted corrosion satisfactorily except the acid-resisting enamels - XR623A Ferro, Barrows, and Erie. These coatings were not attacked, but any imperfections in their application would result in metal destruction underneath. When the enamels were properly applied, one coat served as well as two coats.

The Pyrex-glass test specimens showed no evidence of corrosion but showed small, inconsequential loss due to breakage.