APPENDIX C

REPORT OF MANUFACTURING AND TEST PANEL

CONTENTS

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PART C1

TASK ASSIGNMENT AND IMPLEMENTATION

Panel 2 was assigned the responsibility of reviewing manufacturing and testing associated with spacecraft equipment involved in the flight failure as determined from the review of the flight data and the analysis of the design. In particular, the Panel was to examine discrepancies noted during the fabrication, assembly, and test of components of the oxygen portion of the cryogenic gas storage system within the service module in order to determine any correlations between such preflight discrepancies and the actual inflight events.

Members of the Panel observed actual assembly of an oxygen tank and the oxygen shelf at various stages of assembly at the contractor facilities and reviewed documentation relating to the course of Apollo 13 equipment from manufacturing through test to launch. In addition, the Panel reviewed parts and material qualification data, inspection reports, reliability and quality control records, and preflight test and checkout procedures and results. Throughout the course of its review, Panel 2 concentrated on determining whether manufacturing or test procedures could adversely affect reliable conduct of flight. The steps in the manufacturing and testing of the suspected components were studied so as to evaluate various equipment acceptance procedures. Finally, the Panel attempted to relate observed flight events back to individual points in the manufacturing and testing process in order to determine if any correlation was probable.

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PART C2

ORGANIZATION

Panel 2 was chaired by Mr. H. M. Schurmeier, Jet Propulsion Laboratory, and the Board Monitor was Dr. J. F. Clark, Goddard Space Flight Center. Panel members were:

Mr. E. F. Baehr, Lewis Research Center
Mr. K. L. Heimburg, Marshall Space Flight Center
Mr. B. T. Morris, Jet Propulsion Laboratory

Specific assignments covering such areas as subsystem testing, fabrication process, and reliability and quality assurance were given to each Panel Member. In reaching Panel conclusions, however, all Members participated in the weighing and evaluation of data.

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PART C3

SUMMARY

The basic tank provides a thermally isolated pressure vessel structure that is relatively straightforward to manufacture. The manufacturing process has reasonable controls and provides tanks of high structural quality.

The manufacture of the internally mounted equipment is somewhat more complex because of the large number of parts that are required to make these assemblies. The careful use of jigs, fixtures, and the detailed Manufacturing Operations Procedures (MOP) adequately controls these steps and provides hardware fully meeting the structural design requirements as stated on the engineering drawings.

The most noteworthy manufacturability shortcoming of the design is the routing of the wires from the electrical devices within the tank. The passageways are small, adjacent metal corners are relatively sharp, and the condition of the insulation cannot be inspected after assembly. The assembly process is very difficult and even though detailed MOP's are provided and the technicians are skilled and experienced in these operations, the resultant product is of questionable quality because of the many opportunities to damage the insulation on the wires. Even in the assembled condition, the wires can be damaged because of the lack of support and restraint and the exposure to turbulent fluid during tanking, detanking, and purging operations.

Another notable shortcoming of the design is the very loose tolerances specified for the tank fill tube connecting parts. The tolerance range permitted by the engineering drawings can result in a fill tube assembly that can fall out of place if the parts are at or near the low tolerance limits. The parts cannot be assembled if their size averages much larger than nominal. Even with all parts of the fill tube assembly near the nominal sizes specified, adequate diametral clearance exists for a sizable gas leakage path.

The Globe Industries, Inc., fan motors have had a history of numerous problems. Many design changes were introduced to overcome these problems. The most prevalent problem was dielectric breakdown within the stator windings. Process changes and the addition of 300 volts rms phase-to-phase dielectric tests during stator assembly greatly reduced the incidence rate of this problem.

The standard acceptance procedures adequately cover all functional requirements for normal flight use but do not check the ability of the heater thermostats (thermostatic switches) to function under load,

nor do they state a requirement for proper functioning of the fill tube assembly, which must function as a dip tube during detanking operations.

The manufacturing history of tank no. 2 of Service Module 109 (10024XTA0008) before delivery from Beech was unusual only to the extent that the tank was reworked twice after initial closure, once to replace a heater tube assembly including both motor fans and once to replace pinch-off tube assemblies used in evacuation of the annulus volume between the tank shells.

The test history was unusual only to the extent that the high but acceptable heat leak characteristic caused months of delay in tank acceptance. No direct evidence of any particular characteristic of this tank at delivery from Beech, as distinguished from any other Block II oxygen tank, was found that would correlate with the Apollo 13 flight accident.

The normal procedure at the conclusion of the heat leak tests at Beech Aircraft Corporation, Boulder, Colorado, calls for expelling the last 25 pounds of the remaining liquid oxygen through the "fill" line by applying pressure to the vent line with gaseous nitrogen. Although the tank assembly is on a weighing system which has a resolution of 0.3 pound, and the procedure calls for continuing the application of vent line pressure until both the weighing system and quantity probe indicate the tank is empty, no data were recorded that verify that remaining oxygen was expelled as a liquid. At the time no one indicated that the response of the tank to the procedures was anything but normal, and today careful review of existing data, discussions with the responsible Beech Aircraft and North American Rockwell personnel, and a special test at Beech Aircraft indicates that the detanking of the 0008 tank was most probably normal.

The manufacturing and test procedures and activities for integrating the oxygen storage tanks into the service module were thoroughly detailed and closely monitored with respect to procedures. They involved checkouts with dry gas only, until cryogenic oxygen reaches the tanks during the countdown demonstration test (CDDT) at Kennedy Space Center (KSC) a few weeks before launch. Between the tank acceptance and CDDT only pressure vessel integrity and electrically observable phenomena of the inner tank elements are tested. No tests are performed to check the ability of the thermostats to interrupt either the spacecraft-supplied heater power (about 2.8 amps at 28 V dc) or the GSE power (about 6 amps at 65 V dc).

In August 1968, oxygen shelf assemblies at North American Rockwell (NR), Downey, were scheduled to be modified to add potting to the dc-to-dc converters of oxygen tank vac-ion pumps for electromagnetic interference prevention. During factory procedures with the oxygen shelf assembly incorporating tank 10024XTA0008 in the tank no. 2 position in Service Module 106 at NR, Downey, a handling fixture incident (initiated by failure to remove an unnoticed shelf bolt) subjected this tank to unexpected jolts. These included the apparent shelf damaging contact of the tank with the fuel cell shelf and drop of the tank with the shelf to the normal oxygen mounts. Such elements as the fill tube segments appear vulnerable to this incident. No record of investigation into the internal condition of the tank other than pressure and electrical circuit test could be found. Manufacturing and test records do not show engineering assistance related to conditions internal to the oxygen storage tank.

Service Module 106 was promptly repaired and fitted with a different oxygen shelf already modified (ultimately it flew as Apollo 10). The tank and the oxygen shelf now under review were re-inspected and retested during the first 3 weeks of November 1968. They were then installed in Service Module 109 (used in the Apollo 13 flight). This service module was completed, tested, and checked out normally thereafter, so far as the oxygen system was concerned, and transported to KSC in mid-1969.

During integrated test and checkout at KSC, no major anomaly occurred until the tank-emptying phase of the CDDT, March 23, 1970. After this first cryogenic oxygen loading since February 1967, expulsion of liquid oxygen through the "fill" line under gas pressure applied through the vent line was not achieved. Evidence supporting the assumptions of leakage or dislodgment of the fill line segments (two Teflon elbows and one short Inconel tube) in the top of the quantity probe assembly within the oxygen tank was produced at KSC in the processes of emptying the tank.

Special methods used for emptying on March 27 and 28, 1970, and again on March 30, involved protracted operation of the tank heaters and fans for many hours and at maximum heater voltage. In conjunction with this heating, cyclic gas pressurization and blowdown was used to achieve rapid boiling to remove oxygen from the tank. Analyses of data taken during the early portion of these procedures confirm boiling as sufficient to detank the observed quantities.

These methods were not supported by previous comparable operations with any other Apollo CSM cryogenic oxygen storage tank. Thus it was not demonstrated separately that such operation could be accomplished without degradation or hazard in the subsequent flight use of the tank.

A review of all the evidence available indicates that this tank (at least the fill line segments) most probably arrived at the CDDT in a different condition than that in which it was last tested at Beech Aircraft Corporation.

Tests were conducted at the Manned Spacecraft Center to evaluate the effects of the sustained heater operation during the special detanking operation at KSC on March 27, 1970. These tests demonstrated that the thermostats would weld closed when they attempted to interrupt the 5.9 amps, 65 volts dc GSE power (a condition for which they were neither designed nor qualified) resulting in their failing to limit the temperature inside the tank. The tests also showed that with the heaters on continuously and as the cryogenic liquid boiled away, temperatures in the 700° to 1000° F range would exist on portions of the heater tube in contact with the motor wires. These temperatures severely damaged the Teflon insulation even in the nitrogen atmosphere of these tests. Small-scale tests subjecting Teflon insulated wires to 700° to 1000° F temperature oxygen atmosphere indicated even more severe damage to the Teflon insulation.

Therefore it is reasonable to conclude that the special detanking procedures employed on tank 0008 at KSC prior to launch of Apollo 13 severely damaged the insulation of the motor wiring inside the tank.

A more complete test is being conducted at Beech Aircraft, Boulder, Colorado, to simulate the special detanking operations used at KSC on March 27-28 and 30, 1970. This test will utilize a flight configuration tank, simulated KSC ground support equipment, and will be conducted using oxygen.

PART C-4

REVIEW AND ANALYSIS

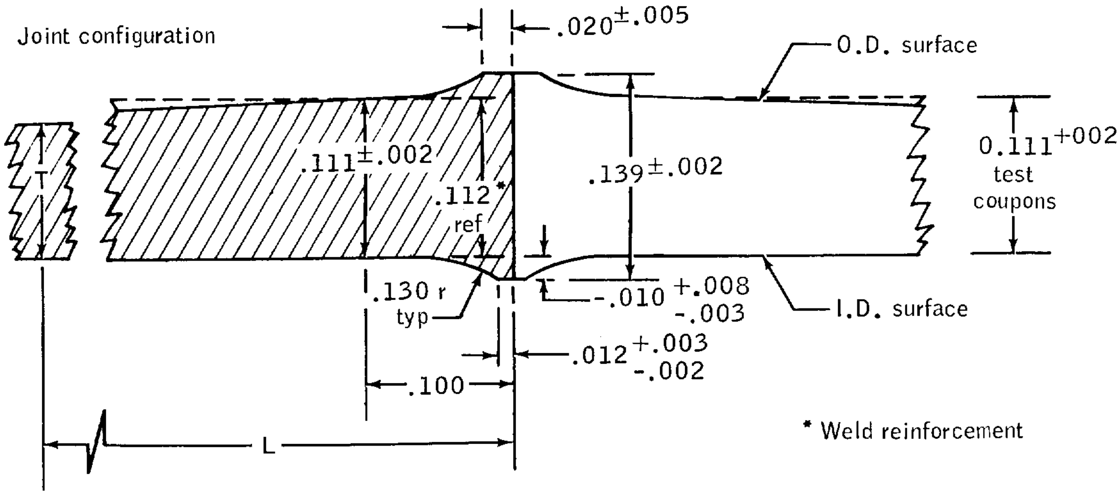
MANUFACTURE AND ACCEPTANCE TESTING OF THE CRYOGENIC OXYGEN STORAGE TANKS

The cryogenic oxygen storage tanks are manufactured by the Beech Aircraft Corporation, Boulder Division, located north of Boulder, Colorado. The tank consists of a spherical high-pressure inner vessel wrapped with multilayer insulation contained within a thin external metal vacuum jacket. Inside the pressure vessel are a heater and fan assembly (two heaters and two fans), a quantity measuring probe, and a temperature sensor. Many of the parts and subassemblies that comprise this tank are purchased by Beech from subcontractors and vendors located throughout the United States.

The detailed instructions for the manufacture and assembly of these tanks and their subassemblies at Beech are controlled by Manufacturing Operations Procedures (MOP). In addition to instructing the technicians, the MOP also calls out the presence and activities of the inspectors.

Summary of the Standard Tank Manufacturing Process

The inner pressure vessel is made from two forged hemispheres of Inconel 718 alloy. The rough-machined heat-treated forgings are supplied by the Cameron Iron Works, Houston, Texas. The physical, chemical, and metallurgical properties (X-ray, ultrasonic scan, and microstructure) of these forgings are tested and certified by Cameron. The Airite Division of Electrodata Corp., Los Angeles, California, does the final machining and electron beam welding. Prior to welding a very thorough inspection is made of each hemisphere. About 430 thickness checks are made to assure compliance to dimensional accuracy requirements. Each hemisphere is thoroughly X-rayed and dye-penetrant inspected for defects. The internal parts that support the heater probe assembly are made by Beech and supplied to Airite for installation prior to making the electron beam equatorial weld. A rather elaborate five-step welding process is used in making this equatorial weld (figs. C4-1 and C4-2). The first step is a series of tack welds. The second step is a seal weld of shallow penetration. The third step is a deep-penetration weld. The fourth step is a shallower and wider weld to blend surfaces. The fifth weld is called a cover pass which is still wider and shallower for final surface blending. The completed vessel is X-rayed and then pressure tested. A hydrostatic proof pressure of 1357 psig $^{+00}_{-35}$ is applied for 3 minutes using water. The volumetric expansion during the proof-pressure test is determined by measuring the weight increase of water contained within the test specimen. A leak test



P/M thickness L	T	Tank radius O.D.	Dimensions I.D.	
1.000	.084 ±.002	14.808 ref_{arc}	12.528 +005 -0	Sph rad
2.000	.067 ±.002	14.808 ref_{arc}	12.528 +005 -0	Sph rad
3.000	.059 + 004 - 000	12.587 ref_{arc}	12.528 +005 -0	Sph rad

Weld schedule (Electron beam weld)

Parameter	Pass sequence 1-tack	2-seal	3-pene.1	4-pene.2	5-cover
Voltage - Kv	80	80	115	95	85
Amperes - MA	1.5	1.5	6.0	4.0	3.0
Beam deflection - in.	0.012	0.012	.024/.036	.040/.080	0.110
Travel - in./min	18	⟶	⟶	⟶	⟶
Vacuum - mm hg	2×10^{-4}	⟶	⟶	⟶	⟶

Notes: (1) 0.002" gap, 0.003" offset (max typ)
(2) No weld repairs allowed
(3) Typical weld sequence shown on attached sketch

Figure C4-1.- Girth weld joint configuration and schedule.

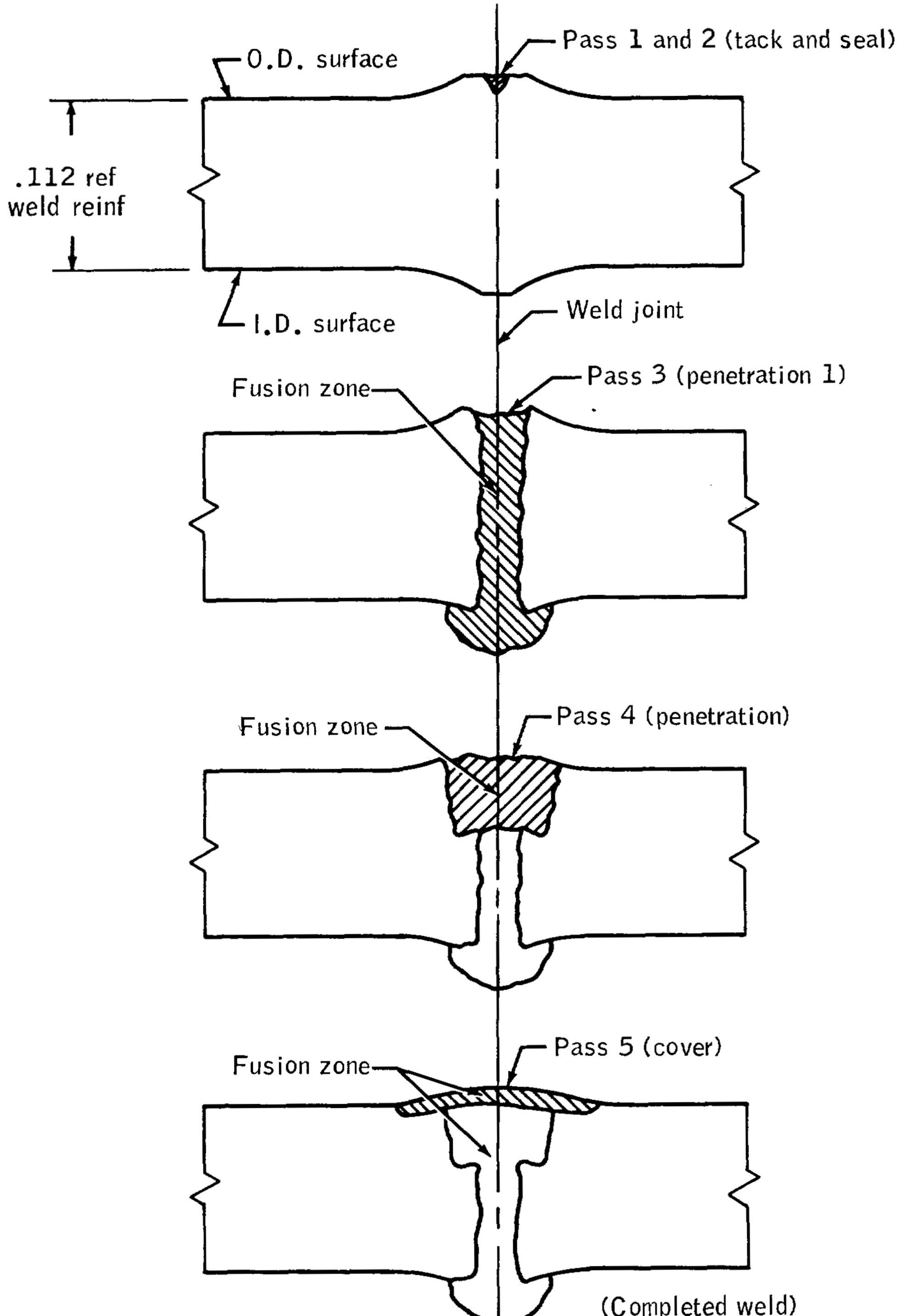


Figure C4-2.- Weld sequence.

is made at 925 psig ±15 using helium. These tests are performed by the Beech Test Department before acceptance. The completed vessels, along with substantiating data, are shipped to Beech for assembly.

The inner pressure vessel is cleaned for oxygen service and sealed in plastic. When scheduled for application of insulation, the vessel, the insulation, and the other necessary piece parts and supplies are moved to a small room annex to an area known as the Respectable Room. (The Respectable Room, its annexes, and the Ultra Clean Room together are known as the Apollo Assembly Area.)

All assembly operations performed in these rooms are in accord with standard clean room techniques, i.e., lint-free gowns, caps, and gloves. A simple entrance airlock has a motorized shoe brush and vacuum cleaner but the brushes are disabled so as not to rotate under motor power. There is no air scrub.

The insulation is applied to the inner vessel in gore panels, a layer at a time. The insulation consists of many layers of Dexiglas Insulation paper (C. H. Dextar & Son, Inc.), fiberglass, mats, aluminum foil, and aluminized Mylar. Each layer is carefully applied to the vessel, temporarily held in place with tape, trimmed for fit, and then finally held in place by thin nylon threads. After the threads are in place the tape is removed. The joints in succeeding layers are shifted so as to effectively block the flow of heat. The aluminum foil layers are checked with an ohmmeter to assure no electrical contact with inner vessel or adjacent foil layers. About halfway through the insulation process, a tube is installed which goes from the vacuum dome area to the equator, around the equator, and back to the dome area. This is called the vapor cool shield (VCS). (See fig. C4-3.)

After all the insulation is applied, the external metal jacket is installed. These parts are made by Chemtronics, Inc. The main upper and lower hemispheres are deep drawn and chem-milled. The equatorial flange is machined from a ring forging (fig. C4-4). All parts are made of Inconel 750 alloy. An assembly of the lower hemisphere and equatorial flange is made by Heli-arc welding. A shield is placed over the insulation in the region of the final closure weld between the lower hemisphere-flange assembly and the upper hemisphere shell. After these parts are positioned over the insulated pressure vessel, the circumferential weld to join them is made by the automatic Heli-arc welding process using argon gas for inerting the weld zone. The welds in the vacuum jacket are then X-ray inspected to insure integrity.

Figure C4-5 shows the major subassemblies required to complete the oxygen tank assembly. All components and piece parts required to build subassemblies are cleaned for liquid oxygen service, grouped as required

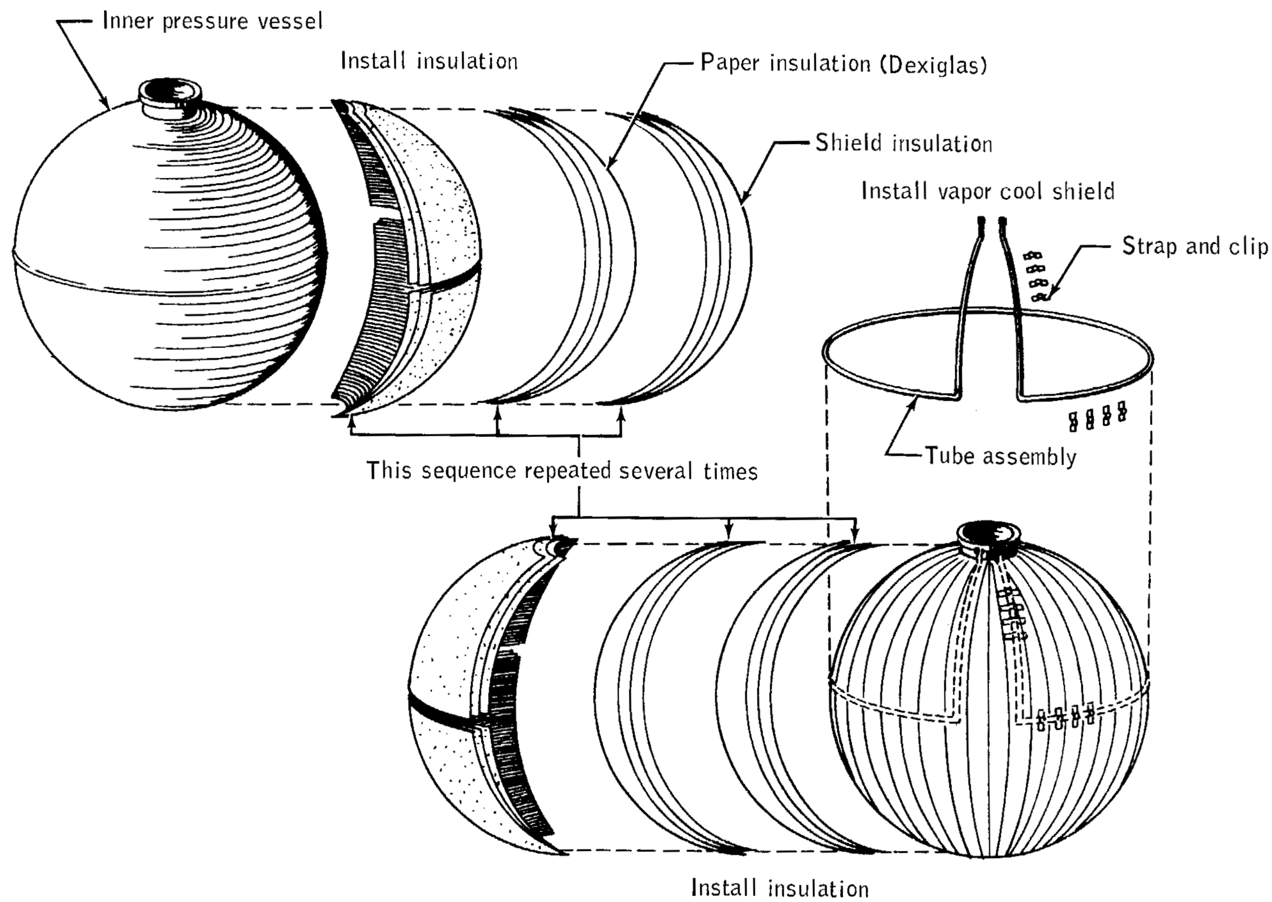


Figure C4-3.- Installation of insulation.

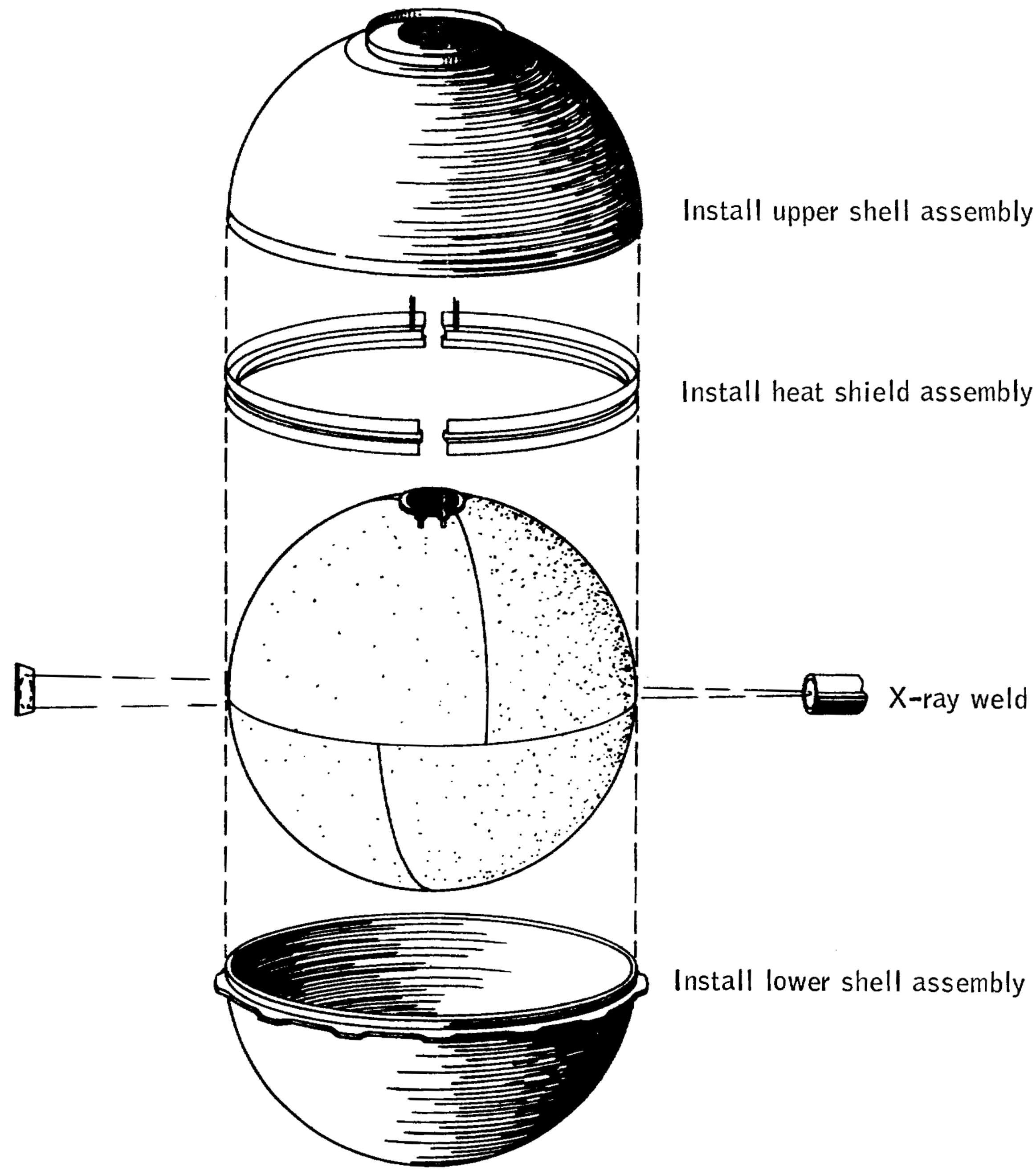


Figure C4-4.- Installation of vacuum jacket.

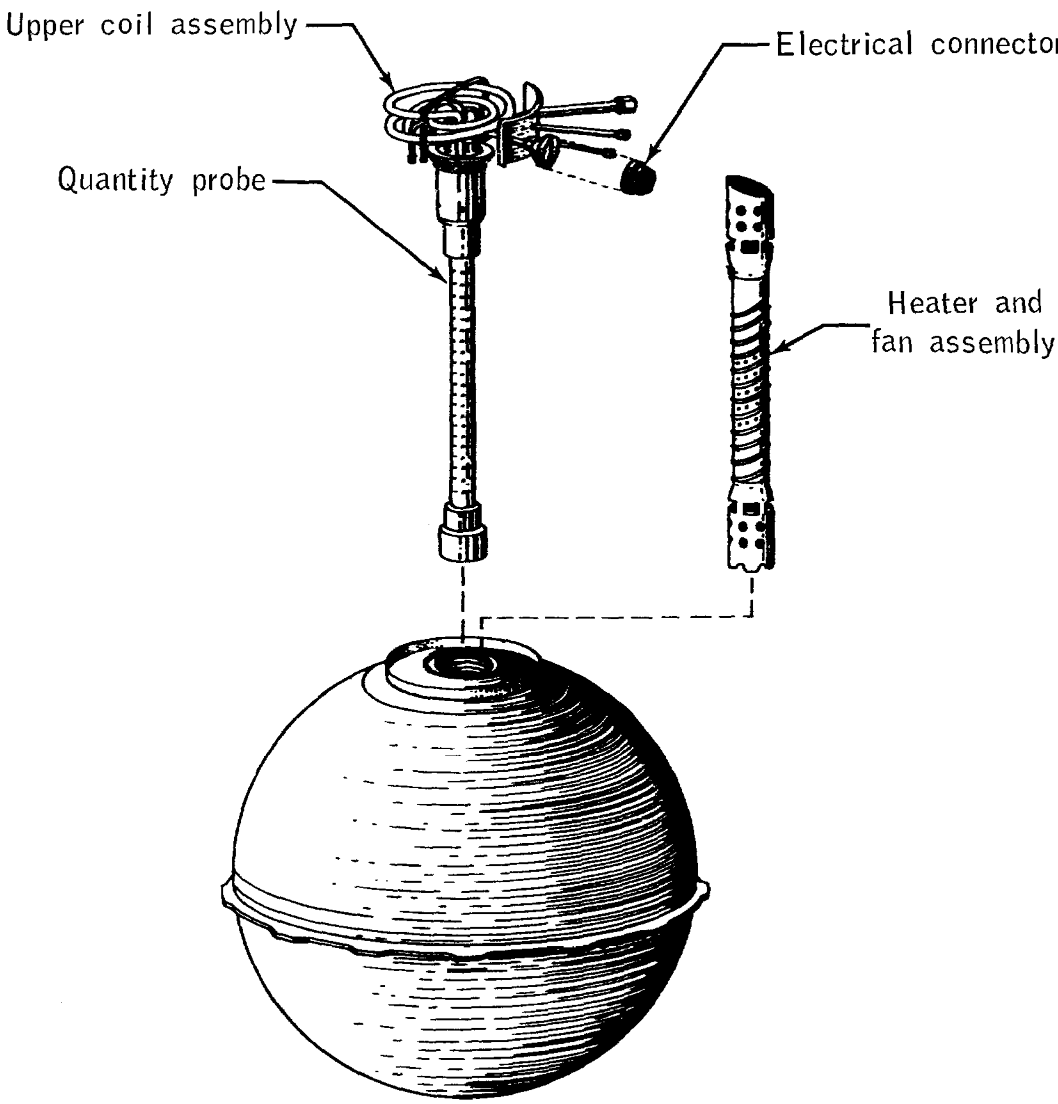


Figure C4-5.- Major subassemblies required for tank assembly.

for each subassembly (kitted), and sealed in a clear nylon plastic bag which is then sealed in a clear polyethylene bag. These kits are stored for the subassembly and assembly operations which are performed in various rooms of the Apollo Assembly Area.

The heater and fan assembly is made from numerous small parts welded, brazed, riveted, or bolted together (fig. C4-6). The first operation installs the lower pump nozzle assembly into the lower motor housing. These parts are positioned in a jig and then fusion welded in place. After this weld is X-rayed, the part is turned to trim the inside diameter and to assure roundness. The lower motor housing is then positioned and welded to the central tube. The weld zone is X-rayed and the entire assembly is pickled and passivated. The two helically preformed stainless-tube-encased nichrome heating elements are then slid in place. Before proceeding the heaters are tested for resistance and isolation from ground. The upper motor housing tube is then positioned and welded to the central heater tube. After this weld is X-rayed, the heaters are positioned and silver soldered in position. After the heater tube is thoroughly cleaned to remove any silver solder flux, the tube (conduit) that routes the wires from the lower motor past the heater elements is installed by riveting the two small clips to the inside of the central tube. Small aluminum shims are riveted to the inner surface of the heater tube to provide a flat surface for the mounting of the thermostats. The unit is then vacuum baked at 200° F to remove any moisture from the heater assembly. The resistance and insulation tests are again run to assure that the brazing has not damaged the heaters and that the units are thoroughly dry.

At this point the heater tube is ready for the installation of the thermostats. The thermostats are purchased from the Spencer Thermostat Division of Metals and Controls, Inc., Attleboro, Massachusetts. Each thermostat is subjected to detailed acceptance testing by Metals and Controls, Inc., and these data are supplied to Beech with the serialized switches. The acceptance testing consists of a 1000 V ac dielectric test for 1 minute, a visual check for workmanship, a dimensional check to drawing size callouts, a 5-minute soak in liquid nitrogen, the opening temperature, the closing temperature, a second 5-minute soak in liquid nitrogen, a recheck of the opening temperature, a recheck of the closing temperature, a leak test to check hermetic seal, a megohm test, the final inspection marking, a recording of number of cycles on the unit as shipped, the actual weight of unit, and visual packing and shipping inspection. Throughout all testing by Metal and Controls, the thermostats are checked by using 6.5 V ac and a small lamp drawing approximately 100 milliamps. Incoming inspection at Beech is limited to a visual examination.

The thermostats are inserted into the tube with their hook-type terminals extending to the outside of the heater tube and bolted in place. This heater tube assembly is then cleaned and bagged for future assembly operations.

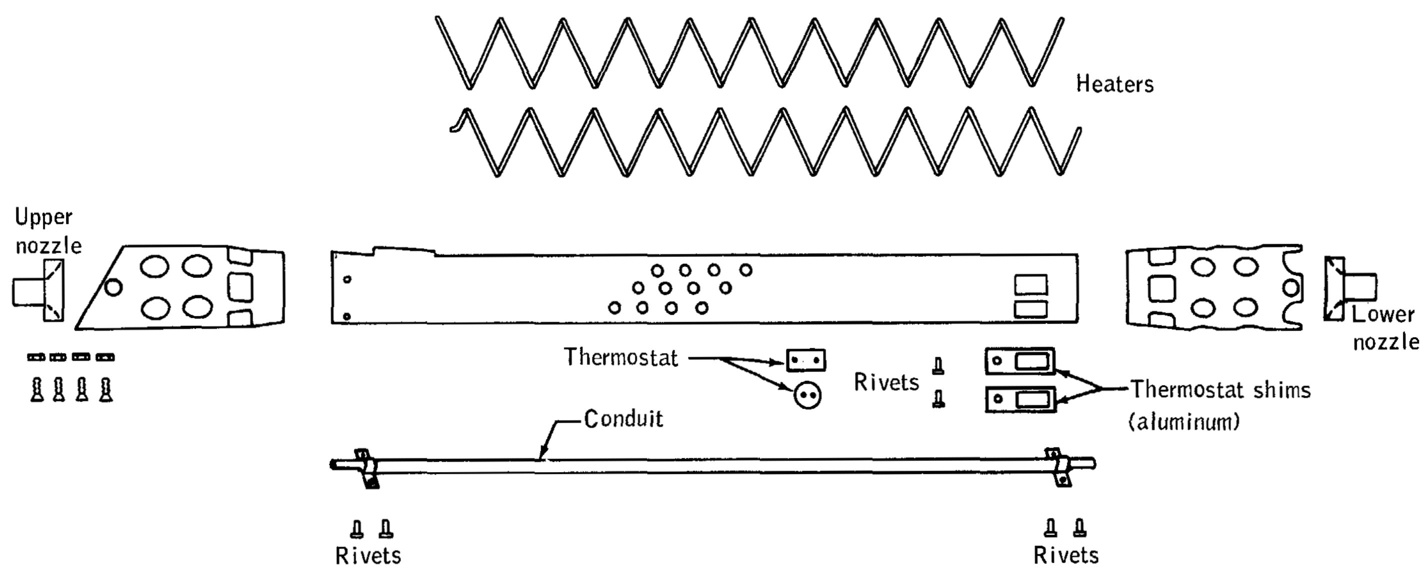


Figure C4-6.- Heater tube assembly.

The electric motor fans are purchased from Globe Industries, Inc. These motors go through a thorough acceptance test at Globe before delivery to Beech. In addition to the normal visual and mechanical inspection, the motors are functionally tested at both ambient and cryogenic conditions. A 1000 V dc dielectric strength test is applied between the windings and case. The isolation must be at least 2 megohms. The motor is then operated on 115 V ac 400 cycles, and the following characteristics are measured and recorded: (1) speed and current of motor when operating with a calibrated test fan, and (2) line current and total power both running and still. The motors are then operated in liquid nitrogen. These checks are limited to assuring that the motor starts and runs smoothly and that coastdown time is at least 30 seconds.

At Beech the normal visual incoming inspection was performed and then these parts were stored until ready to be incorporated into the heater and fan assembly.

The kits of parts and components required for the heater and fan assembly are moved to an annex room of the Respectable Area where this assembly operation is performed on a laminar flow bench. The necessary tools are cleaned and laid out for ease in the assembly process. An assembly aid is used to support the fan and heater tube in the horizontal position.

The lower electric motor is now installed. The electrical leads are provided by the motor supplier (four 26-gage nickel with Teflon insulation twisted 10 turns to the foot with a 2-inch-long Teflon sleeve adjacent to the motor) (fig. C4-7). These leads are routed parallel to the motor shaft through a shallow groove milled half in the motor end cap and half in the motor support tube (figs. C4-8 and C4-9). From this channel the wires are routed against the inner surface of the motor tube in the region of the impeller. The wires then emerge through a hole in the motor housing tube (ungrommeted). The motor is inserted in the end of the tube (fig. C4-10) and the motor end plate is installed. Shims are used as required under this motor end cap to provide 0.030-inch to 0.040-inch end clearance between the impeller and the nozzle. When the proper shims are selected and installed, the four end cap screws are torqued to the required value (fig. C4-11). The end cap is bolted to the support tube by four radial countersunk machine bolts, small segment-shaped shims, and self-locking nuts (all metal).

When the location of the lower motor is verified as having the correct impeller-to-nozzle clearance, the wire routing task continues. The wires travel axially about 2 inches (fig. C4-12) where they go inboard through a Teflon grommet into the inner conduit and travel the length of the heater section to a symmetrical location where they again emerge to the exterior through a Teflon grommet. A single insulated wire is used to pull the motor leads through this conduit route.

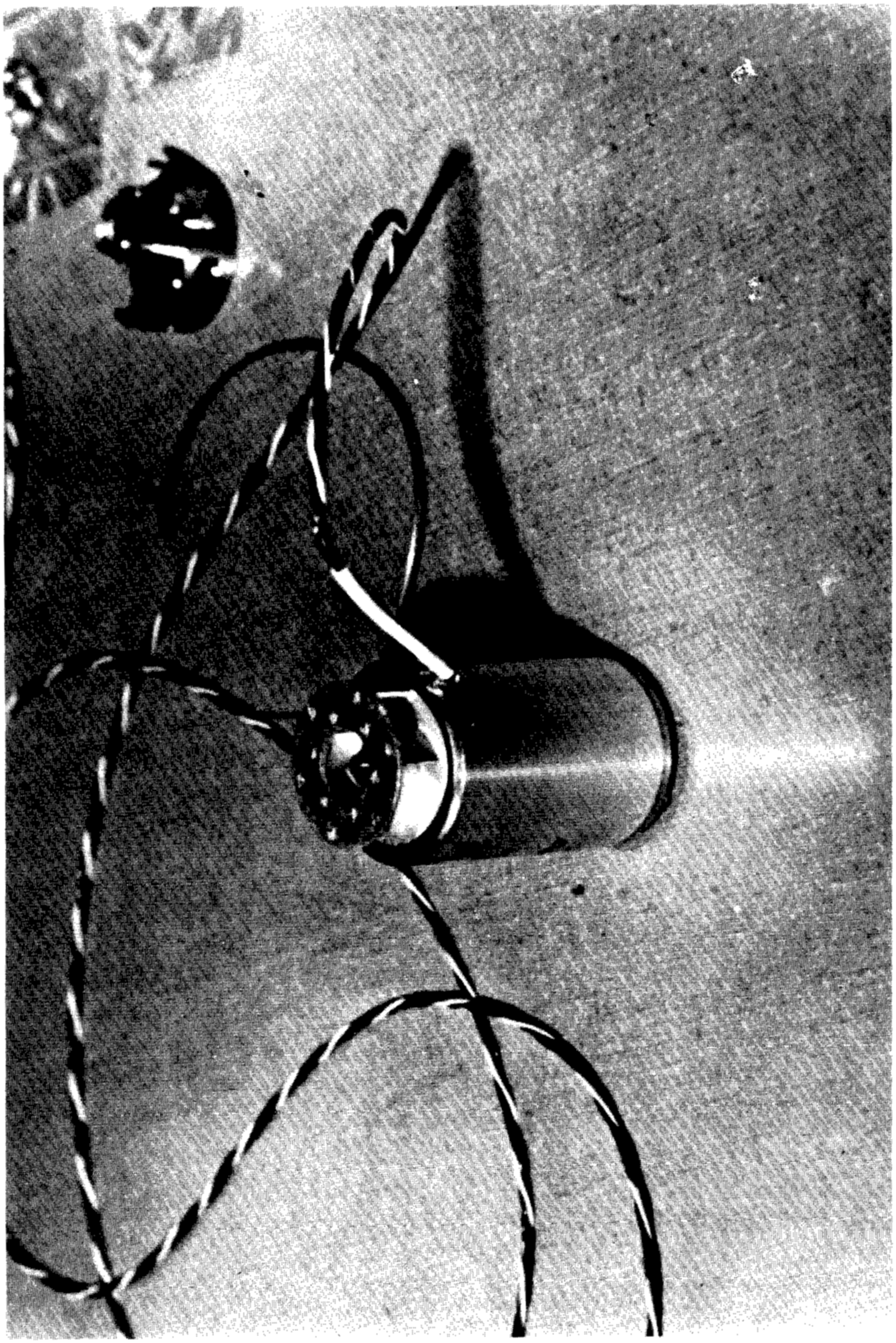


Figure C4-7.- Motor fan with long lead wires.

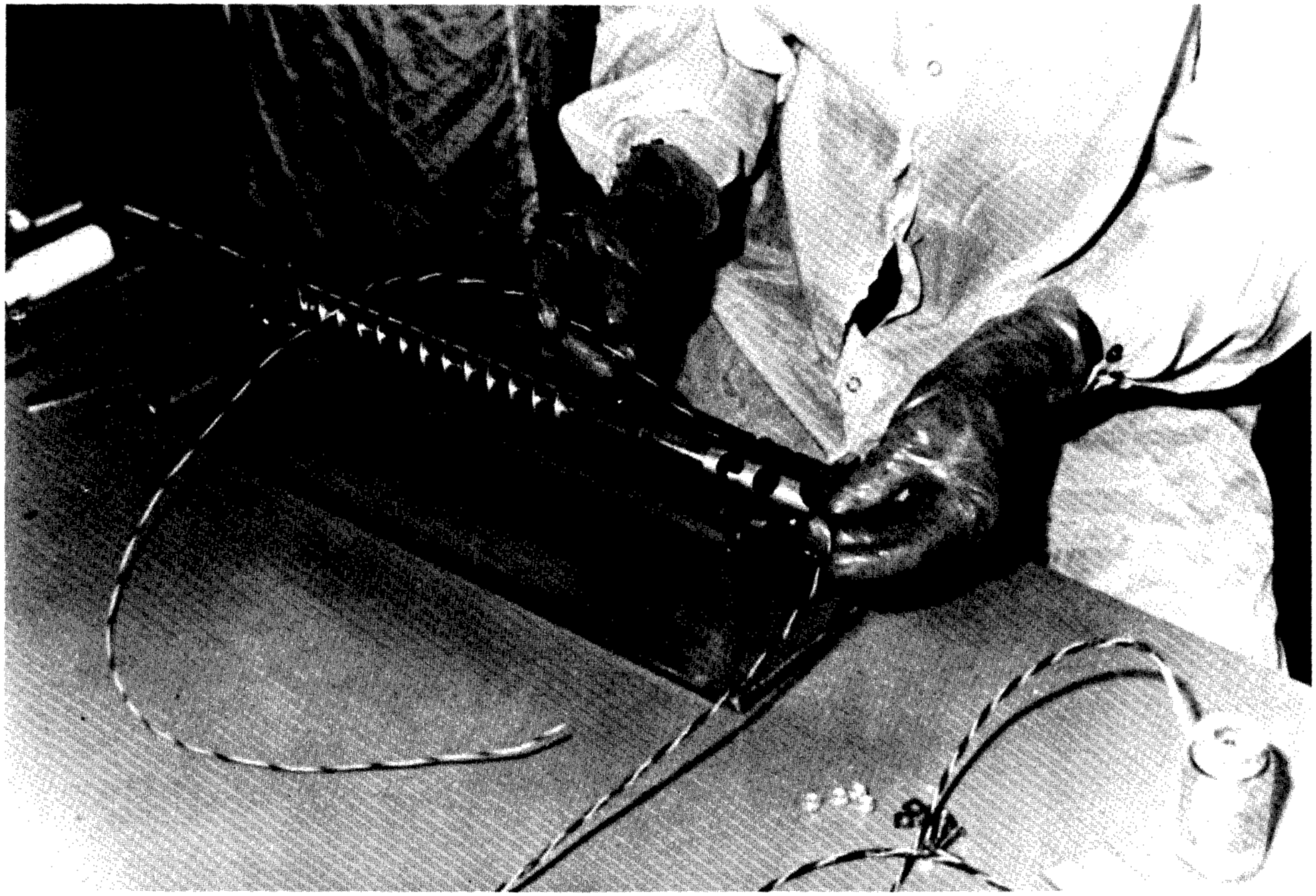


Figure C4-8.- Installing motor lead wires.

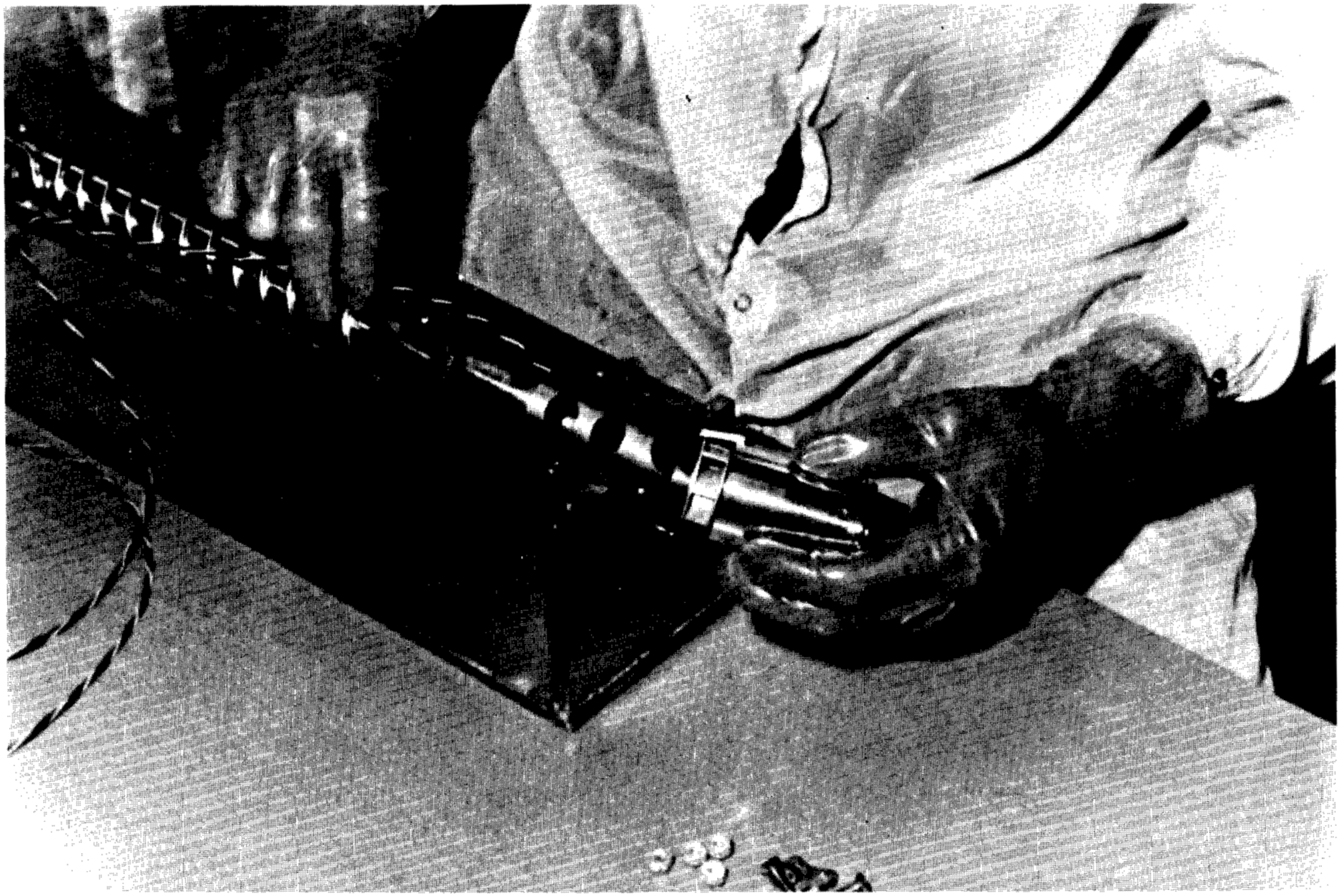


Figure C4-9.- Installing lower fan motor.

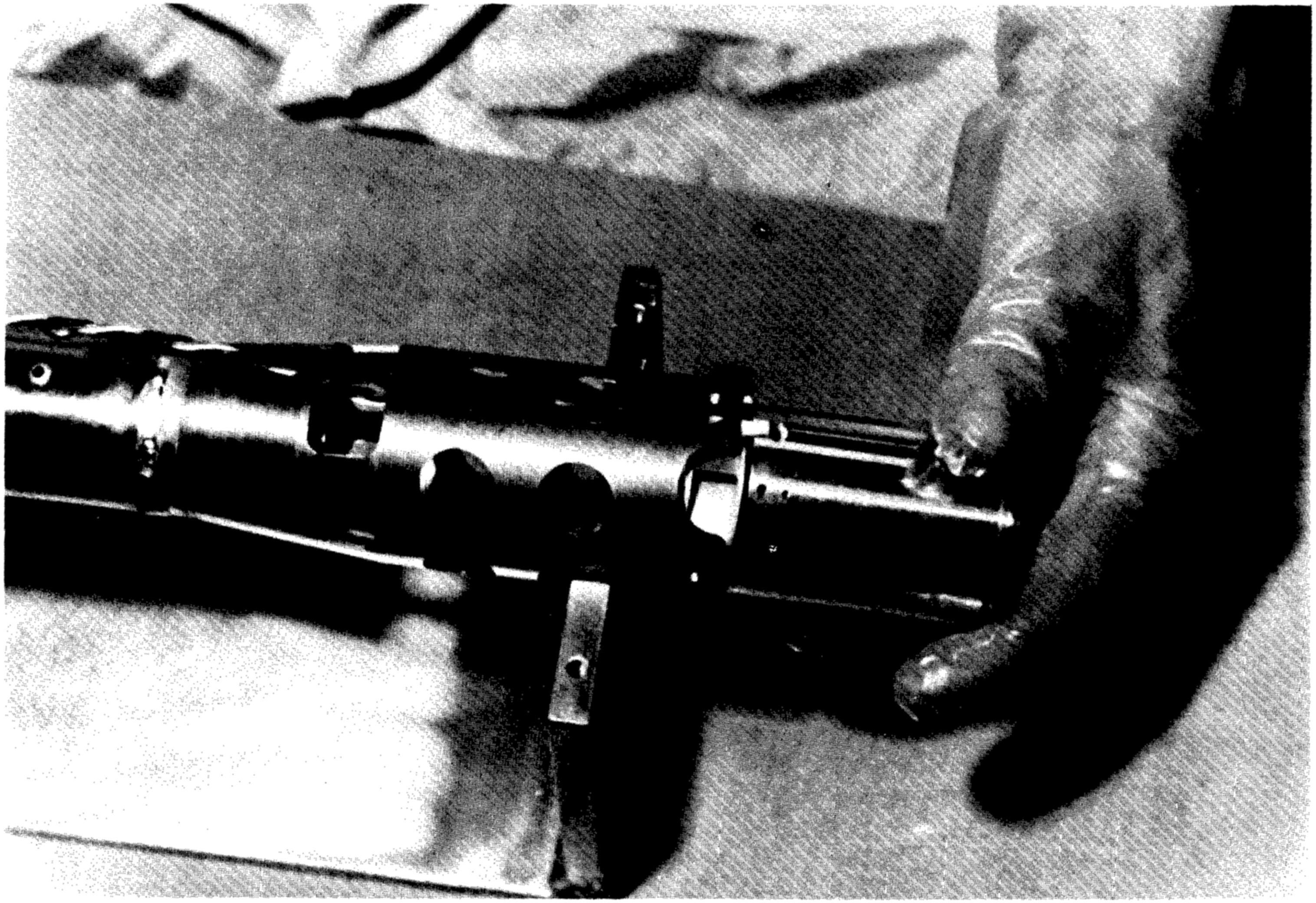


Figure C4-10.- Installing lower fan motor showing wire routing.

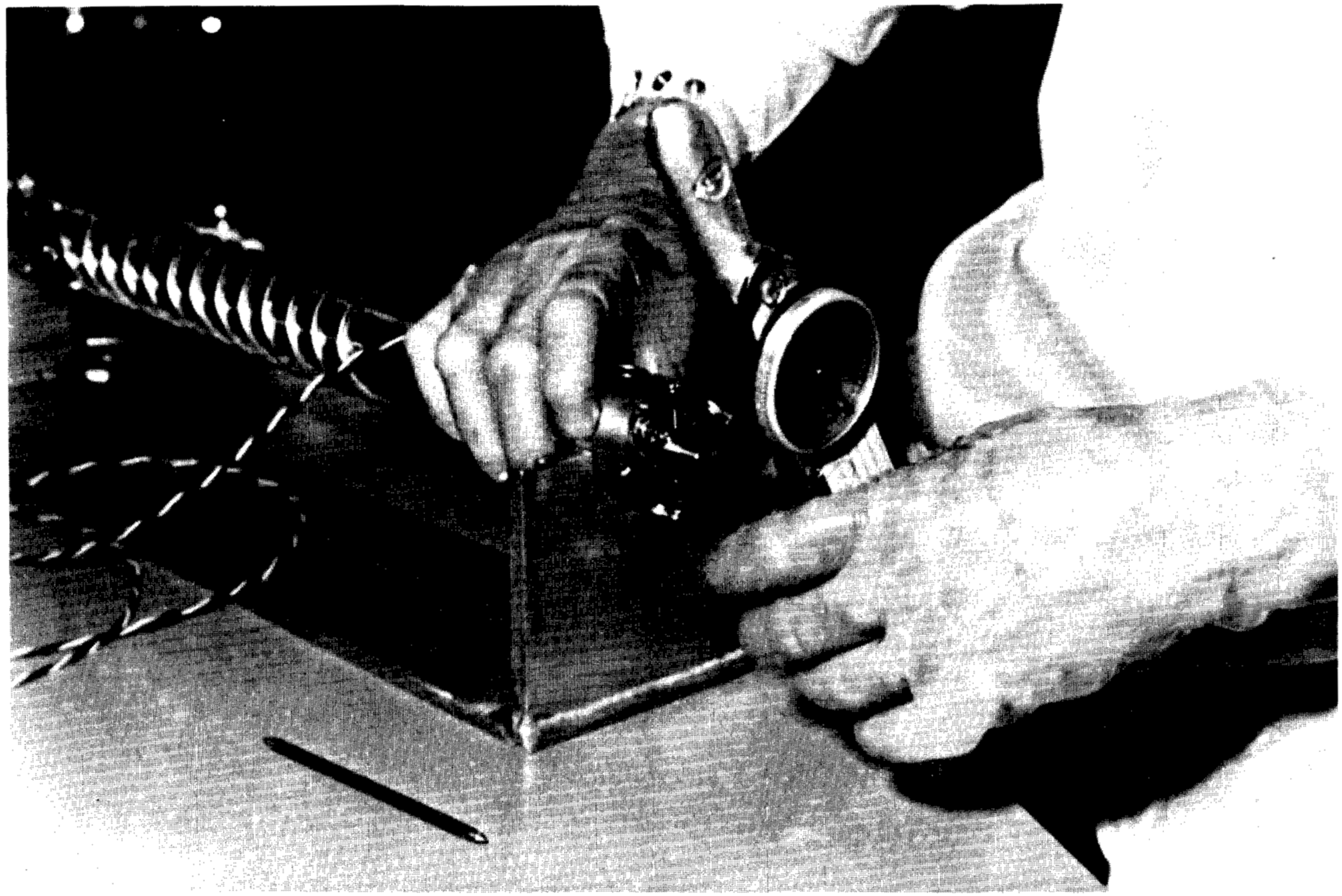


Figure C4-11.- Tightening the motor end cap bolts to establish the proper torque.

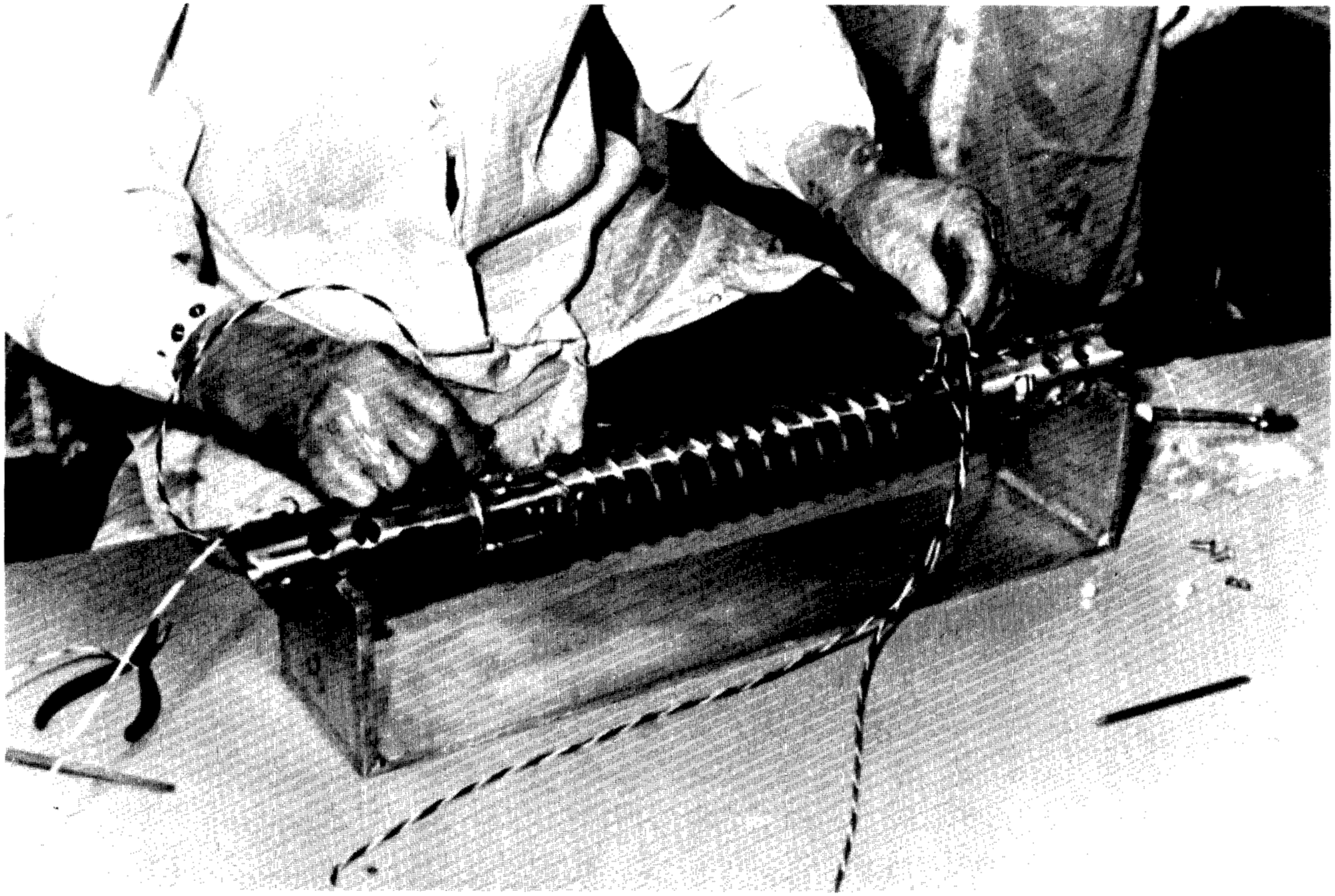


Figure C4-12.- Installing lower motor lead wires in heater conduit.

The installation of the upper motor follows the same general sequence except that once the leads emerge from the tube they do not reenter the heater tube but remain as a twisted bundle of four wires encased in a Teflon sleeve.

Next a small copper band is formed around the upper and lower motor wire bundles in the areas where the impellers of the fans are located to assure that the wires maintain the required clearance with the impellers (approximately 0.030 inch) (figs. C4-13 and C4-14). The ends of these bands are sweat soldered together to retain the wires. The motor leads external to the heater tube are then encased in Teflon shrink tubing. White tubing is used for the lower motor leads and clear tubing is used for the upper motor leads.

The leads are then installed for the heaters. One wire from each heater is soldered to its thermostat. The lead wires (20-gage silver-plated copper with Teflon insulation) are soldered, one to the other terminal of the thermostat and the other wire to the second lead of the nichrome heater element. Separate leads (four total; two for each heater) are provided to extend to the electrical connector fitted outside the dome at the top of the vacuum jacket. Again a cleaning operation is performed to remove any solder flux. Standard 60-percent tin and 40-percent lead solder is used for all electrical connections.

The entire heater and fan probe assembly is subjected to a detailed component acceptance test to assure proper operation. The unit is placed in a controllable temperature oven. Starting from about 100° F, the oven temperature is slowly lowered until the closing of each heater thermostat is noted by means of a Wheatstone bridge. While in this closed position, the resistance value of each heater element is measured and recorded. The oven temperature is then slowly raised to detect the opening temperature for each thermostat. With the unit removed from the oven, the resistance value of each motor winding is measured and recorded. The heaters and motors are subjected to a dielectric strength test at 500 V dc with a maximum allowable leakage current of 0.25 milliamps permitted. The insulation resistance of both heaters and both motors is measured and must indicate a minimum of 2 megohms isolation. The proper operation of the motors is verified in two vertical orientations at full voltage and at two vertical and one horizontal orientations at reduced voltage (80 ± 2 V ac). The time in tenths of hours and number of motor starts are recorded for each test sequence and this is added to the previous history for continuity. The entire assembly is then cleaned for liquid oxygen service, bagged, and stored for future use.

The upper coil assembly as shown on figure C4-5 consists of five coiled tubes to provide the necessary resistance in the heat flow path, an adapter to fit the tank neck, a seal-off plate for the side of the coil housing (vacuum dome), end fittings for the feed lines (that connect

Figure C4-13.- Inserted copper band to retain motor wires.

Figure C4-14.- Forming copper band to retain motor wires.

to the vapor cool shield), and a connector adapter fitting. These tubes are formed by a subcontractor in Denver. The material for all tubes is Inconel 750. All bending is performed using a flexible chain mandrel of Ampco bronze and Ucon lubricant (water soluble). The various piece parts are carefully cleaned and jigged for Heli-arc welding into an assembly. The supply line filter is installed and safety wired. The assembly is X-rayed, recleaned, and bagged for future use.

The quantity probe is a purchased item which is procured from Simmonds Precision complete with leads and temperature sensor installed with leads attached (fig. C4-15). This unit is made of two concentric aluminum tubes for the capacitance-type quantity (density) probe with Teflon spacer buttons located in drilled holes in the inner tube to provide centering action. The lower ends of the concentric tubes terminate in a glass-filled Teflon bushing. This bushing acts as a lower pilot support and also provides a nonconducting extension of the inner tube which is also utilized as a dip tube for the filling and detanking operations. The axial relationship of the inner and outer aluminum tubes is controlled by a single rivet installed through Teflon bushings near the upper end of the assembly.

The upper end of the outer aluminum tube is supported in a large glass-filled Teflon bushing which is riveted to an Inconel tube for final support to the tank adapter. This upper bushing has two axial holes to provide routing for the motor and heater leads. The temperature sensing element is mounted on the side of this bushing. Axially aligned pins through two 0.44-inch cross-drilled holes are used as junction points between the short leads from the temperature sensor and the 48-inch-long extension leads. Two 22-gage wires are used for each extension lead of the sensor (a total of four wires). The capacitance element leads consist of a shielded 20-gage wire for the inner tube and an unshielded 20-gage wire for the outer. Two channel-shaped clips are riveted to the upper ends of the aluminum tubes to solder the lead wires on. The quantity sensor leads are encased in a clear Teflon shrink sleeve. The temperature sensor leads are encased in a separate clear Teflon shrink sleeve. All solder joints are made with 60-percent tin, 40-percent lead solder.

After incoming inspection of this Simmonds-manufactured assembly verifies conformance to the purchase specifications, the unit is cleaned for liquid oxygen service, bagged, and stored for future use.

The parts required for the complete assembly of the quantity probe are then drawn from storage. The first operation is the installation of two insulated pull wires through the holes provided in the quantity probe to route the heater and motor leads. The quantity probe wires, temperature sensor wires, and two pull wires are pulled through the electrical conduit by first pushing a single wire through. All wires are attached to this pull wire to be pulled into the conduit (figs. C4-16 through C4-19). The

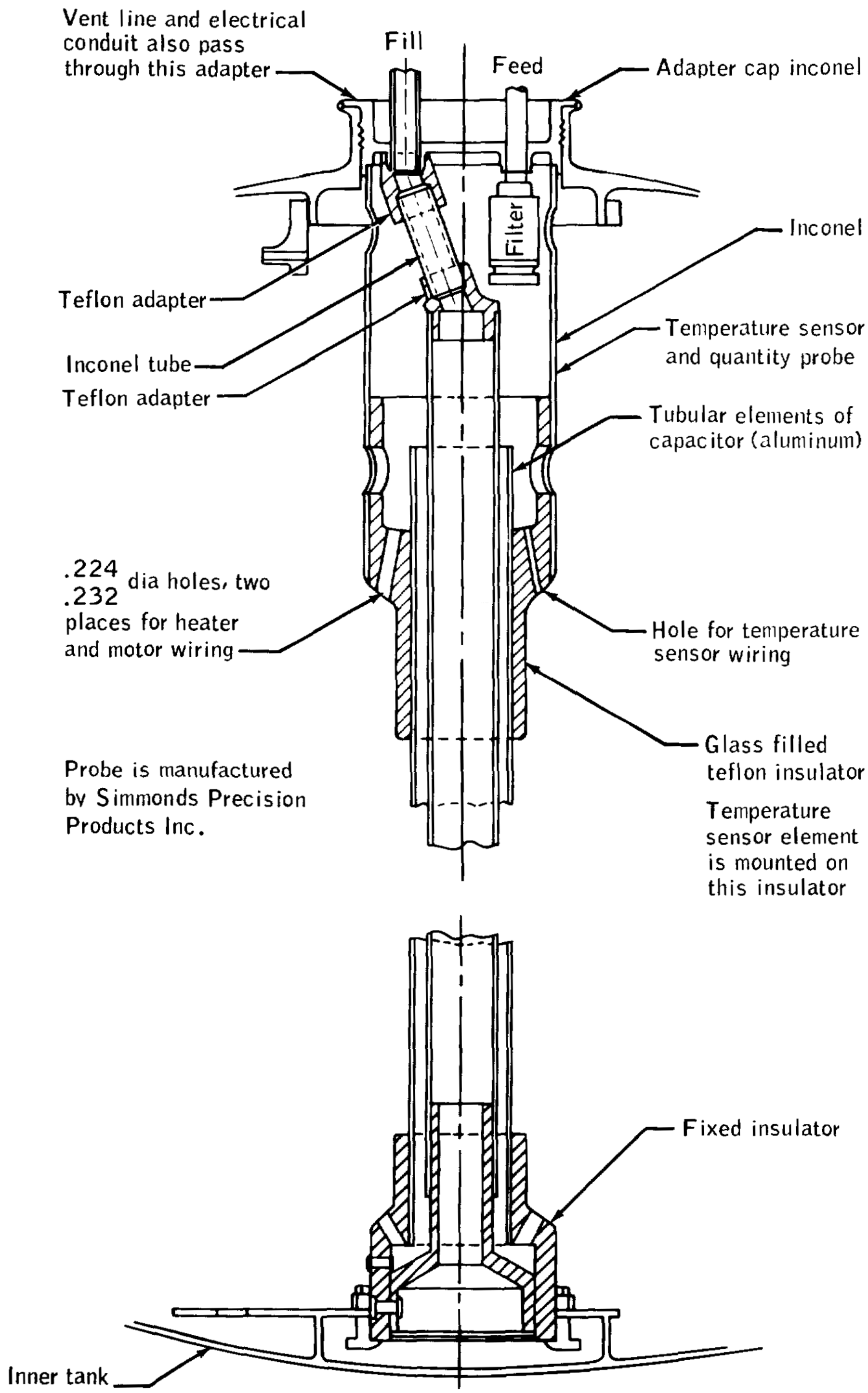


Figure C4-15.- Cross section of quantity probe.

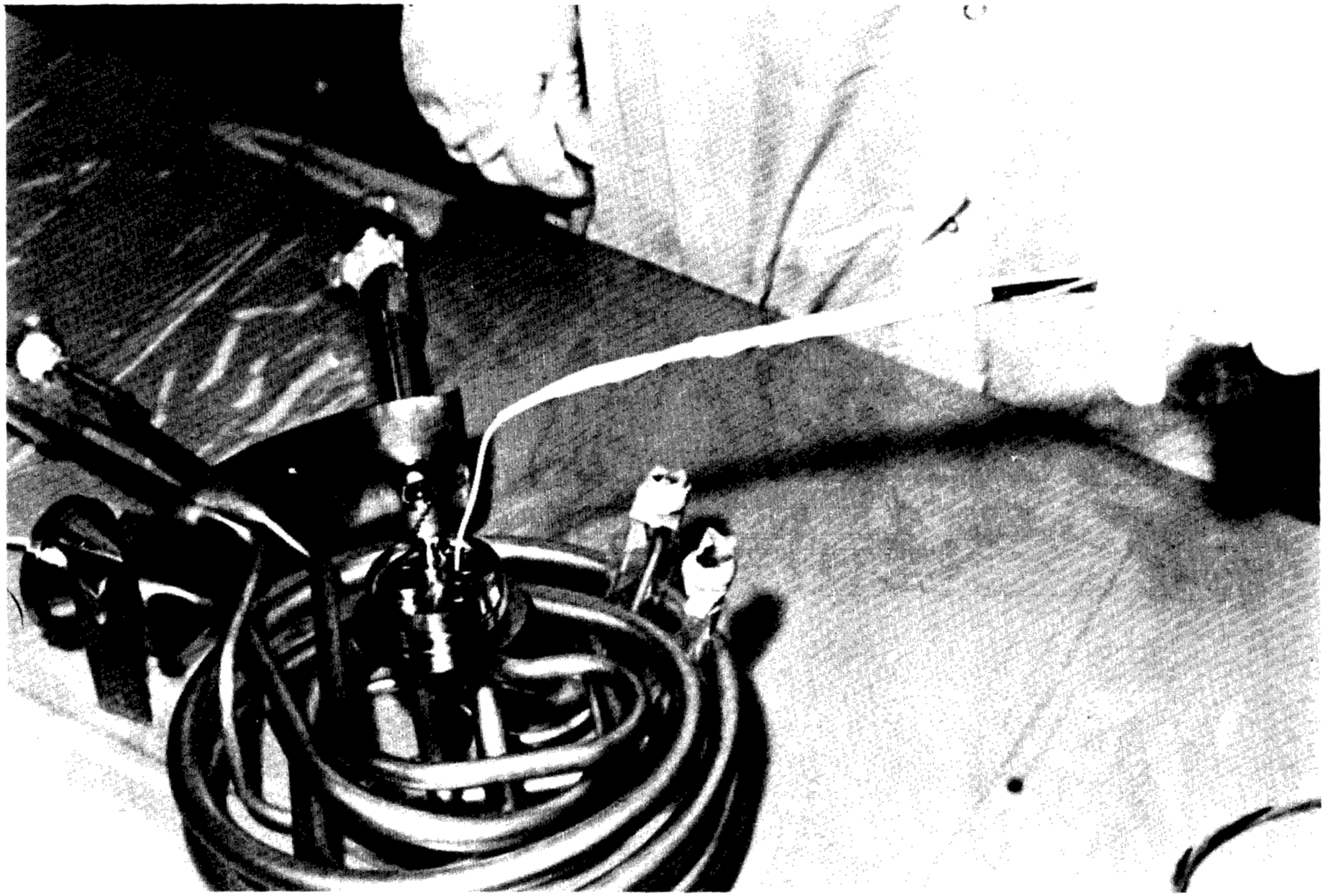


Figure C4-16.- Pulling quantity probe wires into upper coil assembly.

Figure C4-17.- Feeding quantity probe wires into upper coil assembly.

Figure C4-18.- View showing the feeding and pulling used to install wires.

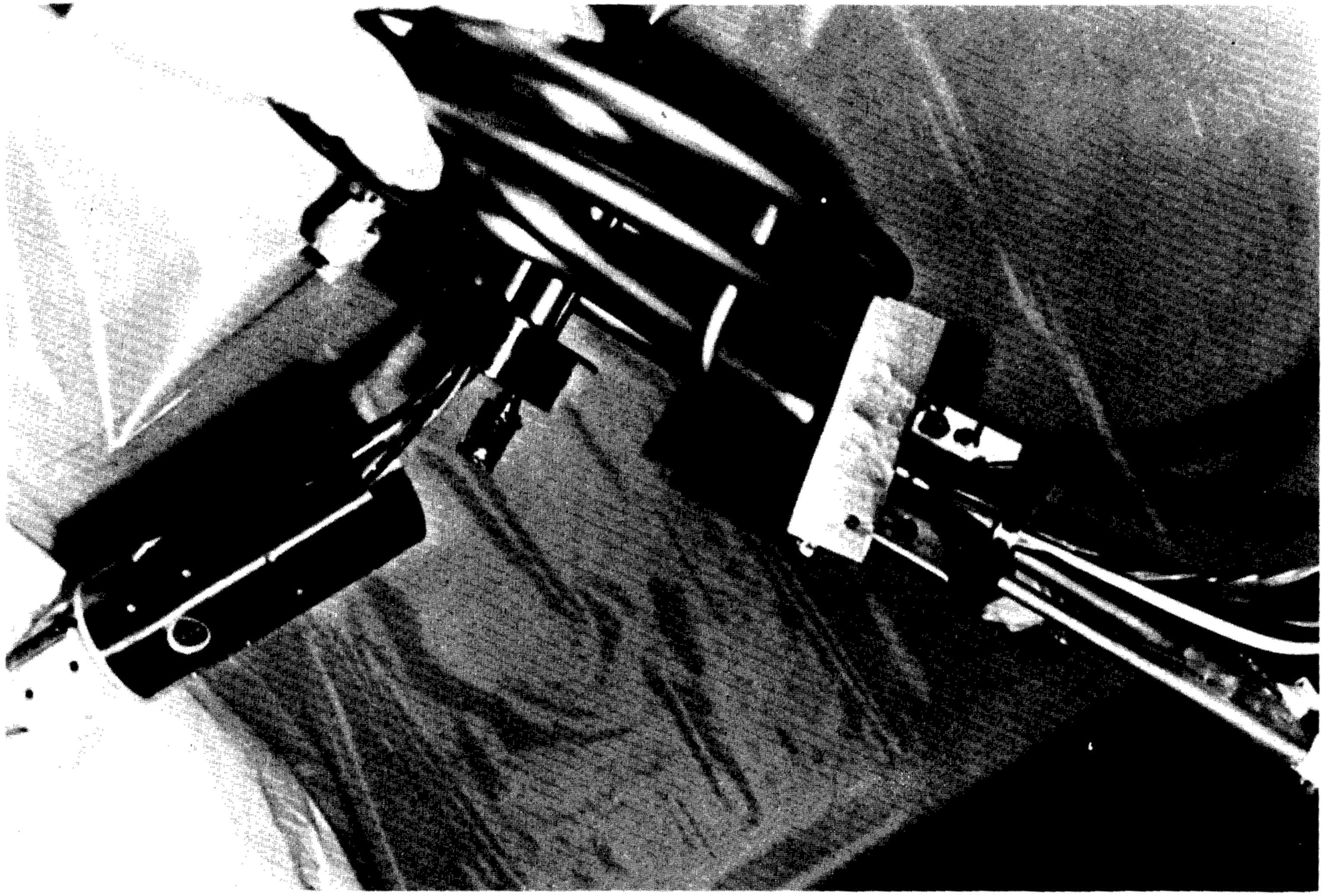


Figure C4-19.- Quantity probe and coil assembly ready to install fill tube connecting parts.

next items to install are the Teflon adapters and the connecting tube for the fill tube (figs. C4-20 through C4-22). With these parts in place, the quantity probe is bottomed in the counter-bore of the tank tube adapter (fig. C4-23). The fill tube parts are then checked to assure that they are in the proper position by use of a blunt probe through the side holes in the outer tube (fig. C4-24). The electrical feedthrough holes are aligned by eye with the electrical conduit and the entire unit is clamped into a jig for welding (figs. C4-25 through C4-27). Four 1/4-inch-long welds are positioned away from wires and the Teflon fill tube adapter to secure the assembly (figs. C4-28 and C4-29). The Unit is then inspected, cleaned, and bagged for future assembly into the tank.

Prior to final assembly of the tank, all major subassemblies are subjected to component acceptance tests. Specifically these major components are the following: pressure vessel, motor heater fan assembly, coil assembly, probe assembly, and the electrical connector. These tests check all functional aspects that are possible at that level of assembly, electrical isolation, pressure integrity, etc., as appropriate for particular components. These components are then moved to an area referred to as the Ultra Clean Room (a class 100,000 laminar flow clean room) for the final assembly. Operations in this area are performed in full lint-free nylon suits, boots, caps, and rubber gloves. Entry to this clean room is from the Apollo Assembly Area with a simple dressing room airlock for changing clothes. All equipment moves into and out of the area through airlocks.

The actual final assembly starts with opening the tank by removing the temporary shipping plug from the tank neck (fig. C4-30). Throughout the entire assembly operation, a vacuum cleaner nozzle is positioned adjacent to the tank to help reduce the possibility of dust or lint entering the tank. The heater assembly is then lowered part way into the tank (figs. C4-31 and C4-32). With the assembly held about halfway into the tank, the wires are fed in beside the heater until they are completely inside the tank. The heater is then lowered until the lower motor adapter pin is in the lower support bracket (fig. C4-33). The last portion of this lowering is accomplished by use of duckbill pliers (fig. C4-34). The top portion is then positioned for the upper bolt to be installed. The bolt is inserted by means of a wire holding loop and started by hand (figs. C4-35 and C4-36). This bolt is tightened with an open-end wrench with final torquing achieved by a combination of the open-end wrench and a standard torque wrench. The torque value is adjusted to account for the combined lever arm effect of the wrenches. At this point the wires are fished from the tank with hook (fig. C4-37). The wires are then checked and any tangles are removed. A small stainless safety wire is attached to the wires and they are lowered into the tank again (fig. C4-38).

Next a probe support fixture is attached to the tank neck and the probe is lowered about two thirds of the way into the tank (fig. C4-39).

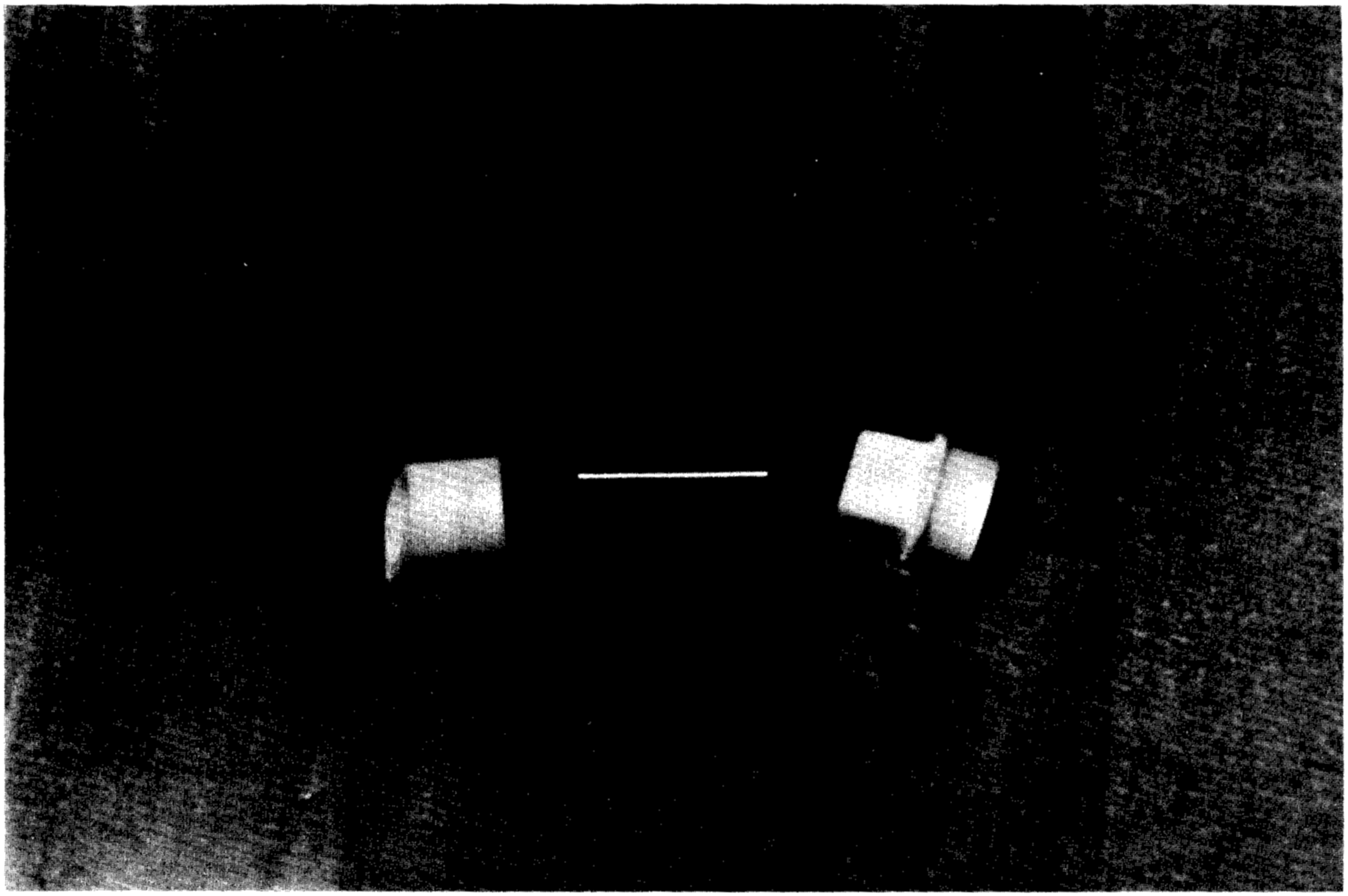


Figure C4-20.- Fill tube connecting parts.

Figure C4-21.- Installing fill tube connecting parts.

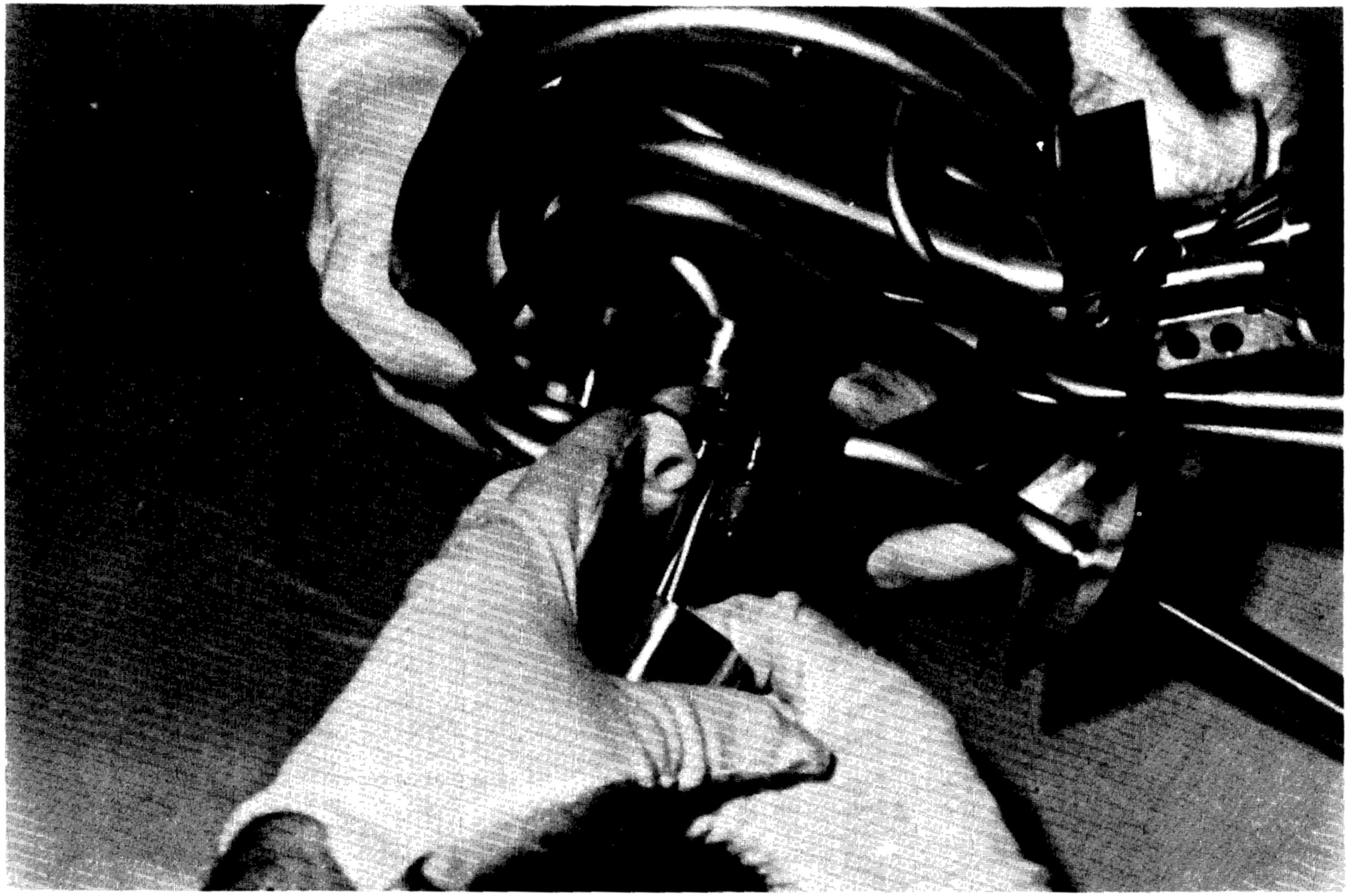


Figure C4-22.- Holding fill tube connecting parts in place.

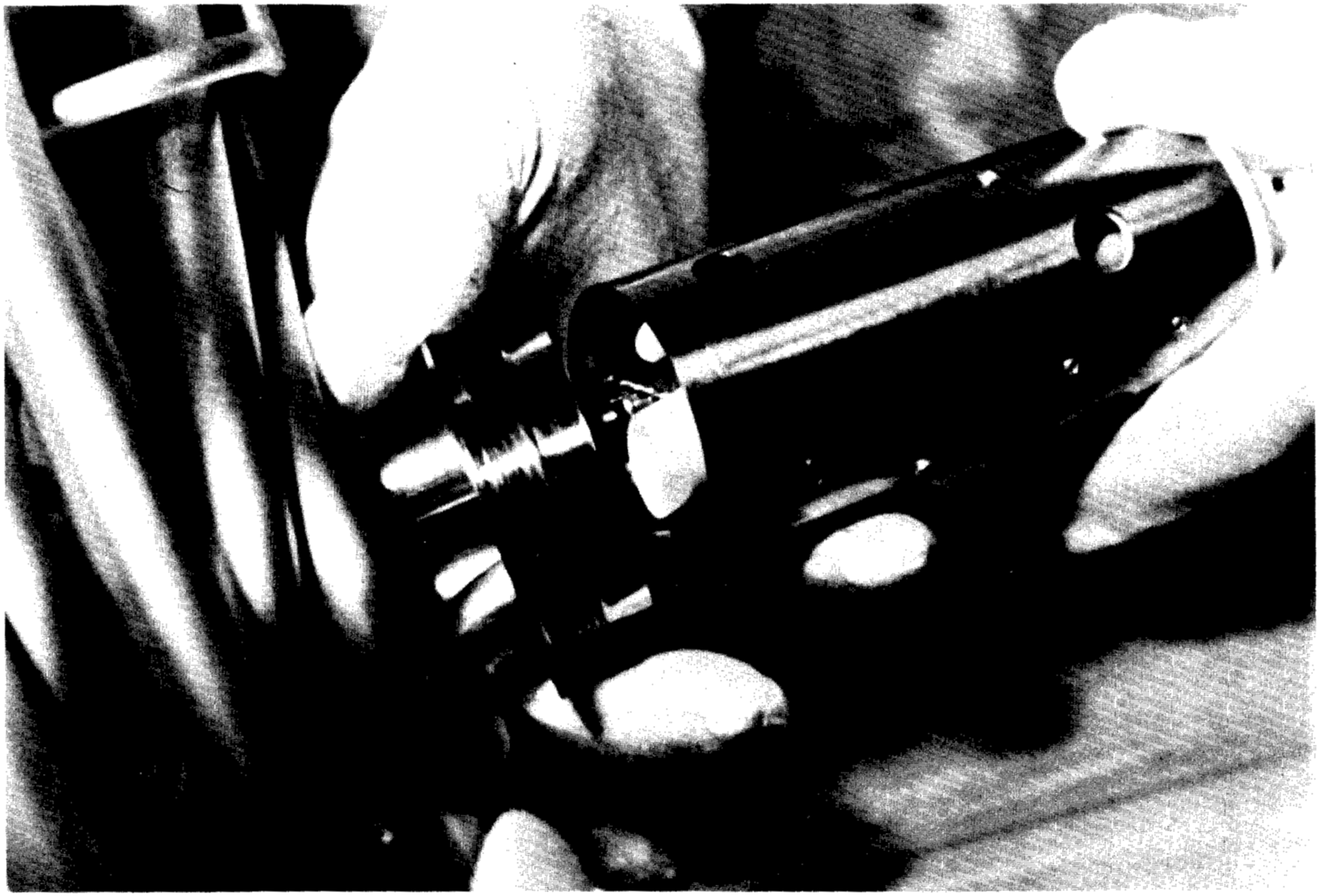


Figure C-4.23 - Final mating of quantity probe and tank adapter.

Figure C4-24.- Probing to assure that fill tube parts are in proper position.

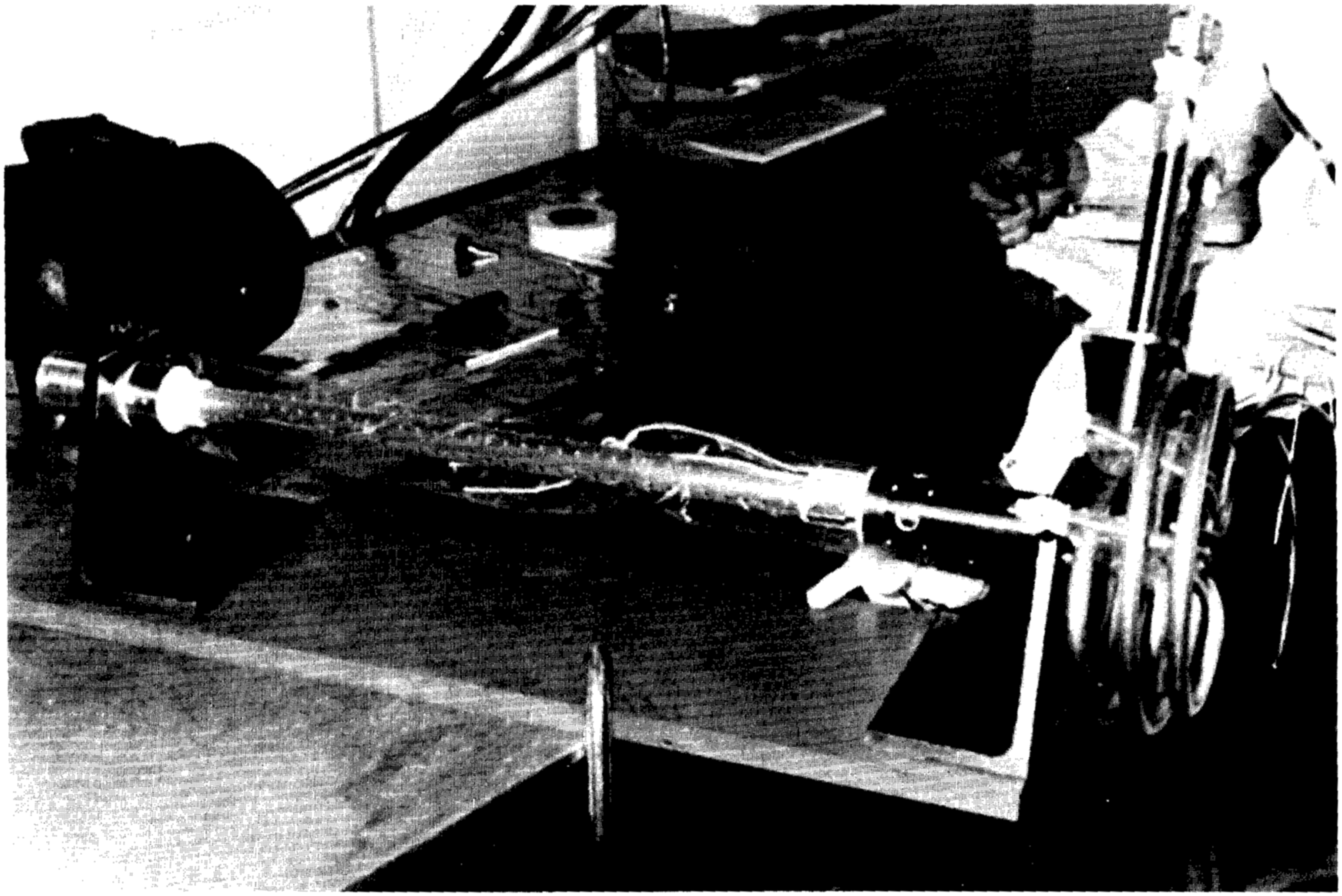


Figure C4-25.- Quantity probe and coil assembly in welding jig.

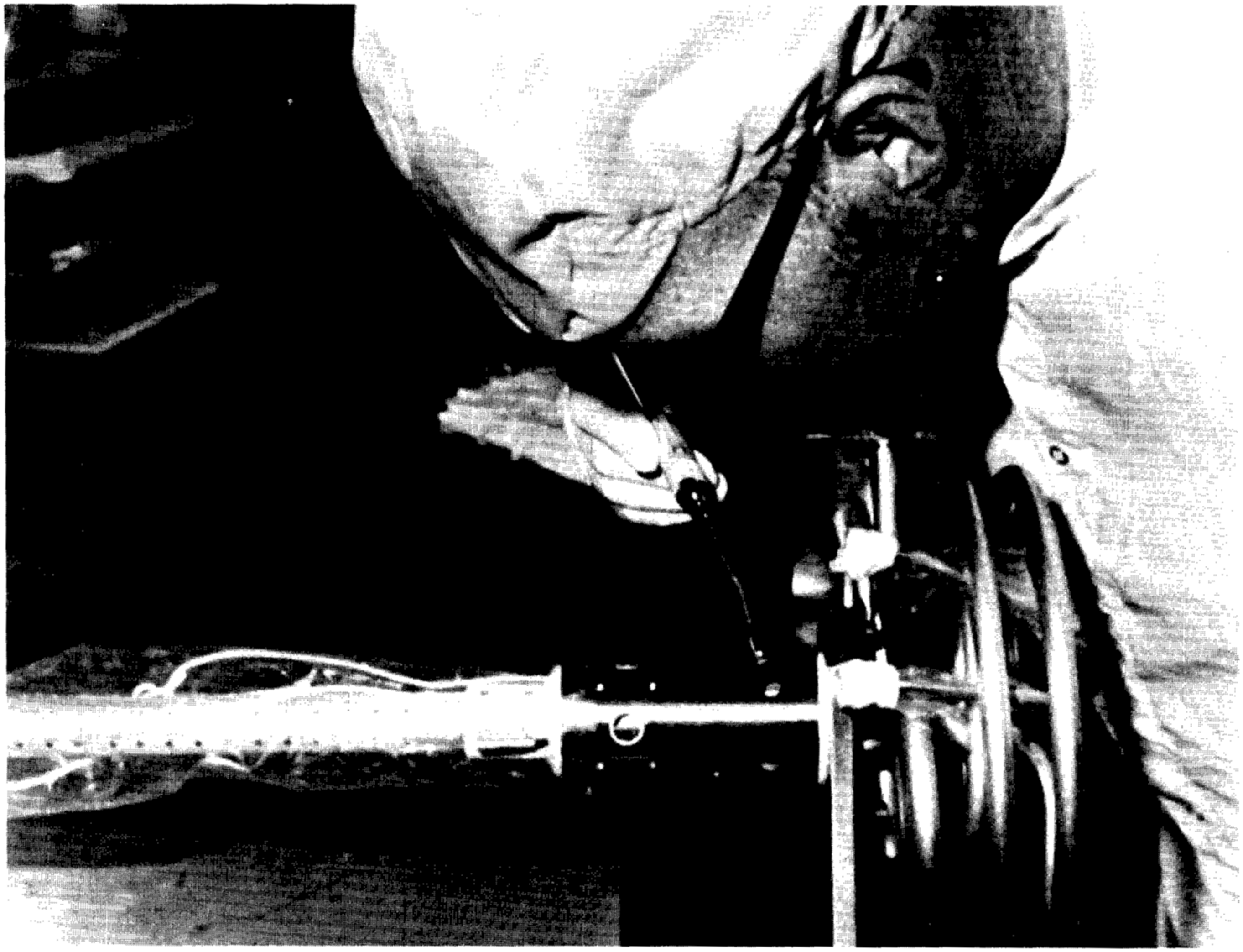


Figure C4-26.- Final inspection of fill tube connecting parts.

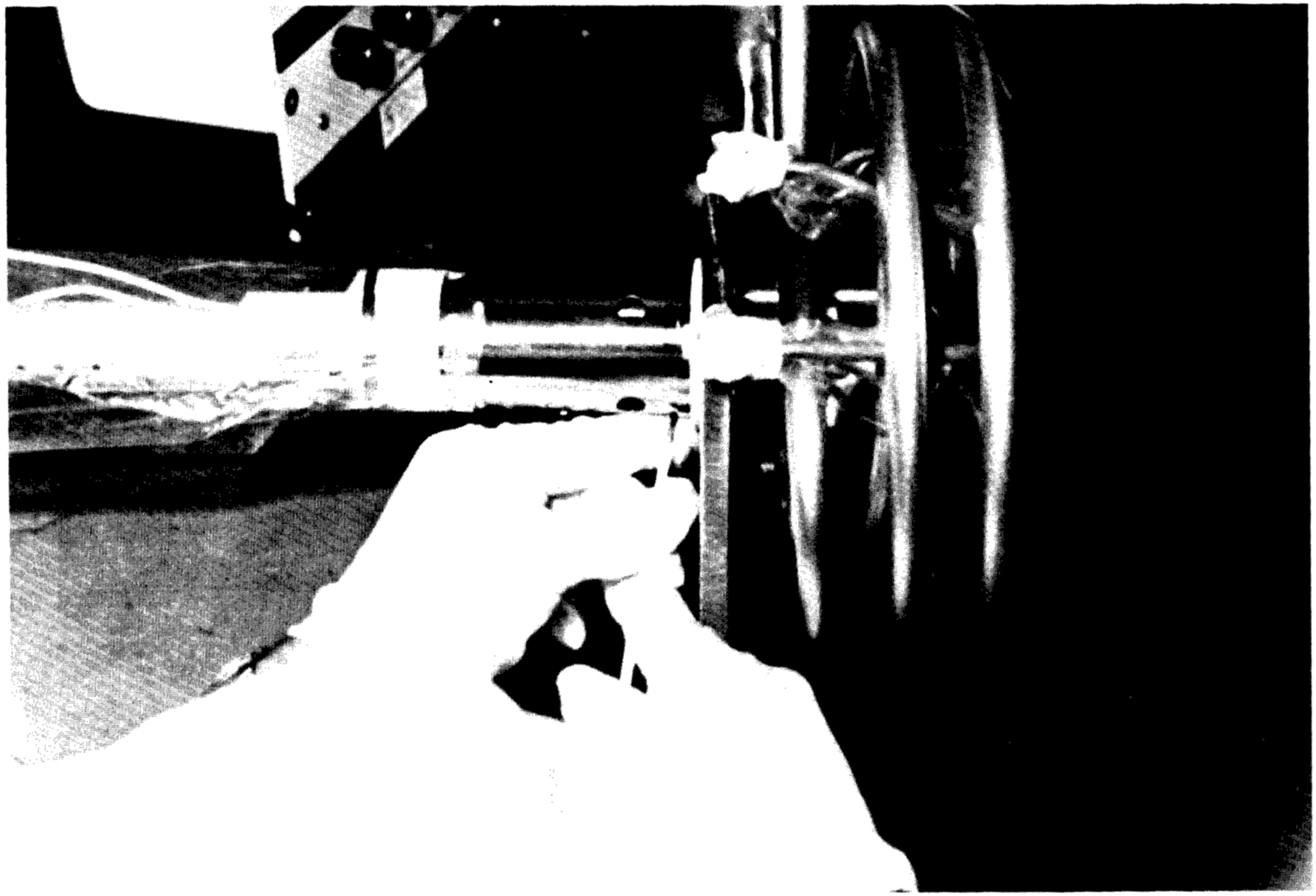


Figure C4-27.- Marking the weld positions.

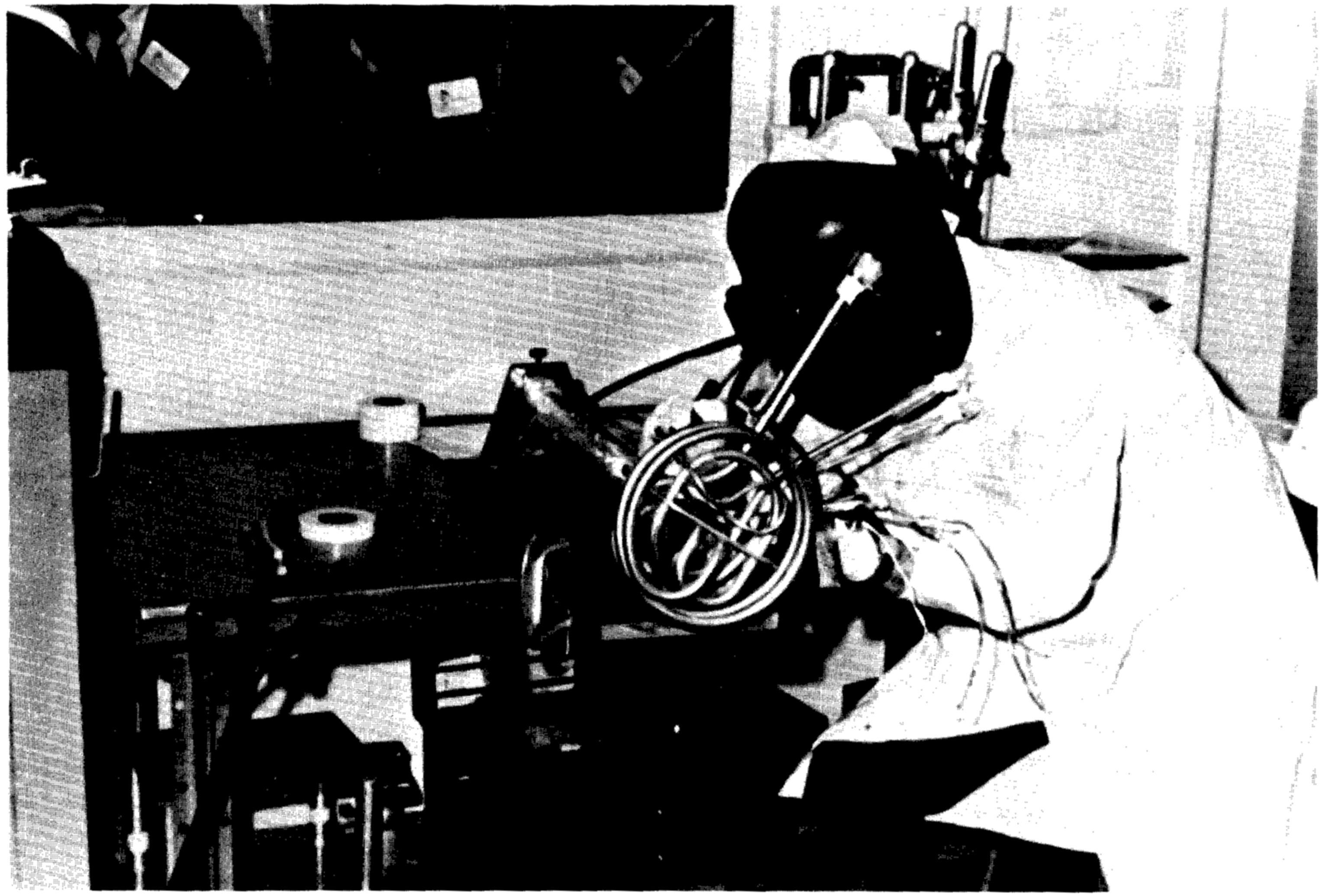


Figure C4-28.- Welding the quantity probe to coil assembly.

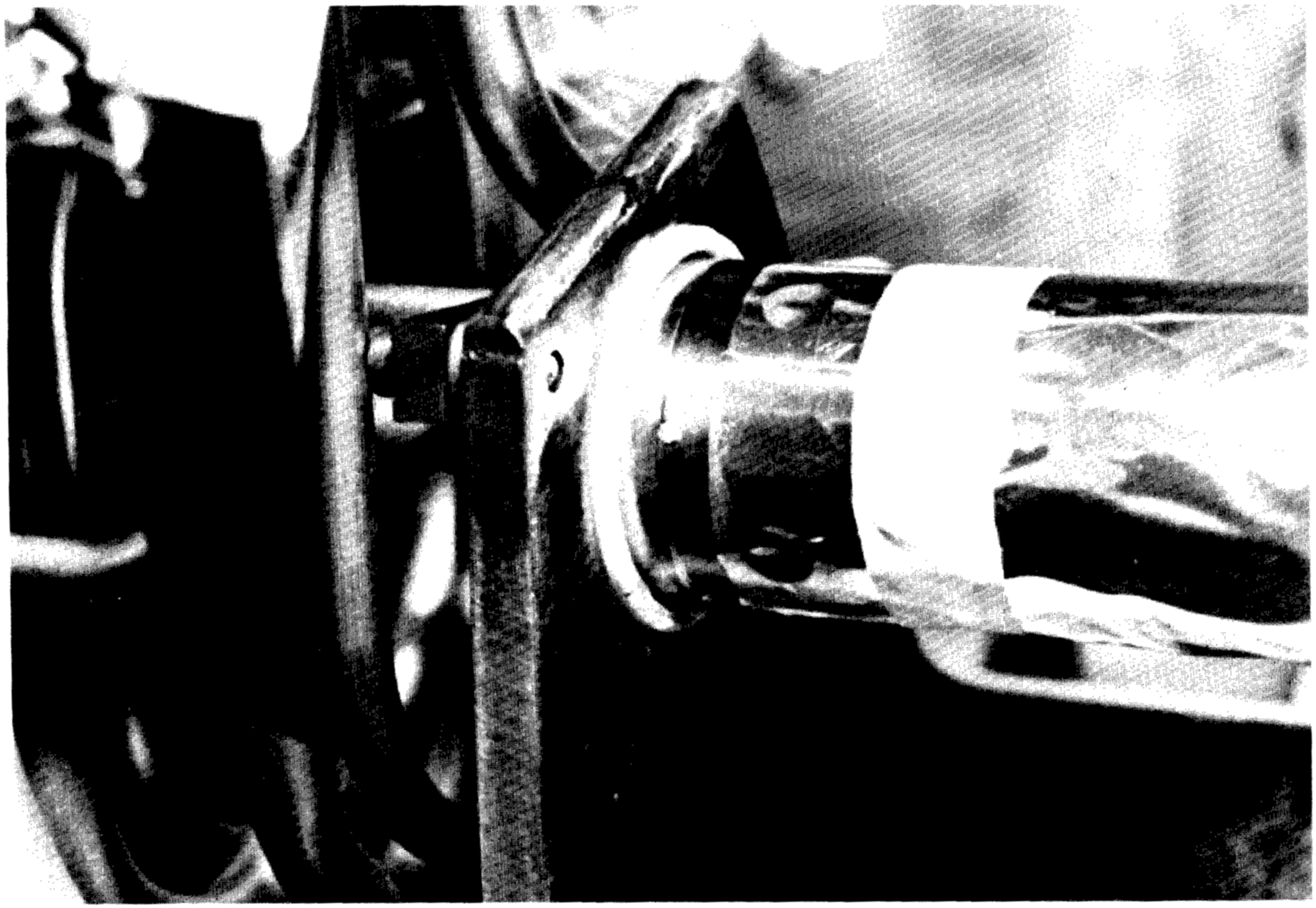


Figure C4-29.- The completed quantity probe to coil assembly welds.

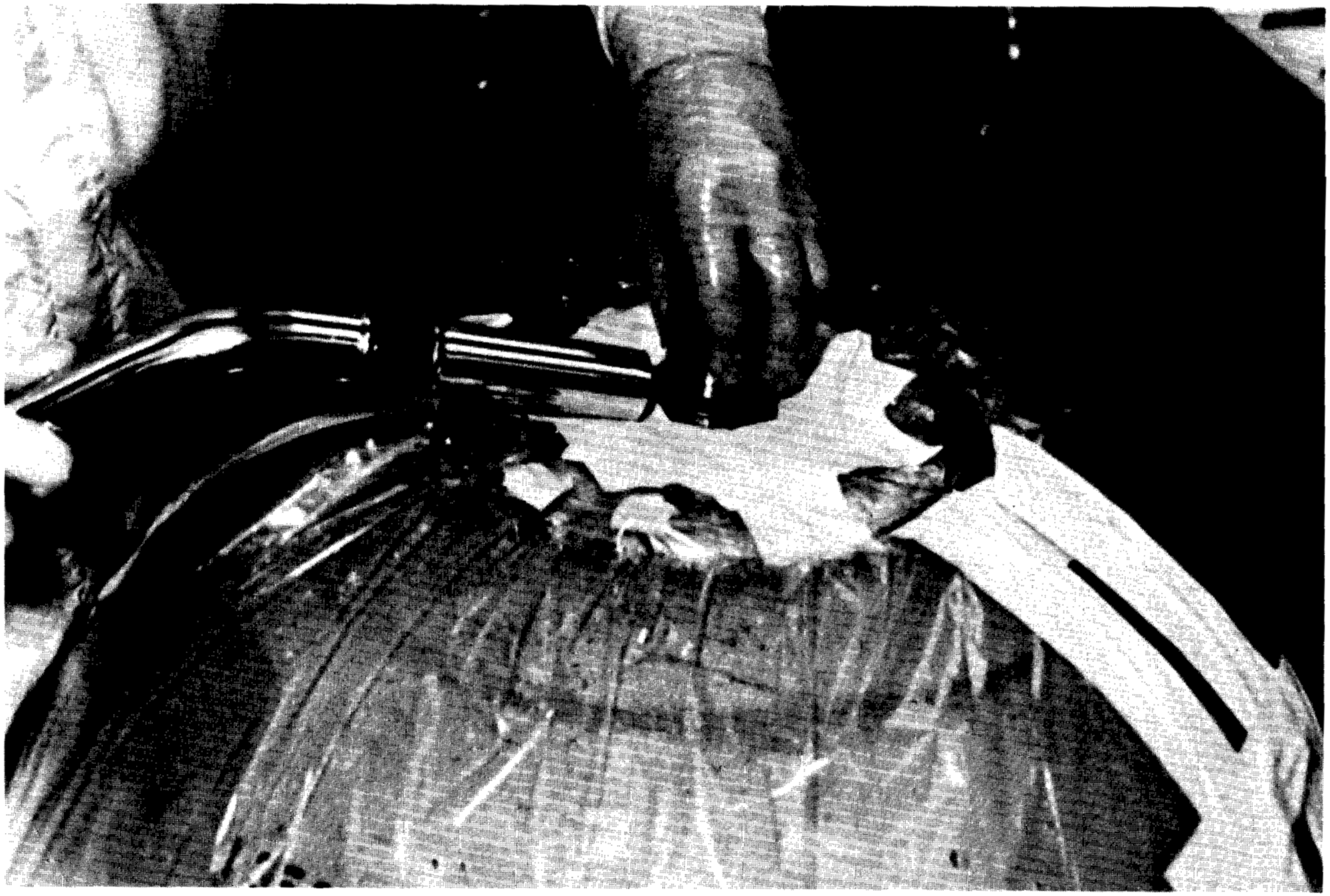


Figure C4-30.- Removing tank shipping plug.

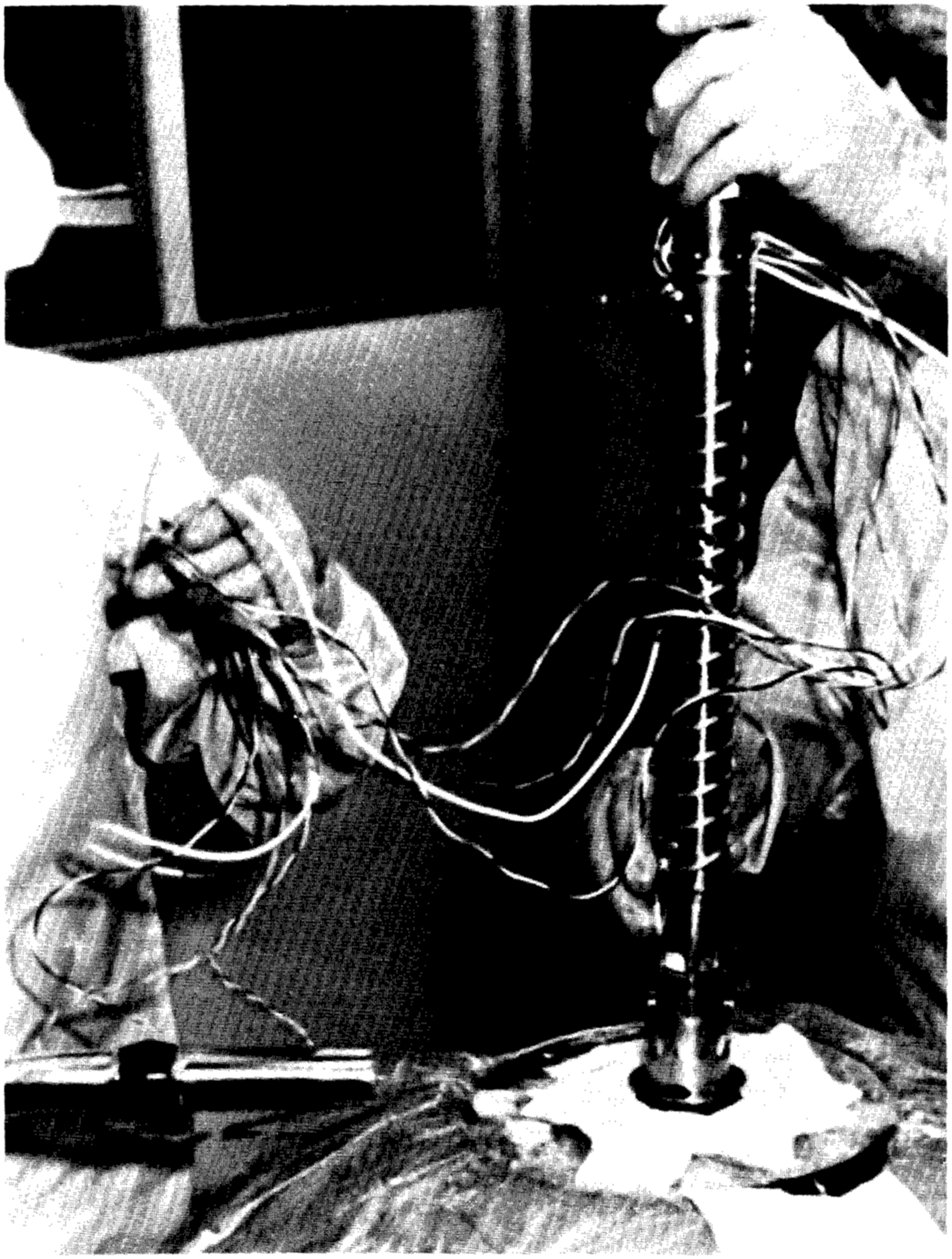


Figure C4-31.- Inserting fan and heater probe.

Figure C4-32.- Feeding wires into tank beside heater probe.

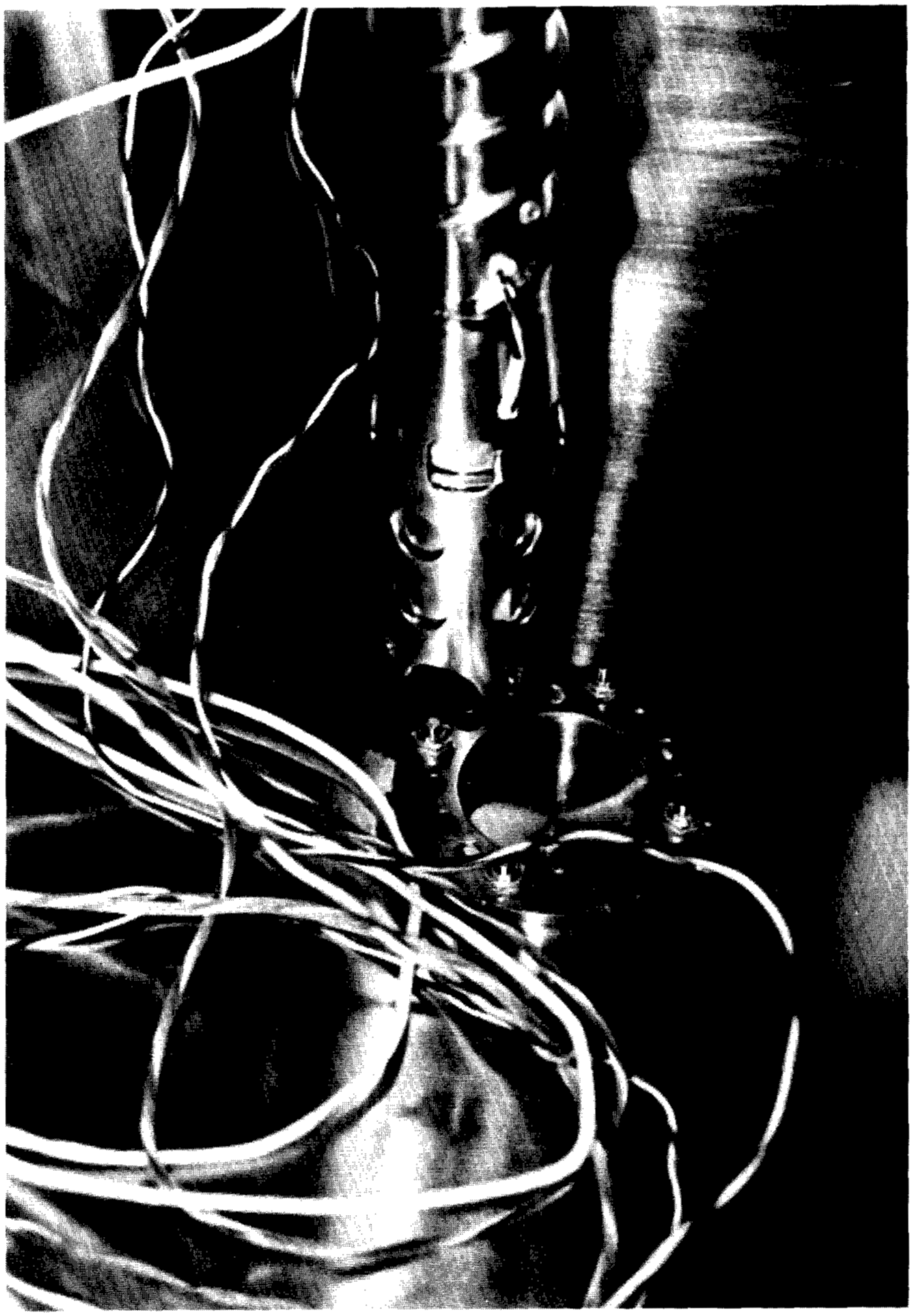


Figure C4-33.- View inside tank showing heater probe in lower support.

Figure C4-34.- Final lowering of heater probe.

Figure C4-35.- Wire loop used to install heater probe retaining bolt.

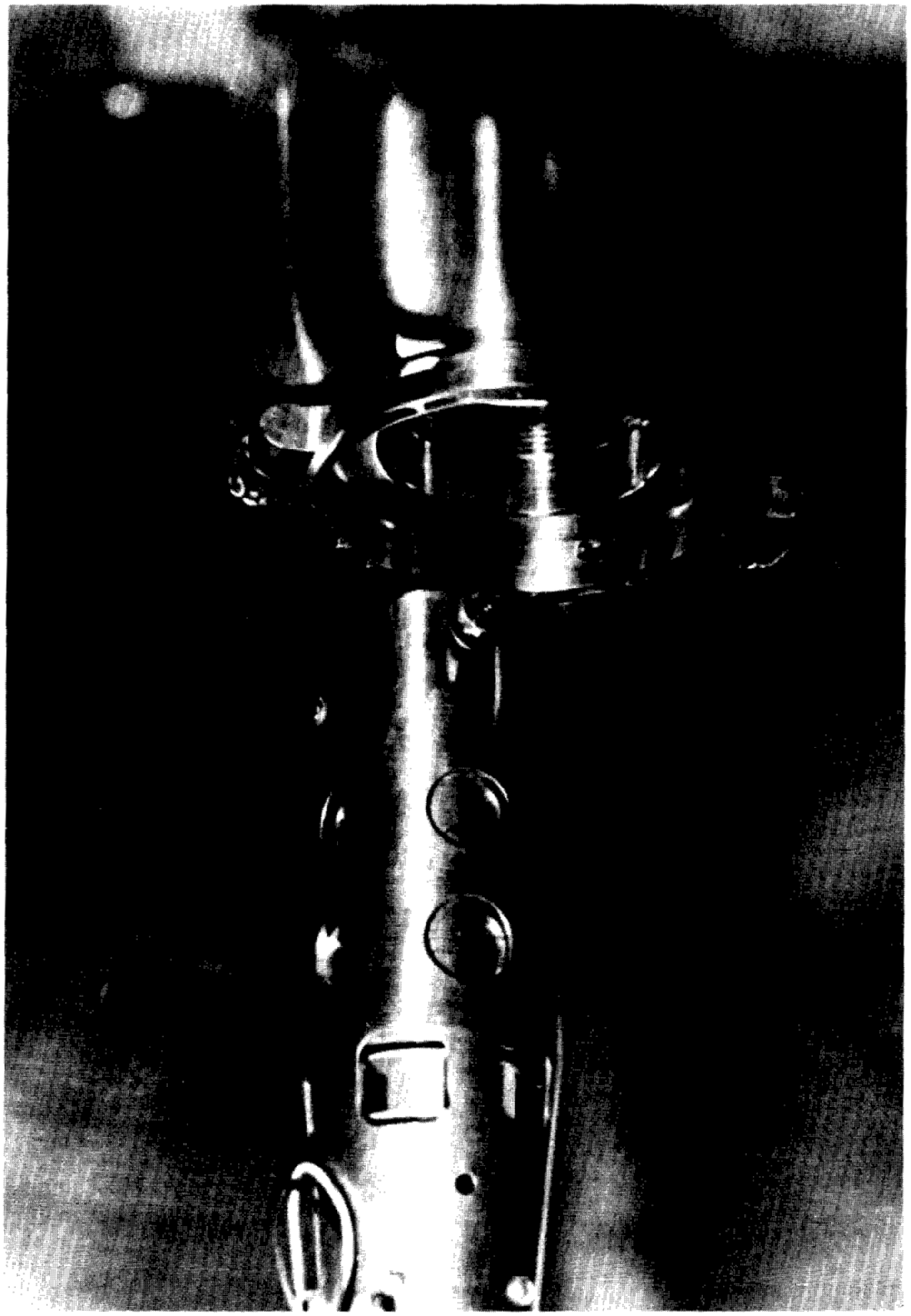


Figure C4-36.- View inside tank showing heater probe upper retaining bolt.

Figure C4-37.- Pulling wires from tank.

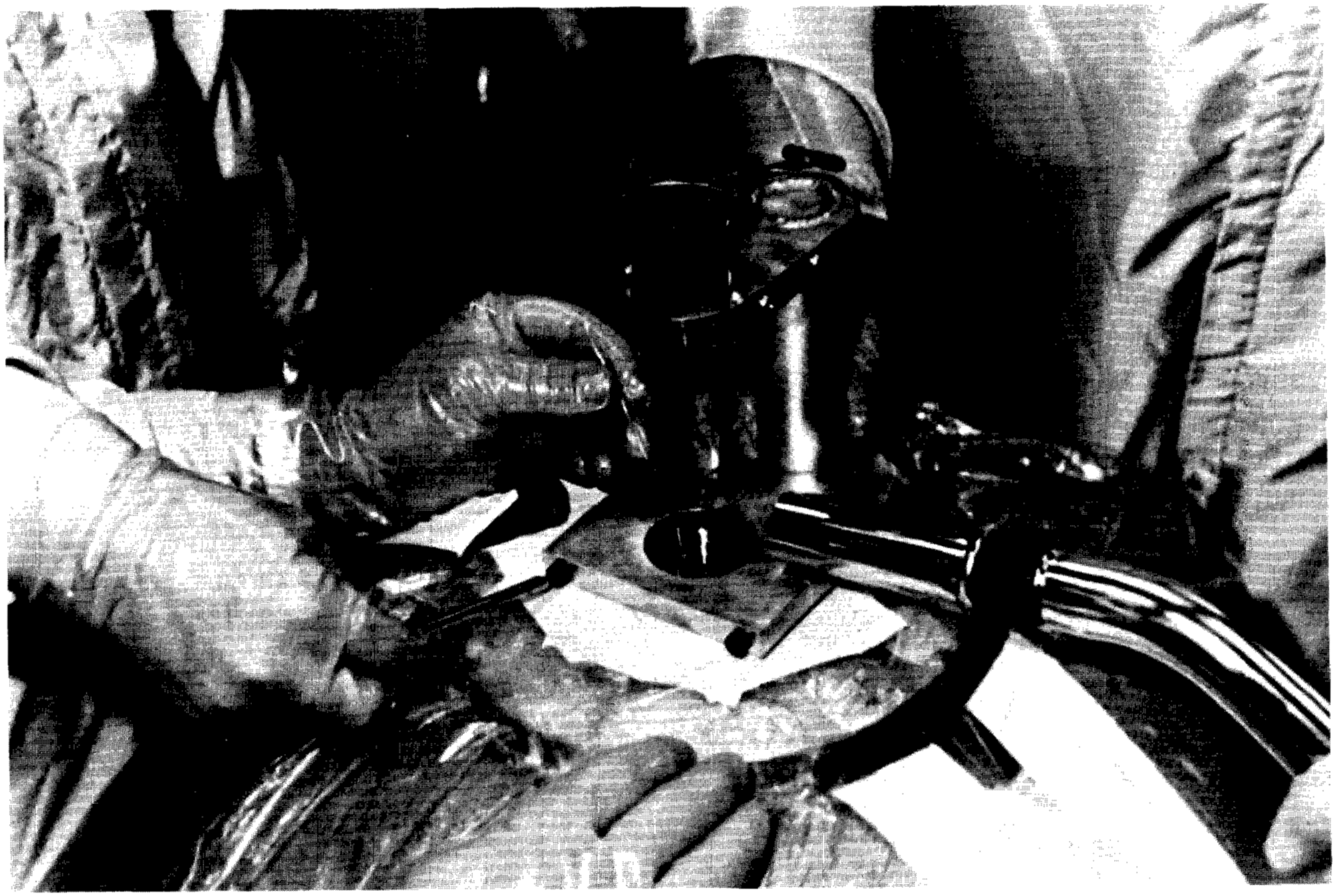


Figure C4-38.- Lowering wires into tank with fixture
to hold quantity probe installed.

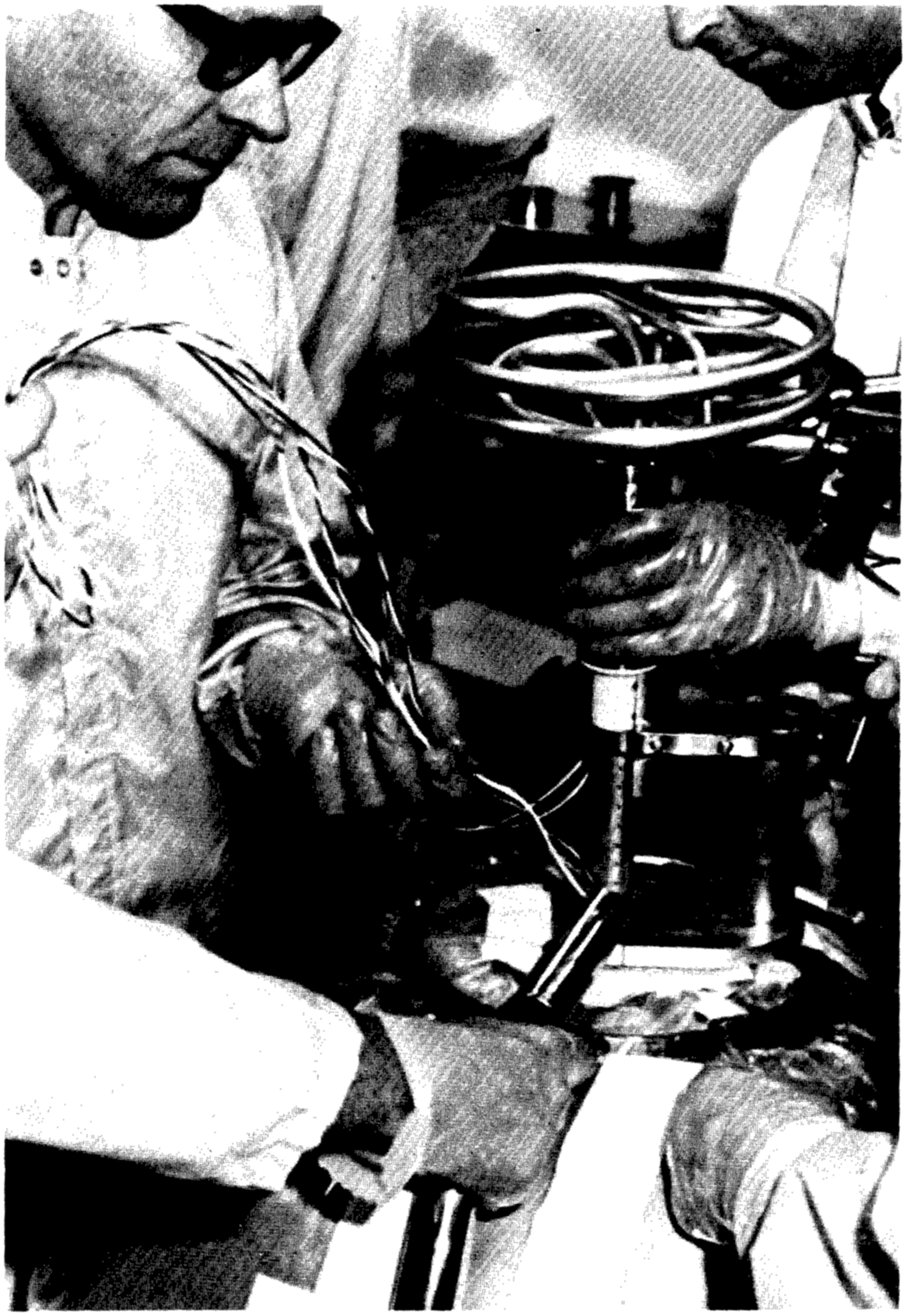


Figure C4-39.- Quantity probe being installed in fixture and heater probe wires being pulled from the tank.

At this point the wires are once again withdrawn from the tank. Again any possible tangles are removed. Then the pull wires previously installed in the probe are soldered to the motor and heater lead bundles. The solder joints are thoroughly cleaned and taped to made a smooth transition from each single pull wire to each bundle of six leads. These wire bundles are pulled into the conduit one bundle at a time with one man feeding the wires at the feedthrough hole in the quantity probe and the other man pulling approximately 25 to 35 pounds on the pull wire (figs. C4-40 through C4-42). The bundles are pulled through until the slack is taken out of the wire bundle with the probe in this elevated position (about 9 inches of slack when probe is lowered into into tank) (fig. C4-43). Then holding the probe assembly, the fixture is removed from the tank neck and the probe is lowered into the tank (fig. C4-44). The probe assembly is then rotated counterclockwise approximately one turn. The unit is then very carefully rotated clockwise to start the quadruple thread and pilot the lower end of the probe into the ring provided at the bottom of the tank. If the probe assembly in the tight position does not result in alignment of the supply tube, then the probe assembly is re-indexed in 90-degree increments to achieve alignment. These procedures are carried out to a specific Manufacturing Operations Procedure and in the presence of quality control inspectors. (Figures C4-45 and C4-46 show the typical routing of wires from the heater and fan probe assembly into the quantity probe.)

The electrical connector is then installed so that a complete checkout can be performed on the electrical operations. The lead wires are cut about 3 inches beyond the connector adapter flange. At this point a 3-inch length of large-diameter Teflon sleeving is installed in the neck of the conduit. About 2 inches is slid into the conduit with about 1 inch protruding into connector space. The wires are thermally stripped, tinned, and soldered into the connector. After a thorough cleaning with alcohol, the connector is inspected with black light to assure complete removal of flux. After the resistance, isolation, and functional tests are completed, the metal sleeve is slid in place and welded. The connector proper is protected during the welding process by a set of copper chills which have cooled in liquid nitrogen. Even so, the weld is made in a series of short segments to limit the heat.

The next operation is the welding of feed line connections and the tank neck adapter. A helium leak test is run on the weld joints using a mass spectrometer leak detector. After satisfactory completion of these checks, the welds are all X-rayed.

Next, insulation is installed in the vacuum dome area. Two layers of aluminized Mylar are applied over the outer shell material that extends under the dome. The tank adapter flange is covered with four layers of aluminized Mylar. All the tubes in the dome area are wrapped with 1-inch aluminized Mylar strips held in place with nylon thread.

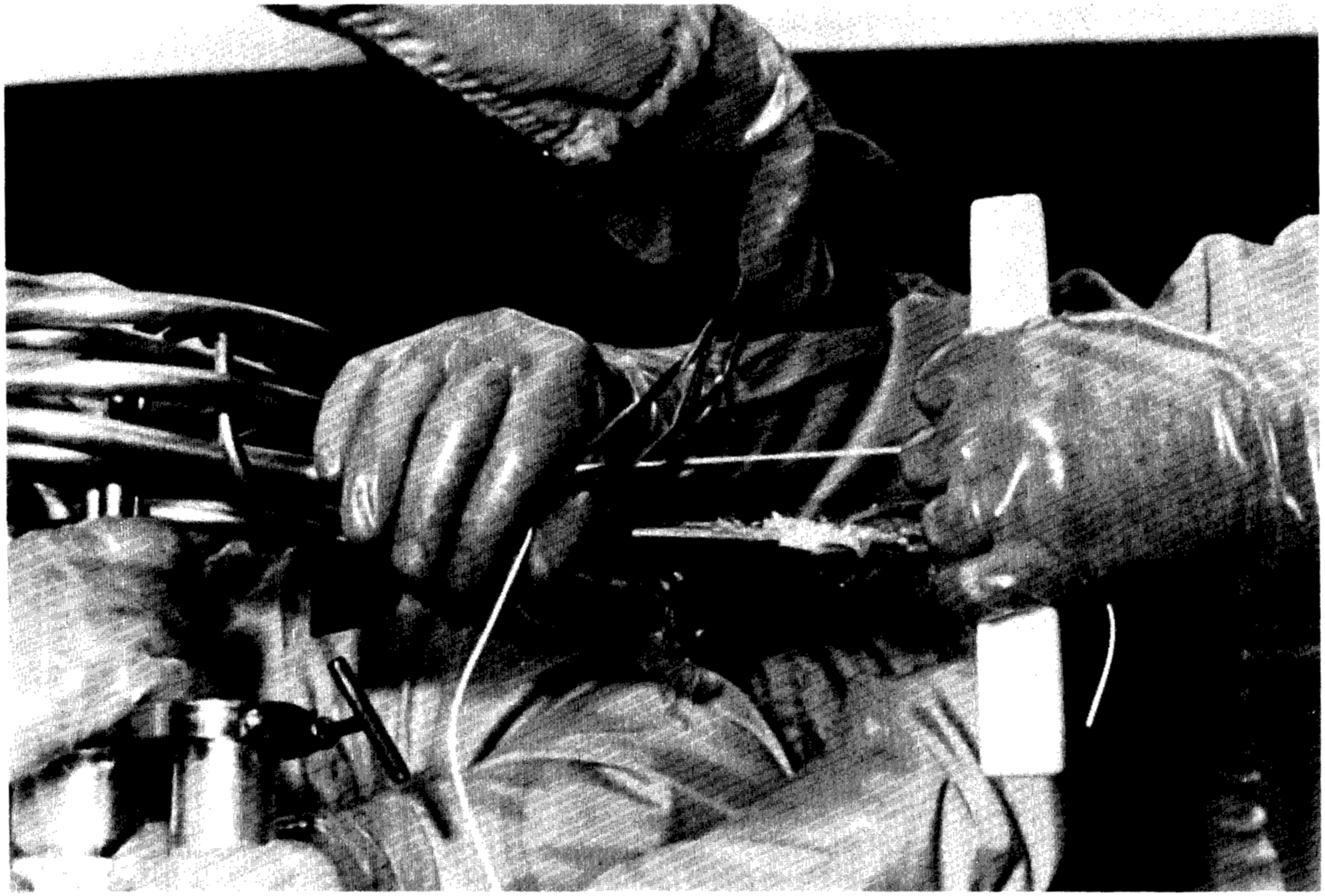


Figure C4-40.- Pulling first bundle of heater and fan motor leads into upper coil assembly.

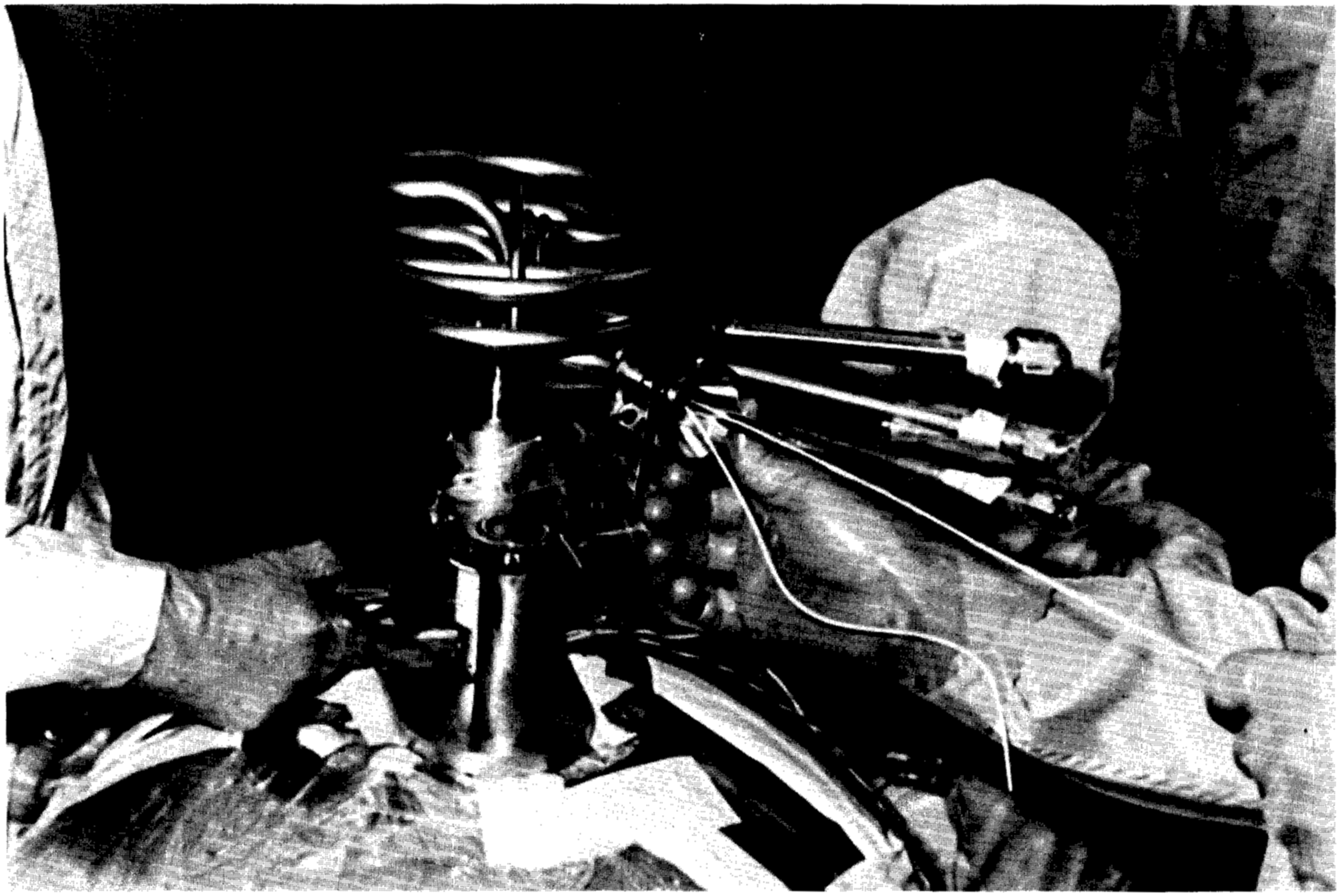


Figure C4-41.- Pull wire used to route heater and fan motor leads into upper coil assembly.

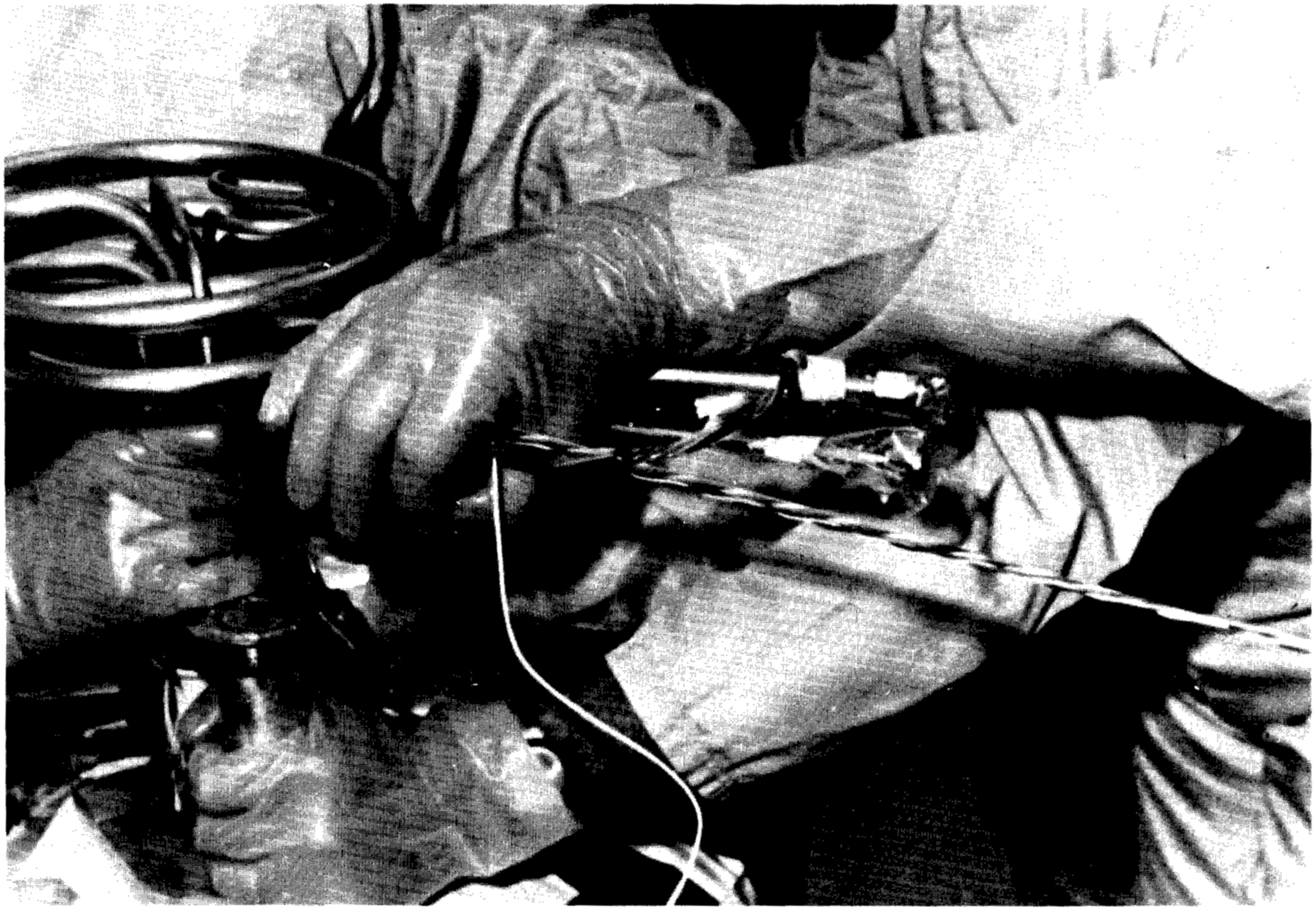


Figure C4-42.- First bundle of heater and fan motor leads pulled through upper coil assembly.

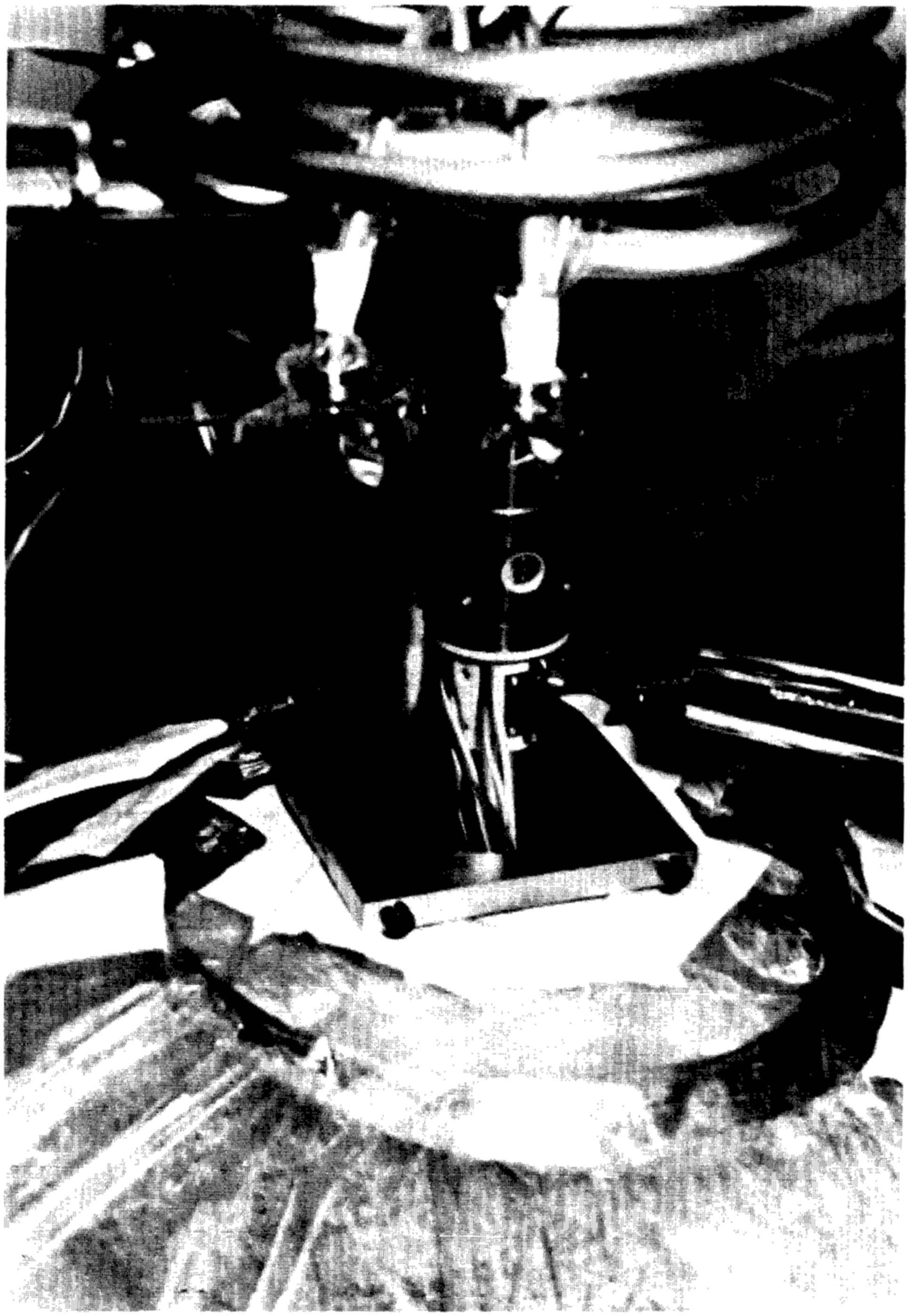


Figure C4-43.- Heater and fan motor lead routing into quantity probe.

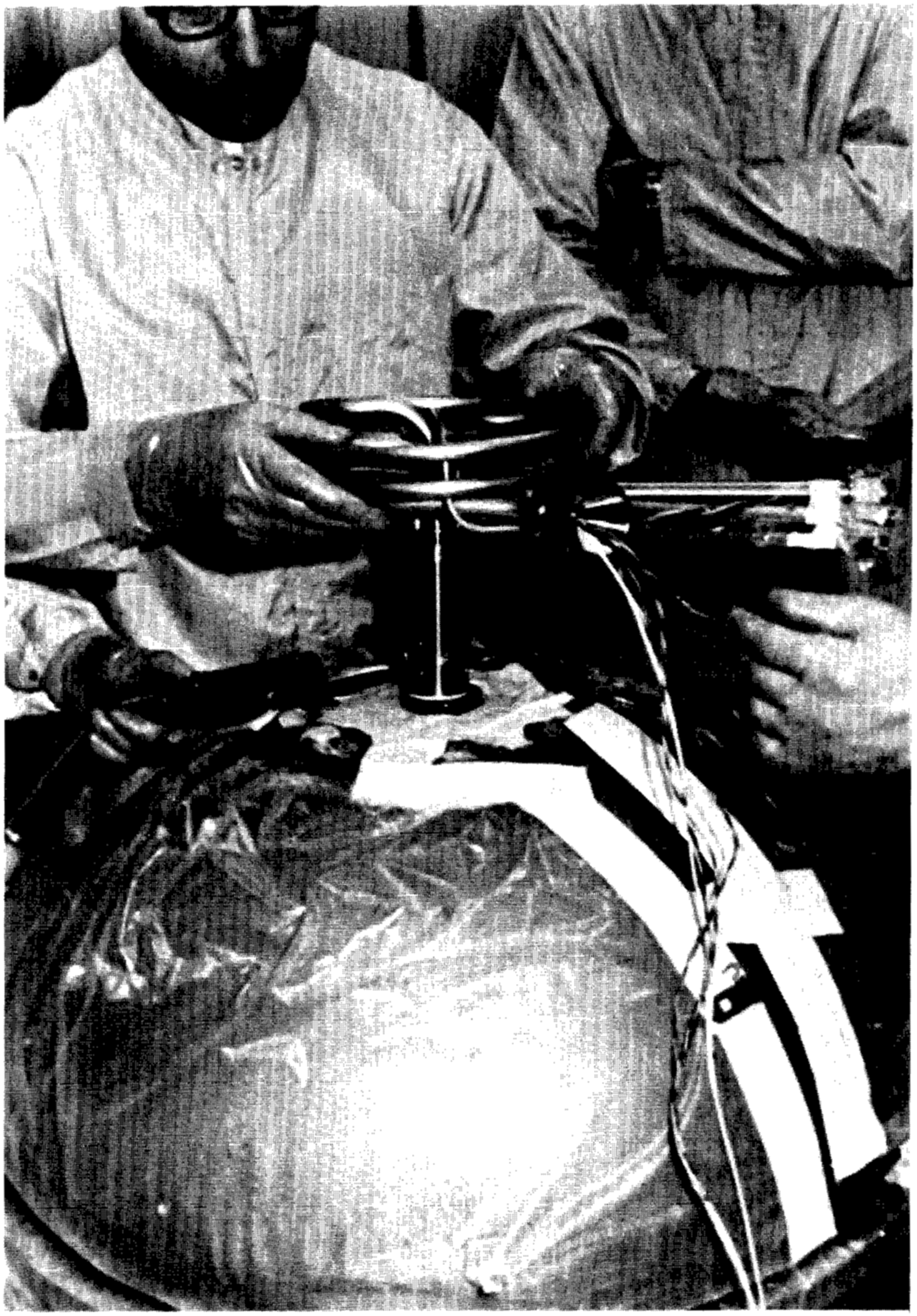


Figure C4-44.- Lowering quantity probe assembly into tank.

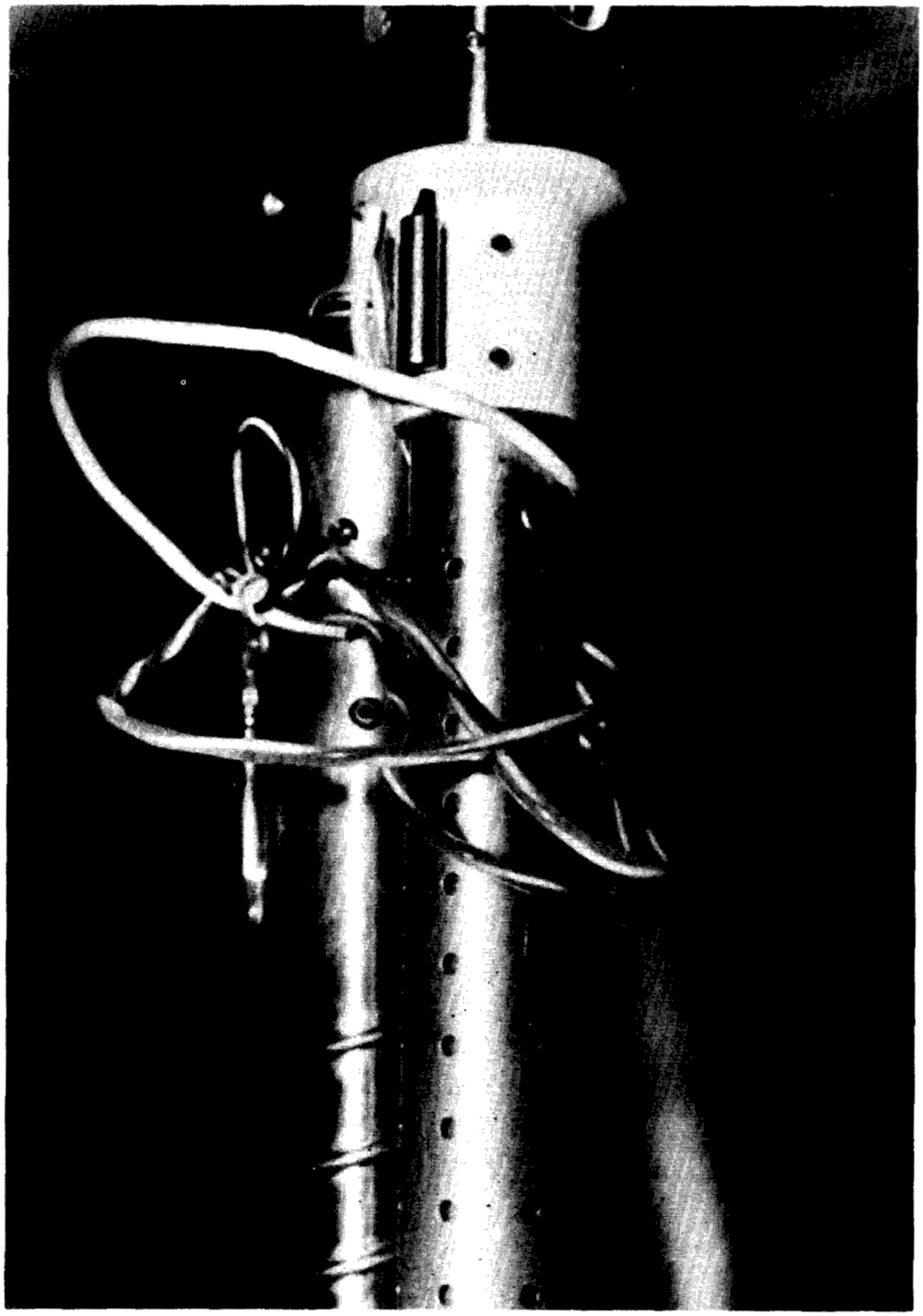


Figure C-4.45 - View inside of tank of typical wire routing from heater probe to quantity probe.

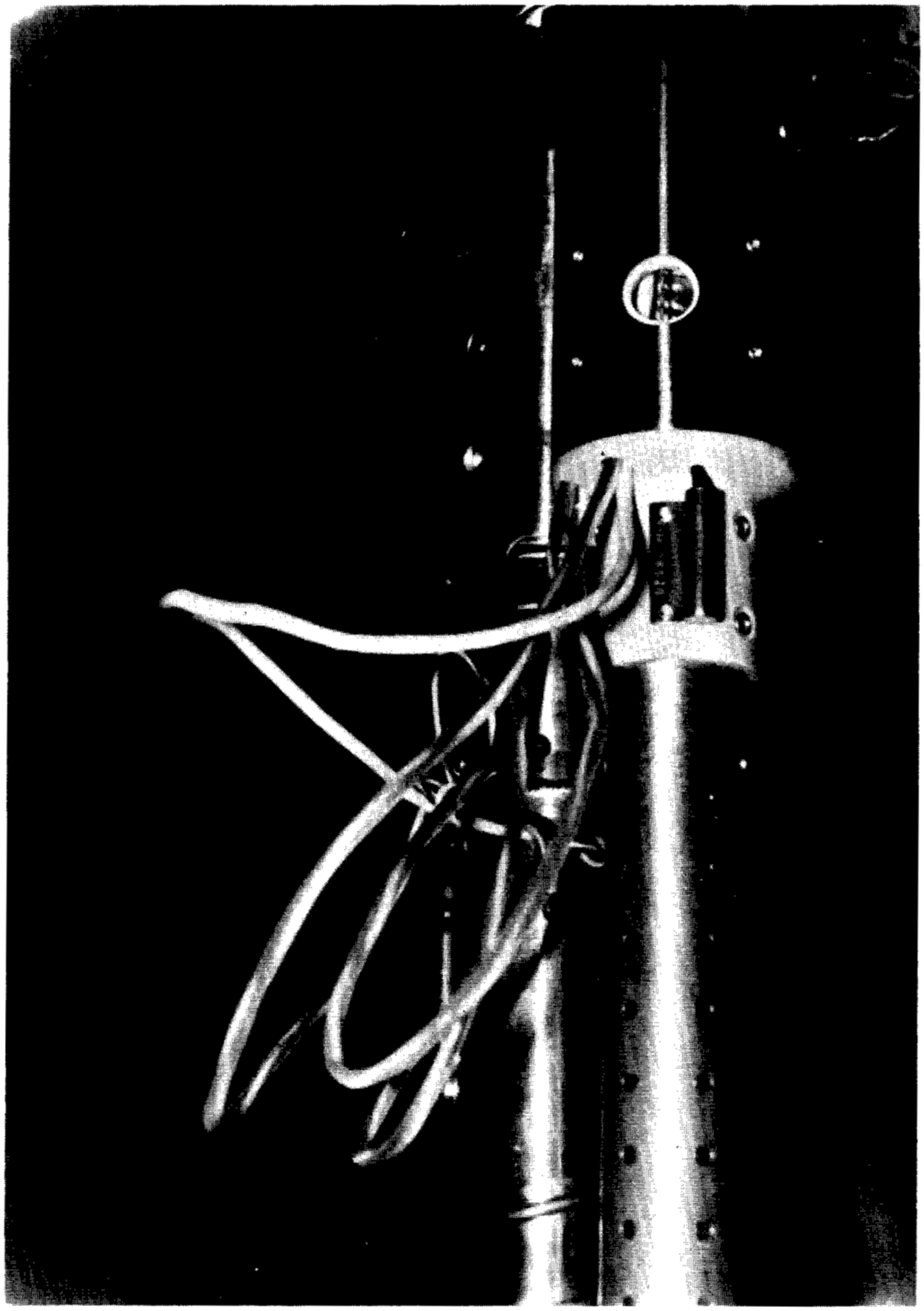


Figure C-4.46 - View inside of tank of typical wire routing of heater probe wires into quantity probe.

The coil housing (dome) cover is now welded in place. The housing contains the vacuum pumpdown tube, the blowout disc, and the vac-ion pump bracket (fig. C4-47). In addition, a pumpdown tube is welded to the lower hemisphere to speed the pumping process. After the welds are X-rayed, a preliminary pumpdown is made.

After a check is made to insure vacuum integrity, the vacuum is broken and additional insulation is stuffed into the dome area through the vacuum pumpdown tube. This insulation consists of 40 square feet of 0.0005-inch gold-coated Kapton which has been crinkled and cut into small pieces with pinking shears. (This represents about 5760 individual pieces approximately 1-inch square with pinked edges. This represents 2.3 ounces of Kapton.)

The actual pumpdown is accomplished in an oven at 190° to 220° F to speed the pumping and to assure a low final pressure. Because of the many layers of insulation, a complete pumpdown requires 20 to 28 days. At the completion of the pumpdown, the vacuum pumpdown tubes are pinched and sealed and protective caps are installed. The installation of the vac-ion pump completes the fabrication process of the tank assembly.

Acceptance Testing

End-item acceptance testing is a long and elaborate process controlled by a detailed written test procedure. The sequence consists of the following: (1) A dielectric strength test of the following wires or groups of wires shorted together. The test is run at 500 V dc and leakage current to ground (tank assembly) shall not exceed 0.25 milliamp; the four temperature sensor wires, the quantity gage outer tube lead, the quantity gage inner tube lead, the quantity gage inner tube lead shield, the eight wires from the two fan motors, the four wires from the two heaters, and the low-voltage input wires to the vac-ion pump; (2) Dielectric strength test of vac-ion converter output to ground (tank assembly) at 400 V dc. Leakage shall be no more than 0.8 milliamp; (3) Insulation resistance test to check that every wire or group of wires that should be isolated from other wires or ground shows a minimum of 2 megohms isolation at 500 V dc; (4) The isolation between the vac-ion pump electrical terminals and ground is tested at 500 V dc and must be at least 50 megohms; (5) The isolation between the vac-ion converter electrical output terminals and the tank assembly (ground) is tested at 500 V dc and must be 50 megohms or greater; (6) The vac-ion pump is functionally tested; (7) The inner vessel is pumped down for 4 hours to assure that the inner vessel is dry; (8) Helium leak test at 500 psi and a helium proof-pressure test at 1335 ± 20 psi; (9) A heater pressurization test and heat-leak test (vessel filled with liquid oxygen and 65 V ac supplied to heaters); (10) Cryogenic proof-pressure test at 1335 ± 20 psi (heaters powered by 65 V ac to raise pressure of liquid oxygen);

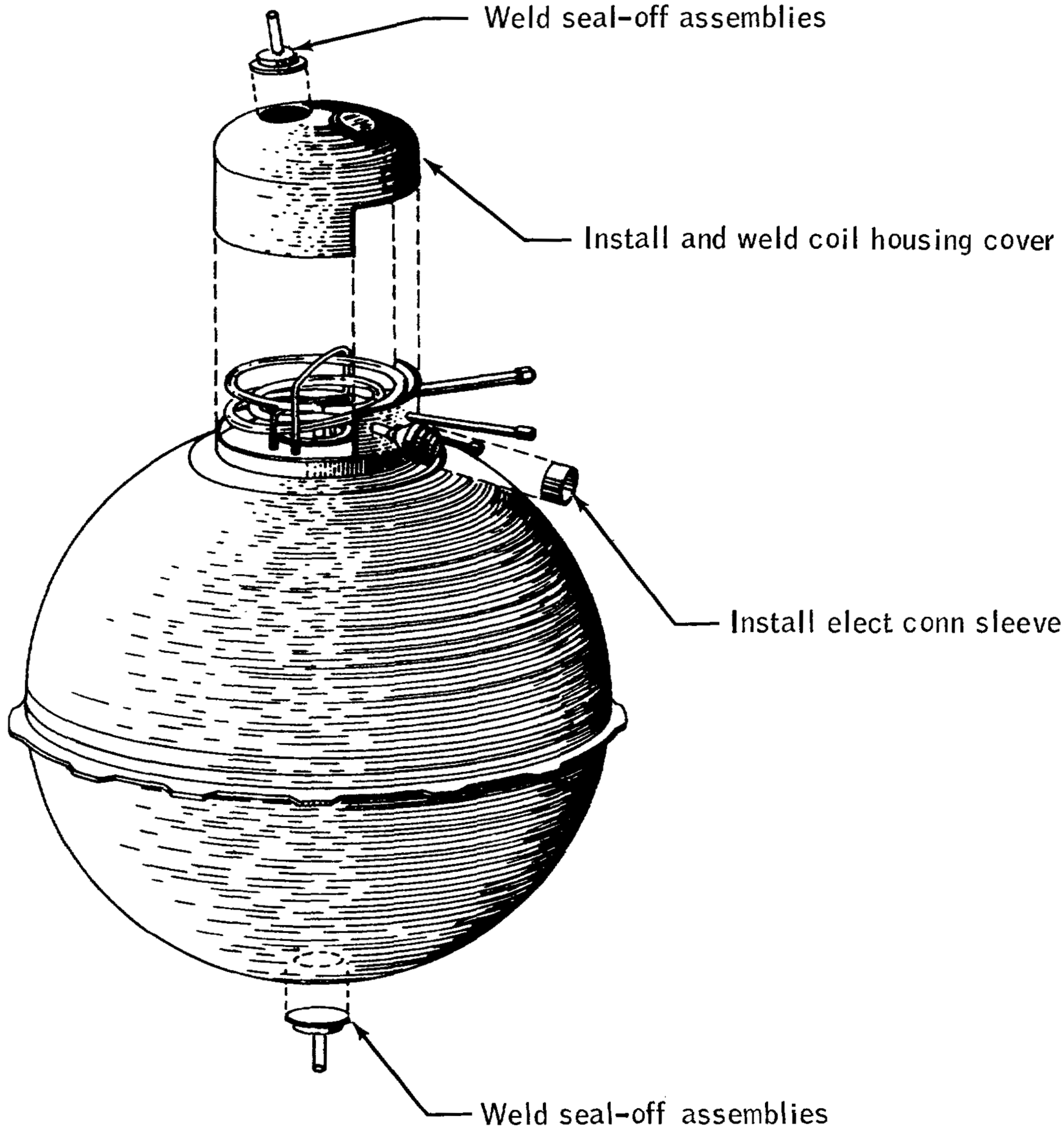


Figure C4-47.- Final vacuum closure operations.

(11) Heat-leak test; (12) Inerting of the vessel with 100° to 160° F nitrogen gas; (13) Check to see that thermostats are open when nitrogen purge temperature of 100° to 110° F flows from exit of tank (30 V ac applied momentarily to verify that thermostats are open); (14) Vac-ion pump final functional test; and (15) Final motor run verification and coastdown. The heat-leak tests consist of many runs to cover a range of ambient conditions and outflow rates. Total testing involves 40 to 60 hours with liquid or supercritical oxygen in the tank. Data sheets on cryogenic performance specified in the procedure are furnished to North American Rockwell in the end-item acceptance data package which accompanies each tank on delivery to North American Rockwell.

At the conclusion of the heat-leak test, approximately 100 pounds of oxygen remain in the tank which must be emptied and purged for delivery. Approximately three-fourths of the mass of oxygen in the tank is released from the tank through the supply line in the process of reducing tank pressure from the initial 925-935 psia to the final pressure of 25-35 psia. To complete emptying, the portion of this oxygen which remains liquid after the pressure bleeddown is expelled through the fill line. The application of warm gas at 30 psia through the vent line to accomplish this expulsion approximates the normal detanking procedure used by KSC at the completion of the CDDT. The CDDT is the next time, after delivery of the tank by Beech Aircraft to North American, that cryogenic oxygen is loaded into and expelled from each tank.

Summary of Significant Aspects of the Manufacture and Acceptance Test of Cryogenic Oxygen Storage Tank Serial No. 10024XTA0008

The manufacturing and test flow for cryogenic oxygen storage tank serial no. 10024XTA0008 is shown in figure C4-48. The item of particular significance is the recycle that was required in the manufacturing process brought on by motor failures.

The manufacturing history of the fan motors installed before or during 1966 contains many incidents of failures encountered in motor tests which resulted in design or fabrication process changes. The failure modes experienced were categorized as:

(a) Contamination failures

(b) Bridge ring (stator laminations) failures

(c) Bearing failures

(d) Phase-to-phase (stator windings) dielectric breakdown or shorts

(e) Grounds (of stator wiring)

(f) Lead wire damage (primarily at Beech)

(g) (Motor fan) speed

(h) Coastdown failures (less than 30 seconds in air or gas)

Design and manufacture process changes to minimize the effect of some of these failure modes were initiated during Block I motor manufacture. Most others were initiated before the motors used in tank 10024XTA0008 were assembled at Globe Industries. Failure mode (d) was the basis for the most recent changes affecting these particular motors. Corrective actions to employ extreme care in stator winding and to use phase-to-phase dielectric checks at 300 V rms were incorporated in the winding process. These were followed by a phase-to-phase dielectric check at 250 V rms after the winding was complete and before the terminals were soldered. Effectivity of these actions caught the lower motor in rework and the upper motor in original stator winding. After installation of the heater tube assembly, including the motor fans, Beech tested the motor wiring, shorted together, with 500 V dc to ground.

A listing of the inspection discrepancies issued against serial no. 10024XTA0008 are listed in table C4-I. In the Beech nomenclature these discrepancies are known as Withholding Forms. As stated previously, the motor problem is considered the significant item. The heat-leak problem was not considered serious because many missions required use rates above the minimum flow capability of tank 0008.

The oxygen storage tank assembly is normally handled and tested at Beech Aircraft in the upright position. Vertical motions may compact the tube set to minimum length so as to contribute to dislodgment by minimizing overlap with the upper stub tube nipple of the tank adapter.

Shortly before shipment from Beech, the tank is rotated (tumbled) while in a handling fixture, "to determine if all parts are secure." Since this is the only known source of side forces applied to the fill tube components and since the detanking was apparently normal in the Beech tests, it lends evidence to the assumption that the fill tube components were in the proper position at that time.

Investigation of Manufacturing Process and Supporting Analysis

To gain a first-hand appreciation of the manufacturing process, a visit was arranged to the Beech Aircraft Corporation, Boulder Division, to observe key assembly operations. In addition to a detailed discussion

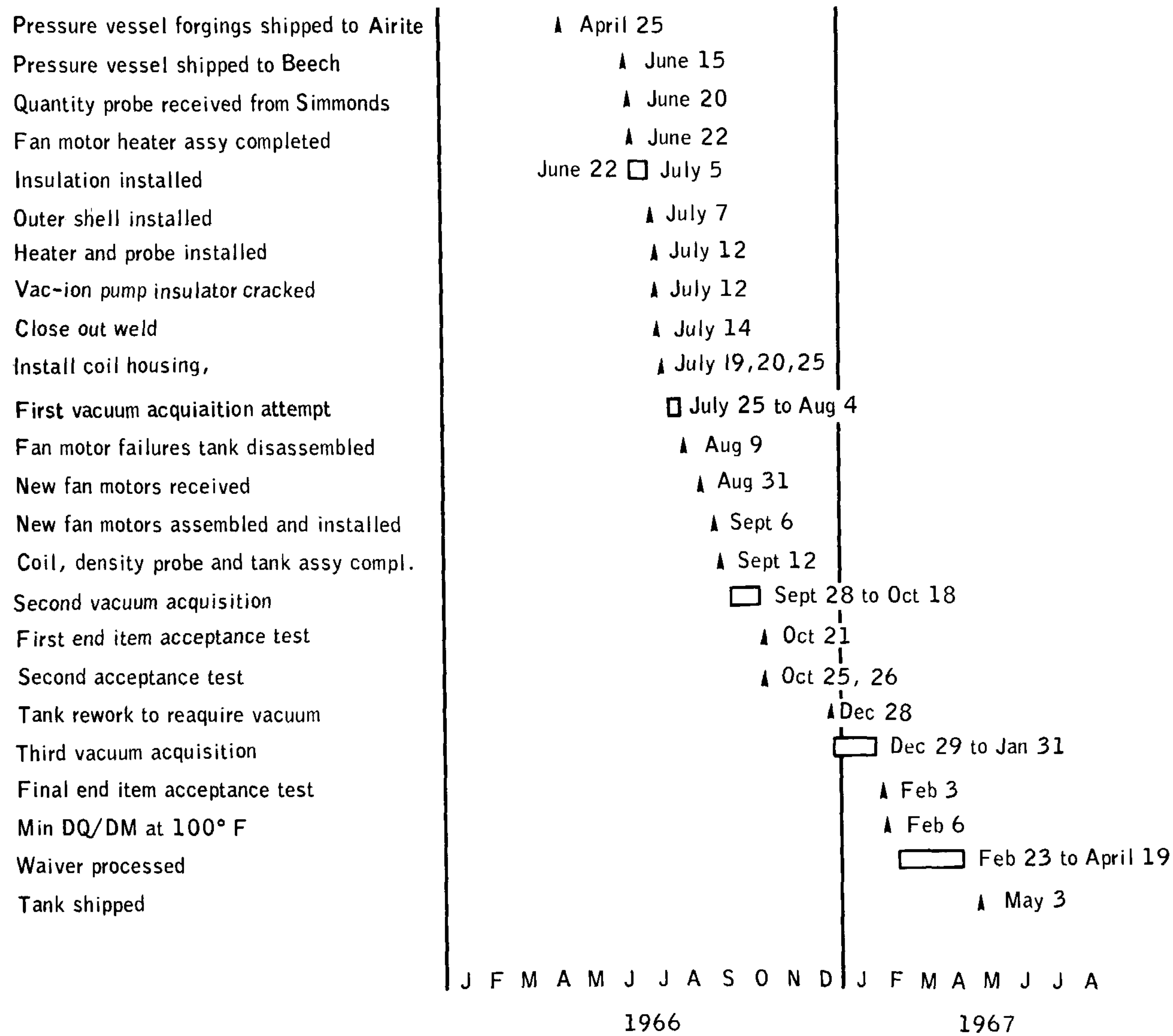


Figure C4-48.- Manufacturing and test flow for the oxygen tank at Beech.

TABLE C4-I.- WITHHOLDING FORMS (INSPECTION DISCREPANCIES)

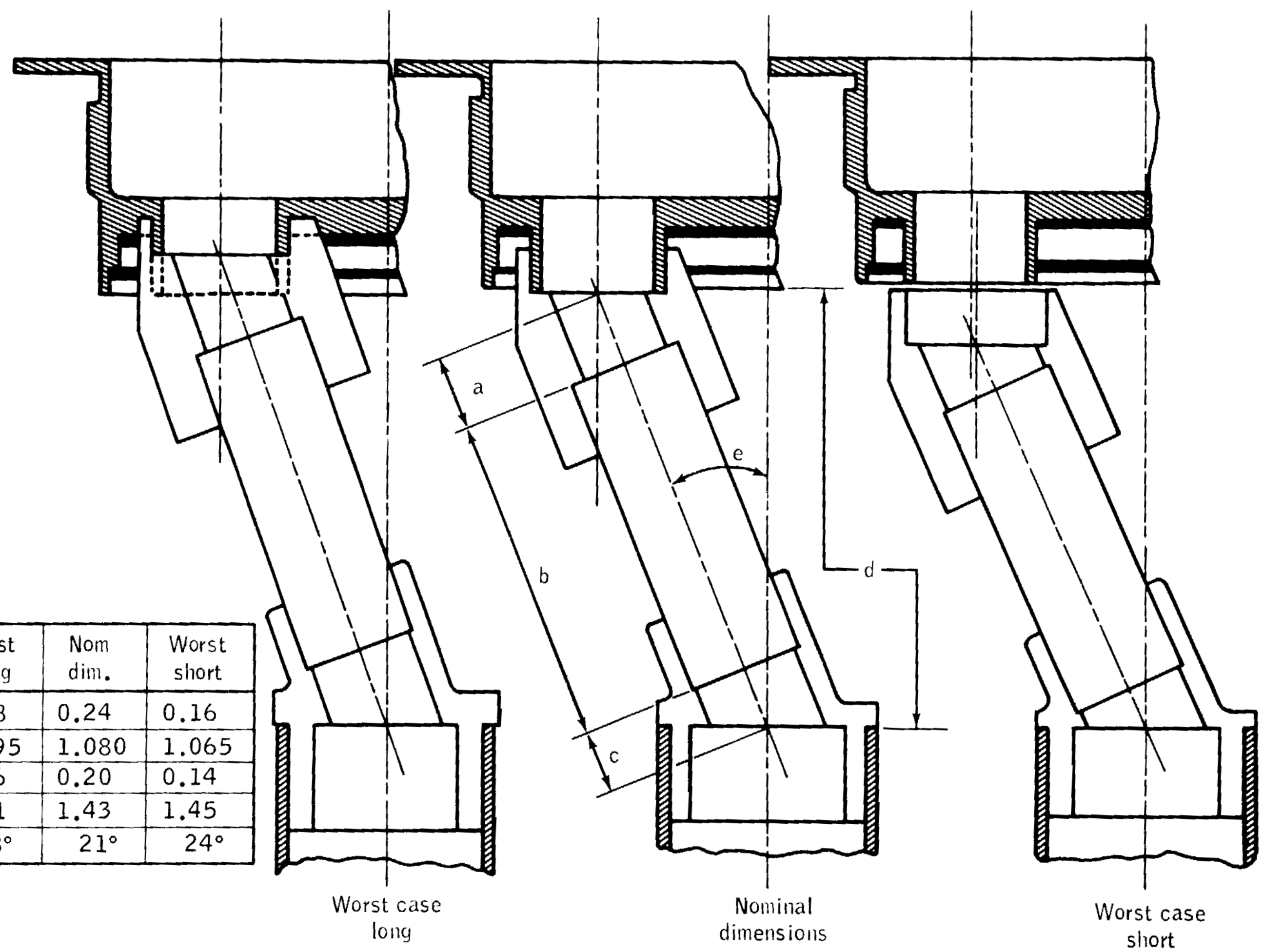
Date	Part name	Part number	Tag number	Reason	Disposition
3-14-66	Heater tube assembly	13532-3527-3	B 00659	Oversize rivet hole 0.132 to 0.128 diameter, 0.006 inch oversize	Acceptable as is
3-28-66	Electrical support	13532-3187-3	C 78515	The 0.180 to 0.190 holes are 0.230 diameter	Acceptable as is
3-28-66	Lower shell assembly	13532-2011-13	C 55461-B	Two oversize pieces of porosity	Grind out and reweld X-ray and leak check
5-10-66	Hemisphere P.V.	13532-3109	C 10846	Out of tolerance condition in clamp ring area - Oversize	Machine to print
5-11-66	Motor fan assembly	13532-4505-3	BO-1133	Motor draws excess current and emits a loud rough noise	Replace
6-1-66	Valve seat	13532-4029-3	B 01073	Valve seat damage when removed per PARR C-55461A	Scrap valve
6-30-66	Coil housing assembly	13532-2086-9	C 43101	Insulator has two cracks along side the weld bead	Replace
7-7-66	Porcelain insulator	13532-4075-1	B 00613A	Parts damaged beyond use	Replace
8-16-66	Motor fan assembly	13532-4505-3	B 01140	Motor failed after 4 hours of operation REFERENCE ONLY	Return to vendor Not acceptable
8-16-66	Motor fan assembly	13532-4505-3	B 01142	Insulation scraped from wire exposing bare conductor REFERENCE ONLY	Return to vendor for repair or replacement
8-23-66	Tank assembly	13532-1501-3	B 01184	Upper motor assembly noisy	Replace
9-2-66	Tank assembly	13532-1501-3	B 01238	MRR voided	Misinterpretation - shadow was thought to be contamination
10-18-66	Heater assembly	13532-2515-3	B 500147	Voided; No W/F required	
12-28-66	Tank assembly	13532-1501-3	B 500016	Flow rate not to specification Call out (CSM 0044)	Waiver approved April 19, 1967

of the step-by-step process, three assembly examples were witnessed within the clean room areas. Specifically, the installation of a lower motor into the heater tube was observed. The assembly of the quantity probe to the tank tube adapter fitting was witnessed. In this particular case, two attempts were required to properly position the small fill tube parts. The entire wire routing process was witnessed. A tank with a large hole in the side provided visibility to the witnesses but not to the assembly technicians. The installation of the heater fan assembly and then the quantity probe provided an appreciation of the real challenge to workmen, that of avoiding damage to the insulation of the wires. This could not have been learned from a study of the drawings alone.

A 10-times-size layout was made of the fill tube connection situation with the parts at the various limits of size permitted by the engineering drawings. In addition to the length tolerances permitted by the drawing dimensions, the diametral clearance also permits the parts to assume angles beyond the ranges stated on the drawings. As an aid to check all the various positions to which these parts could move, individual cutout paper parts were made for the two Teflon bushings and the interconnecting Inconel tube. Figure C4-49 shows that the worst-case short tolerance parts can fall out of position as the tank is moved about. At the other extreme, parts that are at the high end of the permitted tolerances will not assemble. This is shown on the left-hand view. The nominal case provided little or no axial clearance but still does not provide gas-tight seals at the various diameters.

In addition to the tolerance condition that can exist for the fill tube connecting parts, the center tube of the quantity probe could move downward due to Teflon cold flow. The center tube is supported in the axial position by two Teflon bushings installed in the center tube and a semi-tubular rivet. Prolonged heating, such as the vacuum pumpdown cycles (three cycles for this tank assembly resulting in a total of 1532 hours at 190 to 220° F), could result in the thin walls of the center tube slowly cutting into the Teflon bushings.

Table C4-II shows the range of diametral clearances that can exist at ambient conditions (73° F) and at a typical detanking condition (-278° F, which corresponds to the saturation temperature of liquid oxygen at 40 psia). The fit between the Teflon bushing and the tank adapter fitting can result in a maximum 0.003-inch interference. The only other clearance that results in an interference fit occurs if the minimum size holes are provided where the Teflon bushings slide on the 3/8-inch Inconel tube. Tests at liquid nitrogen temperature (-320° F) indicate that the Teflon is not overstressed and does not crack when subjected to interference fits of this type.



Part	Worst long	Nom dim.	Worst short
a	0.28	0.24	0.16
b	1.095	1.080	1.065
c	0.26	0.20	0.14
d	1.41	1.43	1.45
e	18°	21°	24°

Figure C4-49.- Extreme and nominal tolerance cases for fill tube connection parts.

TABLE C4-II.- RANGE OF DIAMETRAL FITS

Zone	Ambient Condition, +73° F			Detanking Condition, -278° F		
	Metal size	Teflon size	Clearance	Metal size	Teflon size	Clearance
Tank adapter fitting to Teflon bushing	0.432 0.456	0.465 0.460	0.033 0.004	0.431 0.455	0.457 0.452	0.026 -0.003
Teflon bushing to Inconel tube (Both ends)	0.375 (Commerical tube size)	0.390 0.380	0.015 0.005	0.374 0.374	0.383 0.373	0.009 -0.001
Teflon bushing to aluminum gaging tube	0.652 (Commercial tube bore)	0.641 0.646	0.011 0.006	0.649 0.649	0.630 0.635	0.019 0.024

Throughout the normal manufacture and test of a cryogenic oxygen storage tank, no intentional procedure calls for the thermostats to interrupt a load. The acceptance testing by the thermostat vendor uses approximately 6.5 V ac to power a small lamp bulb which draws about 100 milliamperes. The fan and heater assembly component acceptance test by Beech uses the thermostats to complete the circuit of Wheatstone bridges to measure the heater resistance values. All other testing by Beech applies power (65 V ac) when tank conditions are such that the thermostats should be closed and remain closed, or momentarily applies a lower power (30 ± 10 V ac) to verify that thermostats are open.

INTEGRATION, SYSTEM TESTING, AND PRELAUNCH CHECKOUT OF THE CRYOGENIC OXYGEN STORAGE TANKS

Summary of Nominal Processes and Procedures

North American Rockwell, Downey, California.- The build-up of an oxygen shelf assembly at NR begins* many weeks before insertion of the cryogenic oxygen tanks with the fabrication of a pie-shaped aluminum honeycomb sandwich structural shelf with large circular cutouts matching the equatorial girth rings of the spherical tanks. On this shelf are next mounted the valves, pressure transducers, flowmeters, and tubing to interconnect these with the fill and vent panel and the storage tanks. Then the tanks are inserted, no. 1 inboard and no. 2 in the outboard position to the left of the fill panel and the valve module (fig. C4-50). To complete the shelf assembly, more tubes and the electrical cabling are added. The Beech signal conditioner assembly for each tank is mounted underneath the shelf.

All oxygen system tubing joints brazed by NR are subjected to X-ray inspection and reheated if necessary to achieve satisfactory joints.

Pressure and leak checks are conducted as are electrical checks of tank circuit elements, i.e., the vac-ion pump, the heater, motor fans, thermostats, and temperature sensor under dry gas conditions within the oxygen tanks. The thermostats are tested for both opening and closing temperatures by use of nitrogen gas purge with variable temperature control and monitoring each thermostat with a digital volt meter. Essentially no current is interrupted in these tests. Such tests are repeated in accordance with detailed Operational Checkout Procedures (OCP's) until all gas leaks or electrical wiring problems have been isolated and corrected and the oxygen shelf assembly is ready for installation in the

*Use of the present tense in this section of the Panel report implies current practices as of 1967-68.

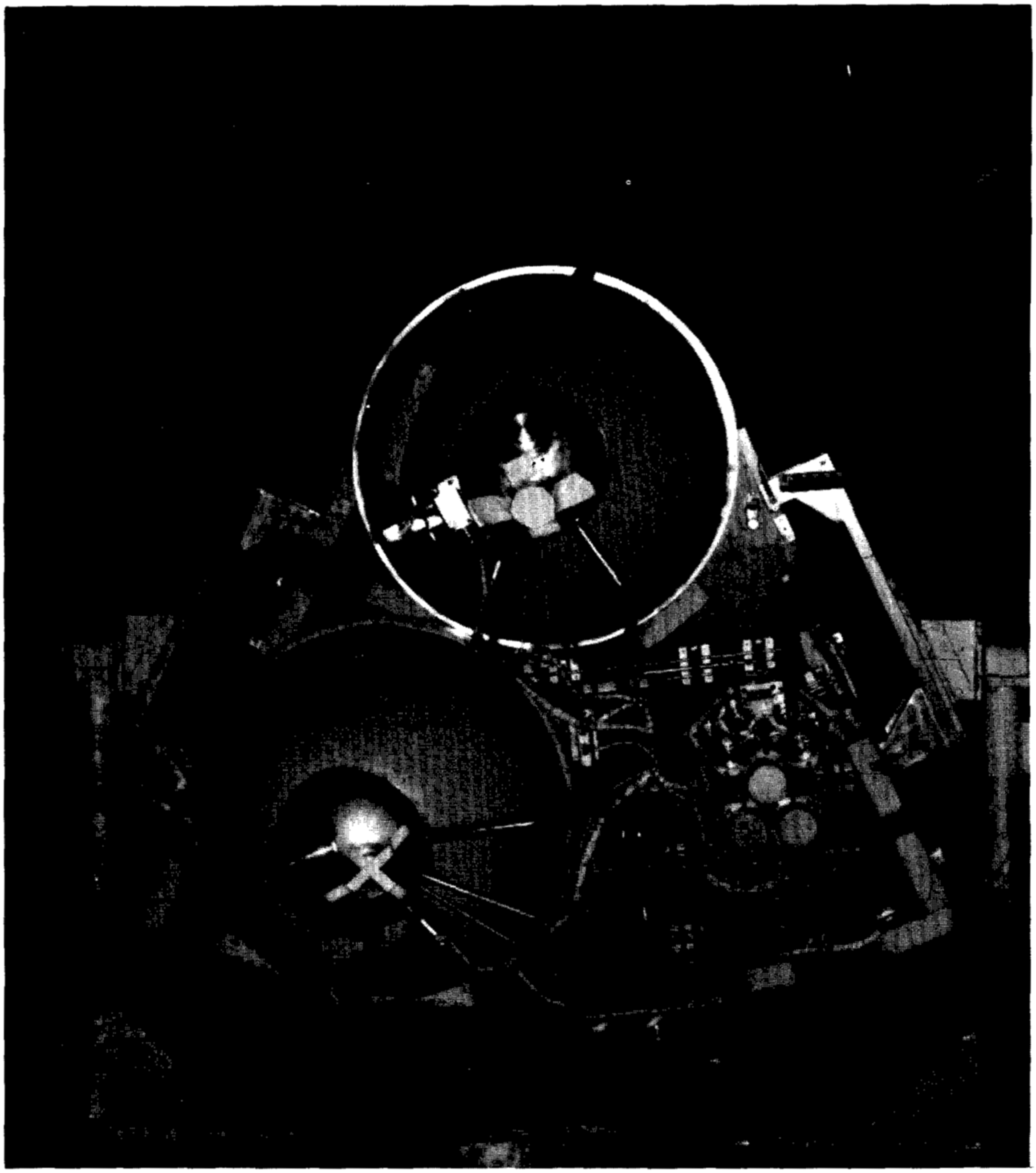


Figure C4-50.- Oxygen shelf with tanks 10024XTA0008 and 10024XTA0009 installed.

service module. A proof gas pressure of 1262 psi is used, followed by leak testing at 745 psi. The vac-ion pumps of the oxygen storage tank vacuum jackets are turned on at least twice during typical oxygen shelf checkout and oxygen system checkout at NR. These tests are conducted with an NR test engineer, manufacturing test conductor, technicians, and quality control personnel, and a NASA quality control representative present. No cryogenic oxygen is used in any of these tests.

After the oxygen shelf assembly is installed in the service module, various gas tubing and electrical connections are completed. The oxygen tank, tubing, and valves thereafter participate in oxygen subsystem testing of the service module, fuel cell simulator tests, and fuel cell interface verification in accordance with Detail Checkout of Systems (DCS's) requirements. Liquid nitrogen is used to introduce a cold nitrogen gas into the oxygen tank to cause the thermostats to close so that a heater circuit continuity test can be conducted. Spacecraft bus power (30 V dc) is applied to the heater circuits and an increase in current is used to verify thermostat closure. After water/glycol system test and final shelf inspection, cryogenic oxygen System Summary Acceptance is accomplished with NASA/MSC participation and recorded in the System Summary Acceptance Document ("SSAD book").

The discipline at NR, Downey, is that of controlled procedures and hardware traceability from the controlled material and equipment stores through assembly and test operations. This discipline produces requests for review or assistance from design engineering for instances of quality or test discrepancy considered to be significant.

<u>Transportation from North American Rockwell to KSC</u>.- Shipment of the service module from NR, Downey, is made on a pallet which holds the axis horizontal in the fore and aft direction of trucks and aircraft (fig. C4-51). The sector in which the oxygen shelf is installed is on the underside in this orientation so that the shelf centerline points vertically down. Shock and vibration instrumentation of various service module flights in the Pregnant Guppy and Super-Guppy special aircraft of Aero Spacelines have shown no peak vibration loads exceeding one-g for vibration-isolated movements of the service module.

<u>Kennedy Space Center</u>.- After command and service module mating, at the Manned Spacecraft Operations Building-KSC, the oxygen shelf assembly as a part of the service module participates in combined system test, altitude chamber test, systems integrated test, and flight readiness test in accordance with established Test and Checkout Procedures (TCP's). These tests are conducted as dry gas pressure and electrical function verifications similar to those of the factory OCP's and DCS's at Downey. No specific test is run to verify thermostat operation; however, during the conduct of a pressure switch test sequence, the thermostats may open the 28 V dc heater load.

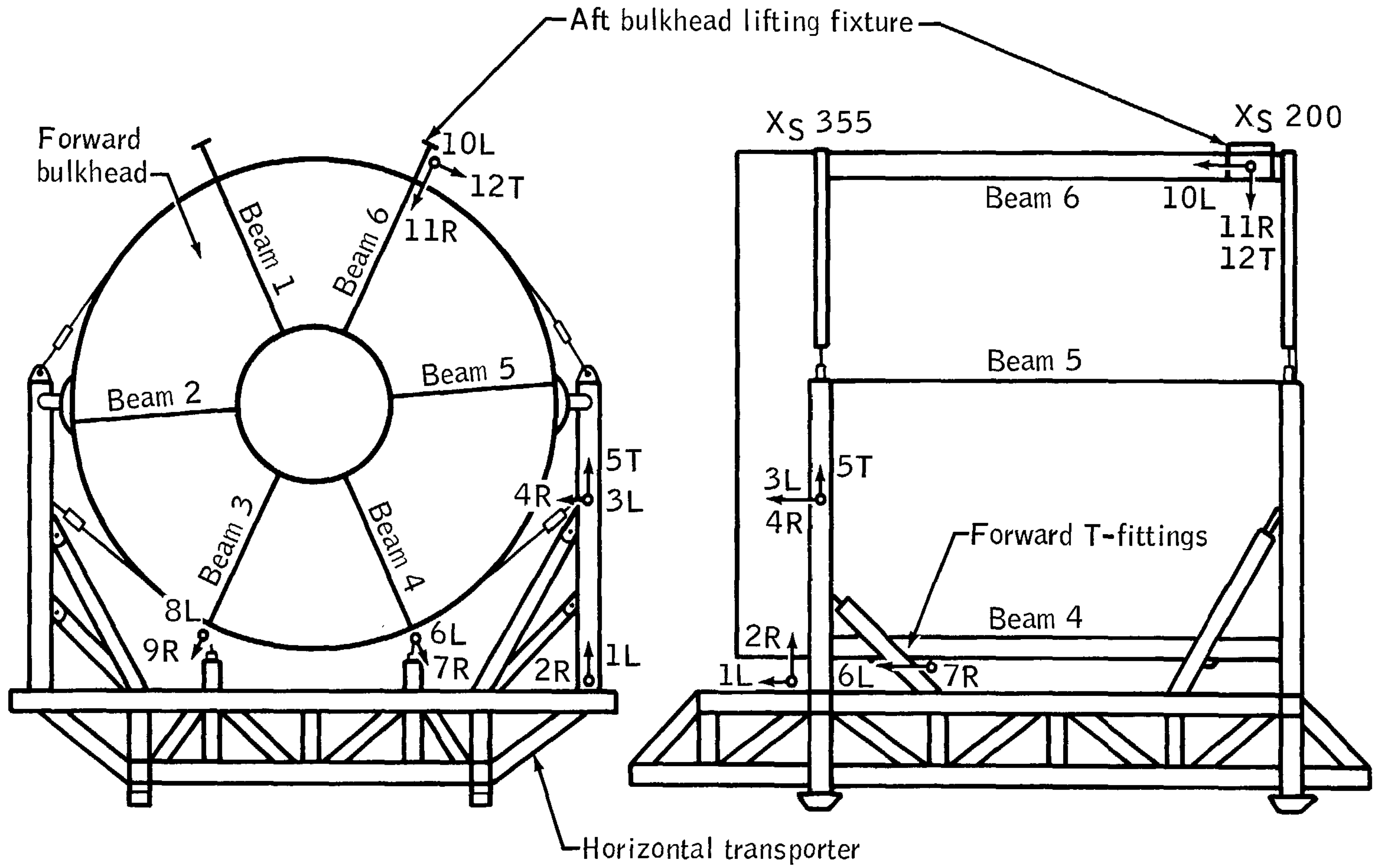


Figure C4-51.- Pallet holding axis horizontal in fore and aft direction of trucks and aircraft.

The vac-ion pumps of the oxygen storage tank vacuum jackets are normally turned on during three test periods at KSC including countdown. The circuit breakers to the vac-ion pumps are opened before launch.

After integration of the CSM with the Saturn launch vehicle in the Vertical Assembly Building, the complete vehicle is moved to Pad 39. As a part of the CDDT, which normally occurs 14 days before launch, the CSM storage tanks are fully loaded with liquid oxygen. The functioning of the fans is checked and heater operation verified by using a ground supply of 65 V dc to raise the tank pressure to about 300 psi. Shortly thereafter it is necessary to partly empty the oxygen tanks through a process known as "detanking." Two or three days later, at the conclusion of the CDDT, detanking is again used to empty the tank.

Initial detanking consists of two sequences. First, the internal pressure of the tank (residual to the CDDT) is vented through the vent. Next, warm gaseous oxygen is fed through the tank vent lines at 80 psia to expel liquid through the fill lines down to 50-percent full. Detanking for tank emptying proceeds similarly at the end of CDDT. Then warm gas is blown through to verify that the thermostats remain closed up to at least -75° F. This step employs the application of only 10 to 15 V dc to the heater circuit.

This loading, checkout, and detanking is the first time the cryogenic functions of the oxygen storage tanks are evaluated since the acceptance test at Beech Aircraft, Boulder, Colorado.

The oxygen tanks are filled to capacity during actual countdown in order to prepare for launch.

During the CDDT and during the final countdown, as long as the Mobile Service Structure (MSS) is connected to the Launch Umbilical Tower (LUT), the heaters are powered from the ground supply system. The power distribution station from where the heaters are powered is located at the base of the LUT. The voltage from this power supply is automatically regulated at 78 ± 2 V dc and recorded. There is approximately 13 volts line drop along the connecting leads, resulting in about 65 V dc across the heaters, producing a current of about 6 amps through each heater element. This higher power operation is used to more rapidly raise the tank pressure to the operating range.

The MSS is disconnected from the LUT at about 18 hours before T - 0 in both the CDDT and the final countdown. For operational reasons the power supply to the heaters is switched at this time to the busses of the spacecraft with 28 to 30 V dc (about 2.8 amperes through each heater element) which are powered through the umbilical from the ground supply system. At T - 4 hours, during the launch preparation, the busses of the spacecraft are switched to the fuel cells. The destratification fans are independent from the heaters and at all times powered from the spacecraft.

Summary of Significant Aspects of Serial No. 0008 Tank Prelaunch Integration Test and Checkout History

North American Rockwell, Downey, California.- Oxygen storage tank 10024XTA0008 was installed in the no. 2 (outside) position of oxygen shelf S/N 06362AAG3277 at North American Rockwell, Downey, California, soon after receipt in May 1967. Two disposition reports were written during October 1967 to require reheat and reinspection of brazed tubing joints on the oxygen shelf found unacceptable in reading of X-rays. These joints were reheated and accepted. Completion of oxygen tank installation, including tank 10024XTA0009 in the no. 1 position, was accomplished March 11, 1968. Manufacturing and test flow for the oxygen shelf is displayed chronologically in figure C4-52.

Two disposition reports noting an "indentation" and a "ding" in the tank outer shell were filed and accepted--use as is--in March and April 1968.

During April and May 1968, 11 disposition reports were written to log tank no. 2 anomalies found during proof-pressure, leak-check, and functional checkout of the assembled oxygen shelf. Eight of these were ascribed to test procedure problems, two to a valve module (check valve) tubing leak and one to an electrical connector pin. The leak was rewelded by a Parker technician and passed leak test. The pin was repaired by NR and checked.

In accordance with the normal OCP and after leak and electrical repairs, the shelf assembly was completed and tested. It was installed in CSM 106 June 4, 1968. Thereafter, in compliance with several DCS's for subsystem test, a fuel cell simulator test, and fuel cell interface verification, the oxygen shelf participated in service module detailed checkout steps.

After installation of this oxygen shelf in SM 106, eight disposition reports were written during installation, additional tubing connection and subsystem line proof-pressure and leak check, and electrical cabling checking. Of these, two problems with a hydrogen relief line mounted adjacent to the oxygen shelf were solved by making up new tubing and later reheating a brazed joint to meet X-ray control requirements. Three oxygen subsystem leaks were solved by retorquing caps and a "B" nut on oxygen lines leading to fuel cell no. 2. The three remaining disposition records expressed questions concerning leak and electrical function testing of the oxygen shelf assembly which were held open pending the next opportunity for shelf assembly testing.

On October 21, 1968, in response to directives requiring rework of the vac-ion pump dc-to-dc converters to reduce electromagnetic

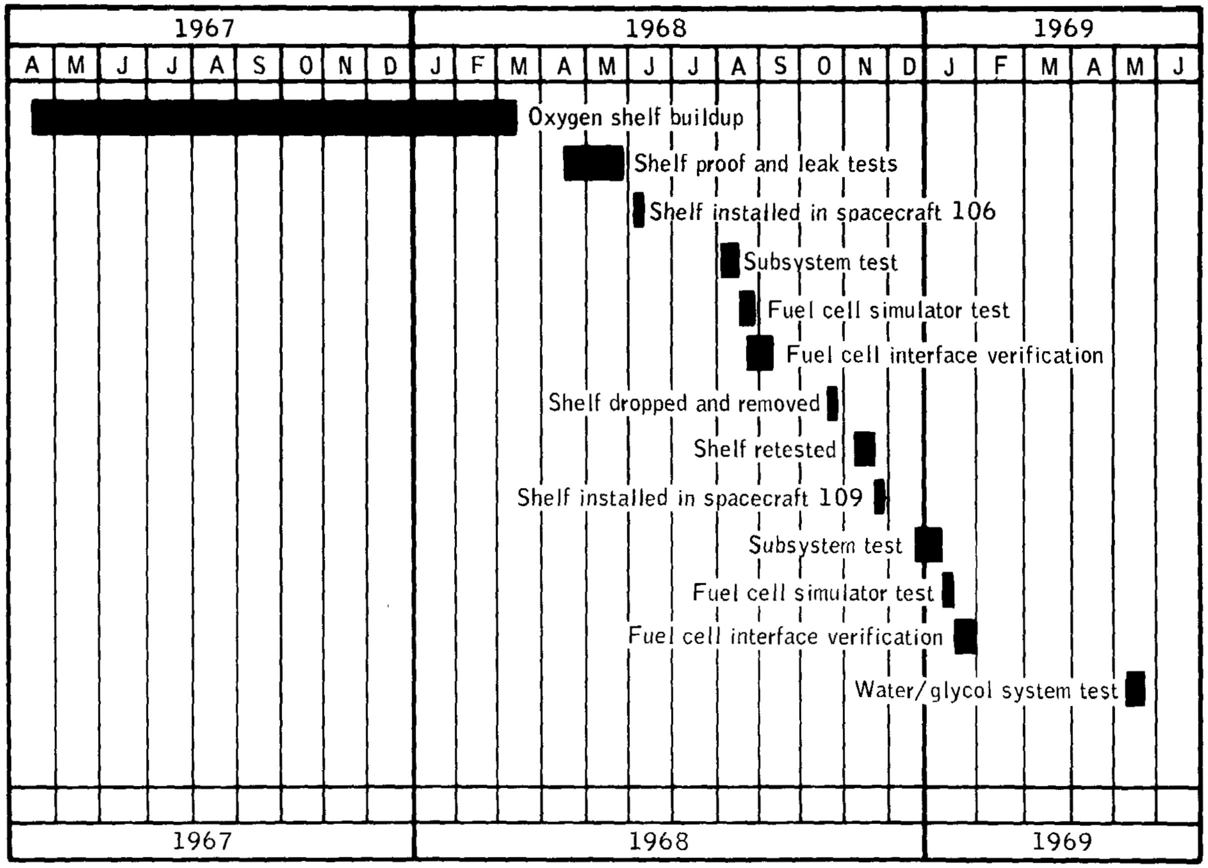


Figure C4-52.- Manufacturing and test flow for the oxygen shelf.

interference problems (a supplementary potting operation performed by Beech personnel at North American Rockwell), an attempt was made to remove the oxygen shelf from SM 106.

In preparation for this attempt, the 10 bolts attaching the shelf to the adjacent beams were removed. The existence of a small, 11th bolt introduced from underneath and behind tank no. 1 was overlooked by all persons involved. The factory crew brought into position a lifting fixture particularly devised for inserting tanks and shelves into sectors of the service module (fig. C4-53).

This fixture is composed of two parts joined at a bolted flange. The universal part is an adjustable counterbalance. The weights of this counterbalance are movable from the factory floor through endless chains. The particular part for handling to the oxygen shelf is a two-tined fork welded together from large thick-walled aluminum tubes. The tine tips are padded where they contact the underside of the shelf to support its inner portion. The outer edge of the shelf is fastened to the lifting fork by means of two screws passing through tabs on the top of the fork cross-member.

Under the particular circumstances of October 21, 1968, the unnoticed 11th bolt into the shelf served as a tie-down beyond the tips of the lifting fork such that raising the fixture produced rotation of the entire assembly, most noticeably the counterbalance. The 11th bolt still was unobserved. Attempts were made to balance the fixture by moving a weight and to lift the assembly by operating the overhead bridge crane. In these steps sufficient load was placed on the fixture to break it above the cross-arm of the fork.

The oxygen shelf moved and came to rest on the supporting beams through what was at the time described as a "2-inch drop". Observation of adjacent portions of SM 106 identified minor damage, including a dent in the underside of the fuel cell shelf above.

Figure C4-54 shows the repair patch over this dent immediately above the vacuum pinch-off cover can of tank no. 2 in the oxygen shelf that replaced the one undergoing the "shelf drop" incident in SM 106.

Further attention to the oxygen shelf containing tank 10024XTA0008 in the no. 2 position after its removal from SM 106 involved a number of quality, test, and repair actions. These were logged on 11 separate Disposition Records (NR numbered forms recording discrepancies observed through manufacturing inspection and test activities at Downey). One other such form was initiated at the time of the "shelf drop" and was treated primarily as a requirement to inspect, repair, and re-inspect the adjacent portions of SM 106, including specifically the dented fuel cell shelf.

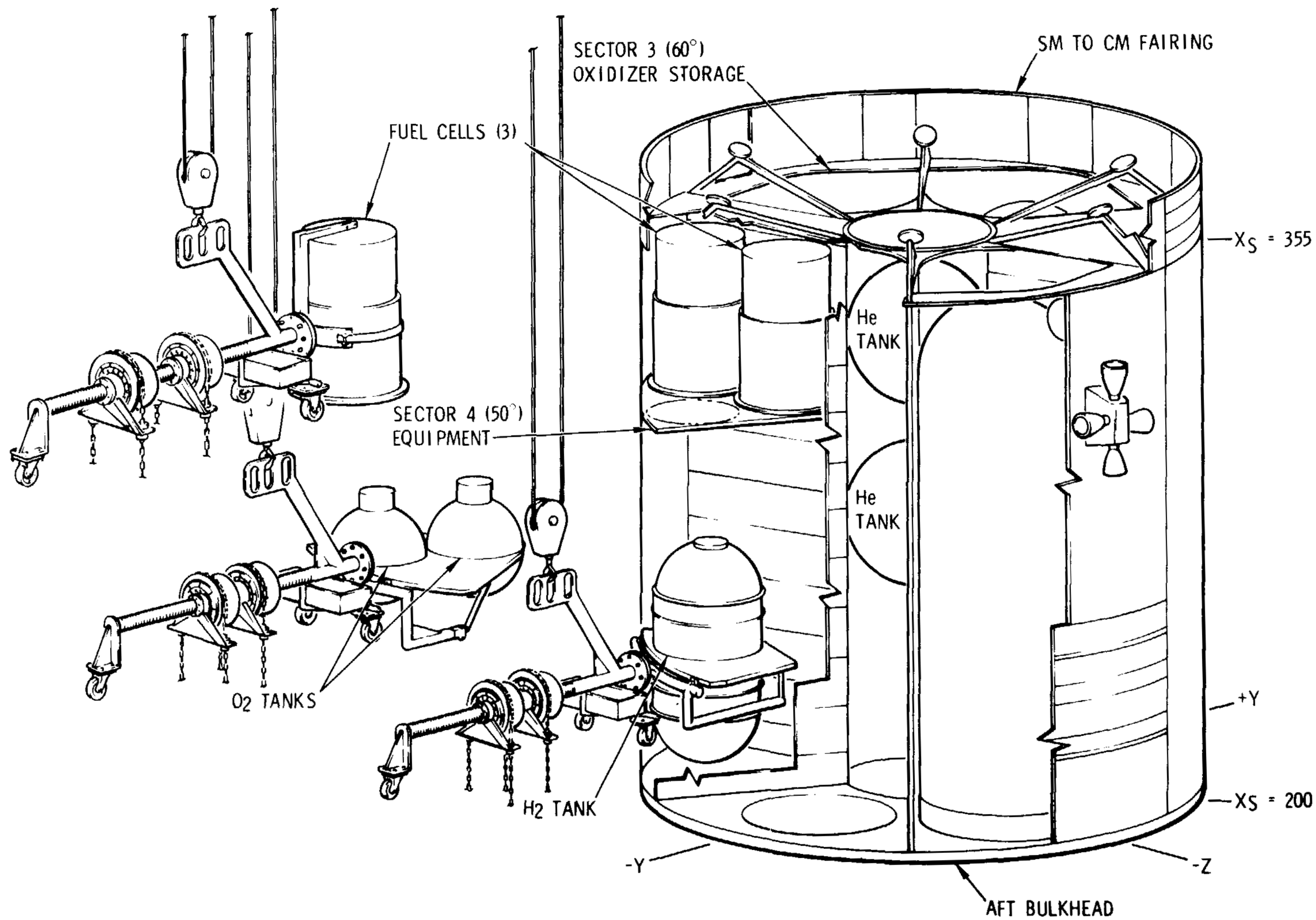


Figure C4-53.- SM bay 4 tank installation.

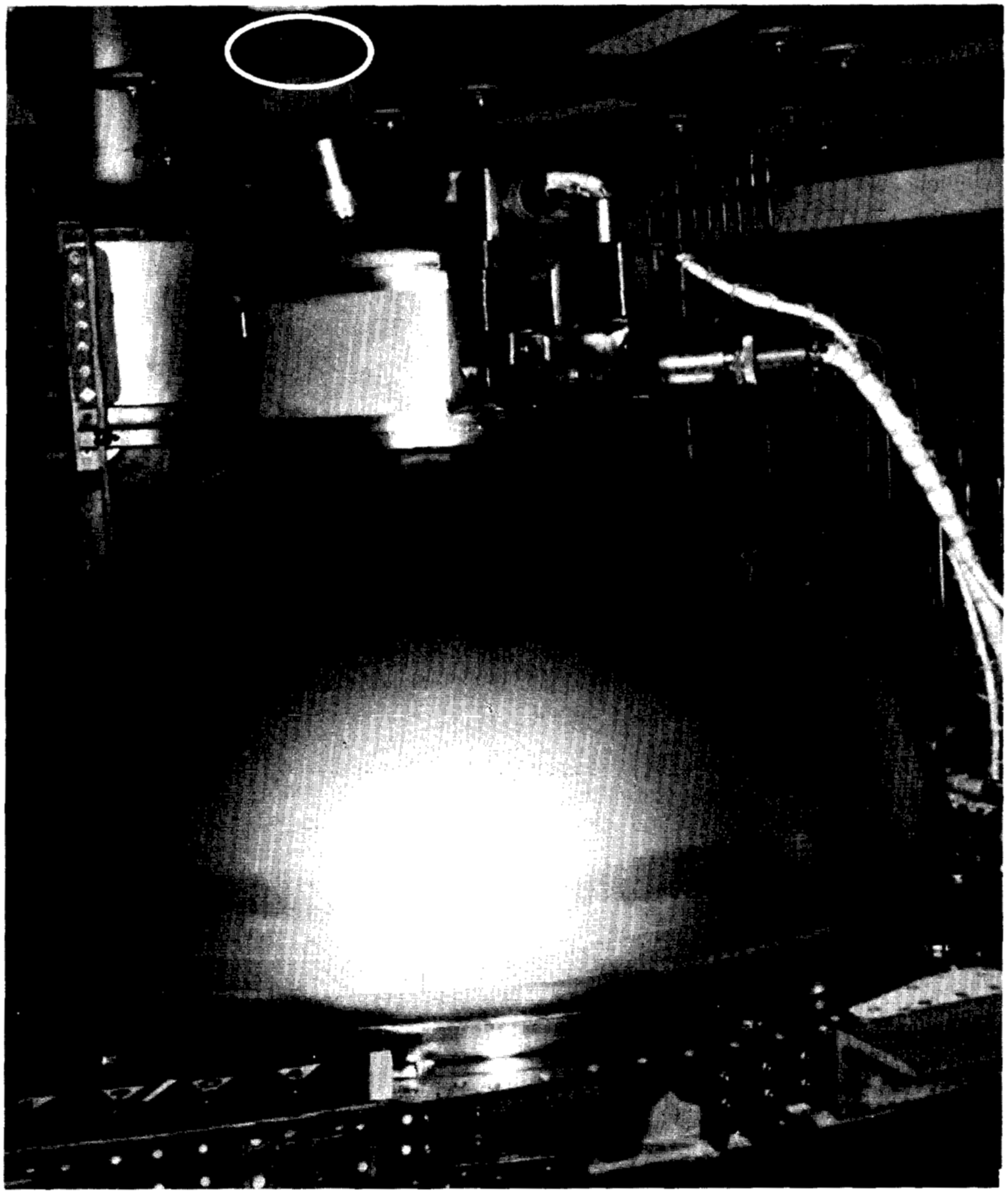


Figure C4-54.- Replacement oxygen shelf installed in Service Module 106. Note repairs to fuel cell shelf over oxygen tank no. 2.

Of the 11 DR's, five report anomalous conditions of detailed portions of the shelf assembly observed and recorded from November 1 to November 19, 1968. In response to these DR's, EMI tests and leakage tests were conducted, results were accepted, and some repairs were made. The leak tests of bent tubing carrying tank no. 1 pressure, upstream from valves, were accepted in material review. The latter involved polishing out tank outer shell scratches, adjusting several electrical connectors, replacing damaged cable clamps, and coating damaged potting. It is not certain but it is possible that some of these conditions relate to the "shelf drop" incident.

The remainder of the DR's of the period relate to testing the oxygen shelf to revalidate it for installation into SM 109. A shortened version of the normal pre-installation OCP, including pressure and external leak testing and verification of electrical functions of most of the tank elements, was conducted. Fan motor, heater, fuel cell reactant valve, relief valve, pressure switch, and motor switch functional checks were omitted. Coupling leak checks and check valve internal leak valve checks were omitted. Signal conditioner checks, for density and temperature signals, were omitted. Verification of these matters was left for and accomplished in oxygen system tests at higher levels of CM and SM integration. The shelf was then installed (fig. C4-55). The upper one of the two accepted bent tubes shows at the extreme right of the figure. The lower one, bent 7 degrees as it joins the back of the fuel cell valve-module, is in the lower right corner.

In December 1968, after concern for a possible oil contamination of facility lines, GSE hose connections were checked for contamination and found acceptable. Vent line samples taken later, at KSC during cryogenic tanking, verified that no contaminants reached the spacecraft interfaces.

Engineering requests for recalibration of the oxygen system pressure instrumentation and the oxygen quantity signal conditioner of the assembly were responded to in January and February, 1969.

Final inspection and cleanup of the shelf in the service module was accomplished on May 27, 1969. The oxygen SSAD book was signed off June 6, 1969, and SM 109 was shipped to KSC.

Transportation from North American Rockwell to KSC.- Shipment of SM 109 from Downey to KSC was accomplished by the normal means, horizontal mounting on a vibration isolating pallet carried on ground vehicles and a Super-Guppy aircraft. No shock was observed in the instruments carried.

Kennedy Space Center.- The oxygen tank and shelf assembly participated in normal service module tests beginning with the Combined Systems Test. Test and checkout flow at KSC are shown chronologically in figure C4-56.

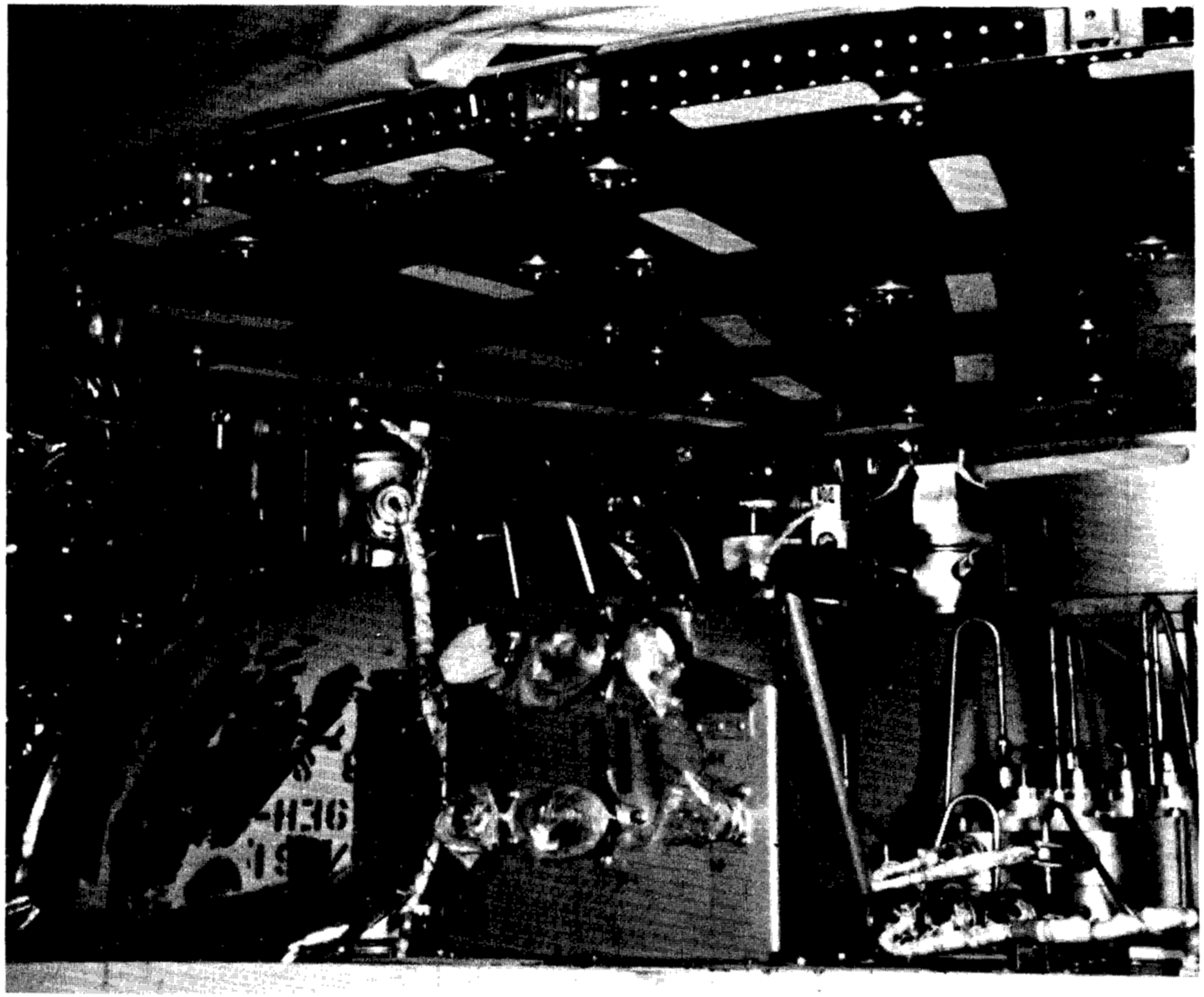


Figure C4-55.- Oxygen shelf installed in service module.

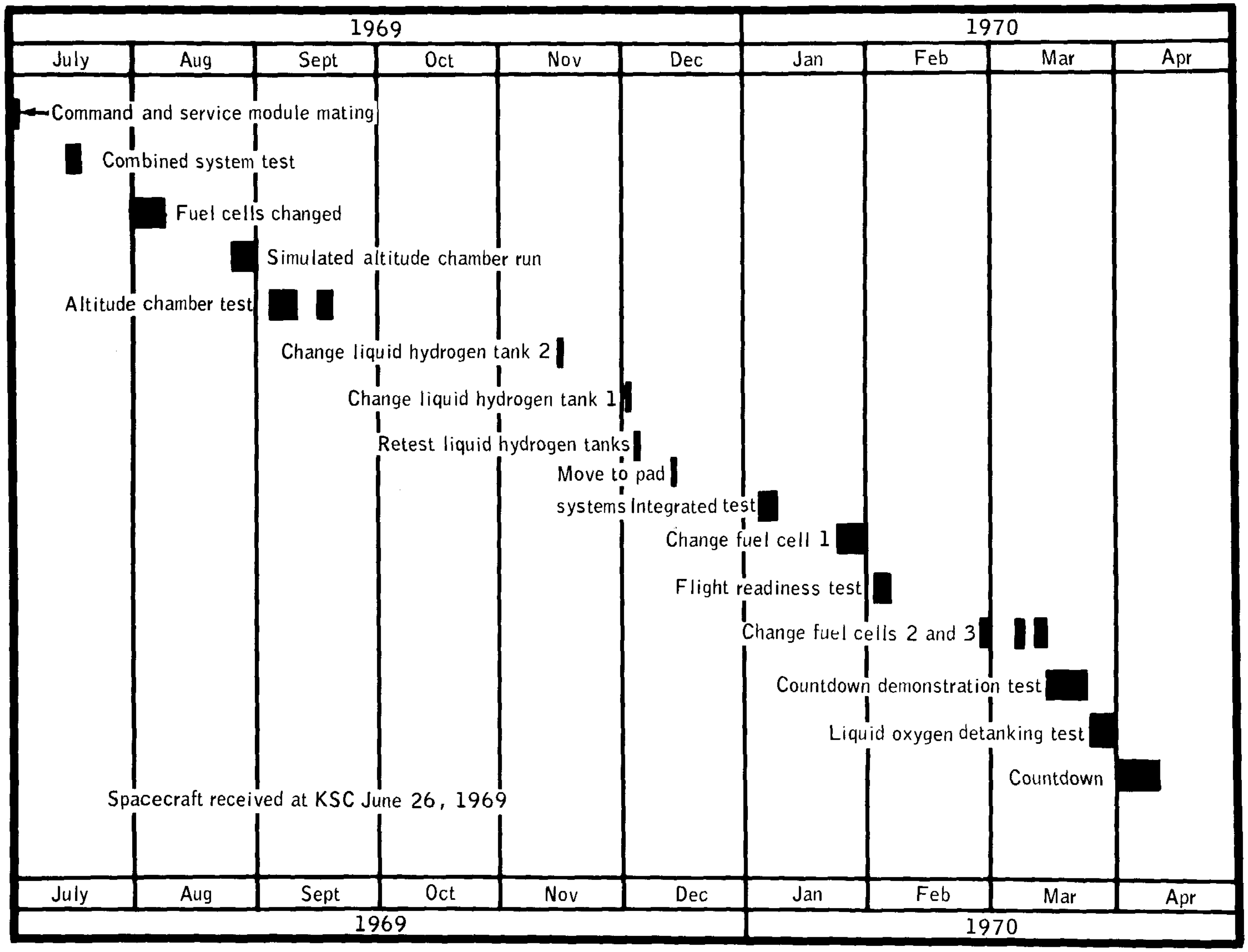


Figure C4-56.- Test flow for oxygen shelf at KSC.

A leak check was performed July 18, 1969, using helium at 94 psia in oxygen tank no. 2. Tank no. 2 was pressurized to 1025 psia to establish the relief valve cracking pressure and to verify the pressure switch operation. The pressure was decreased to 870 psia and then increased to 954 psia during the first integrated test with the launch vehicle simulator. The oxygen tanks no. 1 and no. 2 were evacuated to less than 5mm Hg, to dry the tanks, then pressurized to about 80 psia with reactant grade gaseous oxygen. Instrumentation was verified and fan motors were checked out.

A progress photograph (fig. C4-57) taken at KSC on November 14, 1969, shows the visible condition of the oxygen shelf with tanks, valves, tubing, and cables.

During the Flight Readiness Test in early February 1970, the pressurization cycle was repeated; vacuum to 5mm Hg and oxygen pressure to about 80 psia.

At the CDDT in March after activation of the fuel cells, the same cycle was followed: vacuum of the oxygen tanks to 5mm Hg followed by a gaseous oxygen pressure of about 80 psi. After the cooling of the fuel cells, cryogenic oxygen loading was normal and tank pressurization to 331 psia by using heaters powered from 65 V dc ground power supply was completed without abnormalities.

During these CDDT operations on March 23, tank no. 1 was detanked to the normal 50 percent within less than 10 minutes. Over the space of 45 minutes, tank no. 2 did not detank normally but was observed to retain more than 90 percent of its oxygen. Detanking was suspended until the completion of CDDT.

On March 27, detanking of tank no. 2 was again attempted. The tank had self-pressurized to 178 psia with a quantity of 83 percent indicated. By opening the fill line valve the pressure was depleted to approximately 36 psia in about 13 minutes. The quantity indication went down to about 65 percent (see fig. C4-58).

Next, during detanking attempts for both tanks, a comparison of tank no. 1 and tank no. 2 performance was made. The indicated oxygen quantity of tank no. 1 depleted from 48 percent to zero in less than 10 minutes. The indicated quantity in tank no. 2 remained above 60 percent over a 20-minute period.

Attempts were made over an 80-minute period to deplete the oxygen content of tank no. 2 by cycling up to various pressures and down, but did not reduce the indicated quantity below 54 percent (fig. C4-59). An attempt was made to expedite oxygen expulsion through the use of the tank heaters operated at maximum voltage and the fans. These were turned on for nearly 6 hours while the vent port remained open (fig. C4-60). Still the indicated quantity remained above 30 percent.

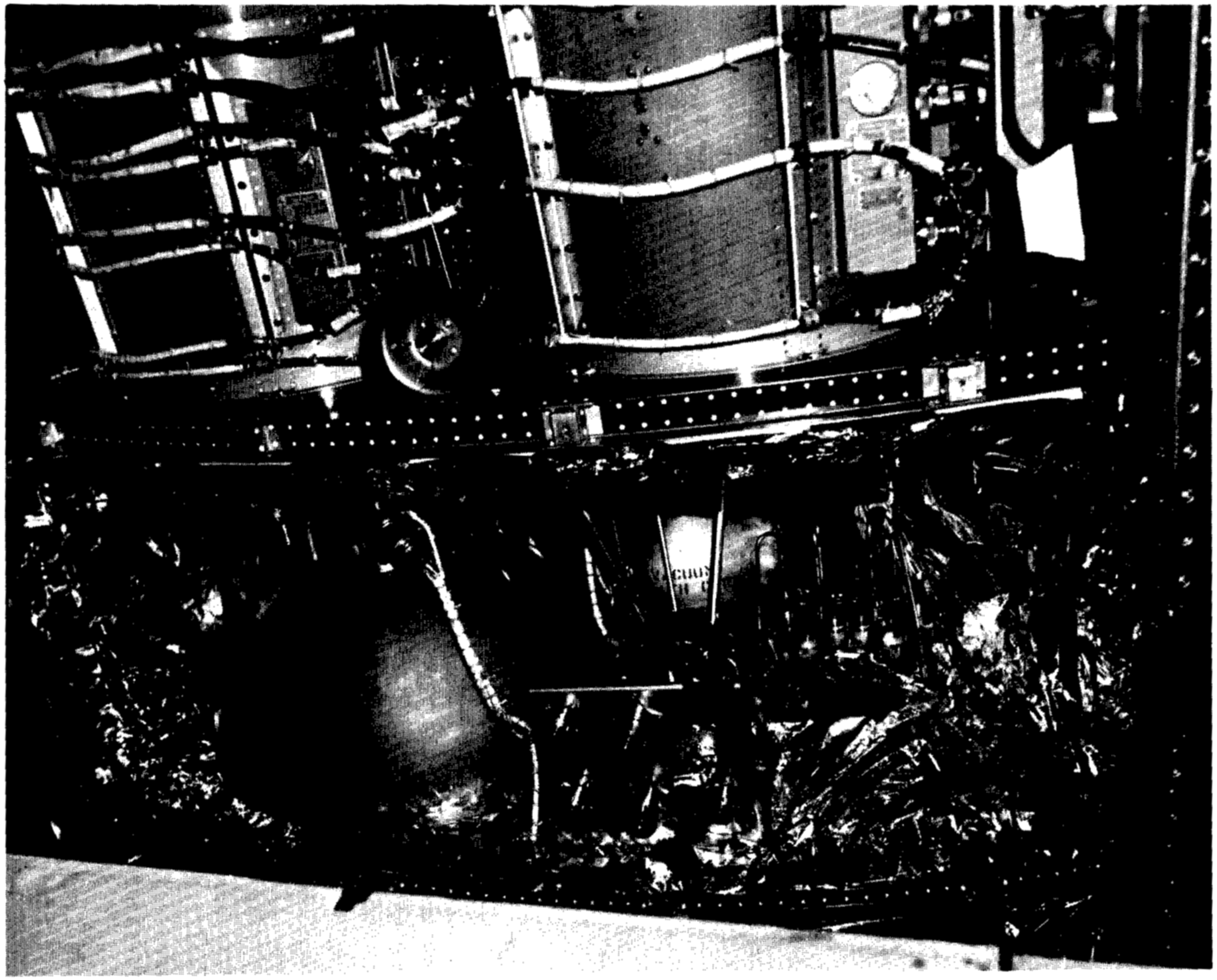


Figure C4-57.- Progress photograph of oxygen shelf taken at KSC
November 14, 1969

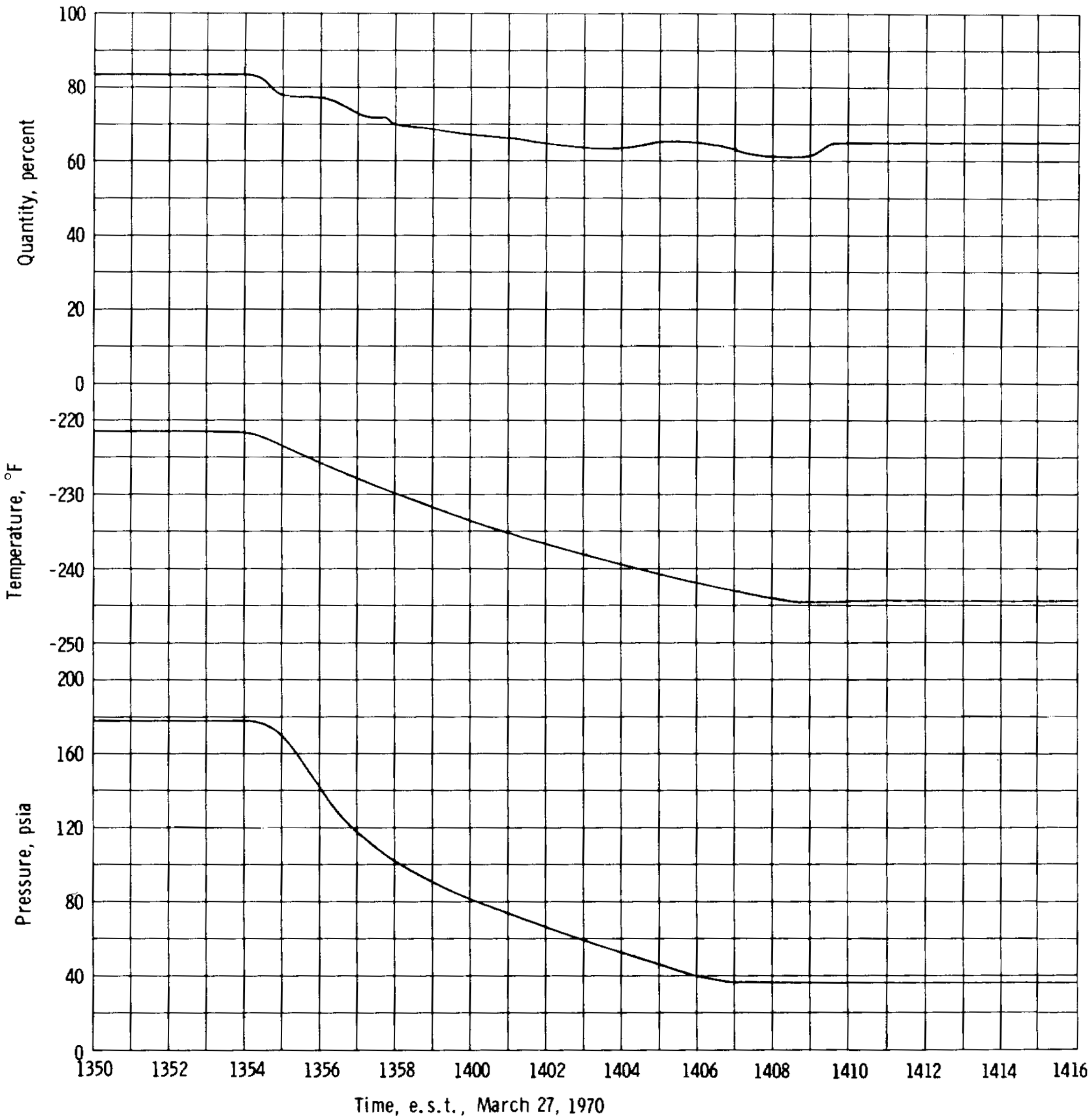


Figure C4-58.- Oxygen tank 2 detanking characteristics (pressure decay through the fill line - CDDT).

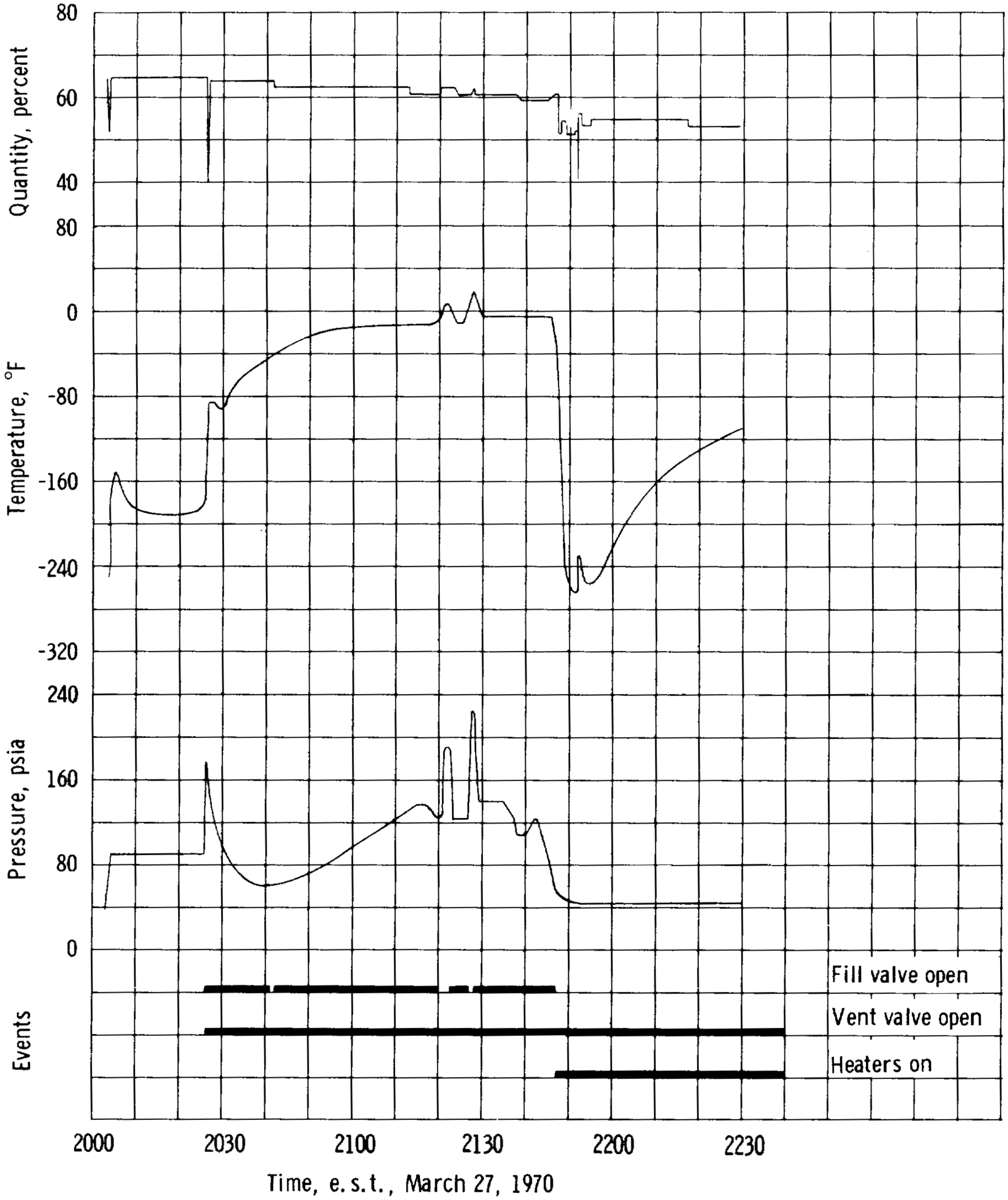


Figure C4-59.- Oxygen detanking attempt using varying purge pressure.

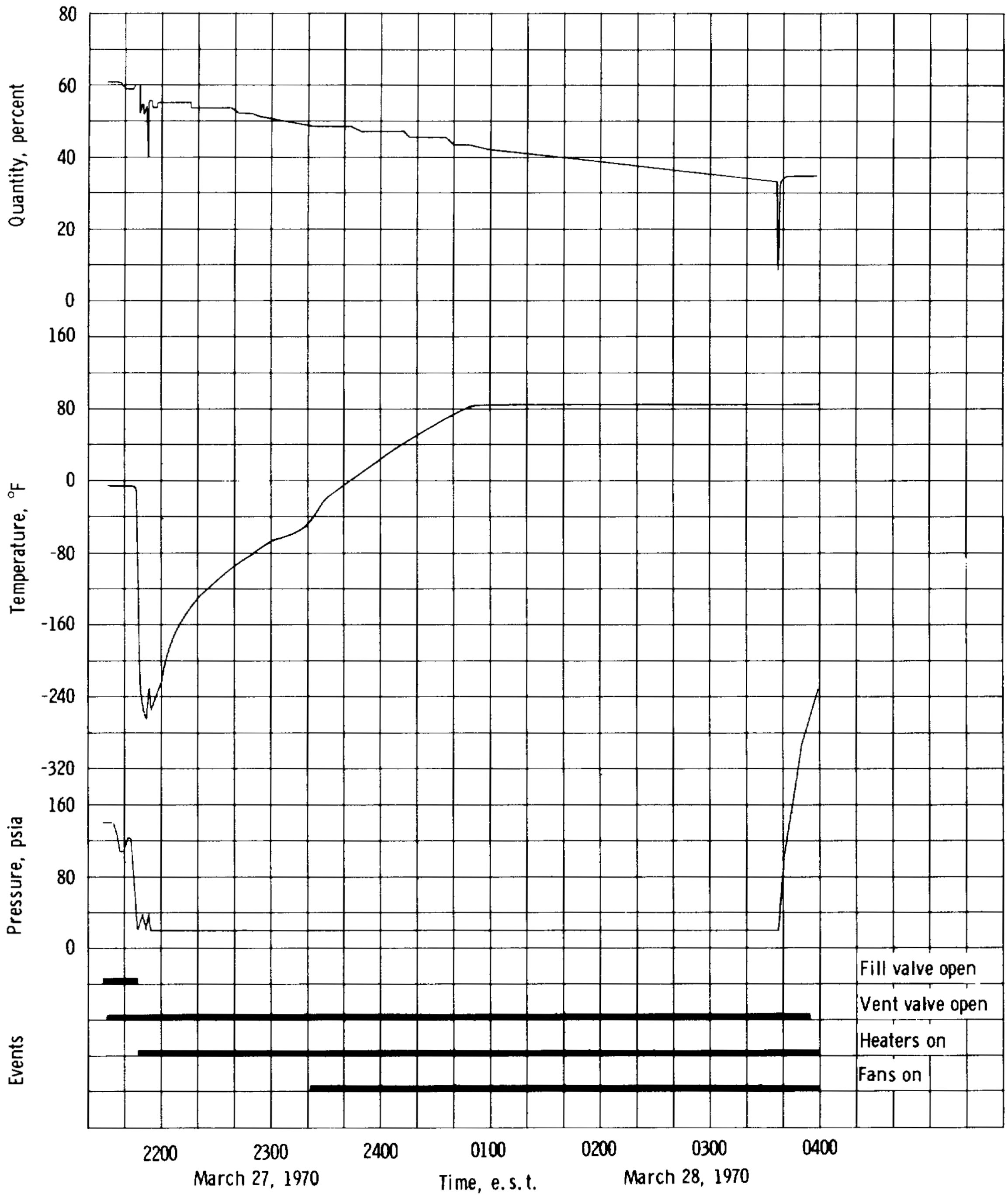


Figure C4-60.- Oxygen detanking attempt using tank heaters.

Then a pressure cycling technique was employed over a 2-1/2 hour period with maximum power being applied continuously to both tank heaters and fan circuits (fig. C4-61). This technique involved raising the tank pressure by external gaseous oxygen to approximately 300 psia and then opening the fill line to induce rapid boil-off. After five cycles, the oxygen tank quantity indicated zero.

Fan responses were observed to be normal throughout these operations. The temperature sensor on the quantity probe reached its indicating limit (+84° F) halfway through the 6-hour heating period. No observations of whether the heaters cycled on and off were made and subsequent review of the power supply voltage recording showed no indication of heater cycling.

Concern developed over two alternate hypothetical tank no. 2 conditions, a leakage path in the fill line within the tank or a clogged fill line.

Gaseous flow tests were used in one attempt to evaluate the latter. Both tank no. 1 and tank no. 2 were pressurized to approximately 240 psia and blown down through the fill lines with no significant differences in blowdown time (fig. C4-62).

A check of the Wintec filter in the GSE for oxygen tank no. 2 was made by the Wintec Corporation. No significant foreign material was found.

The alternate hypothesis, that the short segments of fill tube in the top of the quantity probe of tank no. 2 had large gaps or had become dislodged, was considered as were the operational difficulties associated with the use of a tank in this condition. The concern here was that the loading process might be hampered by the position of the fill line parts. It was noted that the filling was normal for the CDDT.

To verify this judgment and to assure countdown operability, both tanks were filled on March 30 to about 20 percent in approximately 2.5 minutes. Tank no. 1 detanked normally; tank no. 2 did not. Again the procedure of applying heat at maximum voltage and the cyclic application of gas pressure of approximately 250 psia and then venting was used. Five cycles were applied in a 1-1/4 hour period and tank no. 2 was emptied (fig. C4-63). The fan responses were observed to be normal and no indications of heater cycling were observed.

During the countdown, April 8, 1970, the pressurization of oxygen tank no. 2 was hampered by a leak through the vent line pressure-operated disconnect. Installation of the first cap stopped the leak and the pressurization of tank no. 2 was normal with no anomalies noticed during the completion of the countdown.

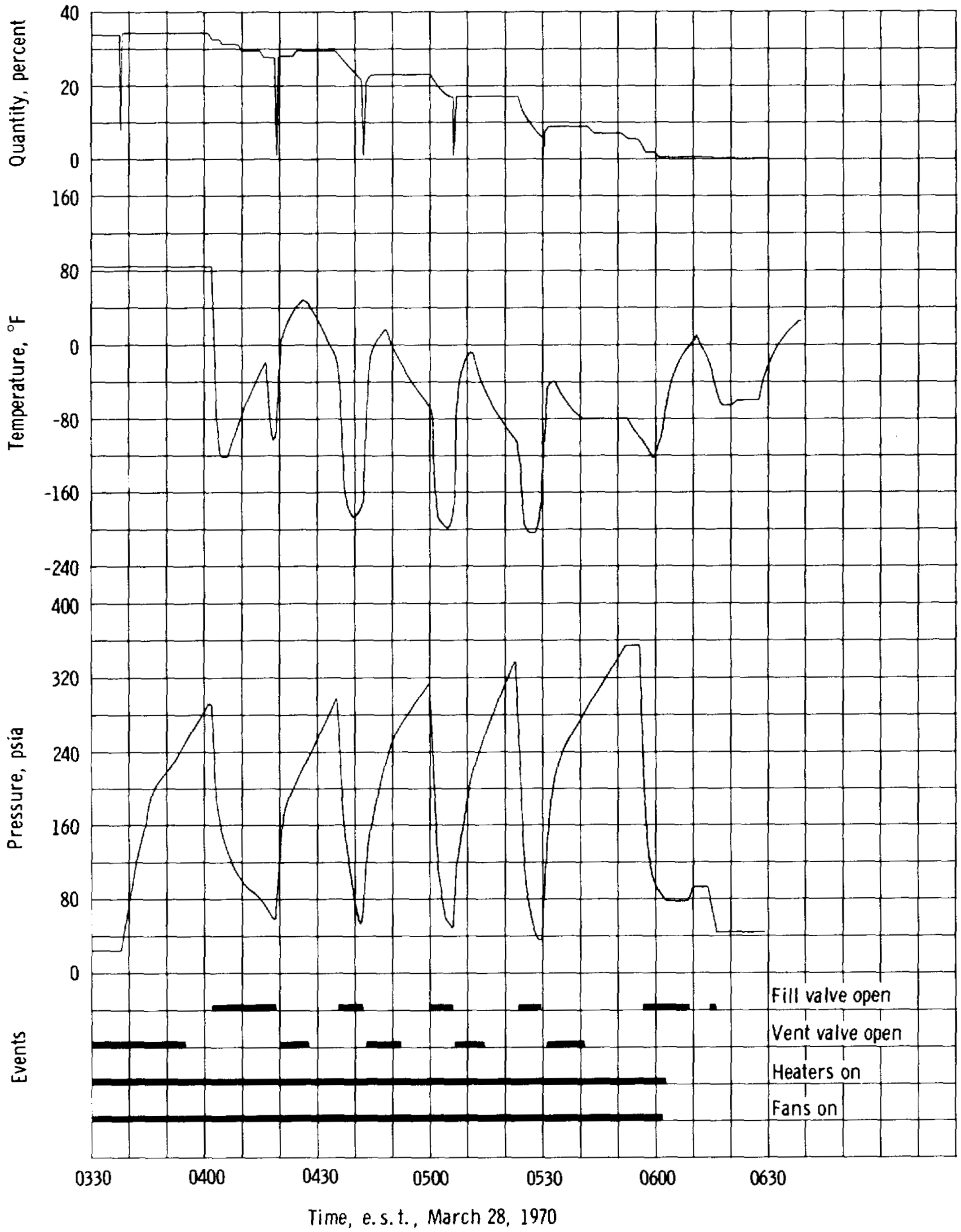


Figure C4-61.- Oxygen detanking using pressure cycles and tank heaters.

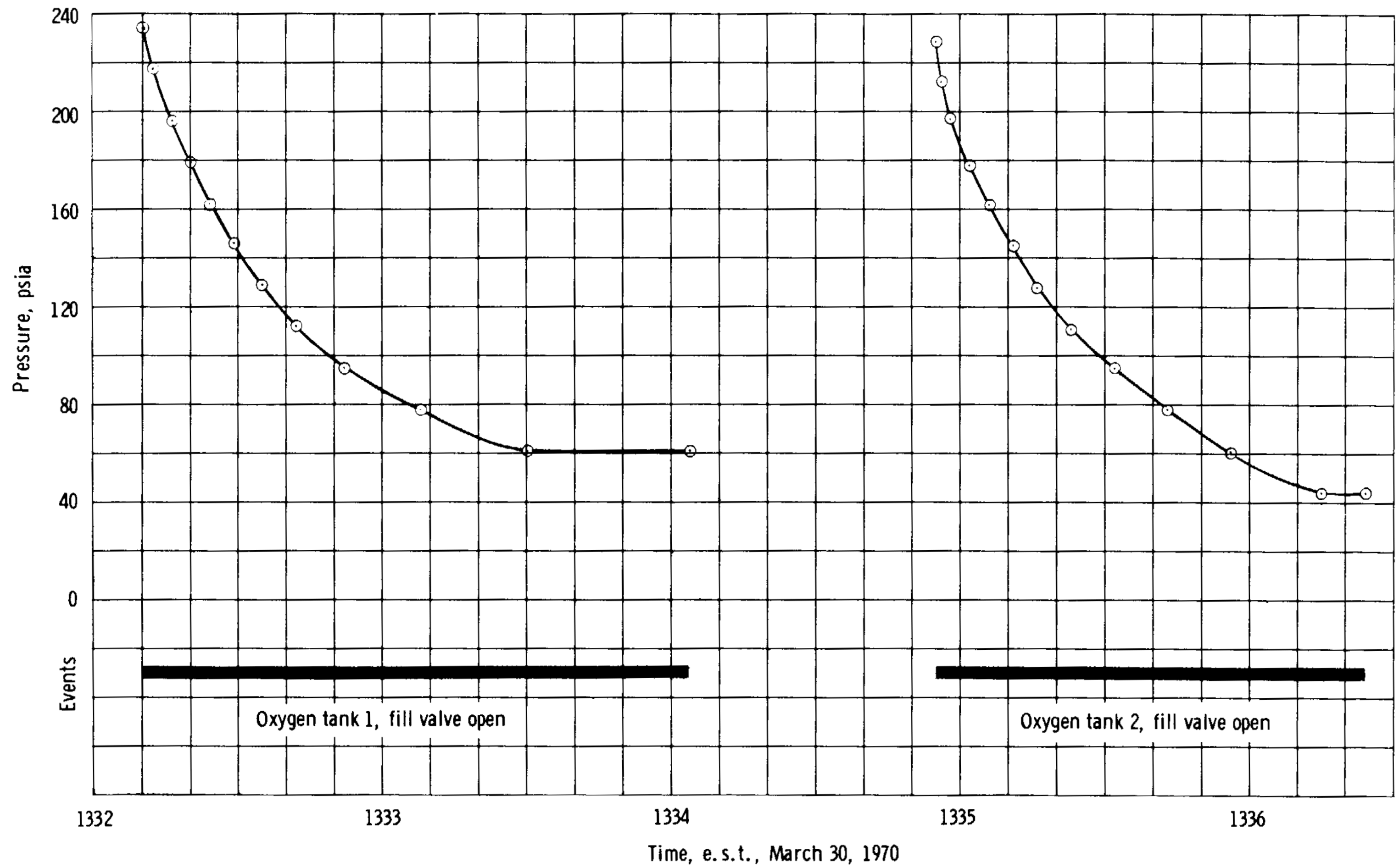


Figure C4-62.- Gaseous oxygen blowdown test, spacecraft 109.

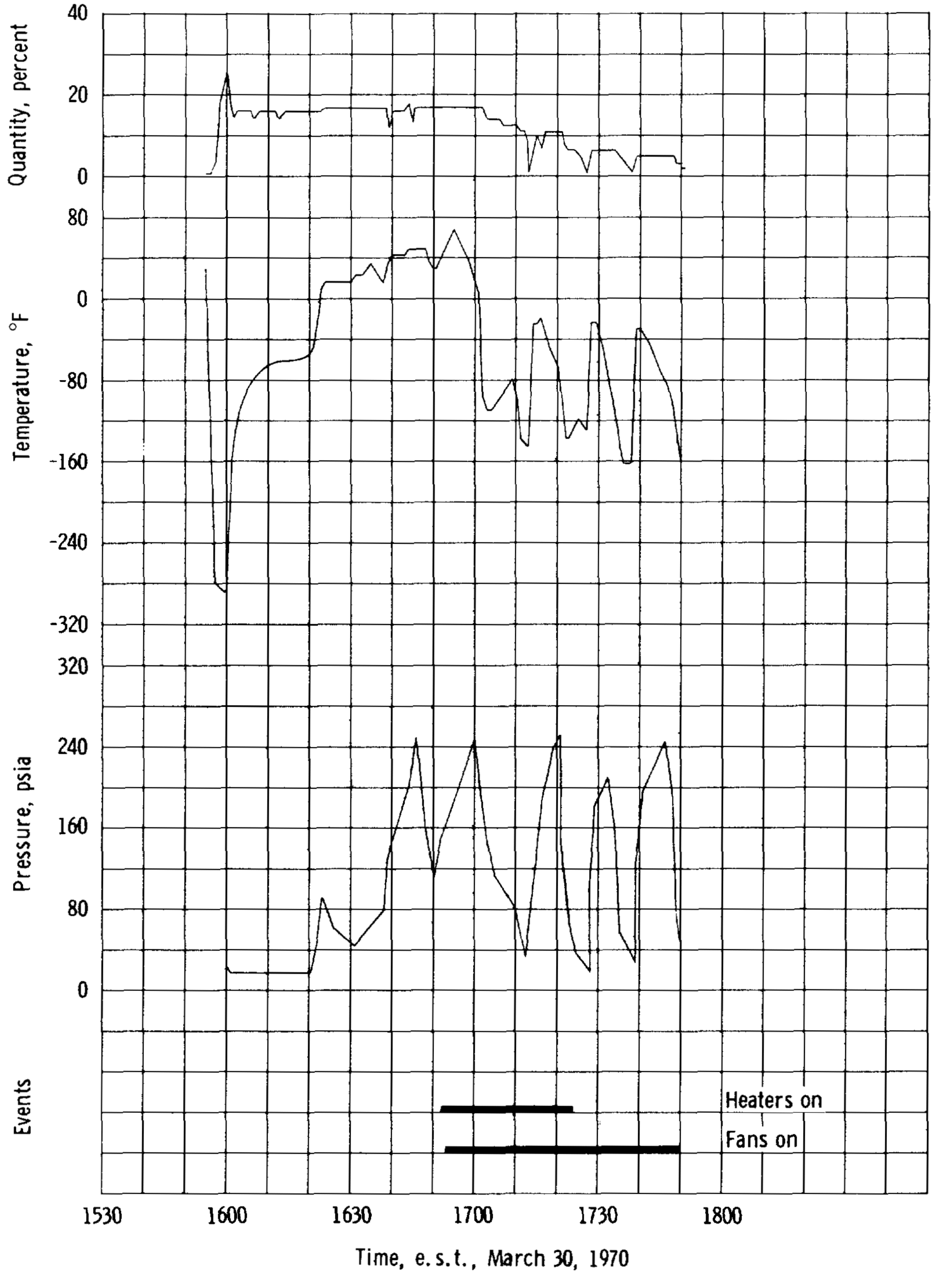


Figure C4-63.- Oxygen detanking using pressure cycles and tank heaters.

Several items of overall tank test and checkout experience should be noted.

Contaminants: Liquid, as well as gaseous, oxygen which entered tank no. 2 was verified by sample analysis. Nothing indicates that contaminants did enter the oxygen tanks. The samples taken from the vents during the servicing met the specification requirements and did not give an indication of tank contamination.

Quantity probe: Throughout all tests, during a period of 11 months resulting in 167 hours 8 minutes operating time including 28 fan on/off cycles over the 17-day period of CDDT and launch count, the quantity gaging system in tank no. 2 exhibited less sensitivity to noise and transients than that of tank no. 1.

Oxygen tank no. 2 pressure cycling: At no time during the testing of oxygen tank no. 2, in systems and subsystems, were the specified pressure limitations or allowable tank cycles exceeded.

Testing of oxygen tank fans: Test records were reviewed of all fan motor operations at KSC for any indications of ac bus transients. Tank no. 2 fans were powered 30 times. No electrical transients were found except those normally connected with fan starting or stopping. Fan motor performance was considered normal.

Investigation and Supporting Work

Causes of detanking difficulties.- Review of information from the Beech acceptance test logs and review with the Beech personnel in charge of these tests does not indicate that the detanking was abnormal. Contrarywise, the data are not substantive to prove that the liquid was expelled through the fill line. No weight or quantity measurement is recorded at the completion of the liquid expulsion; however, the procedure calls for continuing the application of vent line pressure until both the weighing system and the quantity probe indicate the tank is empty. The final tank empty condition is based on the final exit temperature of the warm nitrogen gas purge. At the time, no one indicated that the response of the tank to the procedures was anything but normal, and today careful review of existing data, discussions with the responsible Beech Aircraft and North American Rockwell personnel, and a special test at Beech Aircraft indicate that the detanking of the 0008 tank was most probably normal.

Each oxygen storage tank is stored at NR, Downey, in its shipping container until removal for installation in the assigned oxygen shelf. Thus it is retained in a vertical position until any motion takes place in the shelf assembly fixture.

The shelf assembly fixture used at Downey (fig. C4-50) aligns tank no. 1 so that the fill tube segments in the top of the quantity probe assembly lie nominally in a plane transverse to the axis of fixture rotation. Thus the fixture in the normal position holds the tubes upright but otherwise can rotate them through a full circle, exposing them to dislodging forces in the plane of their nominal location. The situation for tank no. 2 is nearly a right angle to the tank no. 1 situation so that the tube segment plane is nominally parallel to the trunnion axis of the assembly fixture. Thus in all positions other than vertical or inverted, a lateral dislodging force exists relative to the plane of their nominal location.

The highest elevation of the tank assembly, and thus the first area of contact with the underside of the fuel cell shelf at the time of the lifting fixture breakage and the shelf dent, was the cover over the upper vacuum pinch-off tube (fig. C4-55). This point was to the left of the mass centers and lifting forces involved as the counterbalance rotated and broke away from the fork portion of the lifting fixture. (See Appendix D.) Some rotation to lift the outer right corner of the shelf (lower right in fig. C4-55) higher than the outer left would be expected from this configuration. An uneven fall to the shelf supports would follow.

In figure C4-55, showing the installation of the oxygen shelf in SM 109, the condition of the farthest right tubing in the lower part of the picture reflects the comments of two DR's that one tube had a "slight bend" at the valve module and another (lower) was "badly bent." As the highest tubes, farthest from the 11th bolt and the high point of tank no. 2, these two may have participated in the "shelf drop" incident. Neither was found to be in need of repair after leak check.

No mention could be found in review of these DR's of any concern for the condition of the tubes, wires, or motors internal to the oxygen storage tank except as verifiable through routine external gas and electrical testing with NR factory OCP's.

Shipment of SM 109 from NR/Downey, with the SM axis horizontal during ground and air transporation, afforded the next major opportunity for fill tube segment lateral dislodgment.

It appears pertinent to this review to note that during SM transportation the fill tube segments within the upper portion of the oxygen tank no. 2 quantity probe assembly lay with the tank-exit end of the fill tube segments about 20 degrees above the horizontal, if they were still in place after previous handling and the "shelf drop." Neither the wires nor the feed line filter were below it to restrict rotation of the fill tube about the central tube of the quantity probe (fig. C4-64).

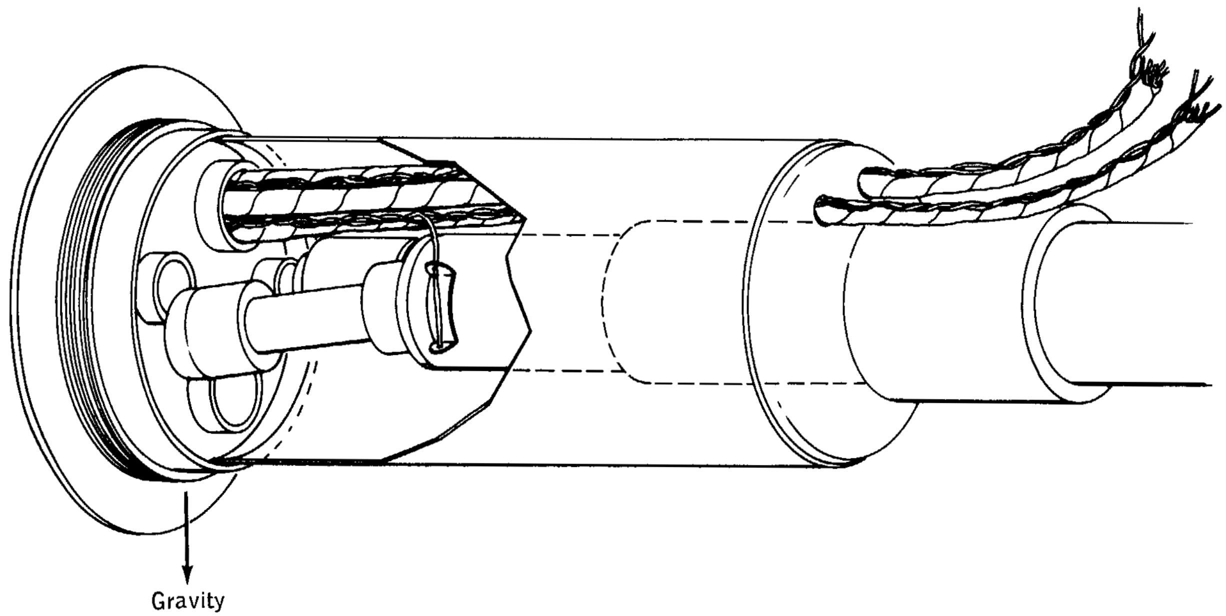


Figure C4-64.- Isometric sketch of quantity probe head as oriented during SM transportation.

This history of exposure of the tank fill tube segments to an unusual dislodgment environment sequence was not recorded during the detanking incidents at KSC nor during the presentation of CSM 109 history reviews to the Apollo Spacecraft Program Manager through either reliability and quality assurance or engineering channels at MSC. However, it does corroborate the recorded real-time judgment of Beech, MSC, and KSC engineers that the tank fill line parts may have been out of place in tank 10024XTA0008 during the detanking problems of March 23-30, 1970.

Since the fill tube parts have dimensional tolerances that could allow these parts to fall out of place, a calculation was made to attempt to establish the configuration of the tank during the detanking operations at KSC. The data from the first detanking attempt of March 27 were used to test the hypothesis that the fill tube parts were disconnected such that no liquid was expelled from the tank. A simple heat balance equation of the tank from the initial condition to the end condition shows that all the mass lost by the tank can be explained by vaporization and it is likely that no liquid was expelled. Figure C4-58 and table C4-III show the data upon which these calculations were based. At the initial and final point the temperature indicated in the data is too warm for the pressure indicated. The saturation temperature was used for each case.

Possible effects of special detanking procedures at KSC.- The use of special detanking procedures at KSC to empty tank no. 2 of CSM 109 has created concern these special procedures may have altered significantly the condition of the oxygen tank.

A number of special tests have been run and other tests are yet to be run in an attempt to determine the nature and degree of degradation that may be expected to occur to the tank internal components and wiring resulting from exposure of this type. The most significant finding to date is the fact that the thermostats fail by welding closed almost immediately when attempting to interrupt 65 V dc.

Several tests were run to determine the temperature that would occur at various points on the heater tube as a result of operation at ground power level as the liquid in the tank is boiled off. These tests were run at MSC using a similar sized tank with an actual flight-type heater fan assembly. The test setup is shown on figure C4-65. Liquid nitrogen was used in the tank for safety reasons. The initial run was made with a later model heater fan assembly that does not utilize thermostats; however, it was felt that as long as liquid nitrogen was present it was not likely that the thermostats would be called upon to operate. During this test very high temperatures were encountered on many locations on the heater tube (figure C4-66). These conditions were considered to be very unrealistic, so the test was rerun using a heater fan assembly equipped with thermostats. When the test was started, one thermostat indicated an open circuit at the initial fill condition. It was decided that a satisfactory test could be run since an extra lead had been extended from the heater elements so that the heaters could be manually operated to coincide with the functioning of the operable thermostat.

TABLE C4-III.- THERMODYNAMIC BALANCE CALCULATIONS

	Initial condition		Final condition	
Quantity, lb	274	(83% indic.)	212	(65% indic.)
Pressure, psia	178		36	
Temperature, ° F Temperature, ° R	-236.5 223.2		-280 179.7	
Density of liquid, lb/ft^3	58.4		68.0	
Volume of liquid, ft^3	4.70		3.10	
Volume of gas, ft^3	.05		1.65	
Weight of liquid, lb	273.85		210.9	
Weight of gas, lb	0.15		1.1	
Enthalpy of liquid, Btu/lb	88		68	
Enthalpy of gas, Btu/lb	158		155	
Total enthalpy of liquid, Btu	24,112		14,341	
Total enthalpy of gas, Btu	24		171	
Heat capacity of metal, 44 lb ΔT° = 43.5° F, sp. ht. 0.086	(Reference Cond.)		-164	
Heat capacity of boil-off gas 62 lb at 156.5 Btu/lb	0		9,703	
Total enthalpy, Btu/lb	24,136		24,051	

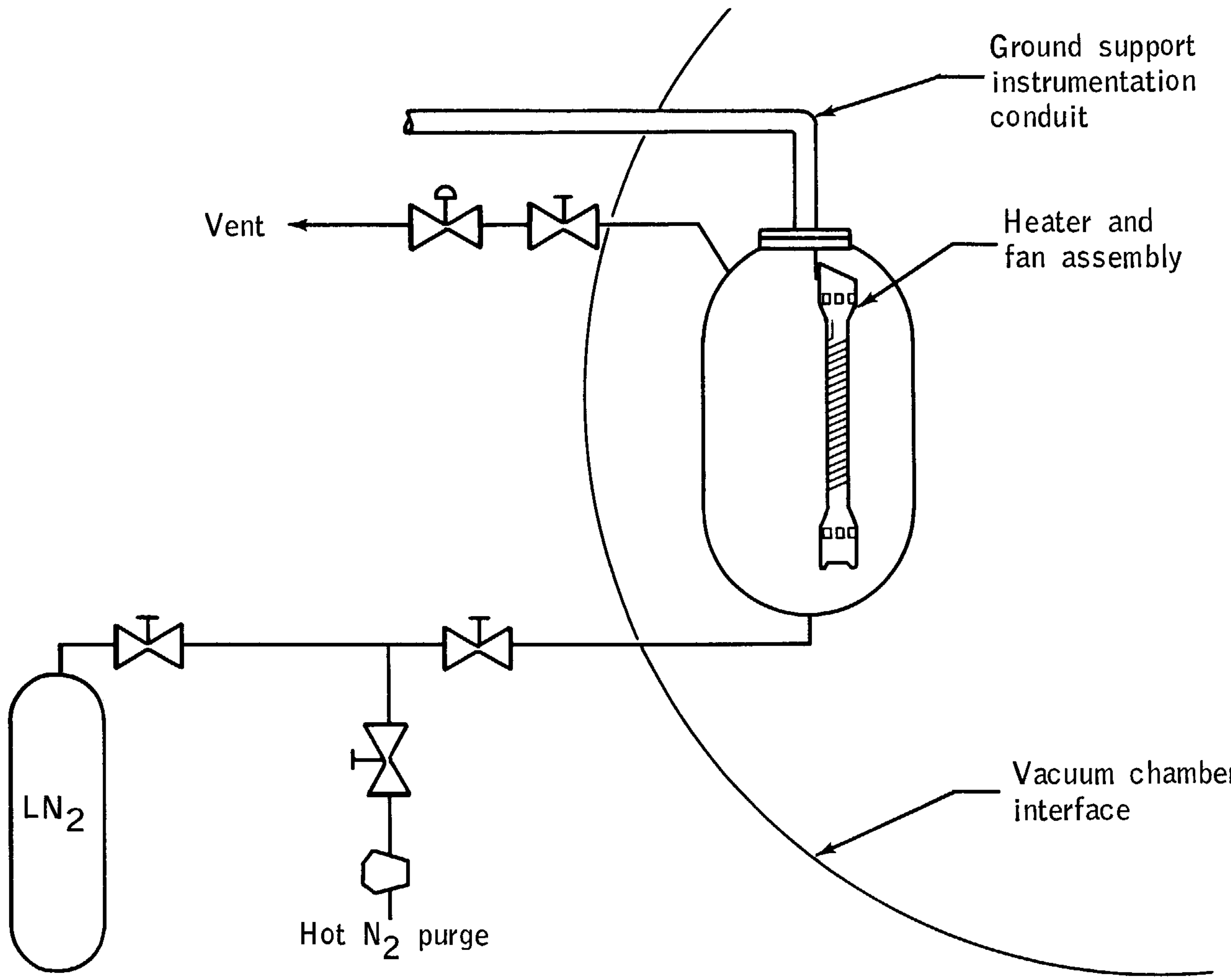
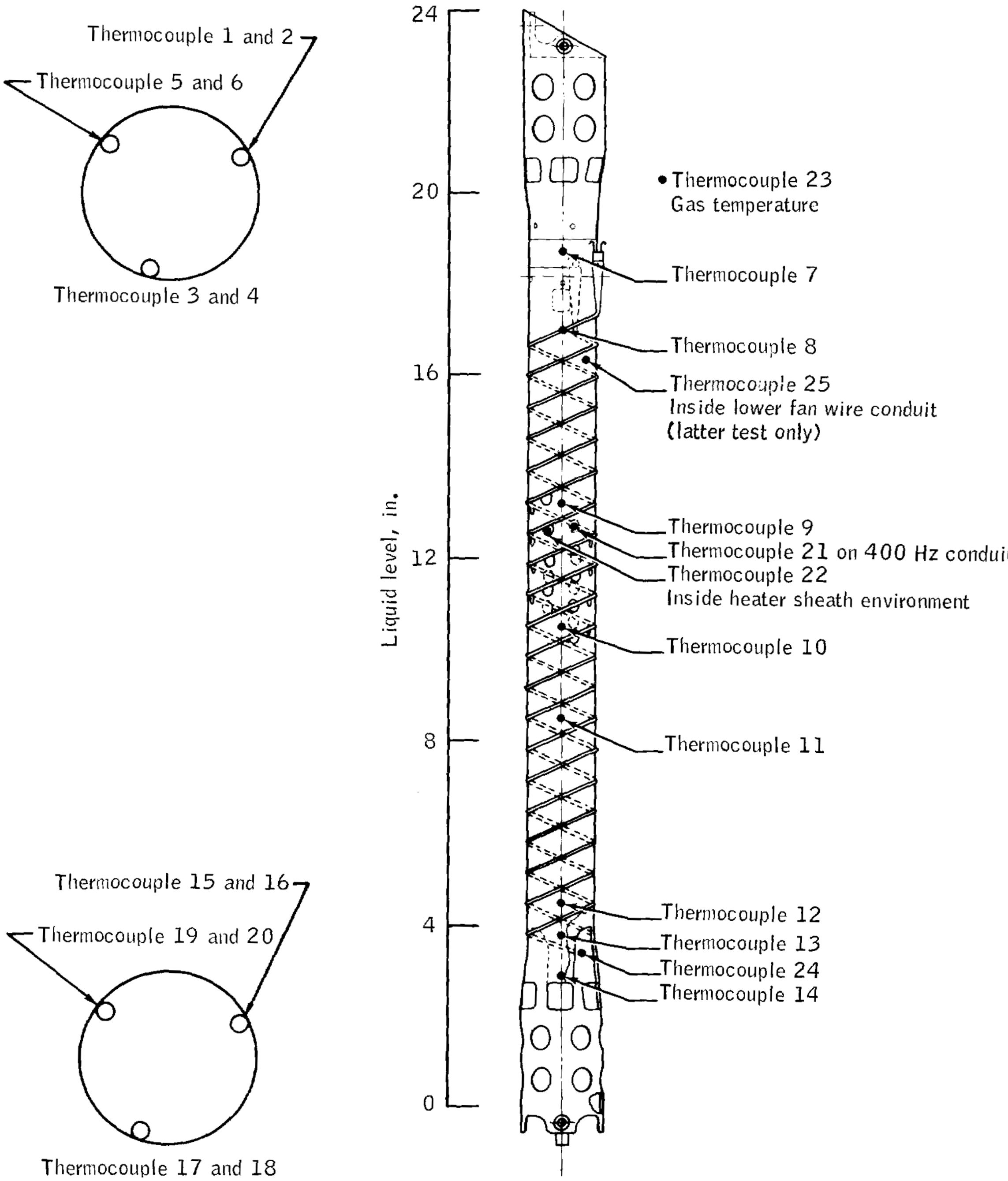
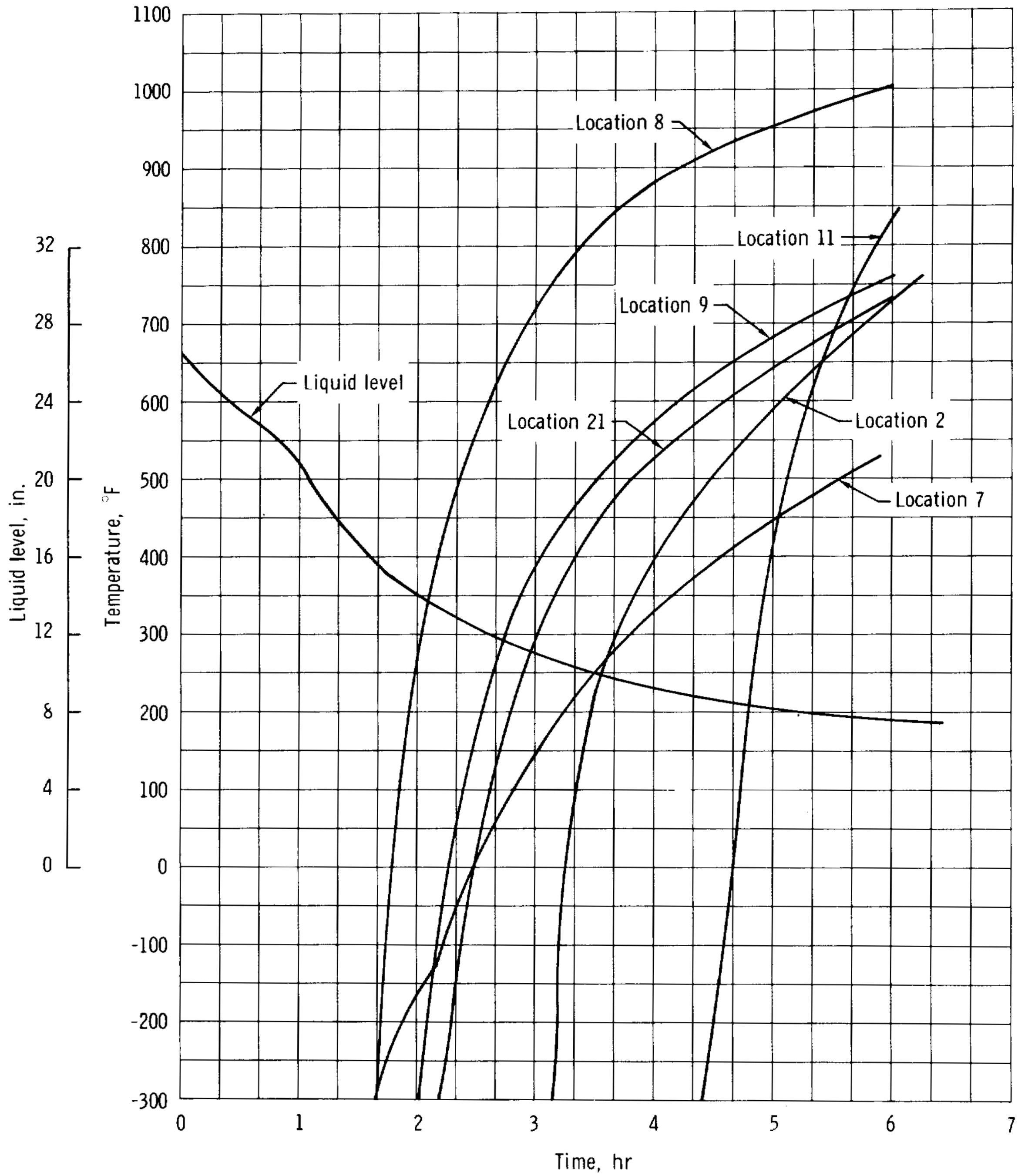


Figure C-4.65.- Heater tube assembly temperature test setup.



(a) Temperature sensor locations.

Figure C4-66.- Heater tube assembly temperature test.



(b) Typical test results.
Figure C4-66.- Concluded.

The test was started and after a few cycles in this mode the previously nonfunctioning (open) thermostat started indicating normal function. At this time it was decided to revert to the originally intended test configuration, i.e., the thermostats directly controlling the heaters. Data from that point on indicated that the thermostats were not cycling the heaters. The heater tube temperature data looked just like the nonthermostat test run. The test terminated at this point and the thermostats were removed and X-rayed. The X-rays indicated that the contact gap was bridged. One thermostat had its case carefully removed to examine the conditions of the contacts (fig. C4-67).

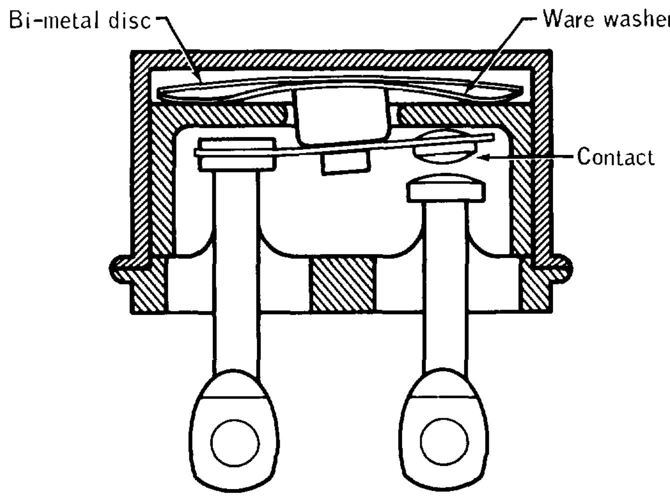
A review of the thermostat design and the manufacturer's ratings indicate that the thermostats are severely overloaded in current-interrupting capability at the ground power condition. Open contact spacing at 65 V dc is such that a sustained arc can be established and the contacts melted at this first attempt to interrupt power of this magnitude.

Inasmuch as thermostat failure would be expected at the first attempt to interrupt the ground power level, the conditions of heater tube temperature measured during the first test of this series would be indicative of those experienced during the KSC special detankings of March 27, 28, and 30. Since a review of the heater ground power supply voltage recordings made during the special detanking operations showed no indication of heater cycling, a special postflight test was conducted at KSC which showed that the cycled load equivalent to the heaters would cause a cycling in the voltage recording. Figure C4-68 shows sections of motor lead wire removed from the heater tube conduit.

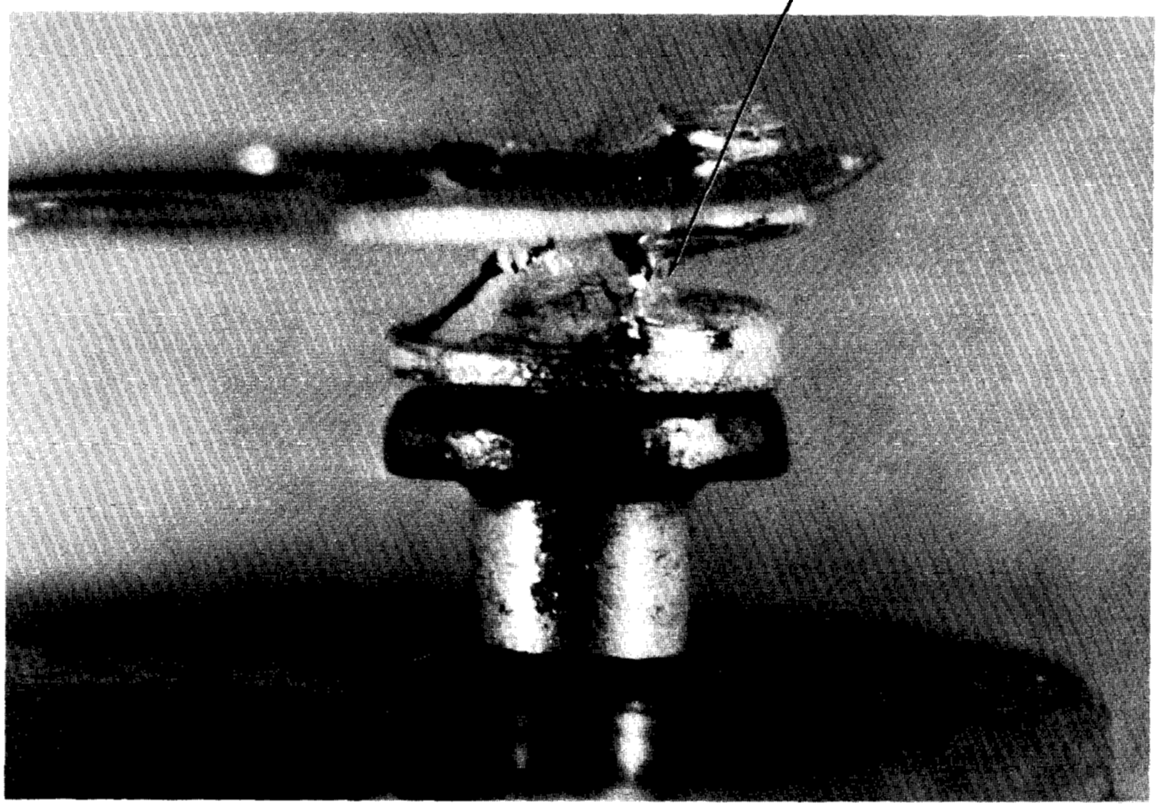
Other tests run at Ames Research Center (see Appendix F) indicate that Teflon-insulated wires run at similar temperatures in an oxygen atmosphere result in even more severe degradation.

A test is being run at Beech Aircraft to simulate all the tanking and detanking conducted on XTA-0008 at KSC. A Block I tank modified to the Block II configuration with the fill tube connecting parts rotated out of position is being used for this test. Temperature measurements on the electrical conduit in the vacuum dome area and posttest inspection will be utilized to evaluate the effects on the wiring of the special detanking operations.

At no time during standard checkout, prelaunch, and launch operations are these thermostats required to interrupt the 65 V dc ground power supply current. As far as could be determined, the special detanking operation was the only time that any thermostats were ever called upon to interrupt this load.



(a) Switch cross section.



(b) Welded contacts after test.

Figure C4-67.- Thermostat configuration and welded contacts.

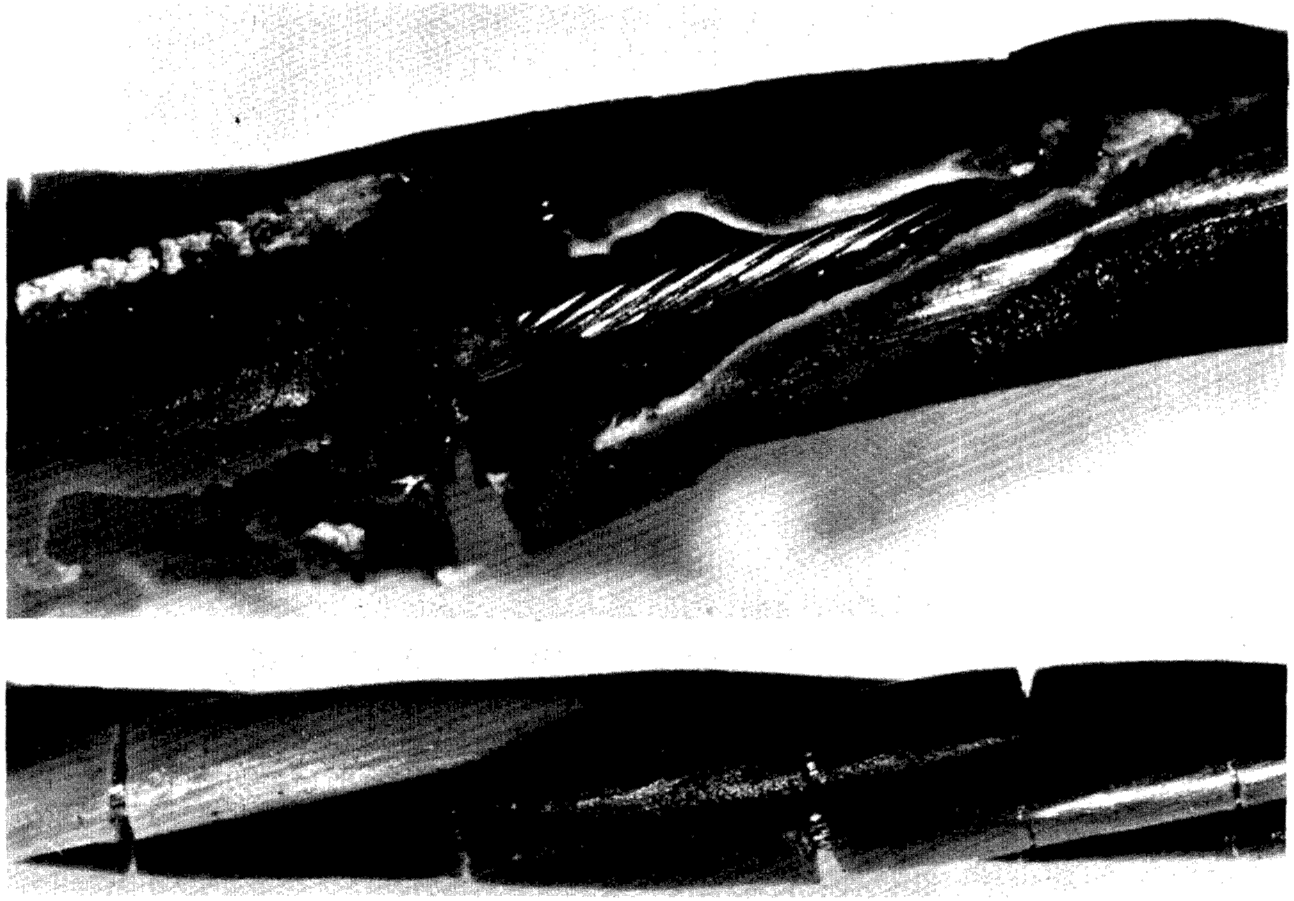


Figure C4-68.- Wire damage from heater tube assembly temperature test.