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RESEARCH REPORT

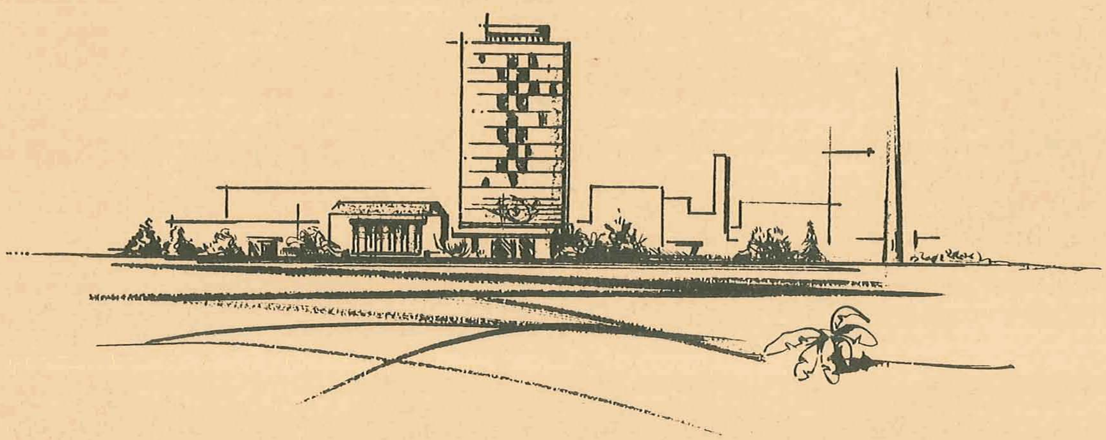
DETERMINATION OF BONDING PARAMETERS AND INSPECTIO
TECHNIQUES FOR CADMIUM-TO-STAINLESS STEEL BONDS
AND ASSEMBLY OF TWO CAPSULE HOUSINGS

to

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Lewis Research Center

February 28, 1968

Contract No. NAS 3-7892-H



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FINAL REPORT

on

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by

J. H. Peterson and P. J. Gripshover

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INTRODUCTION

The NASA-Lewis Research Center conducted a research program at Battelle Memorial Institute to fabricate clad fuel pellet containment vessel assemblies. During this contract (NAS 3-4255), two containment vessel assemblies were fabricated. These assemblies contained tungsten-clad tungsten-UO_2 fuel pellets. In addition to studying the thermal-cycle characteristics of these pellets, another objective of the program was to provide assemblies for irradiation testing at the NASA Plum Brook Reactor.

The primary objective of the subject program (NAS 3-7892-H) was to assemble two capsule housings containing the clad fuel pellet containment vessel assemblies fabricated on NAS 3-4255. In addition to these assembly procedures, bonding parameters and inspection techniques for cadmium-to-stainless steel bonds were developed.

The following report describes the work conducted under this contract.

MATERIALS

Most of the materials used on this program were furnished by NASA. The first containment vessel assemblies were retained at Battelle after fabrication on NASA Contract NAS 3-4255. All components indicated on NASA

Drawing CF 351047 were furnished by NASA except for Part B which was revised. These parts were machined at Battelle from Type 304 L stainless steel bar stock. Type 304 L stainless steel was used for other components such as thermocouple extension tubes.

In the initial experiments, Type 304 stainless steel was bonded to commercially available cadmium sheet. However, in the final experimental work and the capsule housings, thick cadmium plate was used rather than sheet material. A typical analysis of this cadmium plate is given below:

Element	Impurity Level, ppm
B	<10
Cu	20
Ni	10
Pb	10

The brazing alloy used for joining of the stainless steel components in the capsule housing was Nicrobraz 50. This material was purchased from the Wall Colmonoy Corporation.

EQUIPMENT

Equipment used during this program consisted of gas-pressure-bonding equipment capable of temperatures up to 1000 F and pressures to 4000 psi. This special autoclave was 10 ft long to accommodate the capsule housings prepared on this program. Also utilized were machine shop facilities, vacuum heat-treatment furnaces, induction brazing furnaces, nondestructive test equipment, the metallographic laboratory, analytical laboratory, and specialized welding equipment. Facilities not located at Battelle which were used in specialized areas included Lancaster Electro Plating Company, Lancaster, Ohio, for the plating of the cadmium onto the ID of the thin outer tube and Automation Industries, Inc., Columbus, Ohio, for ultrasonic inspection of the cadmium-to-stainless steel bonds.

EXPERIMENTAL WORK

The experimental work in this study was divided into two distinct areas. The first of these involved the determination of bonding parameters for cadmium-to-stainless-steel bonds and suitable inspection techniques to evaluate the quality of the bonds obtained. The second area of effort involved the assembly of two capsule housings.

Determination of Bonding Parameters and Inspection Techniques

To evaluate the bonding of cadmium to stainless steel, flat-plate specimens were used in the initial studies. The most desirable approach was then evaluated with tubular configurations simulating the final assembly. Ultrasonic inspection of the bonded specimens showed excellent correlation with metallography of the same specimens.

Flat-Plate Bonding Experiments

In the first experiment, flat-plate specimens were joined to evaluate bonding parameters and four different surface preparations. The bonding of stainless steel directly to the 0.015-in.-thick cadmium sheet was evaluated as well as stainless steel plated with tin, zinc, and cadmium. To improve the adherence of the platings to the stainless steel, a nickel strike was first applied. The total thickness of the coatings did not exceed 0.0005 in. After edge welding, evacuating, and sealing, the specimens were run at 500 F and 2000 psi gas pressure. Evaluation of the specimens indicated that the bonding of the stainless steel directly to the cadmium did not appear satisfactory. The stainless steel parted easily from the cadmium sheet although metallographic examination showed no gap between the two materials after bonding. Of the three platings evaluated, the cadmium appeared the best. Metallographic examination showed no separation at the interface, and the cadmium sheet could be separated from the stainless steel with some degree of difficulty. The zinc-coated specimen was very similar to the cadmium-plated specimen except for the fact that the separation of the cadmium from the stainless steel was more easily accomplished. In the tin-coated specimen, some melting occurred because the eutectic temperature of the Cd-Sn system (350 F) was exceeded. This specimen also showed that the cadmium, although tightly adherent to the stainless steel, could be separated.

The separation of the stainless steel from the cadmium appeared to occur at the plating-stainless steel interface. In order to improve the adherence of the tin coating to the stainless steel, a tin coating was applied in the molten condition after fluxing of the stainless steel. These tin-coated specimens were run at 350 F and 2000 psi to evaluate bonding to 0.015-in.-thick cadmium sheet. In addition, zinc-plated and cadmium-plated stainless steel were bonded to cadmium sheet in flat-plate specimens at 600 F and 2000 psi gas pressure. Evaluation of these specimens again showed that the bond of the cadmium-plated stainless steel to cadmium sheet was the most tightly adherent.

Bonding of Tubular Specimens

As a result of the flat-plate experiments described above, the most desirable approach for joining of cadmium to stainless steel was selected. This involved the plating of a thin cadmium layer (0.0005 in. thick) over a nickel strike on the stainless steel. The cadmium was then bonded to the thin cadmium plate at 2000 psi and a temperature of about 600 F. In the following series of experiments, the bonding of cadmium to stainless steel was evaluated in a tubular configuration simulating the final capsule housings.

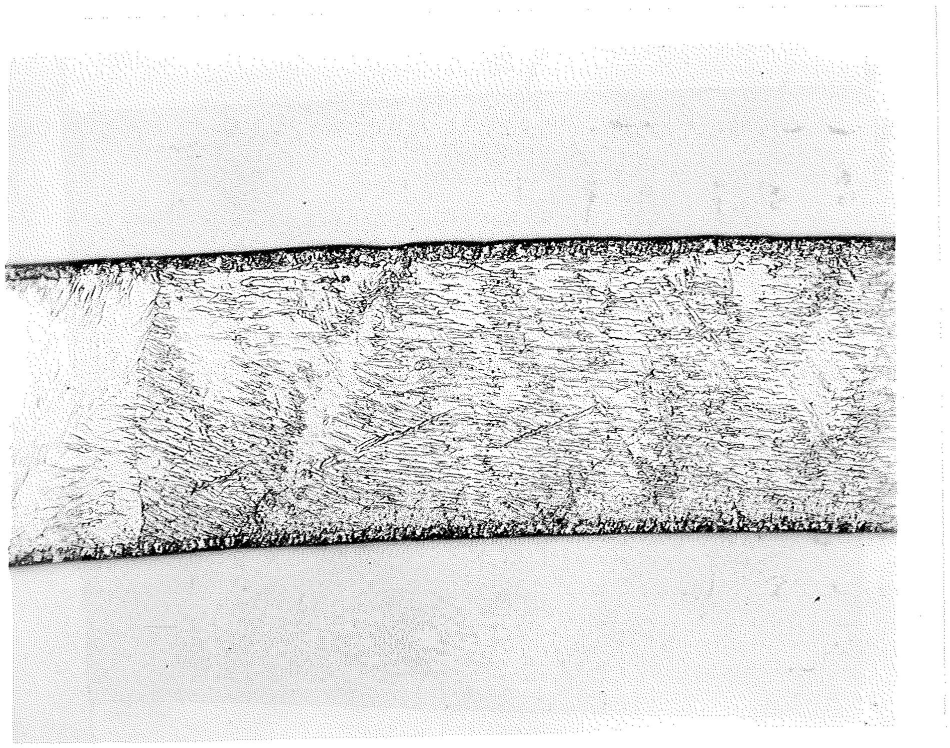
In the first tubular configuration to be bonded, the ID of the thin outer stainless steel tube and the OD of the heavy inner tube were plated with 0.0005 in. of cadmium over a nickel strike. Cadmium sheet, 0.015 in. thick, was placed in the annulus between the tubes. Difficulty was encountered in the welding of the ends because of incomplete removal of the cadmium plating in the weld zone. The specimen was therefore sealed within a thin copper envelope to insure leak tightness during bonding. This specimen was bonded at 600 F and 2000 psi. The container deformed sufficiently to indicate that good pressure transmission had been obtained. The copper was removed, and the tube was inspected ultrasonically. Ultrasonic inspection showed a wide variation in the quality of bonding obtained. Metallographic examination showed shrinkage voids in the cadmium which indicated that the temperature of the specimen was above the melting point of the cadmium. Other specimens run previously at the same nominal temperature had not shown melting. This temperature, 600 F, is only about 10 F below the melting point of cadmium, and a slight temperature excursion could cause melting. It was observed that upon solidification the shrinkage voids were not closed. This indicated that the outer tube of stainless steel offers a great deal of resistance to deformation and that the clearances in the assembly must be held to a minimum.

Another tubular specimen was prepared and assembled, keeping the clearance to a minimum between the cadmium sheet and the stainless steel. Particular care was taken in the removal of cadmium from the weld zones, and no problems in welding were encountered. This specimen was run at 530 F and 2000 psi for a period of 1 hr. Metallographic examination showed that the 0.015-in.-thick cadmium was in good contact with the cadmium plating on the innermost stainless surface (the OD of the thick inner tube). At the interface between the plating on the ID of the thin-wall outer stainless tube and the 0.015-in.-thick cadmium, a very slight separation existed. This is believed to be due to the elastic springback of the outer tube after release of pressure. It was also noted that the movement of the outer tube was not sufficient to completely close the longitudinal joint in the cadmium sheet. This would indicate that either the gas pressure was not high enough to yield the outer tube sufficiently or that the yield strength of the tube was too high.

To minimize springback and to aid in the deformation of the outer tube, two approaches were undertaken. An additional tubular specimen was prepared for bonding using 0.015-in.-thick cadmium sheet between the thin outer tube and the inner tube. Prior to plating of the thin cadmium layer onto the stainless steel, the outer tube was heat treated at 2100 F for 1 hr to fully anneal the tube. Annealing of this outer tube was done to minimize the elastic springback that occurs upon release of pressure and to reduce the yield strength sufficiently to insure deformation of the outer tube. To aid in deforming the outer tube, the use of higher pressures in the pressure vessel used on this program was evaluated. This specimen was bonded at 500-550 F and a gas pressure of 4000 psi. A high-pressure helium bottle and special fittings were obtained to convert the hot wall autoclave used on this program to higher pressures.

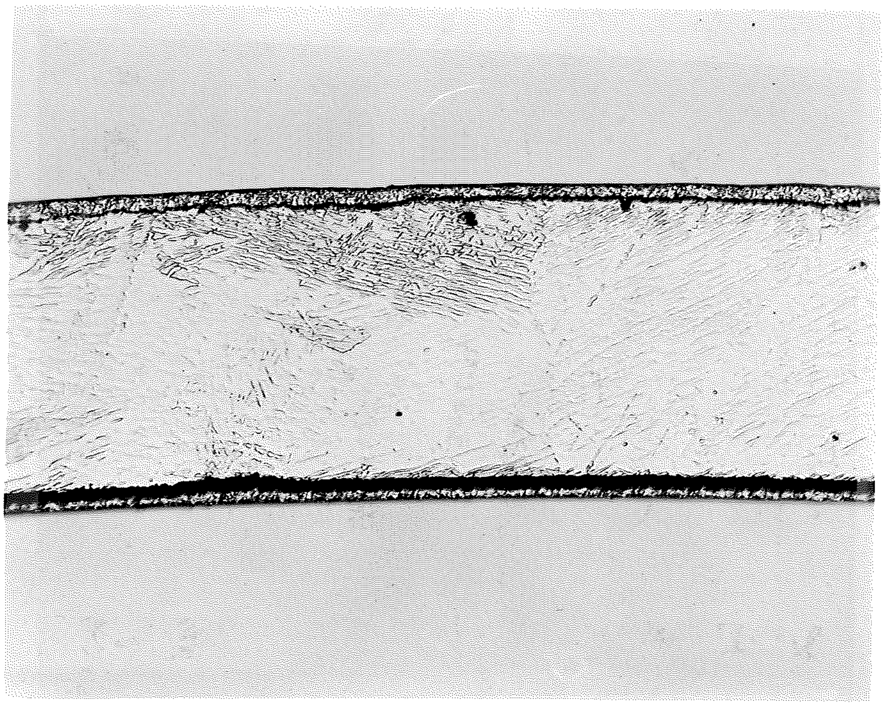
Metallographic examination showed good bonding of the 0.015-in.-thick cadmium sheet to most of the thin outer tube and to a portion of the OD of the inner tube. This is shown in Figure 1. About one-third of the specimen was bonded on the inner surface, and at the point of maximum separation, a small gap also existed at the outer bond interface as shown in Figure 2. It was evident that good contact of all surfaces had been achieved during the run but that springback of the stainless tube had resulted in the separation. The amount of springback obtained, about 0.001 in., was that which would be expected from annealed stainless steel that had been plastically deformed. The longitudinal joint in the cadmium sheet had been completely closed and was well bonded. This fact would also indicate that good pressure transmission through the thin outer tube had been achieved.

Bonding runs using cadmium sheet material indicated that a gap existed between the stainless steel and the cadmium due to the elastic springback of the thin outer tube. This springback cannot be avoided if the necessary clearances for assembly are provided. To prevent deformation of the thin outer stainless steel tube during bonding, no clearance may exist in the assembled specimen. The only practical method of accomplishing this is to assemble a heated outer tube over a chilled inner tube. To evaluate this approach, the feasibility of producing a thick cadmium plating free from voids or inclusions was investigated. Studies indicated that a high-quality plating could be obtained in sufficient thickness (over 0.015 in. thick) on the ID of the thin-wall outer tube.



100X Etchant - H_2O 9A441

FIGURE 1. WELL BONDED SECTION OF TUBULAR SPECIMEN

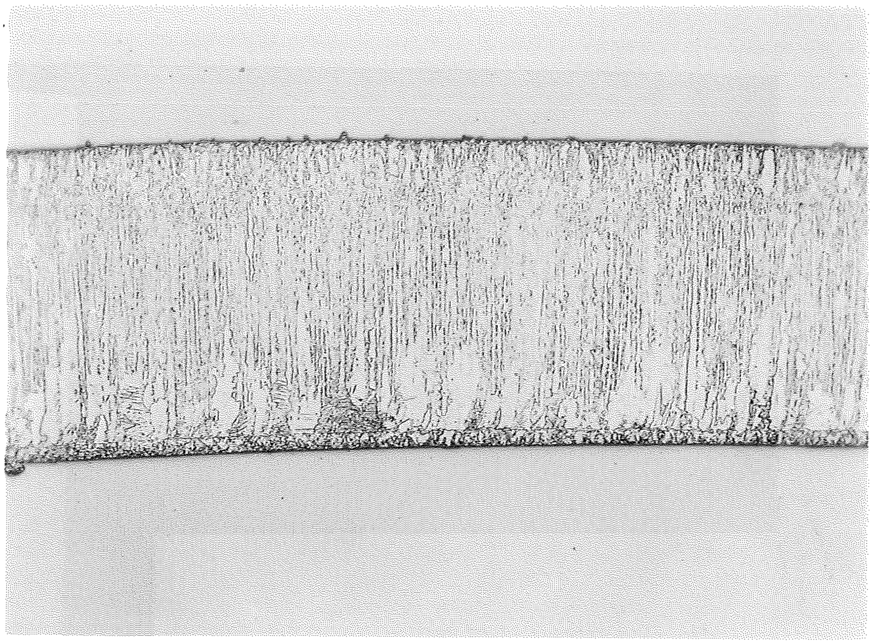


100X Etchant - H_2O 9A442

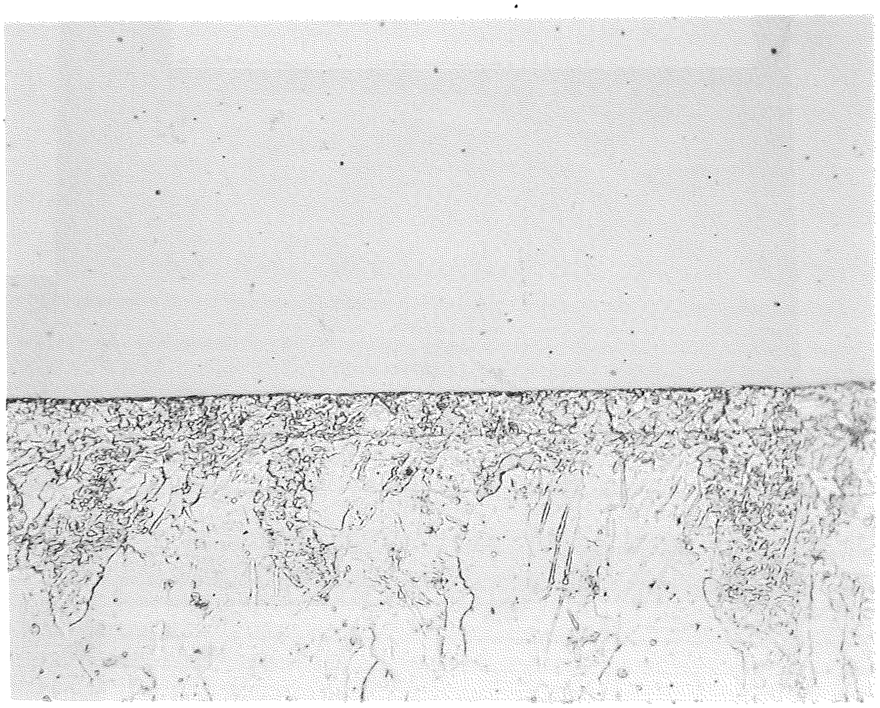
FIGURE 2. SECTION OF TUBULAR SPECIMEN SHOWING SEPARATION AT PLATING-SHEET INTERFACE

A specimen to evaluate this approach was prepared and bonded. The ID of the thin outer tube was plated with about 0.020 in. of cadmium. This was then bored to provide a cadmium thickness of 0.015 in. The inner stainless steel part was plated with 0.0005 in. of cadmium over a nickel strike. This then resulted in a 0.001-in. interference fit between the two parts. The outer part was heated to 200 F and the inner part chilled in liquid nitrogen. The parts were then assembled, outgassed at 220 F for 30 min, and sealed by welding. Following helium leak check, the specimen was bonded at 500-550 F at a gas pressure of 2200 psi. Following bonding, the specimen was ultrasonically inspected, and the only defect noted was a void in the plating that was apparent prior to assembly. This defect area was slightly thicker than the rest of the plated surface and chipped out during machining. The specimen was metallographically examined and found to be well bonded with no separation in any area. Photomicrographs of the bonds obtained are shown in Figure 3. The only area that appeared to contain contamination at the bond zone was near the ends where possible overheating due to welding may have occurred. The use of this approach eliminated any separation after bonding.

This approach for the assembly of the capsule housings would require the chilling of the containment vessel assemblies produced on NASA Contract NAS 3-4255. To determine if any adverse effects resulted from chilling to liquid nitrogen temperatures, a metallographic sample of a brazed and welded assembly was immersed in liquid nitrogen. No damage to the welds or braze joints in the assembly were noted as a result of this treatment. Therefore, a decision was made by NASA and Battelle to use this procedure in the assembly of the capsule housings.



100X a. Etchant - H_2O 1B820



500X b. Etchant - H_2O 1B821

FIGURE 3. WELL BONDED TUBULAR SPECIMEN

This specimen was assembled so that at 0.001 in interference fit existed between the thin outer tube and the inner tube.

Assembly of the Capsule Housings

The primary goal of this program was the assembly of two capsule housings as shown on NASA Drawing No. CF351047. These housings were assembled, brazed, and completed in May, 1967. However, leaks in the thermocouples caused by melting of a low temperature braze material required the re-work of both assemblies. The capsule housings were delivered to NASA-Lewis on January 4, 1968.

Initial Assembly of Capsule Housings

Prior to brazing of the capsule housings, the containment vessel assemblies prepared on NASA Contract NAS 3-4255, were covered with the sacrificial tantalum shielding provided by NASA. This shielding included Parts D, E, and F, shown on Drawing No. CF 351047 and 0.0005-in.-thick columbium foil wrapped around the four thermocouple well extensions. The columbium was held in place by 0.010-in.-diameter tantalum wire. All components were degreased and cleaned prior to assembly.

All tubing and Parts C-1 were passivated in a 25-percent nitric acid solution at 120 F for 30 min. Following two rinses in deionized water, the outlet tubes were brazed to Parts C-1 with Nicrobraz 50 at approximately 1700 F in vacuum. Induction heating was used so that the heating was localized. The assemblies being brazed were contained within a Vycor tube and brazing was controlled by visual observation of the braze material. Following each brazing operation, the braze joints were helium leak checked to insure brazing quality.

The containment vessel assemblies were then inserted into Part C-1 and positioned so that 0.01-0.02 in. clearance existed between the stainless steel housing and the columbium foil wraps surrounding the thermocouple wells.

This position was maintained during brazing by a machined plug which supported the containment vessel assembly. Again, all braze joints were helium leak checked and found to be leak tight.

The thermocouples for both capsule housings were checked for grounding and continuity. Measurements were then taken to assure that the thermocouples would seat on the bottom of the thermocouple well. This was accomplished by making the following measurements with an optical comparator.

1. Determine the distance from the top of the capsule housing to the bottom of the thermocouple well using a pointed probe of known length
2. Determine the distance from the tip of the thermocouple to a scribe mark on the thermocouple
3. Determine the theoretical distance from the top of the capsule housing to the scribe mark on the thermocouple and compare this value with actual measurement with the thermocouple in place.

The thermocouples were then positioned in the capsule housing. Extension tubes for the thermocouple wells were required for three of the thermocouples on each housing. These were brazed in place with the thermocouples. Difficulty was encountered in the brazing of the thermocouples on Assembly 3A and a second brazing cycle was required. The temperature for this cycle was increased to about 1800 F. Following brazing, the distance between the scribe mark on the thermocouples and the top of the capsule was compared with the values obtained before brazing. The thermocouples on Assembly 3A appeared to have moved further into the thermocouple wells as a result of the brazing operation.

Following these operations, Parts B were passivated and the inlet tubes brazed into place. These parts were machined to provide a clearance of 0.07 to 0.09 in. with Part F which had been attached to the containment vessel assemblies. These parts were assembled and the girth joint between Parts C-1 and B TIG welded. After dye-penetrant inspection, the assemblies were pressure checked with helium at 500 psi and all possible locations for leakage checked with a leak detector. No leaks were noted.

Three thin-wall stainless steel outer tubes had been plated on the ID with cadmium. These tubes were machined to the same dimension as the OD of Part C-1. Part C-1 was then plated with 0.0005 in. of cadmium over a nickel strike. This would then provide a 0.001-in. interference fit on assembly. The minimum 0.015-in. required thickness of cadmium was met on both assemblies. For example, the smallest measured ID of the outer tubes was 0.968 in. and the largest OD of Part C-1 was 0.937 in. Disregarding the interference fit, a cadmium thickness of 0.0155 in. would be provided. The outer tubes were placed in a chromium plated copper block after passivation of the exterior surface and heated to about 250 F. The brazed capsule housings were chilled in liquid nitrogen and assembled into the cadmium plated exterior tube. Following outgassing to remove any residual moisture, the ends were welded and electron-beam sealed.

At this point it was noted that the exterior inlet tubes on both assemblies were leaking at the braze joint on Part B. Since the holes for the fast flux foils were not required, the tube was welded to a 0.10-in.-thick flat plate which was in turn welded to Part B. This plate fit into the recess previously machined into Part B.

The inlet tubes were then bent as shown in the drawing and the assemblies were gas-pressure bonded at 500-550 F and 2200 psi for 1 hr. Ultrasonic inspection of Assembly 4A was satisfactory, but Assembly 3A showed lack of bonding over most of the specimen. A leak was detected in one of the welds. This was repaired and the specimen re-run in the autoclave. Ultrasonic inspection then showed satisfactory bonding.

High-pressure leak check at 500 psi showed a small leak in the braze joint of Thermocouple R to Assembly 3A. This leak was repaired by brazing with a defocused beam in an electron beam welder. A radiograph of this joint indicated that the thermocouple wires were bent slightly and subsequent radiographs indicated similar bends in the other thermocouples on this assembly. Radiographs were taken of the thermocouples on Assembly 4A and no bending was noted. This explained, at least in part, the apparent movement of the thermocouples during brazing. The thermocouple wires did not appear to be touching and electrical continuity and grounding of the thermocouples was verified.

The assemblies were evacuated and backfilled with helium to atmospheric pressure. The inlet and outlet tubes were crimped and TIG welded prior to passivation of the entire assembly. After passivation, each assembly was placed in a metal tube and evacuated by a helium leak detector. Assembly 4A showed no leaks, but Assembly 3A showed an unacceptably high leak rate. Two thermocouples appeared to be leaking through the full length of the sheath at approximately 10^{-4} cc/sec. A meeting was held with NASA personnel and it was decided to remove the thermocouples from Assembly 3A and determine the casue of failure.

Failure Analysis and Rework of Assembly 3A

The primary goals of this work were to remove the thermocouples from the assembly to determine the cause of the failure of the braze joint between the tantalum tip and the stainless steel sheath, verify the integrity of the first containment assembly, and re-assemble the capsule with new thermocouples.

The removal of the thermocouples from the assembly was accomplished by sectioning the thermocouple about 1/4 in. above the top of the capsule housing and also just above the external braze joint in the bend area. The thermocouple braze joints were examined metallographically. This examination showed that the transition between the stainless steel and the tantalum sheaths had melted during the brazing of the thermocouples into the thermocouple wells. On this assembly, the brazing temperature was about 1800 F. The braze material for this joint between the tantalum and stainless steel was identified as a silver-manganese braze material, probably silver-15 manganese. This braze has a melting temperature of about 1750 F. The melting of this braze would account for the movement of the stainless steel sheath during the braze operation with Nicrobraz 50. Neither NASA nor Battelle was aware that a braze with this low a melting temperature had been used in the fabrication of the thermocouples. The thermocouple wires were removed and examined. In the location of the transition, the wires were kinked as noted on radiographs of these areas. The tantalum sheath portions of the thermocouples which extend into the first containment assembly did not appear deformed in any manner.

The integrity of the first containment vessel assembly was established by helium leak check. This was accomplished by use of the following procedures.

(1) Evacuate entire assembly.

(2) Fill the volume between the first and second containment vessels with helium.

(3) Flush the volume between the first and second containment vessels with argon until all traces of helium are believed to be removed.

(4) Place assembly in a tube, evacuate with a leak detector, and determine a leak rate if possible. (No helium was detected.)

(5) Pleace entire assembly under helium pressure (100-150 psi) for 1 hr.

(6) Repeat Step 3.

(7) Repeat Step 4.

If a leak had been present, the pressurization with helium would have left residual helium in the first containment vessel that would have been detected in Step 7. Although the first containment vessel was leak tight, leaks into each of the thermocouple wells (probably through the copper braze joint) were detected in all four wells. These leaks were not repaired as the presence of gas in the well is considered desirable.

Techniques were developed whereby the new thermocouples for Assembly 3A could be positioned so that a gap of 2-3 mils existed between the tip of the thermocouple and bottom of the thermocouple well. This is shown in Figure 4. The first joint brazed was between the stainless steel tube and the thermocouple sheath. This was accomplished by localized heating of the brazing area in an electron-beam welder. A defocused beam was used to prevent melting of the stainless steel thermocouple sheath. A copper chill block was used to prevent overheating of the braze joint between the tantalum tip and the stainless steel sheath. Metallographic examination of brazed specimens indicated that no melting of this internal braze joint had occurred. Some erosion of the stainless steel sheath was noted on the side heated by the electron beam. This erosion extended into the sheath about 0.004 in. or about one-third the sheath thickness. Braze metal filled this eroded area however, and the integrity of the couple would not

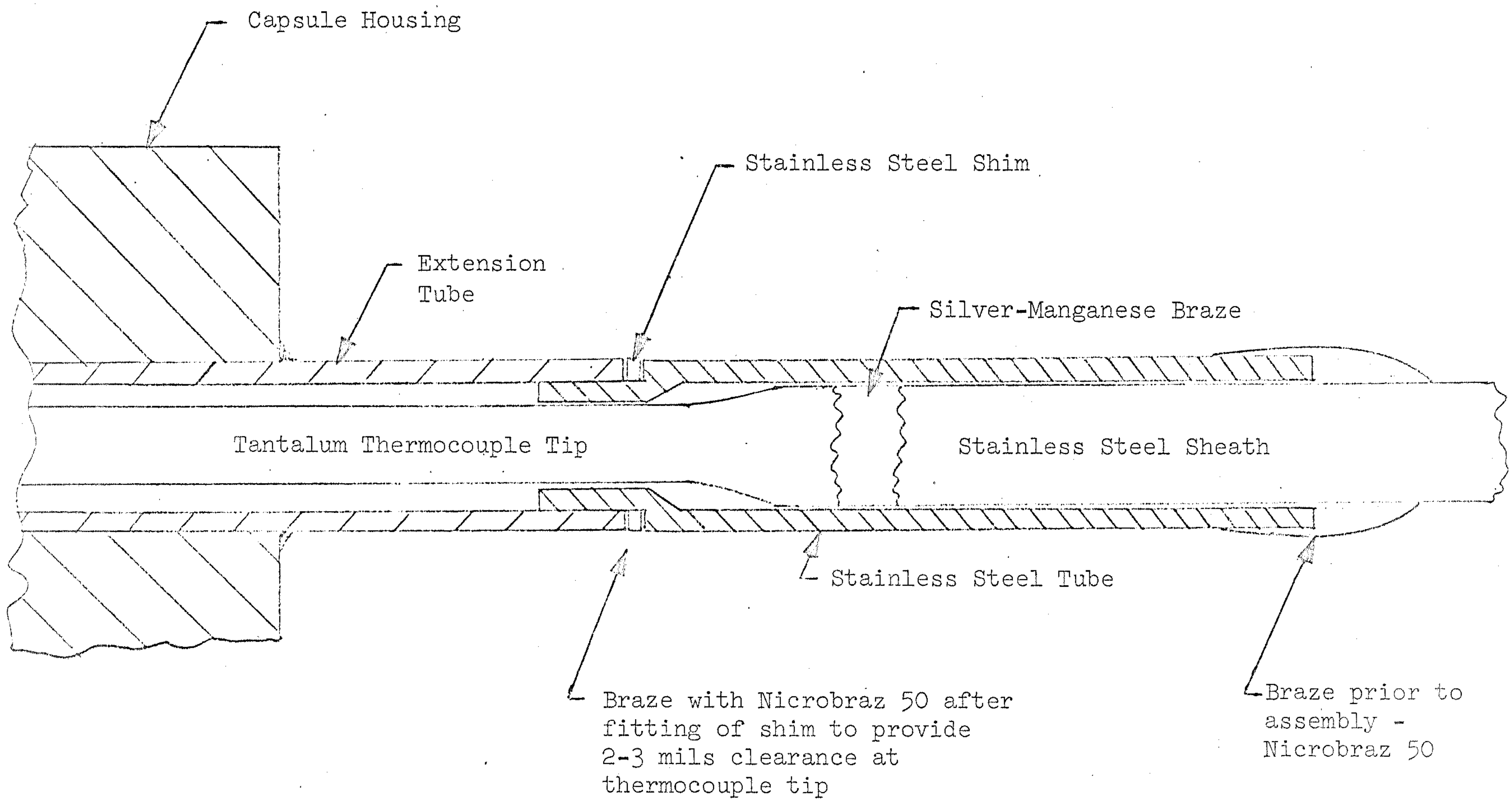


FIGURE 4. THERMOCOUPLE POSITIONING TECHNIQUE

be altered. Prior to brazing, the thermocouples were checked for continuity and grounding, and the weld on the tip of the thermocouple and the braze joint between the tantalum and stainless steel portions of the thermocouple were helium leak checked. The leak checking was accomplished by forcing helium gas through the length of the sheath at 50-60 psi for a minimum of 1 hr. Discarded sheaths had been checked to determine that the helium would pass the full length of the sheath at this pressure in less than 1 hr. Following brazing of the stainless steel extension to the thermocouple, this braze joint was also checked.

The thermocouples were then brazed into Assembly 3A using a defocused electron beam as a heat source. The thermocouples were positioned with stainless steel foil shims to maintain a 0.002- to 0.003-in. clearance between the tip of the thermocouple and the bottom of the well. It was anticipated that only one brazing operation would be required for the attachment of each thermocouple. However, additional cycles were necessary to provide a leak-tight joint. This was probably caused by the large heat sink provided by the capsule assembly. In most cases, it appeared that the braze material did not flow adequately on the extension tube extending from the capsule assembly. Good flow of the braze was noted in all cases on the stainless steel tube brazed onto the thermocouple sheath in a previous operation. The requirement of more than one brazing operation caused a decrease in the clearance between the tip of the thermocouple and the bottom of the well. Apparently, alloying of the liquid braze with the stainless steel components resulted in a reduction of the effective thickness of the shim materials. Measurements to determine the clearance between the tipe of the thermocouple and the bottom of the well were taken and are listed in the Appendix.

Rework of Assembly 4A

Although Assembly 4A appeared to be leak tight, a decision was made by NASA to remove Thermocouple P from the assembly and replace it. Metallographic examination of the braze joint area indicated that a leak through the Ag-Mn braze could likely occur. Small holes were drilled into the other three thermocouple well extensions and helium forced into the sheath under pressure. Leaks were noted in all three thermocouples. These were also removed from the assembly. Leak paths were drilled into each thermocouple well to provide an atmosphere in the well during operation. This was accomplished by drilling a hole into each well parallel to the top surface of the capsule housing and then drilling an intersecting hole through the capsule housing into the cavity between the two containment vessel assemblies. The exposed holes on the exterior surface were sealed by TIG welding.

The procedures used for the brazing of the thermocouples into Assembly 4A were the same as those described above for Assembly 3A. Leak checking of the assembly showed that there were leaks on Thermocouples M and R at the braze joint of the thermocouple well extension to the capsule housing. This leak was directly above the leak hole to the thermocouple well which is 0.035 in. below the surface of the capsule housing. Brazing with a tungsten arc in an inert gas chamber was used as a means of attempting to seal these leaks. This approach did not prove satisfactory in sealing the leaks completely. Although satisfactory brazes were obtained in accessible areas, the thermal stresses caused by brazing in this manner appeared to cause cracking of the braze in areas that could not be reached with the TIG unit.

Additional work was authorized to rework the assembly. The plan for this work involved the removal of the thermocouples, conterboring of the capsule housing, and welding of an adapter plate containing the outlet tube and thermocouple well extensions into the counterbored housing. These procedures are shown in Figure 5. This technique assures an atmosphere in the thermocouple wells. In Figure 6 is shown the method used for brazing of the thermocouples to the housing. This procedure was modified slightly from that used previously to remove the positioning shims from the braze area so that dimensional changes in the clearance between the tip of the thermocouple and the bottom of the well would be minimized. The electrical continuity of the thermocouples and leak tightness of the braze joints were checked in the same manner as that described for Assembly 3A. The pertinent information concerning this assembly is given in the Appendix.

Final Quality Control Procedures for Assemblies 3A and 4A

After brazing of the assemblies had been completed, the electrical continuity and grounding of the thermocouples on both assemblies were verified. The capsule housings were then subjected to ultrasonic inspection to determine if handling during the rework operations had been deleterious to the cadmium-to-stainless steel bonds. High-quality bonds were retained in both specimens as compared to calibration specimens having good bonds and variable bond quality. Two circumferentially oriented strips less than 1/8 in. wide gave a change in signal quality on both specimens. These were in the same identical location on both assemblies and are probably the result of a back reflection resulting from

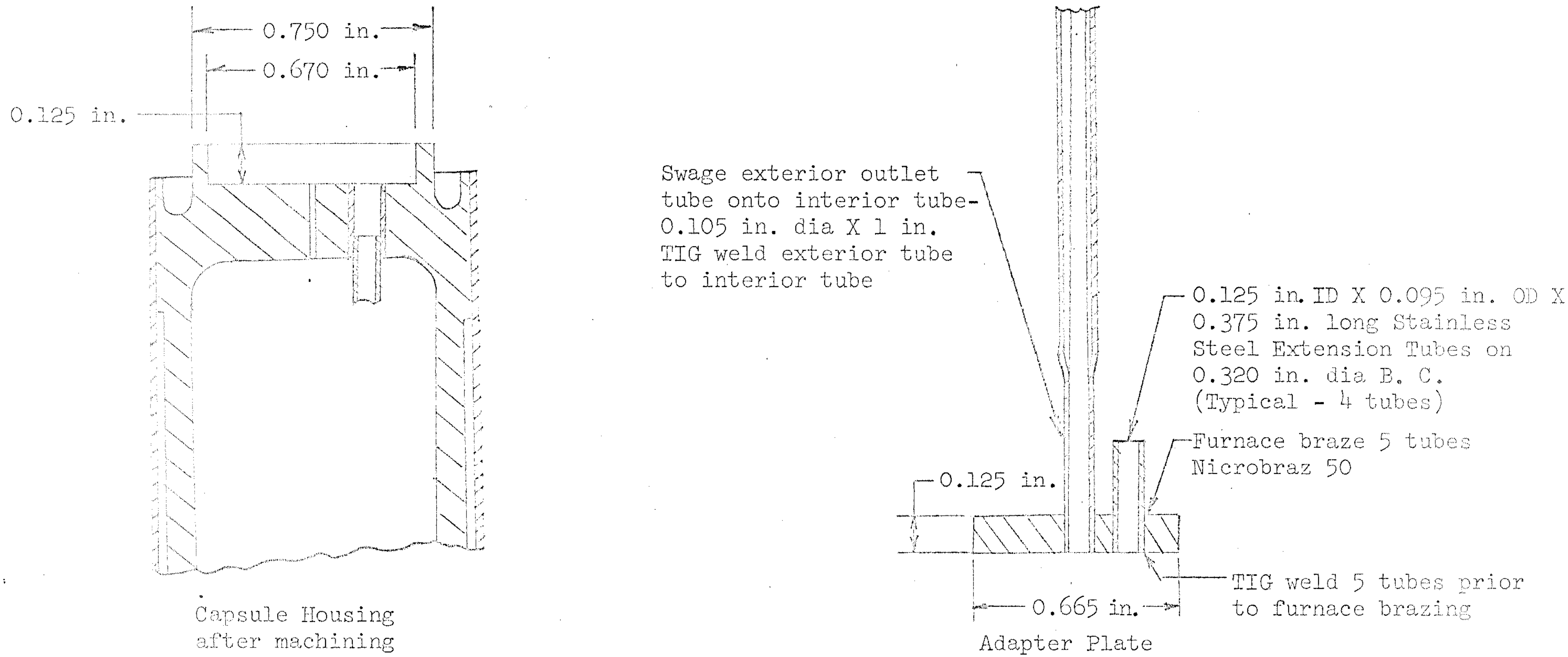


FIGURE 5. PROCEDURES USED IN REWORK OF ASSEMBLY 4A

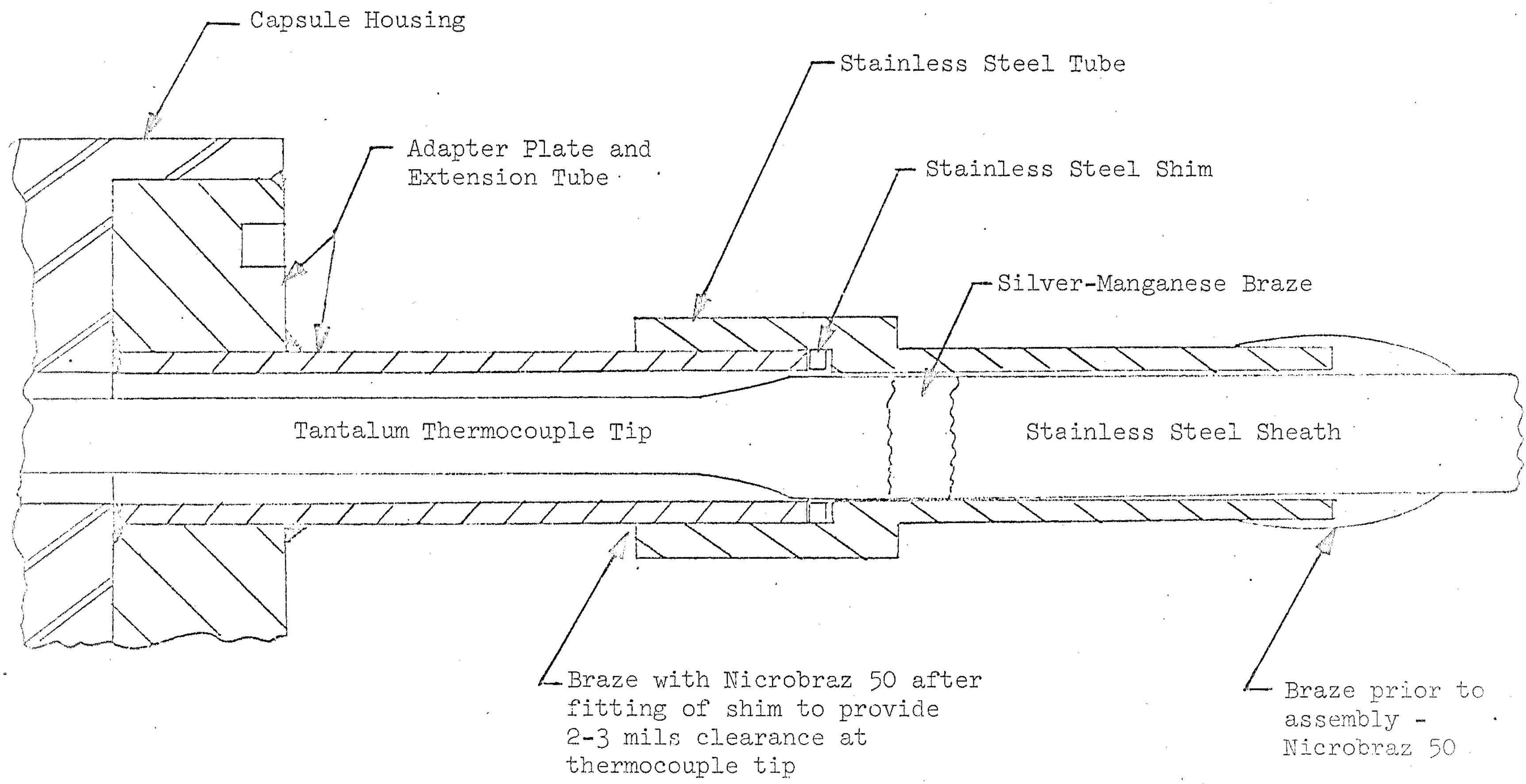


FIGURE 6. THERMOCOUPLE BRAZING TECHNIQUE USED ON ASSEMBLY 4A

the first containment assembly rather than a lack of bonding. The location of these areas is noted in the Appendix.

After ultrasonic inspection, the assemblies were proof tested at 500 psi internal helium pressure for 10 min. During this period, a plastic bag was placed over the capsule housing and the braze joints. The "sniffer" of the helium leak detector was also inserted into the bag, the bag volume reduced as much as possible, and the open end of the bag taped to the "sniffer" and the stainless steel tubes extending out of the capsule housing. During the 10-min period, no indication of leakage was detected on either assembly. Both assemblies were then evacuated and backfilled with helium to a pressure of one atmosphere. The inlet and outlet tube ends were closed by crimping and the ends TIG welded.

Any discolored areas on or near weld and braze zones were cleaned with an abrasive pencil. Alumina was used as the abrasive and was carried in an air stream. The assemblies were then cleaned with solvent, passivated, rinsed twice in deionized water, and dried. The capsule housing was placed in a double plastic bag, and the tubes were protected by Tygon tubing. An attempt was made to seal the open ends of the thermocouple sheaths with Tygon that had a hole pierced in it with a scribe. These thermocouples would still contain helium from previous leak checking, and the ends would require sealing during the final leak check. Each assembly was then placed in a tube and the tube evacuated by a helium leak detector. A large leak was noted on each assembly. Since the proof test had shown no leaks at high pressure, the leaks were probably from the exposed end of the thermocouples. To verify this, the thermocouples and the inlet and outlet tubes were pushed through a rubber stopper so that the thermocouple ends would be outside the chamber evacuated by the leak detector. No leaks were detected on either assembly using this approach. The welded ends of the inlet and outlet tubes for each assembly were individually checked and were found to be leak tight. It was, therefore, concluded that the helium detected when checking the complete assembly was from the exposed end of the thermocouple tubes even though an attempt had been made to seal these.

Following leak checking, the capsule housing assemblies were packed and delivered to the NASA-Lewis Research Center on January 4, 1968. Photographs of the completed assemblies are shown in Figures 7 and 8. This concluded the experimental work on this program.

CONCLUSIONS AND RECOMMENDATIONS

As a result of the research effort on this program, the following goals were achieved.

(1) A procedure was developed for obtaining satisfactory cadmium-to-stainless steel bonds. Shrink fitting of the tubular components to be bonded combined with gas-pressure bonding provide a capsule housing assembly meeting the design requirements.

(2) Ultrasonic inspection techniques were developed for evaluating bond quality of the cadmium-to-stainless steel bonds obtained by gas-pressure bonding.

(3) Two capsule housings were assembled following the procedures developed during this program and were forwarded to NASA for irradiation testing.

Fabrication procedures were investigated and developed during this program that would permit bonding of the cadmium-to-stainless steel prior to

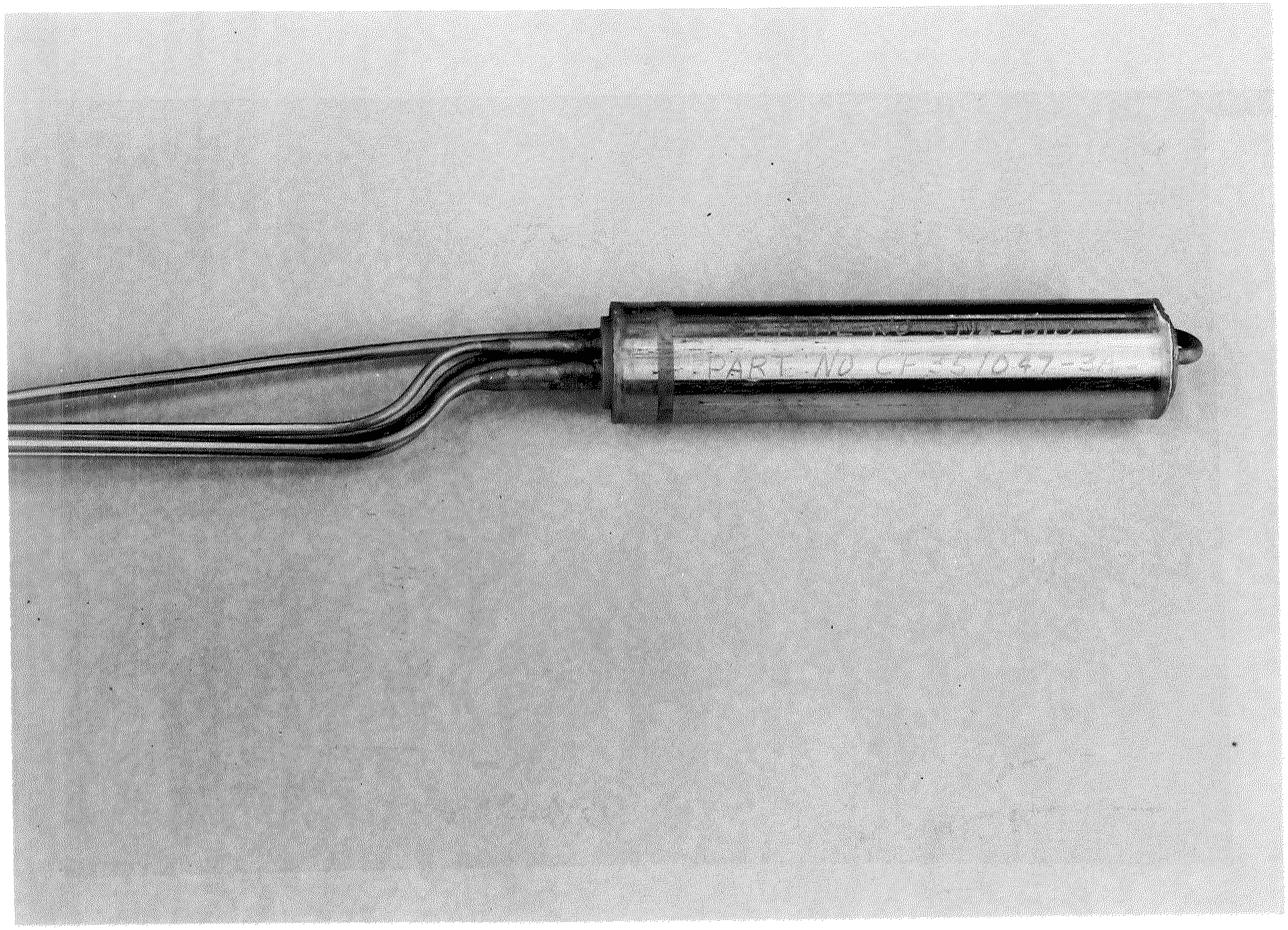


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FIGURE 7. CAPSULE HOUSING ASSEMBLY 3A

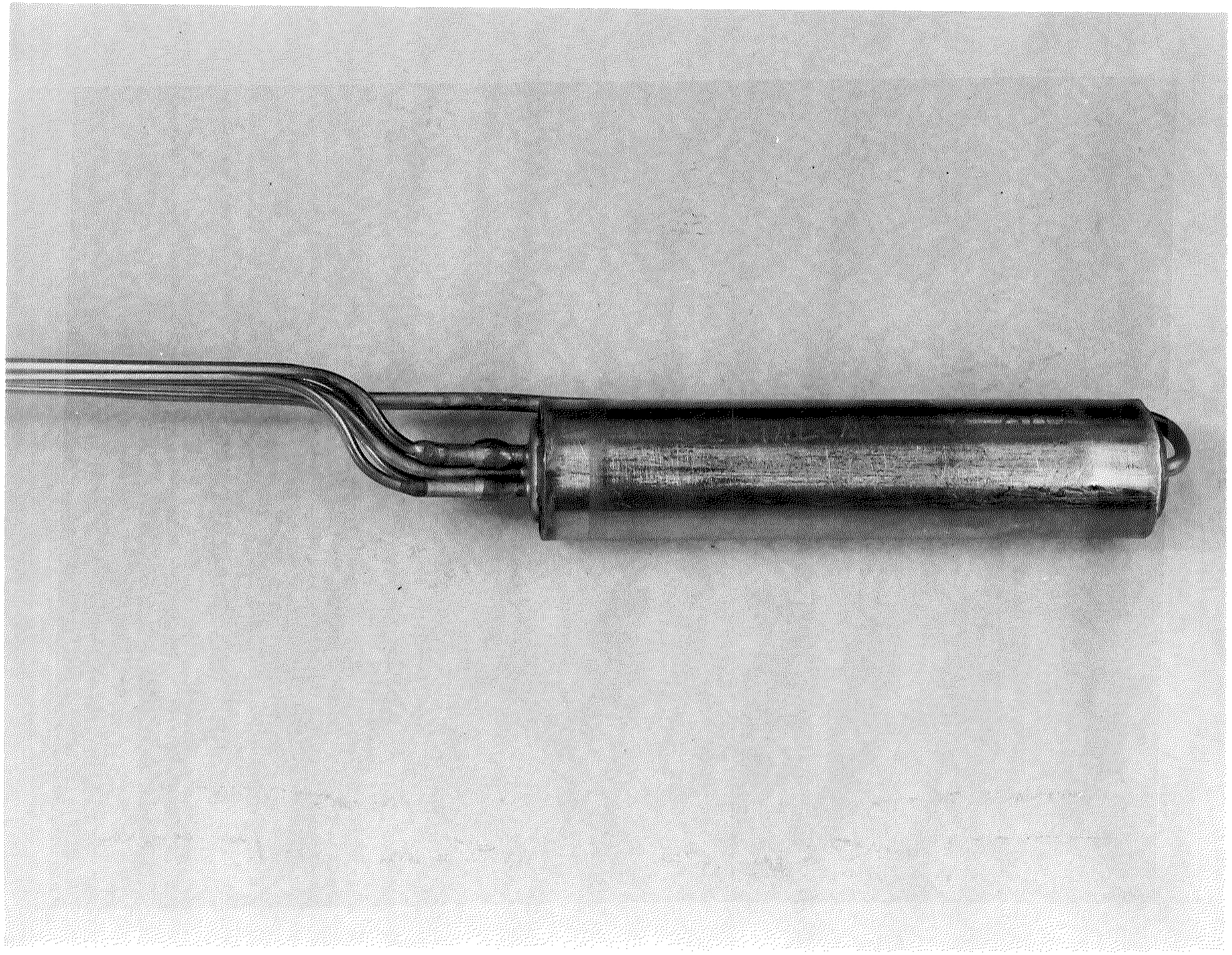

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FIGURE 8. CAPSULE HOUSING ASSEMBLY 4A

insertion of the first containment vessel into the capsule housing. It is recommended that in future designs these procedures be considered to minimize fabrication cost and eliminate low-temperature handling of the brazed assembly.

APPENDIX

DATA SHEETS FOR CAPSULE HOUSING ASSEMBLIES

DATA SHEET

Serial No. 304-010
Part No. CF 350147-3A

First Containment Vessel Data - Recorded in Appendix A
Final Report NASA Contract No. NAS 3-4255

Second Containment Vessel Data -

Thermocouple Location	Thermocouple Piece Number	Distance of Tip From Bottom of Well
M	16	2.7 mils
N	19	0.2 mils
P	17	5.0 mils
R (Long)	1	1.7 mils

Inside diameter of Part C3-1 0.7655 in.

Clearance between Parts F and B 0.077 in.

Ultrasonic indications denoting partial lack of bond or back reflection from interior (first containment vessel)

Indication No. 1

Location - 2-3/4 in. from bottom of assembly
Length - 1/8 in.; 180° circumferential

Indication No. 2

Location - 3-4/16 in. from bottom of assembly
Length - 3/32 in.; 360° circumferential

DATA SHEET

Serial No. 304-011
Part No. CF 350147-4A

First Containment Vessel Data - Recorded in Appendix A
Final Report NASA Contract No. NAS 3-4255

Second Containment Vessel Data -

Thermocouple Location	Thermocouple Piece Number	Distance of Tip From Bottom of Well
M	47	1.8 mils
N	33	3.6 mils
P (Long)	34	2.4 mils
R	42	7.9 mils

Inside diameter of Part C1-1 0.7660 in.

Clearance between Parts F and B 0.081 in.

Ultrasonic indications denoting partial lack of bond or back reflection from interior (first containment vessel)

Indication No. 1

Location - 2-3/4 in. from bottom of assembly
Length - 1/8 in.; 180° circumferential

Indication No. 2

Location - 3-5/16 in. from bottom of assembly
Length - 3/32 in.; 360° circumferential