OAK RIDGE NATIONAL LABORATORY
operated by
UNION CARBIDE CORPORATION
for the
U.S. ATOMIC ENERGY COMMISSION

ORNL-TM-602

FABRICATION OF RADIATORS FOR BOILING HEAT-TRANSFER EXPERIMENTS

E. A. Franco-Ferreira

ORNL-TM-602

Contract No. W-7405-eng-26

METALS AND CERAMICS DIVISION

FABRICATION OF RADIATORS FOR BOILING HEAT-TRANSFER EXPERIMENTS

E. A. Franco-Ferreira

DATE ISSUED

AUG 23 1963

OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee
operated by
UNION CARBIDE CORPORATION
for the
U. S. ATOMIC ENERGY COMMISSION

FABRICATION OF RADIATORS FOR BOILING HEAT-TRANSFER EXPERIMENTS

E. A. Franco-Ferreira

ABSTRACT

Two large heat-transfer devices were built under the supervision of the Welding and Brazing Group of the Oak Ridge National Laboratory Metals and Ceramics Division. These units contained 7-ft-long tapered tubes which were attached to vapor and condensate headers. In one unit, a 12-tube finned radiator, high-conductivity fins were attached longitudinally to the tubes by a combination of welding and brazing. The other unit, a 144-tube unfinned condenser, was fabricated entirely by welding.

INTRODUCTION

The Welding and Brazing Group of the Oak Ridge National Laboratory Metals and Ceramics Division has been responsible for the fabrication of two radiator-type heat-transfer devices. These devices are to be used in conjunction with boiling heat-transfer experiments. One unit was a 12-tube, longitudinally finned radiator shown schematically in Fig. 1, and the other was a 144-tube, unfinned condenser shown schematically in Fig. 2. The former item is to be used for potassium service, while the latter will serve in a water system.

The tubes used for both units were obtained commercially on a special order and were 7 ft long and tapered from 0.700-in. OD at one end to 0.300-in. OD at the other. They were made of type 316 stainless steel, with a uniform 0.049-in.-wall thickness.

In the 12-tube unit, high-conductivity stainless steel-clad copper fins[1,2] were attached to opposite sides of each tube so that they lay in

[1] H. Inouye, ORNL-2065 (Jan. 2, 1957), classified.

[2] G. M. Slaughter and P. Patriarca, Welding and Brazing of High-Temperature Radiators and Heat Exchangers, ORNL-TM-147 (Feb. 20, 1962).

UNCLASSIFIED
ORNL-DWG 63-979

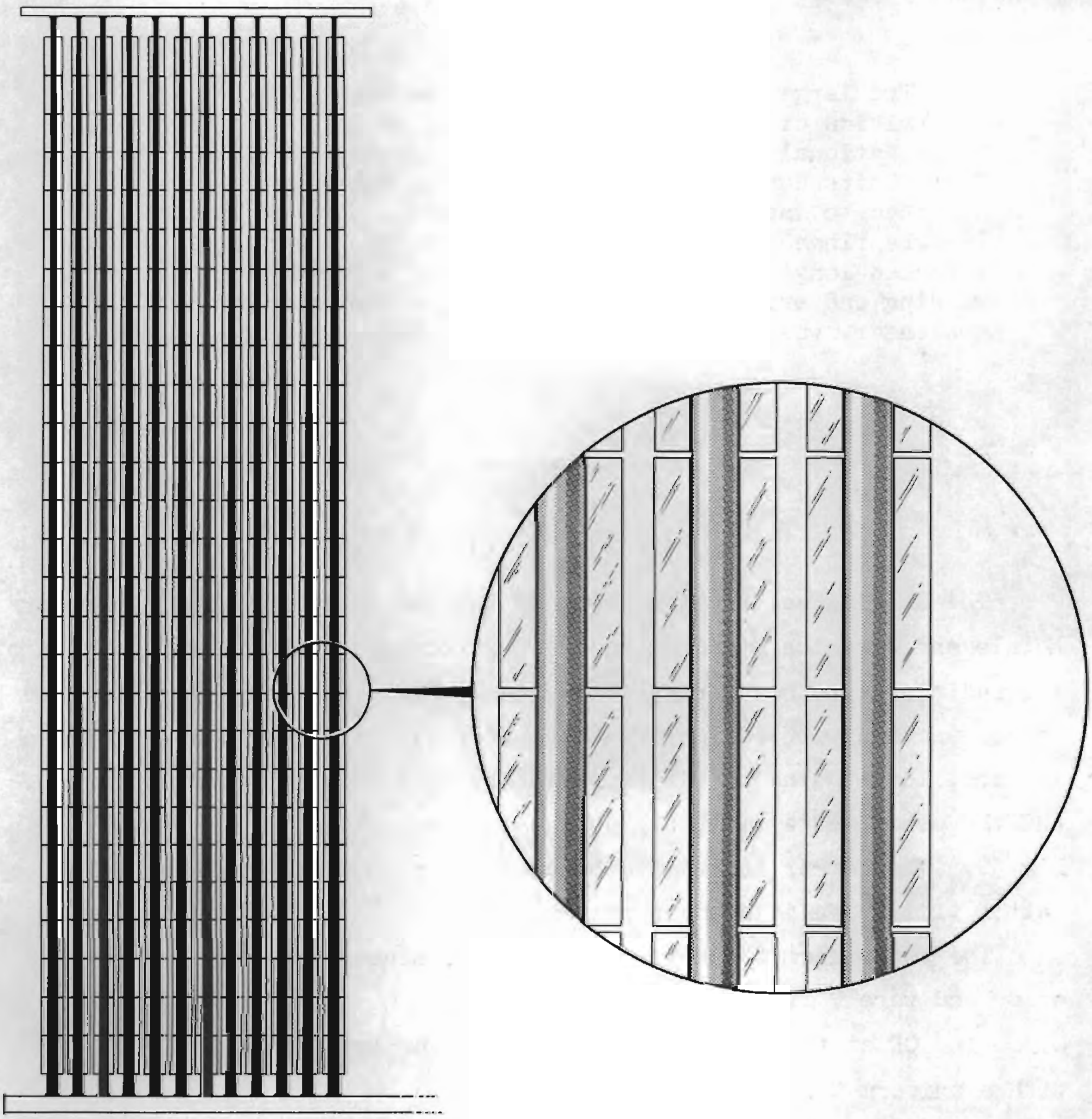


Fig. 1. Schematic Drawing of 12-Tube Longitudinally Finned Radiator.

UNCLASSIFIED
ORNL-DWG 63-978

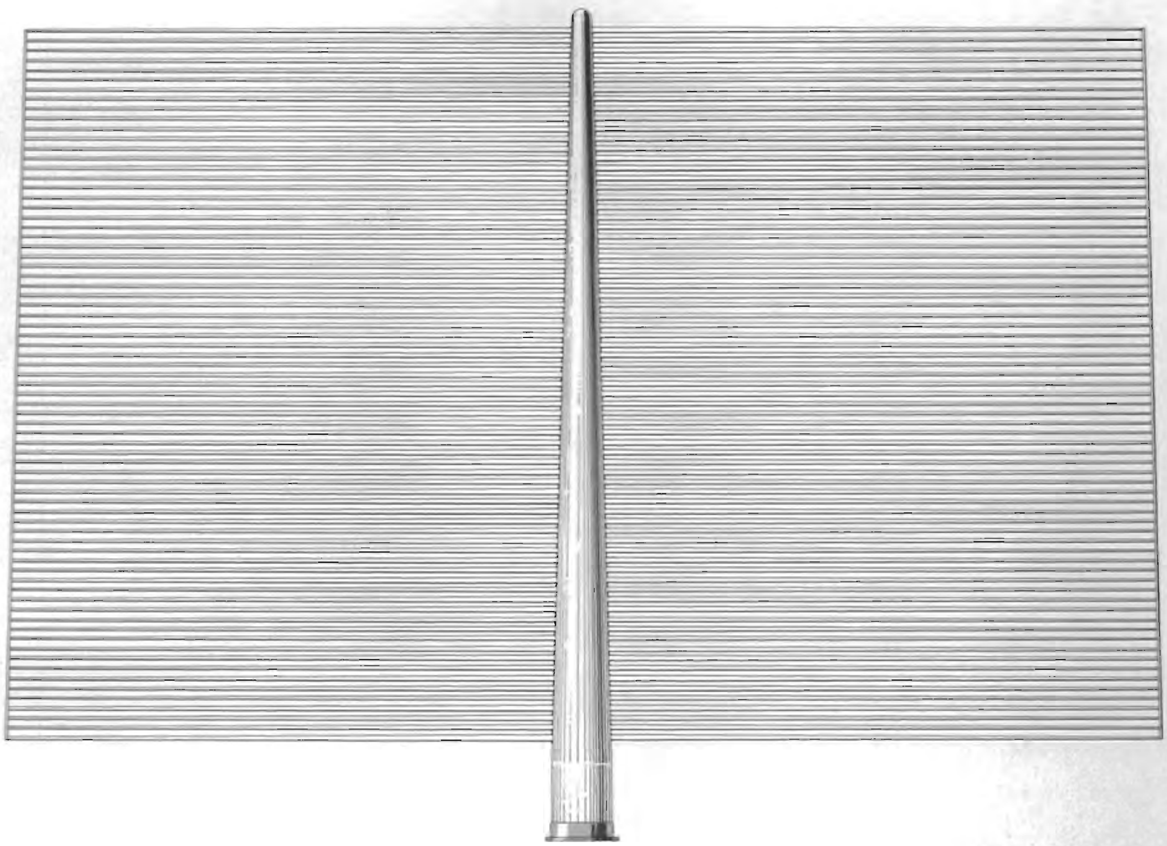


Fig. 2. Schematic Drawing of 144-Tube Unfinned Condenser.

the same longitudinal plane and ran the entire length of the tube. The fins were attached by a combination welding and brazing technique. After the fins were attached to the tubes, the tubes were gas-tungsten-arc welded to vapor and condensate headers at the large ends and small ends, respectively.

For the 144-tube unit, unfinned tubes were merely welded to the vapor and condensate manifolds. Welding procedures similar to those used for the 12-tube radiator were used for the 144-tube unit.

Fabrication of the 12-Tube Radiator

Fin Preparation

The fins were cut into blanks 3 in. long × 9/16 in. wide from commercially procured high-conductivity stainless steel-clad copper sheet stock. This material was 0.009 in. thick, consisting of a 0.005-in. copper core with 0.002 in. of stainless steel cladding on each side.

For operation of this type of fin at elevated temperatures in air, the sheared edges must be protected from oxidation to prevent degradation of the copper layer. For example, Fig. 3a shows a cross-sectional view of a fin which had been held at elevated temperature in air with an unprotected edge. Protection is effected by converting the outer sheared edges of the copper layer to aluminum bronze.[3]

In the aluminizing treatment the blanked fins are stacked between stainless steel platens and all exposed edges are painted with slurry of aluminum powder in lacquer.[4] The stacked fins are then heated in a purified helium atmosphere for 1/2 hr at 800°C to form the aluminum bronze protective layer. For a comparison of performance, Fig. 3b shows the cross section of an aluminized fin which was oxidized under the same conditions (500 hr at 590°C) as the fin in Fig. 3a. No attack of the copper layer is evident.

After the fins were edge protected, 1/16-in.-wide flanges were bent longitudinally on a sheet metal brake along the 3-in. length and at right

---

[3]P. Patriarca, G. M. Slaughter, W. D. Manly, and R. L. Heestand, Fabrication of Heat Exchangers and Radiators for High-Temperature Reactor Applications, ORNL-1955 (June 14, 1956).

[4]Krylon Crystal Clear Spray Coating, Krylon, Inc., Norristown, Pa.

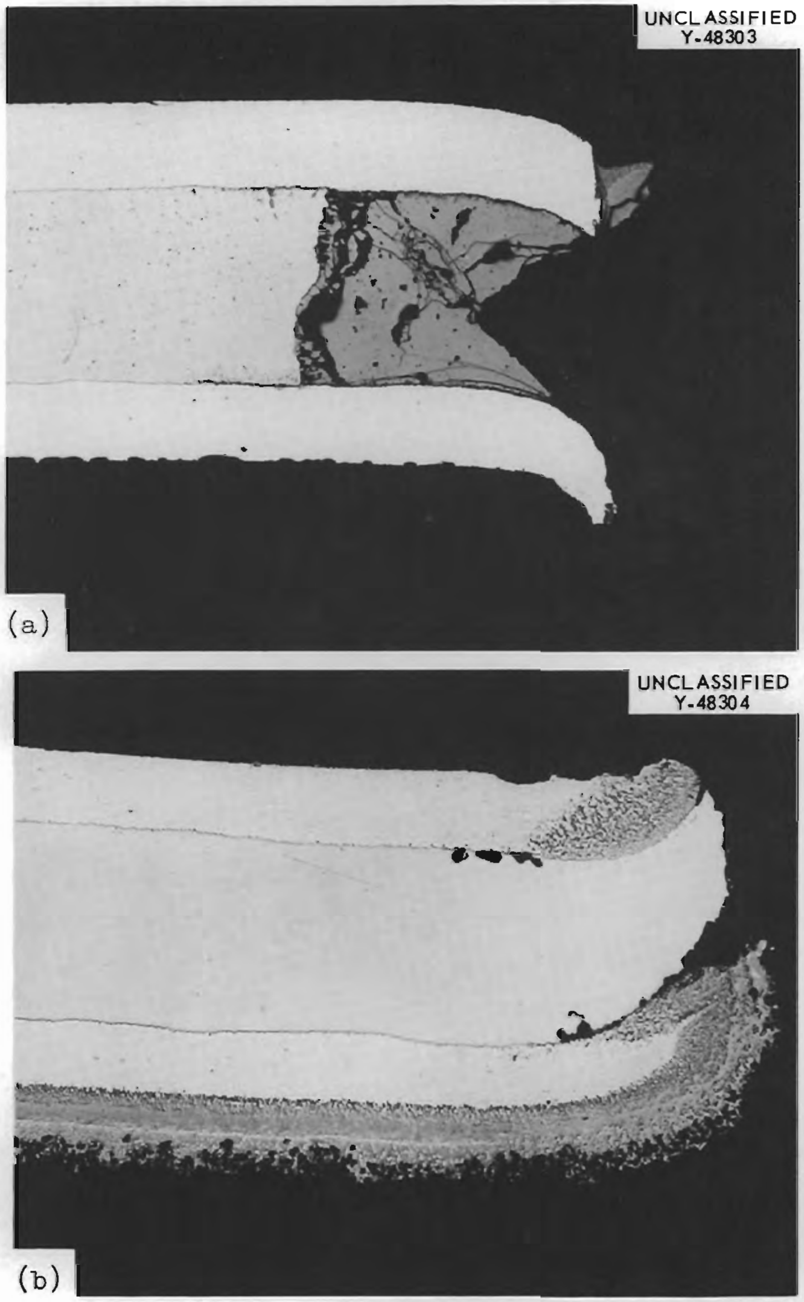


Fig. 3. (a) Unprotected High-Conductivity Fin after High-Temperature Oxidation. Severe attack of the copper is evident. 200X. (b) Aluminum bronze edge-protected fin after oxidation. No attack of the copper layer is evident. 200X.

angles to the fin surfaces. These flanges are used to provide an area for attachment of the fins to the tubes. Figure 4 shows a section of radiator tubing and several fins ready for attachment.

Fin Attachment

Initial positioning of the fins on the tubes was accomplished by capacitor-discharge resistance welding. To do this, the fins were positioned approximately as shown in Fig. 4 with a space of 1/16 in. between adjacent fin ends. The 1/16-in.-wide flange on each fin was then welded to the tube surface with one weld spot every 1/2 in. Fin alignment was ensured by following lines which had previously been scribed longitudinally on each tube.

After the fins were all welded onto each tube, they were brazed in place in order to increase both the strength of attachment and the efficiency of heat transfer.

To prepare the tubes for brazing, a slurry of Nicrobraz 50 alloy (Ni—10 Cr—10 P) powder[5] in a volatile cement binder was added to all the tube-fin joints. After the slurry had hardened in place, the excess was removed by trimming so that a narrow band of alloy lay along the entire length of each joint. The prepared tube was then placed in a furnace boat and six monitor Chromel-P—Alumel thermocouples were spaced at equal intervals along the inside of the tube. The assembly was then furnace brazed in a dry-hydrogen atmosphere.

The furnace used for the brazing operation is shown in Fig. 5. This unit consists of a 13-ft-long, 3-in.-diam stainless steel muffle and a rolling furnace which has a 30-in.-long isothermal hot zone. In operation, the tube to be brazed was placed inside the muffle and the furnace moved along at a slow rate until the entire length of the tube was brazed. A typical brazing cycle, as plotted by the six monitor thermocouples, is shown in Fig. 6.

The appearance of several of the finned tubes after brazing is shown in Fig. 7a. The fins have noticeably warped during the brazing operation. This is thought to be due to the slightly different thermal expansion

[5]Wall-Colmonoy Corp., Detroit, Michigan.

Fig. 4. Section of Radiator Tubing and Fins Ready for Attachment.

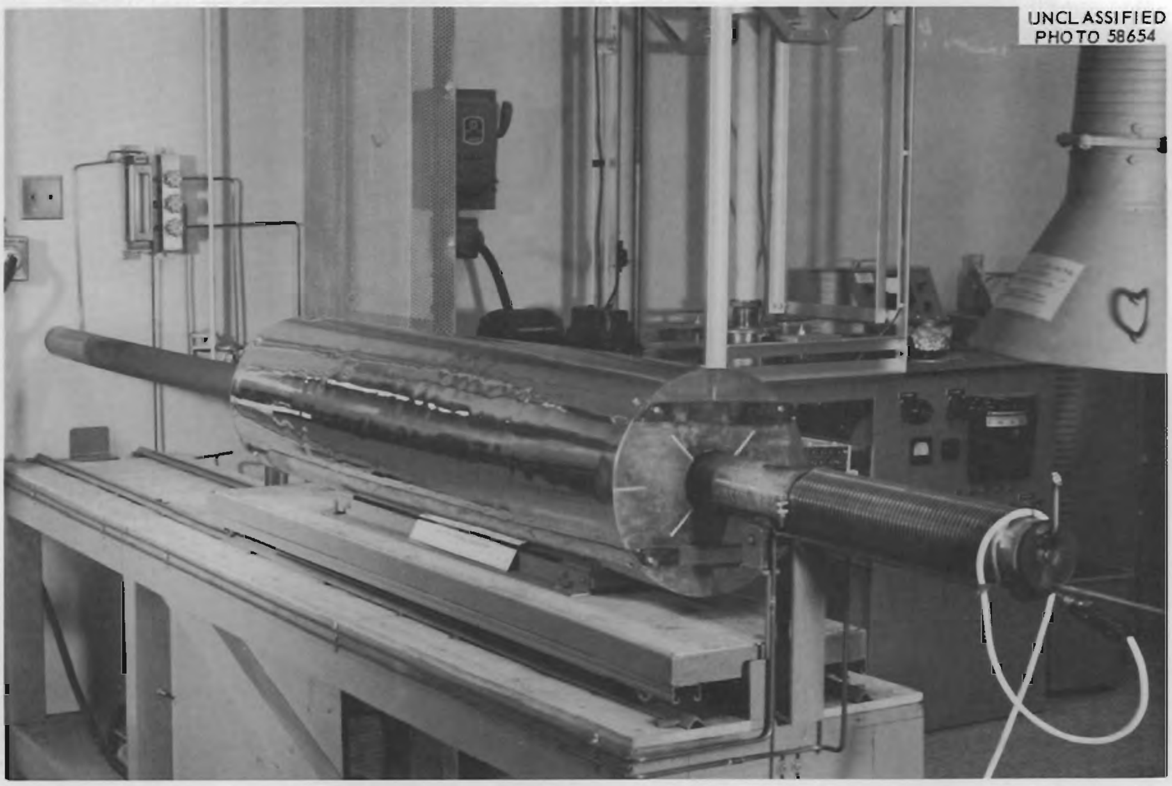


Fig. 5. Rolling Furnace Used in Brazing Fins to Tubes.

UNCLASSIFIED
ORNL-DWG 63-980

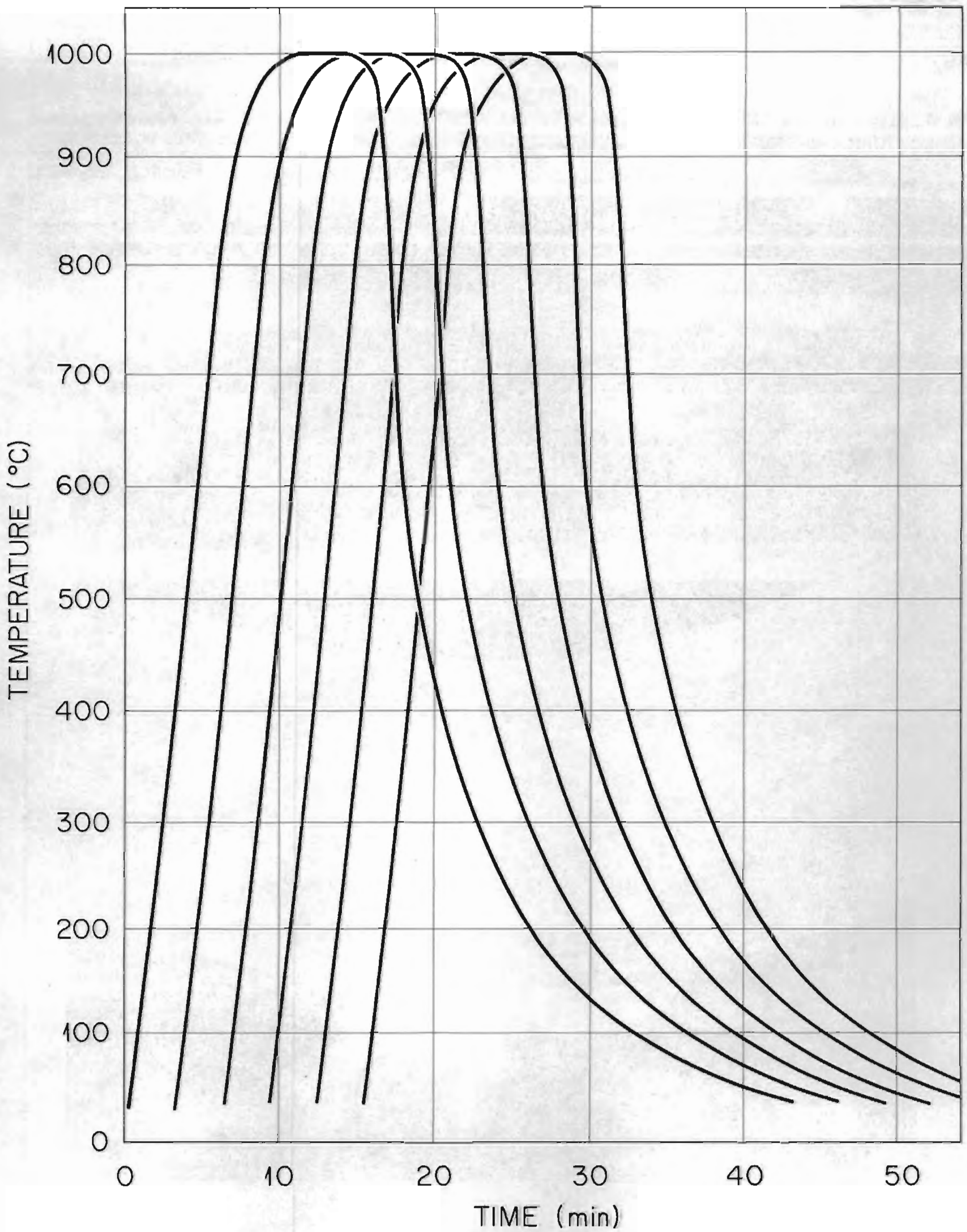


Fig. 6. Typical Brazing Cycle.

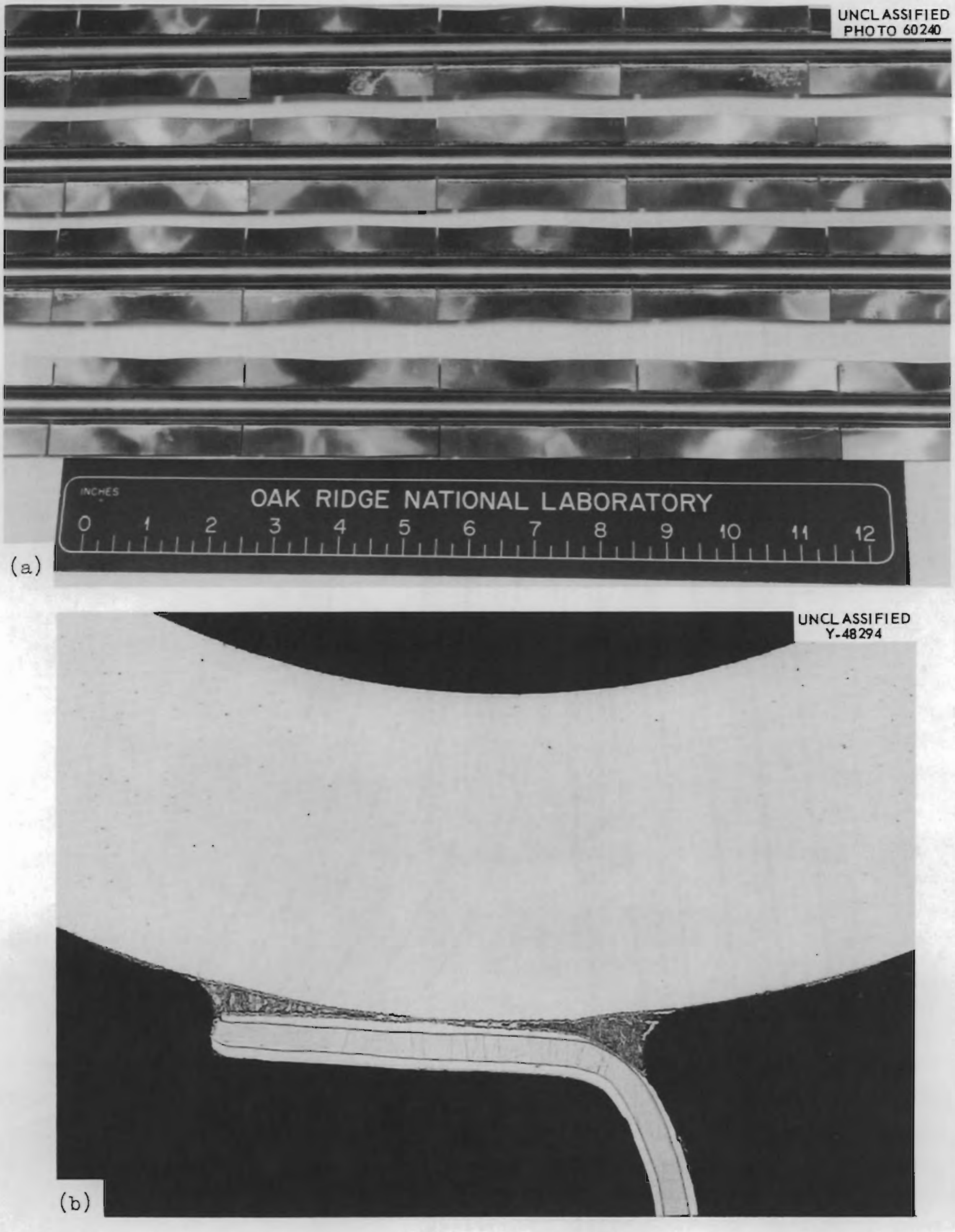


Fig. 7. (a) Finned Tubes after Brazing. Reduced 12%. (b) Typical brazed tube-to-fin joint. As-polished. 36X. Reduced 12%.

characteristics between the tubes and fins. However, all the joints exhibited excellent bonding, as shown in Fig. 7b, and fin warpage should not affect the performance of the radiator.

Attachment of Tubes to Manifolds

After all the tubes were brazed and all braze joints visually inspected, the tubes were ready to be welded to the vapor and condensate manifolds. Welding operations were performed at the Engineering and Mechanical Division Welding and Brazing Facility. Before welding on the actual unit was begun, the welder was qualified on several mockup samples simulating the actual joints.

The vapor manifold was prepared with small extruded (by a punching operation) nozzles at each of the joint locations. Thus, at the joints between the large ends of the tubes and the vapor manifold, smooth transitions could be effected.

A square-butt joint design with no bevel and no gap was prepared (Fig. 8a). Argon was used both as the backup gas and the torch gas. A welding current of 40–50 amp produced a single-pass, full-penetration weld. Type 316L filler wire was used throughout. Root penetration averaged approximately 3/32 in. This penetration was ground flush after welding so that no flow disturbance would result during operation. Figure 8b shows a number of these completed joints.

The joints between the small ends of the tubes and the liquid header were of the saddle-in variety shown in Fig. 9a, with the ends of the tubes being slightly flattened and fitting in elongated slots in the header. A fillet weld was made in a single pass using type 316L stainless steel weld wire. Excess root push-through was minimized as it was not possible to remove any excess after welding. Figure 9b shows a number of these completed joints.

Weld inspection included visual and dye-penetrant checks. All welds passed and no re-welding or repair welding was necessary.

An overall view of the completed radiator is shown in Fig. 10.

UNCLASSIFIED
ORNL-DWG 63-981

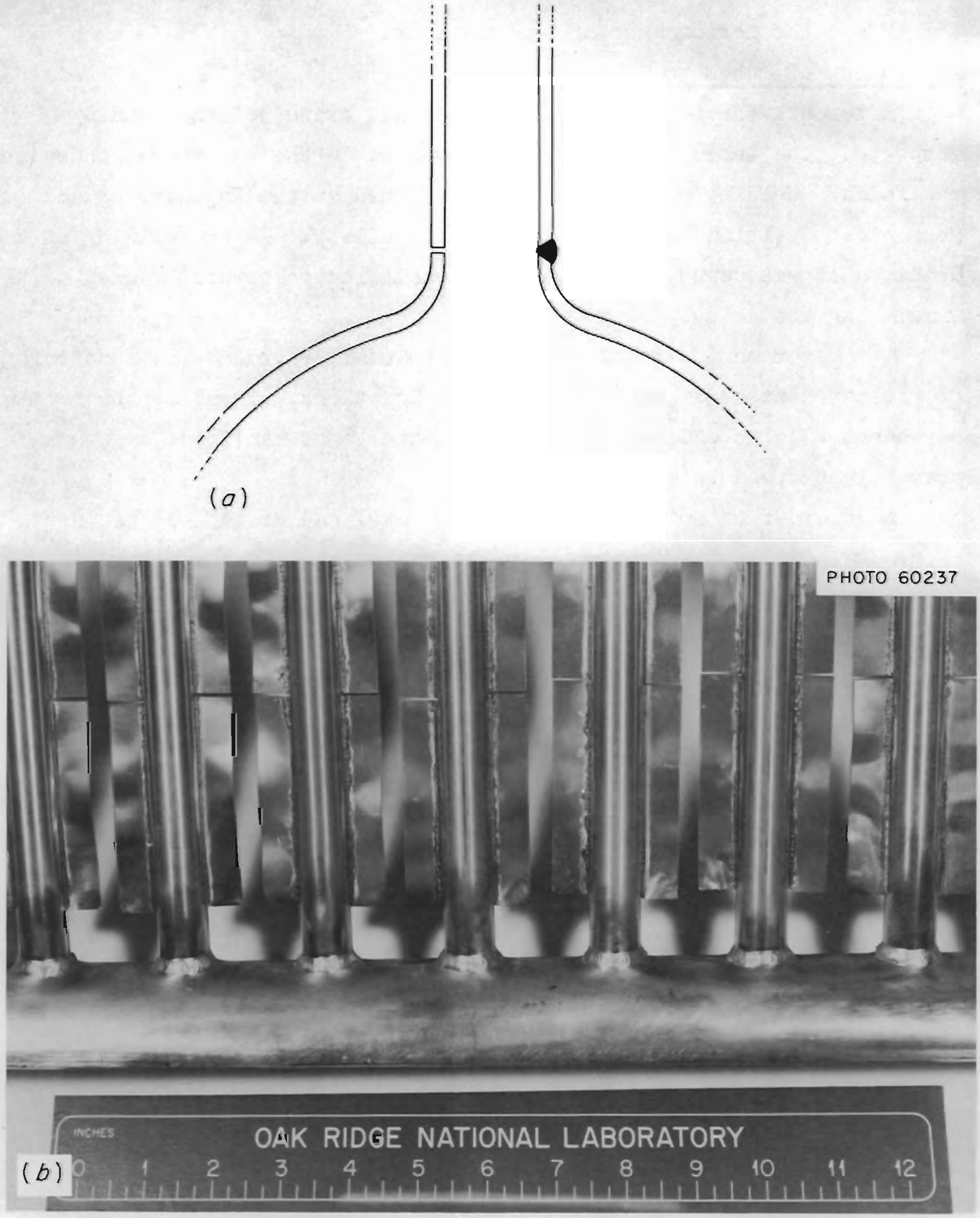


Fig. 8. (a) Joint Design Used for Welding Large Ends of Tubes to Vapor Manifold. (b) Typical completed welds.

UNCLASSIFIED
ORNL-DWG 63-983

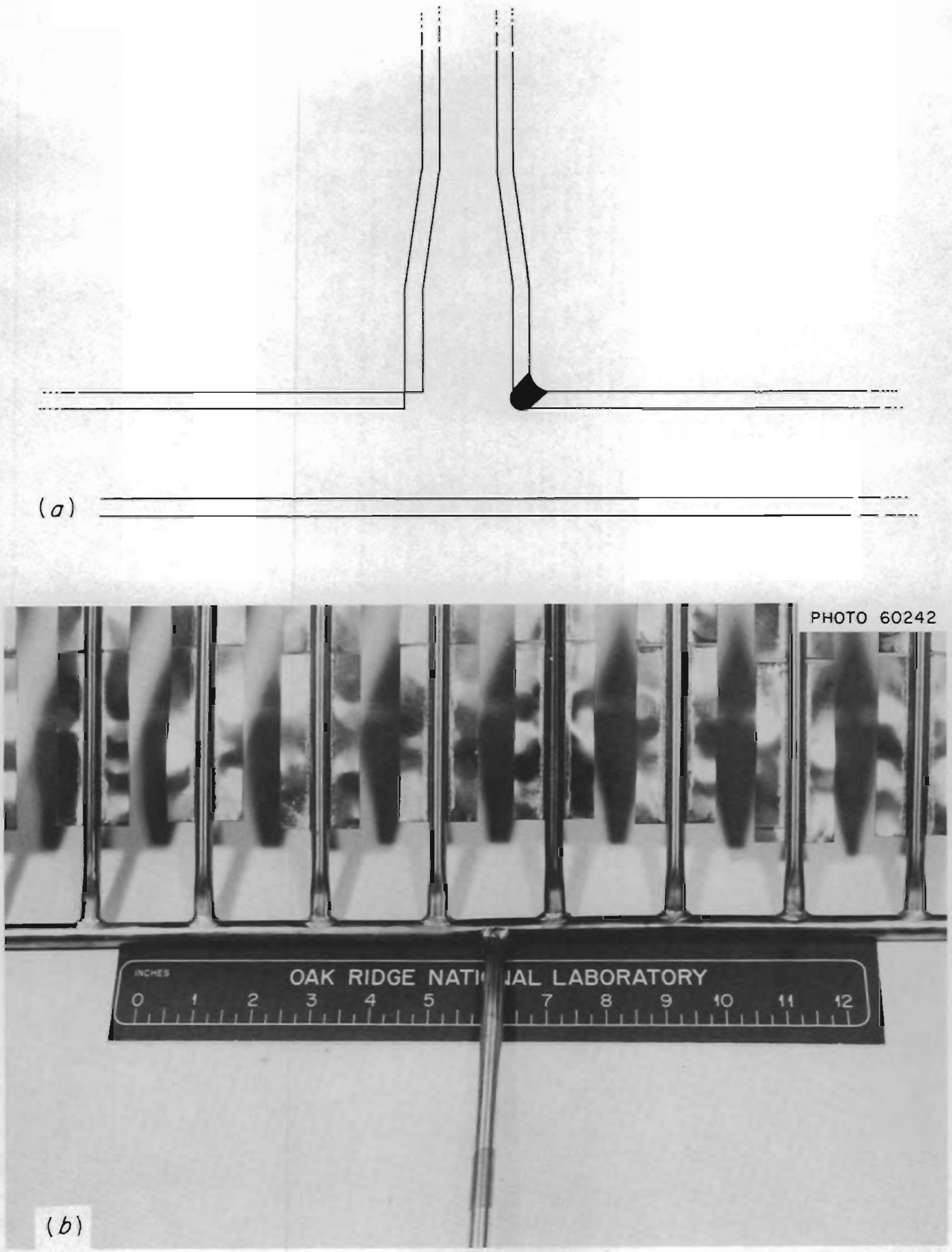


Fig. 9. (a) Joint Design Used for Welding Small Ends of Tubes to Liquid Manifold. (b) Typical completed welds.

UNCLASSIFIED
PHOTO 60239

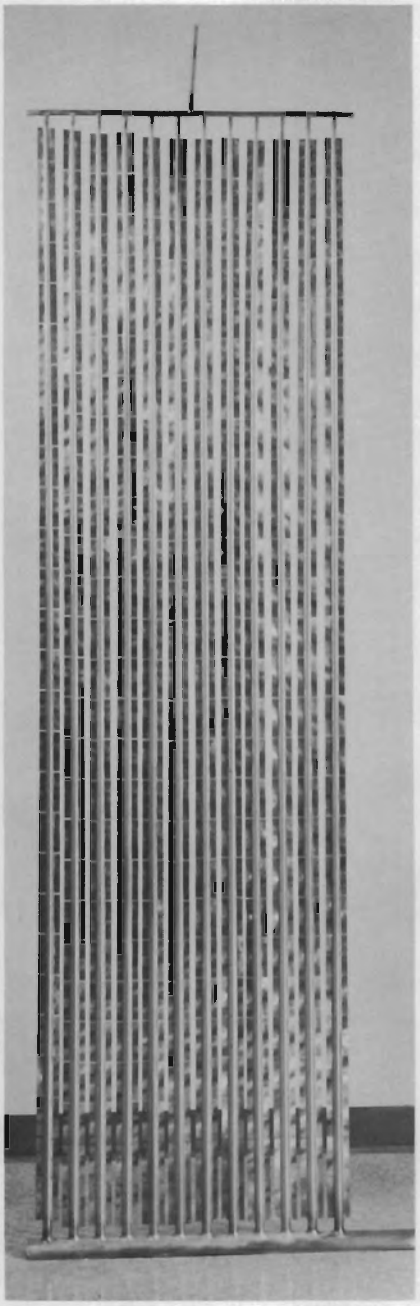


Fig. 10. Completed 12-Tube Radiator.

Fabrication of the 144-Tube Condenser

General

The 144-tube condenser was built to be used in a water-condensing test rather than as a liquid-metal radiator. For this unit, the same tapered tubes were used as with the 12-tube unit, but they were left unfinned in this case. Thus, fabrication work consisted entirely of welding.

The large ends of the tubes were attached to a tapered vapor header in two planes, containing 72 tubes each, with a dihedral angle between them as shown in Fig. 2. The small ends of the tubes were attached to small, cylindrical condensate headers, in sets of 12 tubes per header.

The tapered tubes were initially welded to the 12 small condensate headers. These joints differed slightly from those used for the 12-tube unit in that design considerations did not permit the tube ends to be flattened. A saddle-on design of the type shown in Fig. 11 was thus used. The tubes were fixtured in sets of 12 and welded into place. End caps were welded in each end of the short condensate headers, and Fig. 12 shows a completed 12-tube section prior to removal from the welding jig. The tube-welding conditions used were essentially the same as those used for the 12-tube radiator.

When all the small-end joints were completed and inspected, the large ends of the 12-tube sections were welded to the halves of the vapor header. The basic condenser components at this point are shown in Fig. 13a. The joint design and welding conditions used for these welds were identical to those for the 12-tube finned radiator. An overall view of a completed condenser half-section is shown in Fig. 13b.

When welding of the tubes to both half-sections was completed, the root penetrations at the tube entrances were ground smooth as before. The welds were inspected and the two sections welded together. A view of the completed unit is shown in Fig. 14.

ACKNOWLEDGEMENTS

The writer wishes to thank L. C. Williams of the Metals and Ceramics Division Welding and Brazing Laboratory for his valuable assistance in the brazing work.

UNCLASSIFIED
ORNL-DWG 63-982

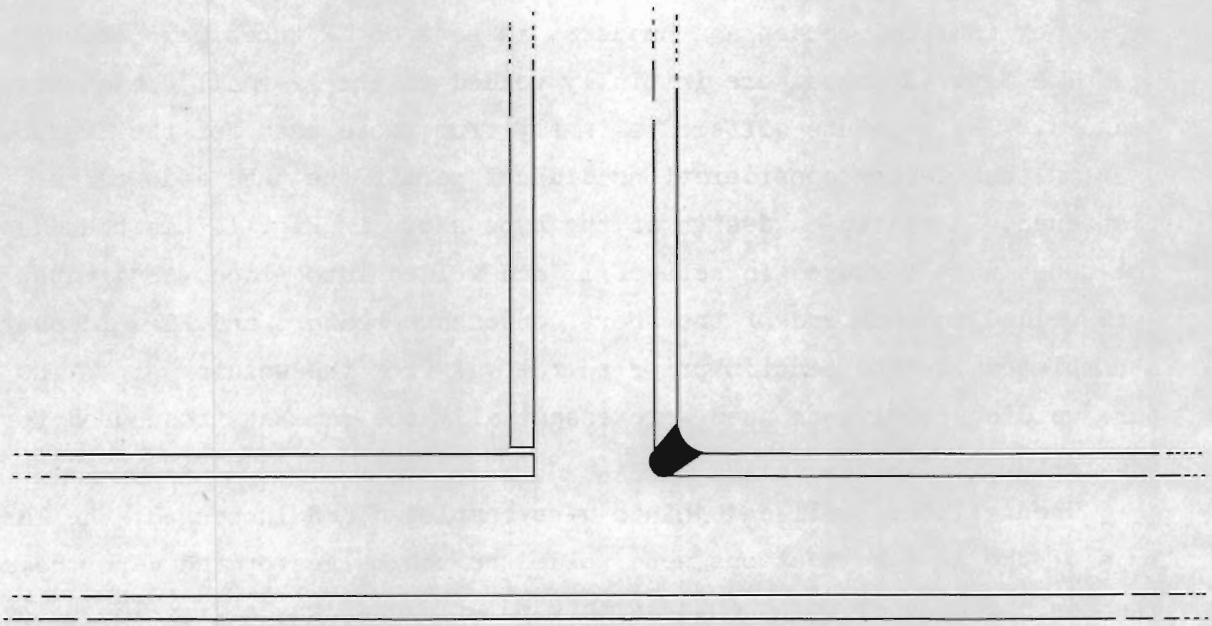


Fig. 11. Joint Design Used for Welding Small Ends of Tubes to Condensate Header in 144-Tube Condenser.

UNCLASSIFIED
PHOTO 60460

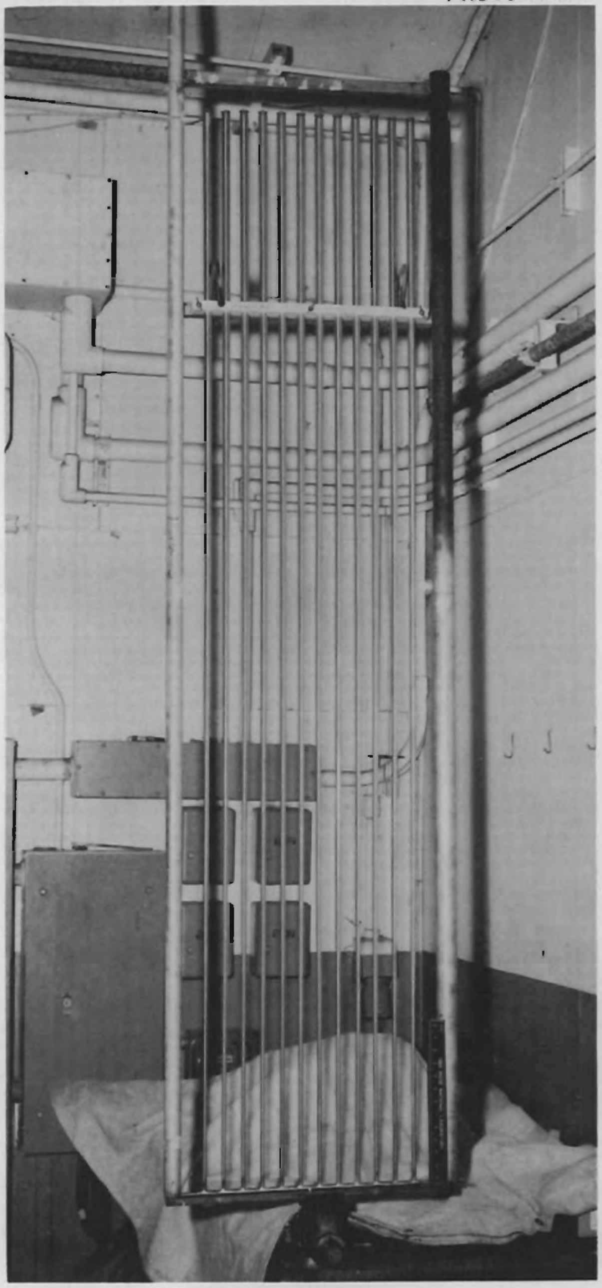
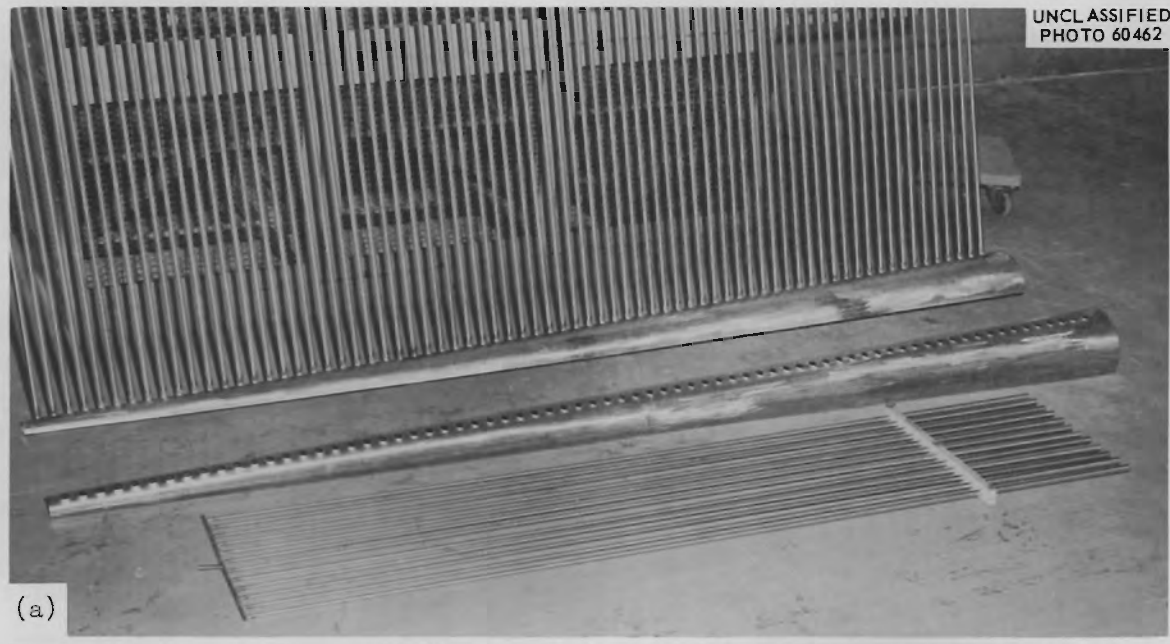


Fig. 12. Completed 12-Tube Section of 144-Tube Condenser.



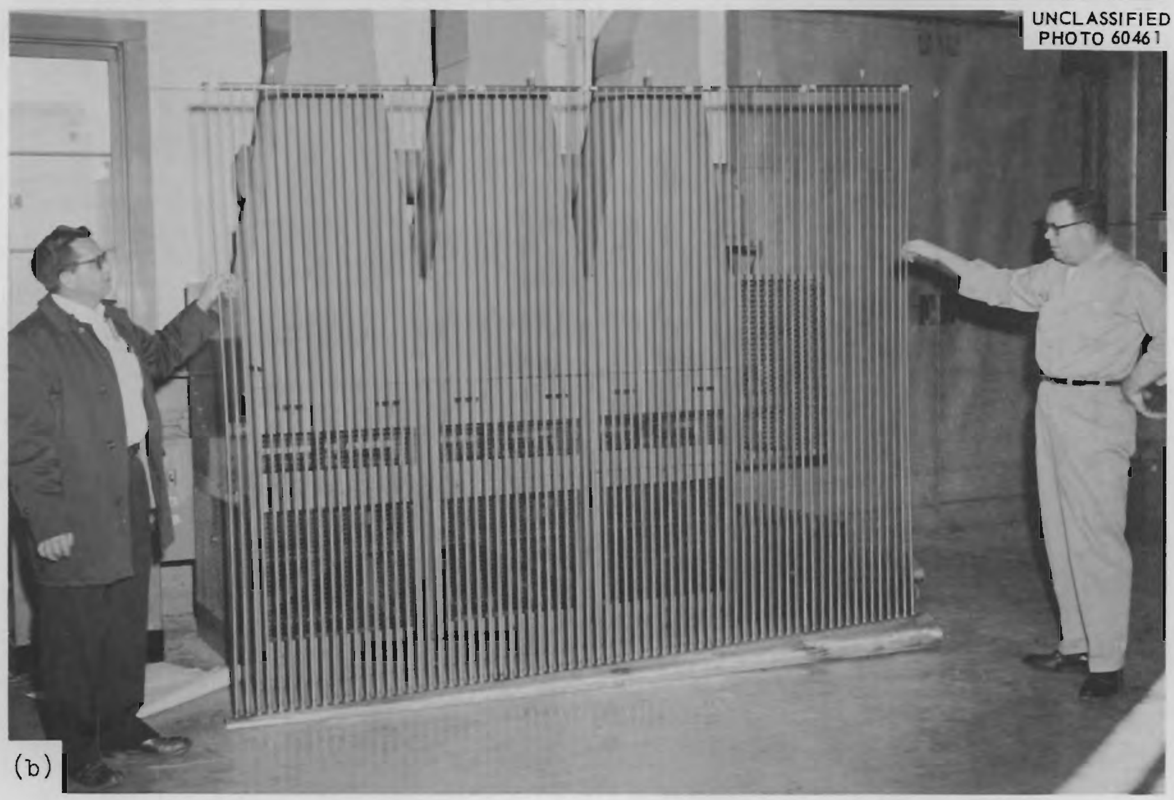


Fig. 13. (a) Subassembly Components Used for Fabricating 144-Tube Condenser. (b) Completed half-section.

Fig. 14. Completed 144-Tube Condenser.

Thanks are also due to C. E. Shubert, J. B. Gheen, and W. C. Fox of the Engineering and Mechanical Division Welding and Brazing Facility for the welding of both units.

DISTRIBUTION

1–2. Central Research Library
3–4. Document Reference Section
5–24. Laboratory Records
25. Laboratory Records (LRD-RC)
26–27. Reactor Division (ORO)
28. ORNL Patent Office
29. G. M. Adamson
30. E. P. Blizard
31. J. E. Cunningham
32. J. H. DeVan
33. D. A. Douglas
34. J. Foster
35. A. P. Fraas
36–40. E. A. Franco-Ferreira
41. J. H Frye, Jr.
42. L. C. Fuller
43. C. H. Gabbard
44. A. G. Grindell
45–48. M. R. Hill
49. H. W. Hoffman
50. J. K. Jones
51. J. J. Keyes
52. R. B. Korsmeyer
53. M. E. LaVerne
54. R. N. Lyon
55. H. G. MacPherson
56. R. E. MacPherson
57. W. D. Manly
58. J. W. Michel
59. A. J. Miller
60. P. Patriarca
61. H. W. Savage
62–66. G. M. Slaughter
67. E. Storto
68. A. Taboada
69. W. C. Thurber
70. W. C. Tunnell
71. M. M. Yarosh
72. G. Young
73. H. C. Young

EXTERNAL DISTRIBUTION

74–75. Research and Development Division (ORO)
76–90. Division of Technical Information Extension (DTIE)