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FABRICATION OF BOILER SECTION FOR BOILING-LIQUID-METAL LOOP

E. A. Franco-Ferreira

ABSTRACT

The Welding and Brazing Group of the Metallurgy Division successfully fabricated a 4-ft-long boiler for a boiling-liquid-metal loop to be operated by the Reactor Division. This involved brazing massive copper blocks between a thin-walled stainless steel tube and a thin-gage stainless steel jacket. Essentially 100% bonding to the tube was required while a few areas of nonbond were permitted in the copper-to-jacket braze.

The brazing was accomplished in vacuum, using an electroless-deposited nickel-phosphorus alloy and slurry-deposited nickel-chromium-phosphorus alloy. Bonding was better than 99% complete in the copper-to-tube braze and was approx 92% complete in the copper-to-jacket braze.

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INTRODUCTION

In order to provide more information on two-phase heat transfer in liquid metals, an experiment was designed by the Heat Transfer and Physical Properties Section of the Reactor Division of the Oak Ridge National Laboratory (ORNL) for measuring boiling and condensing coefficients at temperatures up to 1700–1800°F. A flow diagram of the system is shown in Fig. 1. Liquid metal is pumped through a throttle valve into a vertical, electrically heated boiler. This boiler, which is approx 4 ft long, is a critical portion of the loop.

The boiler design is shown schematically in Fig. 2. It consists of an 0.375-in.-OD x 0.028-in.-wall, type 347 stainless steel tube centrally bonded to a 44-in.-long stack of twenty-one 2-in.-thick x 5-in.-OD copper disks. The copper disks are also brazed to the inside of a type 310 stainless steel containment jacket for protection against oxidation during service. Axial heat flow along the boiler is minimized by 1/8-in.-thick stainless steel spacers between each of the copper disks. Stainless steel-sheathed Chromel-Alumel thermocouples are positioned (but not brazed) within each disk to measure radial temperature profiles. Individually controlled clam-shell heaters for each disk provide a heat flux of 500,000 Btu/hr-ft^2 at the central tube.

The Welding and Brazing Group undertook the responsibility for fabricating the boiler. However, in view of the unique geometry of the assembly and the exceptionally high quality brazes required, an extended developmental program was required in order to arrive at suitable fabrication procedures.

PRELIMINARY EXPERIMENTS

Hydrogen Brazing

Initial brazing experiments were performed with Coast Metals No. 52 alloy[1] using mockups containing from two to four disks. The copper disks

[1] A nickel-silicon-boron brazing alloy produced by Coast Metals, Inc., Little Ferry, N. J. (Alloy corresponds to AMS-4778).

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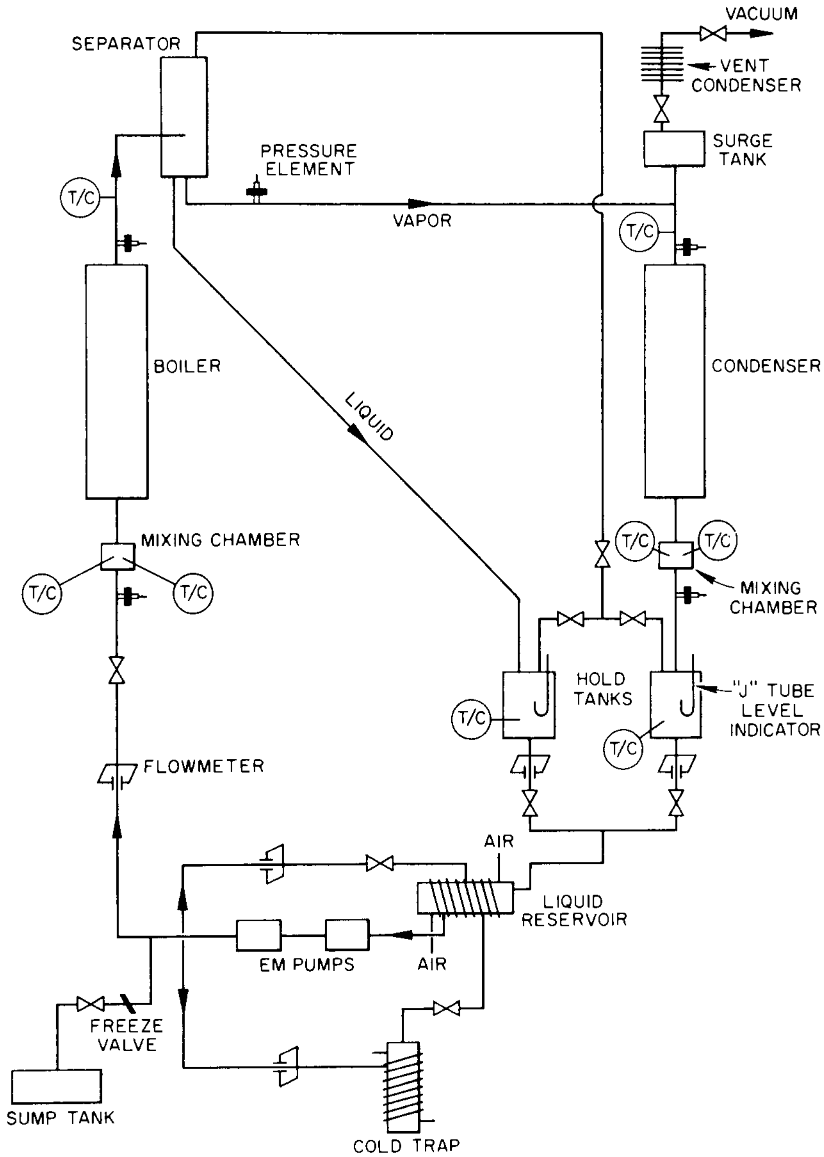

Fig. 1. Schematic Flow Diagram of Boiling-Liquid-Metal Experiment.

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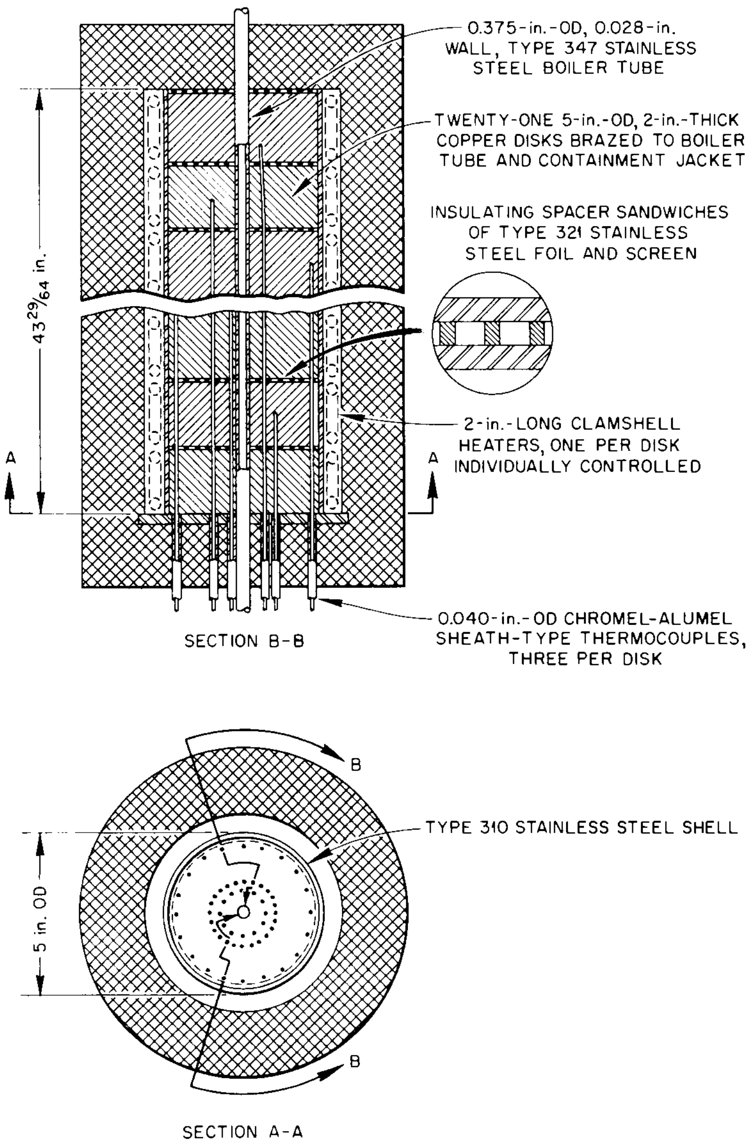

Fig. 2. Experimental Boiler for Boiling-Liquid-Metal Experiments.

were machined from phosphorus-deoxidized plate. Brazing was performed in a purified hydrogen atmosphere of approx -80°F dew point, but it was impossible to obtain a high quality braze using this procedure. The faying surfaces of the stainless steel were always slightly oxidized and poor alloy flow resulted.

It was first postulated that high residual oxygen levels in the copper might be responsible for the poor results. Consequently, subsequent disks were machined from oxygen-free, high-conductivity (OFHC) copper. Using the same procedure described previously, except for the type of copper, additional brazing tests were performed. The results were somewhat improved, but adequate bonding was still not obtained.

It appeared, from the design geometry, that the long and relatively inaccessible capillaries through which the brazing alloy had to flow were not being adequately purged by the hydrogen atmosphere. Thus, adsorbed gases, hydrogen-metal oxide reaction products, and entrapped air could readily result in high local concentrations of oxygen and water vapor which oxidized the base metals and brazing alloy.

Vacuum Brazing

As a result of the experiments and analyses discussed above, it was decided that an adequately pure "atmosphere" could most readily and reliably be obtained by using vacuum-brazing techniques. Thus, high local concentrations of contaminants would not accumulate since they would provide their own driving force for removal. Preliminary experiments with subsize specimens verified this approach since no evidence of surface oxidation could be detected even in the areas of limited access. A further modification in procedure was also introduced at this time in order to improve the reliability of the braze. Preliminary experiments associated with this general problem had indicated that phosphorus-containing alloys were more suitable for brazing stainless steel to copper than was the boron-containing Coast Metals No. 52. A slurry of Nicrobraz No. 50 (nickel-chromium-phosphorus alloy)[2] was consequently placed in machined grooves in the copper disks. Also, in order to facilitate

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[2]Wall-Colmonoy Corporation, Detroit, Michigan.

wetting, all mating surfaces of stainless steel and copper were preplated with a deposit of electroless nickel-phosphorus alloy.[3]

Vacuum-brazing experiments on sample tube-to-disk joints showed this to be a feasible brazing method. Attempts were made to use the outer stainless steel can as the vacuum retort and to pump directly on it while brazing. This did not provide adequate evacuation and considerable nonbonding still resulted.

The method which was chosen for the final assembly utilized an outer stainless steel can which had been slotted between disks to aid pump out. The entire specimen was then placed in a separate vacuum retort. After brazing, the slots were closed by welding in order to preserve the protective aspect of the can. Two four-disk brazing tests made with this procedure gave very satisfactory results.

The pertinent features finally developed for the boiler fabrication sequence were as follows:

1. OFHC copper was used for disks.
2. All surfaces to be brazed were plated with 0.003 in. of electroless nickel-phosphorus alloy.
3. Additional Nicrobraz 50 (nickel-chromium-phosphorus) alloy was added to grooves in the disks in slurry form.
4. The outer stainless steel can was circumferentially slotted at the locations of the spaces between disks.
5. The entire unit was brazed in a vacuum retort at a vacuum of at least 1×10^{-3} mm Hg.

BRAZING OF JOB SAMPLES AND BOILER

The work on the vacuum brazing of the four-disk samples was performed in a vacuum furnace at Y-12. However, a vacuum furnace large enough to braze the actual boiler, which was more than five times as long, was not available in Oak Ridge. Therefore, the Union Carbide Nuclear Company Purchasing Division contacted a large number of potential owners of suitable

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[3] P. Patriarca _et al._, _Electroless-Plated Brazing Alloys_, ORNL-2243 (March 19, 1957).

furnaces (including job-shop, heat-treating and brazing companies, aircraft and missile companies, furnace manufacturers, and nuclear energy installations). The Superior Tube Company of Norristown, Pennsylvania, which has a 30-ft-long vacuum furnace for annealing titanium and zirconium tubing, was selected.

Figure 3 shows the boiler during assembly. The maze of thermocouples penetrating through the copper disks is evident. Figure 4 shows both the boiler (top) and the job sample (bottom) on their brazing jigs. Two job samples were brazed in the Superior Tube Company's furnace in order to check out the furnace and brazing procedure. Visual inspection of the samples after brazing revealed good filleting of the brazing alloy, and ultrasonic inspection indicated excellent over-all bonding.

Metallographic evaluation of the braze joints in one of the test samples was also performed and excellent bonding was observed. Figure 5 is a cross-sectional view of a single-disk section of a boiler job sample with tube and can brazed in place. The reservoirs for the preplacement of brazing alloy are evident. Figure 6 shows the microstructure of the brazed joint with the copper being located at the top of the picture.

The actual boiler unit was then brazed. The specified cycle for all the brazing runs was as follows:

1. Use maximum rate-of-rise to 1820°F (approx 500°F/hr).
2. Hold at temperature for 15 min.
3. Furnace cool.
4. Vacuum must be better than 10^{-3} mm Hg.

Figure 7 is a close-up view of one end of the boiler after brazing, illustrating the large number of thermocouples which were built into the unit.

Inspection

Methods for inspecting both the stainless steel tube-to-copper joint and the stainless steel can-to-copper joint were developed by the Nondestructive Testing Development Group of the Metallurgy Division. The test methods employed ultrasound[4] and were correlated in sensitivity with known defects

[4] J. K. White, R. W. McClung, and J. W. Allen, Implications of Ultrasonic Attenuation to Nondestructive Testing, ORNL-2651 (March 30, 1959).

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Fig. 3. Boiler During Assembly.

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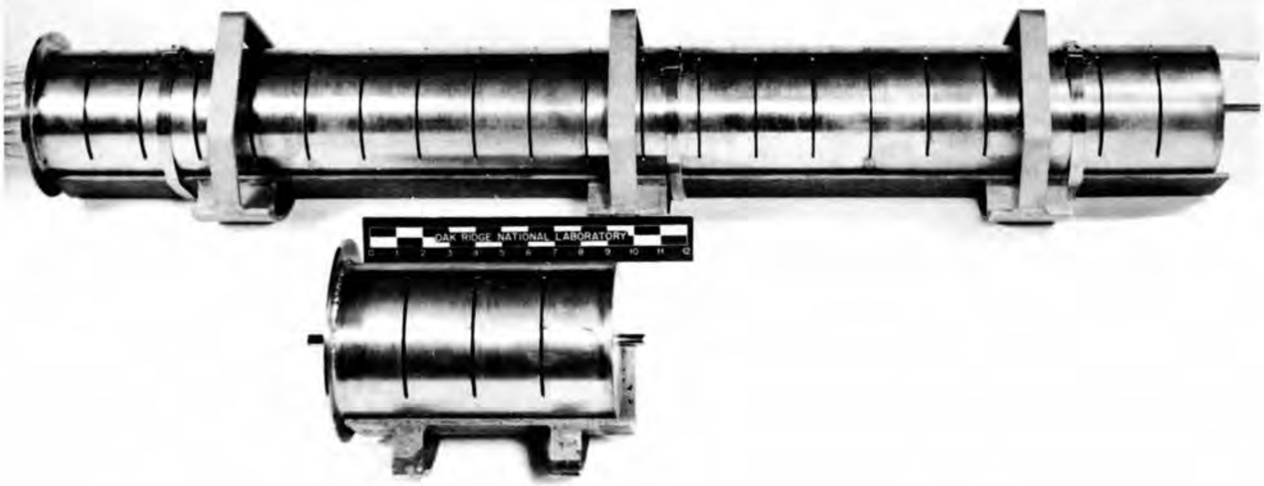

Fig. 4. Boiler and Job Sample in Place on Brazing Jigs Prior to Brazing.

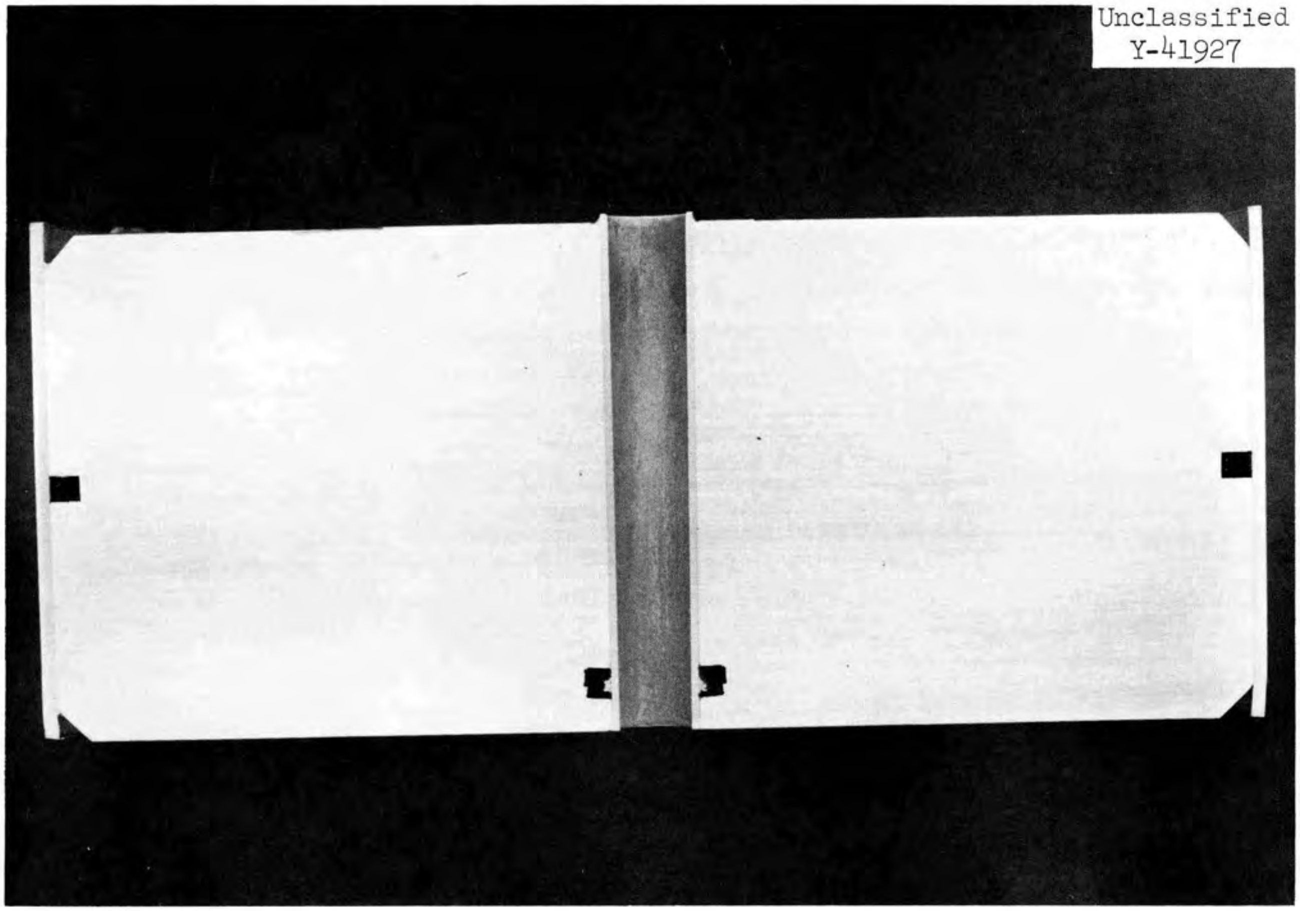

Fig. 5. Cross-Sectional View of a Single Disk Section of a Boiler Job Sample after Brazing with Can and Tube in Place.

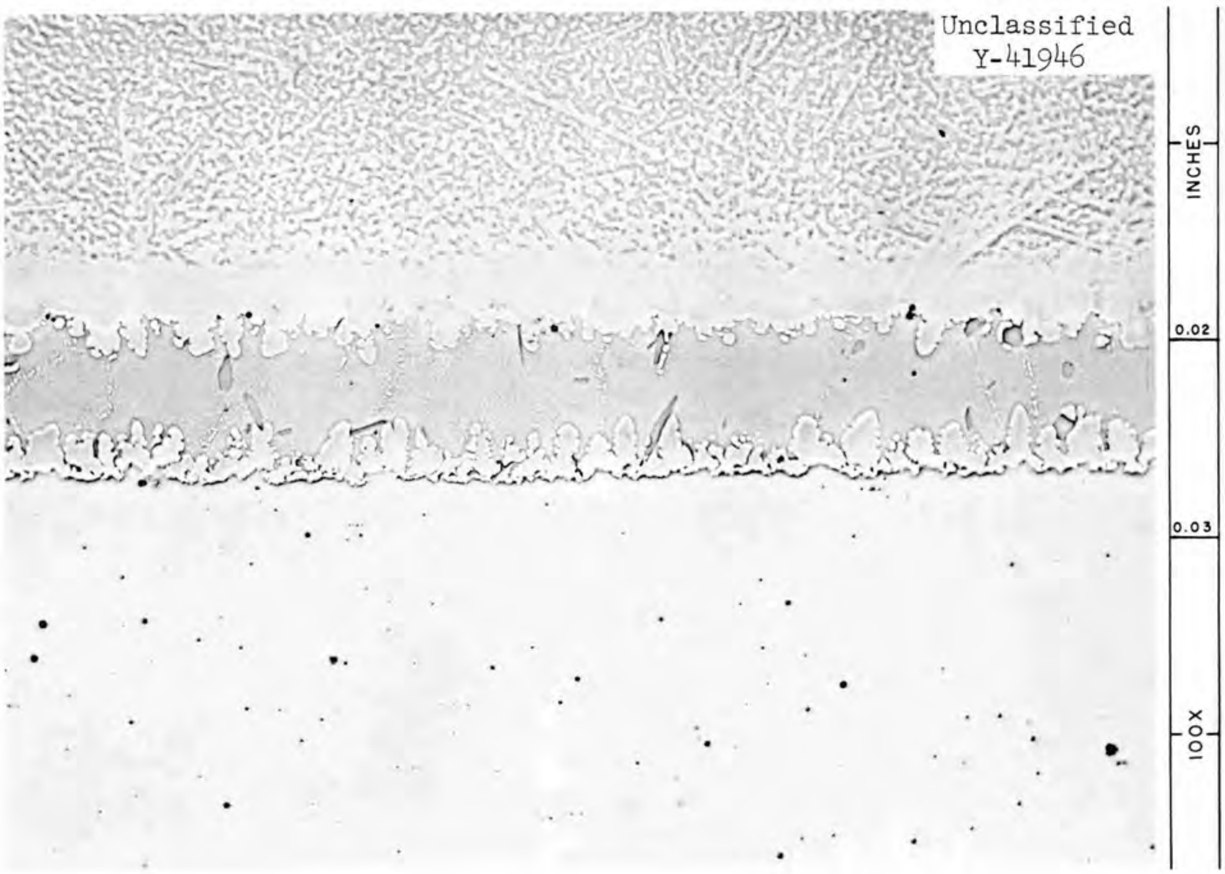

Fig. 6. Microstructure of a Typical Copper-to-Stainless Steel Brazed Joint Showing Excellent Bonding.

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Fig. 7. One End of Boiler after Brazing Showing the Thermocouples.

in job samples. The test methods were quite sensitive and were capable of picking up very small areas of nonbond. For nondestructive inspection of the boiler, the sensitivity of the ultrasonic system was adjusted to detect nonbonds 1/8 in. x 1/16 in. in size. In the tube-to-copper joint, very few such nonbonds were detected and it appeared that the tube was brazed with 99% or better bonding.

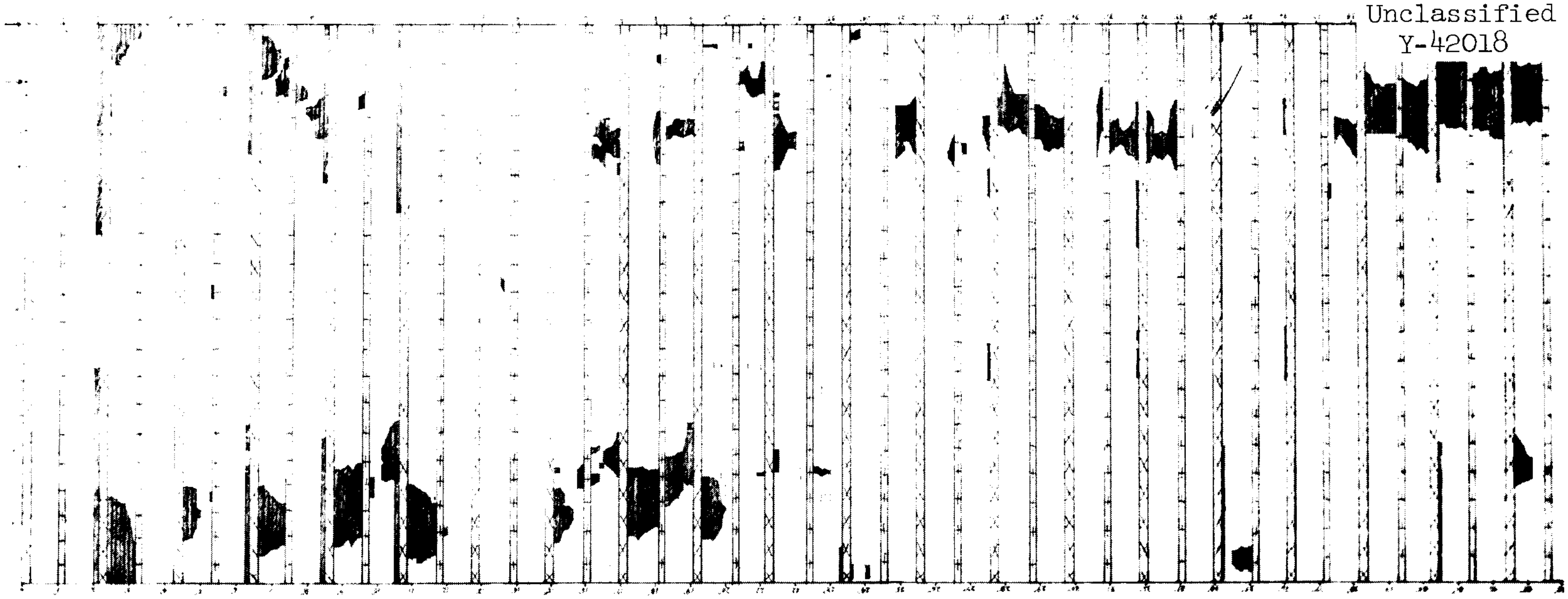
The stainless steel can-to-copper disk joint revealed somewhat larger areas of nonbond. Figure 8 is a pictorial presentation of the data. The dark patches are areas of nonbond on the cylindrical boiler plotted on a recording chart. The top and bottom portions of the chart correspond to the top of the boiler as it was positioned in the furnace. Most of the nonbonded areas were at the top of the boiler, a condition which might be expected since the brazing alloy tended to run to the bottom because of the somewhat loose initial fit-up of the can-to-copper joint. Nevertheless, measurement of the nonbonded areas in the can-to-copper joint shows that the total nonbond did not exceed 8% of the total joint area. This 8% nonbonded area was acceptable to the loop designers.

Completion of Boiler

Following inspection of the boiler, the slots in the can were closed so that a protective helium atmosphere may be maintained inside the can during operation. To prevent weld cracking from phosphorus contamination, the brazing alloy which had flowed on the can exterior was removed by grinding. The slots were closed by welding type 310 stainless steel strips 1/2 in. wide by 0.030 in. thick over them. A view of typical slot covering is shown in Fig. 9.

CONCLUSIONS

A large boiler assembly, approx 4 ft in length, was successfully fabricated for a boiling-liquid-metal experiment. This involved brazing massive copper disks between a thin-walled stainless steel tube and a thin-gage stainless steel jacket. The brazing was performed in vacuum using phosphorus-containing brazing alloys. Good bonding between the mating surfaces was accomplished.



Legend: + indicates machined grooves
for brazing alloy preplacement;
x indicates inter-disk spacing; and
(shaded areas) indicate nonbond.

Fig. 8. Graphical Presentation of Nonbond Data for the Can-to-Copper Joint.

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Fig. 9. View of Three Slot Covers after They Were Welded in Place on the Outside of the Boiler.

ACKNOWLEDGMENTS

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