NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Technical Memorandum 33-633

Design and Operation of a 1000°C Lithium–Cesium Test System

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16. Abstract

A 100 kWt cesium-lithium test loop was fabricated of niobium-1% zirconium for experiments on erosion and two-phase system operation at temperatures of 980° C and velocities of 150 m/s. Although operated at design temperature for 100 hours, flow instabilities in the two-phase separator interfered with the achievement of the desired mass flow rates. A modified separator was fabricated and installed in the loop to alleviate this problem. Because of program cancellation, the test system has been placed in standby condition for storage. This report documents the test system.

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III

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PREFACE

The work described in this report was performed by the Propulsion Division of the Jet Propulsion Laboratory.

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ABSTRACT

A 100 kWt cesium-lithium test loop was fabricated of niobium-1% zirconium for experiments on erosion and two-phase system operation at temperatures of 980°C and velocities of 150 m/s. Although operated at design temperature for 100 hours, flow instabilities in the two-phase separator interfered with the achievement of the desired mass flow rates. A modified separator was fabricated and installed in the loop to alleviate this problem. Because of program cancellation, the test system has been placed in standby condition for storage. This report documents the test system.

I. INTRODUCTION

Power generation for advanced space missions and central station power by a liquid metal magnetohydrodynamic cycle has been studied extensively (Refs. 1-4). A promising system for power levels above about 100 kWe is based on the two-component separator cycle using lithium and cesium as working fluids (Refs. 5 and 6). Cesium is mixed with lithium at high temperature at the inlet of a nozzle as shown in Fig. 1. The cesium vaporizes and the mixture is accelerated in the nozzle to high velocity. Impingement on an inclined surface produces a low-void fraction stream that is predominantly liquid lithium. This stream is decelerated in an MHD generator, producing electric power, and is subsequently returned by its remaining kinetic energy through the heat source to the nozzle inlet. The other flow leaving the separator is a high-void fraction stream that consists of cesium vapor with carryover of liquid and vaporous lithium. This mixture is condensed and returned by a pump to the nozzle inlet.

The characteristics of this system have been partially determined by analysis (Ref. 6), by component experiments using ambient water-nitrogen, NaK, and NaK-nitrogen mixtures (Refs. 7 and 8), in system experiments with water-nitrogen and NaK-nitrogen mixtures (Ref. 8), and through high-temperature, corrosion-erosion experiments with lithium (Refs. 9 and 10). However, information on the following subjects requires testing with cesium and lithium at the peak system temperatures:

(1) Erosion of surfaces by lithium impingement at the design velocity of 150 m/s.

(2) Performance of a two-phase nozzle with a cesium-lithium mixture.

(3) Condensation characteristics of cesium-lithium mixtures.

(4) Nonequilibrium behavior of cesium-lithium flows where solution or dissolution are occurring.

In order to investigate these subjects a flow system was fabricated from niobium-1% zirconium alloy to operate with cesium-lithium at a peak temperature of 980°C. Erosion can be determined by measuring the depth of attack or deposit on a wedge with an optically flat surface which was located in the flow stream at the nozzle exit. Nozzle performance can be derived from the measured thrust produced by the flow on a target cone which was designed to turn the flow by 90 deg. Cesium condensation coefficients can be determined by measurements on the NaK-cooled compact condenser. Nonequilibrium behavior would be inferred by deviations from the thermodynamic cycle calculations.

The test system was operated with simultaneous cesium and lithium flow at the design temperature of 980°C for about 100 hours. Figure 2 is a photograph of operation at high temperature and low flow rates. Flow instability prevented attainment of the design mass flow rates and impingement velocities. Modifications to the separator component to eliminate the instability were nearly completed when the NASA liquid metal MHD project was cancelled. The test system has been placed in a standby condition pending further investigations oriented toward commercial power generation.

Appendixes A, B, C, and D present, respectively, loop operating procedures, test system schematics, fabrication drawings of the test system, and loop operating characteristics.

II. DESCRIPTION OF TEST SYSTEM

The two-component liquid metal MHD system being studied and the Cs-Li test system are most closely related to the Rankine cycle. The flow paths and processes can be illustrated by reference to Fig. 3, which is a schematic of the liquid metal circuits of the test system. Lithium is heated to the maximum temperature in the heater component and flows to the nozzle, where it is injected at point 1.

Cesium liquid is also injected in the nozzle at point 2. Part of the cesium vaporizes and the remainder goes into solution with the lithium, which remains mostly in the liquid state. The cesium vapor is accelerated to high velocity and low pressure in the nozzle. As the pressure decreases, more cesium comes out of solution and vaporizes. Shear and pressure forces resulting from the expanding cesium vapor cause breakup and acceleration of the lithium droplets to high velocity. The mixture impinges on the target and on a mesh separator within the receiver component. The lithium pump increases the pressure to the maximum of the cycle and returns the flow to the heater. The cesium vapor leaves the receiver vessel and flows to the desuperheater. Subcooled liquid cesium is injected at that point to reduce the cesium vapor (which is highly superheated) to the saturated state. The vapor then enters the condenser, where the heat of vaporization is removed by flowing NaK, is condensed, and returns to the cesium pump. The pump pressurizes the cesium and returns it to the nozzle and through a cooler to the desuperheater.

Figure 4 is a photograph of the cesium and lithium circuits prior to testing. All components and piping were fabricated from Nb-1%Zr. All weldments were performed in a high-purity argon atmosphere. This part of the test system was mounted on the door of a getter-ion pumped vacuum chamber which was operated in the 10^{-7} torr range to protect the refractory metals from oxidation during high-temperature operation. Description of the test system components and their performance is summarized below.

A. Two-Phase Nozzle

The two-phase nozzle for the test system was designed to provide cesium and lithium flow over a range of conditions. The design pressure gradient was established from the pressure variation measured on a larger nozzle, using water-nitrogen and freon-water flows. This gradient was used in the two-phase, two-component nozzle program to calculate the contour. The resulting geometry is summarized in Fig. 5. Figure 6 is a photograph of the nozzle prior to final welding.

The nozzle was calibrated with water and nitrogen to compare the exit velocity with that calculated by the computer program. The test setup is given in Fig. 7. As shown in Fig. 8, the agreement between the calculated and measured exit velocity was quite good. The computer program was then used to calculate the nozzle flow rates as a function of inlet temperature and mass ratio with the result shown in Fig. 9. At saturated Cs vapor conditions at the inlet, there is a unique relation between the cesium and lithium flow rates. The information from Fig. 9 was used to determine the flow rates and operating conditions of the test system for the desired values of mass ratio and nozzle inlet temperature.

B. Thrust Target and Separator

The relation of the nozzle and thrust target is given by Fig. 10. The two-phase lithium-cesium flow impinging on the thrust target is turned by 90 deg. The thrust produced is transmitted through a stainless-steel bellows which is joined to the Nb-1%Zr alloy by a coextruded joint. The measured thrust thus provides an indication of the nozzle exit velocity. The separated lithium falls to the bottom of the separator and is returned to the lithium pump. The cesium vapor is separated from the lithium by a mesh-type separator and flows to the desuperheater.

The thrust target with the erosion specimen mounted in place is shown in Figs. 11 and 12. The erosion specimen is an optically flat wedge which extends beyond the nozzle exit diameter. Erosion depth was to have been measured with a traversing microscope as was done on a previous test (Ref. 10). The basic wedge is Nb-1%Zr alloy; the insert, which was electron-beam-welded to the Nb-1%Zr, is T-111 alloy.

Figure 13 shows the thrust target mounted in the separator body. The Nb-1%Zr mesh was wrapped on the outside of the perforated annulus as shown in the assembly drawing of Fig. 14.

The entire unit was assembled and tested with water-nitrogen flows. The thrust measured by the thrust target agreed to within ±5% with the values measured for the nozzle alone. The nozzle exit velocity was varied from 90 to 155 m/s for these measurements. Liquid carryover in the gas exit ranged from 2-7% of the primary liquid flowrate, acceptable values for the high-temperature flow system. Complete separation of gas from the liquid outlet flow was made possible by adding baffles, as shown in Fig. 15. However, these same baffles resulted in excessive lithium holdup during the lithium-cesium tests.

In order to eliminate this holdup problem a cyclone separator was designed for the lithium-cesium test system. A model was tested (Fig. 16) with water and nitrogen with a liquid carryover in the gas outlet of less than

0.1% and gas-free flow at the liquid outlet. Figure 17 shows the cyclone separator fabricated of Nb-1%Zr ready for installation in the test system.

C. Lithium Pump

The lithium pump is a helical induction electromagnetic pump. The pumping element shown in Fig. 18 is a Nb-1%Zr structure that fits within a stainless-steel, thermally-insulated sleeve. The electromagnetic body forces are supplied through the stainless-steel sleeve by an air-cooled, three-phase motor stator shown in Fig. 19. The pump was operated for more than 1000 h at temperatures exceeding 1000°C and for more than 4000 h above 650°C.

The calculated performance curve is given in Fig. 20. Previous tests with lithium flow nozzles at 1100°C gave measured performance data which agreed quite closely with the calculated performance (Ref. 9). A serious limitation of the pump which became apparent during the testing was the tendency of vapor to accumulate within the pump body and cause flow oscillations. Extensive shakedown testing was required to evolve a startup procedure that minimized this problem. Although vapor accumulation was a problem, the pump was able to operate with a negative suction head. The most successful two-phase startup procedure consisted of injecting cesium while the pump operated with lithium flow at 980°C and zero pressure at the inlet.

D. Lithium Heater

The heater to raise the lithium to the maximum temperature of 980°C consisted of four "cal-rod" type elements welded in a Nb-1%Zr shell. Figures 21 and 22 are photographs of this unit before final welding. The heating elements are tantalum center conductors with beryllia insulation and swaged Nb-1%Zr sheaths. The beryllia was removed to a depth of 6 mm to enable the Nb-1%Zr sheaths to be TIG-welded to the Nb-1%Zr shell without degrading the ceramic insulation. As shown in Fig. 21, the body and elements are curved to provide flexibility to accommodate thermal stresses. The unit was operated for over 3000 h, heating lithium at temperatures ranging from 650-1000°C. After this time a small leak occurred at one of the sheath weldments. The leak was repaired and the unit was to have been used on succeeding tests. Electron-beam welding of the sheaths rather than TIG welding would have enabled a greater depth of penetration, which probably would have eliminated this problem.

E. Lithium Flowmeter

The electromagnetic flowmeters used for the lithium and cesium are shown in Fig. 23. The calculated characteristics of the lithium flowmeter are given by Fig. 24. Calibration of this flowmeter with 1100°C lithium flow nozzles showed the measured flow to agree to within ±5% of the calculated values.

F. Cesium Pump

The cesium pump is of similar construction to the lithium pump. The stator is seen in Fig. 19, adjacent to the stator for the lithium pump. The flow was controllable with a throttling valve during the periods of operation at lower flow rates. Attempts to run the pump at higher pressure rise with a low inlet pressure and low flow rate resulted in excessive temperature rise and vaporization of the cesium at the pump inlet. A small jet pump was fabricated which should have eliminated this problem when installed.

G. Cesium Flowmeter

The cesium flowmeter of Fig. 23 was used only at very low flow rates. The calculated output curve is given in Fig. 25.

H. Cesium Desuperheater

The cesium vapor leaving the separator is highly superheated and has a very poor heat transfer coefficient. The desuperheater of Fig. 26 was designed to lower the temperature to saturated vapor conditions by injection of subcooled cesium liquid. The large surface area afforded by the small liquid metal droplets more than compensates for the poor coefficients.

An alternative method to desuperheat the Cs vapor is a heat exchanger with large internal surface area. A radiant heat exchanger with internal Nb-1%Zr fins was fabricated (Fig. 27) to replace the original desuperheater. This would enable the subcooled cesium bypass flow to be used for the cesium jet pump discussed previously.

I. Cesium Condenser

The condenser for the cesium was constructed of both Nb-1%Zr and stainless steel. The niobium alloy is required for the condensing cesium, while stainless steel is the material of construction for the NaK cooling system that rejects the latent heat of vaporization from the cesium.

The condenser assembly is shown in Fig. 28 before welding and in Fig. 29 after final assembly. The transition between the stainless-steel tees and center section and the niobium end pieces that weld to the Nb-1%Zr cesium tubing was achieved by brazing with a cobalt-nickel alloy. The condenser performed satisfactorily at the low Cs vapor flow rates tested.

J. NaK Heat Rejection Loop

The NaK heat rejection loop was constructed of type 316 stainless steel. NaK flow is produced by an electromagnetic AC conduction pump. The flow piping enters the vacuum chamber through a thermal sleeve. The entering NaK removes heat from the cesium subcooler and condenser and exits the vacuum chamber through another thermal sleeve. It flows through an expansion tank, heater, and air-blast heat exchanger (to reject the heat) back to the pump. The function of the heater was to control the NaK temperature during low-load operation and to heat the NaK during purification operations. A titanium-zirconium hot trap was provided for initial purification. The heat rejection system is shown in Fig. 30 before insulation.

K. Vacuum Chamber

The vacuum chamber and getter-ion pump are shown in Fig. 31. The chamber is heated so that the temperatures of all liquid metal lines can be maintained at at least 200°C to prevent solidification. All ports have bakeable metal seals. The main door seal is Viton-A cooled to less than 100°C. During testing the chamber operated in the 10^{-7} torr range, with the liquid metal system at 980°C and the chamber at 250°C.

L. Instrumentation and Controls

Liquid metal pressure was measured directly with bonded strain gage transducers. The transducers and pressure lines were maintained at 230°C to prevent solidification. Installation of the transducers in the heated enclosure is shown in Fig. 32. Valving was provided to enable calibration during operation of the test system.

Chromel-alumel thermocouples were used for temperature measurement. Attachment to the Nb-1%Zr piping and components was made by welding the wires to a tantalum foil which, in turn, was welded to the niobium alloy. Only two thermocouples of 53 failed during more than 3000 hours of testing.

All instrumentation readout and control of the loop was accomplished remotely. Figure 33 shows the control console and alarm system which was used during the test. Schematic diagrams of the instrumentation and control circuits are given in Appendix B.

III. Operating Experience

The test system was operated for over 3000 h with liquid metal flow to determine the proper startup sequencing and flow characteristics with cesium and lithium. Achievement of stable flow with both liquid metals was very difficult and tedious. For proper functioning with cesium condensation in the condenser, no cover gas (argon) could be tolerated. Yet it was found that heating the evacuated system from ~200 to ~650°C while lithium was flowing always caused argon to evolve from the lithium. Attempts to reduce the pressure while circulating lithium produced instabilities and the loss of the pumping action unless extremely gradual reductions in pressure were used (~ 0.1 - 0.2 atm/day). Another problem which occurred early in the test sequence was lack of control of the cesium flow rate. Attempts to start the cesium pump at a low flow rate and without a control valve inevitably resulted in injection of a cesium flow which was too large for the conditions of lithium temperature and flow. The result was entrainment of cesium in the lithium circuit and the subsequent loss of the lithium pump due to cesium vaporization in the pump. This latter problem was eliminated by installation of a valve in the cesium line and an externally controlled cesium injection system for startup.

With these modifications, relatively stable cesium and lithium flow was obtained at lower flow rates (~0.1 kg/s). Attempting to further increase the lithium flow resulted in severe flow oscillations, cesium entrainment, and loss of the lithium pump. The reason for the flow oscillations is the holdup of lithium in the separator because of the baffles which were installed after hydraulic testing. Use of the centrifugal separator of Fig. 17 should eliminate this problem and enable the attainment of higher flow rates. Figure 34 is a schematic of the test loop as it should appear after the above modifications are made.

IV. SUMMARY

The cesium-lithium test system proved to be a reliable installation for obtaining lithium and cesium flow at 980 °C. However, stability problems were encountered as the flow rates were increased above about 0.1 kg/s. Minor modifications to the separator should enable attainment of the 0.4-kg/s design flow rate with stable operation.

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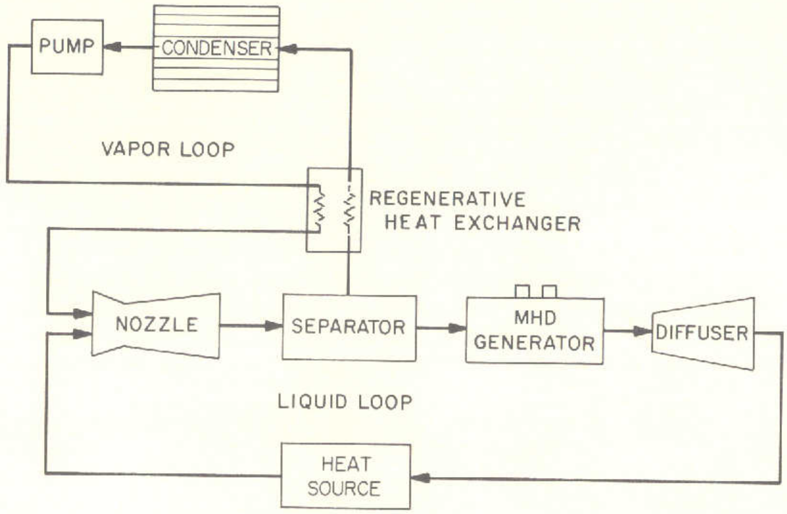


Fig. 1. Schematic diagram of cesium-lithium MHD power system

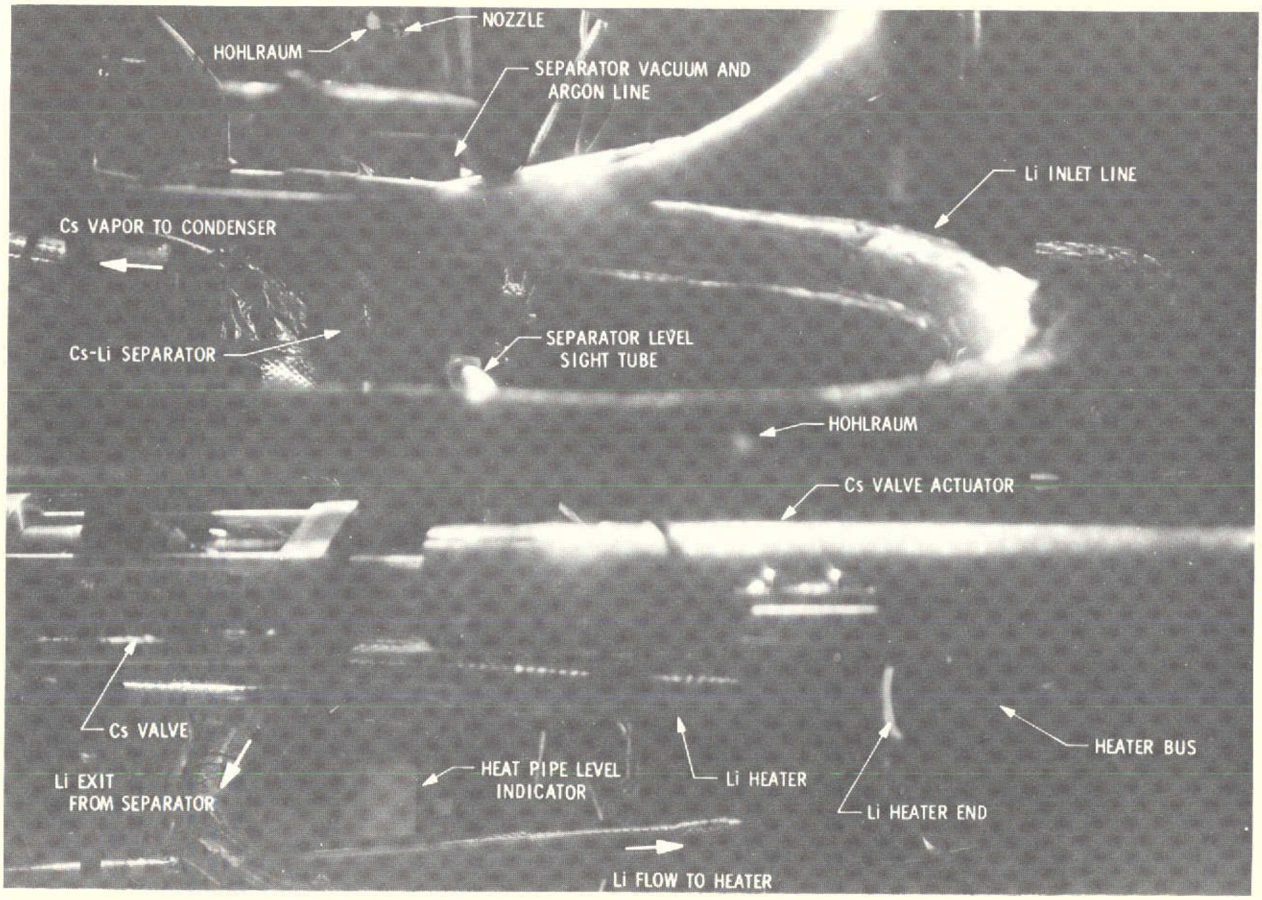
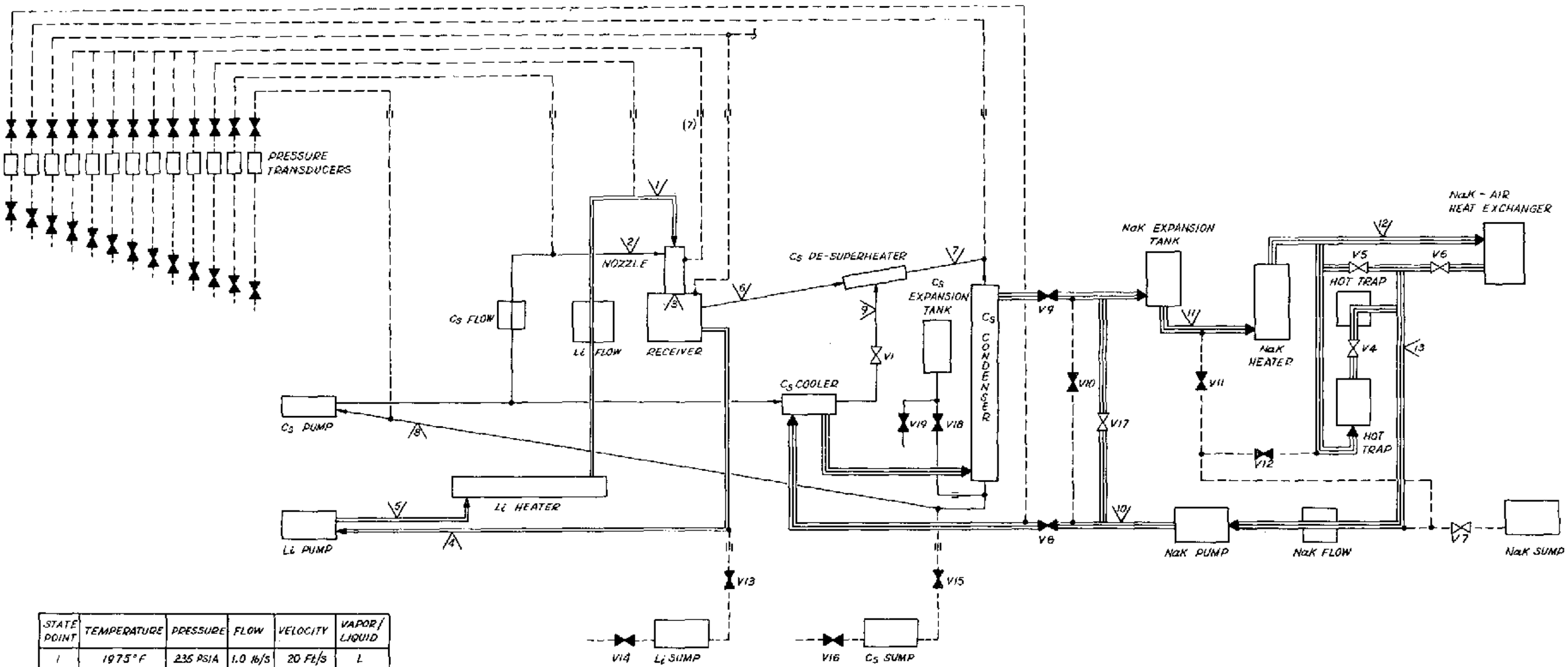


Fig. 2. Cesium-lithium erosion loop at 980°C



STATE POINT	TEMPERATURE	PRESSURE	FLOW	VELOCITY	VAPOR/ LIQUID
1	1975°F	235 PSIA	1.0 lb/s	20 Ft/s	L
2	1650°	235	.16	20	L
3	1915°	30	1.16	515	L, V
4	1915°	30	1.00	20	L
5	1940°	245	1.00	20	L
6	1915°	28	.16	175	V
7	1400°	27	.22	200	V
8	1250°	26	.22	20	L
9	1250°	200	.06	20	L
10	700°	30	.50	20	L
11	1100°	25	.50	20	L
12	1100°	25	.50	20	L
13	700°	20	.50	20	L

LEGEND:

- PRIMARY Cs CIRCUIT
- PRIMARY Li CIRCUIT
- PRIMARY NaK CIRCUIT
- ANCILLARY LIQUID METAL LINES
- REFERENCE STATE POINT
- VALVE - HAND OPERATED
- VALVE - REMOTE ACTUATION
- COEXTRUDED JOINT

Fig. 3. 100-kW erosion loop liquid metal circuits schematic diagram

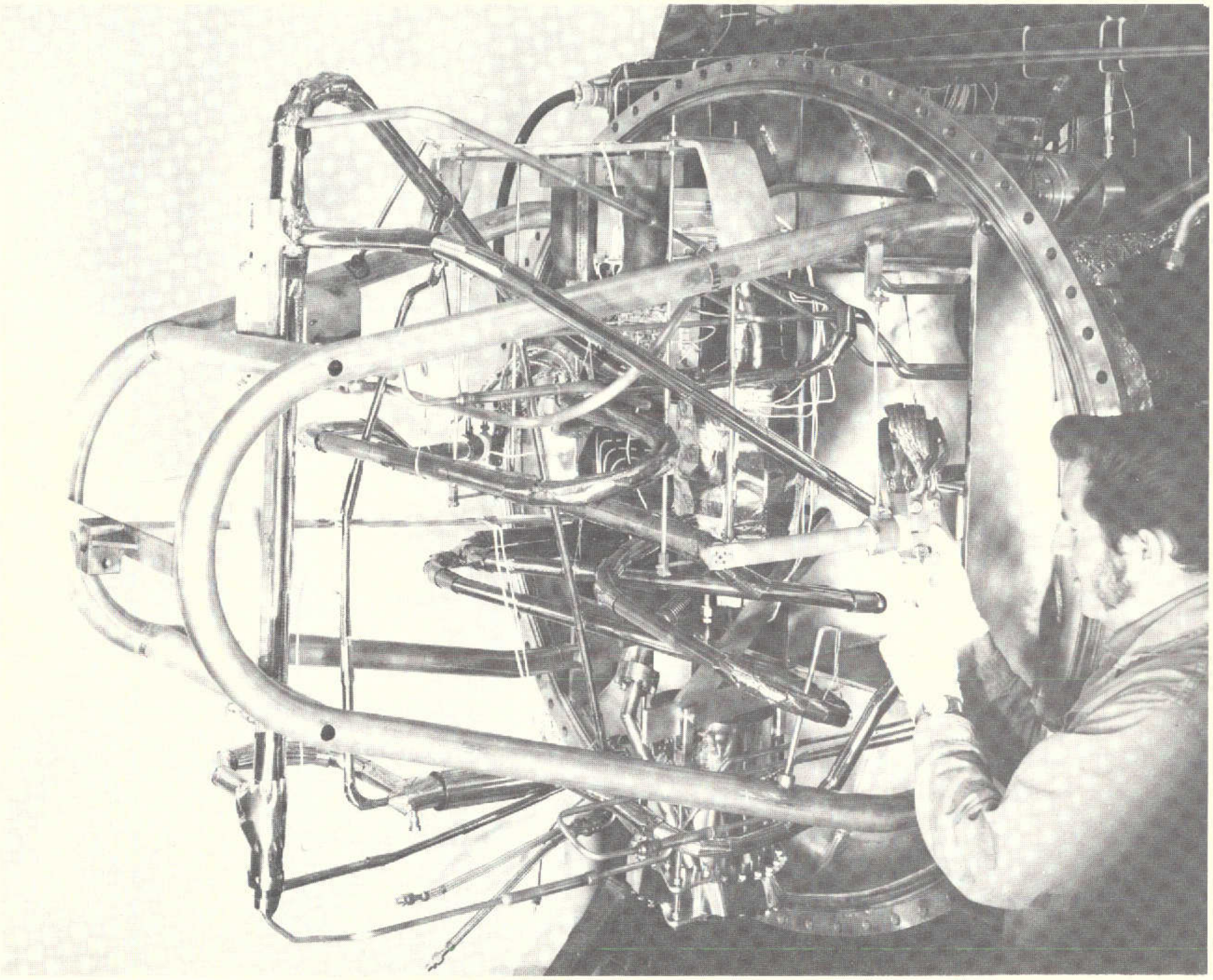


Fig. 4. Cesium-lithium test circuits before activation

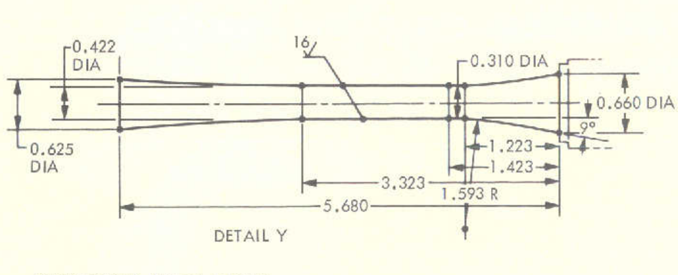


Fig. 5. Cesium-lithium nozzle geometry

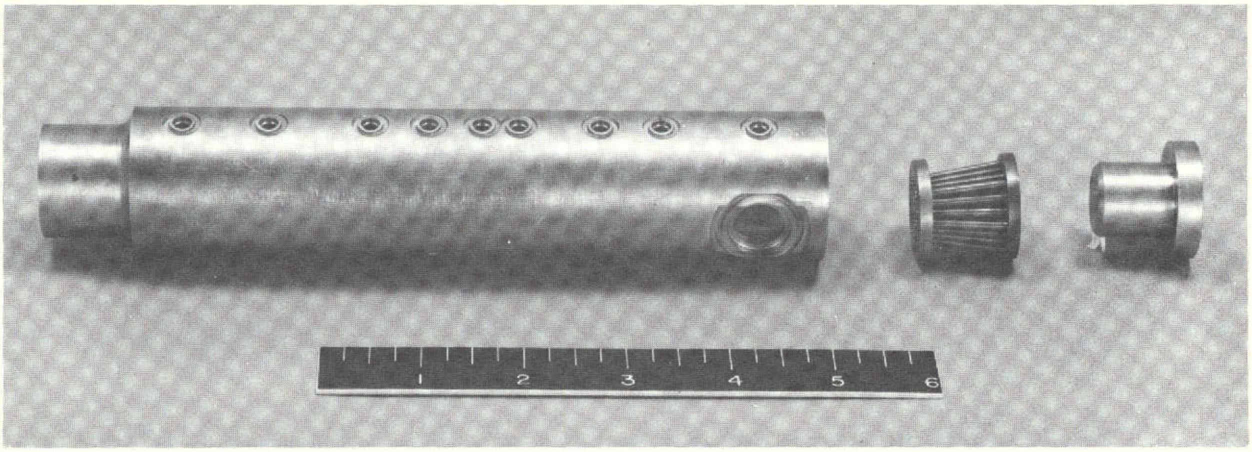


Fig. 6. Cesium-lithium nozzle before welding

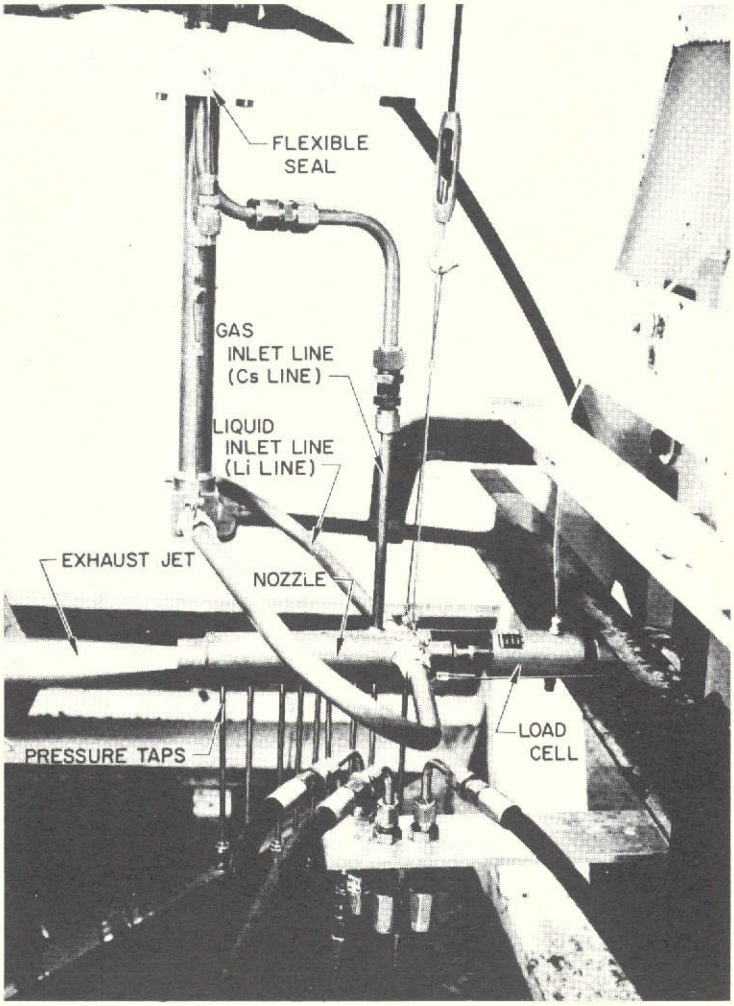


Fig. 7. Water-nitrogen test of nozzle for
cesium-lithium loop

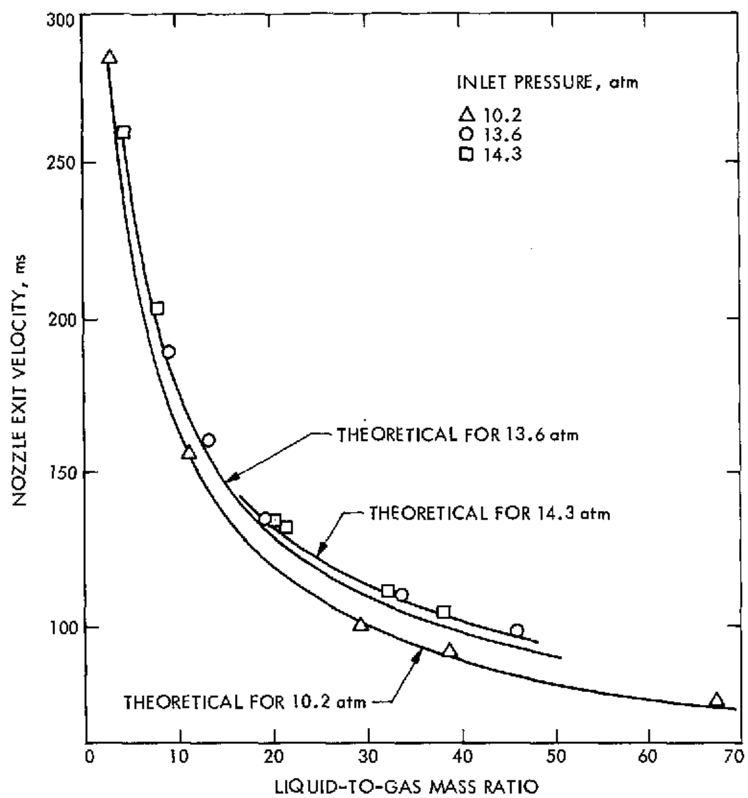


Fig. 8. Comparison of experimental and theoretical exit velocities for cesium-lithium loop nozzle operating with nitrogen and water

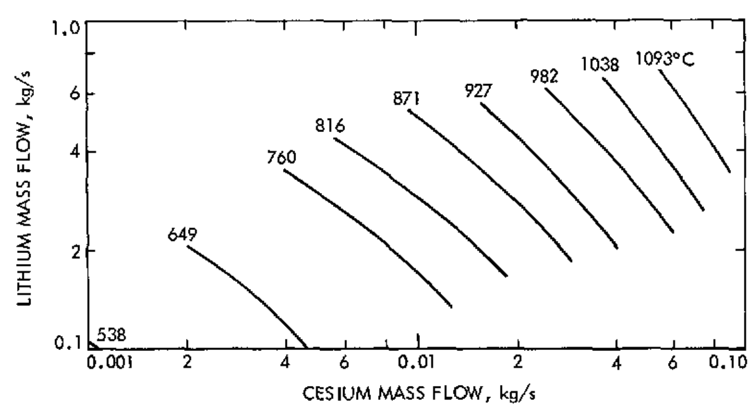


Fig. 9. Cesium-lithium nozzle flow for different nozzle inlet temperatures (saturated vapor)

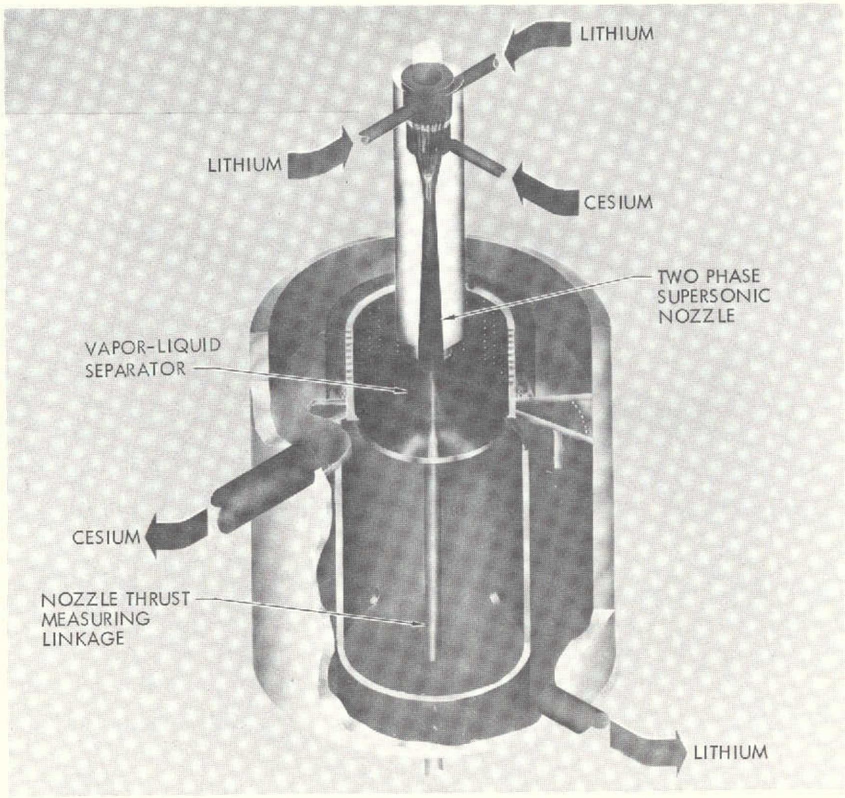


Fig. 10. Nozzle-separator assembly

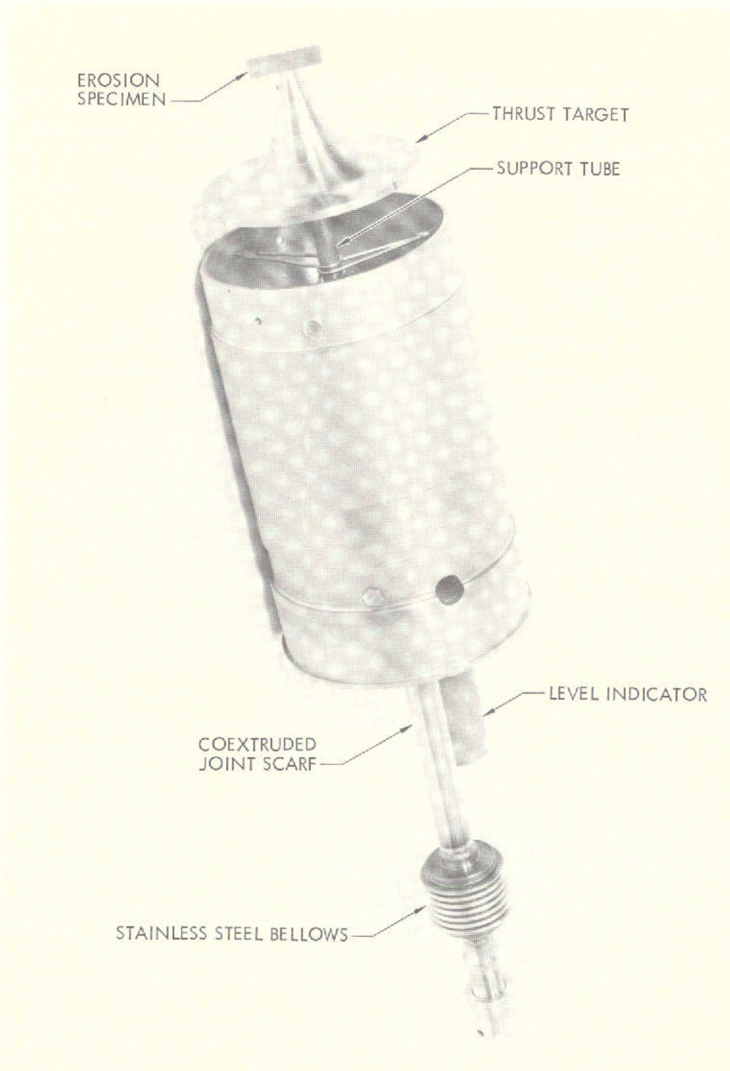


Fig. 11. Thrust target assembly

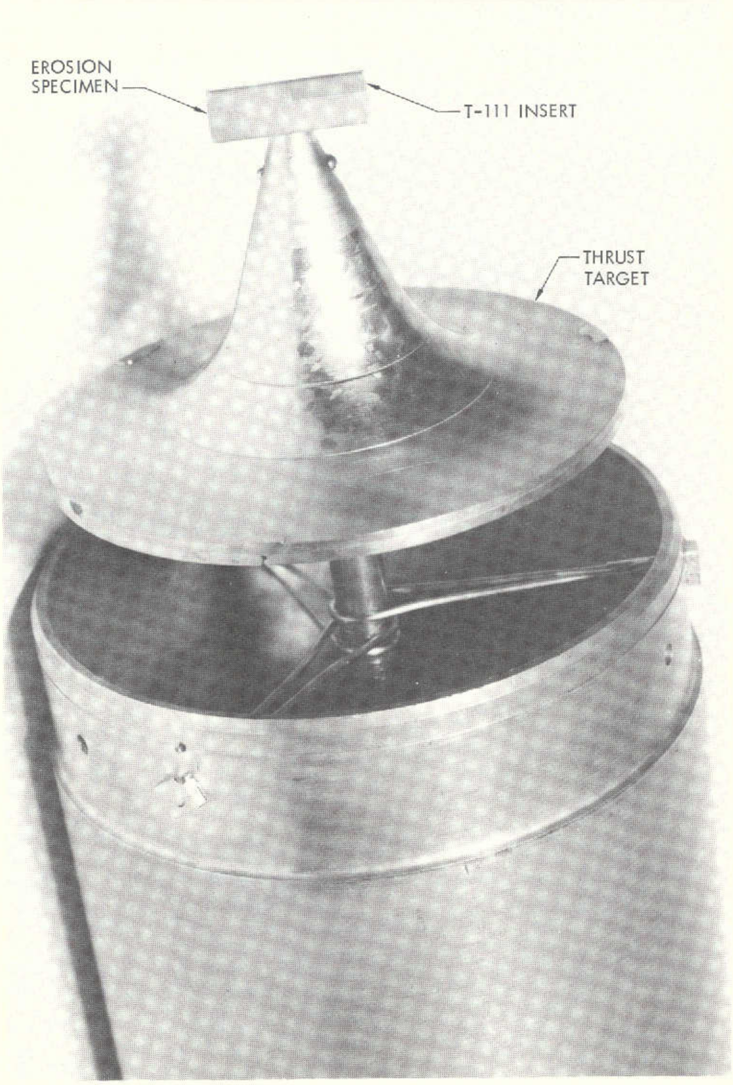


Fig. 12. Erosion specimen mounted on thrust target

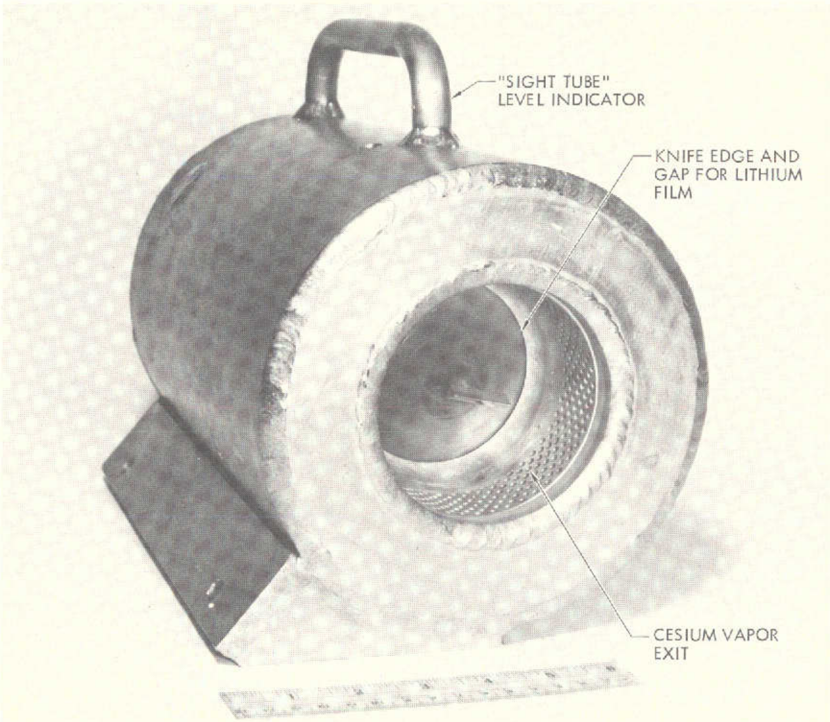


Fig. 13. Thrust target mounted in separator body

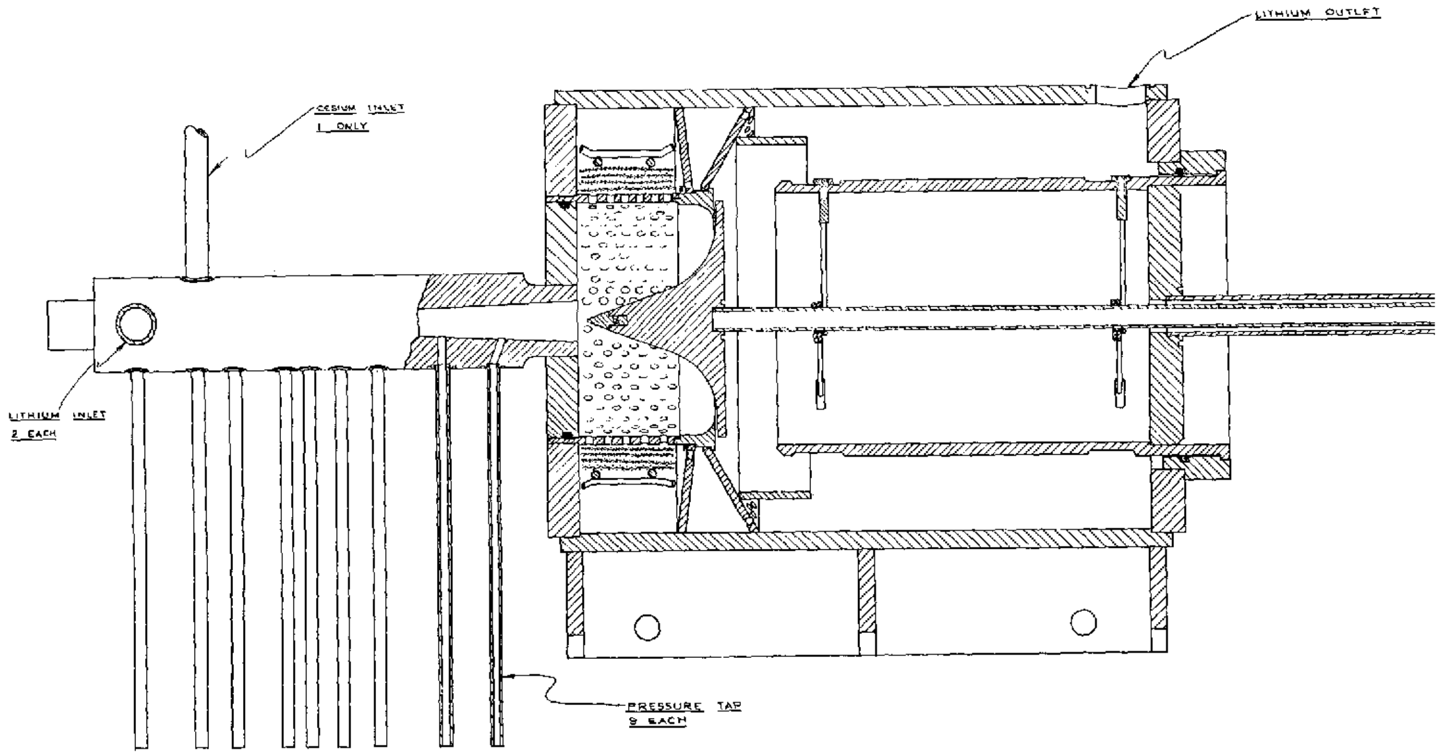


Fig. 14. Separator assembly

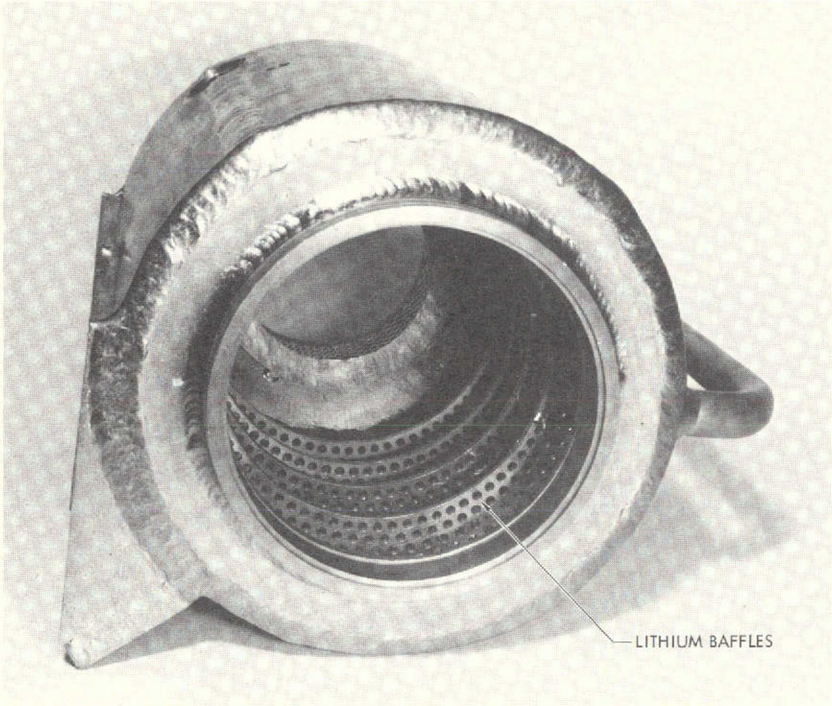


Fig. 15. Lithium baffles

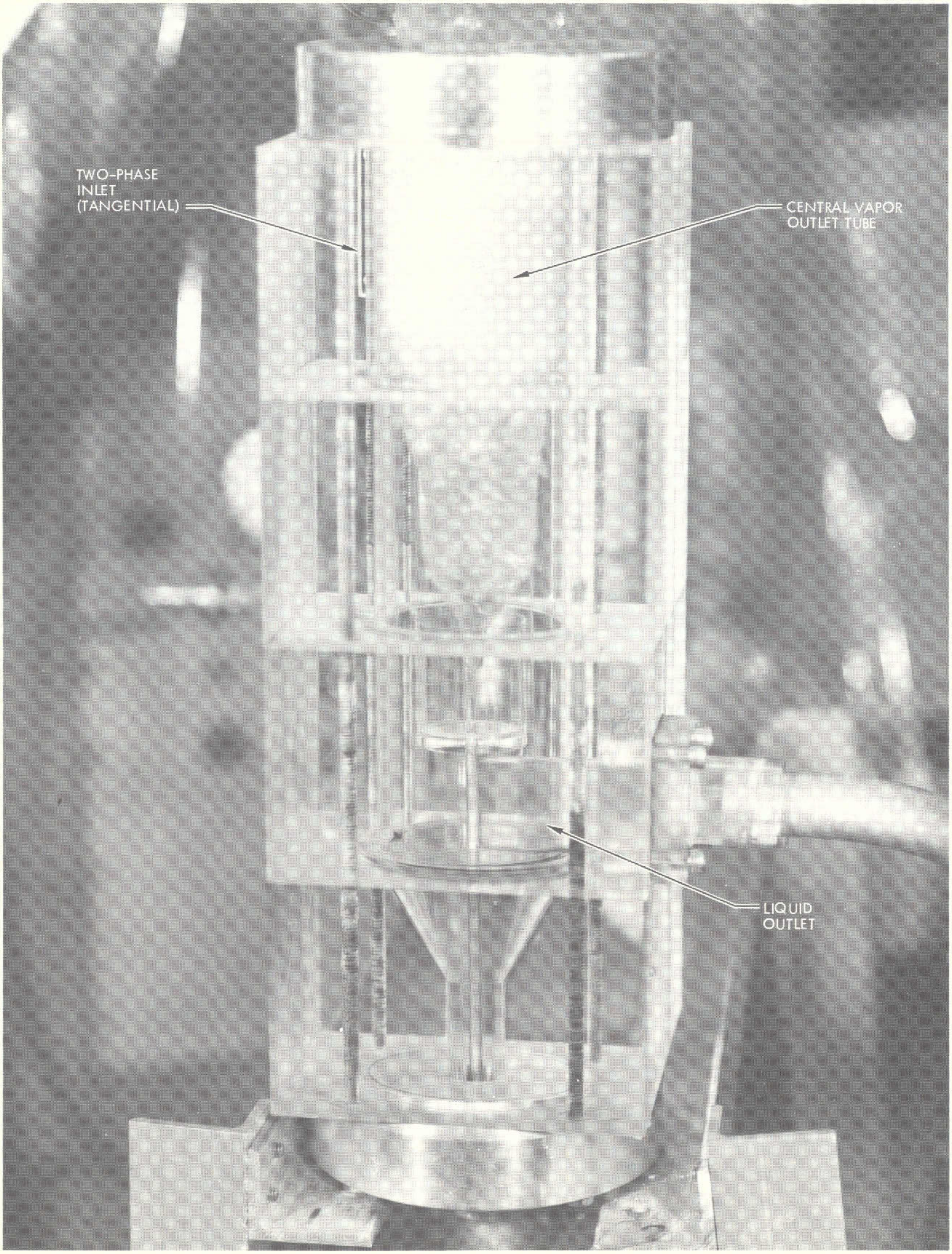


Fig. 16. Two-phase cyclone separator operating with H_2O and N_2

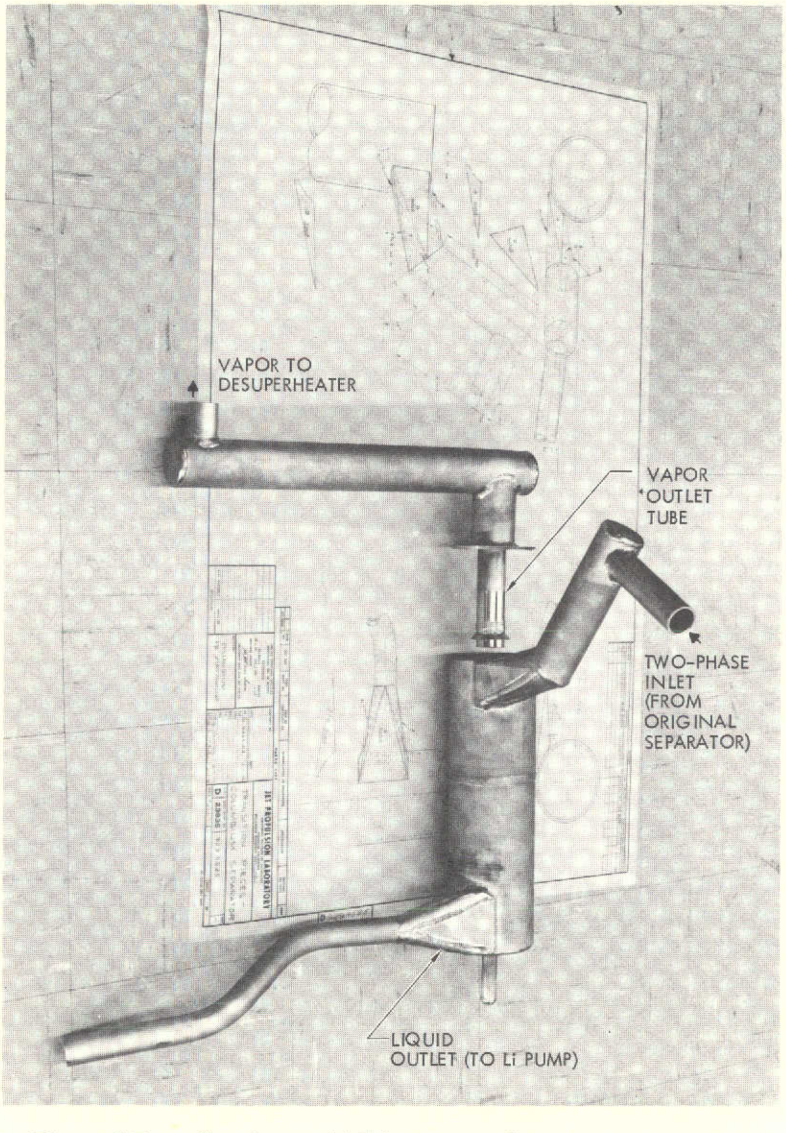


Fig. 17. Cesium-lithium cyclone separator

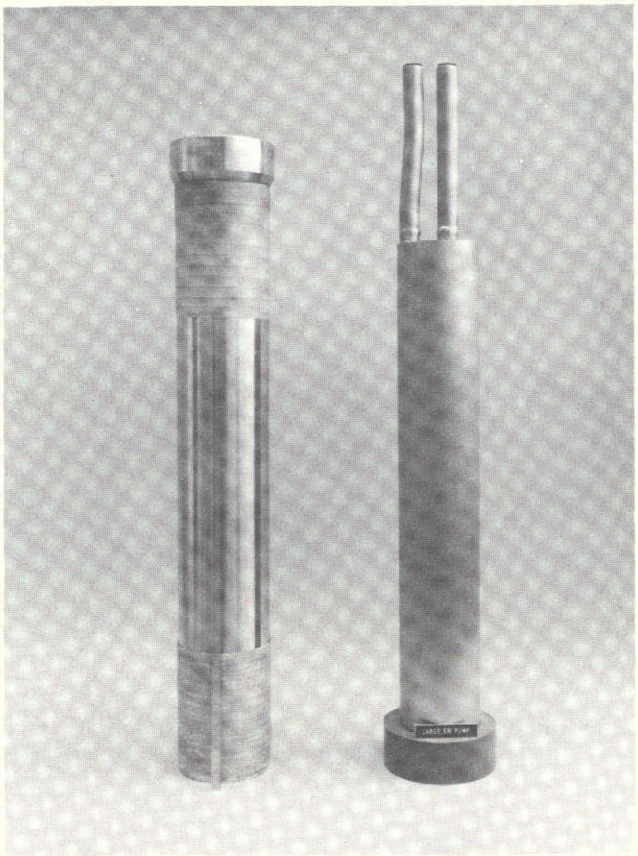


Fig. 18. Pumping element for
lithium pump

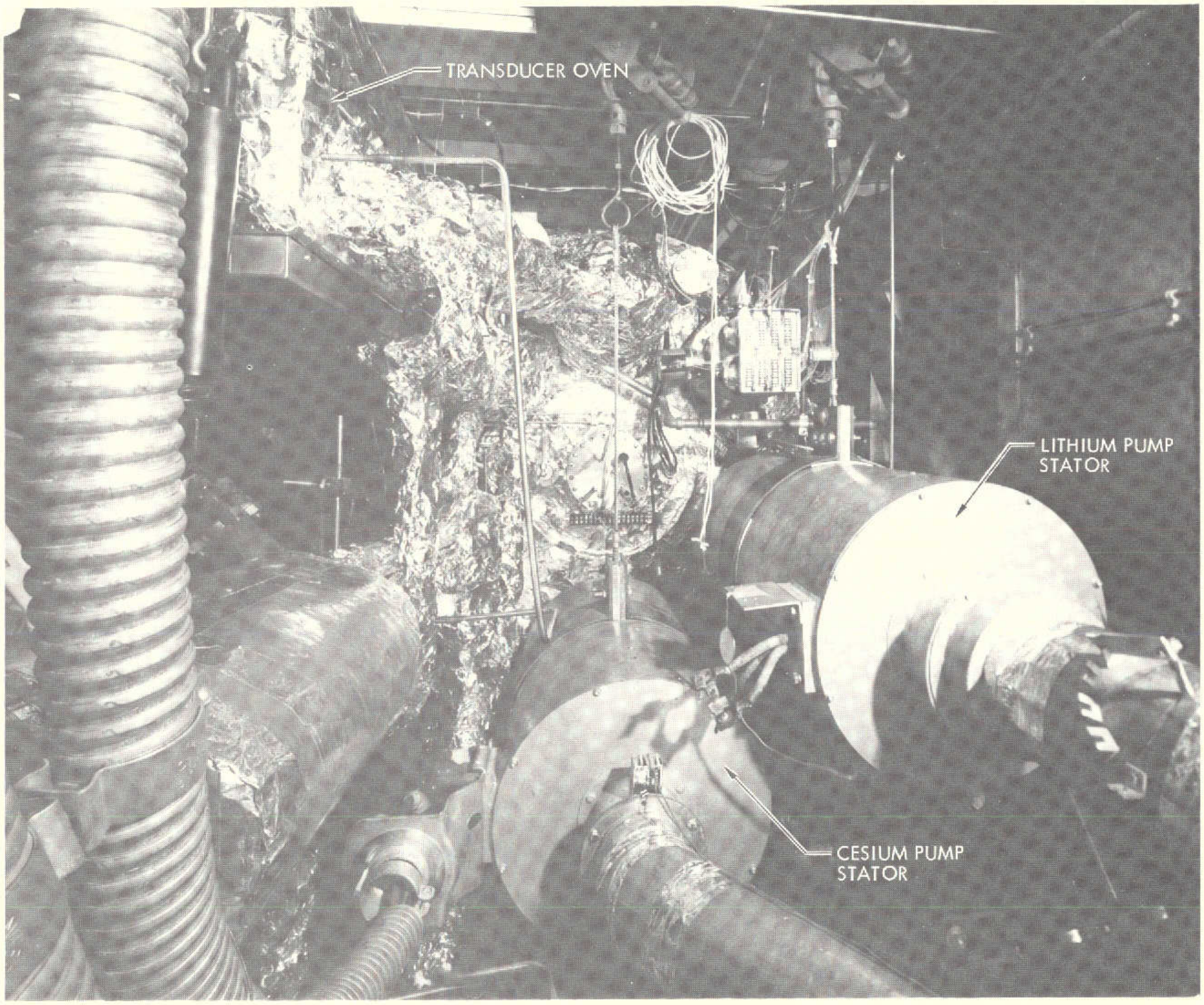


Fig. 19. Helical induction pump stators

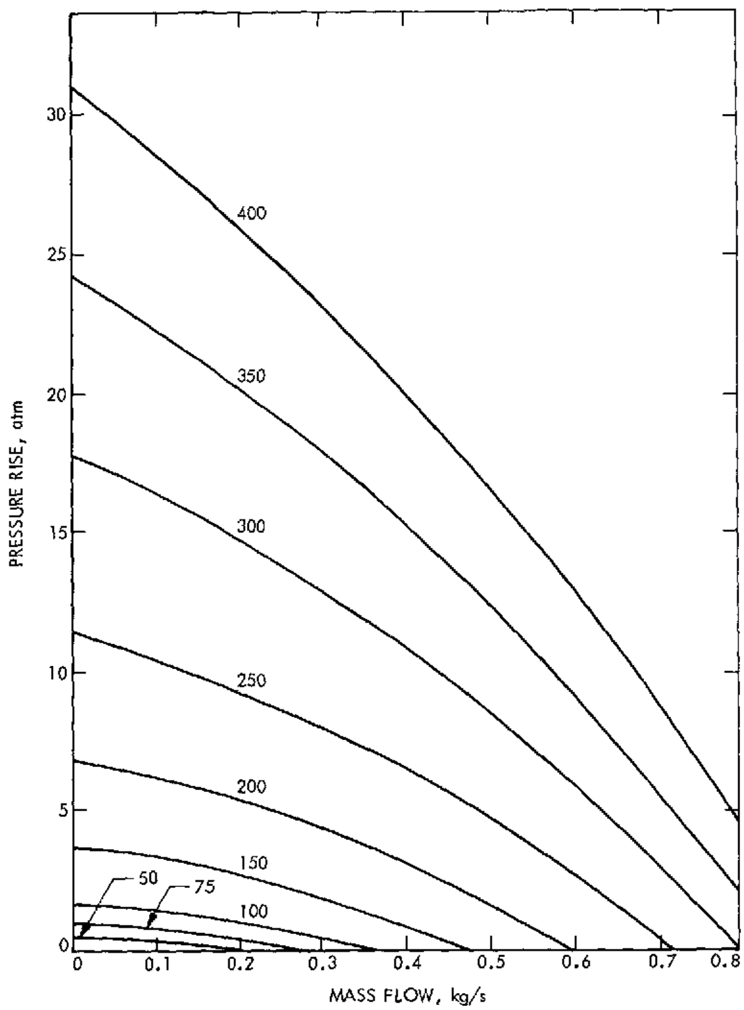


Fig. 20. Lithium pump characteristic at 980° C

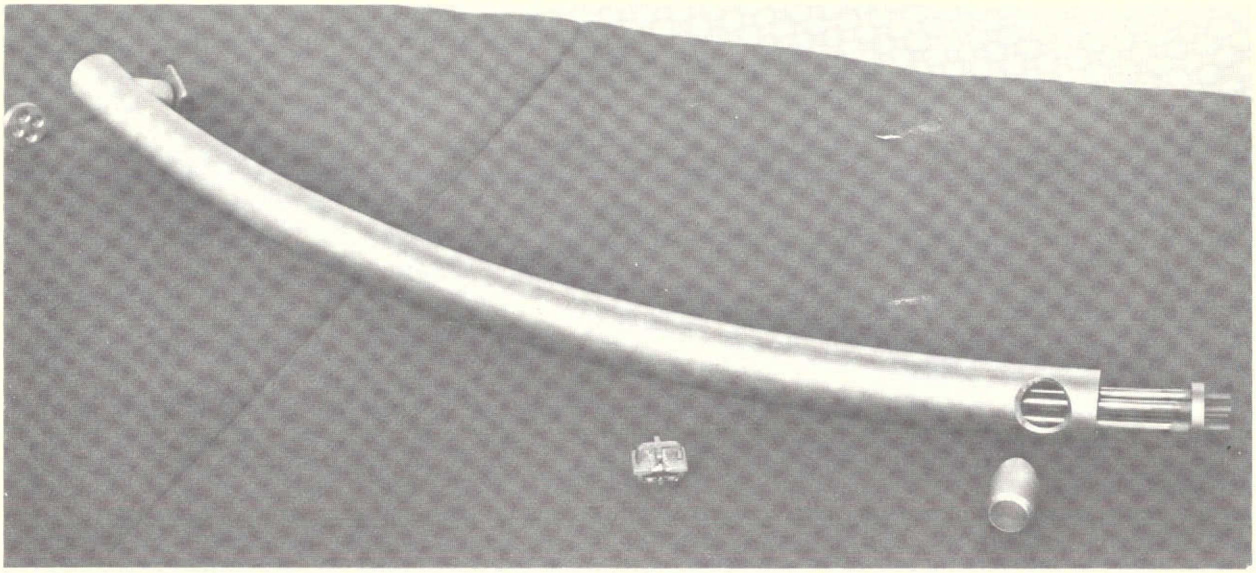


Fig. 21. Lithium heater before welding

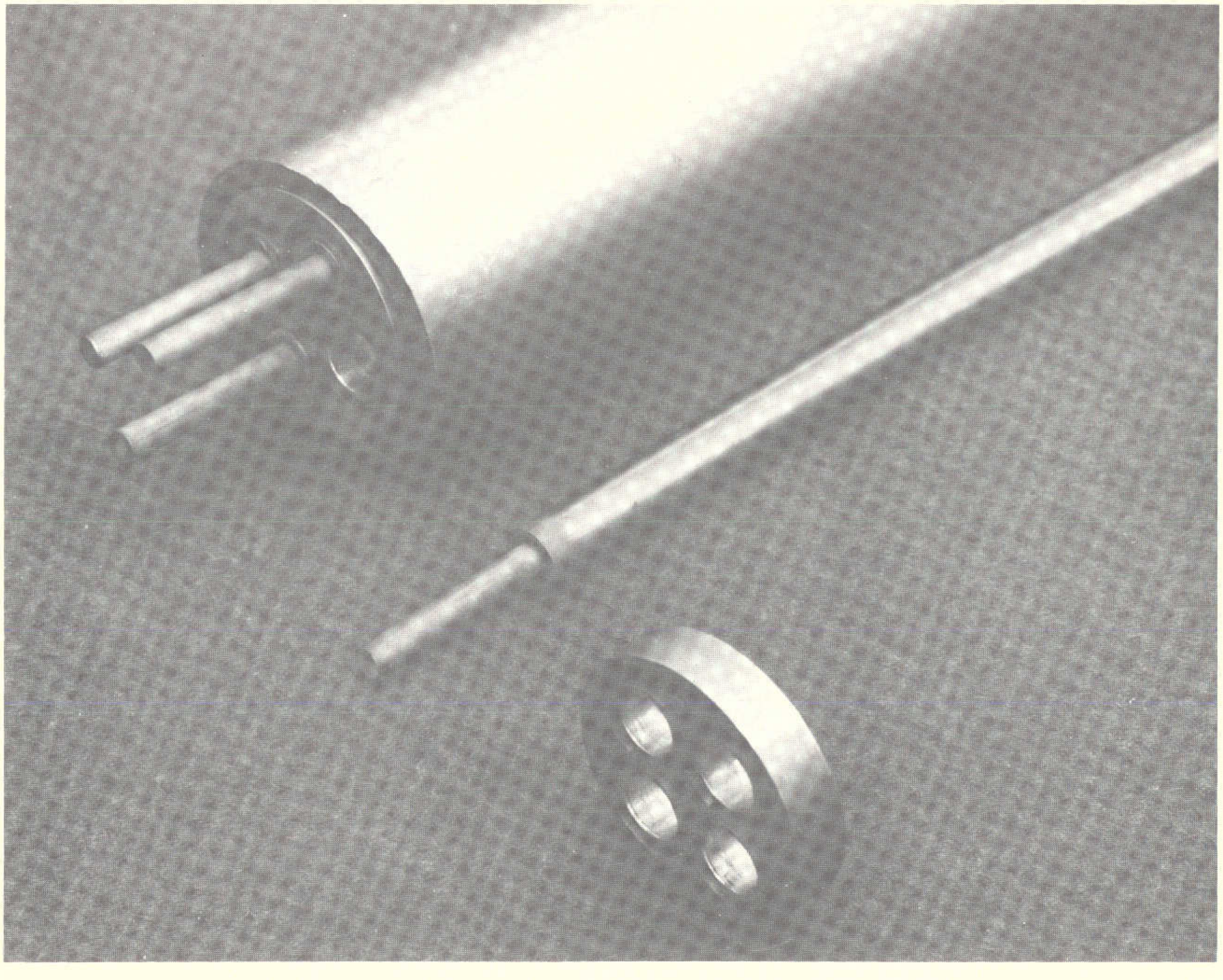


Fig. 22. Lithium heater end before welding

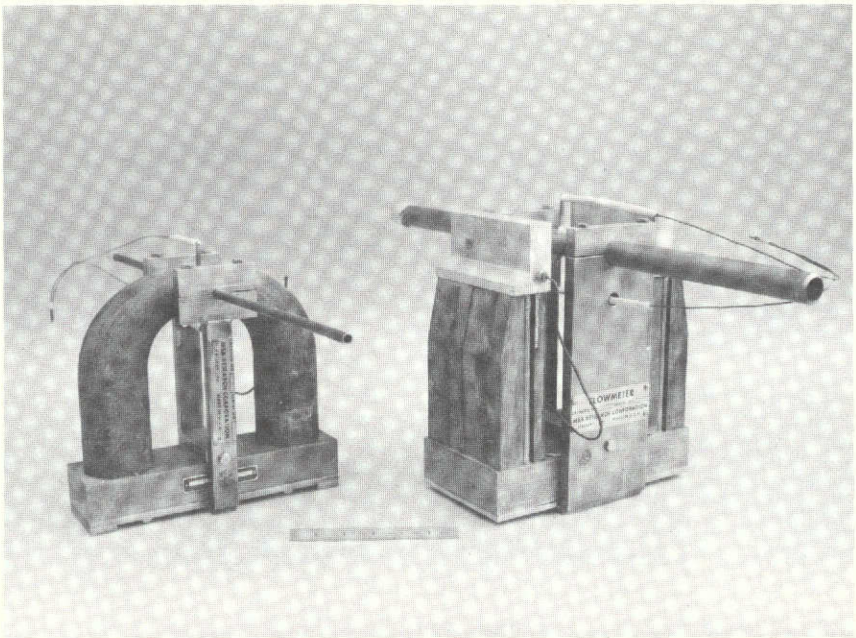


Fig. 23. Cesium and lithium flowmeters

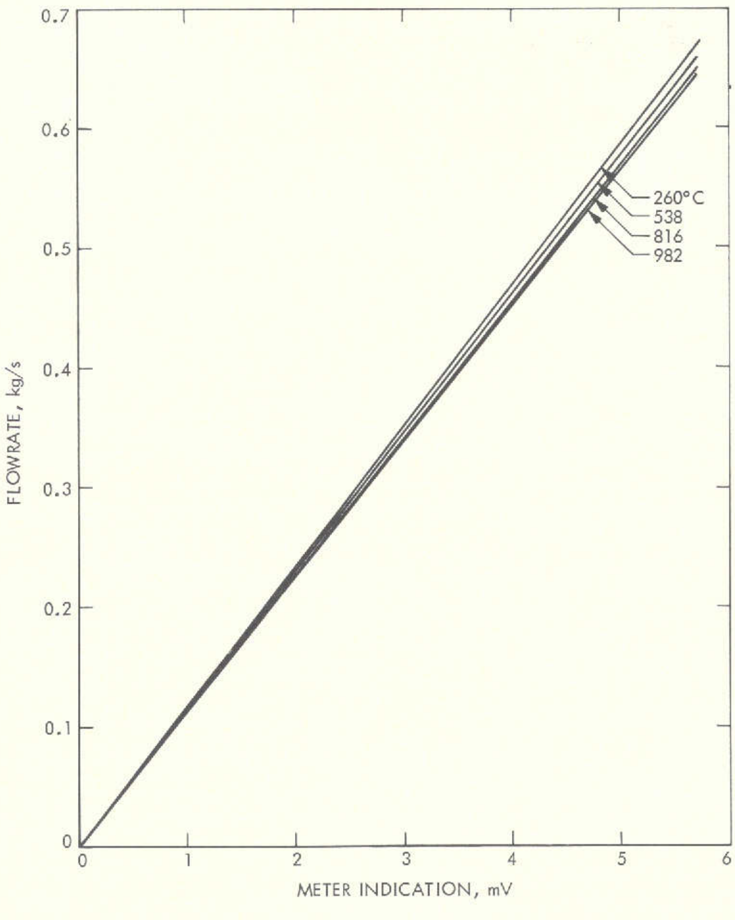


Fig. 24. Lithium flowmeter calibration
(776 gauss)

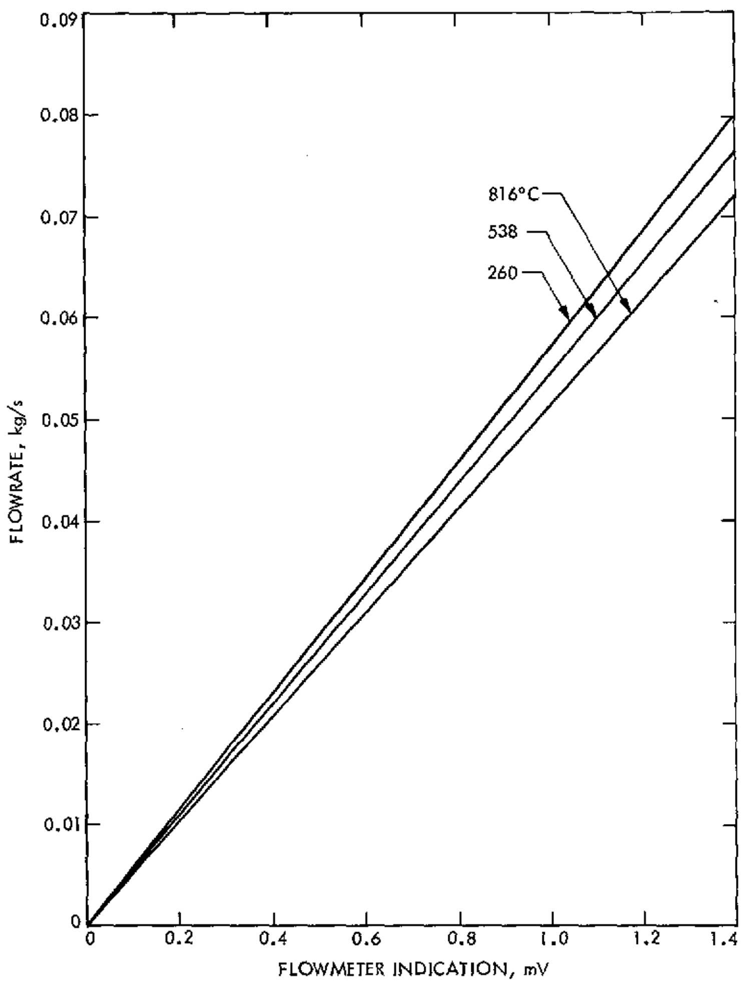


Fig. 25. Cesium flowmeter calibration (2355 gauss)

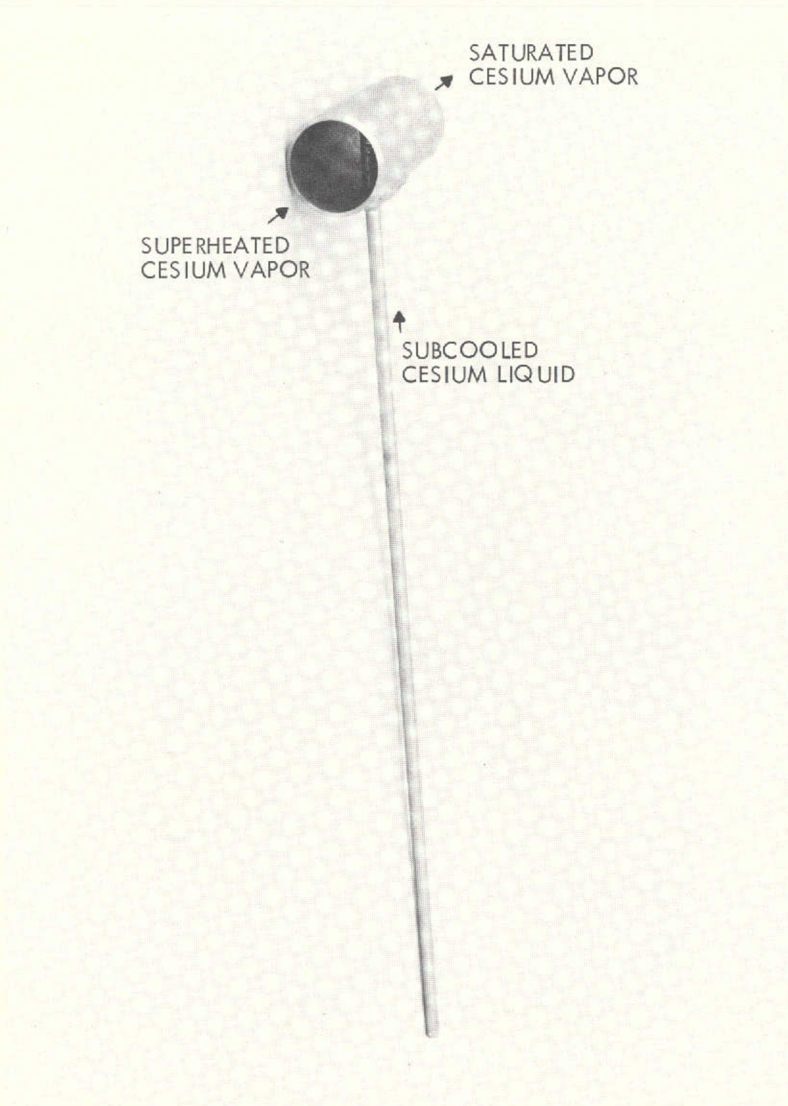


Fig. 26. Cesium desuperheater

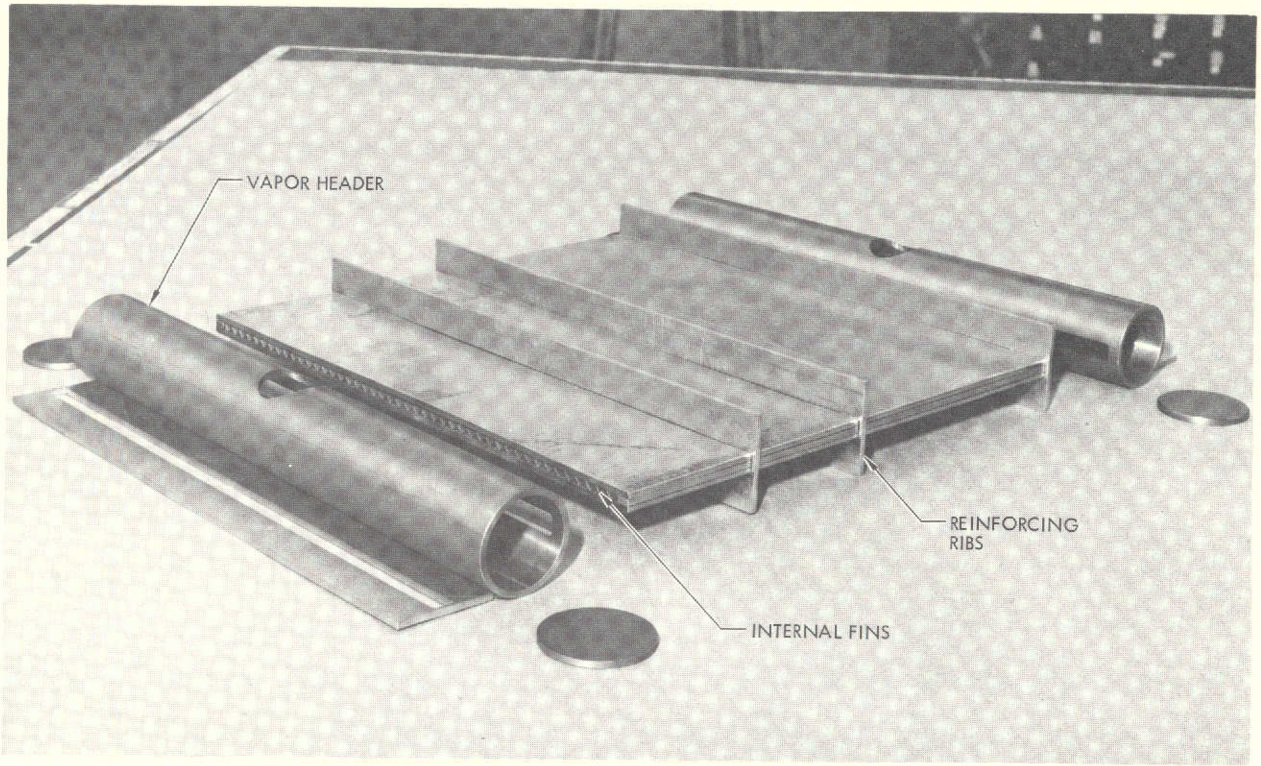


Fig. 27. Radiant cesium desuperheater before welding

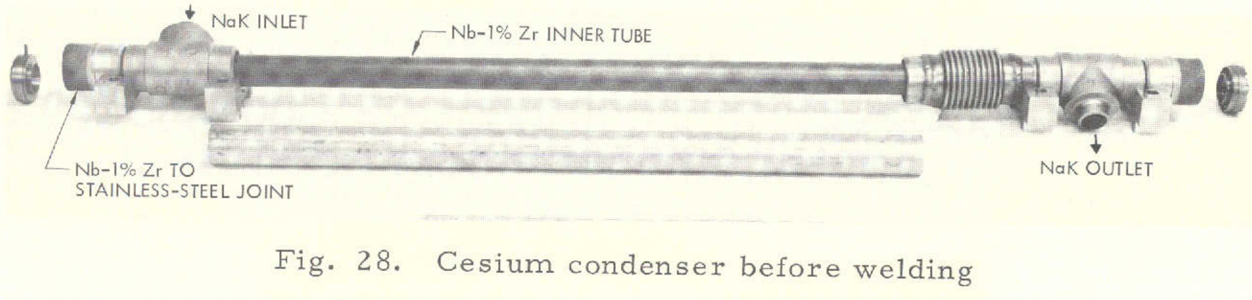


Fig. 28. Cesium condenser before welding

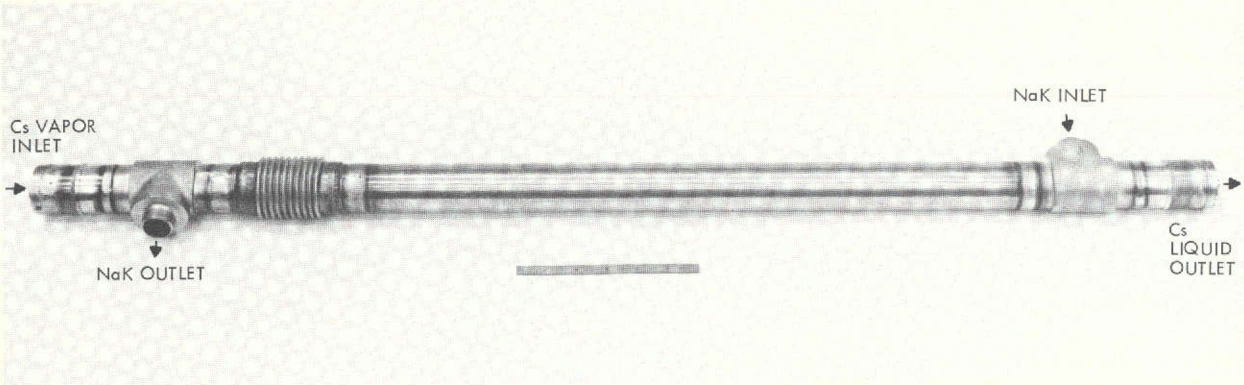


Fig. 29. Cesium condenser after welding

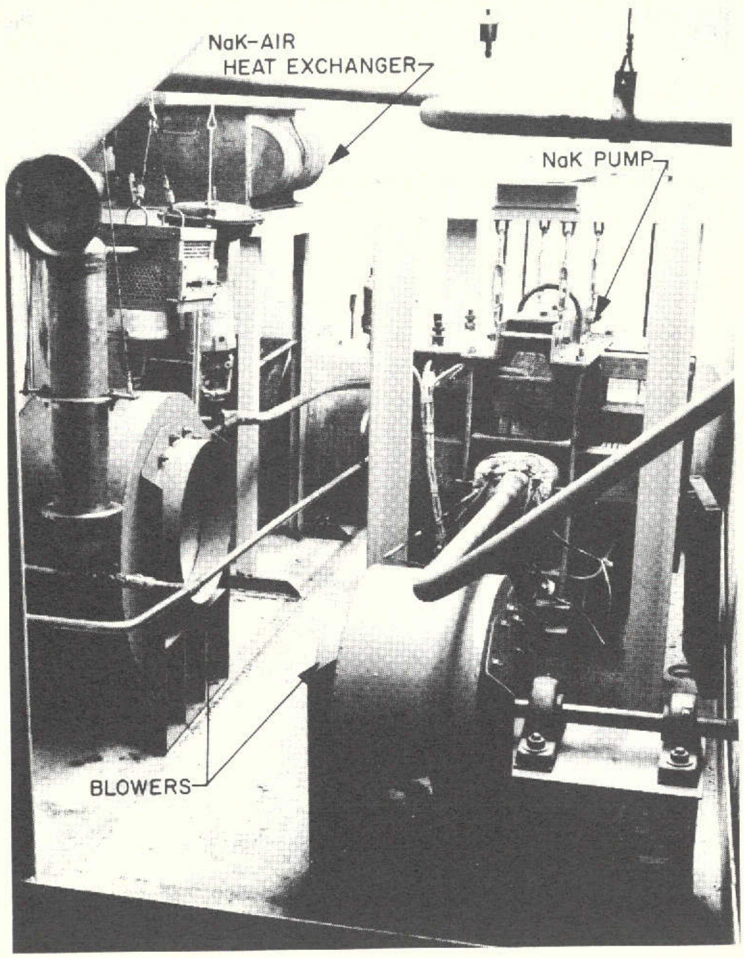


Fig. 30. NaK heat rejection system
before insulation

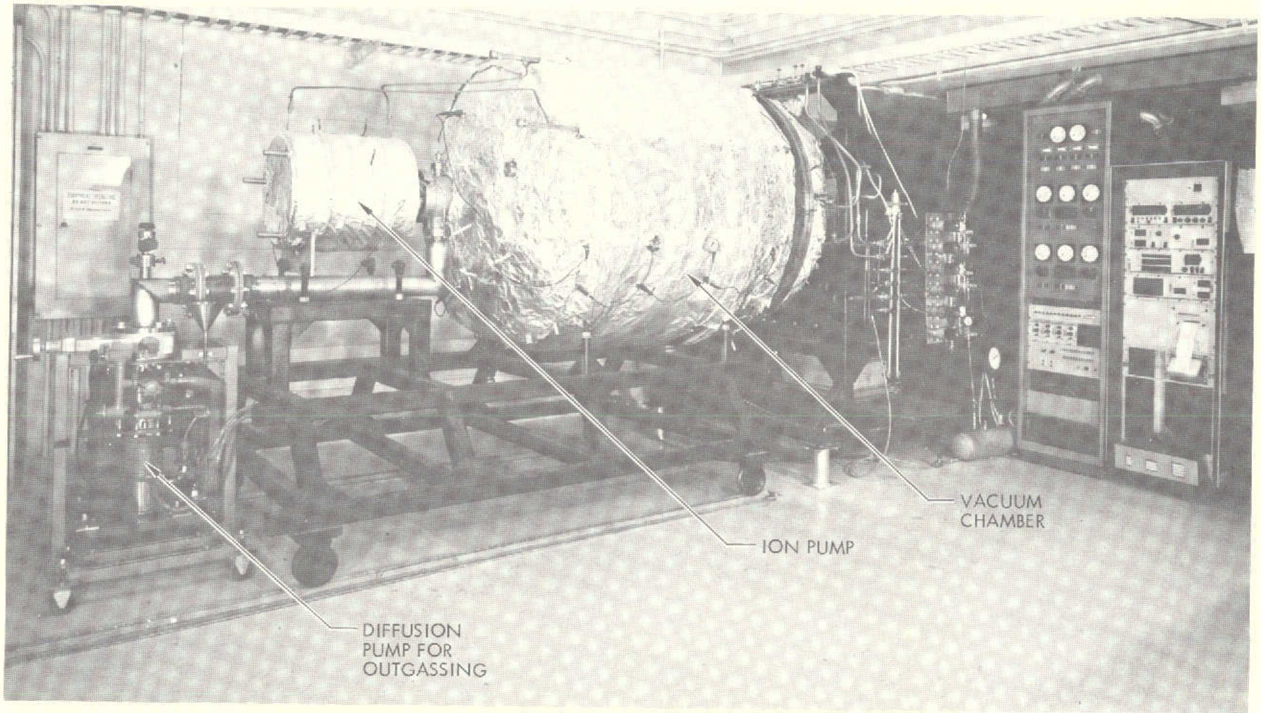


Fig. 31. Vacuum chamber and ion pump for cesium-lithium erosion loop

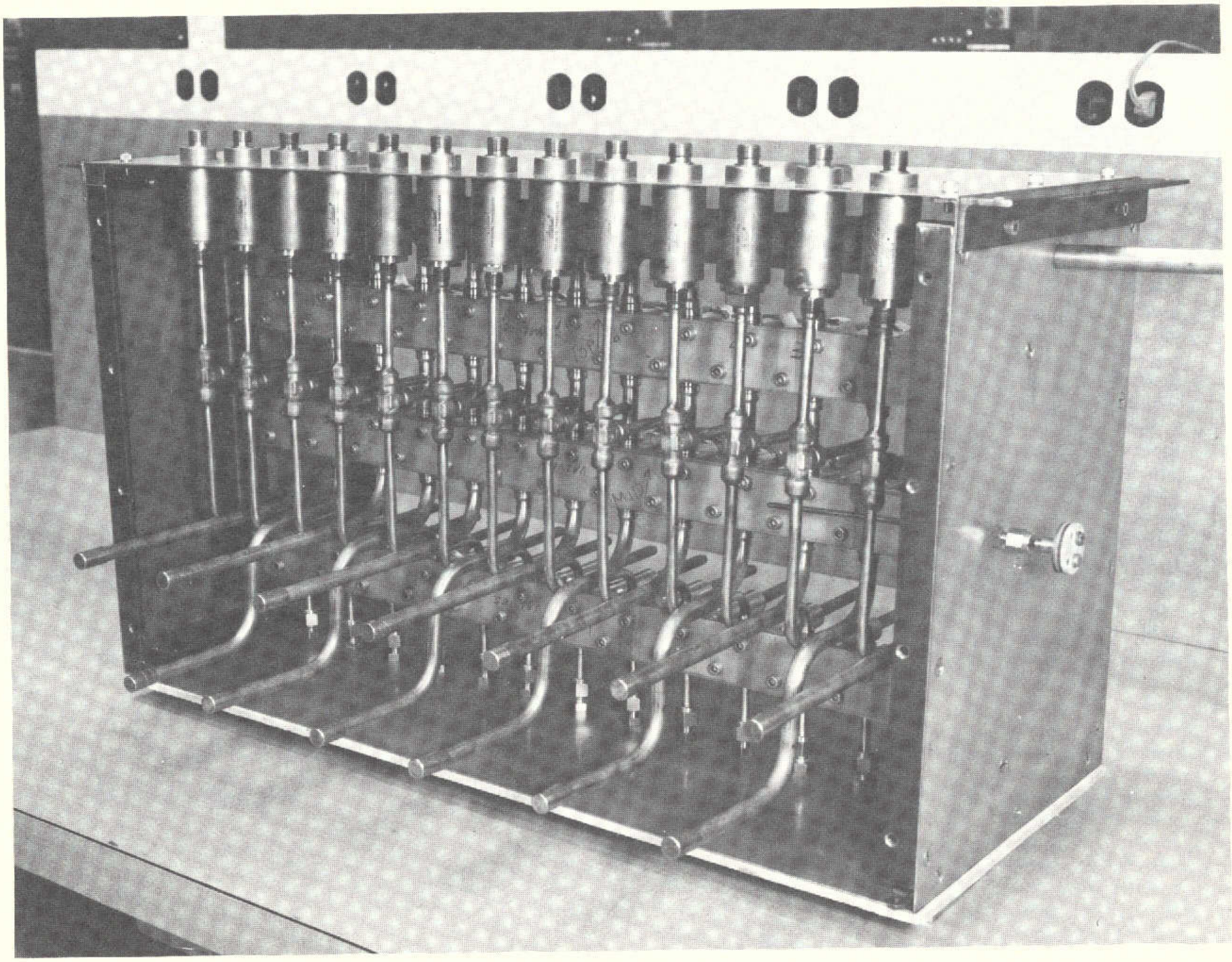


Fig. 32. Pressure transducer installation

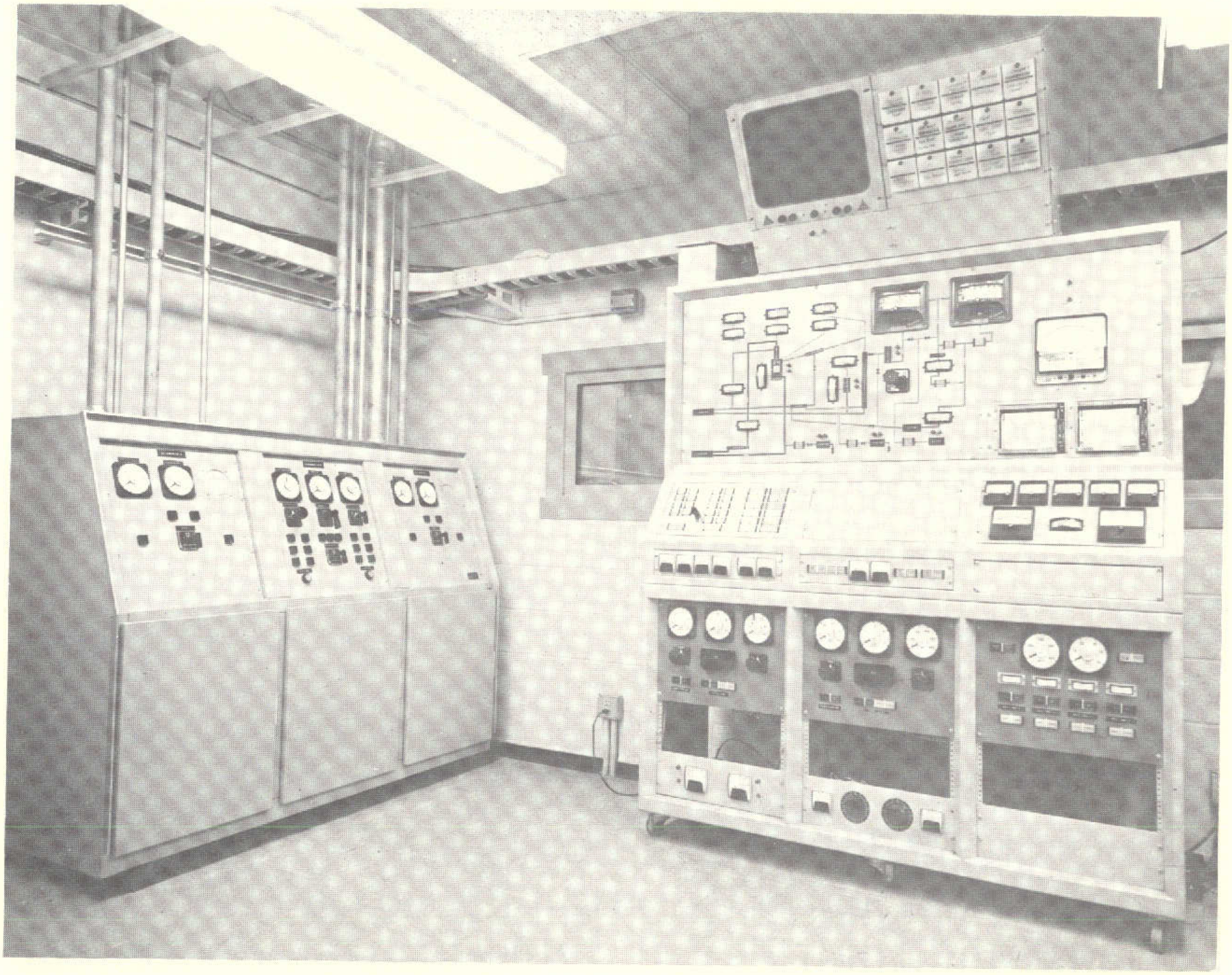


Fig. 33. Control console for cesium-lithium test system

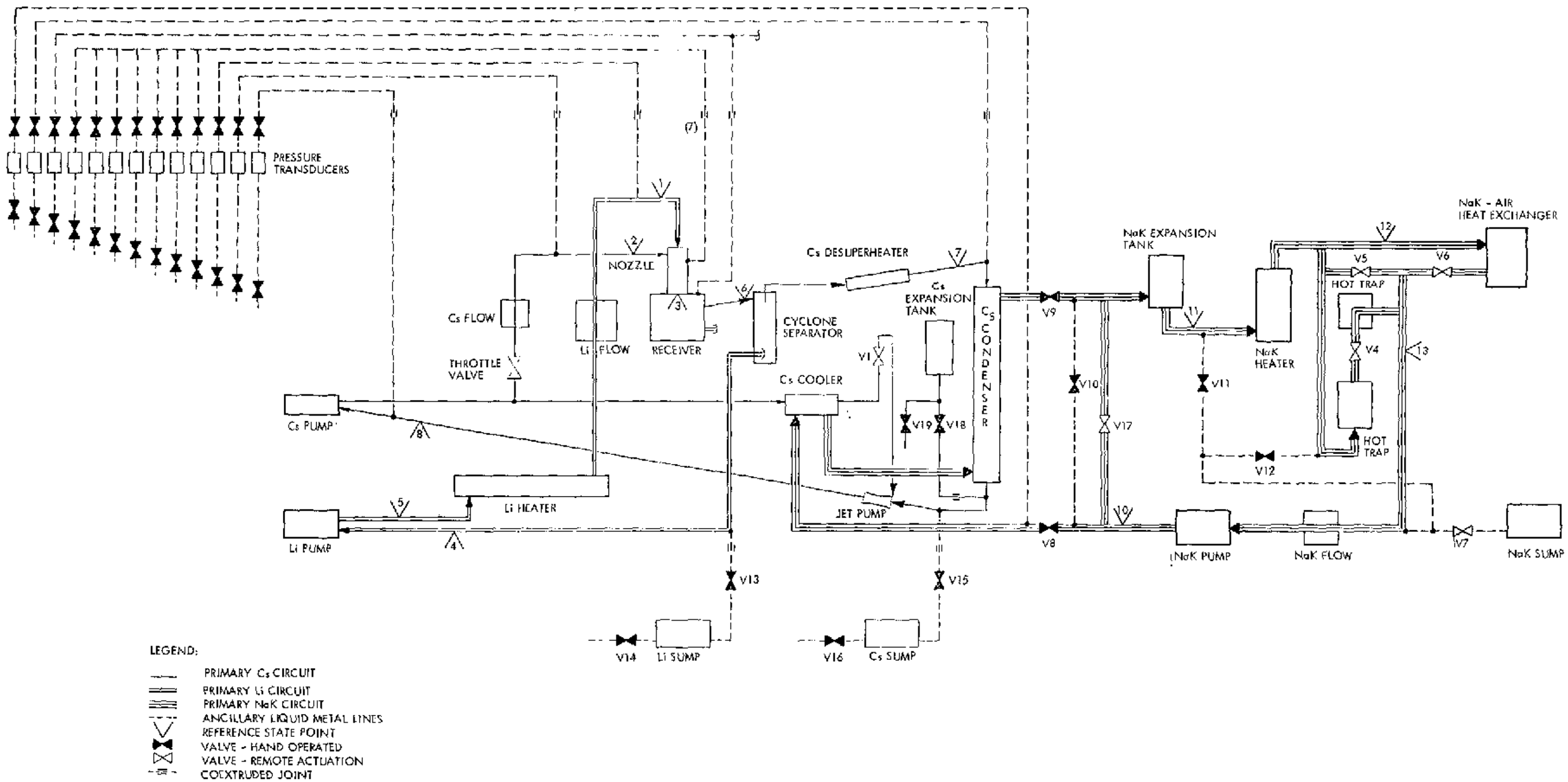


Fig. 34. Modified version of cesium-lithium erosion loop

APPENDIX A

LOOP OPERATING PROCEDURES

The startup and shutdown procedures used for the test loop are summarized below. The main modification required was installation of a cesium injection system and its actuation prior to starting the cesium pump (step 17). Full flow (steps 18-22) was not realized because of the problems discussed in the text. Values of temperatures, pressures, and flows are given in English units since the instrumentation and gauges are all in these units.

STARTUP PROCEDURES FOR Cs-Li LOOP

Startup Step	Values of Key Parameters
1. Evacuate loop to less than 10 microns by opening manual valves HT-1 and HV-1. Evacuate chamber to less than 10 microns by opening vacuum valve MV-1 to roughing manifold. Turn on load cell and O-ring cooling air flange, and bus cooling water. Turn on makeup air in NaK room.	Pressure of chamber — 10^{-2} torr on multi-torr gauge.
2. Turn on the chamber heaters to 5 A in each leg. Increase by 5-A steps over 10-12 h time until current is 20 A. Continue pumping until pressure is below 10 microns again. Close all transducer valves to loop. Backfill with argon to 75 mm.	Final chamber temperature $\approx$ 500°F. Loop temperature $\approx$ 450°F.
3. Start diffusion pump; open to chamber; close vacuum valve MV-1 to roughing manifold. Close manual values HT-1 and HV-1.	Chamber pressure of 10^{-5} torr.
4. Adjust pressure on lithium sump to 15 psig. Heat to 500°F.	Current setting of 5 A on trace heater to obtain 500°F.
5. Actuate Li pump. Adjust voltage until T-9 reads 450°F. Shut off pump.	T-9 = 450°F. Li pump voltage $\approx$ 45 V.
6. Open lithium fill valve, V13, slowly. Monitor TC-3 to determine when receiver is filled to proper level. When TC-3 actuates, close V13.	T-3 should raise from 450 to 500°F in 2-3 s when lithium is at the proper level.
7. Adjust pressure on cesium sump to 15 psig. Heat to 200°F.	Current setting of 3 A on trace heater to obtain 200°F.
8. Actuate Cs pump. Adjust voltage until T-21 reads 300°F. Shut off pump.	T-21 = 300°F. Cs pump voltage $\approx$ 35 V.
9. Open cesium fill valve, V15, slowly. Monitor TC16 to determine when cesium leg is filled to proper level. Close V15 and V1.	T-16 should lower from 450 to 200°F in 2-3 s when Cs is at the proper level.
10. Evacuate NaK loop through HV5. Open V8, V9, and V17; continue evacuation while vacuum manifold is <10 microns. Close HV5.	Manifold vacuum should be < 10 μm at 4 h.
11. Increase the argon on the supply tank to 8 psig; open the auxiliary drain valves (V11 and V12), then the main drain valve (V7), slowly and only enough to insure flow. It is best to fill the system slowly. When the liquid level has reached the desired level in the expansion tank, close the drain valves (V7, V11, and V12), then the heat exchanger bypass valve (V5), the exit valve on the heat exchanger (V6), the hot trap bypass valve (V4), and the Cs-Li loop bypass valve (V10). Open the two loop valves V8 and V9. Listen for NaK flow in the loop lines. As a final step, adjust the level by adding or draining NaK to the predetermined level as discussed in a previous section. Set the pressure at 10 psig on the reservoir and supply tank.	Level indicator light on Nak reservoir will change from red to yellow at proper level.
12. Turn the NaK pump powerstat up slowly until the liquid metal is flowing in the loop. Keep a constant watch on the flowmeter. If there is no immediate indication of flow, stop the pump immediately and determine the trouble.	CAUTION: This is a high-capacity pump and cannot be operated without flow or liquid metal in the pumping section. In the event that there is no indication of flow, double-check the electrical connection on the flowmeter and pump, all valve settings, and the liquid level. If everything

Startup Step	Values of Key Parameters
12. (contd)	appears in order, try the pump again. Watch for a flow indication and also use an ammeter to check that the current is flowing to the pump. A humming or buzzing sound will be heard if power is reaching the pump. The above instructions may seem rather pessimistic, but the most important point to remember is that power must not be left on this pump for more than a few seconds without liquid metal flowing.
13. Turn the NaK immersion heater on and set the temperature for 650°F. Close the valve (V4), isolating the hot trap from the system. Do not circulate cold liquid metal through the hot trap. By adjusting the flow through the heat exchanger, the desired temperature can be reached. Once the loop temperature has reached 650°F, operate at this point for an hour to ensure that the flowmeter is wet. Set the pump current at 19.5 A for a flow of 0.33 lb/s. The next step is to raise the loop temperature to 1000°F. Actuate the cooling blower for the pump when the loop temperature exceeds 850°F. Circulate at this temperature for a period of 24 h to ensure that oxides and impurities are absorbed in the liquid metal. Maintain as high flow in the heat exchanger as practical in order to ensure that the insides of these tubes are also cleaned.	
14. Operate the hot trap, starting the flow slowly, 1/4 - 1/2 gpm, through the hot trap by opening the valve (V4). The flow in the main loop should be 1 lb/s through the heat exchanger. All portions of the loop must be at a minimum of 1000°F while hot trapping to ensure that any oxide present is in solution. Maintain the temperature at a minimum of 1000°F and the flowrate through the loop at some reasonable rate (1/2 - 1 lb/s). The time required to reduce the oxide content to an acceptable level is dependent on the quantity present and the operating temperature of the hot trap. The oxide removal rate is greater at 1200 than 1000°F. Experience indicates for a system of this size that a minimum of 12 h would be necessary to initially clean the system. Reduce the heater voltage until the loop temperature is 800°F.	
15. Start Li pump at 25 V. Gradually increase until flow rate F1 is 0.3 lb/s. Start freeze stem flow at maximum flow rate. Remove insulation from Li pump duct port and Cs pump port.	1.16 mV on F1 = 0.3 lb/s at 500°F. Pump voltage ≈ 50 V.
16. Actuate Li heater at 200 A. Increase current until Li inlet temperature TC-1 is 1200°F (100°F/h).	E3 = 2.25 V at 200 A. E3 ≈ 4.7 V for 1200°F.
17. (a) Set Li pump at 90 V. (b) Start Li pump blower. (c) Start Cs pump at 80 V. (d) Actuate Cs pump blower. (e) Set heater at 9.1 V.	Cs flow, F2 = 0.0076 lb/s (0.06 mV) at E2 = 80 V Li flow F1 = 0.3 at 90 V

Startup Step

17. (contd)
Open valves to transducers. Reduce freeze valve flow until T-26 = 450°F. Actuate load cell motor until the gap is reduced to 0.010 in.

18. Increase Li inlet temperature in 100°F steps by first increasing the heater voltage, then the lithium flow, then the cesium flow. Keep chamber pressure in the 10^{-5} range. Actuate the ion pump when 1800°F is reached and pressure is declining. Valve off diffusion pump. When the Cs pump temperature TC21 reaches 1100°F, evacuate Cs expansion tank through manual valve HV2, close manual valve HT2, open the manual valve V18 to the expansion tank until the first level thermocouple TC-52 is actuated, close the manual valve V18. When Cs temperature TC-21 reaches 1300°F, drain loop through the Cs drain line V18 until the second level thermocouple TC-53 is actuated.

19. Adjust the separator gap until the NaK outlet temperature TC-33 is minimized. Change V1 until saturated vapor is obtained (compare TC14 and P11).

20. Adjust the Li pump and Cs pump, heater and NaK temperature until P1 = 137 psia at a value of F1/F2 = 10.

21. Measure nozzle thrust. Vary stem position by +0.010 in. in 0.002-in. increments to determine spring constant.

22. Freeze stem by increasing the Dowtherm flow to the full flow rate.

Values of Key Parameters

T1	E1	E2	E3	n	
1300	110	100	11.2	0	
1400	136	125	13.1	0	
1500	165	153	15.0	0	C1 = 0.05
1600	198	186	17.0	0	
1700	231	236	18.2	.818	
1800	279	293	21.2	.891	
1700	233	226	13.8	.449	C1 = 0.02
1800	283	277	16.4	.509	

The values under key parameters are for a lithium carryover fraction of 0.05. Different values will result in different heater settings to attain the required temperatures.

VALVE POSITIONS FOR EROSION LOOP STARTUP

Startup Step	Valve No. V 1	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	0	X	X	X	X	X	X	X	X	X	X	X	X	X	X	0	X
2	0	X	X	X	X	X	X	X	X	X	X	X	X	X	X	0	X
3	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
4	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
5	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
6	X	X	X	X	X	X	X	X	X	X	0/X	X	X	X	X	X	X
7	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
8	0	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
9	0/X	X	X	X	X	X	X	X	X	X	X	X	0/X	X	X	X	X
10	X	X	X	X	X	0	0	X	X	X	X	X	X	X	0	X	X
11	X	0/X	0/X	0/X	0/X	0	0	0/X	0/X	0/X	X	X	X	X	0	X	X
12	X	X	X	X	X	0	0	X	X	X	X	X	X	X	0	X	X
13	X	X	0	0	X	X	0	X	X	X	X	X	X	X	0	X	X
14	X	0/X	0	0	X	X	0	X	X	X	X	X	X	X	0	X	X
15	X	X	X	X	X	0	0	X	X	X	X	X	X	X	0	X	X
16	X	X	X	X	X	0	0	X	X	X	X	X	X	X	0	X	X
17	X	X	X	X	X	0	0	X	X	X	X	X	X	X	0	X	X
18	0	X	X	X	X	0	0	X	X	X	X	X	X	X	0	0/X	X
19	0	X	X	X	X	0	0	X	X	X	X	X	X	X	0	X	X
20	0	X	X	X	X	0	0	X	X	X	X	X	X	X	0	X	X
21	0	X	X	X	X	0	0	X	X	X	X	X	X	X	0	X	X
22	0	X	X	X	X	0	0	X	X	X	X	X	X	X	0	X	X

Startup Step	Valve No. SA 1	2	3	4	5	6	7	8	9	10	Valve No. SV 1	2	3	4	5	6	7	8	HT 1	2	HV 1	2	3	4	5	6	MV 1
1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	0	0	0	X	X	0	X	X	0
2	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	0	0	0	X	X	0	X	X	0
3	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
4	X	X	X	X	X	X	0	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
5	X	X	X	X	X	X	0	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
6	X	X	X	X	X	X	0/X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
7	X	X	X	X	X	0	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
8	X	X	X	X	X	0	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
9	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
10	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	0/X	X	X
11	X	X	X	0/X	0/X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
12	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
13	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
14	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
15	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
16	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
17	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
18	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
19	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
20	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
21	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
22	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

X Closed

0 Open

NORMAL SHUTDOWN FOR EROSION LOOP

1. Decrease the Li pump and Cs pump voltages concurrently by 25-V steps until a Li pump flow rate of 0.3 lb/s is reached. Reduce flow to freeze valve and increase gap to 0.045 in.

2. Decrease the Cs pump voltage further until a setting of 25 V is reached.

3. Decrease the Li heater power until a lithium inlet temperature of 1000°F is reached (100°F/hr).

4. Turn off cesium pump.

5. Turn off Li heater.

6. Decrease Li pump voltage by 25-V increments until it is off.

7. Turn off NaK flow.

8. Set Li sump pressure to 5 psig and loop pressure to 15 psig. Open SA3 manual valve HT1 and V13 to drain lithium. Drain until sump pressure rises. Repeat for Cs sump using SA3 manual valve HT1 and V15. Close SA3 and drain valves V13 and V15. Evacuate loop through SV6 and manual valve HV1. Close SV6 and manual valves HV1 and HT1.

9. Evacuate both sumps through HV3 and HV4. Close HV3 and HV4.

10. Heat both sumps to 400°F. Heat chamber and pumps to 800°F. Open V13 and V15. Monitor fill and dump line temperature TC-43. When TC-43 drops to ~400°F the loop is drained. Close V13 and V15. Turn off all heaters.

EMERGENCY PROCEDURES FOR EROSION LOOP

Emergency	Function	Location of Function
1. Liquid metal leak in chamber	a. Turn off Li, Cs, NaK pumps, Li heater, ion pump.	CR
	b. Close manual dp valve (if open).	HB
	c. If O-ring temperature rises to 300°F, open argon flood for chamber, SA-8.	HB
	d. Increase cooling flow on chamber to limit temperature rise.	HB
	e. If NaK level drops, pressurize NaK reservoir to 10 psig, and drain through V7 to NaK sump. Watch chamber pressure.	CR
	f. Keep system under observation as temperature cools.	CR/HB
2. Liquid metal leak in NaK room	a. Turn off Li, Cs, NaK pumps, Li heater, bus cooling water.	CR
	b. Turn off heat exchanger blower and makeup air blower.	CR
	c. Close heat exchanger damper by setting controller on 1400°F.	CR
	d. Pressurize NaK reservoir to 10 psig, drain through V7 to NaK sump.	CR
	e. When leak stops, extinguish fire if safe.	HB
3. Liquid metal leak in door area	a. Turn off Li, Cs, NaK pump, Li heater, bus cooling water.	CR
	b. Turn off heat exchanger blower and makeup air blower.	CR
	c. Close heat exchanger damper by setting controller on 1400°F.	CR
	d. If safe, turn off flange water and transducer oven.	HB
	e. If NaK level drops, pressurize NaK reservoir to 10 psig and drain through V7 to NaK sump.	CR
	f. If leak is from transducer box, valve off all transducers, if safe.	HB
	g. When safe, extinguish fire.	HB
CR = control room HB = high bay		

APPENDIX B

TEST SYSTEM SCHEMATIC DIAGRAMS

All instrumentation, control, flow, argon and vacuum, and electrical schematics for the test system are contained in this appendix (see Figs. B-1 through B-30).

The following manufacturers' manuals are available at the Jet Propulsion Laboratory, care of Section 383 files, Mr. L. H. Huebner.

1. Technical Manual, Helical Induction Electromagnetic Pump, Model 5KY414PK1 (Lithium), General Electric Company.
2. Technical Manual, Helical Induction Electromagnetic Pump, Model 5KY414PJ1 (Cesium), General Electric Company.
3. Instruction Manual, TrioVac, 500 liter/s Triode Ion Pump, Model 22TP300, General Electric Company.
4. Instruction Book, Type WSH-Arc Welder, 1000A, Westinghouse Electric Company.
5. Miscellaneous instrumentation and auxiliary component calibration sheets and instruction manuals.

INSTRUMENTATION FUNCTIONS

Transducer Connections

	Inside Chamber	TC Panel 1	
TC- 1	Nozzle inlet - lithium	1 &	2
2	Nozzle inlet - cesium	3	4
3	Receiver lithium fill	5	6
4	Receiver cesium exit	7	8
5	Receiver lithium exit	9	10
6	Lithium pump return line	11	12
7	Lithium pump exit	13	14
8	Lithium pump duct A	15	16
9	Lithium pump duct B	17	18
10	Heater bus A	19	20
11	Heater bus B	21	22
12	Heater body	23	24
13	Lithium flowmeter magnet	25	26
14	Condenser, cesium inlet	27	28
15	Condenser, cesium exit	29	30
16	Condenser, cesium fill	31	32
17	Cesium line, cooler to de-sup	33	34
18	Cesium pump return line	35	36
19	Cesium pump exit	37	38
20	Cesium pump duct A	39	40
21	Cesium pump duct B	41	42
22	Cesium flowmeter magnet	43	44
23	Receiver level indicator	45	46
24	Co-extruded joint, pressure taps	47	48
25	Co-extruded joint, loop vacuum	49	50
26	Co-extruded joint, load cell stem	51	52
27	Receiver	53	54
28	Nozzle inlet lithium	55	56
29	Nozzle inlet cesium	57	58
30	Nozzle body	59	60
31	Sight glass, 3-1/4 in. high	61	62
32	Sight glass, 4-1/2 in. high	63	64

	Outside Chamber	TC Panel 2	
TC-33	NaK exit piping	65 &	66
34	Expansion tank	67	68
35	Heater	69	70
36	Hot trap	71	72
37	Hot trap flowmeter	73	74
38	Heat exchanger out	75	76
39	Main flowmeter	77	78
40	Pump outlet	79	80
41	NaK pump windings	81	82
42	Pressure tap lines	83	84
43	Fill and dump lines	119	120
44	Lithium pump windings	121	122
45	Cesium pump windings	123	124
46	Transducer oven	125	126
47	Heater feedthru A	127	128
48	Heater feedthru B	129	130
49	Chamber body	131	132
50	Ambient	133	134
51	Thermocouple ambient	135	136
52		137	138

Instrumentation Functions
Transducer Connections (contd)

Pressure Functions		Pressure Panel Amp. Out Connections
P- 1	Nozzle, lithium inlet	1 to amplifier 105 & 106
2	Nozzle, cesium inlet	2 to amplifier 107 & 108
3	Receiver pressure	8 to amplifier 109 & 110
4	Nozzle tap A	3
5	Nozzle tap B	4
6	Nozzle tap C	5
7	Nozzle tap D	6
8	Nozzle tap E	7
9	Nozzle tap F	12
10	Nozzle tap G	13
11	Condenser cesium inlet	9 to amplifier 111 & 112
12	Cesium pump inlet	10
13	NaK bypass	11 to amplifier 139 & 140

Flowmeter Functions		Flowmeter and Feedthru			
F-1	Lithium flow	85 &	86	95 &	96
1a	Lithium flow (standby)	87	88	97	98
2	Cesium flow	89	90	99	100
2a	Cesium flow (standby)	91	92	101	102
		93	94	103	104
F-3	Main NaK flow	113	114	(outside)	
F-4	Hot trap flow	115	116	(outside)	
F-5	NaK bypass flow	117	118	(outside)	

Instrumentation Functions

Meter - Relays

Cable No. 71 to Main Control Panel (CBA)						Meter No.
Subcable	1	AK	27	&	28	1
	2	AM	1		2	2
	3	AP	3		4	3
	4	DDX	115		116	4
	5	FDX	113		114	5
	6	CHX	111		112	6
	7	BKX	109		110	7
	8	EJX				8
	9	GOX	85	&	86	9
	10	BMX	105		106	10
	11	ENX	45		46	11
	12	BPX	107		108	12
	13	EPX	89		90	13

Cable No. 71 to Controllers						Controller No.
Subcable	22	C1	69	&	70	22
Subcable	23	C2	75	&	76	23
Subcable	24	C3	125	&	126	24

Cable No. 71 to Secondary Panel (CBD)						Meter No.
Subcable	14	AC	81	&	82	14
	15	AF	121		122	15
	16	AM	123		124	16
	17	BD	127		128	17
	18	BN	131		132	18
	19	BK	15		16	19
	20	AK	39		40	20
	21	AP	143		144	21

Cable No. 72 to Strip Chart			
Subcable	1	No. 1	5 & 6
	2	No. 2	31 & 32
	3		
	4	pair 7 -	bus shunt
	5		53 & 54
	6		61 & 62
	7		63 & 64

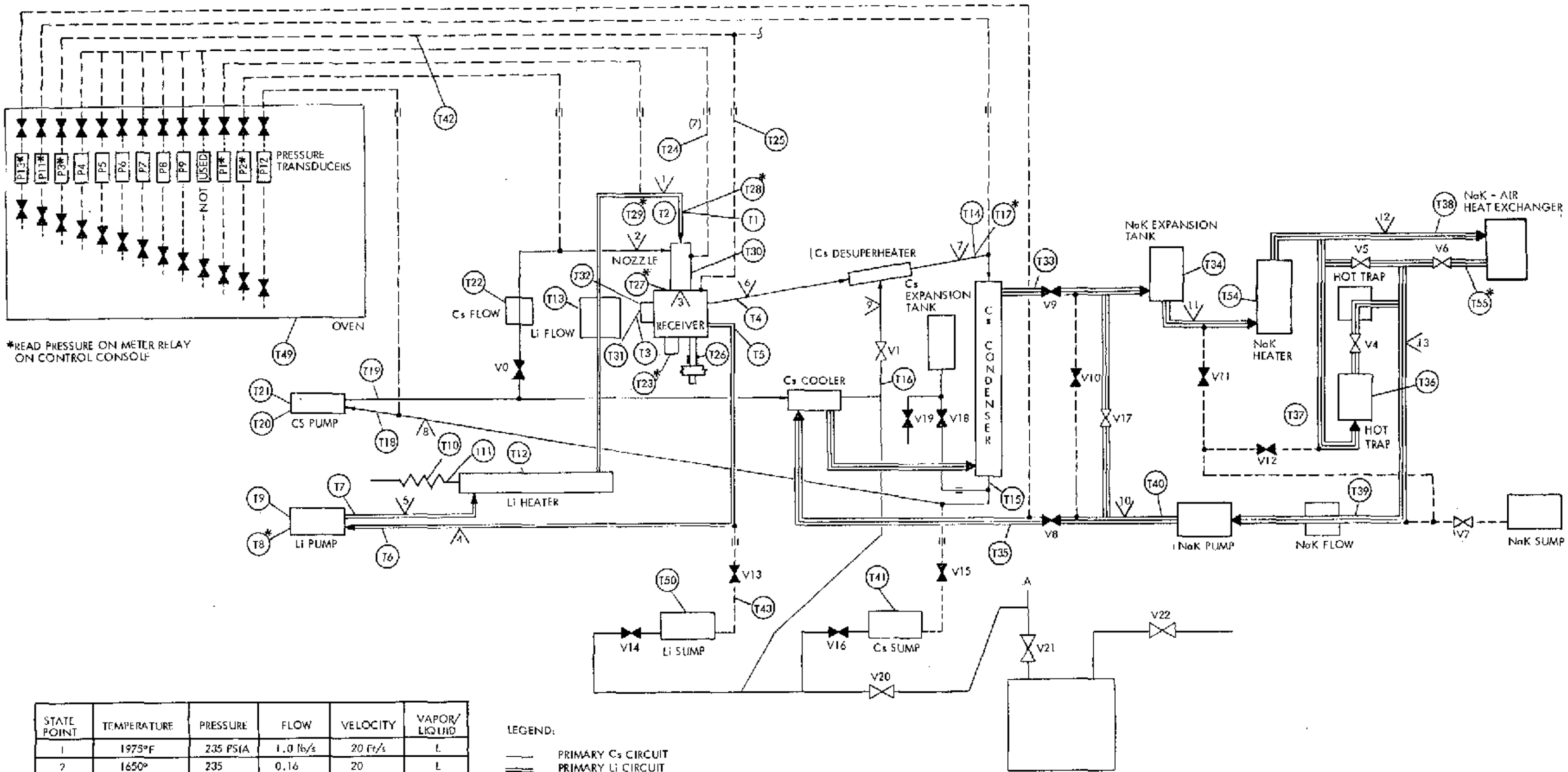
Instrumentation Functions
Meter - Relays (contd)

Cable No. 45
Multi-Point Recorder 1

Channel				
1-26	P4		3	(pressure) pressure cable number
2-27	P5		4	
3-28	P6		5	
4-29	P7		6	
5-30	P8		7	
6-35	P9		12	
7-36	P10		13	
8-33	P12		10	
9-34	139	&	140	- 34 amp 6
10	19		20	
11	21		22	
12	25		26	
13	43		44	
14	77		78	
15	73		74	
16	129		130	
17				load cell enc. temp.
18				
19	125	&	126	
20	47		48	
21	49		50	
22	51		52	
23				vacuum
24	135	&	136	

Cable No. 46
Multi-Point Recorder 2

Channel			
1	23	&	24
2	1		2
3	9		10
4	11		12
5	17		18
6	17		18
7	13		14
8	37		38
9	3		4
10	7		8
11	27		28
12	29		30
13	35		36
14	41		42
15	33		34
16	75		76
17	79		80
18	65		66
19	67		68
20	69		70
21	71		72
22	83		84
23	119		120
24			



STATE POINT	TEMPERATURE	PRESSURE	FLOW	VELOCITY	VAPOR/ LIQUID
1	1975°F	235 PSIA	1.0 lb/s	20 Ft/s	L
2	1650°	235	0.16	20	L
3	1915°	30	1.16	515	L, V
4	1915°	30	1.00	20	L
5	1940°	245	1.00	20	L
6	1915°	28	0.16	175	V
7	1400°	27	0.22	200	V
8	1250°	26	0.22	20	L
9	1250°	200	0.06	20	L
10	700°	30	0.50	20	L
11	1100°	25	0.50	20	L
12	1100°	25	0.50	20	L
13	700°	20	0.50	20	L

LEGEND:
PRIMARY Cs CIRCUIT
PRIMARY Li CIRCUIT
PRIMARY NaK CIRCUIT
ANCILLARY LIQUID METAL LINES
REFERENCE STATE POINT
VALVE - HAND OPERATED
VALVE - REMOTE ACTUATION
COEXTRUDED JOINT
THERMOCOUPLE
TC READOUT ON METER RELAY

Fig. B-1. 100-kW erosion loop liquid metal circuits schematic diagram

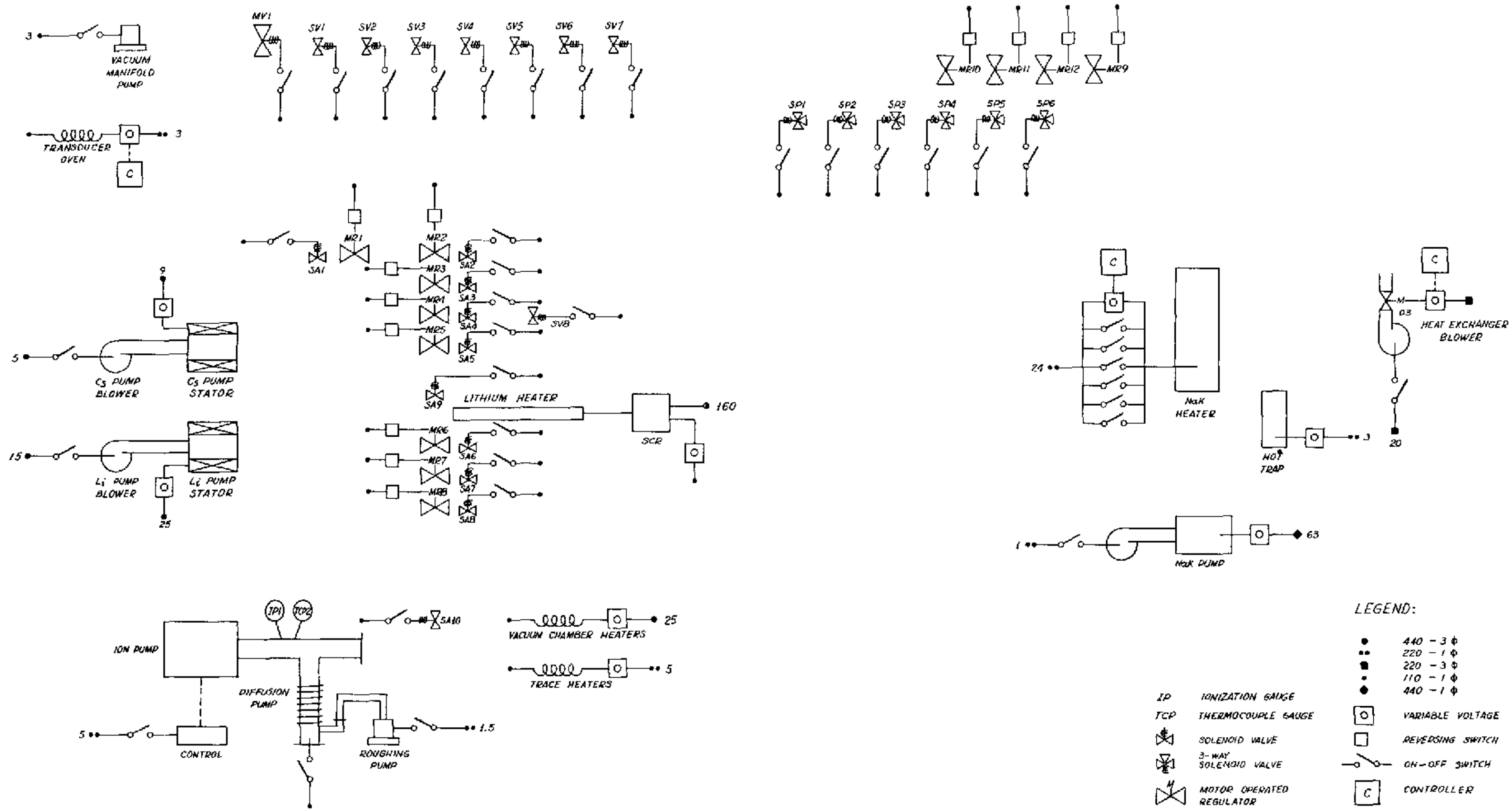


Fig. B-2. 100-kW erosion loop electrical schematic diagram

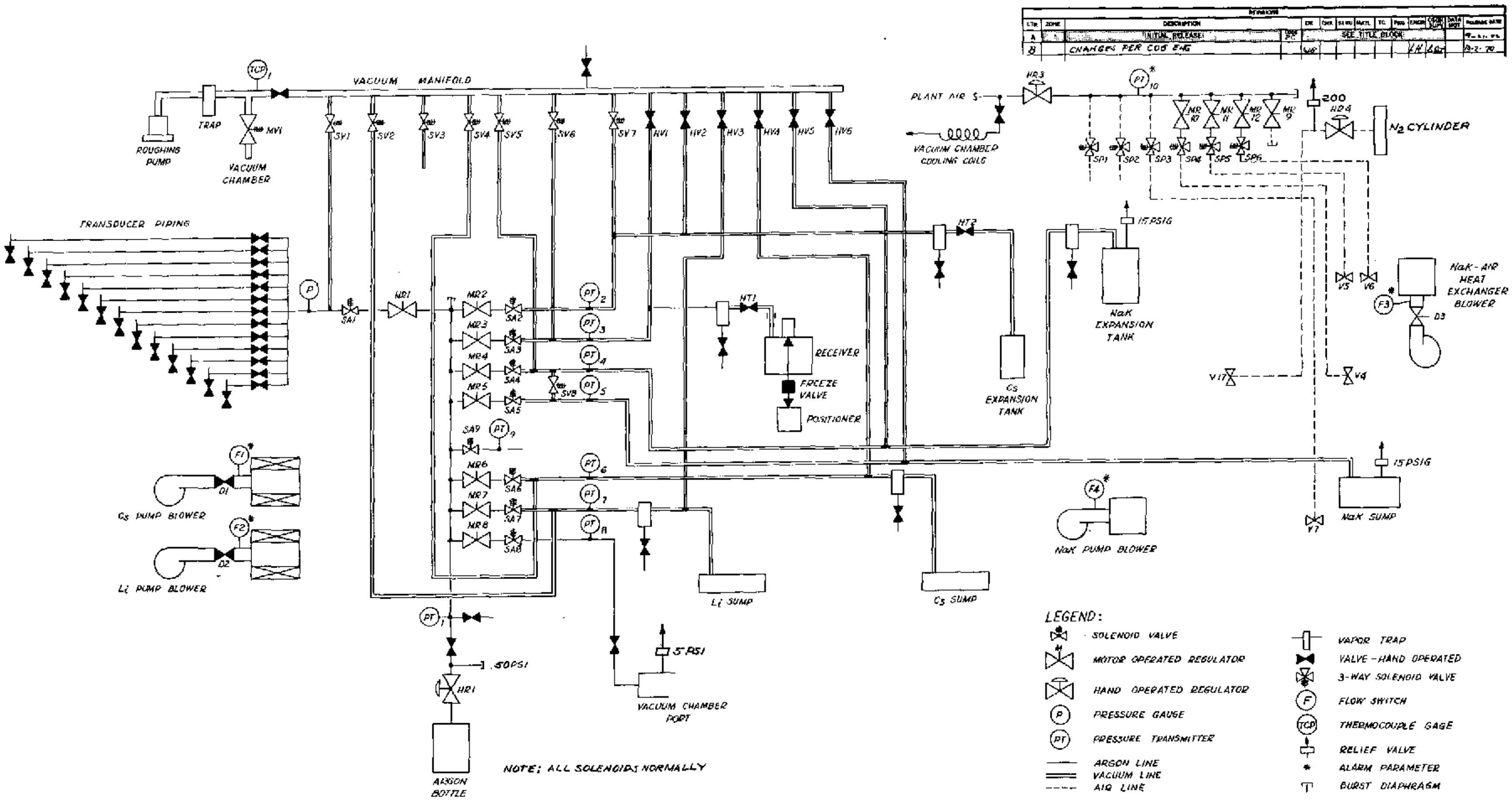
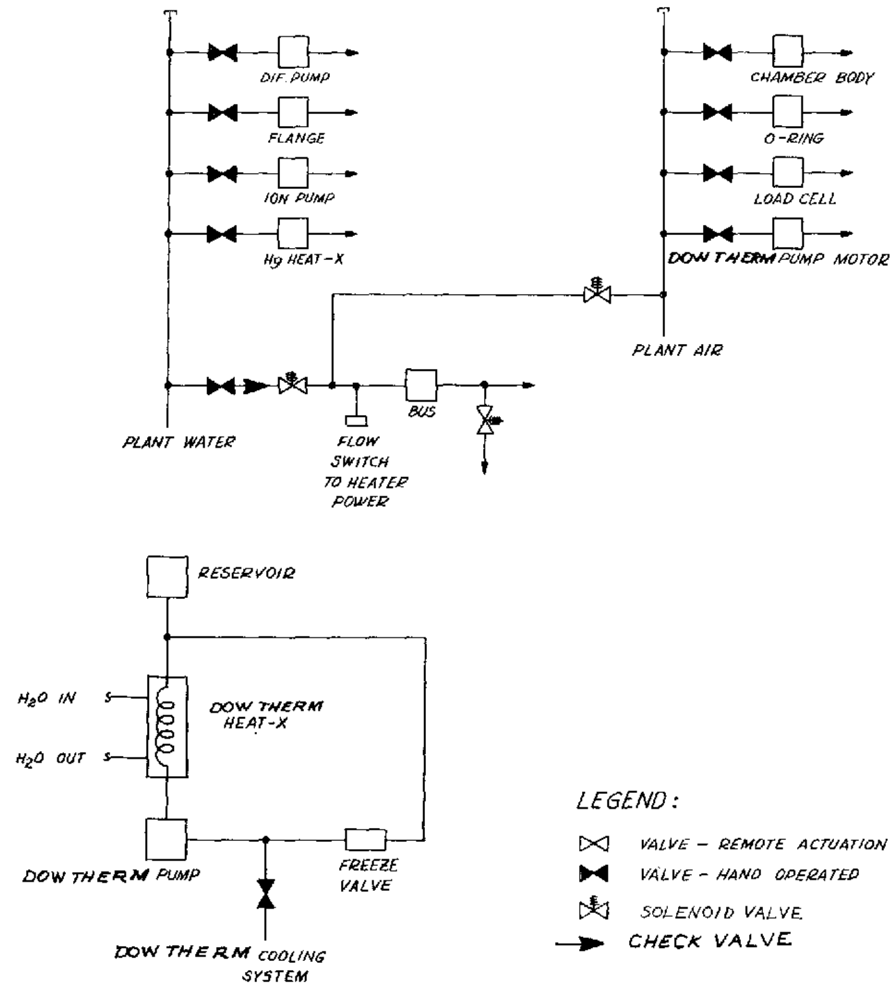


Fig. B-3. 100-kW erosion loop argon, vacuum, and air circuits schematic diagram



REVISIONS													
LTR	ZONE	DESCRIPTION	CODE	DR	CHK	STRU	MATL	TC	PKG	ENGR	DSGN SUPV	DATA MGT	RELEASE DATE
A		INITIAL RELEASE	2C	SEE TITLE BLOCK									9-21-70
B		CHANGES PER COG ENG		[illegible]						LH	[illegible]		10-2-70

Fig. B-4. 100-kW erosion loop cooling circuits schematic diagram

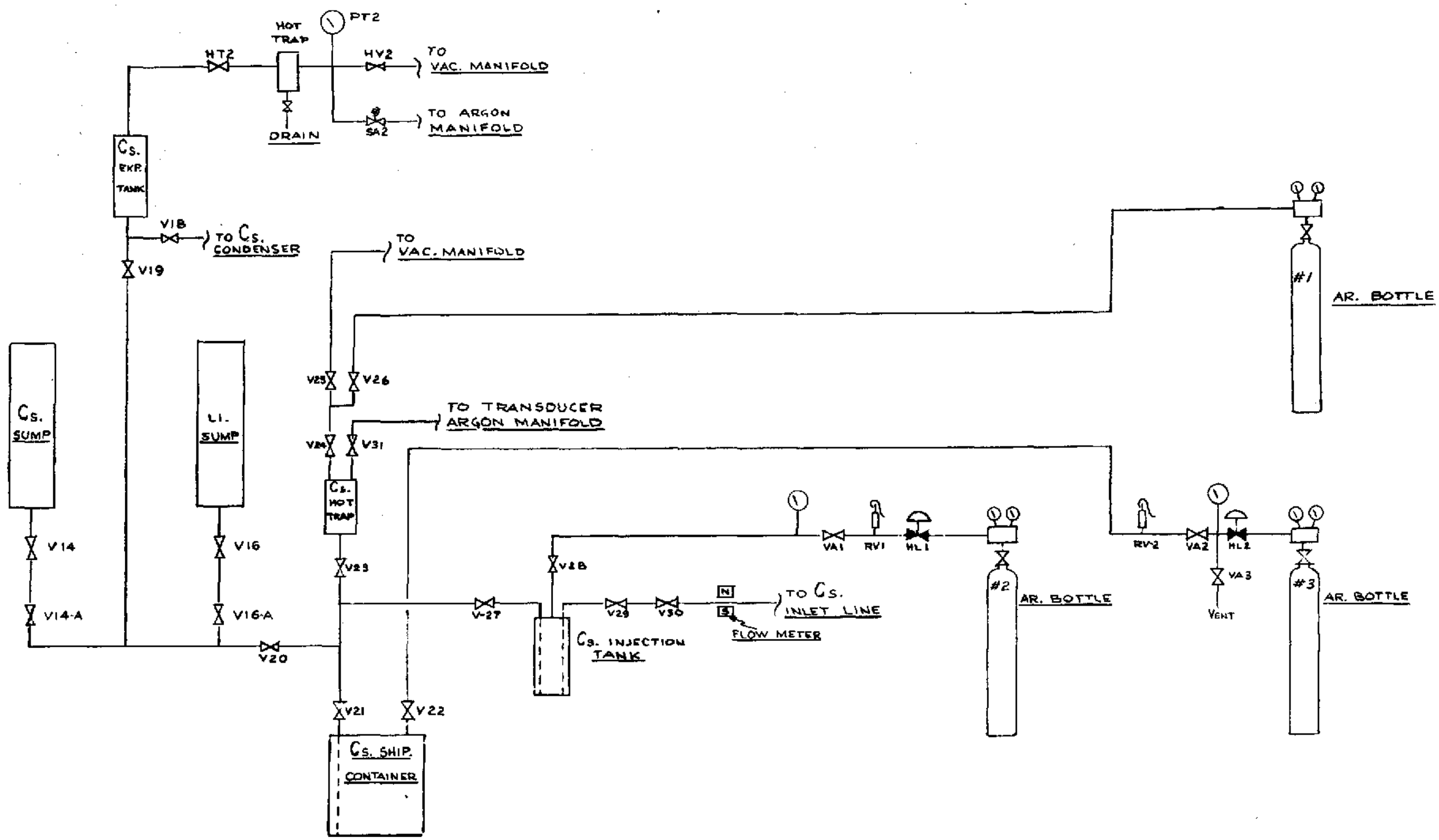


Fig. B-5. 100-kW erosion loop Cs injection and separation circuit schematic diagram

FOLDOUT FRAME 1

FOLDOUT FRAME 2

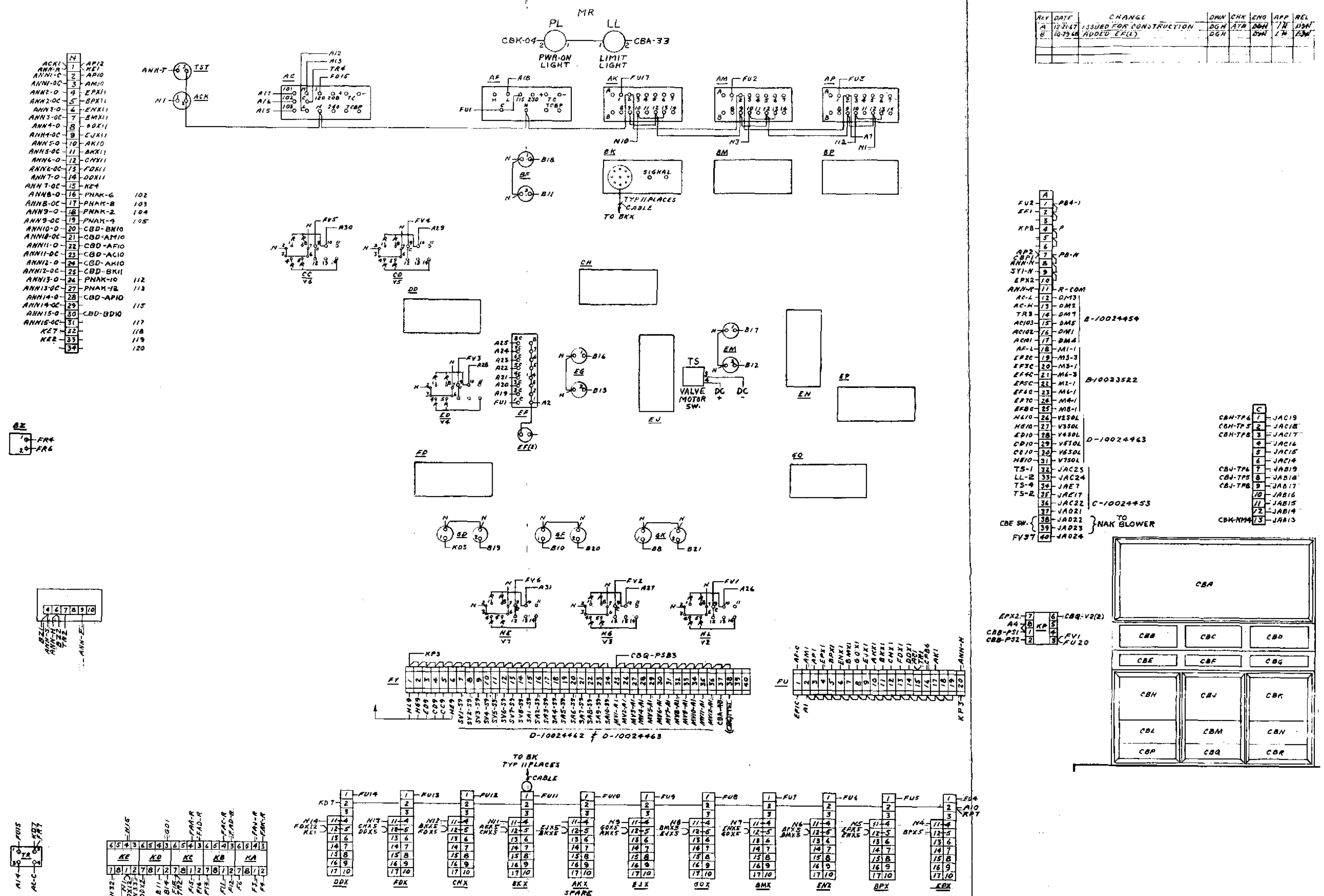


Fig. B-6. Building 148 panel CBA wiring diagram

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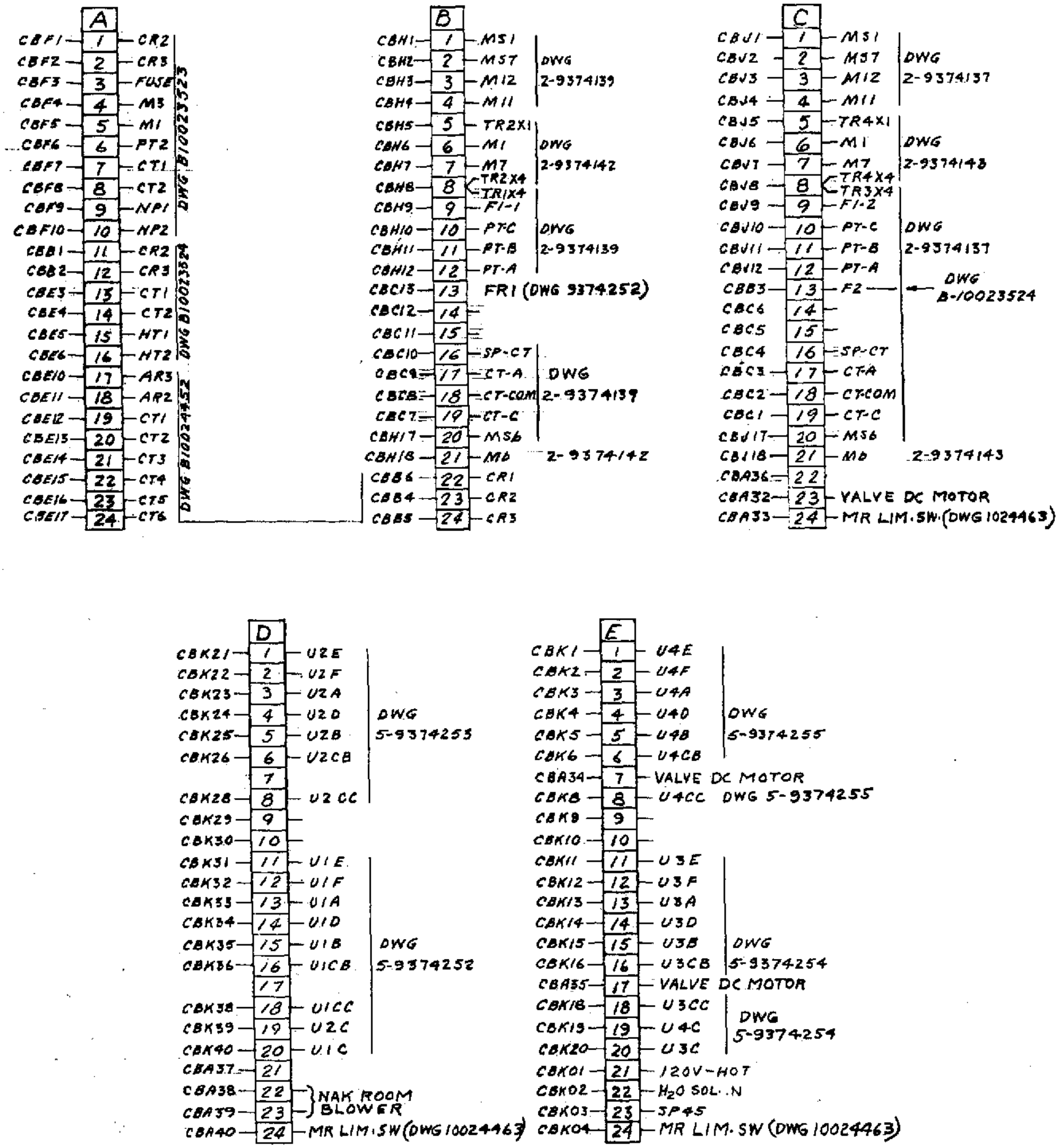


C	10-5-70	CHANGED B13, C23, C24, D22-23-24, E7-17-24	LG		LH	GWP
B	11-11-68	CHANGED WIRES AT B14, B15, B17, B18 & C14, C15, C17, C18	DGH		RAH	LH
A	11-20-67	ISSUED FOR CONSTRUCTION	DGH	ATB	RAH	LH
LETTER	DATE	CHANGE	BY	CHK	ENG	APVD

Fig. B-7. Building 148 junction box JA interconnection diagram

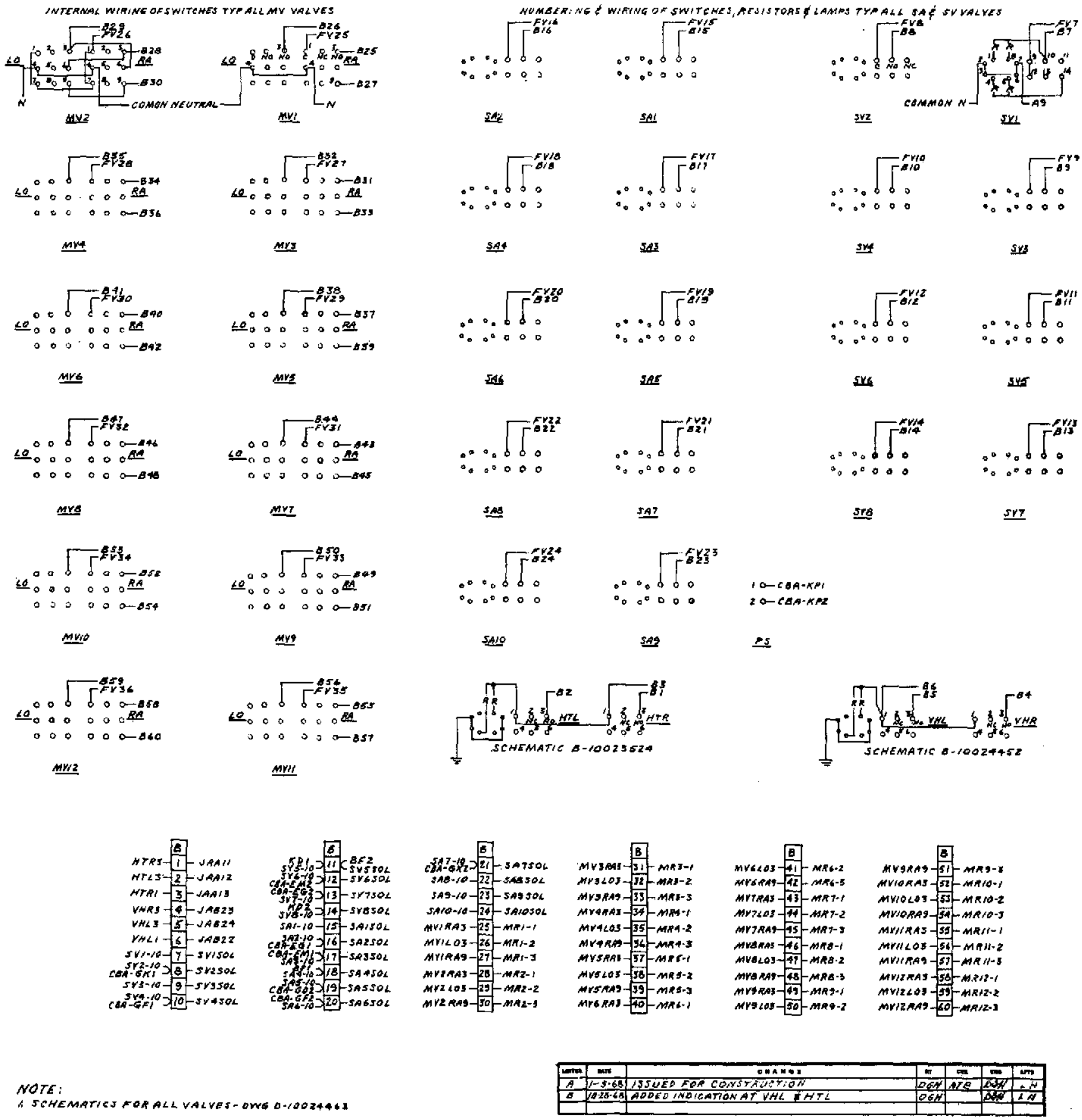


Fig. B-8. Building 148 panel CBB wiring diagram

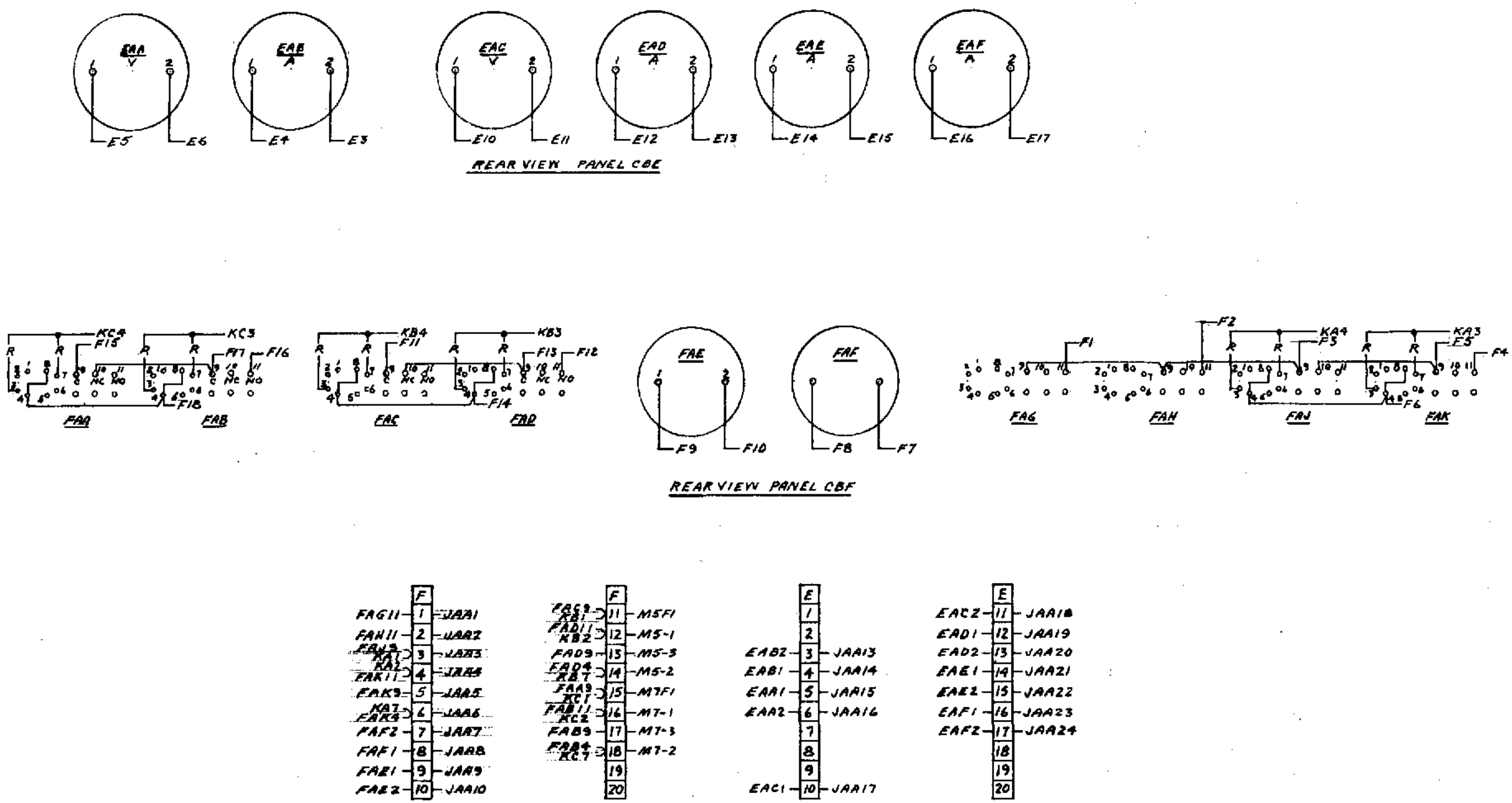
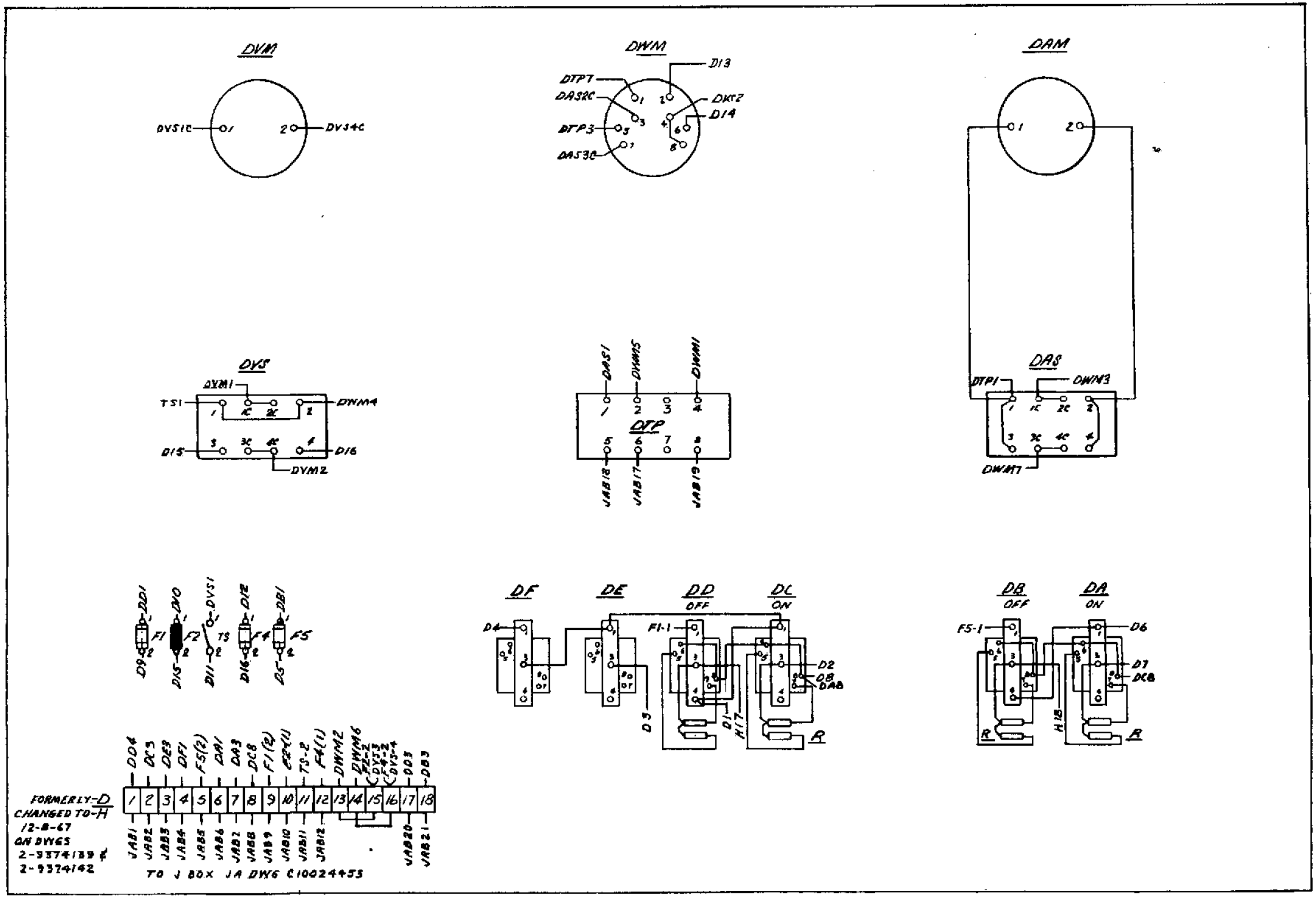


Fig. B-9. Building 148 panels CBE and CBF wiring diagram



LETTER	DATE	CHANGE	BY	CHK	ENG	APPD
A	2/26/65	REVISED CIRCUITRY THROUGHOUT.	RFH	DGH	DGH	
B	12-8-67	REVISED FOR 100KW TEST	DGH	ATB	DGH	LH
C	11-11-68	ADDED LIGHT AT DB & DD	DGH		DGH	LH

Fig. B-10. Magnetohydrodynamic facility panel CBH wiring diagram

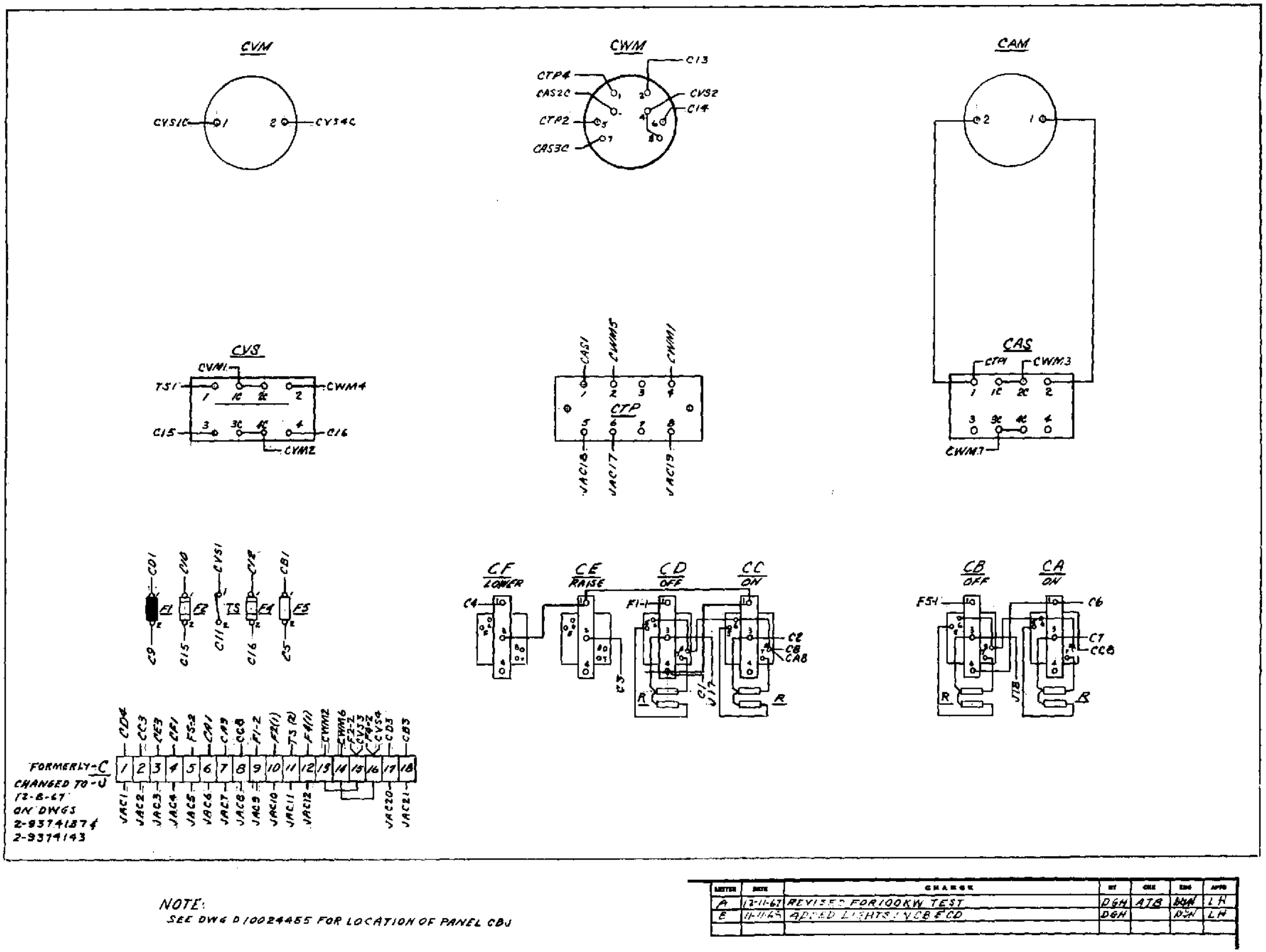


Fig. B-11. Magnetohydrodynamic facility panel CBJ wiring diagram

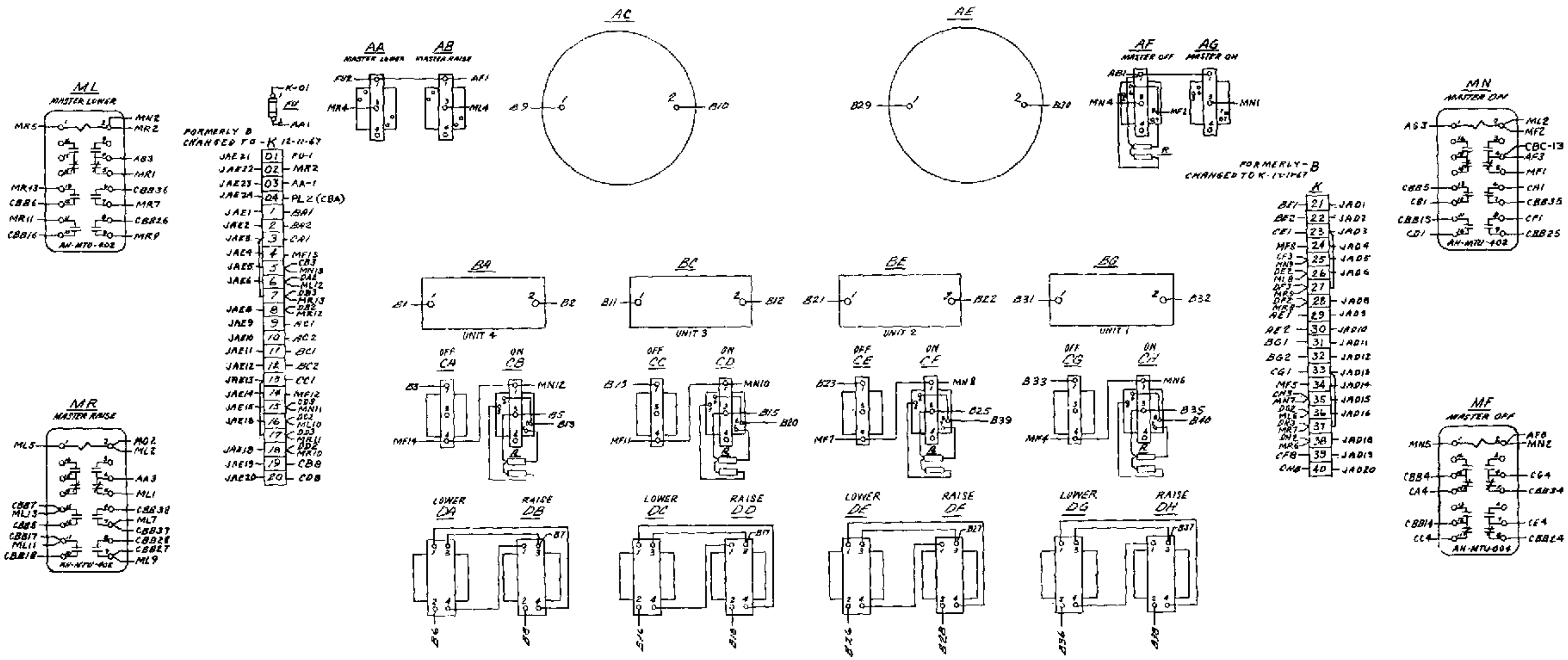
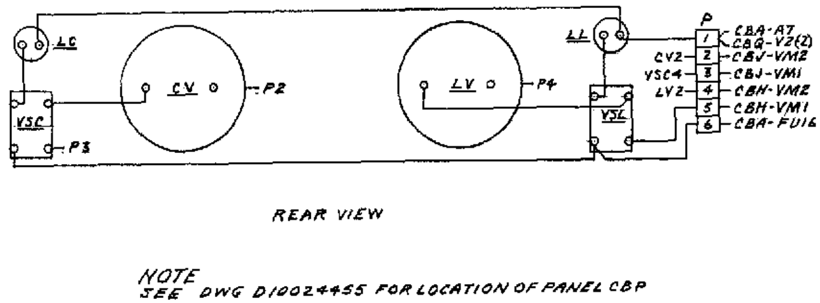
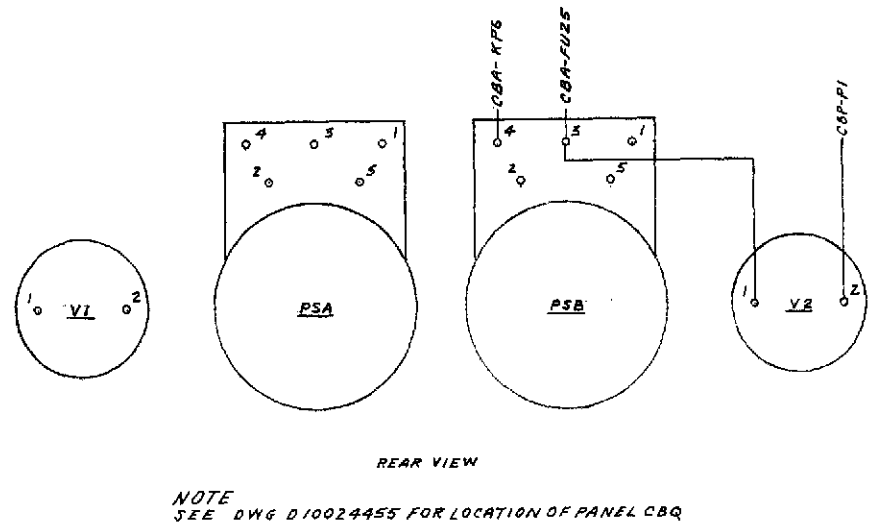


Fig. B-12. Magnetohydrodynamic facility panel CBK wiring diagram



REV	DATE	CHANGE	DWN	CHK	ENG	APPVD
B	11-11-68	CHANGED CALLOUT AT P1	DGH		DGH	LH
A	8-5-68	AS BUILT	DGH		DGH	LH

Fig. B-13. Building 148 panel CBP wiring diagram



REV	DATE	CHANGE	DWN	CHK	ENG	APPVD
B	10-28-68	CHANGED HOOKUP OF PSB	DGH		DGH	
A	8-5-68	AS BUILT	DGH		DGH	LH

Fig. B-14. Building 148 panel CBQ wiring diagram

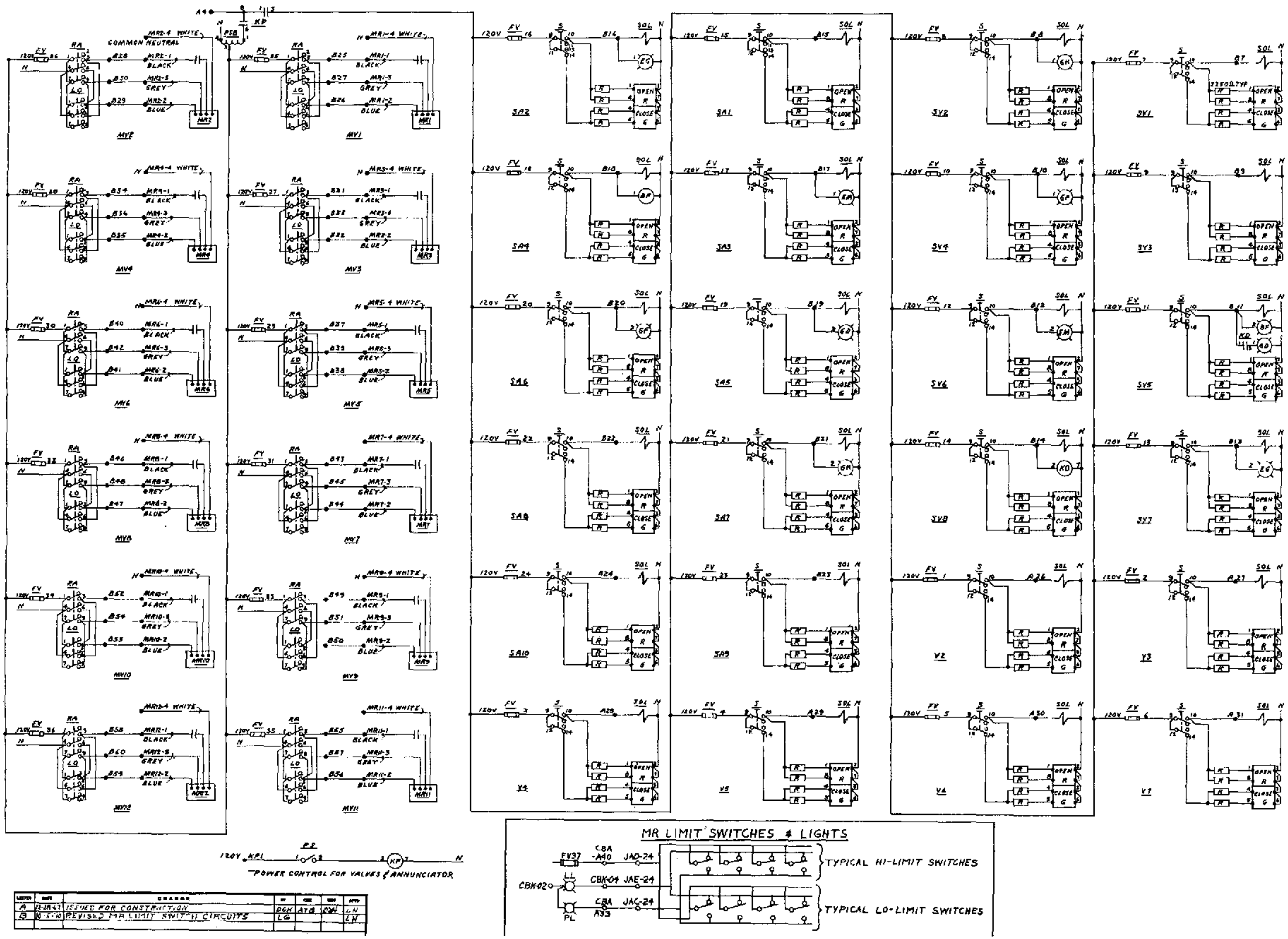
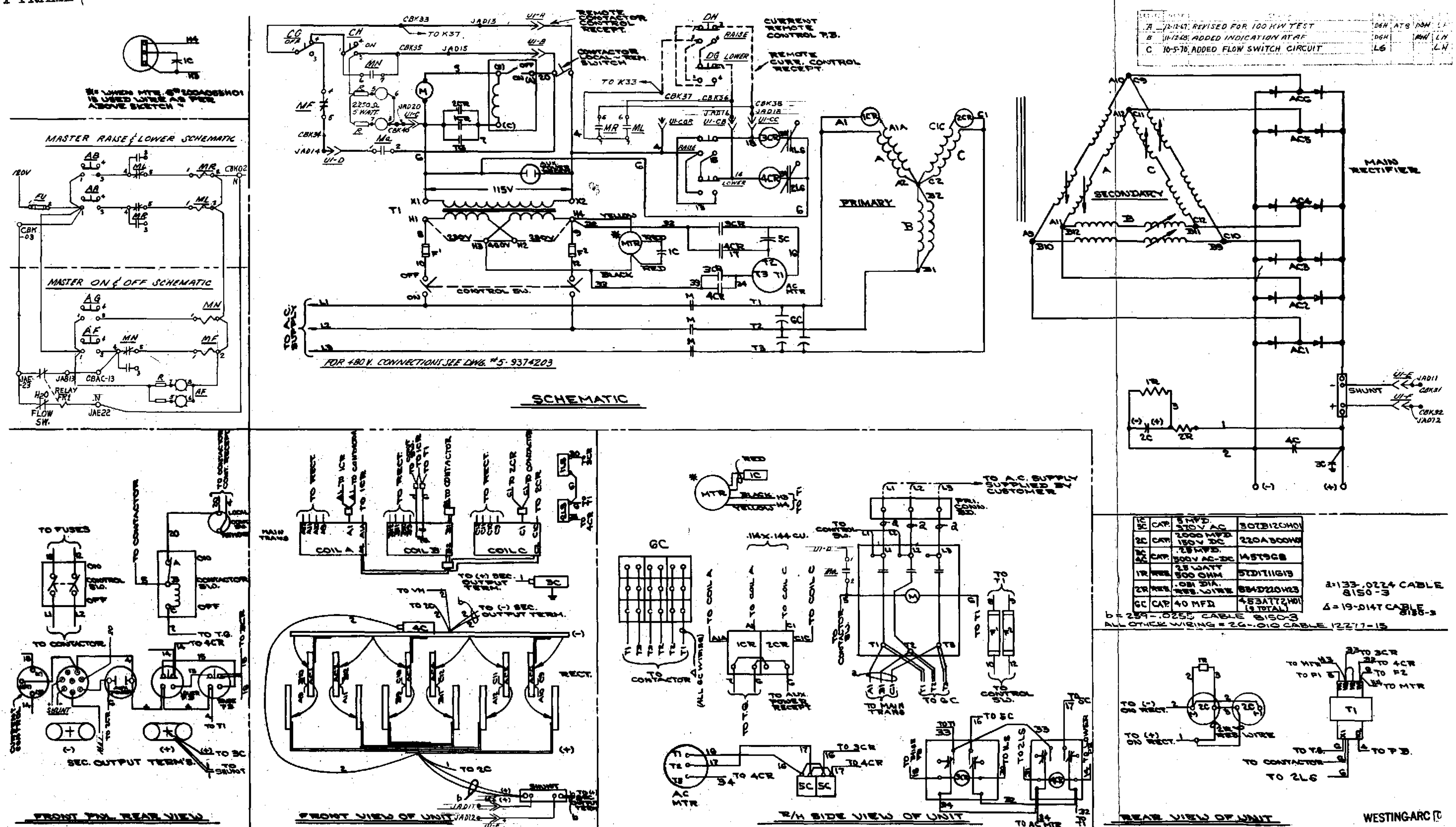


Fig. B-15. Building 148 100-kW test valves schematic diagram

FOLDOUT FRAME 1

FOLDOUT FRAME 2



NOTE: 1. WESTINGHOUSE ELECTRIC CORP. DWG. NO. 8560060 TITLE "TYPE WSH WELDER ~ 1000 AMP. WIRING & SCHEMATIC"

2. WESTINGHOUSE ENGR. REF. DWG. NO. 848 D075

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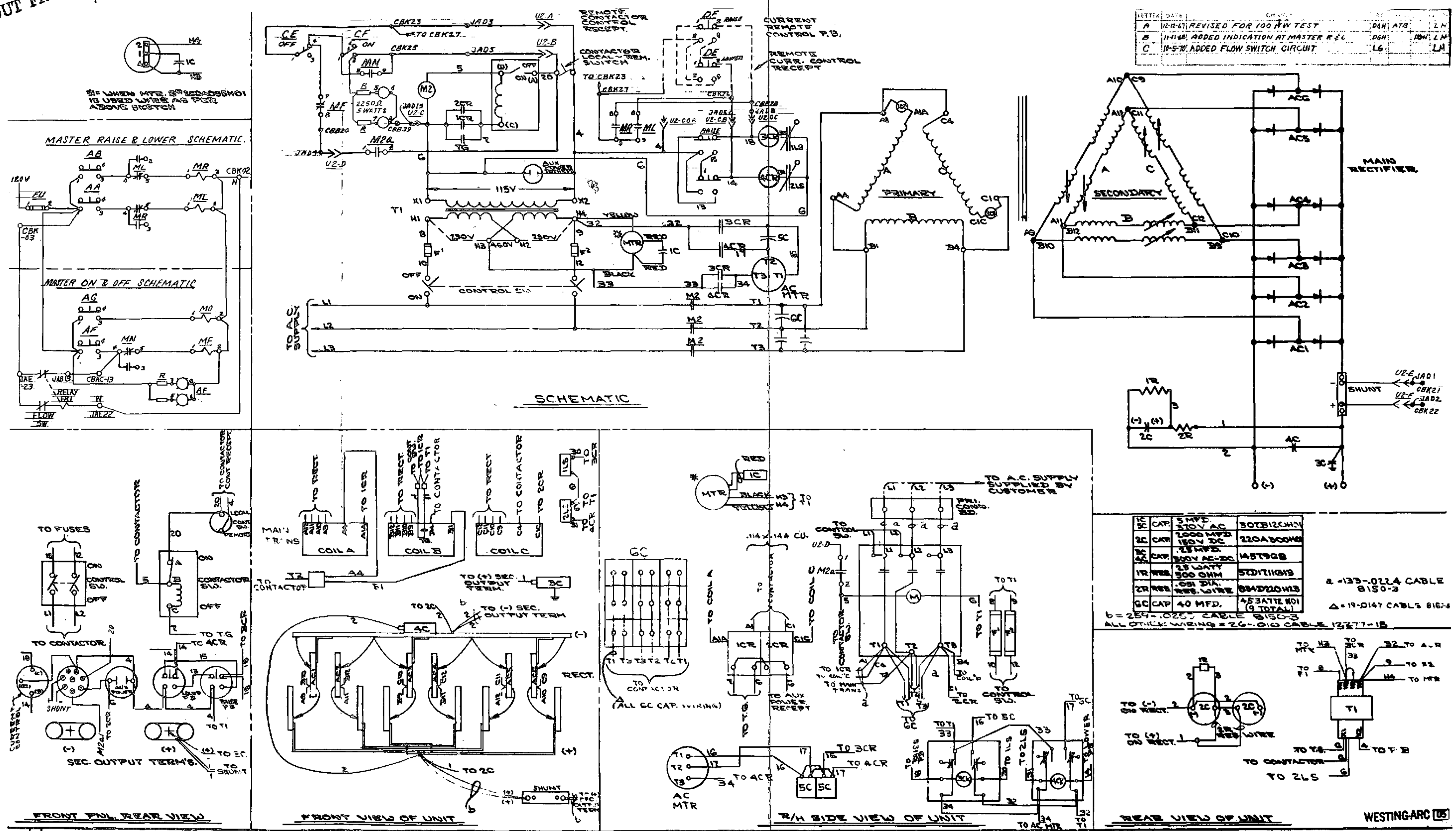
Fig. B-16. Magnetohydrodynamic facility type WSH welder 1000 A, unit 1, wiring and schematic

FOLDOUT FRAME 1

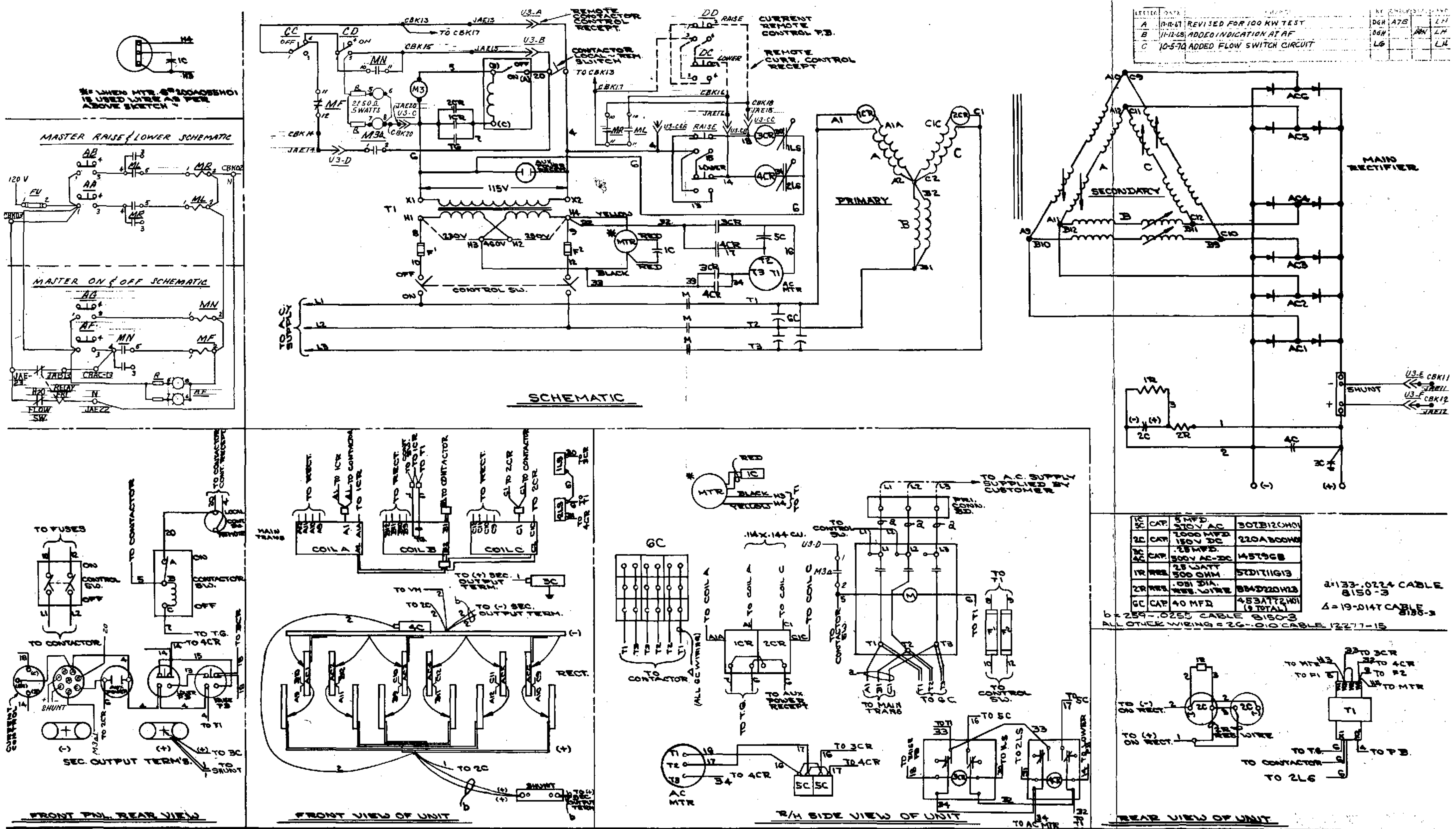
FOLDOUT FRAME 2



NOTES: 1 REF NO. WESTINGHOUSE ELECTRIC CORP DWG NO. 856D059 TITLE "WSH WELDER ~ 1000 AMP - WIRING & SCHEMATIC"

2 WESTINGHOUSE ENGR. REF DWG NO. 848D075

Fig. B-17. Magnetohydrodynamic facility type WSH welder 1000 A, unit 2, wiring and schematic

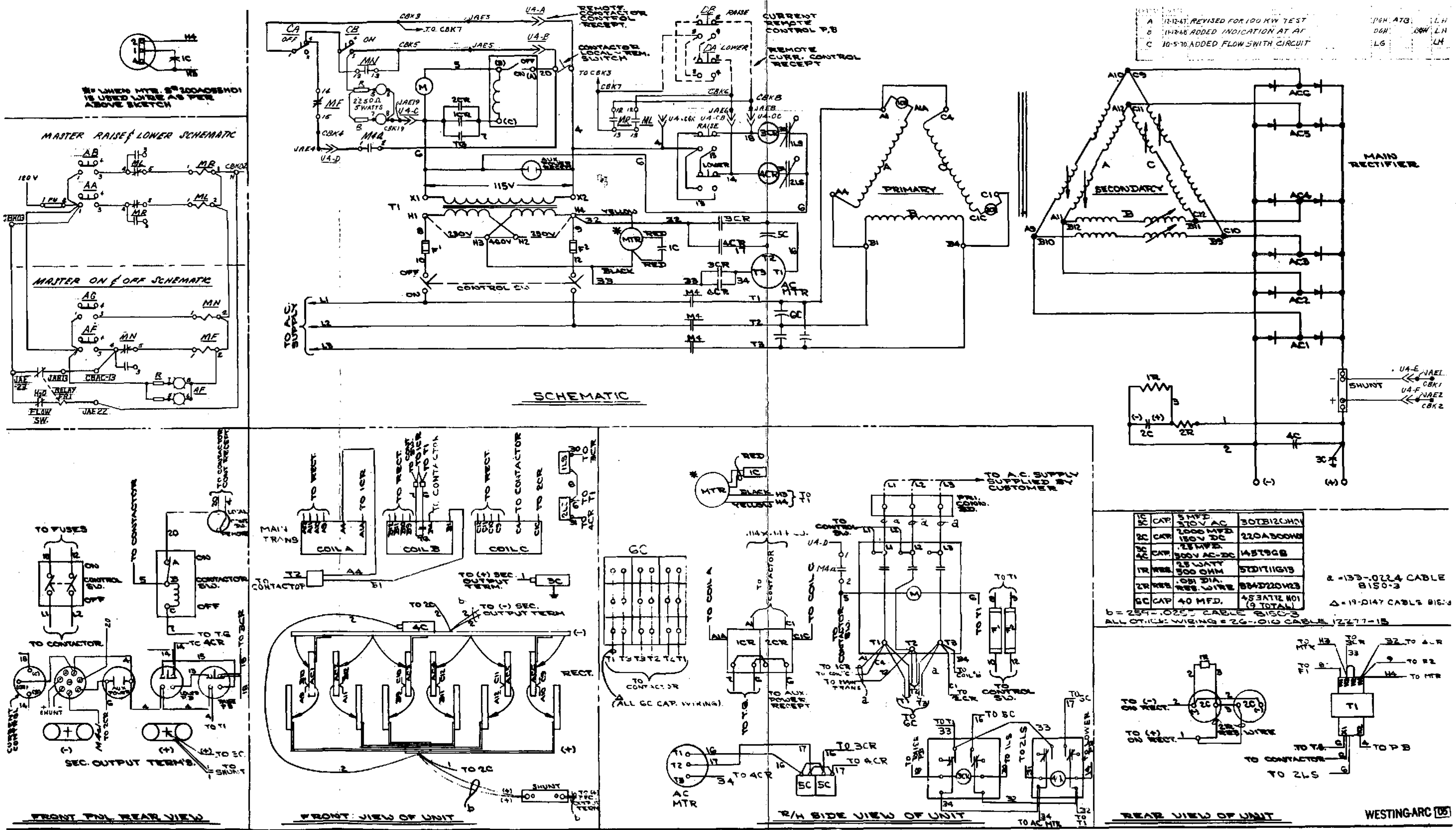


LETTER	DATE	CHANGE	BY	CHECK	SUP.	APVD
A	11-12-67	REVISED FOR 100 KW TEST	DGH	A7B		LH
B	11-12-68	ADDED INDICATION AT AF	DGH		AAN	LH
C	10-5-70	ADDED FLOW SWITCH CIRCUIT	LG			LH

1C 5C	CAP.	5 MFD. 370V AC	307B120H01
2C	CAP.	2000 MFD. 150V DC	220A800H01
3C 4C	CAP.	.25 MFD. 300V AC-DC	1457968
1R	RES.	25 WATT 500 OHM	5CD1711G13
2R	RES.	.081 DIA. RES. WIRE	884D220H23
6C	CAP.	40 MFD.	453A772H01 (9 TOTAL)

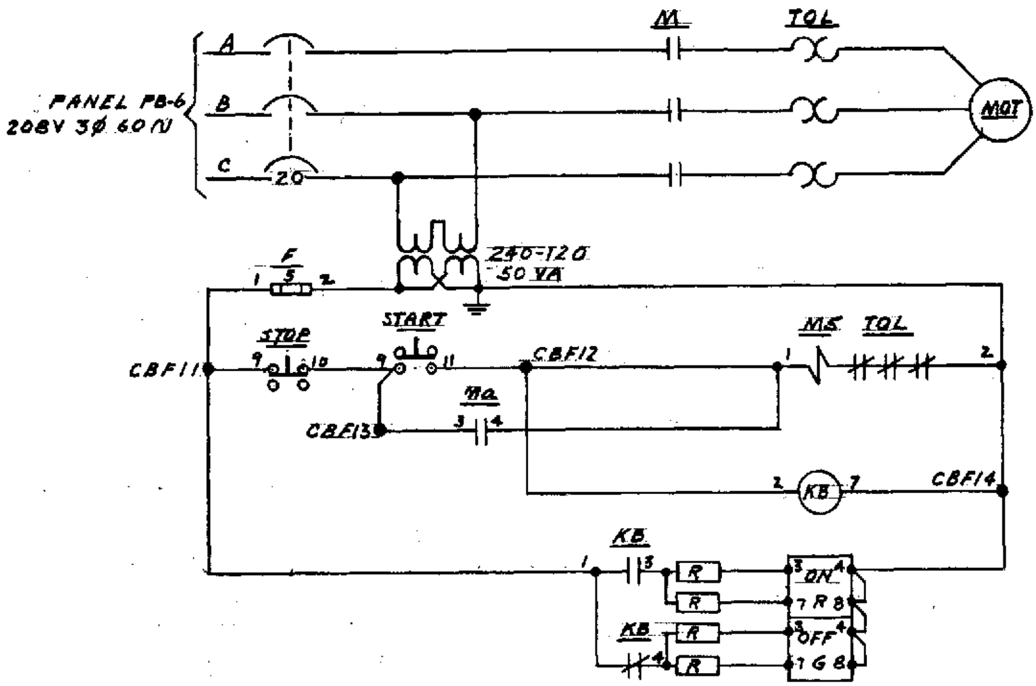
NOTES: 1. WESTINGHOUSE ELECTRIC CORP. DWG. NO 856D060 TITLE "TYPE WSH WELDER ~ 1000 AMP - WIRING & SCHEMATIC
2. WESTINGHOUSE ENGR' REF DWG. NO 848D075

Fig. B-18. Magnetohydrodynamic facility type WSH welder 1000 A, unit 3, wiring and schematic



NOTES: 1 WESTINGHOUSE ELECTRIC CORP DWG NO. 856D059.
TITLE "TYPE WSH WELDER ~ 1000 AMP - WIRING & SCHEMATIC"
2 WESTINGHOUSE ENGR REF DWG. NO 848D075

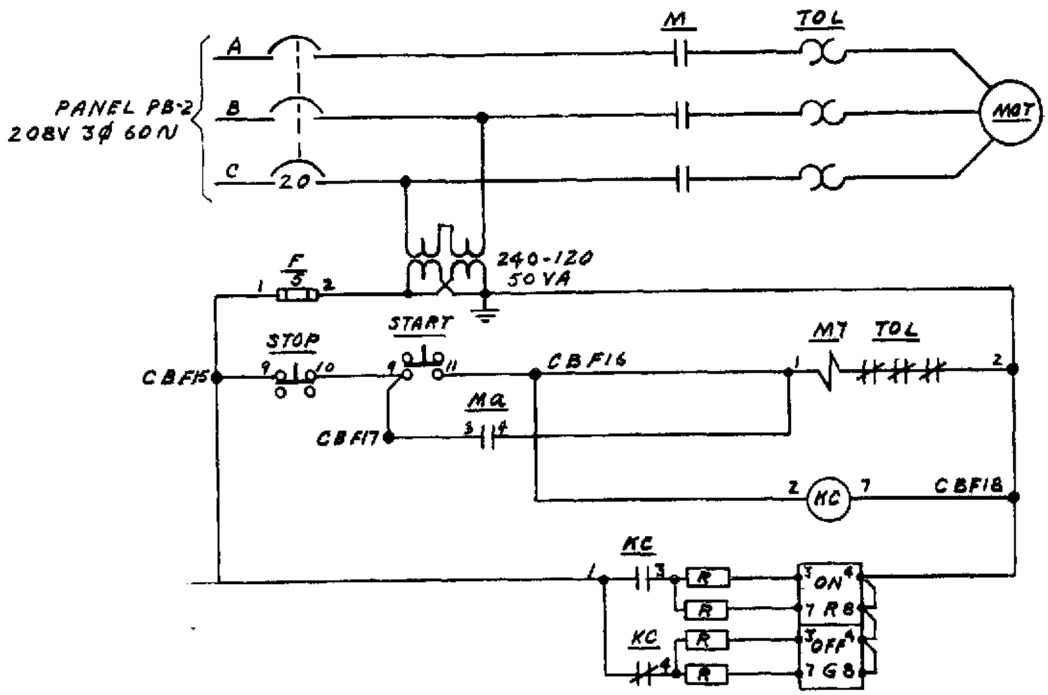
Fig. B-19. Magnetohydrodynamic facility type WSH welder 1000 A, unit 4, wiring and schematic



LEGEND		
SYMBOL	DEVICE	LOCATION
M	WESTINGHOUSE SIZE O MAG. SW	NEAR PB
TOL	" CAT # H32	IN M
STOP, START	MICRO SW #2D68	PANEL CBF
ON, OFF	" " OPER. IND. # 2C1	" "
R	RES 2250Ω 5W	" "
KB	POTTER BRUMFIELD KRP11AN	" "
MOT	US 1 HP FRAME 143.1	AT NAK PMP

A	11-10-67		DGH	ATB	RSH	LTV	RSH
REV	DATE	CHANGE	DWN	CHK	ENG	APP	REL

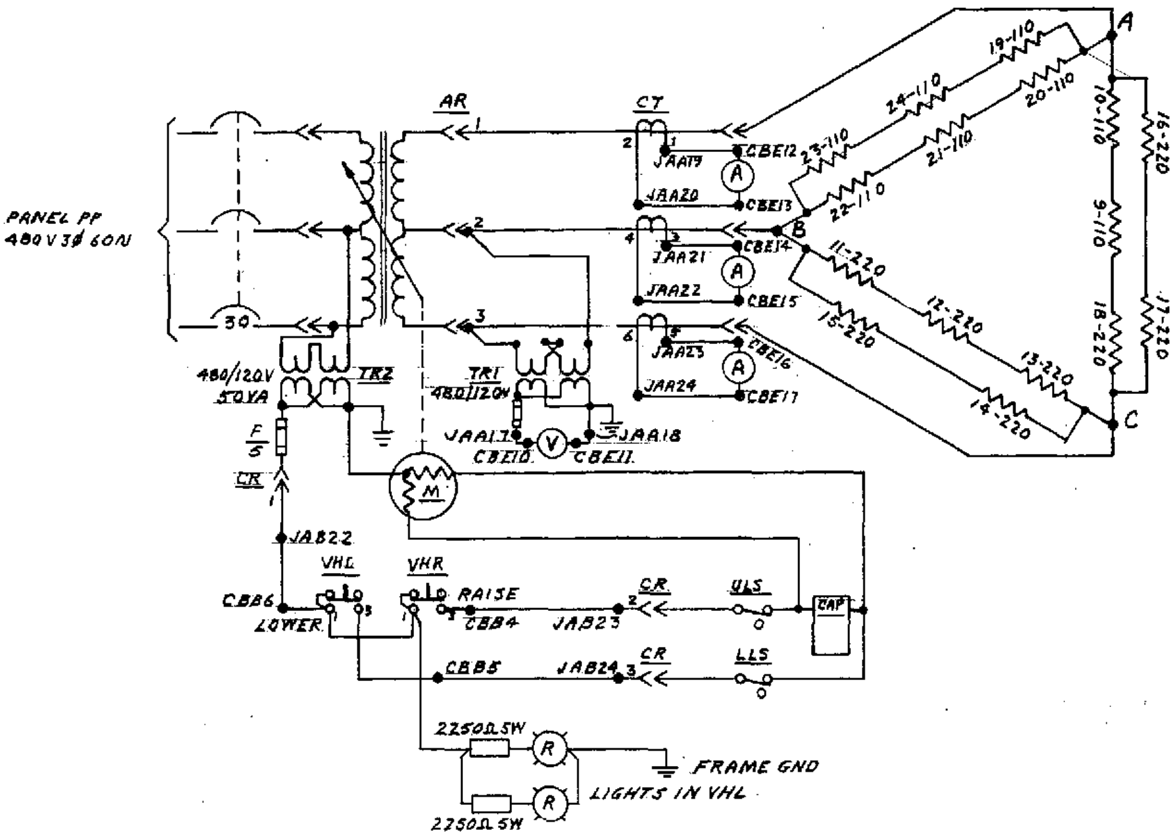
Fig. B-20. Building 148 NaK pump blower schematic diagram



LEGEND		
SYMBOL	DEVICE	LOCATION
M	WESTINGHOUSE SIZE 0 MAG. SW	NEAR PB
TOL	" CAT # H42	IN M
STOP, START	MICRO SW #2D68	PANEL CBF
ON, OFF	" " OPER. IND. #2C1	" "
R	RES 2250Ω 5W	" "
KC	POTTER BRUMFIELD KRP11AN	" "
MOT	US 3HP FRAME 184T	AT NAK HTR

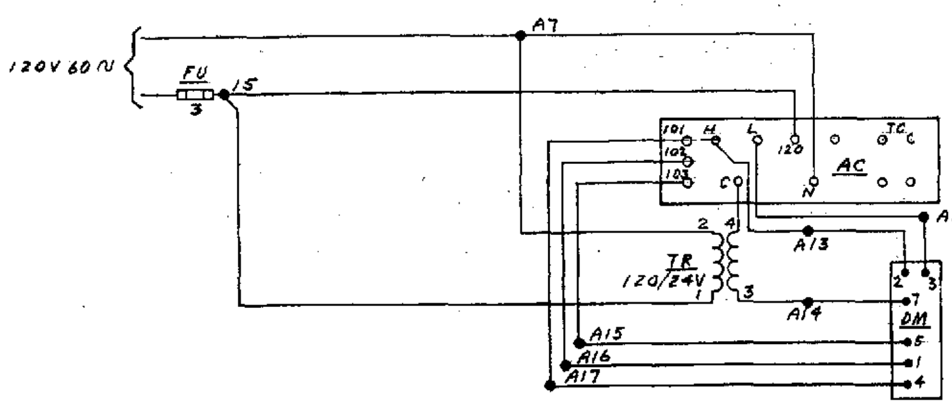
A	11-13-67	ISSUED FOR CONSTRUCTION	DGH	ATB	[illegible]	LH	[illegible]
REV	DATE	CHANGE	DWN	CHK	ENG	APP	REL

Fig. B-21. Building 148 heat exchanger blower schematic diagram



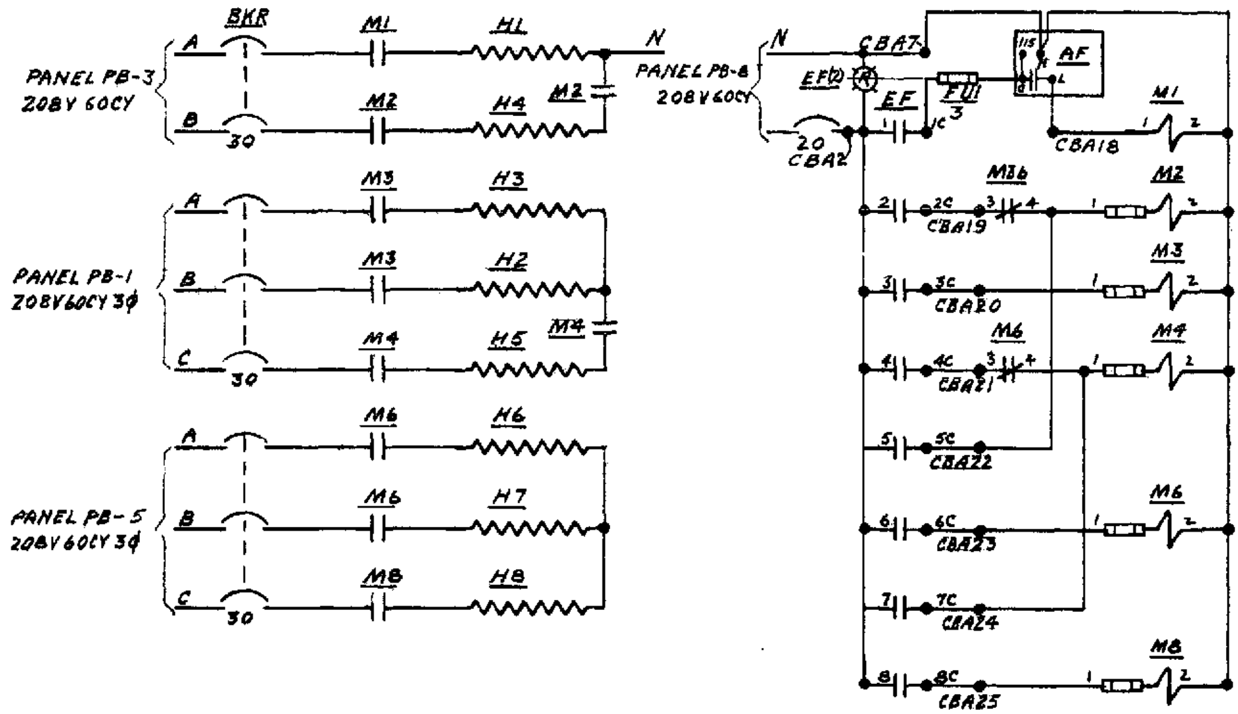
C	10-28-68	ADDED LIGHTS IN VHL	DGH		DGH		
B	9-19-68	ADDED TR1	DGH		DGH	LH	DGH
A	11-14-67	ISSUED FOR CONSTRUCTION	DGH	ATB	DGH	LH	DGH
REV	DATE	CHANGE	DWN	CHK	ENG	APP	REL

Fig. B-22. Building 148 vacuum vessel heater schematic diagram



LEGEND		
SYMBOL	DEVICE	LOCATION
AC	WEST CONTROLLER MODEL JV	PANEL PB
TR	CONTROL TRANSFORMER	" "
FU	LITTELFUSE 3AG 3A	" "
DM	MOTOR ACTUATOR	AT DAMPER

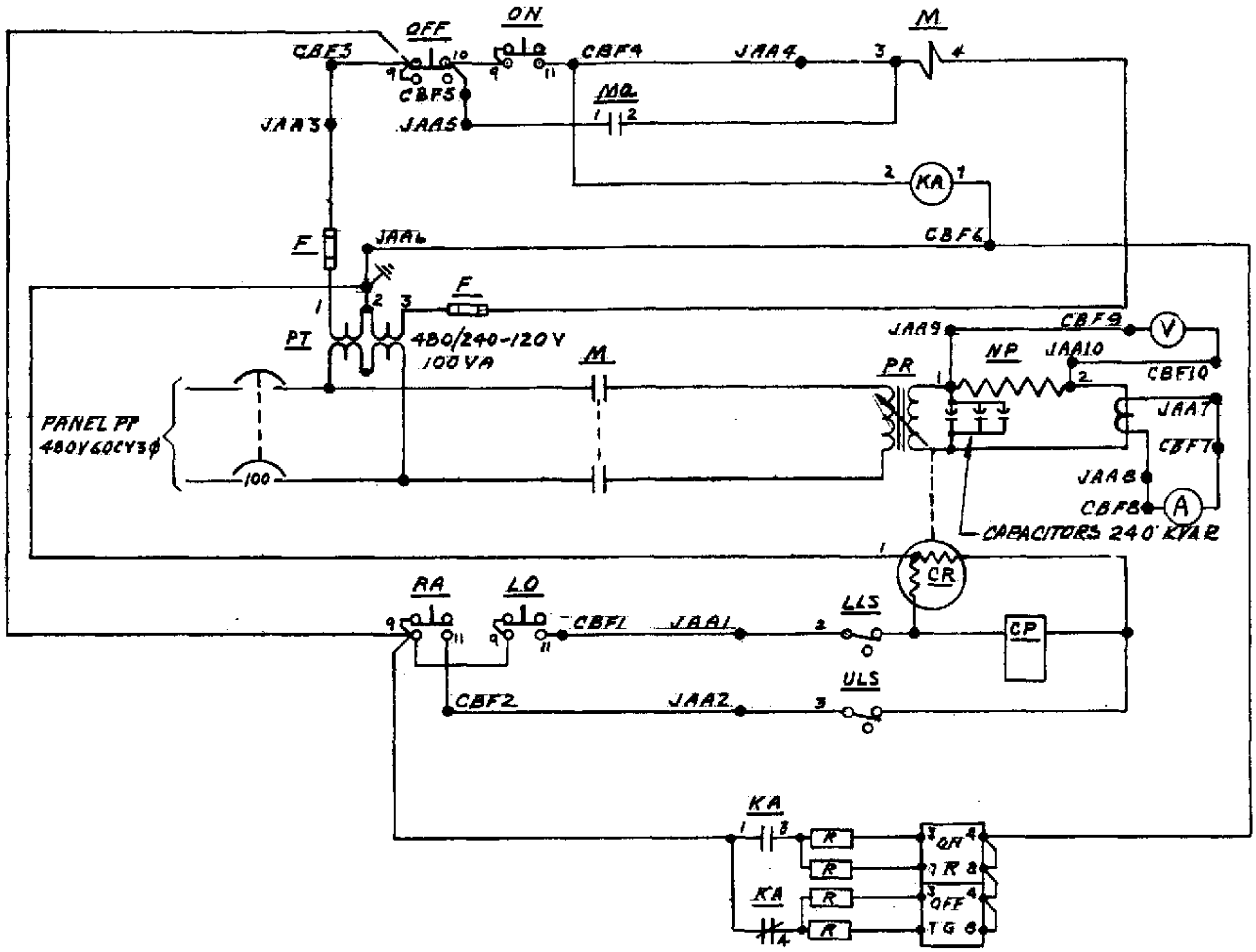
Fig. B-23. Building 148 damper control schematic diagram



LEGEND		
SYMBOL	DEVICE	LOCATION
BKR	ITE EE OR EH	PANEL PB
M1, M8	C.H. MODEL 6-11-2 BUL. 9575 #797	NEAR "
M2, M4	WESTINGHOUSE STYLE 28-E-1938 SIZE 0	" "
M3, M6	GE 15D21GZ SIZE 0	" "
H1 TO H8	CHROMOLOX 120V 3000W H6 #P473A30	NAK HTR
AF	WEST CONTROLLER	PANEL CBA
EF	ALLIS CHALMERS ROTARY SW.	" "
F1	3 A BUS FUSE	" CB

B	11-11-68	ADDED EF(2)	DGH		DGH	LN	DGH
A	11-3-67	ISSUED FOR CONSTRUCTION	DGH	ATB	DGH	LN	DGH
REV	DATE	CHANGE	DWN	CHK	ENG	APP	REL

Fig. B-24. Building 148 100-kW test, NaK heater schematic diagram



NOTES

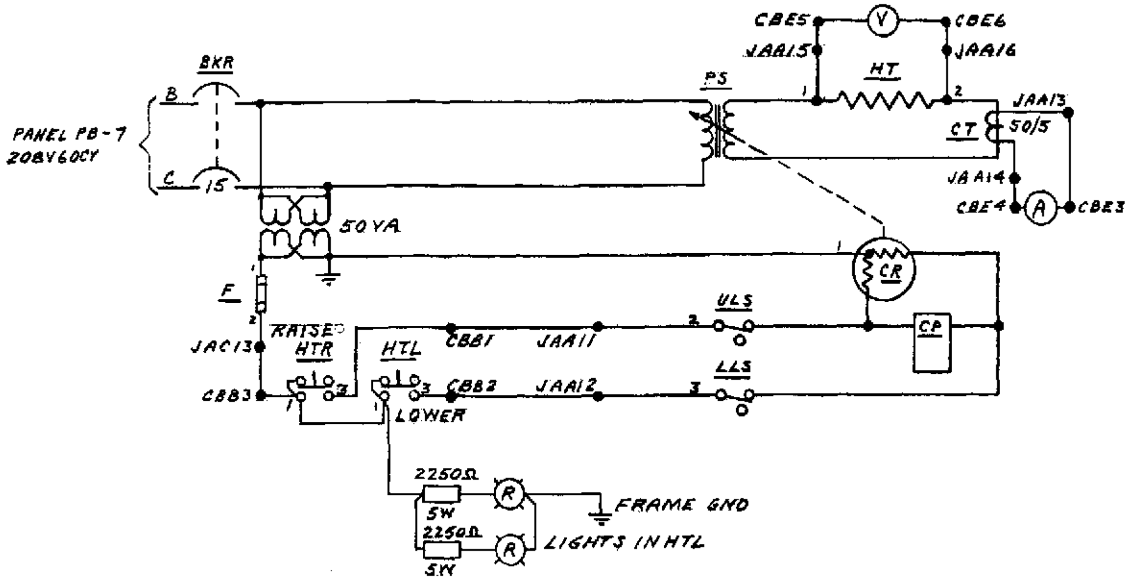
~~1. CAPACITORS CONSIST OF 2 BANKS OF 480V. 1φ UNITS (TOTAL OF 240 KVAR) MOUNT BANKS ON EAST WALL OF RECTIFIER ALCOVE IMMEDIATELY UNDER GUTTER. CONNECT TO SECONDARY TERMINALS~~ OF VARIABLE TRANSFORMER W/ 2 - #4/0 CABLE IN 1½" FLEX CONDUIT.

2. CHECK OUT CAPACITORS PRIOR TO CONNECTION

3. RECONNECT EXIST. CAPACITORS FOR LITHIUM PUMP AND CESIUM PUMP AS REQUIRED.

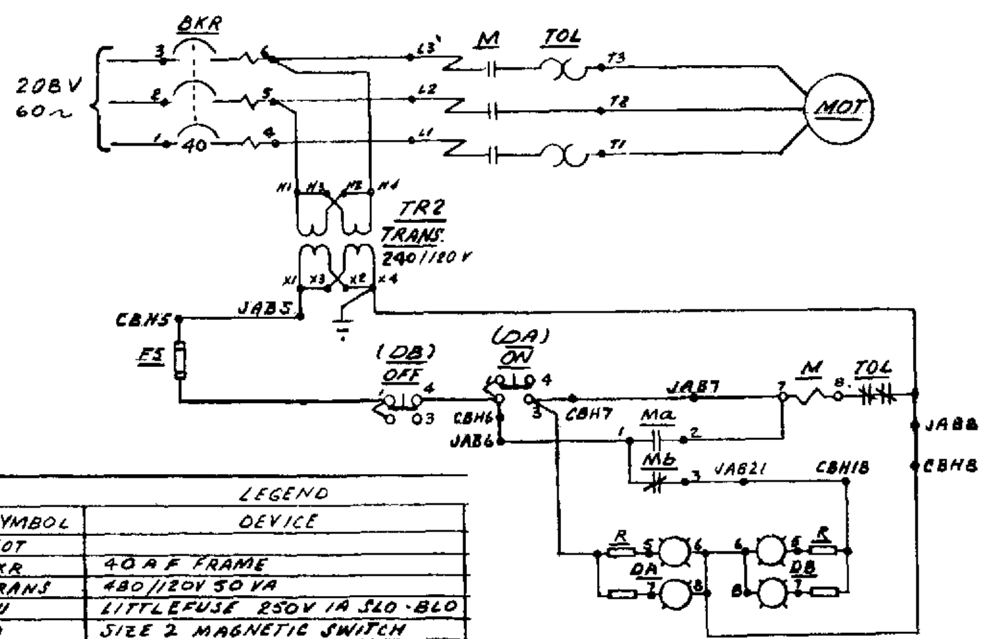
REV	DATE	CHANGE	DWN	CHK	ENG	APPV	REL
C	10-5-70	CHANGED CAPACITORS TO 240 KVAR	L.G.		LH	WP	LH
B	10-23-69	ADD CAPACITORS TO NAK PUMP	RVS	[illegible]	[illegible]	[illegible]	LH
A	11-6-67	ISSUED FOR CONSTRUCTION	DGH	ATB	[illegible]	[illegible]	[illegible]

Fig. B-25. Building 148 NaK pump schematic diagram



B	10-28-68	ADDED LIGHT IN HTL	DGH		BJH		
A	11-6-67	ISSUED FOR CONSTRUCTION	DGH	ATB	DWH	LH	BJH
REV	DATE	CHANGE	DWN	CHK	ENG	APP	REL

Fig. B-26. Building 148 hot trap schematic diagram

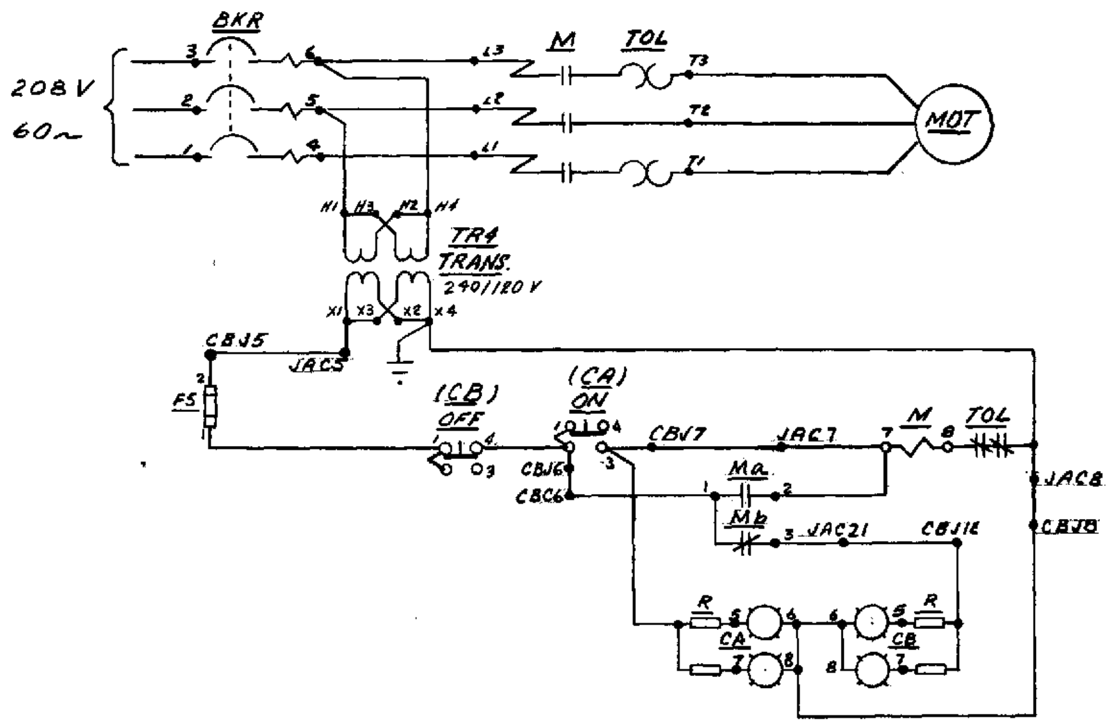


LEGEND	
SYMBOL	DEVICE
MOT	
BKR	40 A F FRAME
TRANS	480/120V 50 VA
FU	LITTLEFUSE 250V 1A SLO-BLO
M	SIZE 2 MAGNETIC SWITCH
OFF/ON	MICRO-OPERATOR - IND 263
TOL	THERMAL OVERLOADS
R	RES 2250 Ω 5W

NOTE:
SEE DWG D10024455 FOR LOCATION OF PANEL CBH

B	11-11-68	ADDED LIGHT (DB)	DGH		BJH	LH
A	12-8-67	REVISED FOR 100KW TEST	DGH	ATB	DWH	BJH
REV	DATE	CHANGE	DWN	CHK	ENG	REL

Fig. B-27. Magnetohydrodynamic facility 15-hp blower schematic diagram

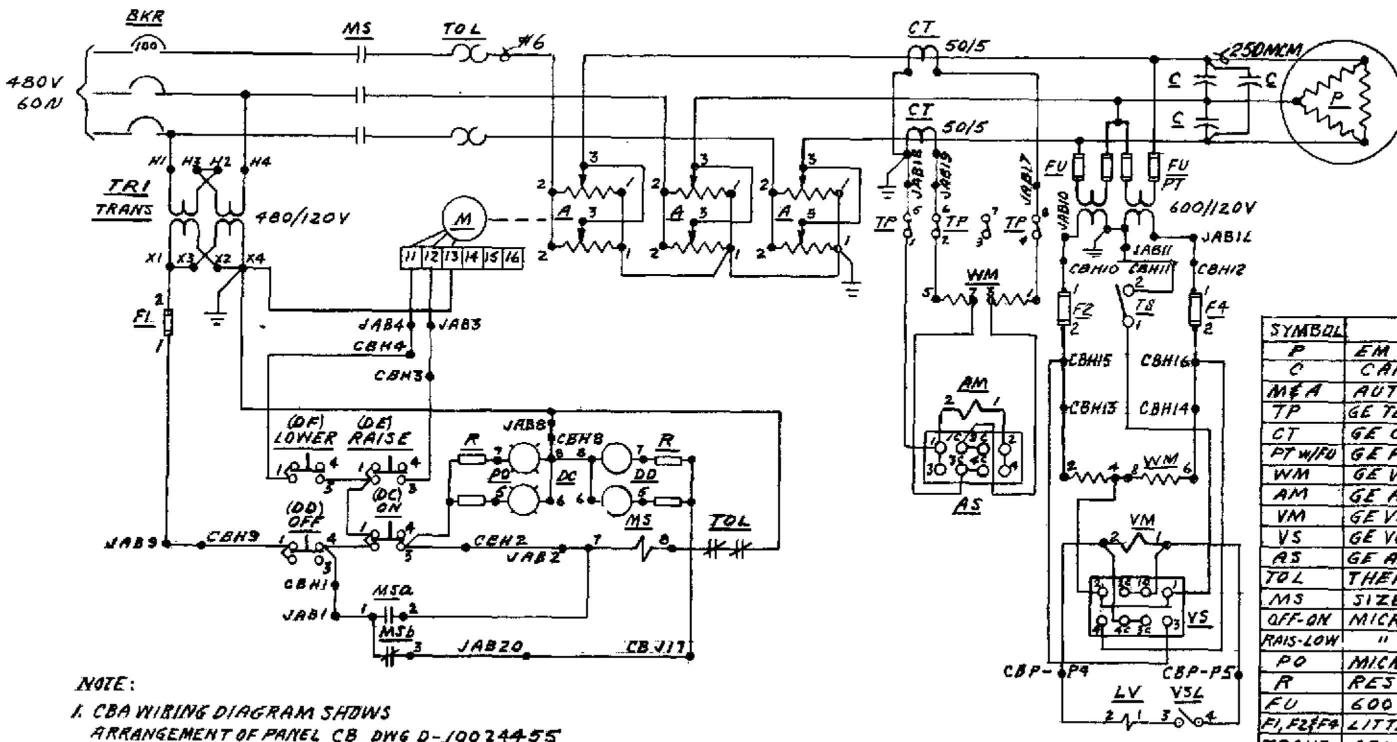


LEGEND		
SYMBOL	DEVICE	LOCATION
MOT		
BKR	15AF FRAME	
TRANS	480/120V 50VA	
FS	LITTLE FUSE 1A SLO-BLO	PANEL CBC
M	SIZE 1 MAGNETIC SWITCH	
CA&CB	MICRO-SWITCH 2068	PANEL CBC
TOL	THERMAL OVERLOADS	
R	RES. 2250 Ω 5W	PANEL CBC
PO	MICRO-OPERATOR-IND 2C1	" "

NOTE:
SEE DWG D10024455 FOR LOCATION OF PANEL CBJ

B	11-11-68	ADDED LIGHT (CB)	DGH		DGH	LH	DGH
A	12-8-67	REVISED FOR 100 KW TEST	DGH	ATB	DGH	LH	DGH
REV	DATE	CHANGE	DWN	CHK	ENG	APP	REL

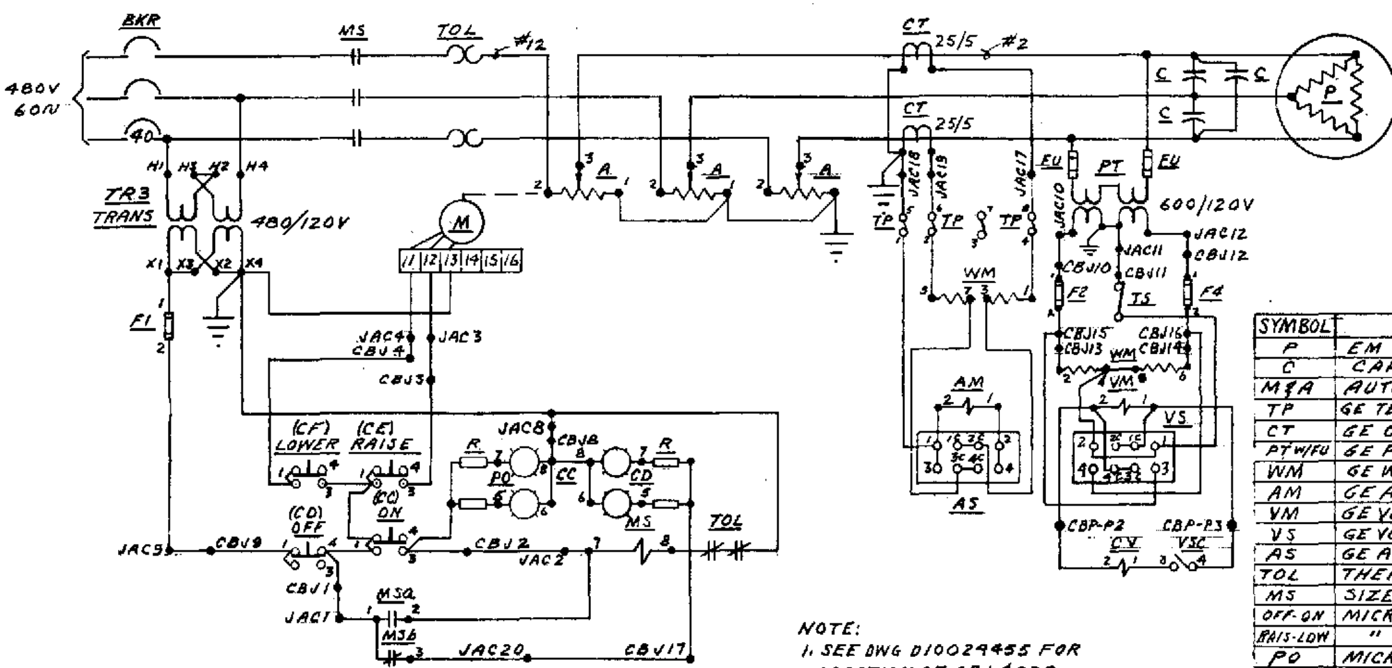
Fig. B-28. Magnetohydrodynamic facility 1-1/2-hp blower schematic diagram



SYMBOL	DEVICE
P	EM PUMP #5KY414 PK1
C	CAPACITORS
M&A	AUTOTRANSFORMER
TP	GE TEST BLOCK # 642212063
CT	GE CURRENT TRANS #JL-9 255 X17
PT w/FU	GE POT TRANS #JVP-0 760X22G13
WM	GE WATTMETER # AB-18-50-100-221
AM	GE AMMETER # AB-18-50-1001131LSNT
VM	GE VOLTMETER # AB-18-50-100021PZSJ
VS	GE VOLTMETER SW # 10AA002
AS	GE AMMETER SW # 10AA012
TOL	THERMAL OVERLOADS IN MS
MS	SIZE 3 MAGNETIC SWITCH
OFF-ON	MICRO SWITCH 2D68
RAIS-LOW	" " "
PO	MICRO OPERATOR-IND 2C1
R	RES 2250Ω 5W
FU	600V INST. FUSE
F1, F2&F4	LITTELFUSE 250V 3A SLO-BLO
TRANS	480/120V 150VA
BKR	100A F FRAME

REV	DATE	CHANGE	DWN	CHK	ENG	REL
E	11-11-68	ADDED LIGHT-DD	DGH		DGH	LH
D	12-1-67	REVISED FOR 100 KW TEST	DGH	ATB	[illegible]	[illegible]
C	2-26-63	REVISED CIRCUIT - CHANGED CONNECTIONS	RFN	[illegible]	DGH	[illegible]
B	1-18-65	CHANGED WM CONNECTIONS & ℄ LOCATION	RVS	RR	DGH	[illegible]
A	11-25-64	ADDED TERM NUMBERS	DGH		DGH	DGH

Fig. B-29. Magnetohydrodynamic facility lithium pump schematic diagram



REV	DATE	CHANGE	DWN	CHK	ENG	REL
D	11-11-68	ADDED LIGHT-CD	DGH		RSH	LA
C	12-7-67	REVISED FOR 100 KW TEST	DGH	ATB	RSH	RSH
B	1-18-65	CHANGED WM CONNECTIONS & Q LOCATION	RYS.	RR.	DGH	RH
A	11-25-64	ADDED TERM NUMBERS	DGH		DGH	DGH

SYMBOL	DEVICE
P	EM PUMP #5KY414 PJ1
C	CAPACITORS
M & A	AUTOTRANSFORMER
TP	GE TEST BLOCK # 6422120G3
CT	GE CURRENT TRANS # JL-9 258X14
PT W/FU	GE POT TRANS # JVP-0 -760X22G13
WM	GE WATTMETER # AB-18-50-100-221
AM	GE AMMETER # AB-18-50-100131LSNJ
VM	GE VOLTMETER # AB-18-50-100021PZS
VS	GE VOLTMETER SW # 10AA002
AS	GE AMMETER SW # 10AA012
TOL	THERMAL OVERLOADS IN MS
MS	SIZE 2 MAGNETIC SWITCH
OFF-ON	MICRO SWITCH 2D68
RAIS-LOW	" " "
PO	MICRO OPEATOR-1.VD 2C1
R	RES 2250Ω 5W
FU	600V INST. FUSE
F1, F2 & F4	LITTELFUSE 250V 3A 3L0-BL0
TRANS	480/120V 100VA
BKR	40 A F FRAME

Fig. B-30. Magnetohydrodynamic facility cesium pump schematic diagram

APPENDIX C

FABRICATION DRAWINGS OF TEST SYSTEM

The fabrication drawings of the cesium-lithium test system are included in this appendix (see Figs. C-1 through C-53). In some cases minor deviations and/or modifications have been made for the reasons discussed in the text. However, the essential features of the components and piping arrangement are identical to the drawings.

FOLDOUT FRAME 1

FOLDOUT FRAME 2

FOLDOUT FRAME 3

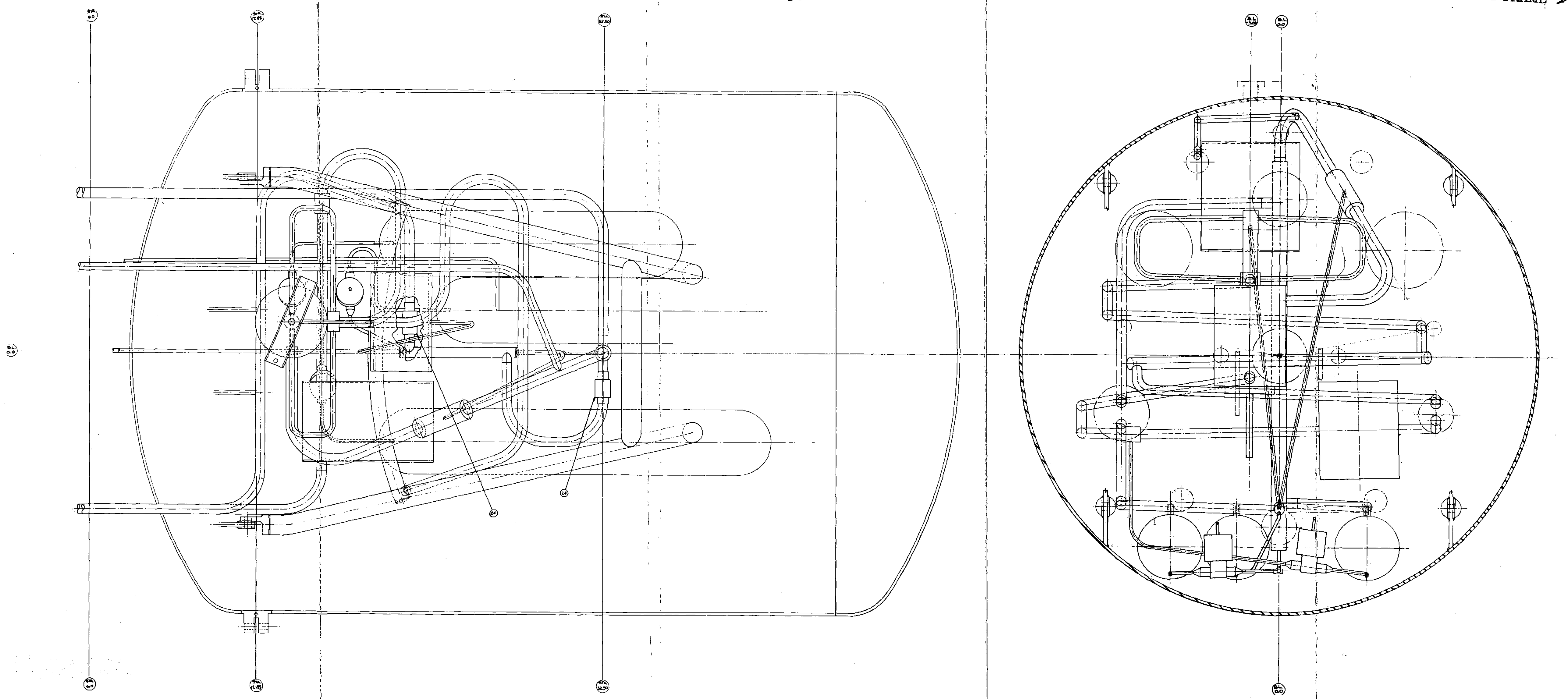


Fig. C-1. Layout and installation – 100-kW MHD ac generator erosion loop

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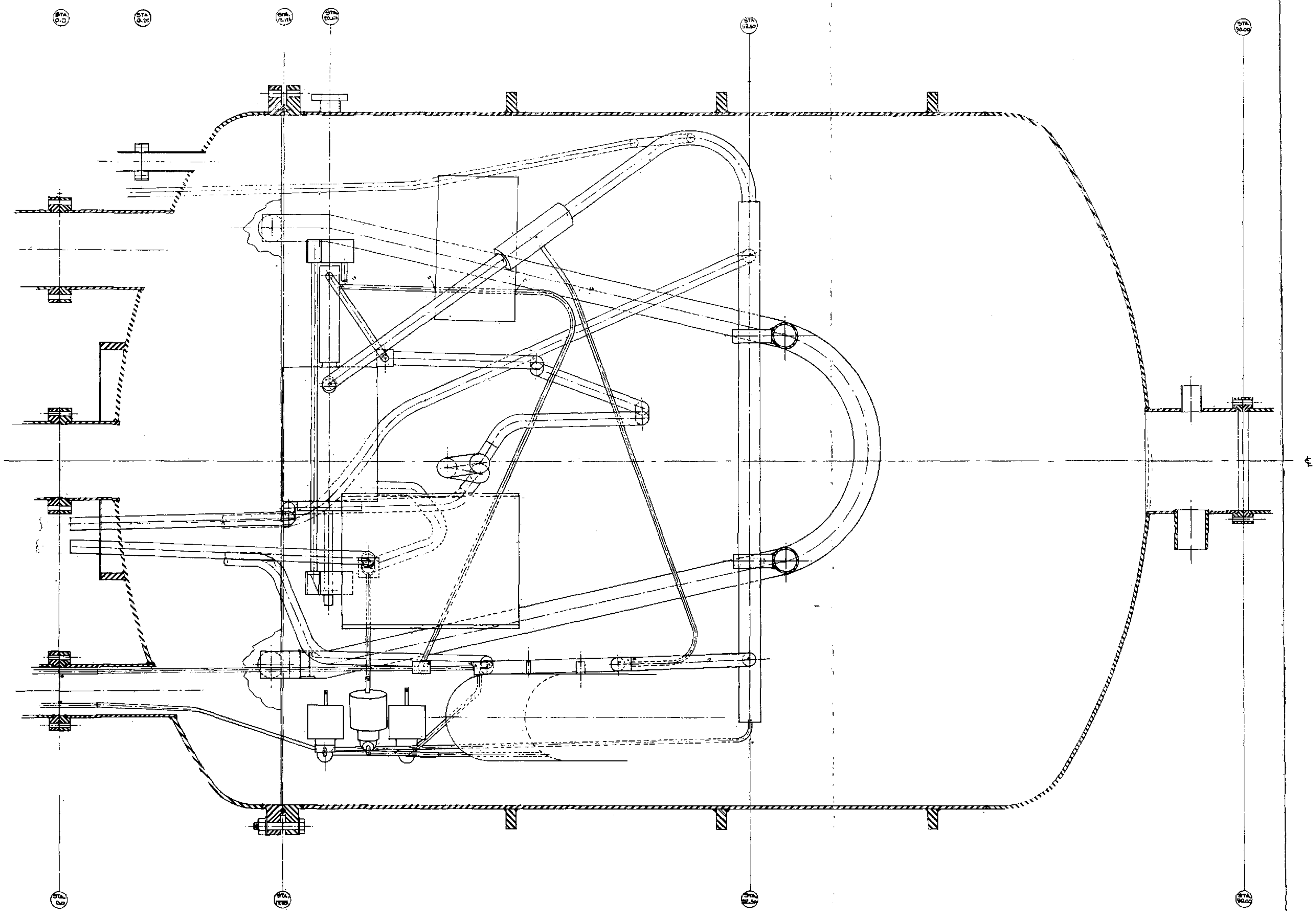
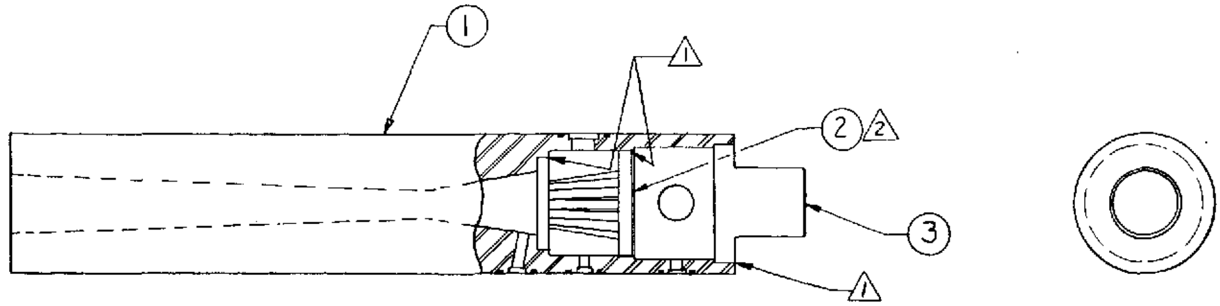
FOLDOUT FRAME 1

FOLDOUT FRAME 2



	Dwg or Part No.	Description	Specification / Source	Qty	Item No.
					26
					25
SEE SHT #2 —	18-11-10-409	BELLOWS	BOLA FLEX, SAN DIEGO	2	24
		PUMP - ION		1	23
		PUMP - NaK		1	22
		PUMP - LITHIUM		1	21
		PUMP - CESIUM		1	20
		SUPER DEHEATER		1	19
	J911 7906-1	INSTALL. & DETAILS - COMPONENT SUPPORTS		1	18
	D911 7845	COOLER		1	17
	D911 7794-3	SUMP - NaK		1	16
	D911 7794-2	SUMP - CESIUM		1	15
	D911 7794-1	SUMP - LITHIUM		1	14
	D911 7774	ASSY - SEPARATOR		1	13
	J911 7709	INSTALL - BUS BARS		1	12
	D911 7550	VALVE - SHUT OFF		3	11
	J911 7351	CONDENSER		1	10
	J911 7141	INSTALL - TANK HEAT & COOL, EXTERNAL		1	9
	D911 7140	FRAME - LOOP SUPPT		1	8
	D911 7136	ASSY - FRAME DOOR SUPPT		1	7
	D911 7135	ASSY - FRAME, TANK SUPPT		1	6
REWORK AT ASSY —	J911 7123	ASSY - LOAD CELL		1	5
	D911 7118	ASSY - HEATER		1	4
	J911 7112	TANK ASSY - VACUUM		1	3
	B 501480	FLOWMETER - Li	MSA RESEARCH, CALLERY PA #FM 14	1	2
	B 501489	FLOWMETER - Cs	MSA RESEARCH, CALLERY PA #FM 15	1	1

Fig. C-1 (contd)

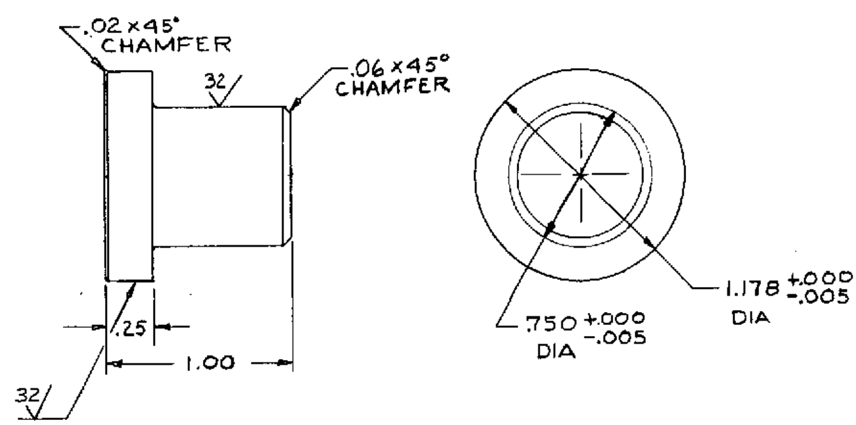


2. REMOVE APERTURE PLATE FROM NEEDLE ASSY. & WELD IN POSITION. THEN INSTALL NEEDLE ASSY & WELD.

1. ALL WELDS TO BE ELECTRON BEAM.

DWG PART OR NO.	DASH NO.	DESCRIPTION	SPECIFICATION	STOCK SIZE / REF DESIGNATION - ELEC DWG	MATERIAL	NO. REQD	FIND NO.
C911-7274		PLUG, HOUSING				1	3
D911-7275		NEEDLE ASSY				1	2
J911-7273		HOUSING				1	1

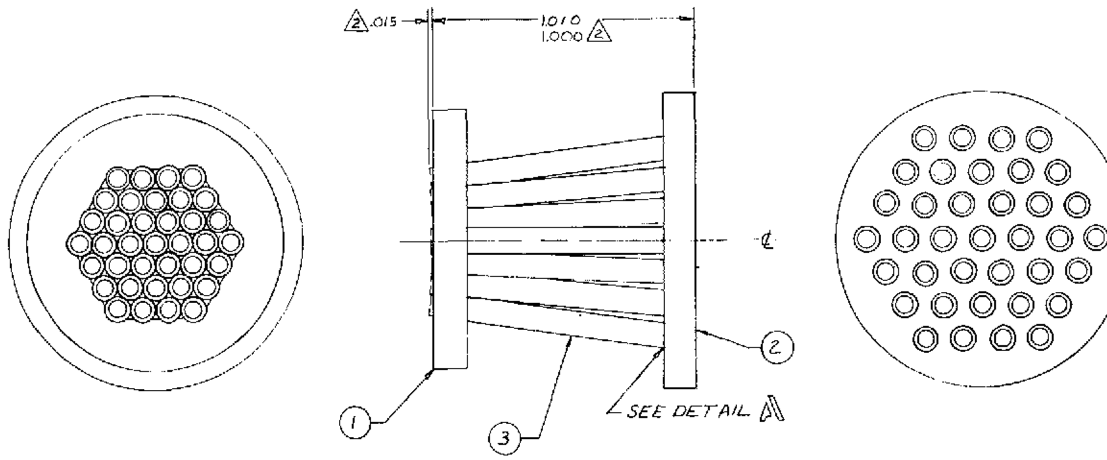
Fig. C-2. Weldment injector assembly

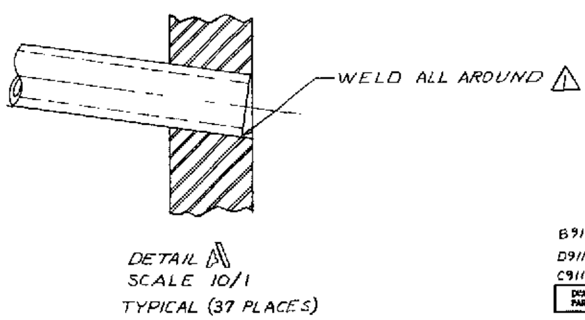


3. MACHINE FINISH 125.
2. BREAK CORNERS .005-.015 RAD.
1. MACHINED FILLET RAD. .020.

DESCRIPTION	SPECIFICATION	STOCK SIZE / REF DESIGNATION - ELEC DWG	MATERIAL
PLUG		1¼ DIA 1½ LG	Cb-1%Zr

Fig. C-3. Plug, housing injector assembly



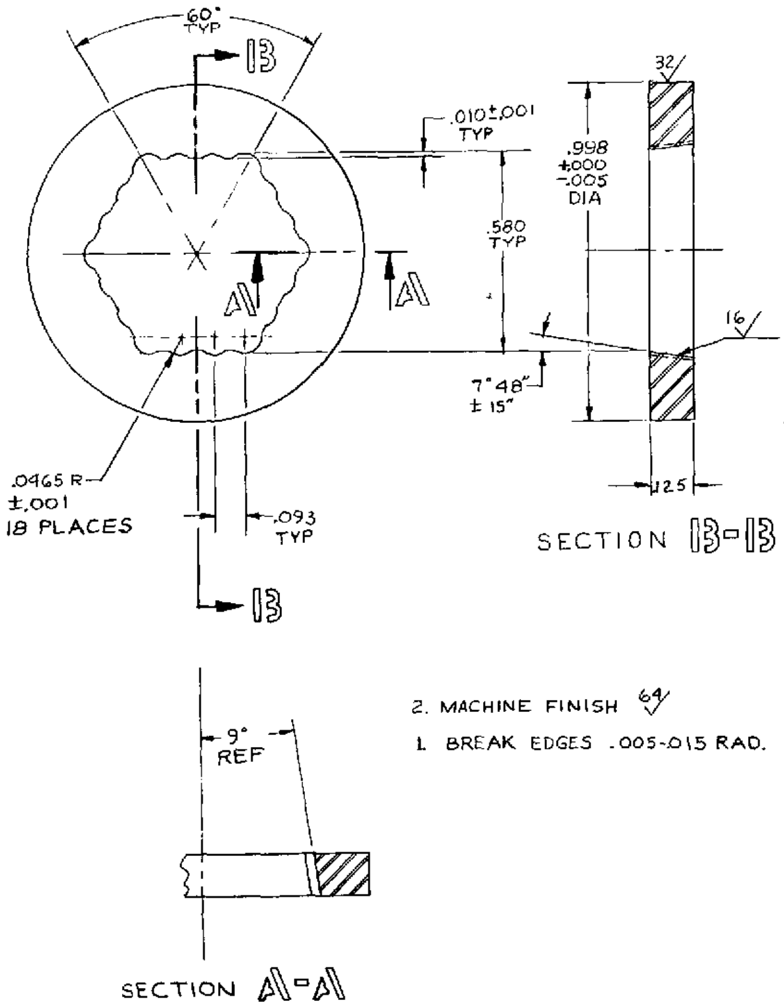


2 INSTALL (1) TO 1.010, GRIND TO 1.000 AFTER TUBE WELDING.

1 ELECTRON BEAM WELDING TO BE USED THROUGH-OUT.

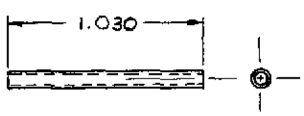
DWG OR PART NO.	DASH NO.	DESCRIPTION	SPECIFICATION	STOCK SIZE / REF DESIGNATION - ELEC DWG	MATERIAL	NO. REQD	FIND NO.
B911-7277		TUBE				37	3
D911-7278		HOLDER, TUBE				1	2
C911-7276		APERTURE PLATE				1	1

Fig. C-4. Needle assembly



APERTURE PLATE		1 3/16 DIA × 3/16	Cb-1% Zr
DESCRIPTION	SPECIFICATION	STOCK SIZE / REF DESIGNATION - ELEC DWG	MATERIAL

Fig. C-5. Aperture plate



1. CLEAN & DEBURR TUBE ENDS. MEASURE & RECORD I.D. & WALL ON ALL TUBES.

TUBING		.0935 O.D. .014 WALL	Cb-1% Zr
DESCRIPTION	SPECIFICATION	STOCK SIZE / REF DESIGNATION - ELEC DWG	MATERIAL

Fig. C-6. Tube, needle assembly

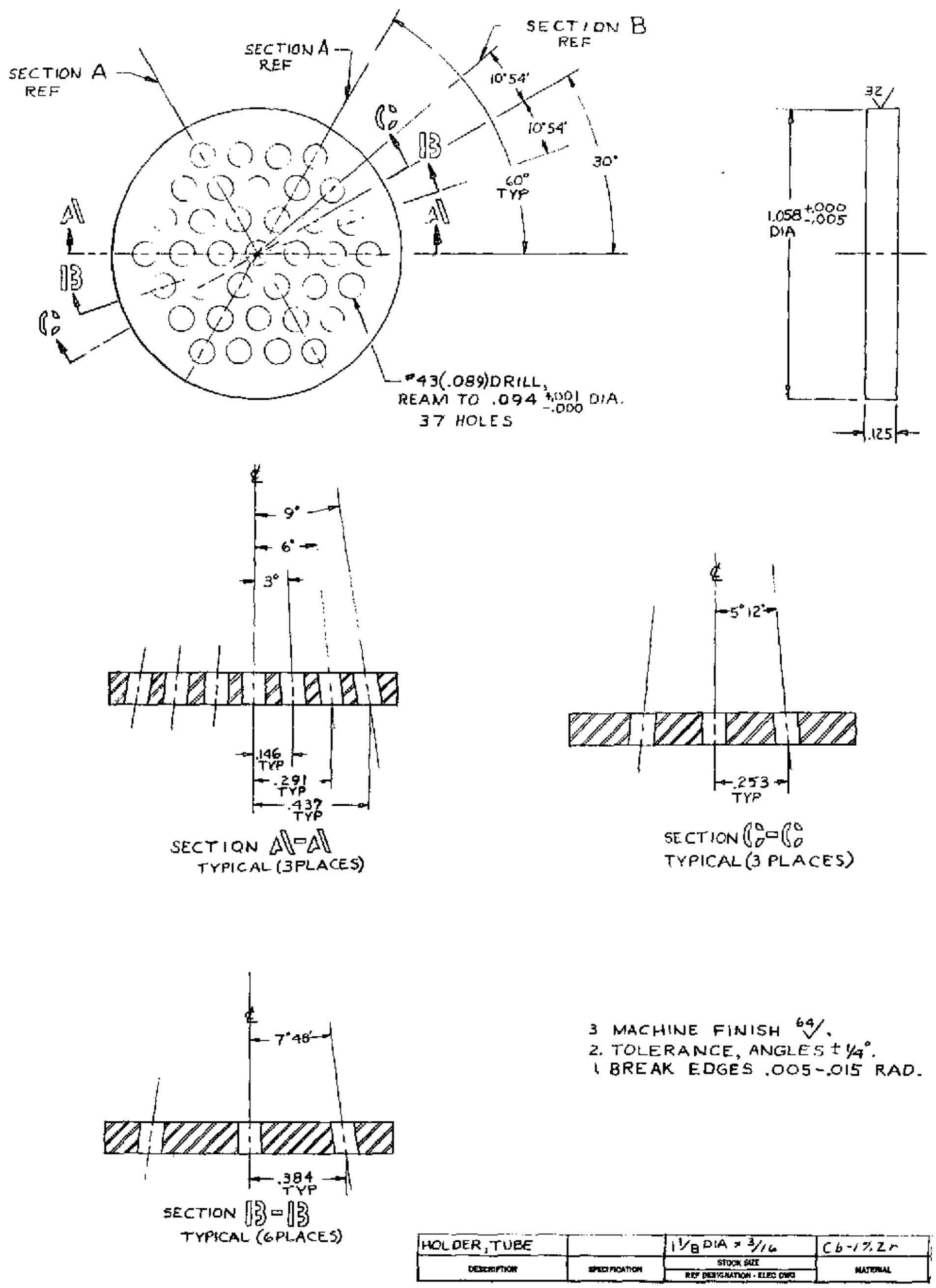


Fig. C-7. Holder, tube

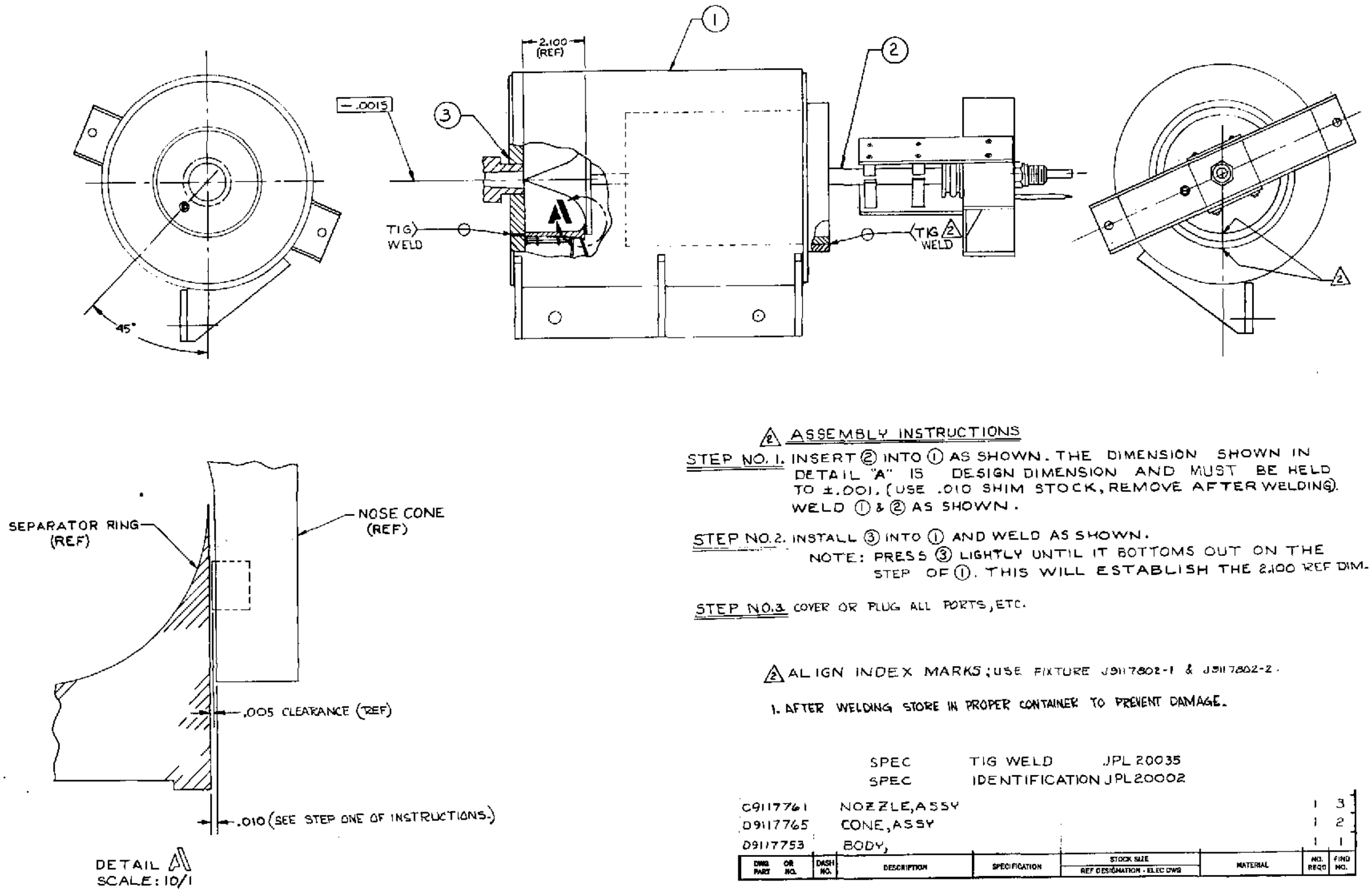


Fig. C-8. Separator — 100-kW erosion loop

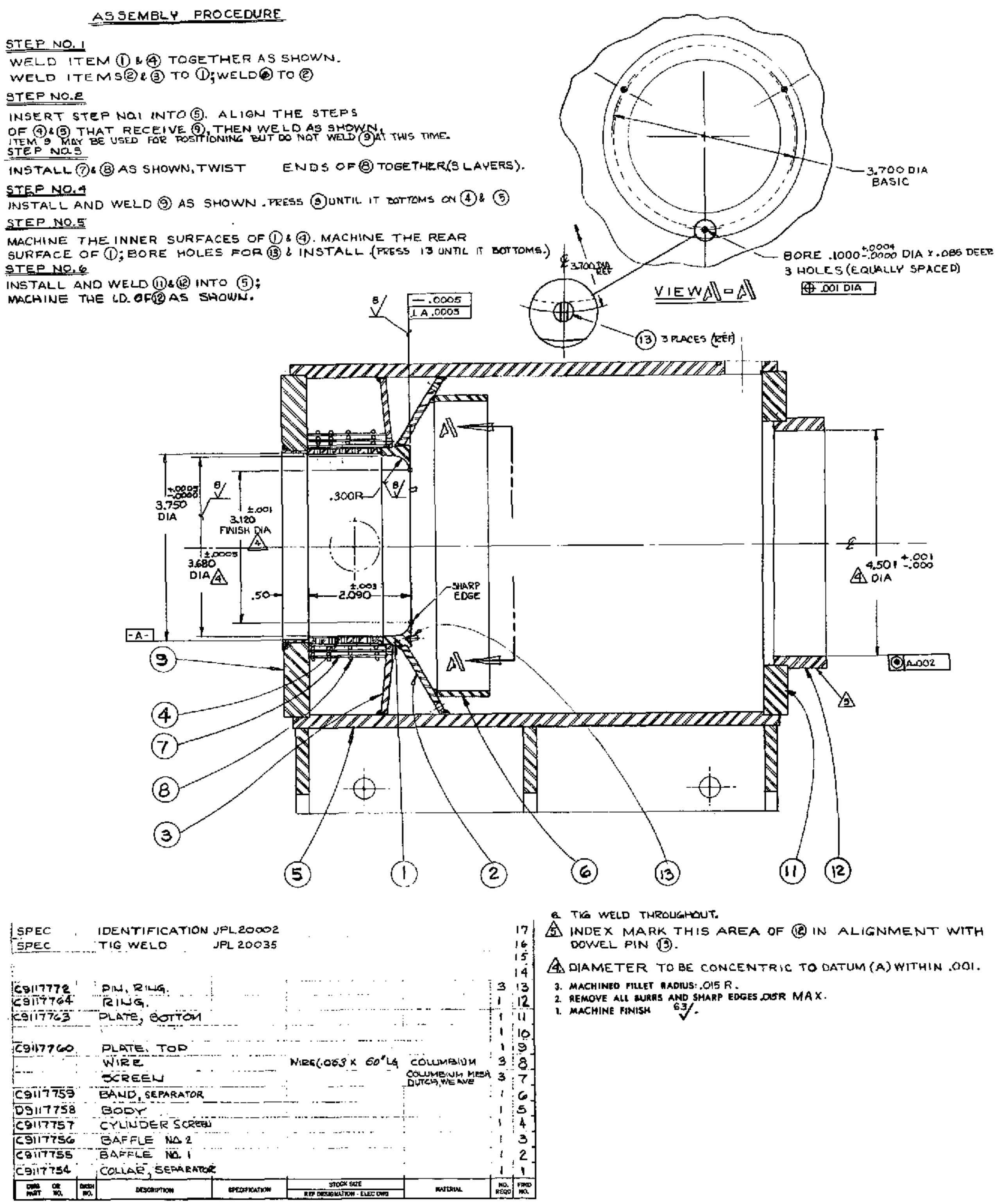
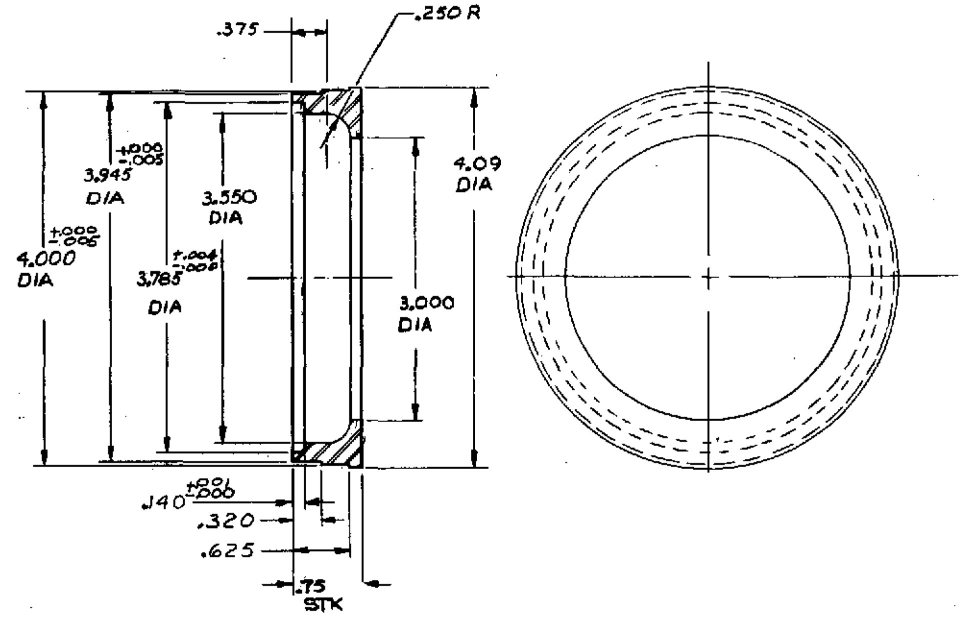


Fig. C-9. Assembly, body, separator — 100 kW erosion loop

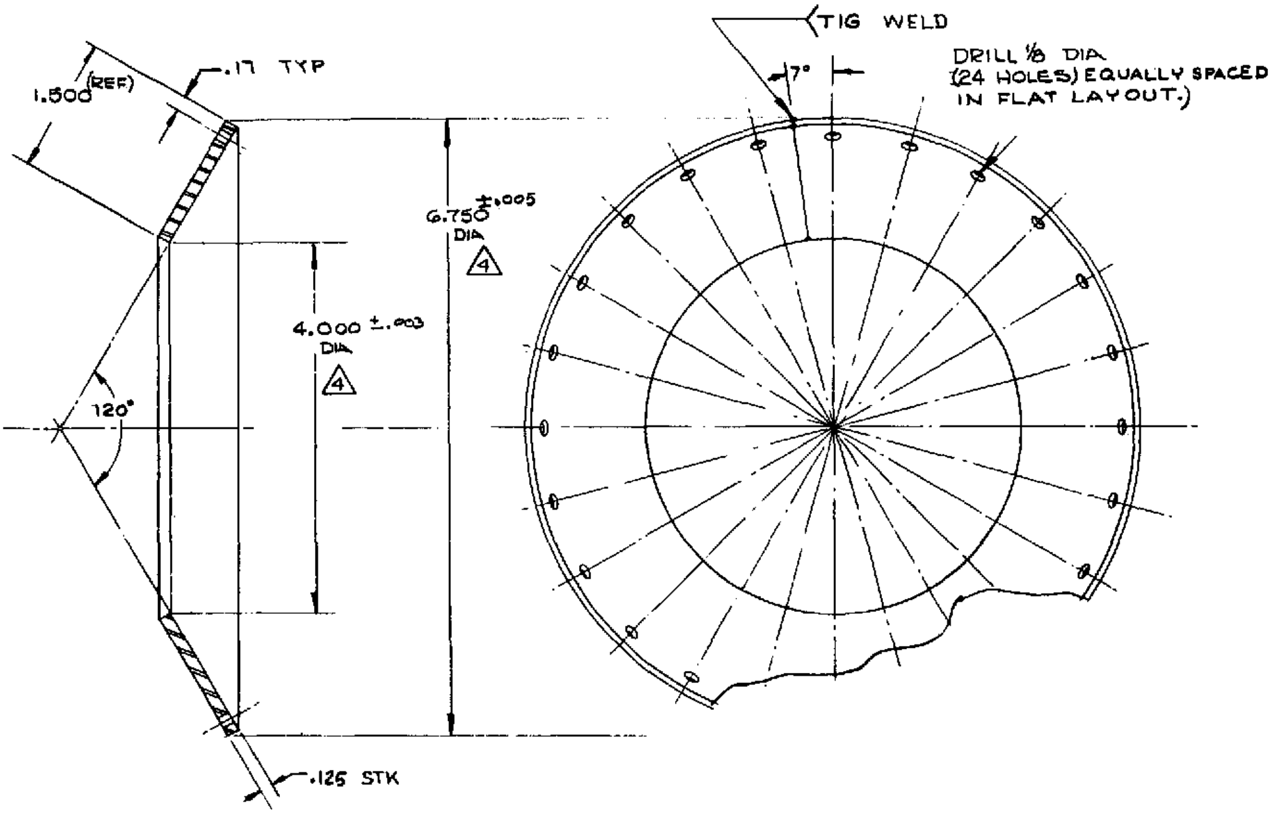


4 ALL DIAMETERS TO BE CONCENTRIC WITHIN .005, EXCEPT 4.09 DIA.

3. MACHINED FILLET RADIUS: .005 R
2. REMOVE ALL BURRS AND SHARP EDGES .010 R.
1. MACHINE FINISH 63/.

SPEC		IDENTIFICATION	JPL20002				3
							2
		COLLAR		3/4 × 4 1/8 DIA	Cb-1% Zr		1
DWG PART OR NO.	DASH NO.	DESCRIPTION	SPECIFICATION	STOCK SIZE / REF DESIGNATION - ELEC DWG	MATERIAL	NO. REQD	FIND NO.

Fig. C-10. Collar separator — 100-kW erosion loop



4 TO BE CONCENTRIC WITHIN .001 AFTER WELDING.

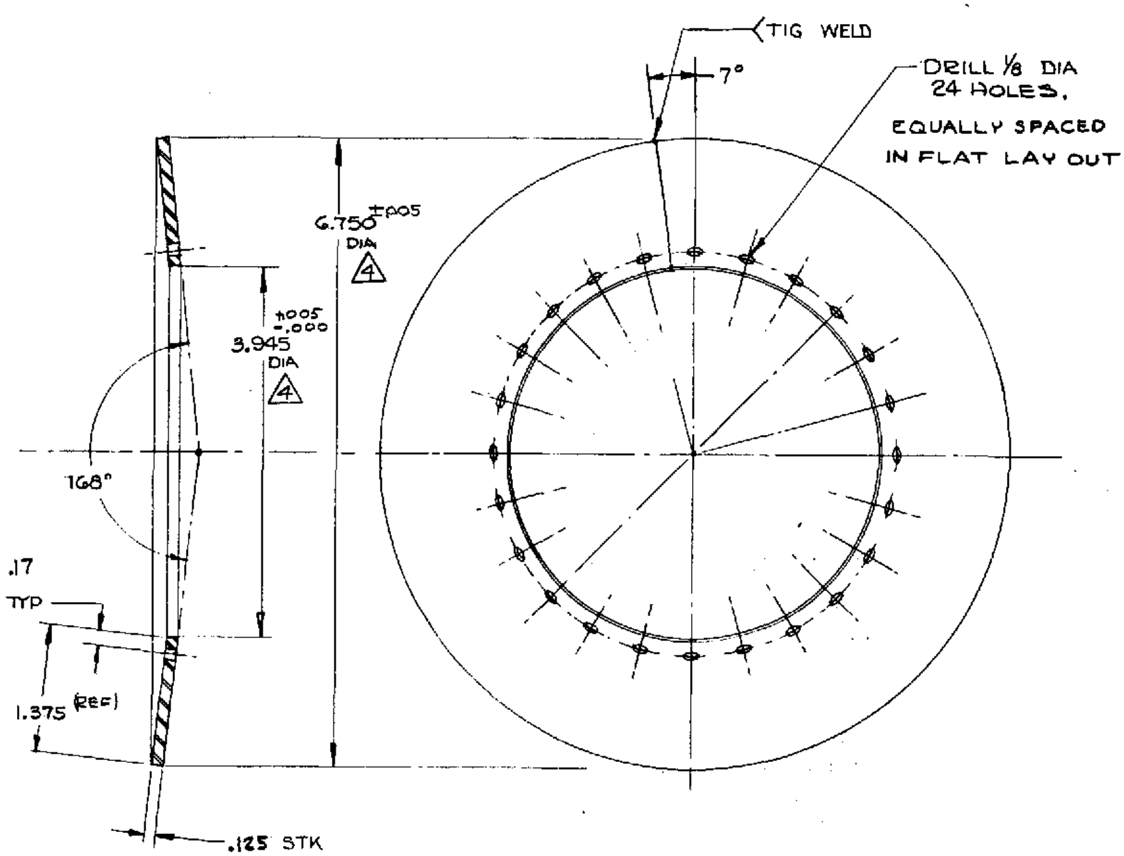
3. MACHINED FILLET RADIUS:

2. REMOVE ALL BURRS AND SHARP EDGES .015 R MAX.

AACHINE FINISH 63

SPEC		TIG WELD	JPL 20035				
SPEC		IDENTIFICATION	JPL 20002				
		BAFFLE NO. 1		.125 x 8.25 DIA	Cb-1%Zr		1
DWG OR PART NO.	DASH NO.	DESCRIPTION	SPECIFICATION	STOCK SIZE / REF DESIGNATION - ELEC DWG	MATERIAL	NO. REQD	FIND NO.

Fig. C-11. Baffle 1, separator — 100-kW erosion loop

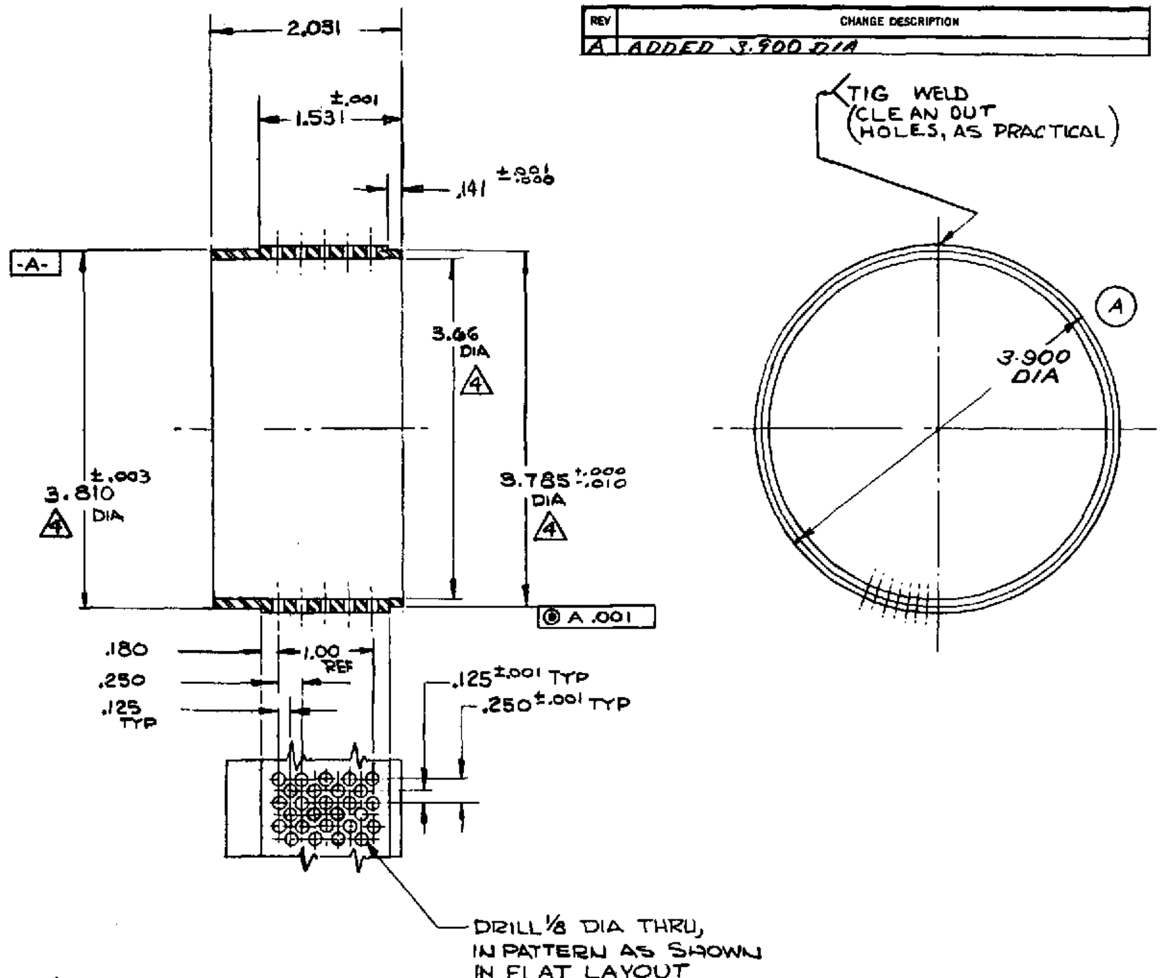


4 TO BE CONCENTRIC WITHIN .001 AFTER WELDING.

3. MACHINED FILLET RADIUS:
2. REMOVE ALL BURRS AND SHARP EDGES .015 R MAX.
1. MACHINE FINISH 63√

DWG OR PART NO.	DASH NO.	DESCRIPTION	SPECIFICATION	STOCK SIZE / REF DESIGNATION - ELEC DWG	MATERIAL	NO. REQD	FIND NO.
SPEC		IDENTIFICATION	JPL20002				
SPEC		TIG WELD	JPL 20035				
		BAFFLE NO. 2		.125 X 7 DIA	Cb-1% Zr.		1

Fig. C-12. Baffle 2, separator — 100-kW erosion loop

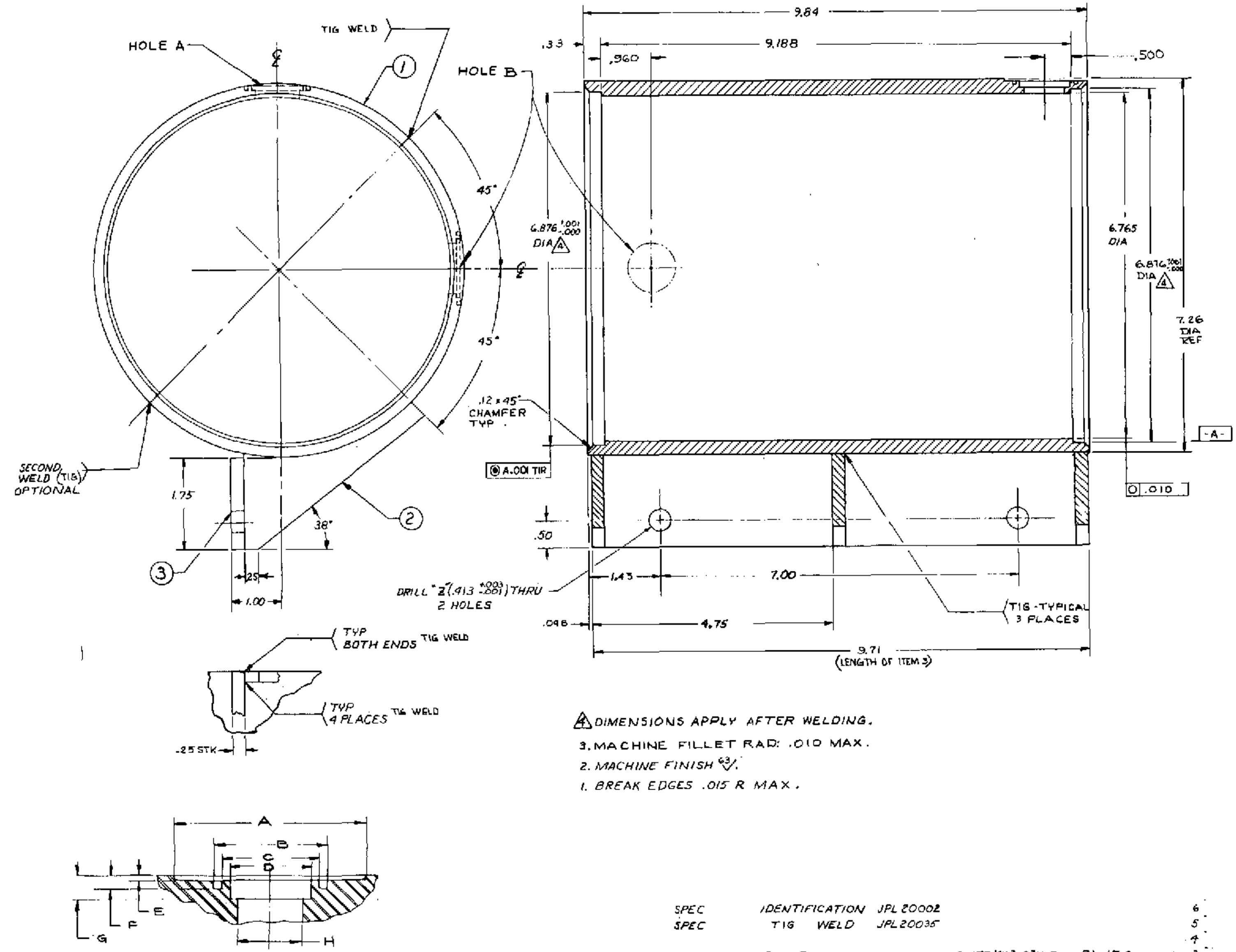


4 AFTER WELDING.

3. MACHINED FILLET RADIUS: .010 MAX.
2. REMOVE ALL BURRS AND SHARP EDGES .005 R MAX.
1. MACHINE FINISH 63/

DWG PART OR NO.	DASH NO.	DESCRIPTION	SPECIFICATION	STOCK SIZE / REF DESIGNATION - ELEC DWG	MATERIAL	NO. REQD	FIND NO.
SPEC		IDENTIFICATION	JPL 20002				4
SPEC		TIG WELD	JPL 20035				3
							2
		CYLINDER SCREEN		3/16 x 2 1/16 x 12 3/8 LG.	Cb-1% Zr		1

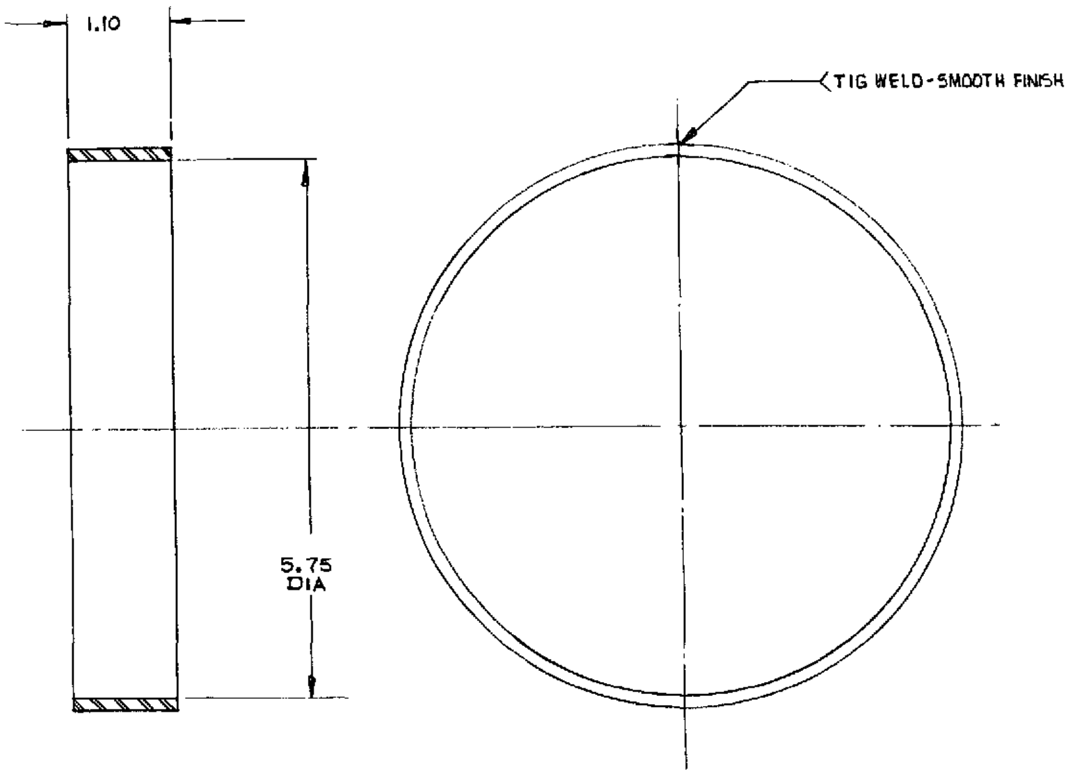
Fig. C-13. Cylinder screen, separator — 100-kW erosion loop



HOLE	A DIA.	B DIA.	C DIA.	D DIA.	E	F	G	H DIA.
A	1.760 ±.005	1.500 ±.005	1.250 ±.005	1.000 +.002 −.000	.056	.180	.150 ±.008	.750 +.004 −.001
B	1.750 ±.005	1.375 ±.005	1.250 ±.005	1.125 +.002 −.000	.056	.120	.150 ±.003	1.000 +.006 −.001

DWG PART OR NO.	DASH NO.	DESCRIPTION	SPECIFICATION	STOCK SIZE / REF DESIGNATION - ELEC DWG	MATERIAL	NO. REQD	FIND NO.
SPEC		IDENTIFICATION	JPL 20002				6
SPEC		TIG WELD	JPL 20035				5
							4
	3	PLATE		PLATE 1/4 x 3/4 x 9 3/4 LG	Cb-1% Zr	1	3
	2	PLATE		PLATE 1/4 x 1 1/16 x 4 1/2 LG	Cb-1% Zr	3	2
	1	BODY		PLATE 1/4 x 10 x 22 3/4 LG	Cb-1% Zr	1	1

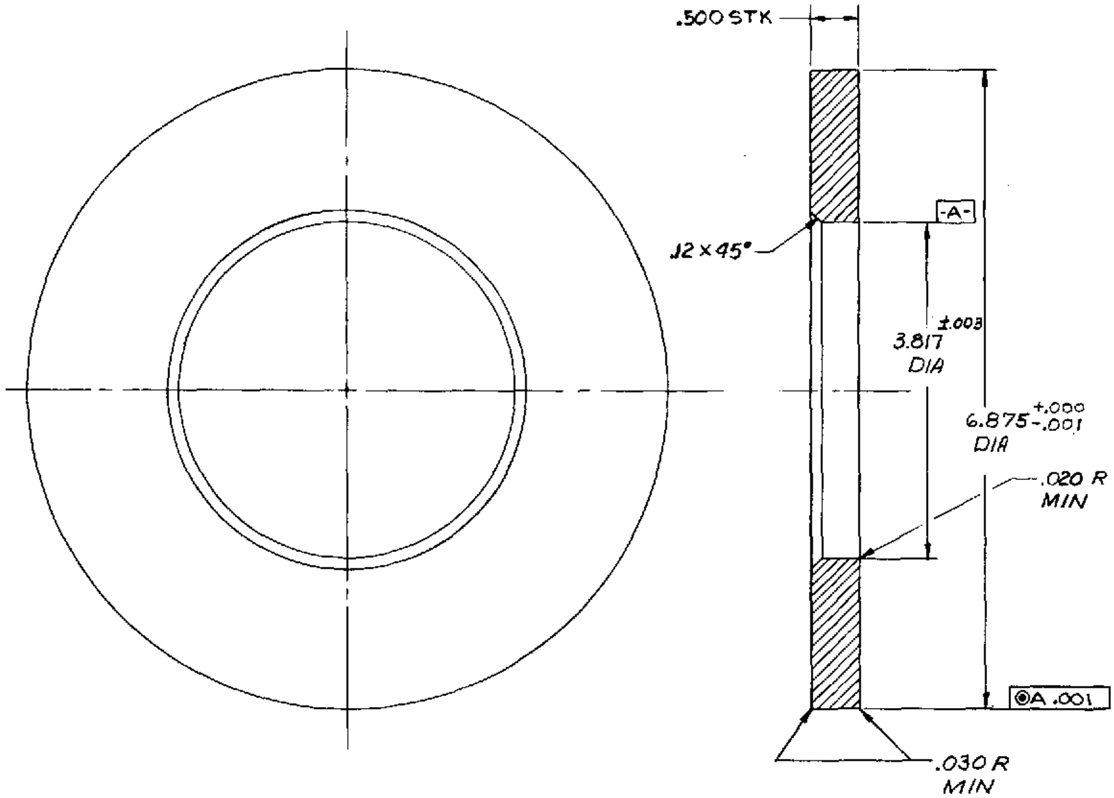
Fig. C-14. Body, separator — 100-kW erosion loop



4. DIMENSIONS AFTER WELDING.
3. MACHINED FILLET RADIUS:
2. REMOVE ALL BURRS AND SHARP EDGES .03 R MAX.
1. MACHINE FINISH 63

DWG OR PART NO.	DASH NO.	DESCRIPTION	SPECIFICATION	STOCK SIZE / REF DESIGNATION - ELEC DWG	MATERIAL	NO. REQD	FIND NO.
SPEC		IDENTIFICATION	JPL20002				
SPEC		TIG WELD	JPL20035				
		BAND		.125 X 1 1/8 X 19 LG	Cb-1% Zr		1

Fig. C-15. Band, separator — 100-kW erosion loop

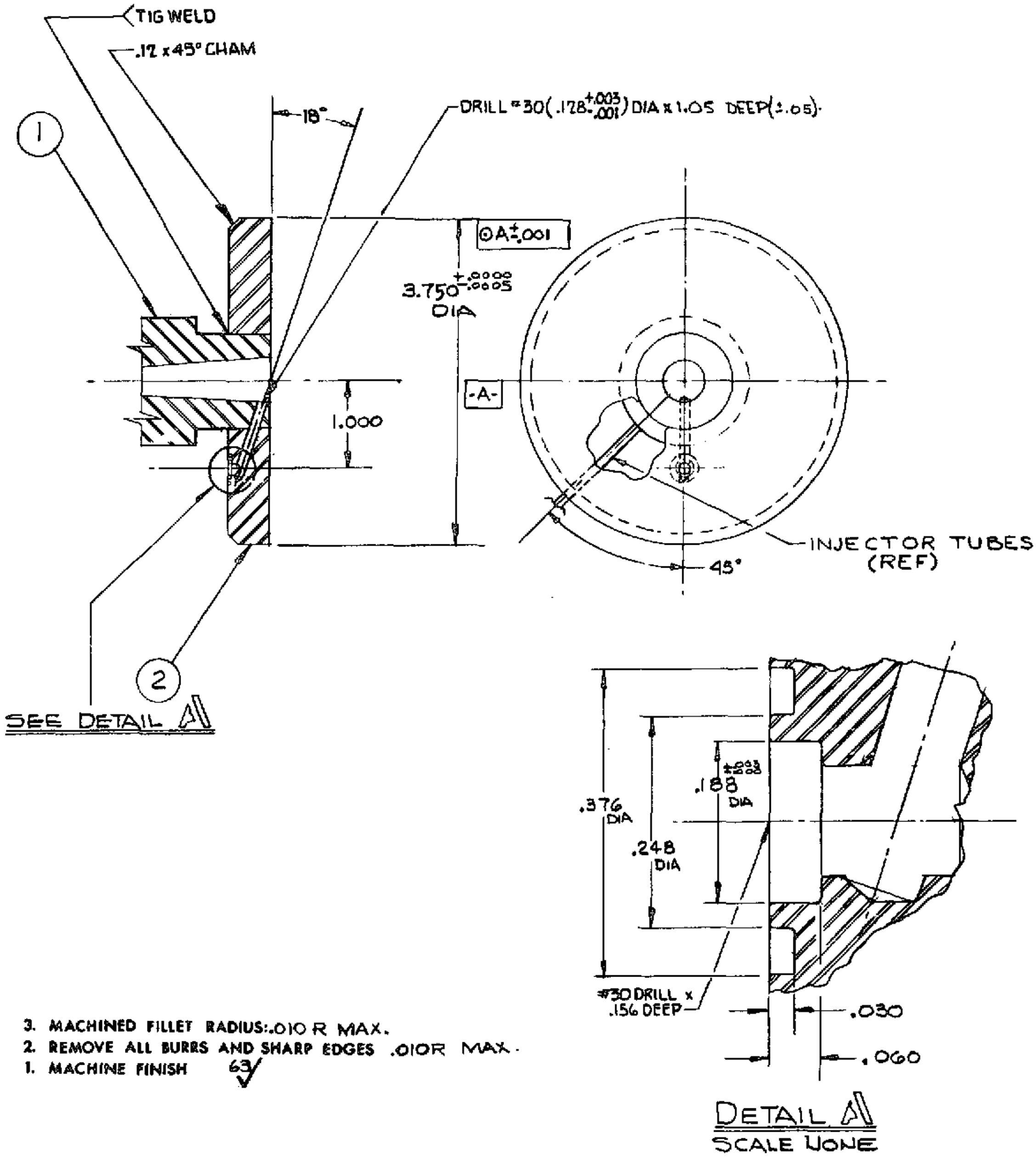


2. BREAK EDGES .015 R.

1. MACHINE FINISH $\sqrt[63]{}$.

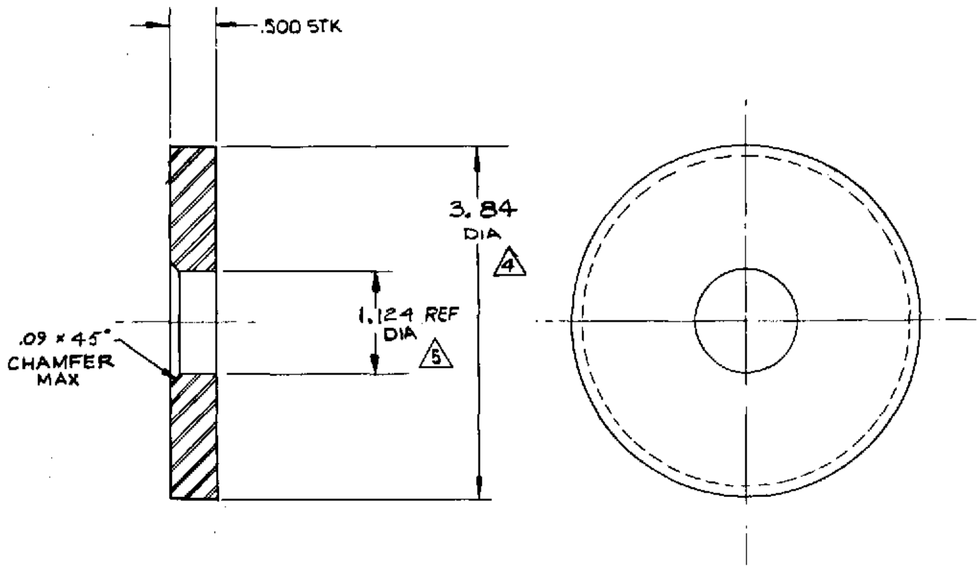
DWG PART OR NO.	DASH NO.	DESCRIPTION	SPECIFICATION	STOCK SIZE / REF DESIGNATION - ELEC DWG	MATERIAL	NO. REQD	FIND NO.
SPEC		IDENTIFICATION	JPL 20002				3
							2
		PLATE, TOP		PLATE ½ X 7 DIA	Cb-1% Zr		1

Fig. C-16. Plate, top, separator — 100-kW erosion loop



DWG OR PART NO.	DASH NO.	DESCRIPTION	SPECIFICATION	STOCK SIZE / REF DESIGNATION - ELEC DWG	MATERIAL	NO. REQD	FIND NO.
SPEC		TIG WELD	JPL20035				
SPEC		IDENTIFICATION	JPL20002				
C9117762		RING, NOZZLE				1	2
C9117272		INJECTOR ASSY				1	1

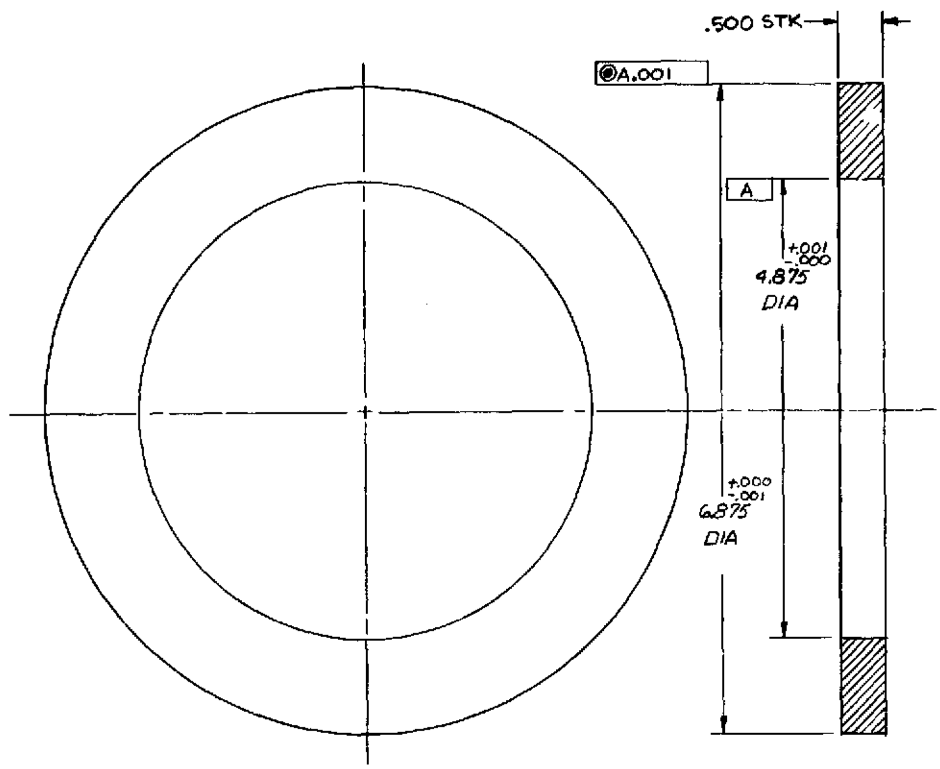
Fig. C-17. Nozzle assembly, separator – 100-kW erosion loop



5 MACH. AS REQD TO FIT C9117262 NOZZLE.
4 MAKE FROM CORE REMOVED FROM C9117763, IF FEASIBLE.
3. MACHINED FILLET RADIUS:
2. REMOVE ALL BURRS AND SHARP EDGES .015R MAX.
1. MACHINE FINISH 63

	DWG PART OR NO.	DASH NO.	DESCRIPTION	SPECIFICATION	STOCK SIZE / REF DESIGNATION - ELEC DWG	MATERIAL	NO. REQD	FIND NO.
	SPEC		IDENTIFICATION	JPL 20002				2
4			RING		½ x 3⅞ DIA	Cb-1% Zr		1

Fig. C-18. Ring, nozzle, separator — 100-kW erosion loop

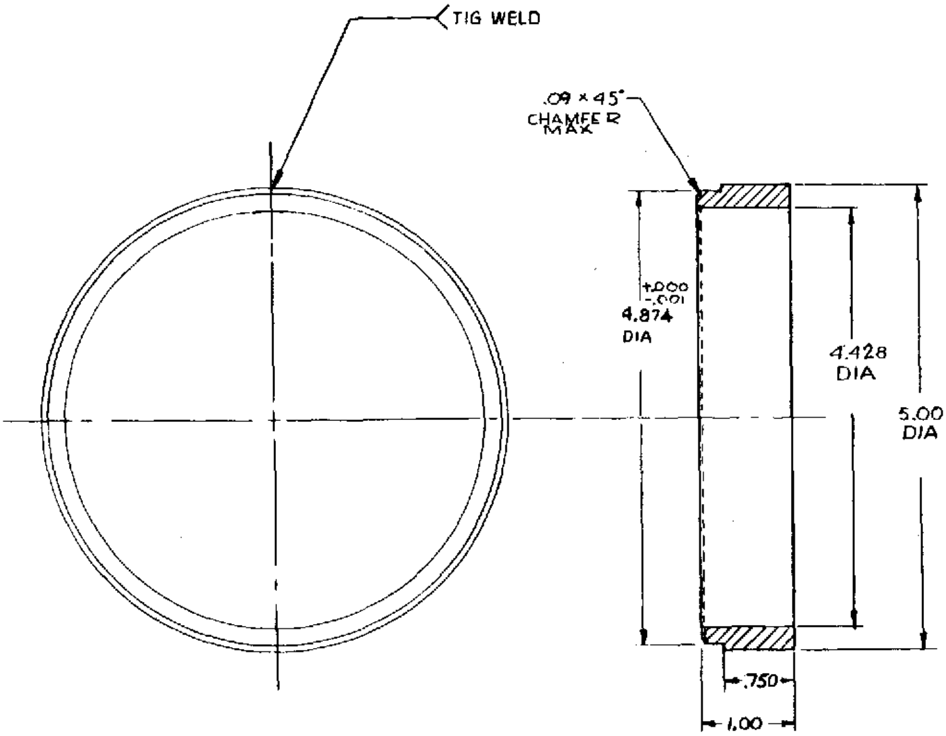


4. THE REMOVED CORE WILL BE USED TO PRODUCE C9117762.

3. MACHINED FILLET RADIUS:
2. REMOVE ALL BURRS AND SHARP EDGES .030R MAX.
1. MACHINE FINISH 63√

DWG PART OR NO.	DASH NO.	DESCRIPTION	SPECIFICATION	STOCK SIZE / REF DESIGNATION - ELEC DWG	MATERIAL	NO. REQD	FIND NO.
SPEC		IDENTIFICATION	JPL 20002				4
							3
							2
		PLATE, BOTTOM		PLATE ½ x 7 DIA	Cb-1% Zr		1

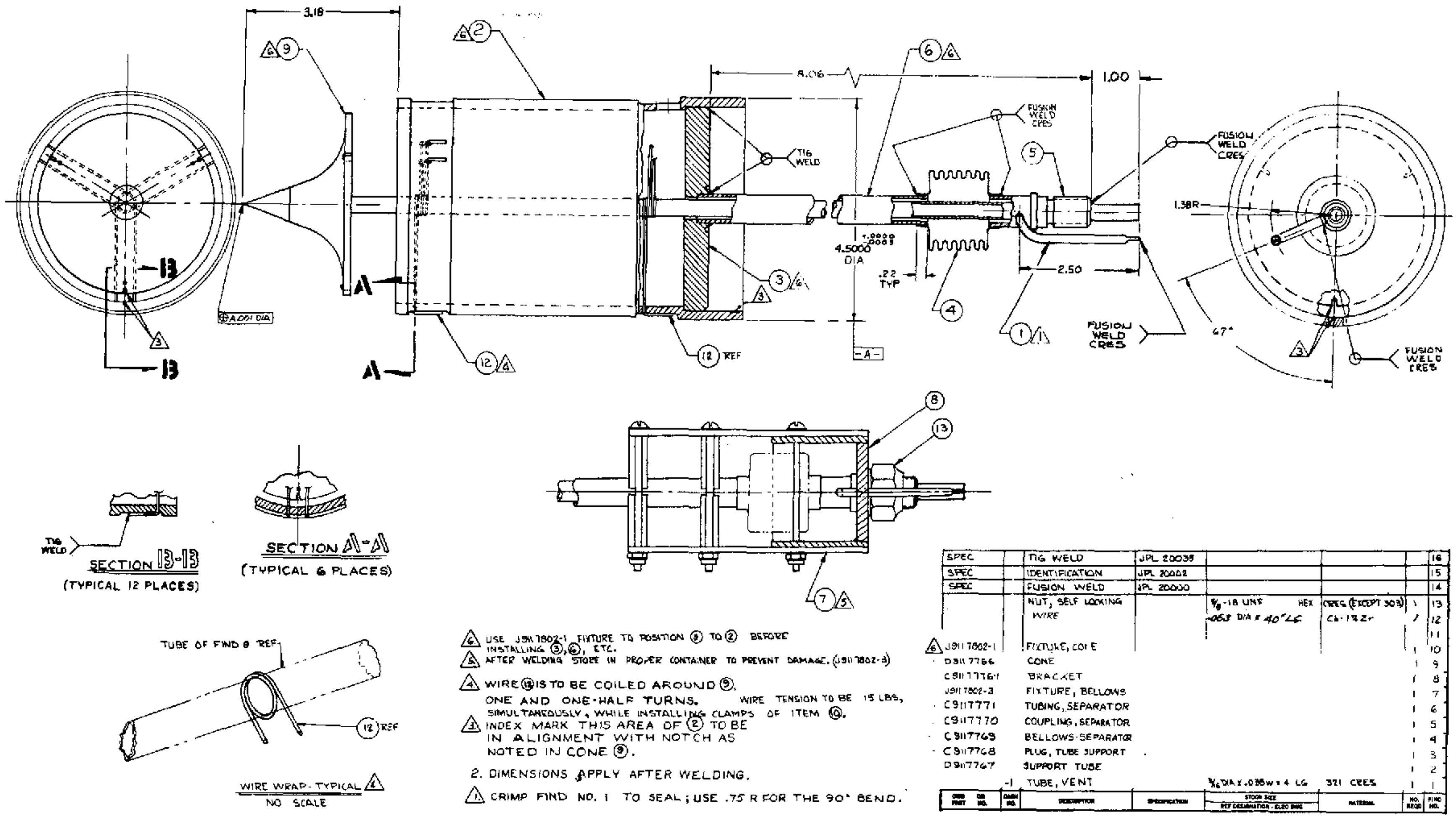
Fig. C-19. Plate, bottom, separator — 100-kW erosion loop



3. MACHINED FILLET RADIUS: .030 MAX.
2. REMOVE ALL BURRS AND SHARP EDGES .015 R.
1. MACHINE FINISH 63√

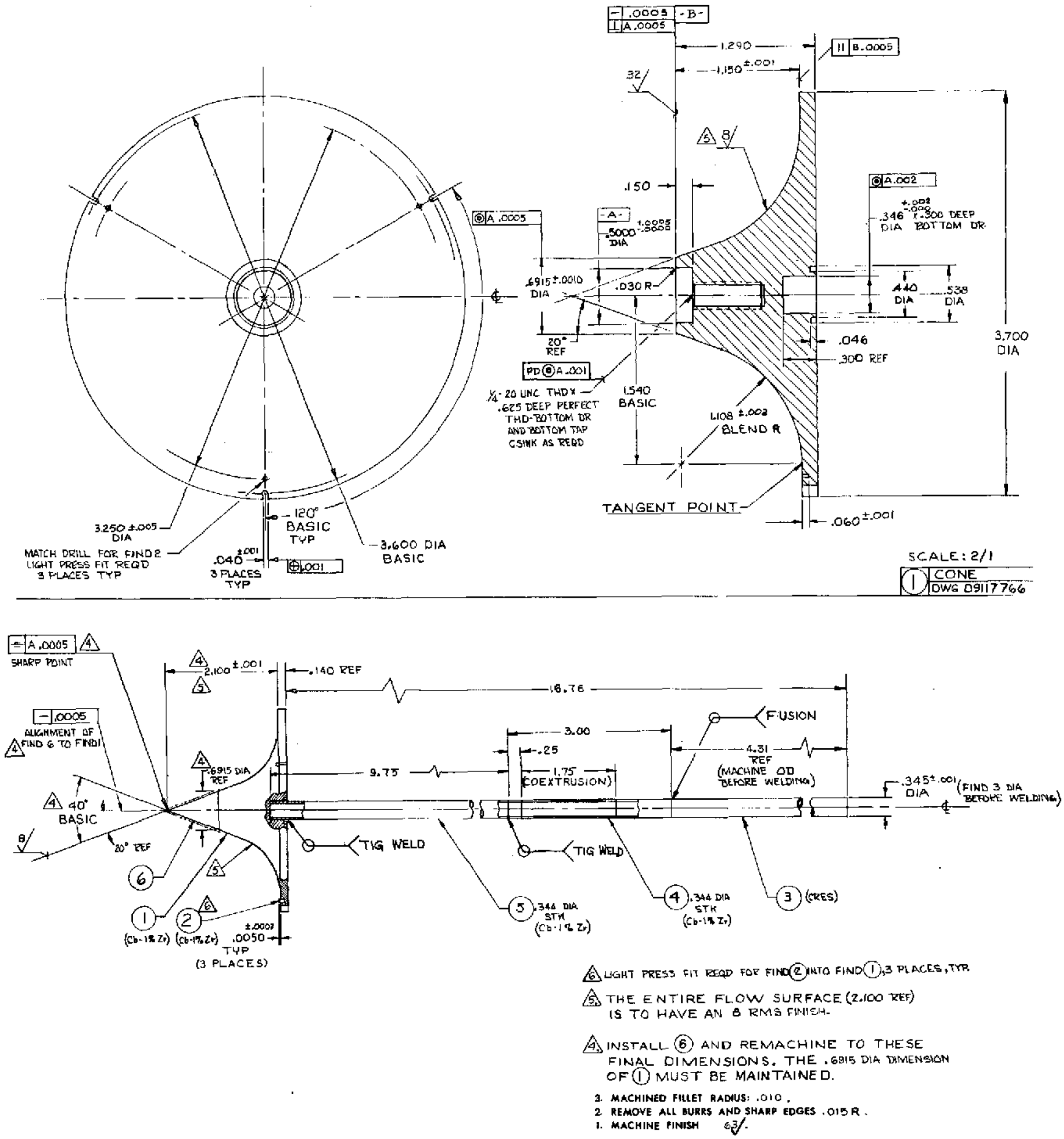
DWG PART	DR NO.	DASH NO.	DESCRIPTION	SPECIFICATION	STOCK SIZE / REF DESIGNATION - ELEC DWG	MATERIAL	NO. REQD	FIND NO.
SPEC			IDENTIFICATION	JPL 20002				4
SPEC			TIG WELD	JPL 20035				3
								2
			RING		PLATE 5/16 × 1 1/16 × 15 3/8 LG	Cb-1% Zr		1

Fig. C-20. Ring, separator — 100-kW erosion loop



DWG PART NO.	DASH NO.	DESCRIPTION	SPECIFICATION	STOCK SIZE / REF DESIGNATION - ELEC DWG	MATERIAL	NO. REQD	FIND NO.
SPEC		TIG WELD	JPL 20035				16
SPEC		IDENTIFICATION	JPL 20002				15
SPEC		FUSION WELD	JPL 20000				14
		NUT, SELF LOCKING		⅜-18 UNF HEX	CRES (EXCEPT 303)	1	13
		WIRE		.063 DIA × 40" LG	Cb-1%Zr	1	12
							11
6 J9117802-1		FIXTURE, CONE				1	10
D9117766		CONE				1	9
C9117761		BRACKET				1	8
J9117802-3		FIXTURE, BELLOWS				1	7
C9117771		TUBING, SEPARATOR				1	6
C9117770		COUPLING, SEPARATOR				1	5
C9117769		BELLOWS-SEPARATOR				1	4
C9117768		PLUG, TUBE SUPPORT				1	3
D9117767		SUPPORT TUBE				1	2
	-1	TUBE, VENT		⅛ DIA × .035W × 4 LG	321 CRES	1	1

Fig. C-21. Assembly, cone and support, separator — 100-kW erosion loop



DWG OR PART NO.	DASH NO.	DESCRIPTION	SPECIFICATION	STOCK SIZE / REF DESIGNATION - ELEC DWG	MATERIAL	NO. REQD	FIND NO.
SPEC		FUSION WELD	JPL20000				10
SPEC		TIG WELD	JPL20035				9
SPEC		IDENTIFICATION	JPL20002				8
							7
C9117773		NOSE CONE				1	6
	5	TUBE		.344 OD x .04 W x 10 LG	Cb-1% Zr	1	5
	4	COEXTRUDED JOINT		.344 OD x .04 W x 3½ LG	Cb-1% Zr & 321 CRES	1	4
	3	TUBE	MIL-T-8808	3/8 OD x .065 W x 4½ LG	321 CRES	1	3
	2	PIN		.031 DIA x ¼ LG	Cb-1% Zr	3	2
	1	CONE		3⅞ DIA x 1⅜	Cb-1% Zr	1	1

Fig. C-22. Cone assembly, separator — 100-kW erosion loop

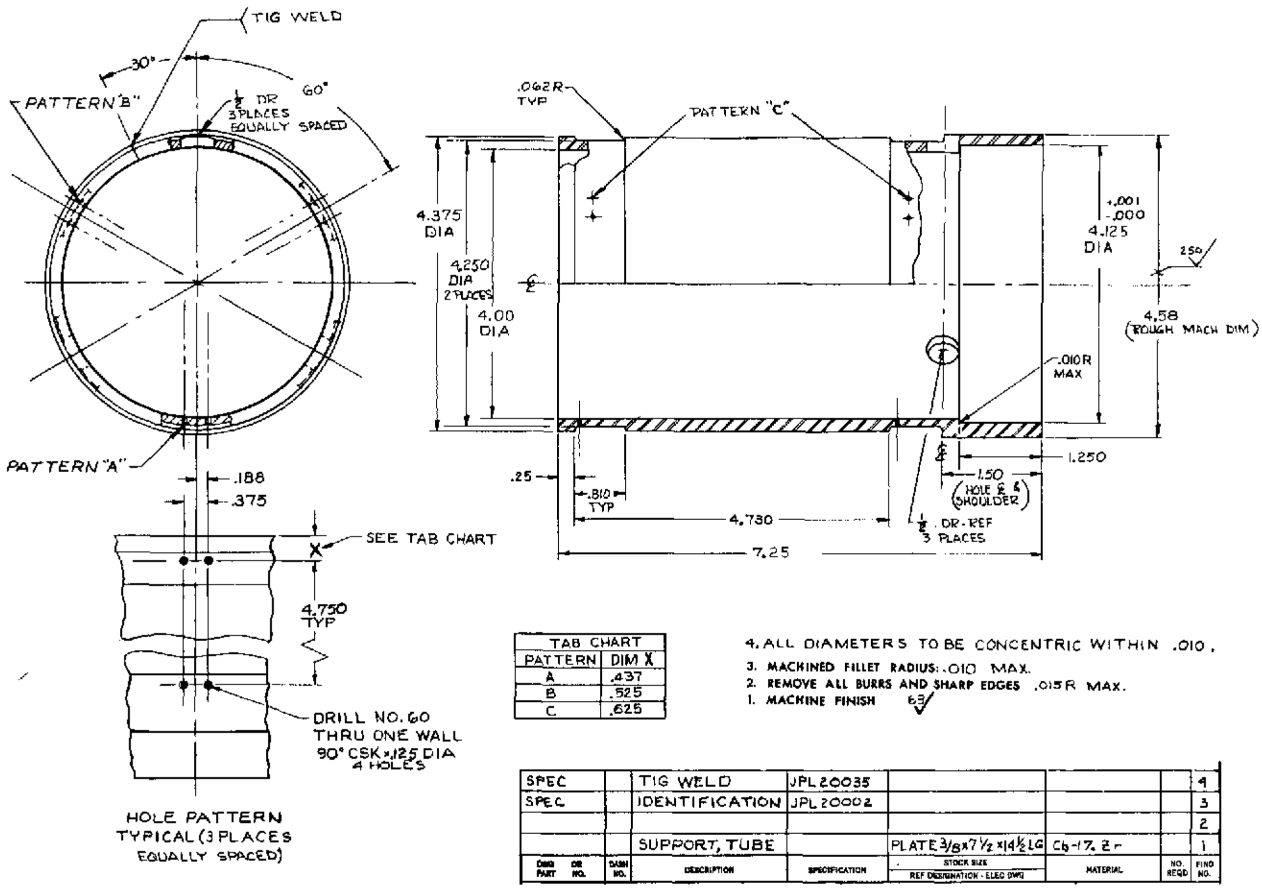
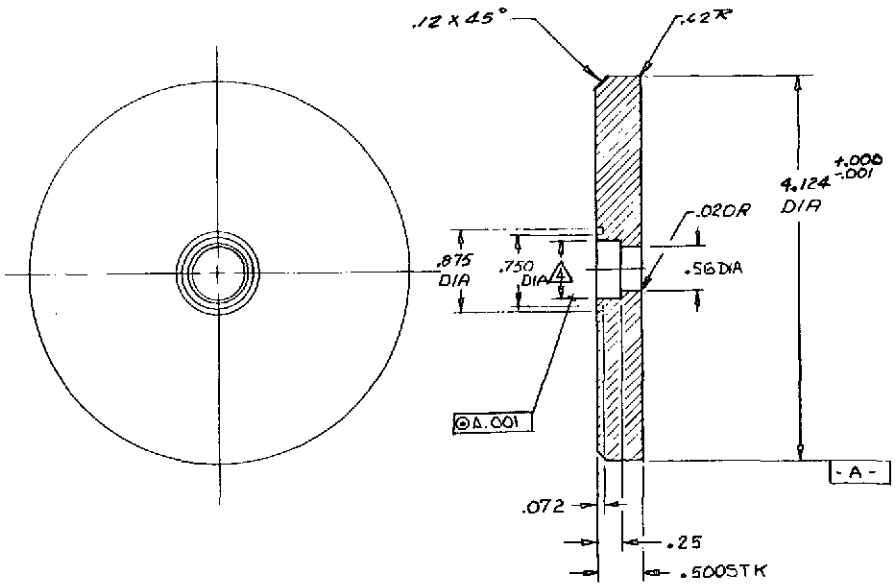


Fig. C-23. Support, tube, separator — 100-kW erosion loop

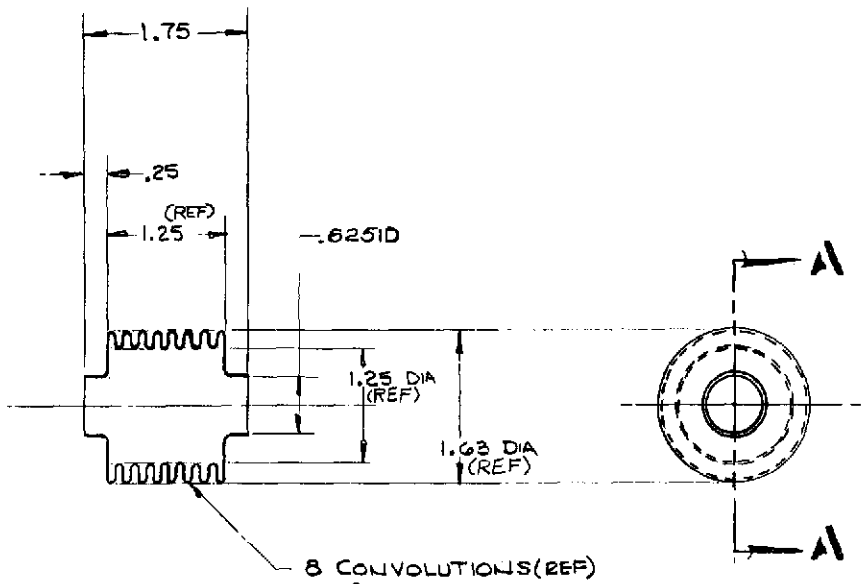


4. MATCH FIT WITH PART NO. C9117771, FOR SNUG FIT.

3. MACHINED FILLET RADIUS: .010 MAX.
2. REMOVE ALL BURRS AND SHARP EDGES .010 R MAX.
1. MACHINE FINISH 63/

DWG PART	OR NO.	DASH NO.	DESCRIPTION	SPECIFICATION	STOCK SIZE / REF DESIGNATION - ELEC DWG	MATERIAL	NO. REQD	FIND NO.
SPEC			IDENTIFICATION	JPL 20002				3
								2
			PLUG, TUBE SUPPORT		PLATE ½ x 4¼ DIA	Cb-1% Zr		1

Fig. C-24. Plug, tube support—100-kW erosion loop separator



SECTION A-A

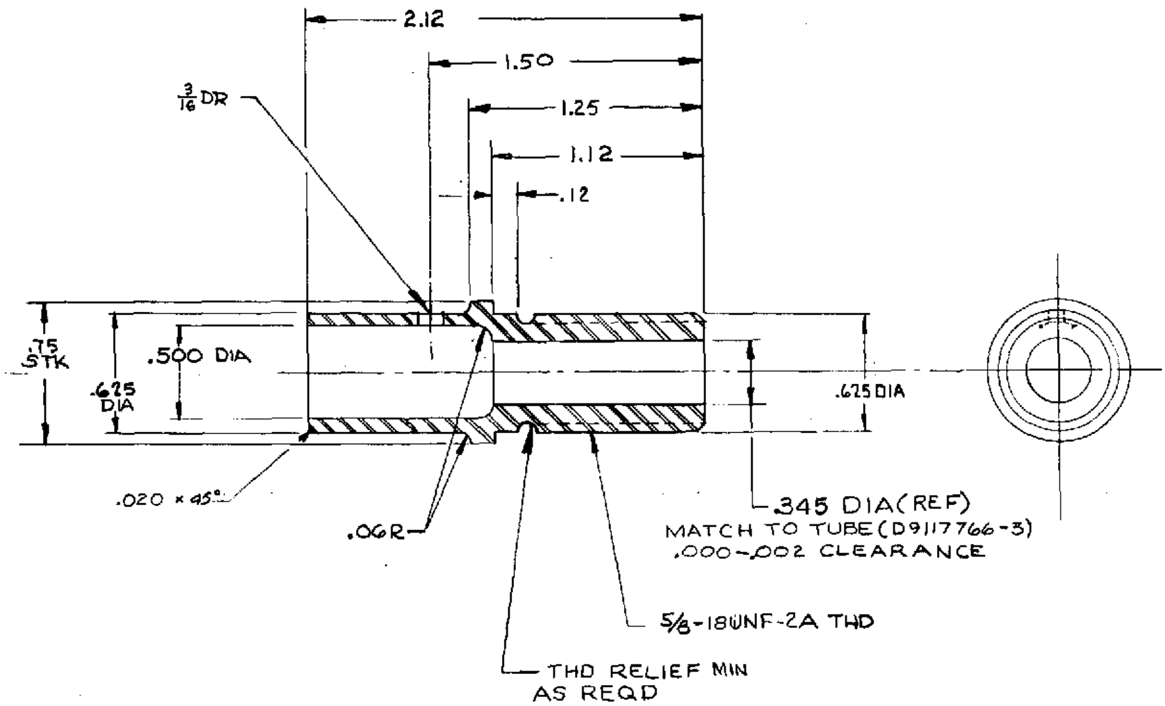
(REF DIMENSIONS EXIST ON ARROWHEAD BELLOWS NO. 21012)

△2 BELLOWS TO HAVE A NO. 6 END CUFF TERMINATION, REDUCED DIAMETER AS SHOWN
MATERIAL .005; 1 PLY, 100 PSI AT 800°F,
MAX DEFLECTION .25; SPRING RATE 68/LB IN.;
EFFECTIVE AREA 1.63 SQ IN.

△1 SIMILAR TO ARROWHEAD NO. 21012, ARROWHEAD PRODUCTS,
4411 KATELLA AVE.,
LOS ALAMITOS CALIF., OR EQUAL.
(BULLETIN NO. 501-R)

	SPEC		IDENTIFICATION	JPL 20002				
△1			BELLOWS		SEE △2	347 CRES	1	1
	DWG PART OR NO.	DASH NO.	DESCRIPTION	SPECIFICATION	STOCK SIZE / REF DESIGNATION - ELEC DWG	MATERIAL	NO. REQD	FIND NO.

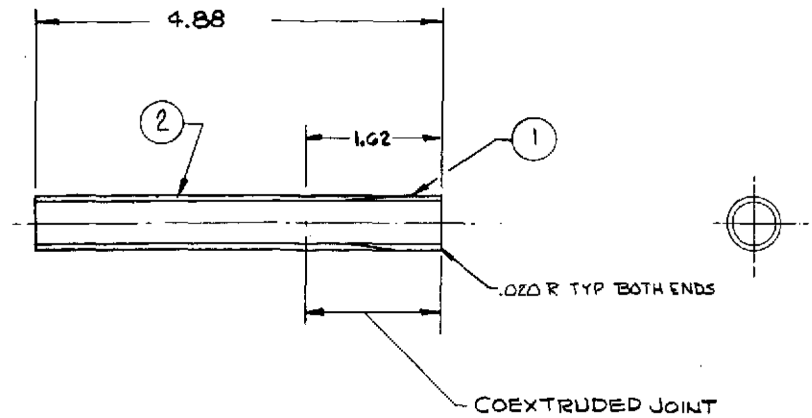
Fig. C-25. Bellows, separator — 100-kW erosion loop



3. MACHINED FILLET RADIUS: .020 MAX
2. REMOVE ALL BURRS AND SHARP EDGES .015 R MAX
1. MACHINE FINISH 63/.

SPEC		IDENTIFICATION	JPL 20002				
		COUPLING		3/4 DIA X 2 1/2 LG	321 CRES		1
DWG PART OR NO.	DASH NO.	DESCRIPTION	SPECIFICATION	STOCK SIZE / REF DESIGNATION - ELEC DWG	MATERIAL	NO. REQD	FIND NO.

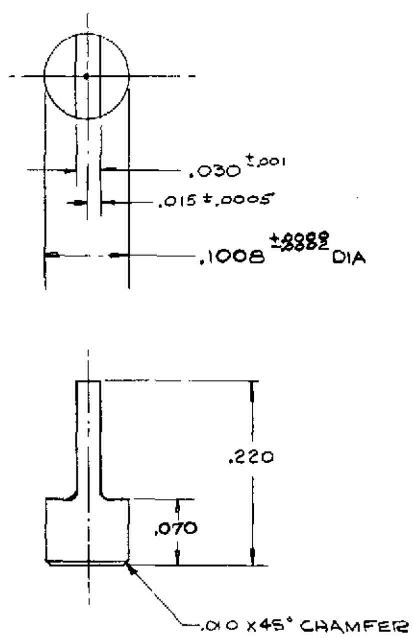
Fig. C-26. Coupling, separator — 100-kW erosion loop



3. MACHINED FILLET RADIUS:
2. REMOVE ALL BURRS AND SHARP EDGES .002 R MAX.
1. MACHINE FINISH COML

DWG OR PART NO.	DASH NO.	DESCRIPTION	SPECIFICATION	STOCK SIZE / REF DESIGNATION - ELEC DWG	MATERIAL	NO. REQD	FIND NO.
SPEC		IDENTIFICATION	JPL20002				3
	2	TUBING NO. 2		.625 OD X .50 ID	321 CRES	1	2
	1	TUBING NO. 1		.625 OD X .50 ID	Cb-1% Zr	1	1

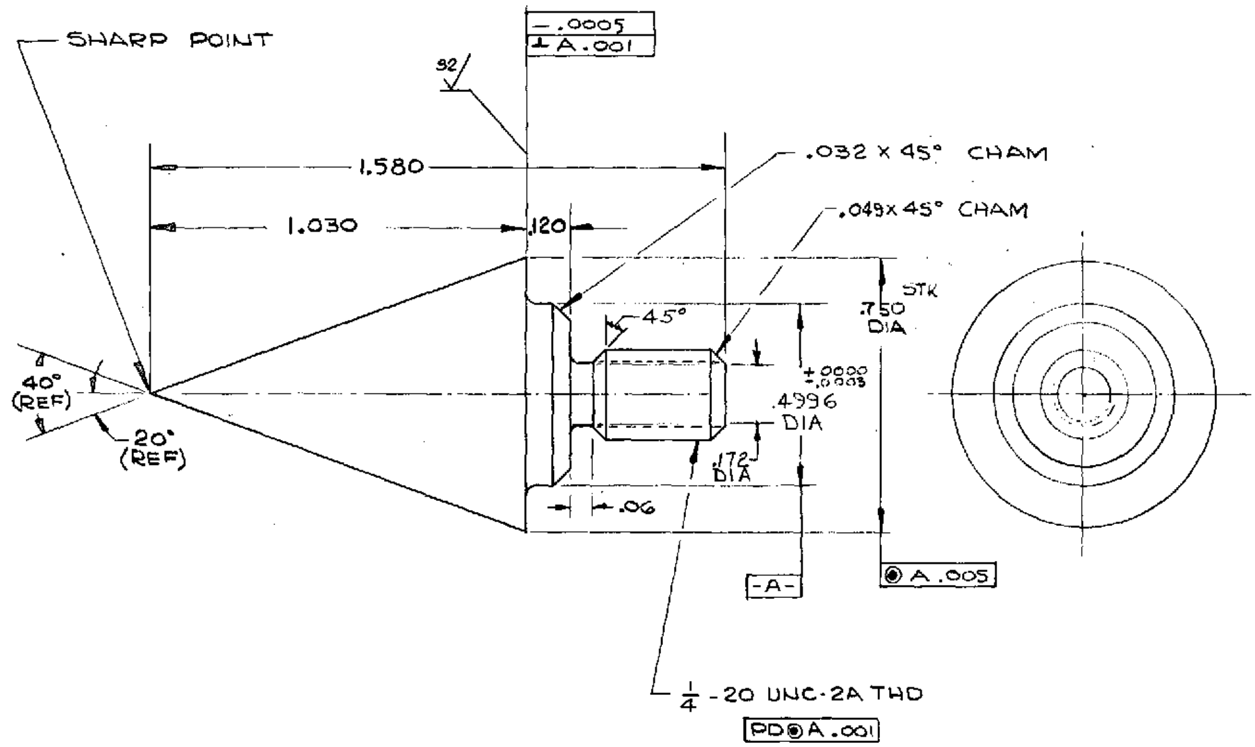
Fig. C-27. Tubing, separator — 100-kW erosion loop



3. MACHINED FILLET RADIUS: .010 R.
2. REMOVE ALL BURRS AND SHARP EDGES .005R MAX.
1. MACHINE FINISH 16

DWG OR PART NO.	DASH NO.	DESCRIPTION	SPECIFICATION	STOCK SIZE / REF DESIGNATION - ELEC DWG	MATERIAL	NO. REQD	FIND NO.
SPEC		IDENTIFICATION	JPL 20002				
		PIN		.125 DIA x 1/2 LG.	Cb-1% Zr		1

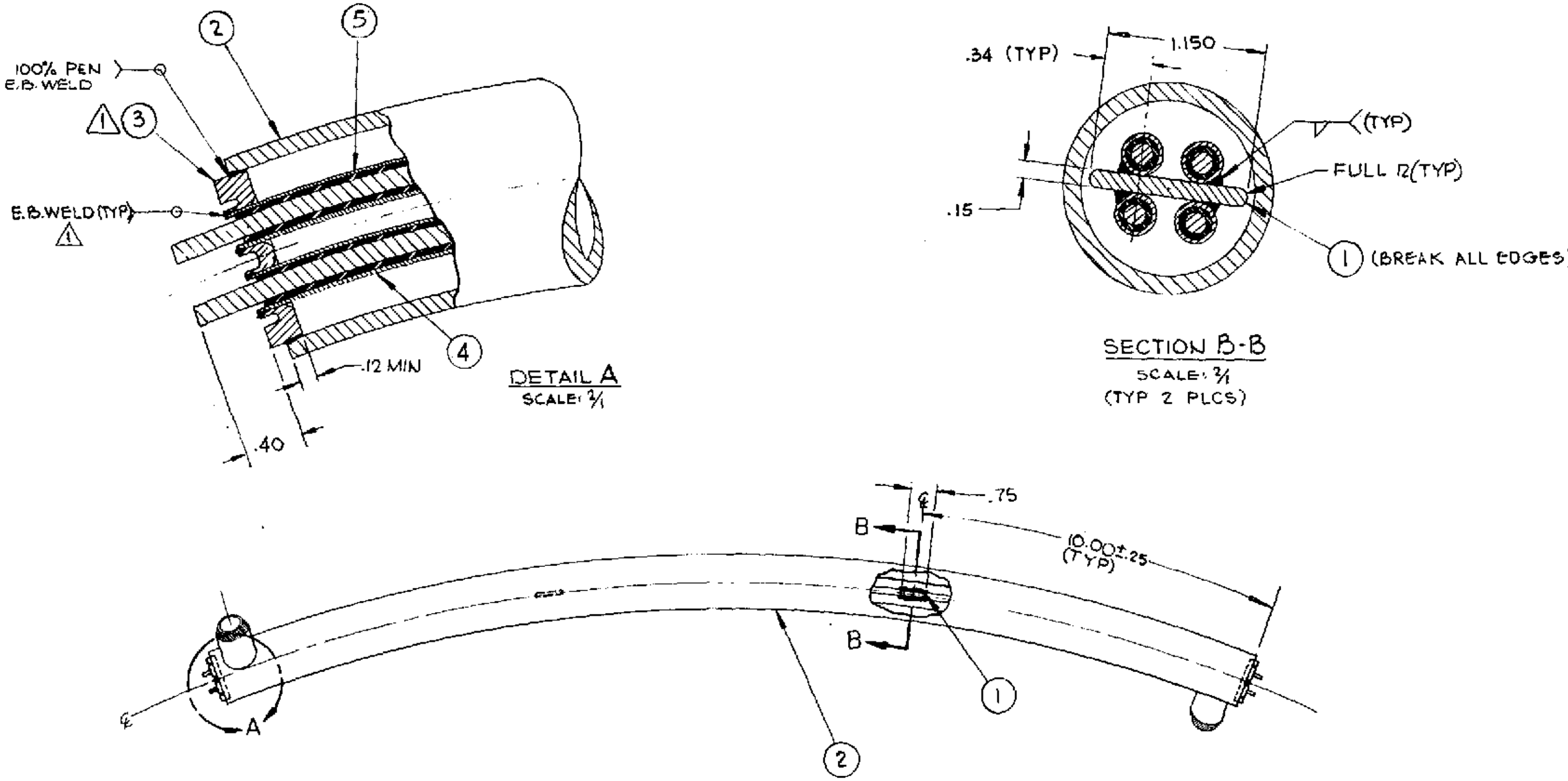
Fig. C-28. Pin ring, separator — 100-kW erosion loop



4. MATERIAL TO BE DETERMINED BY THE COG. ENGR.
3. MACHINED FILLET RADIUS: .015 R MAX.
2. REMOVE ALL BURRS AND SHARP EDGES
1. MACHINE FINISH 63

SPEC		IDENTIFICATION	JPL 20002				6
	5	NOSE CONE		3/4 DIA x 1 5/8 LG	SEE NOTE 4		5
	4	NOSE CONE		3/4 DIA x 1 5/8 LG	SEE NOTE 4		4
	3	NOSE CONE		3/4 DIA x 1 5/8 LG	SEE NOTE 4		3
	2	NOSE CONE		3/4 DIA x 1 5/8 LG	SEE NOTE 4		2
	1	NOSE CONE		3/4 DIA x 1 5/8 LG	SEE NOTE 4		1
DWG OR PART NO.	DASH NO.	DESCRIPTION	SPECIFICATION	STOCK SIZE / REF DESIGNATION - ELEC DWG	MATERIAL	NO. REQD	FIND NO.

Fig. C-29. Nose cone, separator — 100-kW erosion loop



④ △ BEFORE INSTALLATION OF ITEMS 4 & 5, REAM HOLES IN ITEM 3, .000 TO .002 DIAMETRAL CLEARANCE, FOR BASIC FIT.

REV	CHANGE DESCRIPTION	EFFECTIVITY	DL	RELEASE DATE	DWN	CHK	STRU	MATL PROC	T C	PRO ENGR	ENGR	DES CHIEF
A	ITEM 4 & 5 WAS 5 & 6, ITEM 3 WAS 4, DIA.CLEARANCE WAS				MM							
	.002-.004 IN GENERAL NOTES			2-25-65	MM							G.P.

DWG PART OR NO.	DASH NO.	DESCRIPTION	SPECIFICATION	STOCK SIZE / REF DESIGNATION - ELEC DWG	MATERIAL	NO. REQD	FIND NO.
SPEC		IDENTIFICATION	JPL 20002				7
							6
9117120-2		ELEMENT ASSY				2	5
9117120-1		ELEMENT ASSY				2	4
9117121		BULKHEAD				2	3
9117119		SHELL				1	2
	-1	POSITIONER		5/32 × 1.00 × 1.25	Nb - 1% Zr	2	1

Fig. C-30. Heater assembly — 100-kW erosion loop

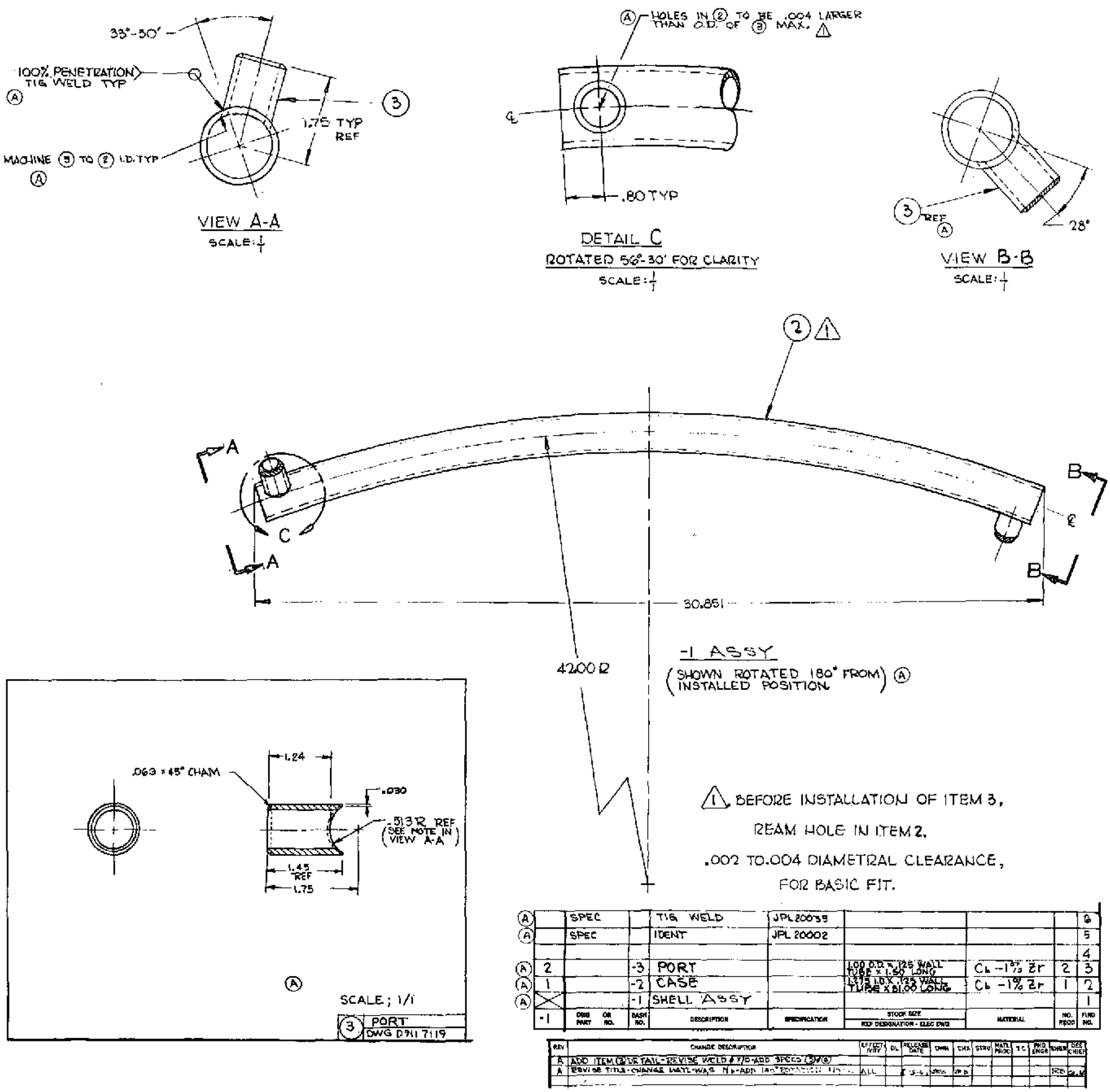
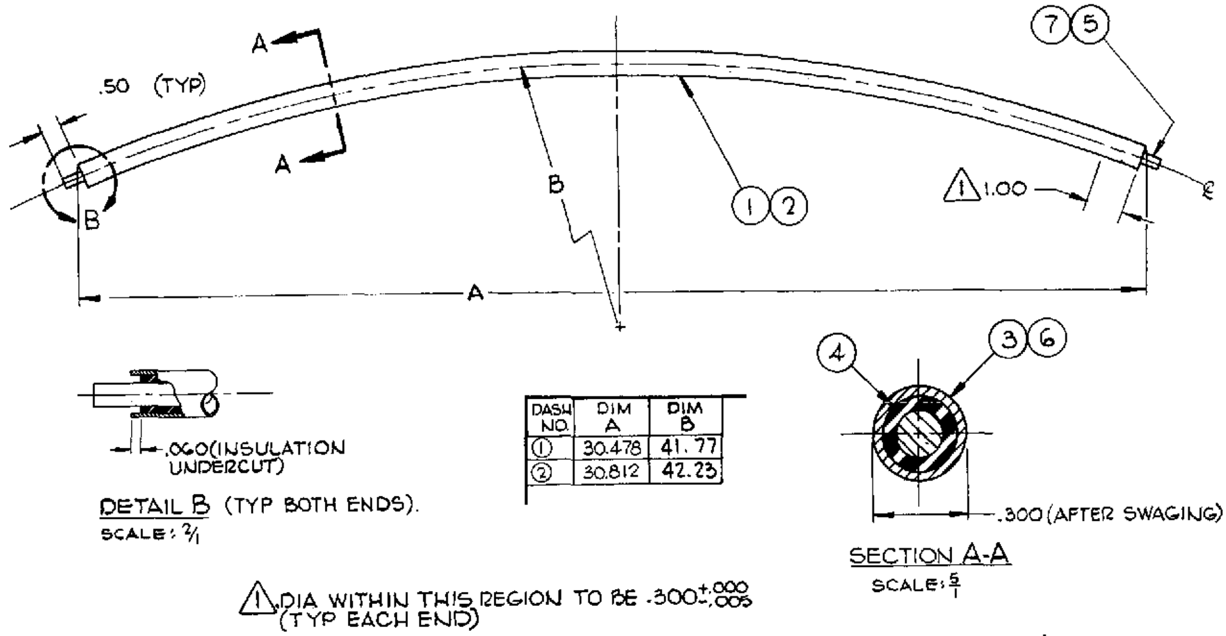


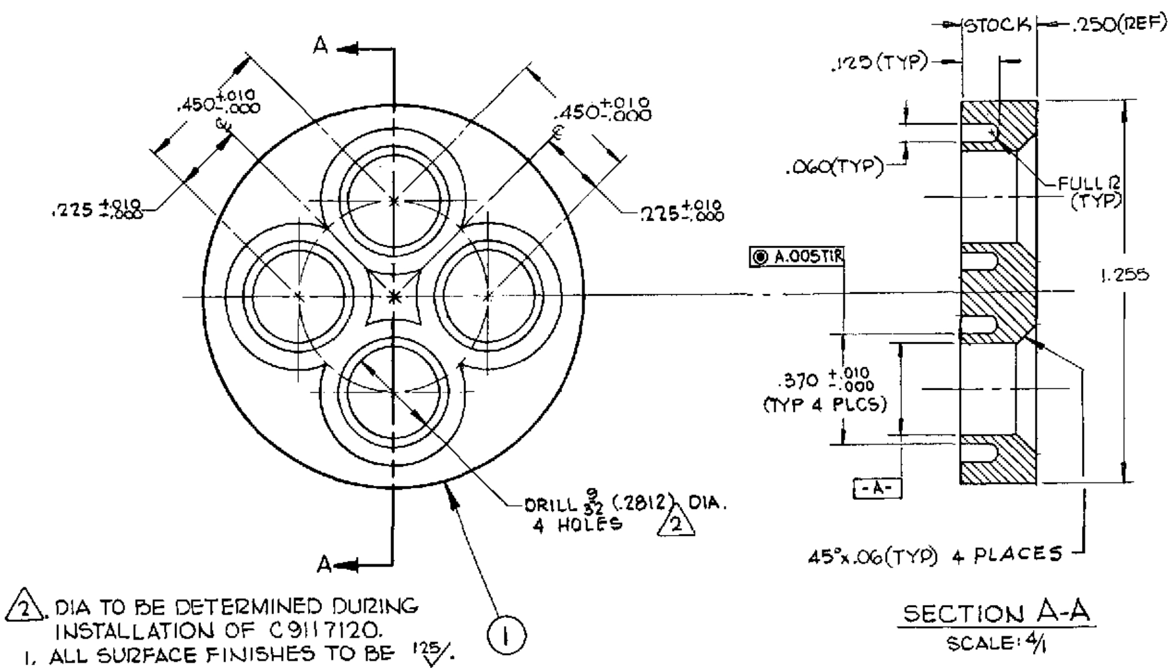
Fig. C-31. Shell, lithium heater — 100-kW erosion loop



DASH NO.	DIM A	DIM B
1	30.478	41.77
2	30.812	42.23

-2	-1	DWG PART OR NO.	DASH NO.	DESCRIPTION	SPECIFICATION	STOCK SIZE / REF DESIGNATION - ELEC DWG	MATERIAL	NO. REQD	FIND NO.
1			-7	ROD		.157 DIA	TANTALUM		7
1			-6	SHIELD		5/16 OD x .030 WALL	Nb-1% Zr		6
	1		-5	ROD		.157 DIA	TANTALUM		5
AR	AR		-4	INSULATION		.040 THK	BeO		4
	1		-3	SHIELD		5/16 OD x .030 WALL	Nb-1% Zr		3
			-2	ELEMENT ASSY					2
			-1	ELEMENT ASSY					1

Fig. 32. Element assembly, lithium heater



DWG PART OR NO.	DASH NO.	DESCRIPTION	SPECIFICATION	STOCK SIZE / REF DESIGNATION - ELEC DWG	MATERIAL	NO. REQD	FIND NO.
		BULKHEAD		.250 PLATE	Nb-1% Zr		1

Fig. C-33. Bulkhead, lithium heater

FOLDOUT FRAME 1

FOLDOUT FRAME 2

FOLDOUT FRAME 3

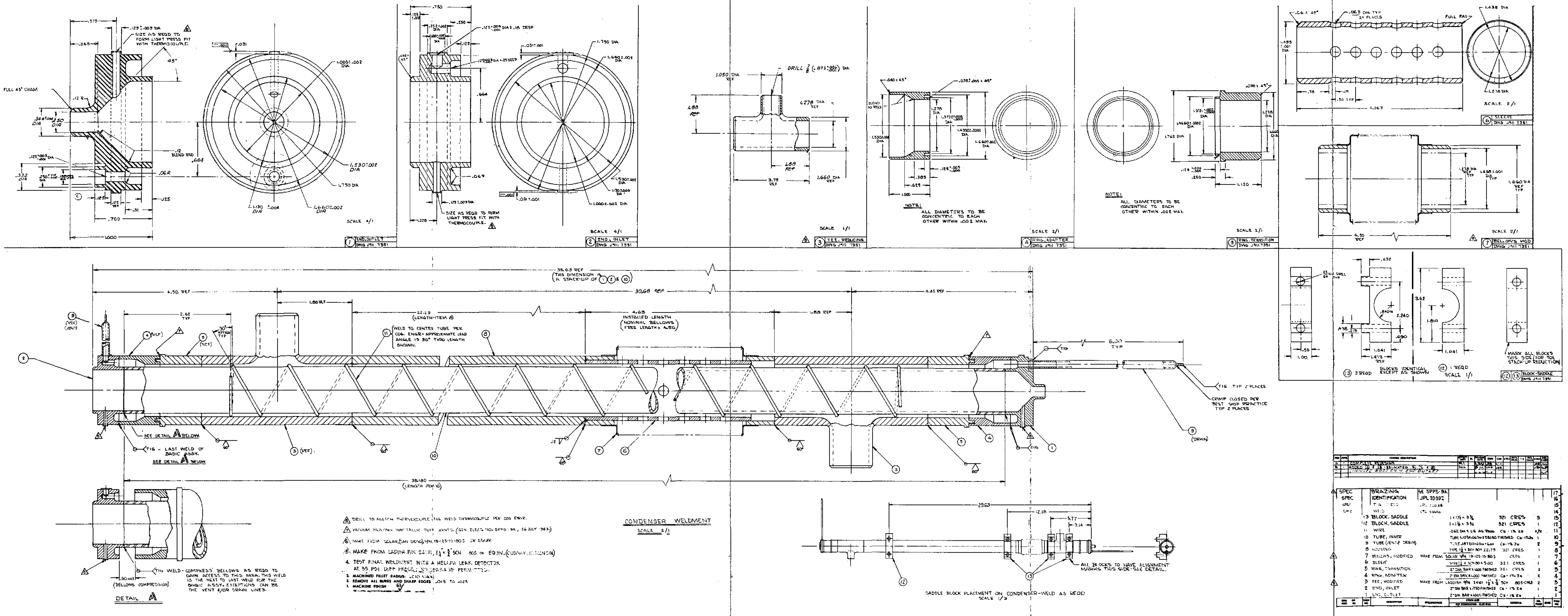


Fig. C-34. Condenser – 100-kW erosion loop, cesium

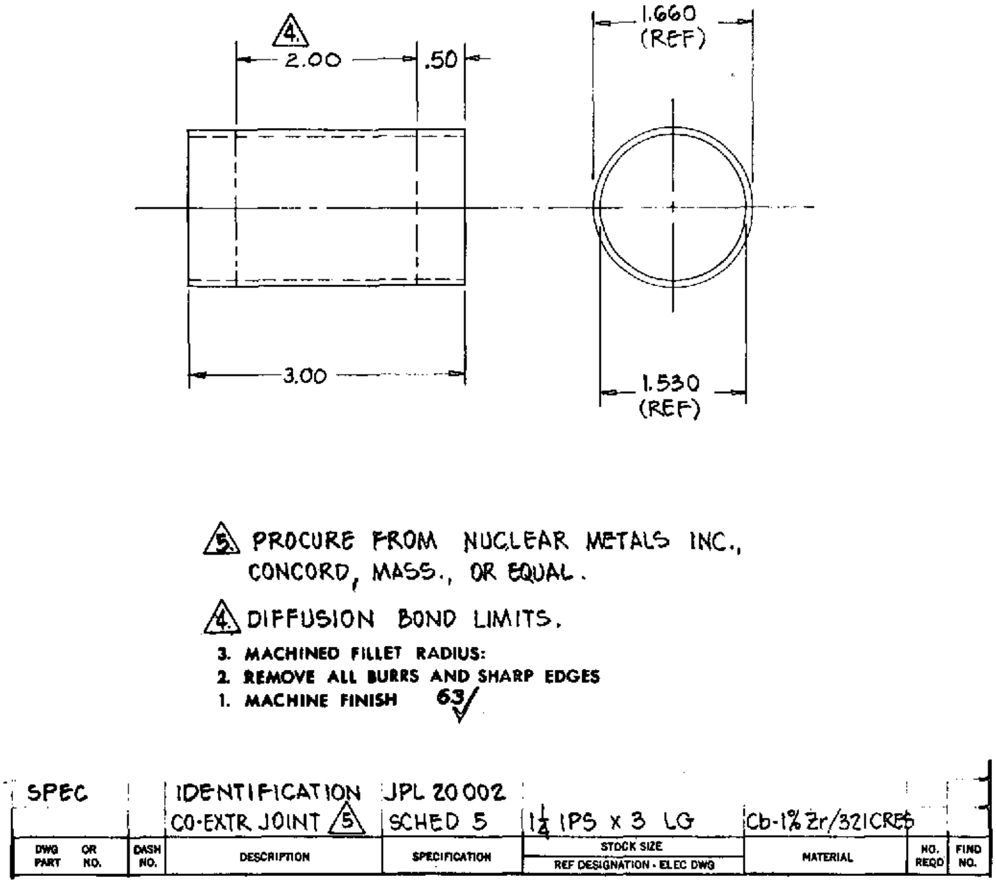
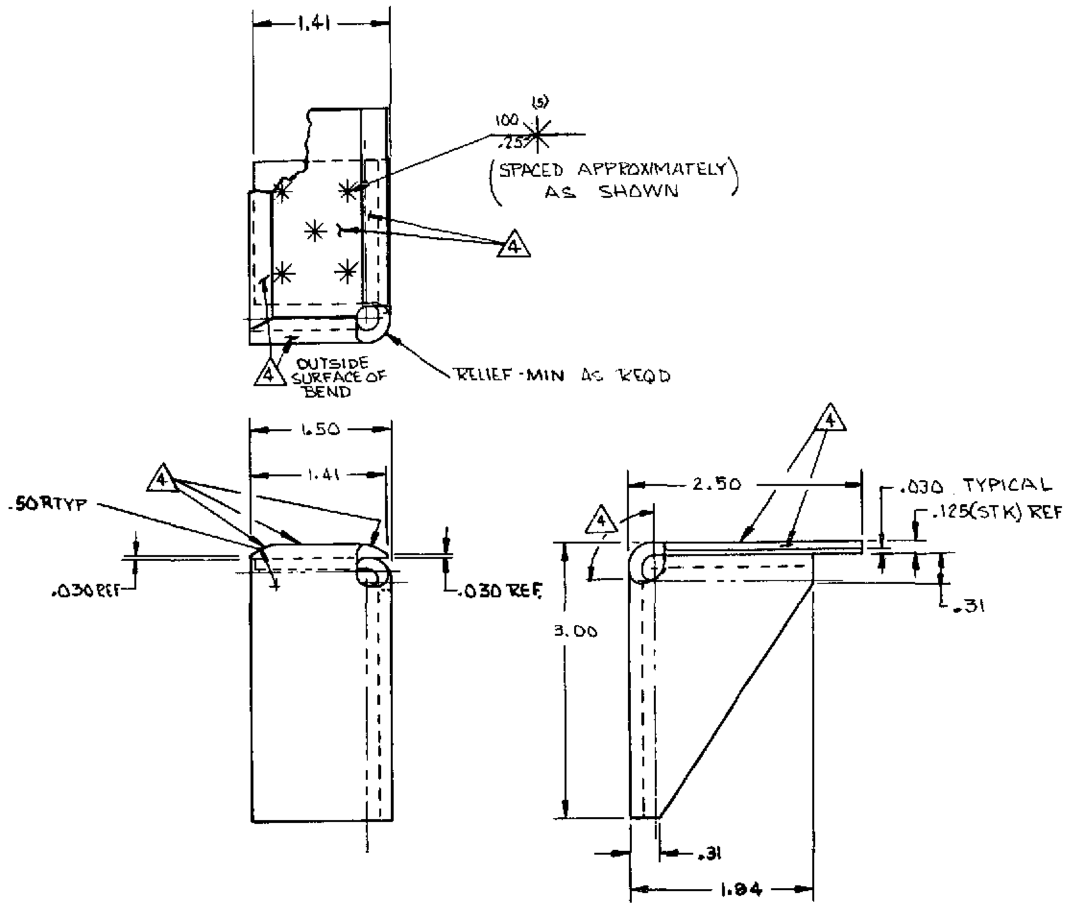


Fig. C-35. Joint, coextruded — erosion loop cesium condenser

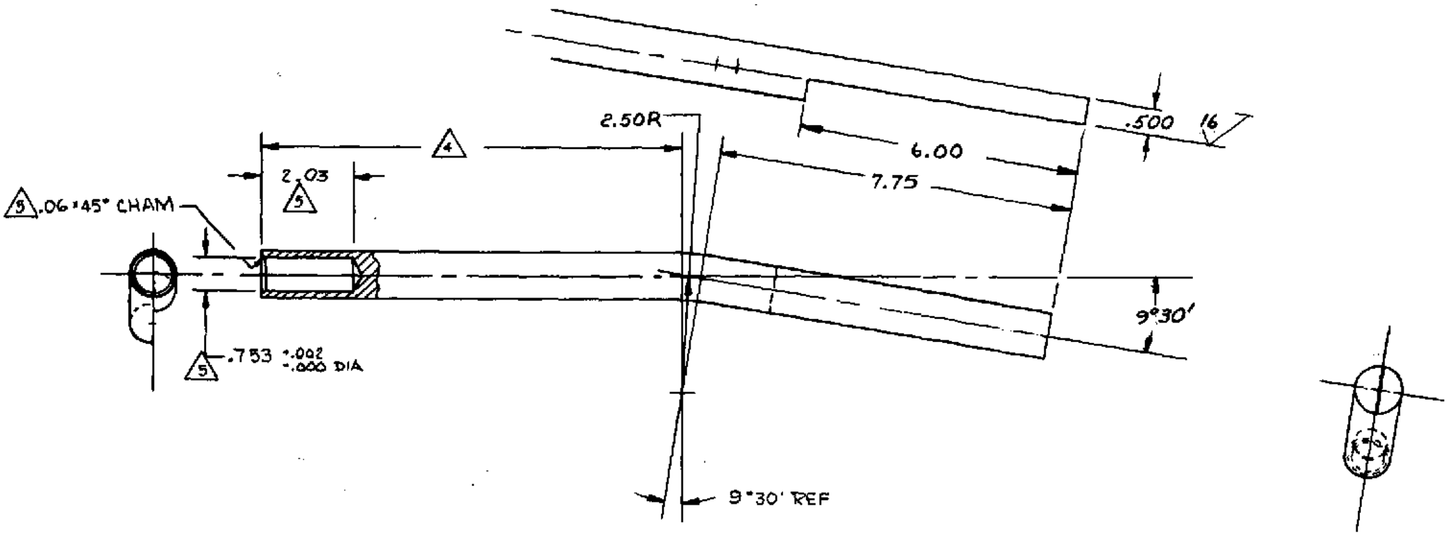


-1 BRACKET - SHOWN - LH
-2 " - OPPOSITE - RH

4. THESE SURFACES COATED .020 to .030 THK ALUMINA, (90% PURE MIN.) AFTER WELDING.
3. MACHINE FINISH 64
2. REMOVE ALL BURRS, ETC.
1. ALL BEND RADII = .19"

DWG OR PART NO.	DASH NO.	DESCRIPTION	SPECIFICATION	STOCK SIZE / REF DESIGNATION - ELEC DWG	MATERIAL	NO. REQD	FIND NO.
SPEC.		IDENTIFICATION	JPL 20002				4
							3
	2	BRACKET		.125 (11GA) x 3 1/2 x 5 5/8 SH	304 CRES		2
	1	BRACKET		.125 (11GA) x 3 1/2 x 5 5/8 SH	304 CRES		1

Fig. C-36. Bracket, bus support, inner (LH and RH)



5 PERFORM THESE FUNCTIONS AFTER 4

4 DETERMINE LENGTH AT NEXT ASSY.

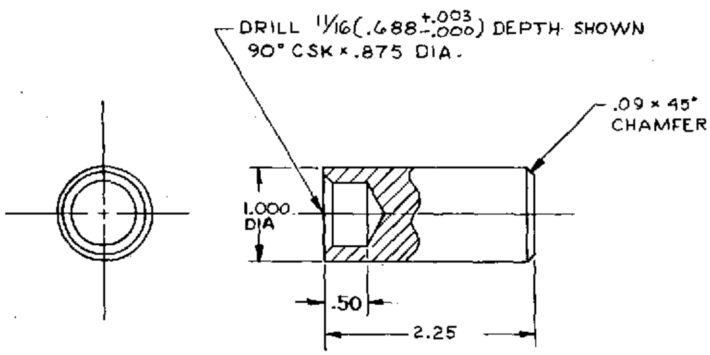
3. MACHINED FILLET RADIUS: .030 R.

2. REMOVE ALL BURRS AND SHARP EDGES .030 R.

1. MACHINE FINISH 63√

DWG PART NO. OR NO.	DASH NO.	DESCRIPTION	SPECIFICATION	STOCK SIZE / REF DESIGNATION - ELEC DWG	MATERIAL	NO. REQD
SPEC		IDENTIFICATION	JPL 20002			REF
	1	BAR		BAR 1 DIA × 18¼ LG	OFHC COPPER	1

Fig. C-37. Bar, bus, lead-in (RH)



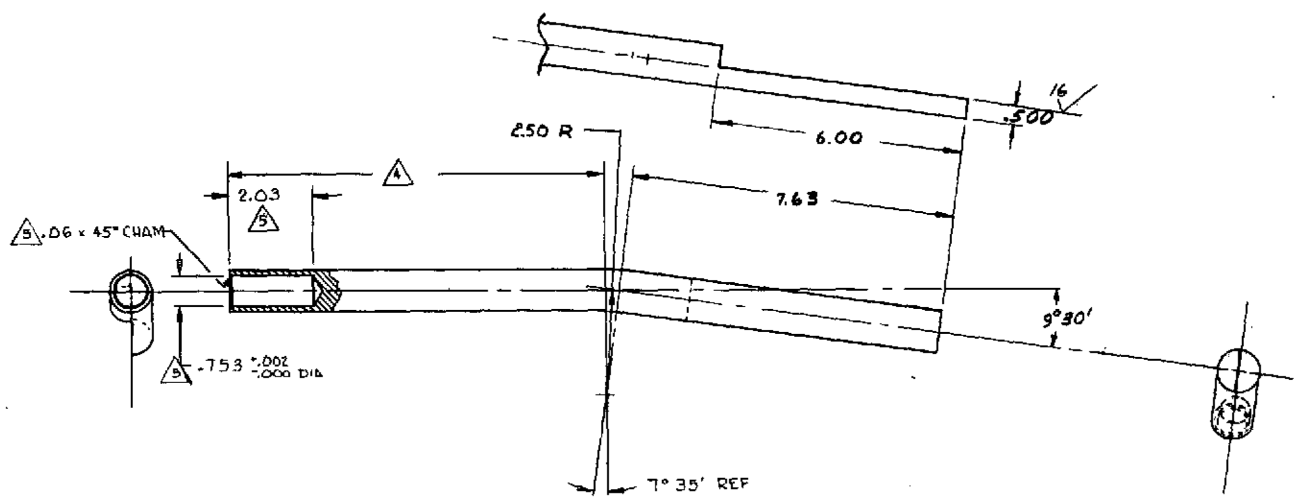
3. MACHINED FILLET RADIUS:

2. REMOVE ALL BURRS AND SHARP EDGES .015 R.

1. MACHINE FINISH 63√

DWG PART NO. OR NO.	DASH NO.	DESCRIPTION	SPECIFICATION	STOCK SIZE / REF DESIGNATION - ELEC DWG	MATERIAL	NO. REQD	FIND NO.
SPEC		IDENTIFICATION	JPL 20002				3
							2
		ADAPTER, AFT		BAR 1"DIA X 3 1/2 LG	347 CRES		1

Fig. C-38. Adapter, aft



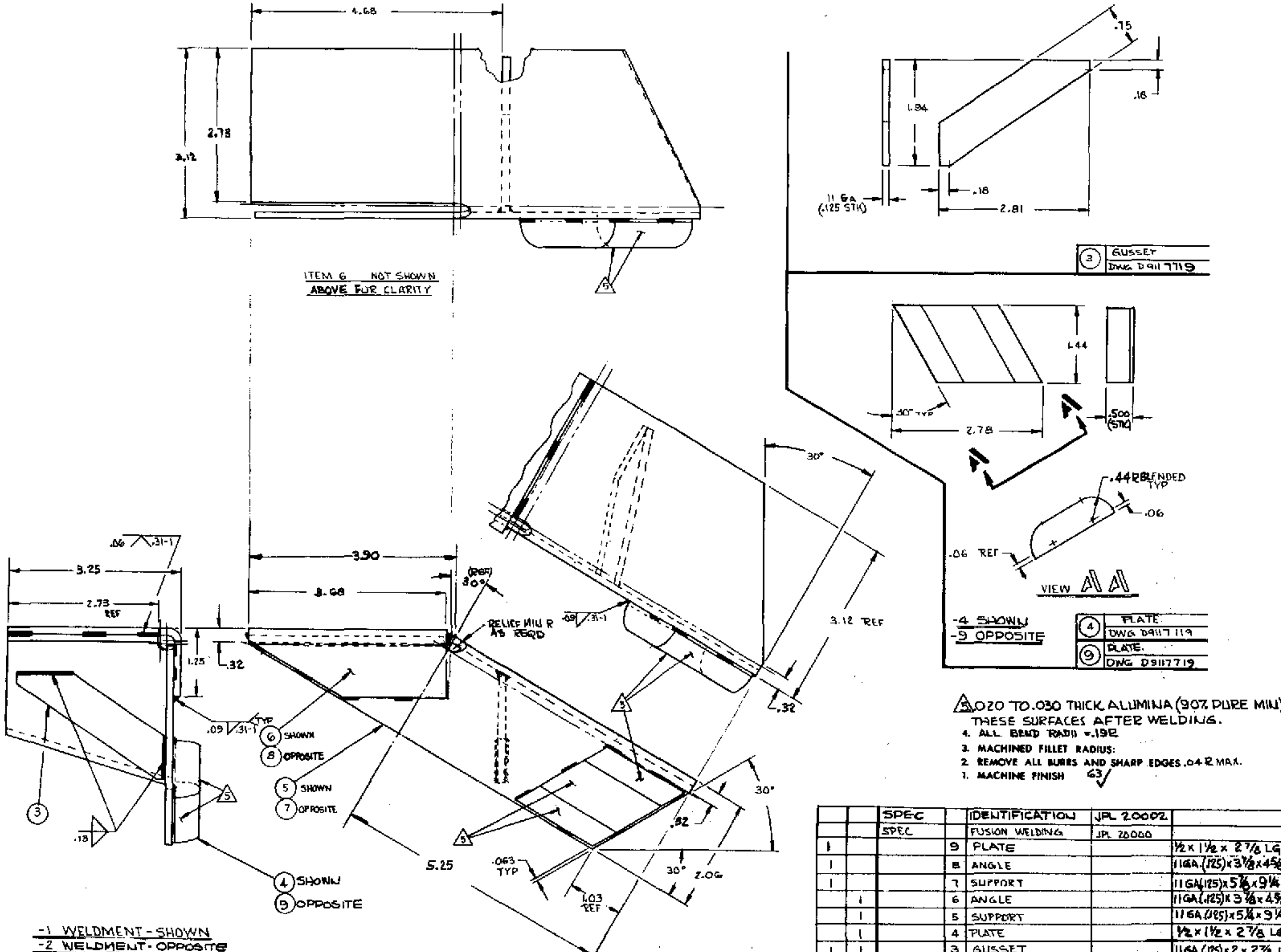
5 PERFORM THESE FUNCTIONS AFTER 4.

4 DETERMINE LENGTH AT NEXT ASSY.

3. MACHINED FILLET RADIUS: .030 R.
2. REMOVE ALL BURRS AND SHARP EDGES .030 R.
1. MACHINE FINISH 63✓

SPEC		IDENTIFICATION	JPL 20002			REF
	1	BAR		1 DIA x 18 LG-BAR	OFHC COPPER	1
DWG OR PART NO.	DASH NO.	DESCRIPTION	SPECIFICATION	STOCK SIZE / REF DESIGNATION - ELEC DWG	MATERIAL	NO. REQD

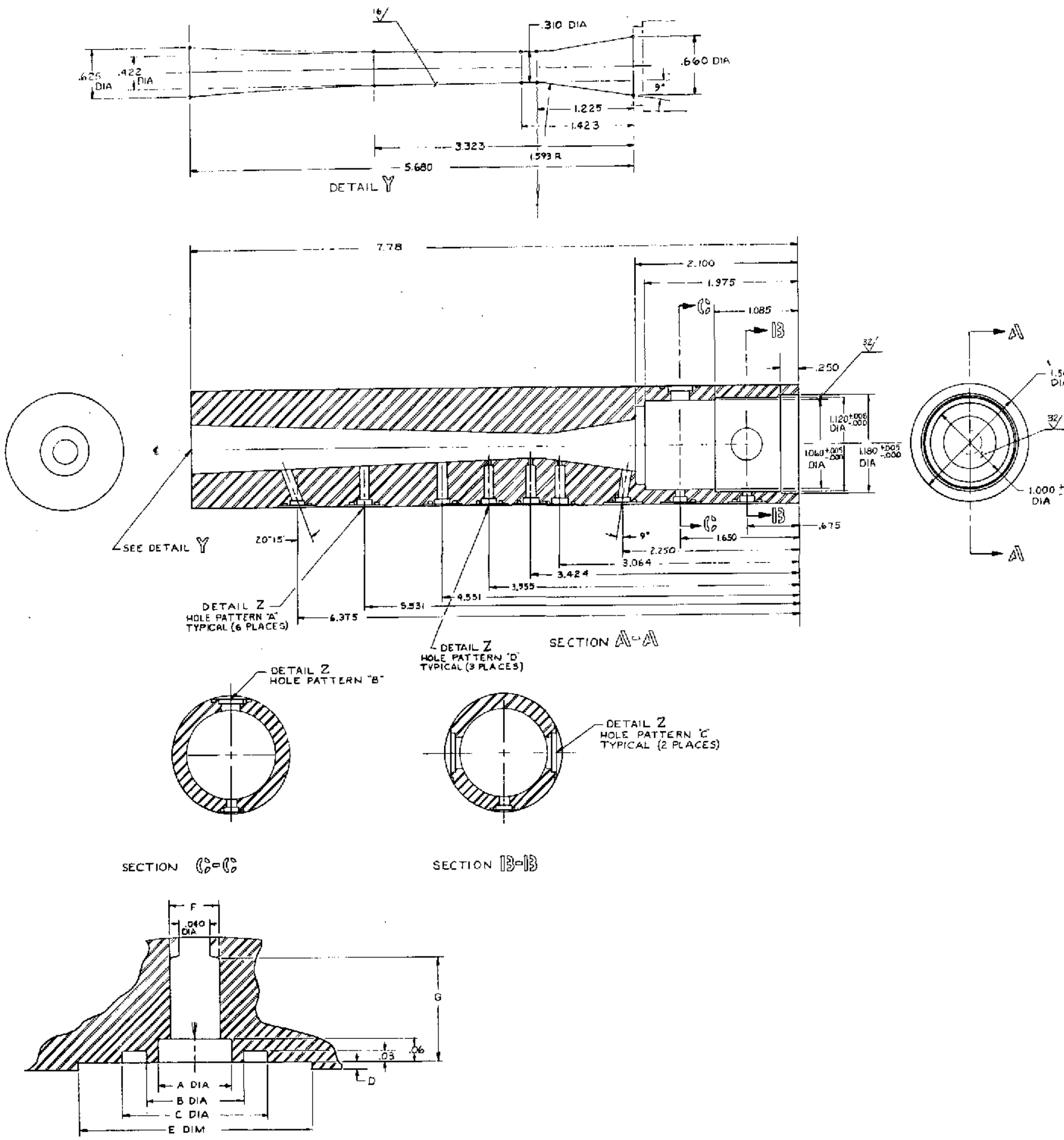
Fig. C-39. Bar, bus, lead-in (LH)



5 .020 TO .030 THICK ALUMINA (90% PURE MIN) THESE SURFACES AFTER WELDING.
4. ALL BEND RADII = .19R
3. MACHINED FILLET RADIUS:
2. REMOVE ALL BURRS AND SHARP EDGES .04 R MAX.
1. MACHINE FINISH 63√

DASH NO. 2	DASH NO. 1	DWG PART OR NO.	DASH NO.	DESCRIPTION	SPECIFICATION	STOCK SIZE / REF DESIGNATION - ELEC DWG	MATERIAL	NO. REQD	FIND NO.
		SPEC		IDENTIFICATION	JPL 20002				11
		SPEC		FUSION WELDING	JPL 20000				10
1			9	PLATE		½ × 1½ × 2⅞ LG	304 CRES-PL		9
1			8	ANGLE		11GA (.125) × 3⅛ × 4⅝ LG	304 CRES		8
1			7	SUPPORT		11GA (.125) × 5⅜ × 9¼ LG	304 CRES		7
	1		6	ANGLE		11GA (.125) × 3⅛ × 4⅝ LG	304 CRES		6
	1		5	SUPPORT		11GA (.125) × 5¼ × 9¼ LG	304 CRES		5
	1		4	PLATE		½ × 1½ × 2⅞ LG	304 CRES-PL		4
1	1		3	GUSSET		11GA (.125) × 2 × 2⅞ LG.	304 CRES		3
X			2	WELDMENT					2
	X		1	WELDMENT					1

Fig. C-40. Bracket, bus support, outer



3. ALL INTERNAL DIAMETERS TO BE CONCENTRIC WITHIN .005 T.I.R.
2. MACHINE FINISH 63
1. BREAK CORNERS .005-.015 RAD.

TAB CHART

SYM	DIA F	DIA. 'A'	DIA 'B'	DIA 'C'	DIM. 'D'	DIM. E	DIM. G
A	#30 (.128) DRILL	$.188^{+.003}_{-.000}$	.248 ± .005	.376	—	—	THRU
B	1/4 (.250) DRILL	$.344^{+.004}_{-.000}$	.438 ± .005	.562	.03	.75	THRU
C	1/2 (.500) DRILL	$.625^{+.008}_{-.000}$	.750 ± .005	.875	.07	1.00	THRU
D	#30 (.128) DRILL	$.188^{+.003}_{-.000}$	.248 ± .005	.376	—	—	.45

		HOUSING		1 1/2 DIA x 8 LG	Cb-1% Zr			
DWG PART / OR NO.	DASH NO.	DESCRIPTION	SPECIFICATION	STOCK SIZE / REF DESIGNATION - ELEC DWG	MATERIAL	NO. REQD	ZONE	FIND NO.

Fig. C-41. Housing, injector assembly

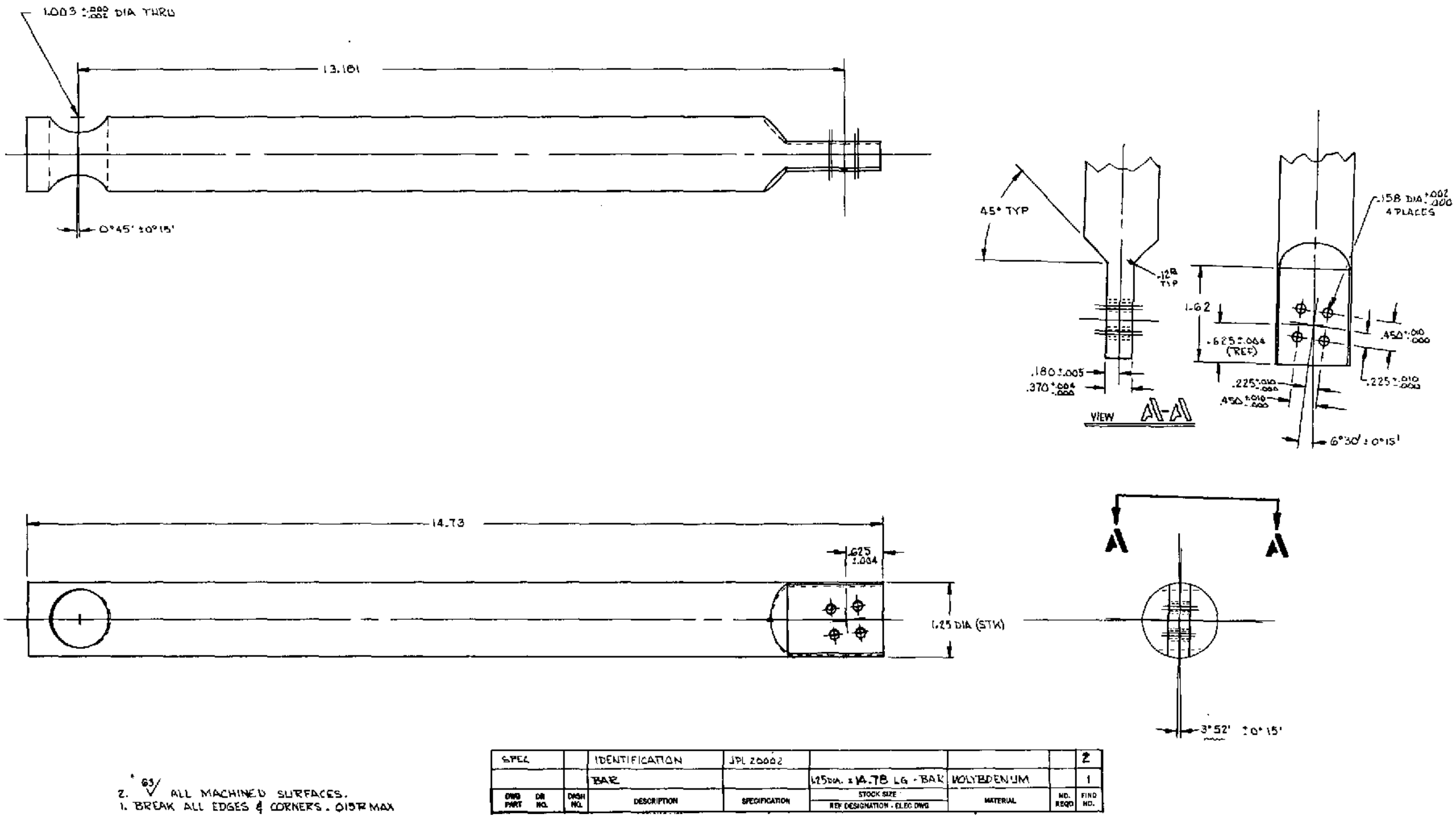
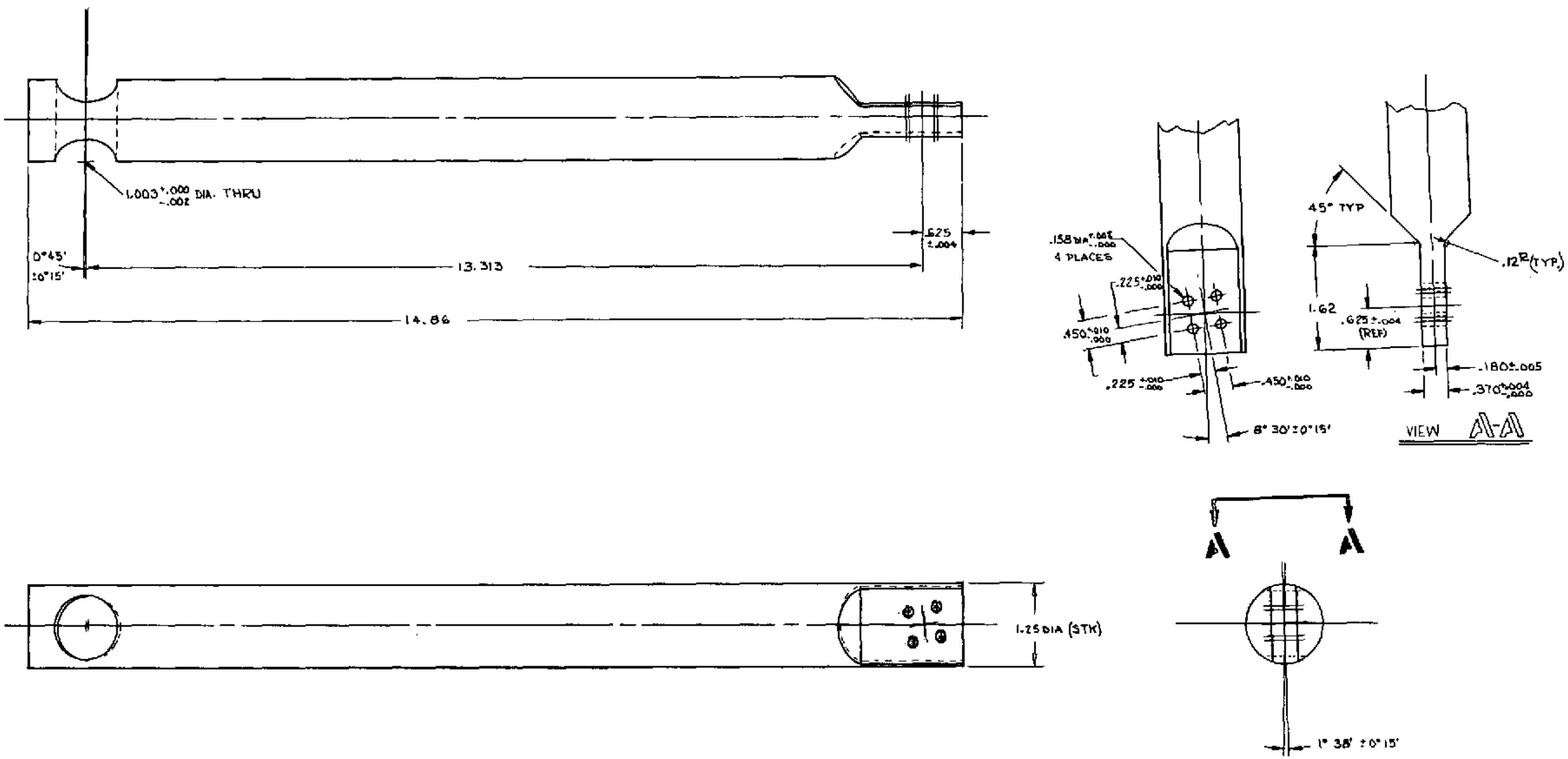


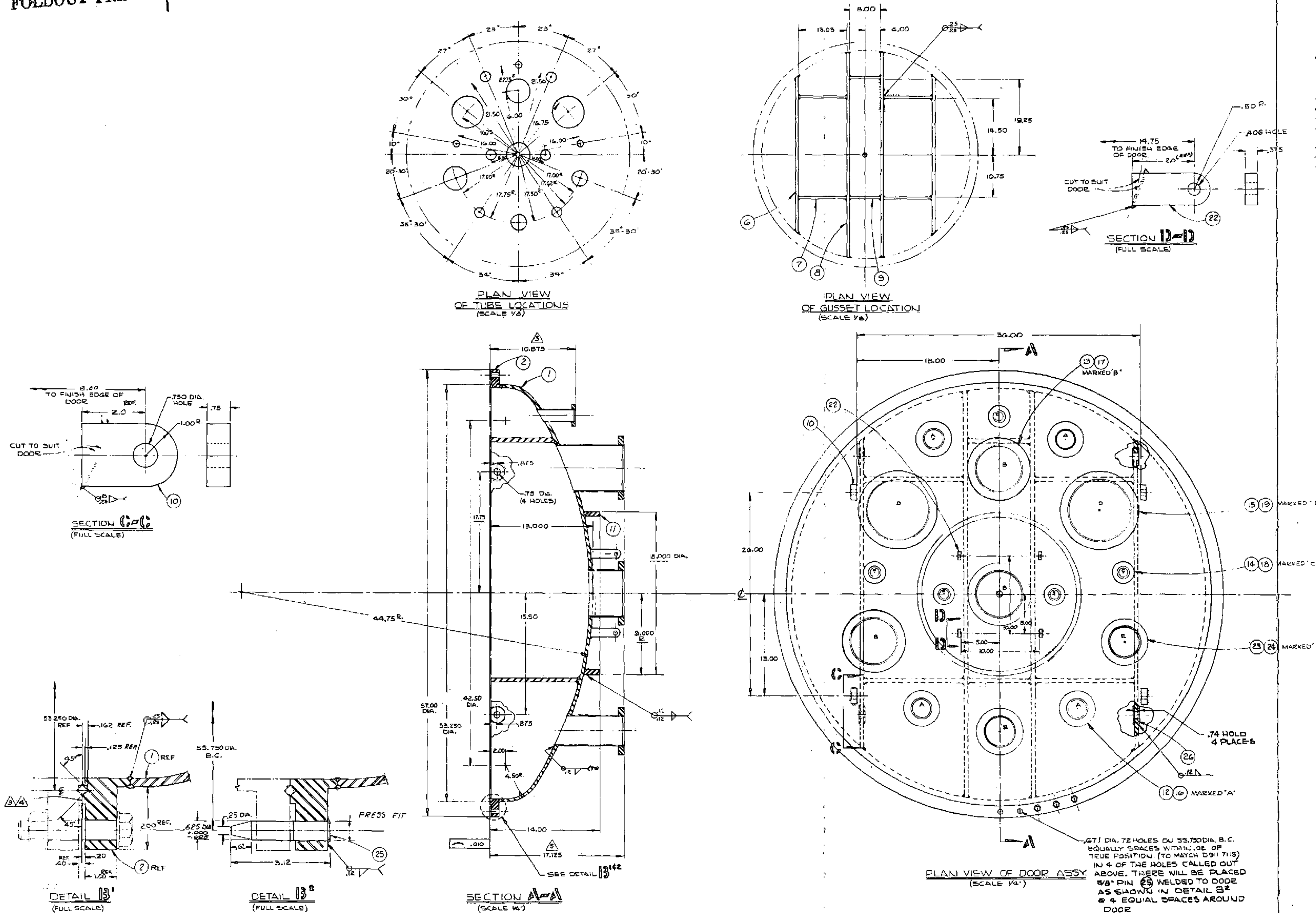
Fig. C-42. Bar, bus transition (LH)



2. 63 ALL MACHINED SURFACES.
1. BREAK ALL EDGES & CORNERS .015 R MAX.

SPEC		IDENTIFICATION	JPL 20002				2
		BAR		1.25 DIA x 14.94 LG - BAR	MOLYBDENUM		1
DWG OR PART NO.	DASH NO.	DESCRIPTION	SPECIFICATION	STOCK SIZE / REF DESIGNATION - ELEC DWG	MATERIAL	NO. REQD	FIND NO.

Fig. C-43. Bar, bus transition (RH)



Note	DWG PART OR NO.	DASH NO.	DESCRIPTION	SPECIFICATION	STOCK SIZE / REF DESIGNATION - ELEC DWG	MATERIAL	NO. REQD	ZONE	FIND NO.
		26	PLATE		2 DIA. X 5/16 THK.	SST. 304	8	5B	26
		25	PIN		.675 DIA. X 3/8 LG.	SST 304	4	5A	25
		24	TUBE		4 O.D. .188 WALL X 12 LG.	SST. 321	2	3B	24
1	954-5050	23	FLANGE	VARIAN	6" O.D.		2	3B	23
		22	LUG		3/8 x 1 x 2 1/2 LG.	SST. 304	4	4C	22
	SPEC		IDENTIFICATION	JPL 20002					21
	SPEC		WELD FUSION	JPL 20000					20
2		-19	TUBE		8 OD x .188 WALL x 12 LG.	SST. 321	2	3B	19
2		-18	TUBE		1 1/2 O.D. x .065 WALL x 12 LG.	SST. 321	5	3B	18
2		-17	TUBE		4 OD x .188 WALL x 12 LG.	SST. 321	3	3B	17
2		-16	TUBE		2 1/2 OD. x .120 WALL x 12 LG.	SST. 321	4	3A	16
1	954-5083	-15	FLANGE	VARIAN	10" O.D.		2	3B	15
1	954-5069	-14	FLANGE	VARIAN	2.75 O.D.		5	3B	14
1	954-5096	-13	FLANGE	VARIAN	8" O.D.		3	3B	13
1	954-5078	-12	FLANGE	VARIAN	4.5 O.D.		4	3A	12
		-11	RING, MOUNTING		1/2 x 1 3/4 X 58 LG	SST. 304	1	5B	11
		-10	LUG		3/4 x 2 x 3 LG.	SST 304	4	4C	10
		-9	GUSSET		3/8 x 8 x 12 5/8 LG	SST 304	2	4C	9
		-8	GUSSET		3/8 x 12 5/8 x 53 LG	SST. 304	2	4C	8
		-7	GUSSET		3/8 x 12 1/2 x 19 5/16 LG.	SST. 304	4	4C	7
		-6	GUSSET		3/8 x 12 5/8 x 53 LG	SST. 304	2	4C	6
									5
									4
									3
	911 7115		FLANGE				1	5C	2
		-1	SHELL DOOR		.250 [illegible]	SST. 304	1	5C	1

6. EXTERIOR SURFACE OF DOOR TO BE TRACED WITH COOLING COIL.

5. DIMENSION 10.875 @ TOP OF DOOR ONE PLACE ONLY. ALL OTHERS MOUNTING FLANGES 17.125

4. REMOVE ALL BURRS & SHARP EDGES

3. MACHINE FINISH

2. TUBE SALES 2211 TUBEWAY LOS ANGELES, CALIF. 90022

1. VARIAN ASSOCIATES 611 HANSEN WAY, PALO ALTO, CALIF. (CONFLAT HIGH VACUUM FLANGES)

Fig. C-44. Door assembly – 100-kW erosion loop

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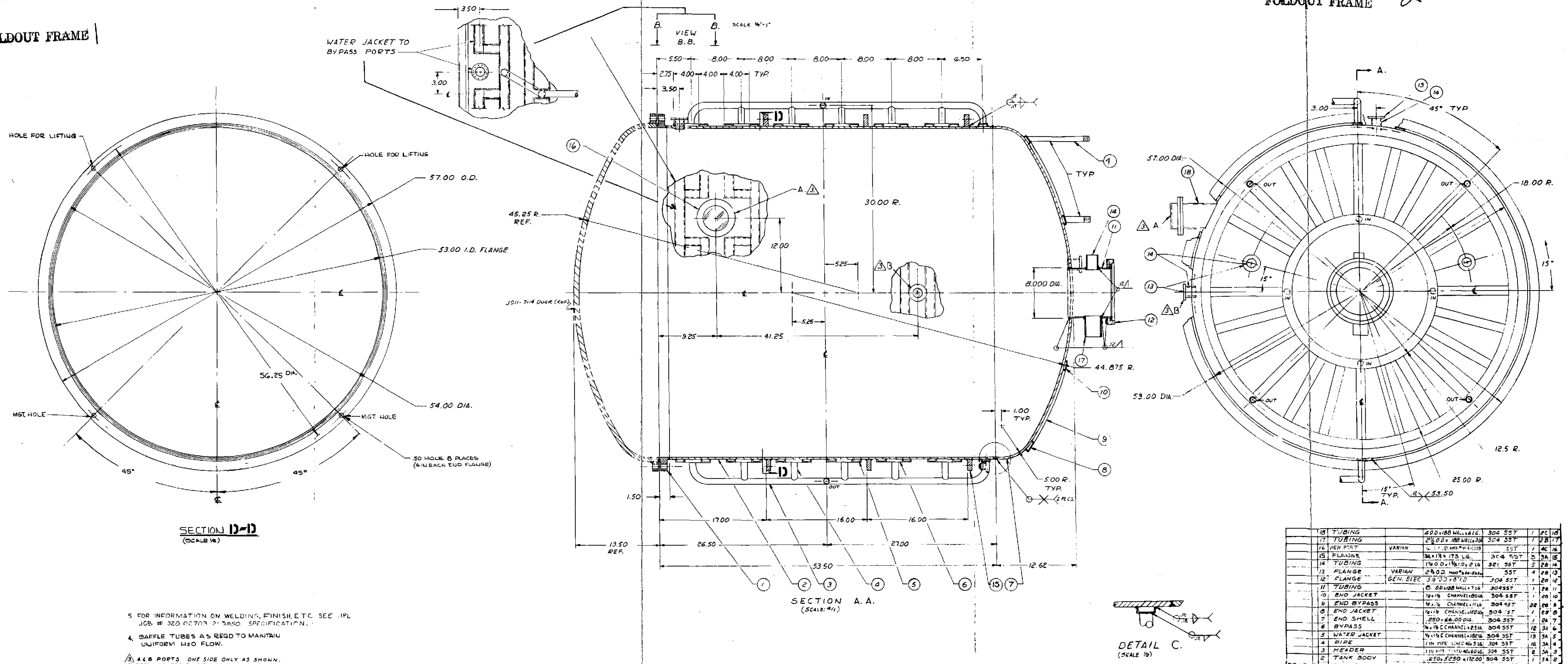
FOLDOUT FRAME 1

FOLDOUT FRAME 2

FOLDOUT FRAME 3



DWG PART	DR NO.	DASH NO.	DESCRIPTION	SPECIFICATION	STOCK SIZE / REF DESIGNATION · ELEC DWG	MATERIAL	NO. REQD	ZONE	FIND NO.
		18	TUBING		4 O.D. x .188 WALL x 6 LG.	304 SST	1	2C	18
		17	TUBING		2½ O.D. x .188 WALL x 3 LG	304 SST	1	2B	17
		16	VIEW PORT	VARIAN	[illegible]	SST	1	4C	16
		15	FLANGE		3/4 x 1½ x 17.3 LG.	304 SST	3	3A	15
		14	TUBING		1½ O.D. x 1⅜ I.D. x 2 LG	321 SST	5	2B	14
		13	FLANGE	VARIAN	2¾ O.D. [illegible]	SST	4	2B	13
		12	FLANGE	GEN. ELEC.	5¼ O.D. x 8 I.D.	304 SST	1	2B	12
		11	TUBING		8 O.D. x .188 WALL x 7 LG	304 SST	1	2B	11
		10	END JACKET		½ x 1½ CHANNEL x 80 LG.	304 SST	1	2B	10
		9	END BYPASS		½ x ½ CHANNEL x 11 LG	304 SST	22	2B	9
		8	END JACKET		½ x 1½ CHANNEL x 160 LG	304 SST	1	2B	8
		7	END SHELL		.250 x 66.00 DIA.	304 SST	1	2A	7
		6	BYPASS		½ x 1½ C CHANNEL x 25 LG.	304 SST	12	3A	6
		5	WATER JACKET		½ x 1½ C CHANNEL x 182 LG	304 SST	13	3A	5
		4	PIPE		1 IN PIPE SCHED 40 x 3 LG.	304 SST	18	3A	4
		3	HEADER		1 IN PIPE SCHED 40 x 60 LG.	304 SST	2	3A	3
		2	TANK BODY		.250 x 52.50 x 172.00	304 SST	1	3A	2
D311-7115		1	FLANGE				1	3A	1

5. FOR INFORMATION ON WELDING, FINISH, ETC. SEE JPL JOB # 320-02703-2-3850 SPECIFICATION.

4. BAFFLE TUBES AS REQD TO MAINTAIN UNIFORM H_2O FLOW.

3. A & B PORTS ONE SIDE ONLY AS SHOWN.

2. BREAK ALL EDGES .015 MAX.

1. ALL WELDING SHALL BE TO A.W.S. STANDARDS

Fig. C-45. Vacuum tank assembly – 100-kW erosion loop

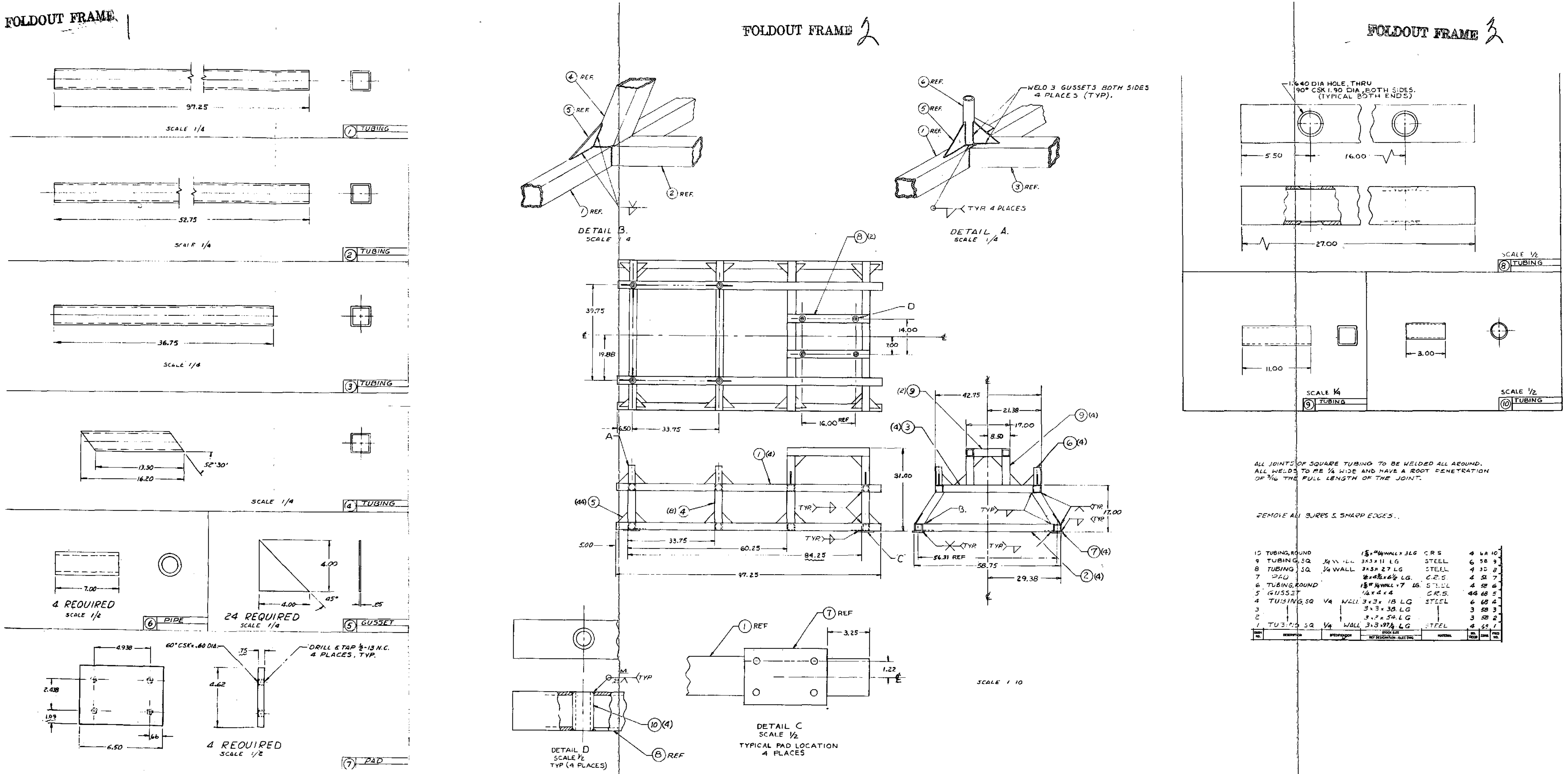
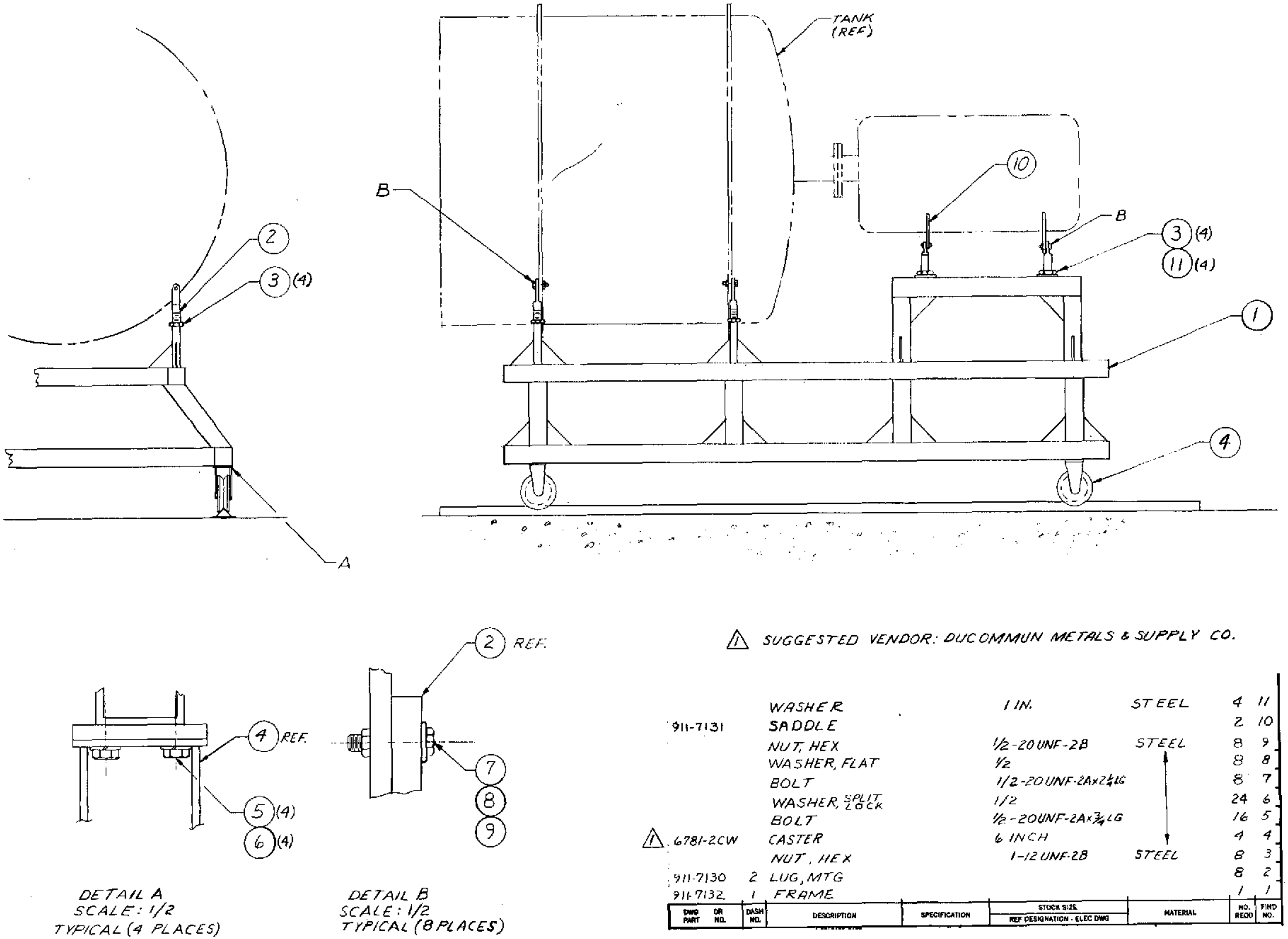


Fig. C-46. Frame, weldment, vacuum tank support



DWG PART NO.	OR NO.	DASH NO.	DESCRIPTION	SPECIFICATION	STOCK SIZE / REF DESIGNATION - ELEC DWG	MATERIAL	NO. REQD	FIND NO.
			WASHER		1 IN.	STEEL	4	11
911-7131			SADDLE				2	10
			NUT, HEX		1/2-20UNF-2B	STEEL	8	9
			WASHER, FLAT		1/2		8	8
			BOLT		1/2-20UNF-2A×2 1/4 LG		8	7
			WASHER, SPLIT LOCK		1/2		24	6
			BOLT		1/2-20UNF-2A×3/4 LG		16	5
⚠1 6781-2CW			CASTER		6 INCH		4	4
			NUT, HEX		1-12UNF-2B	STEEL	8	3
911-7130		2	LUG, MTG				8	2
911-7132		1	FRAME				1	1

Fig. C-47. Frame, assembly

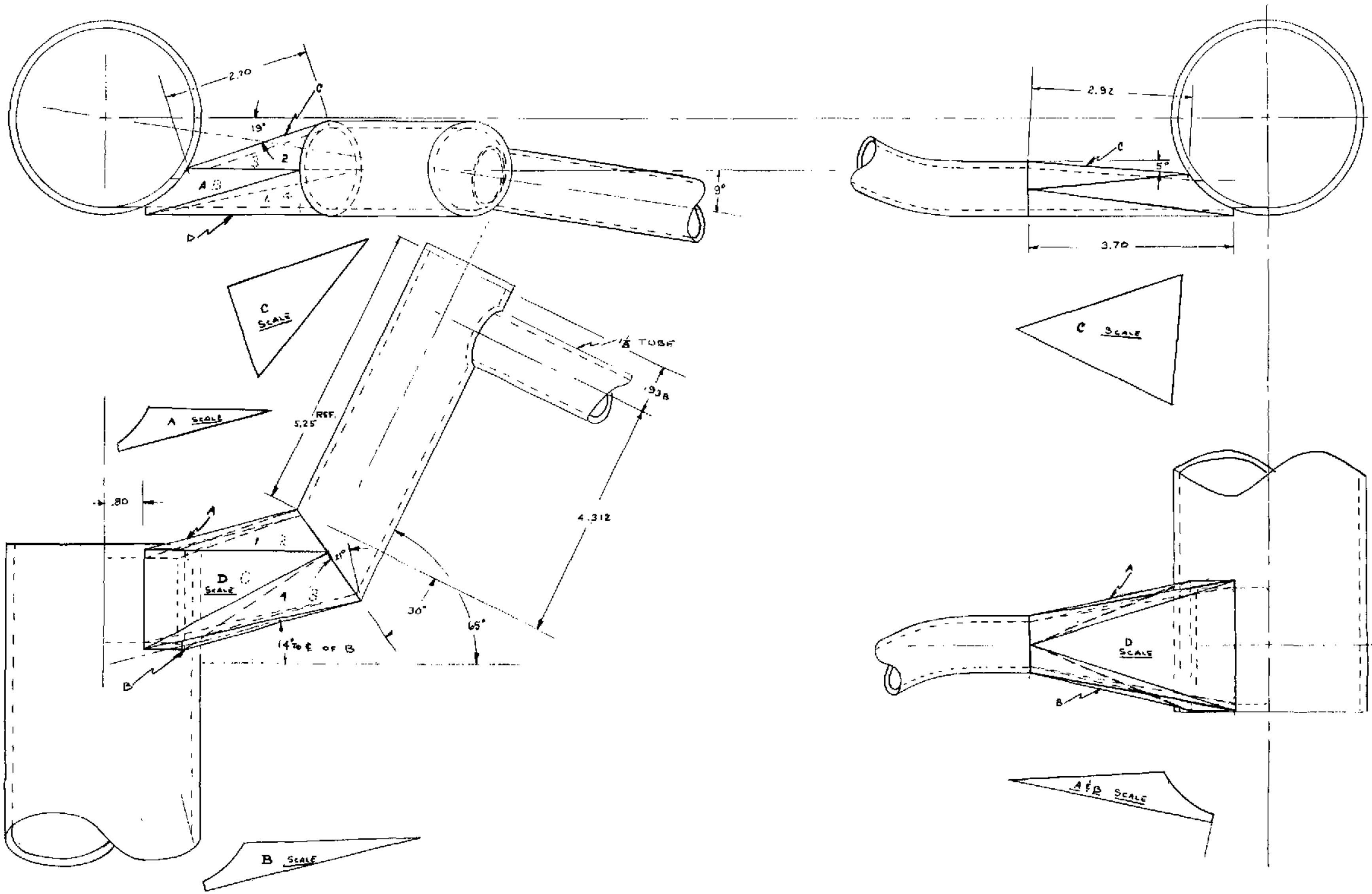
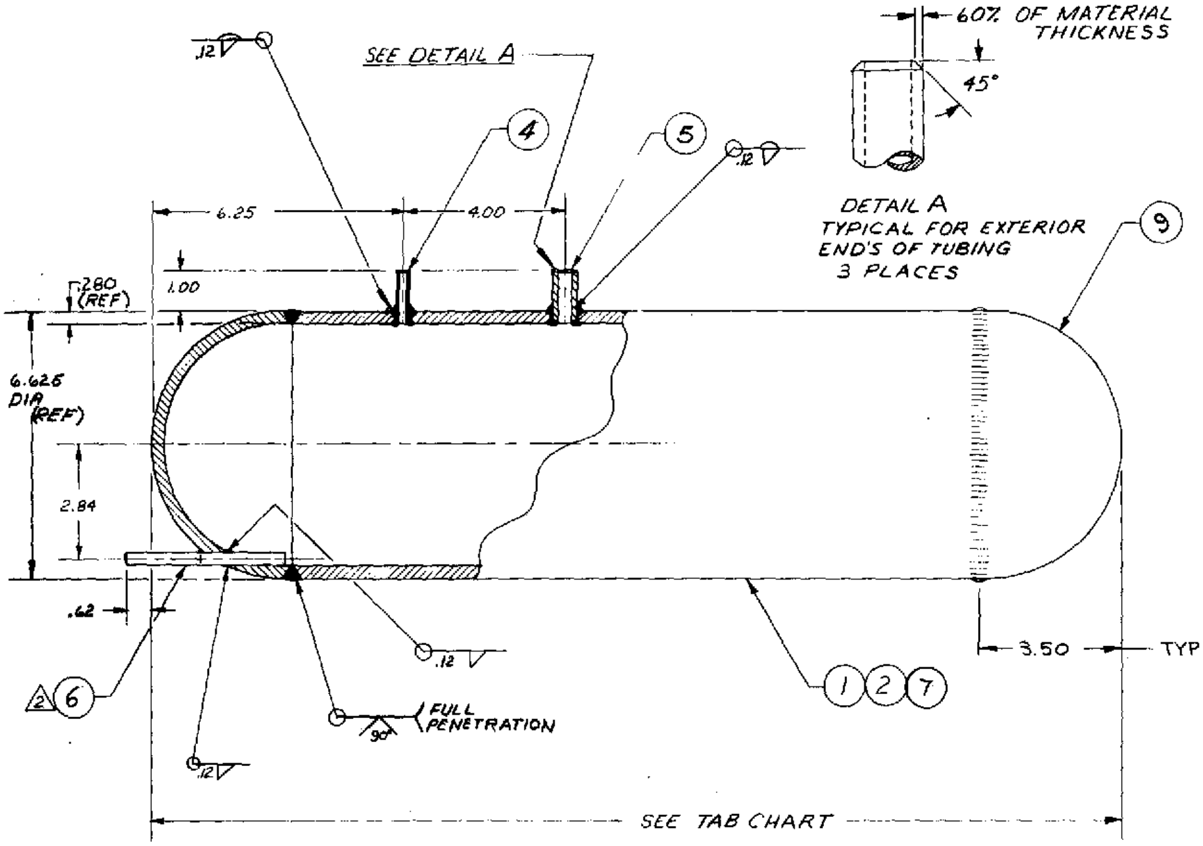


Fig. C-48. Transition pieces, columbium separator



3 LENGTH TO BE FURNISHED BY COG. ENGINEER.

2 LOCATE ITEM 6 AS SHOWN, WITH THE BOTTOM TANGENT TO THE INNER WALL OF THE PIPE.

2. REMOVE ALL BURRS AND SHARP EDGES

1. MACHINE FINISH 63

TAB CHART		
SYS	DASH NO.	LENGTH
Li	-1	40.00
Cs	-2	31.00
NaK	-3	3

			SPEC		IDENTIFICATION	JPL 20002				12
			SPEC		WELDING	JPL 20000				11
										10
2	2	2			CAP, PIPE		6" PIPE SCHED 40	321 CRES		9
										8
1	-	-		-7	PIPE-BODY		6" PIPE-SCHD 40 x 3 LG	321 CRES		7
2	2	2		-6	TUBING		5/16 O.D. .031 WALL 4 LONG	321 CRES		6
1	1	1		-5	TUBING		5/8 O.D. .062 WALL 1.44 LONG	321 CRES		5
1	1	1		-4	TUBING		5/16 O.D. .031 WALL 1.44 LONG	321 CRES		4
										3
-	1	-		-2	PIPE-BODY		6" PIPE, SCHED 40 24" LONG	321 CRES		2
-	-	1		-1	PIPE-BODY		6" PIPE SCHED 40 33" LONG	321 CRES		1
-3	-2	-1	DWG PART OR NO.	DASH NO.	DESCRIPTION	SPECIFICATION	STOCK SIZE / REF DESIGNATION - ELEC DWG	MATERIAL	NO. REQD	FIND NO.

Fig. C-49. Sump weldment – cesium, lithium and NaK (tabulated)

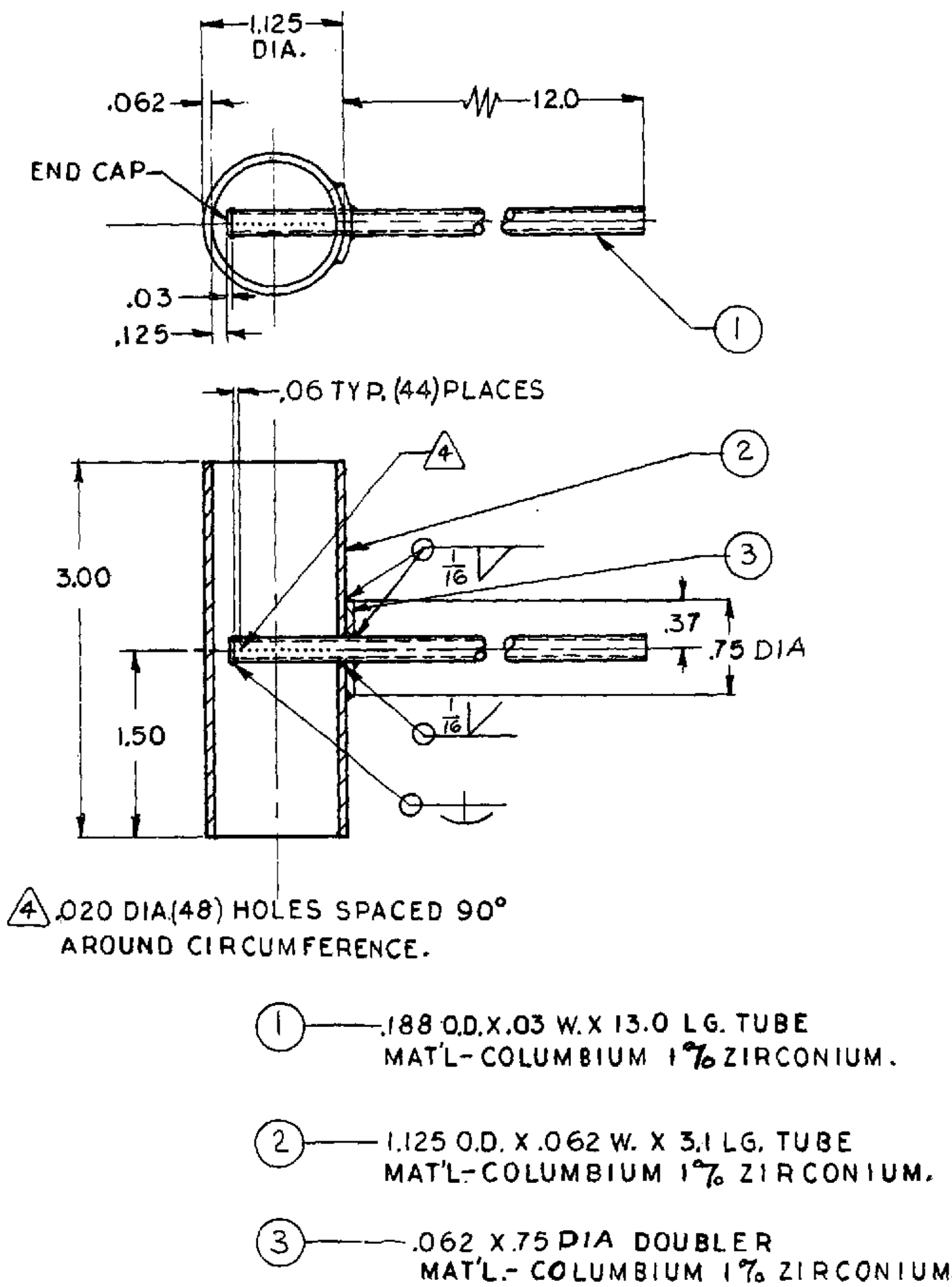
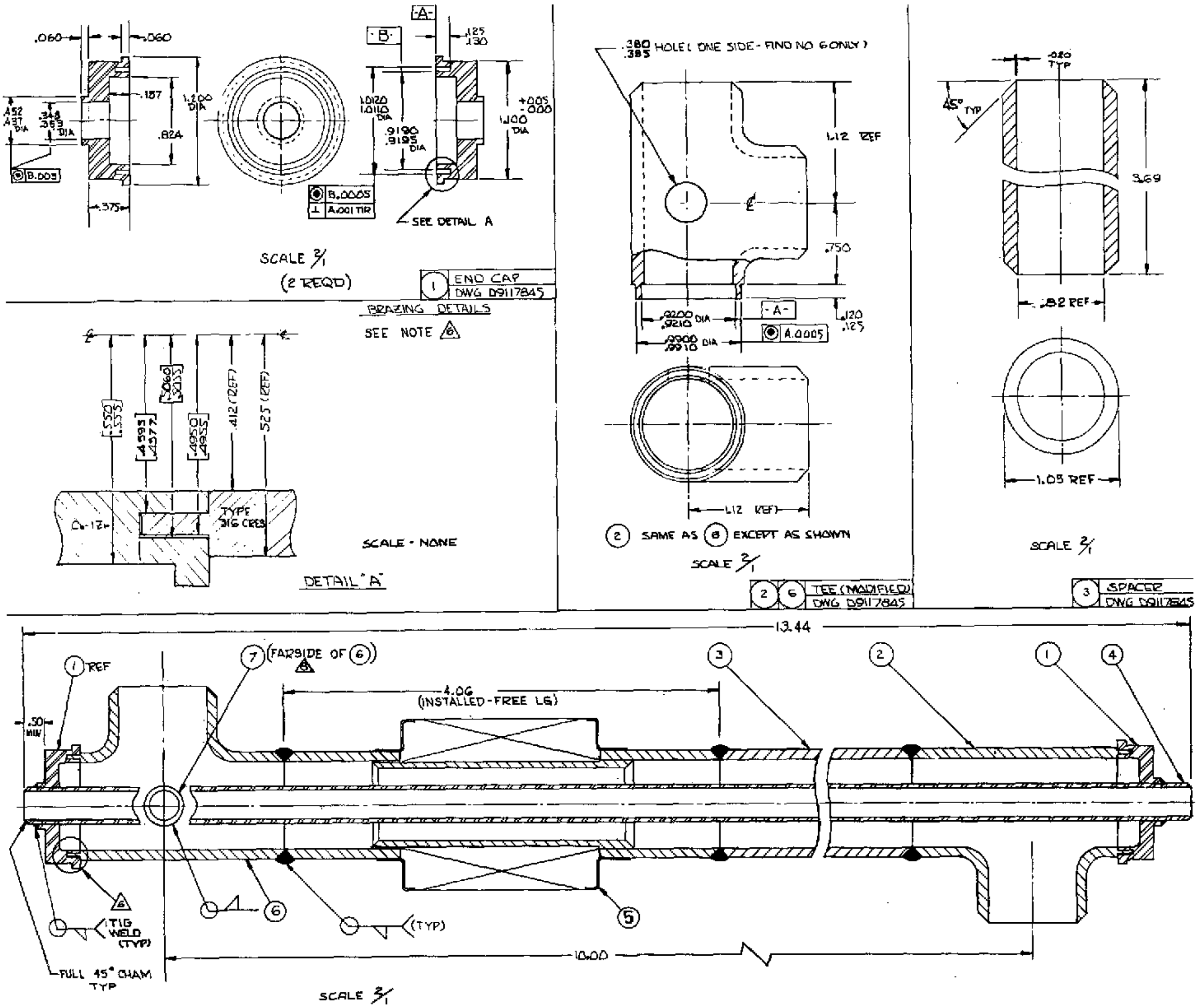


Fig. C-50. Sketch, desuperheater, erosion loop



8. MACHINE END TO MATCH I.D. CONTOUR OF (6) TEE.
7. LADISH CO., CUDAHY, WISCONSIN, OR EQUIV. (NO. 24000-⅜ PIPE-SCH 40)
6. VACUUM BRAZING BIMELLAC TUBE JOINTS. (GEN ELECT. NO. SPPS-9A, 26 JULY 1963)
5. SOLA-FLEX BELLOWS TO HAVE FLOW LINER INSTALLED WHEN ORDERED:- SOLAR, SAN DIEGO OR EQUIV.
4. FIND NOS. (2) AND (6) ARE ALIKE EXCEPT THAT ONE HAS A .380 HOLE. SEE DETAIL
3. MACHINED FILLET RADIUS: .010 MAX.
2. REMOVE ALL BURRS AND SHARP EDGES .010 TO .020
1. MACHINE FINISH 63

	DWG PART OR NO.	DASH NO.	DESCRIPTION	SPECIFICATION	STOCK SIZE / REF DESIGNATION - ELEC DWG	MATERIAL	NO. REQD	FIND NO.
	SPEC		IDENTIFICATION	JPL 20002				13
	SPEC		TIG WELD	JPL 20035				12
	SPEC		FUSION WELD	JPL 20004				11
6	SPEC		BRAZING	GE SPPS-9A				10
								9
								8
8		-7	DRAIN TUBE		.375 OD X .049 W 1.00 LG	CRES 321	1	7
7		-6	STRAIGHT TEE		M/F LADISH NO. 24000	CRES - 316	1	6
5			BELLOWS (MOD)	SOLA FLEX	19-75-10-409	CRES - 316	1	5
		-4	TUBING		.344 OD X .046 WALL X 13.56 LG	Cb-1Zr	1	4
		-3	SPACER		⅜ SCH 40 PIPE × 3.81 LG	CRES - 316	1	3
7		-2	STRAIGHT TEE		M/F LADISH NO. 24000	CRES - 316	1	2
		-1	END CAP		1.200 DIA X .437 LG	Cb-1Zr	2	1

Fig. C-51. Cooler, 100-kW erosion loop

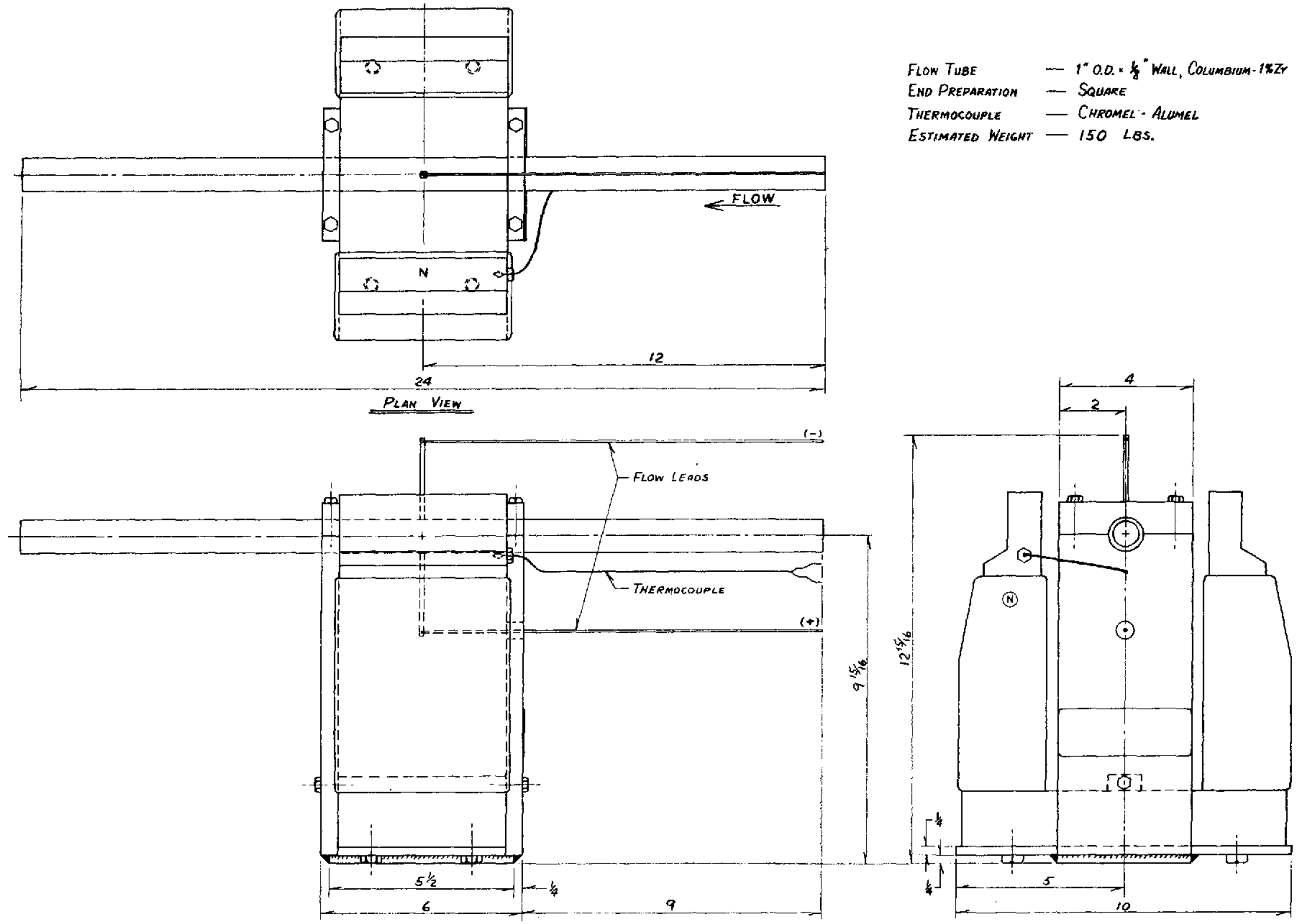


Fig. C-52. Flowmeter FM-14

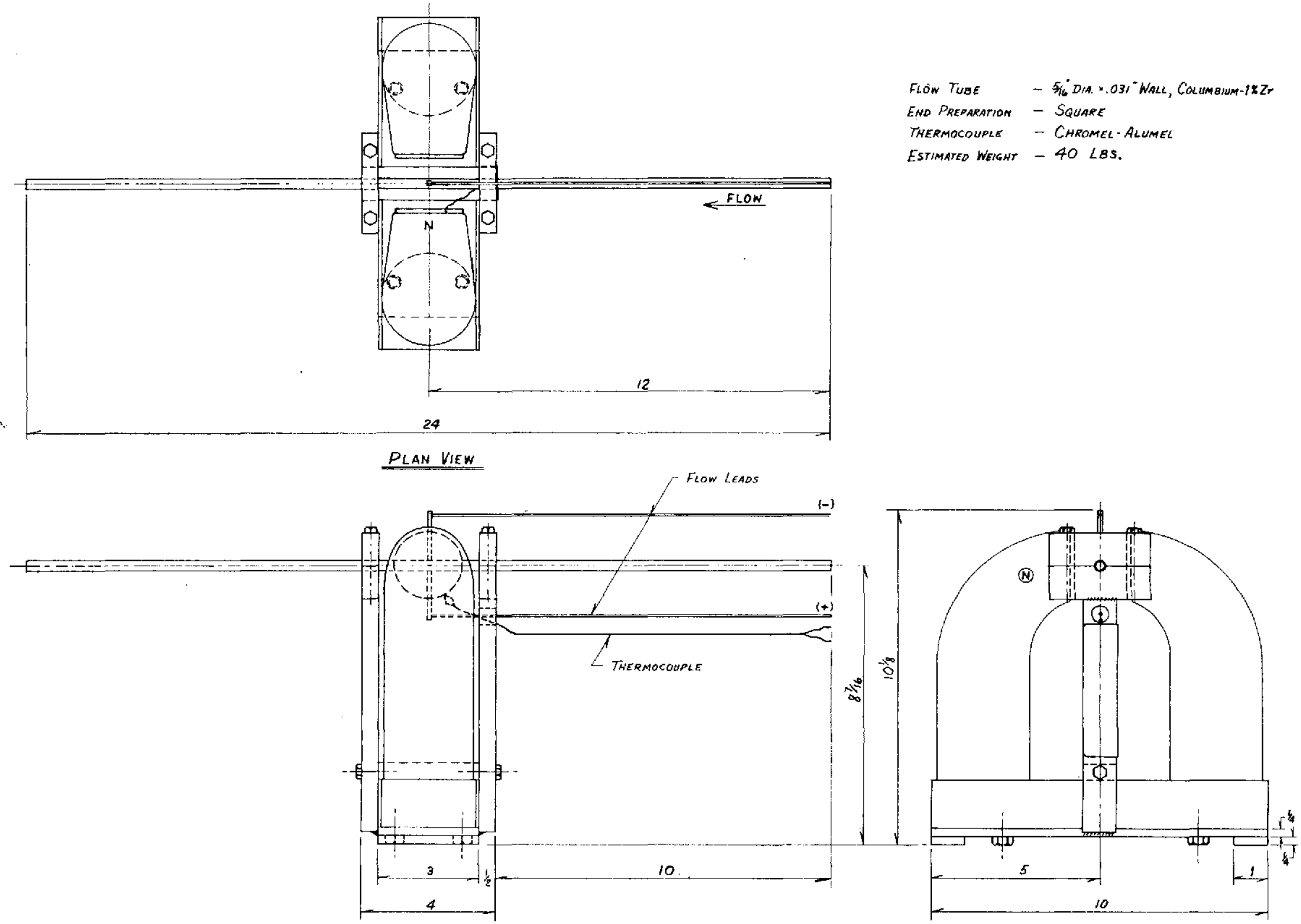


Fig. C-53. Flowmeter FM-12

APPENDIX D

CESIUM-LITHIUM LOOP OPERATING CHARACTERISTICS

The operating characteristics of the Cs-Li loop were determined by modeling the performance of the major components (Li pump, Cs pump, Li heater, Cs condenser, Cs subcooler, bypass valve) and combining the relations together with the hydraulic and heat loss characteristics of the system. The CAL program resulting from this effort is given in this appendix. The results of variation of key parameters over a range of interest is summarized in Fig. D-1. The independent variables are taken to be the pump voltages E_1 and E_2, the heat rejection rate Q, the NaK pump current I, the lithium heater voltage E_3, and the number of turns opening of the bypass valve N. The variations of the condenser temperature T_2, mass ratio r_c, NaK temperature T_3, and lithium temperature T_1 are shown for individual variations in the independent parameters. At the design point of:

$$T_1 = 1800°F$$

$$T_2 = 1300°F$$

$$T_3 = 900°F$$

$$C_1 = 0.02$$

$$r_c = 10$$

the control variables should have the following settings (from the figure):

$$E_1 = 304\ V$$

$$E_2 = 283\ V$$

$$E_3 = 11.3\ V$$

$$Q = 24.3\ kW$$

$$T = 18.3\ A$$

$$N = 0.45\ \text{turns}$$

The effect of variations of the control parameters from the design point can be determined by following the appropriate curve.

NOMENCLATURE

A1	α_B	fraction of cesium in lithium at nozzle exit
A2	A	area of loop at highest temperature, ft^2
B1	β_B	fraction of lithium vapor in cesium at nozzle outlet
*C1	C_0	fractional lithium carryover
C2	$Cp_{cs_{10}}$	specific heat of cesium liquid and vapor at T_{10}, Btu/lb°F
C3	Cp_{Li_ℓ}	specific heat of lithium at T_{12}
C4	Cp_{19}	specific heat of lithium and cesium mixture into desuperheater
*D1	Δp_{f1}	frictional drop in lithium lines, psi
*D2	Δp_{f2}	frictional drop in cesium lines, psi
D3	ΔT_B	drop in bulk temperature in nozzle, °F
E1	E_1	lithium pump voltage
E2	E_2	cesium pump voltage
E3	E_3	lithium heater voltage
E4	E	emissivity of foil insulation
L1	Lv_{Li}	latent heat of lithium vapor, cal/g
L2	Lv_{Li}	latent heat of lithium vapor, B/lb
L3	Lv_{cs}	latent heat of cesium vapor, cal/g
L4	Lv_{cs}	latent heat of cesium vapor, B/lb
M1	$\dot{m}_T$	total nozzle flowrate, lb/s
M2	$\dot{m}_{Lit}$	lithium flowrate in nozzle, lb/s
M3	$\dot{m}_{pl}$	lithium flowrate in pump, lb/s

M4	$\dot{m}_{cs_N}$	cesium flow in nozzle, lb/s
M5	$\dot{m}_{cs_{\ell 9}}$	mass flowrate of dissolved cesium, lb/s
M6	$\dot{m}_{Li_{v9}}$	mass flowrate of lithium vapor, lb/s
M7	$\dot{m}_{cs_{Ds}}$	desuperheater flowrate, lb/s
M8	$\dot{m}_{p2}$	cesium pump flowrate, lb/s
N1	n	number of layers of radiation shielding
P0	p_0	inlet pressure of lithium, psi
P1	p_1	nozzle inlet pressure, psi
P2	p_{12}	condenser pressure, atm
P3	p_{12}	condenser pressure, psi
Q1	Q_1	heat input from lithium pump, kW
Q2	Q_2	heat input from cesium pump, kW
Q3	Q_3	heat input from lithium heater, kW
Q4	Q_4	radiant heat loss, Btu/hr
Q5	Q_5	heat transfer in subcooler
Q6	Q_4	radiant heat loss, kW
Q7	Q_R	heat rejection date required, kW
R1	ρ_{Li}	lithium density, lb/ft^3
*R2	r_c	mass ratio of lithium to cesium in nozzle
R3	ρ_{cs}	cesium density, B/ft^3
R4	ρ_{Li}	lithium density, g/cm^3

R5	ρ_{cs}	cesium density, g/cm^3
*T1	T_1	nozzle inlet temperature of lithium, °F
*T2	T_{12}	condenser temperature, °F
T3	T_{34}	potassium low temperature, °F
T4	T_{12}	condenser temperature, °K
T5	T_1	nozzle inlet temperature, °F, °C
T6	T_{19}	temperature into desuperheater, °F
T7	T_{10}	nozzle exit temperature, °C
T8	T_{12}	condenser temperature, °C
T9	T_{10}	nozzle exit temperature, °K
X1	T_c	temperature of vacuum chamber
X2		temperature factor
X3		temperature factor
X4		temperature factor
X5	T_{10}	nozzle exit temperature, °F

```
1.00 DEMAND C1,T2,T1,P0,T3,R2,A3
1.01 T4=(T2-32.0)/1.8+273.16
1.011 A2=10.12
1.012 N1=.15
1.013 X1=800
1.014 E4=.15
1.02 P2=10^(3.3629-(3617.76/T4)+0.16005*LOG10 (T4))
1.03 P3=14.696*P2
1.031 V1=.498*P0^.288/(P3^.178*R2^.443)
1.04 M1=.00381*(P0^.90)*(R2^.47)
1.05 M2=(M1*R2)/(1.0+R2)
1.06 M3=M2*(1.0-C1)
1.07 T5=(T1-32.0)/1.8
1.08 R4=.124+(5.306/(10.^3.))*(2900.-T5)^.5+(4.135/(10.^5.))*(2900.-T5)
1.09 R1=62.4*R4
1.11 M4=M1/(1+R2)
1.12 D3=(.0902*P0^1.465)/(R2^.515*P3^.431)
1.13 A1=(1.985*P0^.531*P3^.889)/(10^5)
1.14 B1=(.00292*P0^.443*R2^.0973)/(P3^1.02)
1.15 X5=T1-D3
1.16 M5=A1*M2
1.17 T6=T3+100
1.18 M6=B1*(M4-M5)
1.19 T7=(X5-32)/(1.8)
1.20 C2=.0684-(8.032*T7)/10^5+(7.996*T7^2)/10^8
1.21 T8=T4-273
1.22 C3=1.0577-(1.2152*T8/10^4)+(5.3477*T8^2/10^8)
1.23 C4=(C2)/(1+C1*R2)+(C1*R2*C3)/(1+C1*R2)
1.24 T9=T7+273
1.25 L1=5061.2*(1-T9/3173)^.3725
1.26 L2=1.8*L1
1.27 L3=147.12*(1-T4/2043)^.3547
1.28 L4=1.8*L3
1.29 M7=(M4*C2*(X5-T2)+M6*L2+C1*M5*L4+M2*C1*C3*(X5-T2))/(C4*(T2-T6)+L4)
1.30 M8=M4+M7
1.31 R5=.434+(2.495*(1770-T8)^.5)/(10^2)+(2.083*(1770-T8))/(10^4)
1.32 R3=62.4*R5
1.321 U1=.2419*10^(5.41921-155.991/(T5+273)-1.61506*LOG10(T5+273))
1.3211 U1=U1/3600
1.322 D1=(11.47*M3^2)/(R1)*((26.6+115*U1^.25)/(M3^.25))
1.323  E1=(((P0-P3+D1)*R1)/(-.0347*M3+.00274*R1))^.5
1.324 U2=.2419*10^(.84005+205.902/T4-.27958*LOG10 T4)
1.3241 U2=U2/3600
1.325 D2=4.91*1E4*U2^.25*M8^1.75/R5+3.46*1E3*M4^2/R5+2.84*1E4*U2^
        .25*M4^1.75/R5
1.326 D2=D2/62.4
1.33 E2=(((P0-P3+D2)*R3)/(-.397*M8+.0022*R3))^.5
1.34 Q1=(4.5*E1^1.72)/(10^4)
1.341 Q2=(1.39*E2^1.72)/(1E4)
1.342 X2=(M7*C2)+(M2*C1*C3*M7)/(M8)
1.343  X3=T2-100+1.055*(Q2)/((M8*C2)+(M2*C1*C3))
1.35 Q2=(1.39*E2^1.72)/(10^4)
1.351 L5=147.12*(1-(T5+273)/(2043))^.3547
1.352 L6=1.8*L5
1.353 C5=1.0577-(1.2152*T5/1E4)+((5.3477*T5^2)/1E8)
1.354 C6=.0684-(8.032*T5)/1E5+(7.996*T5^2)/1E8
1.355 X6=T1+(1/((1-A3)*(R2*(1-C1)))-(A3/(1-A3))*((1/(R2*(1-C1)))+1
))*(L6/C5)+((C6/(R2*(1-C1)*C5))+(C1/((1-C1)*C5)))*(T1-X3)
1.36 Q3=.947*M3*C5*(X6-T1+D3)-Q1
1.361 E3=(11.22*Q3)^.5
1.37 Q4=.174*E4*A2*((T1+460)^4-(X1+460)^4)/(N1*1E8)
1.38 X2=(M7*C2)+(M2*C1*C3*M7)/(M8*M7)
1.39 X3=T2-100+Q2/X2
1.40 X4=T6+100
1.41 Q5=X2*(X3-X4)*.947
1.42 Q6=Q4/3413
1.43 Q7=Q1+Q2+Q3-Q6+Q5
1.431 U=1/(.0024*M8^.438+.000243)
1.432 X6=(Q7-Q5)*(3413)/(.685*U)
```

```
1.433 M9=1
1.434 X7=(Q7-Q5)*(.947)/(.21*M9)
1.435 X8=(Q5*.947)/(.21*M9)
1.436 X9=(X7)/LOG(1/(1-(X7)/(T2*T3*X8)))
1.437 M9= IF ABS((X9-X6)/X6)>.01 THEN (1+(.1)*(X6-X9)/X6)*M9 ELSE
          IF ABS((X9-X6)/X6)<.01 THEN M9 ELSE M9
1.438 TO STEP 1.434 IF ABS((X9-X6)/X6) > .01
1.439 I=46.7*M9^.74
1.44 TYPE E1,E2,E3,P0,P3,T1,T2,D3,C2,M4,L2
1.441 TYPE X6
1.442 V7=2930*M7/R3
1.443 K=9290*(P0-P3)/(R3*V7^2)
1.444 N=34.6/K^.5
1.445 TYPE N,M9,X7,X8,I
1.45 TYPE M1,M2,M3,M5,M6,M7,M8
1.46 TYPE Q1,Q2,Q3,Q5,Q6,Q7
1.461 TYPE D1,D2
1.47 TO STEP 1.00
```

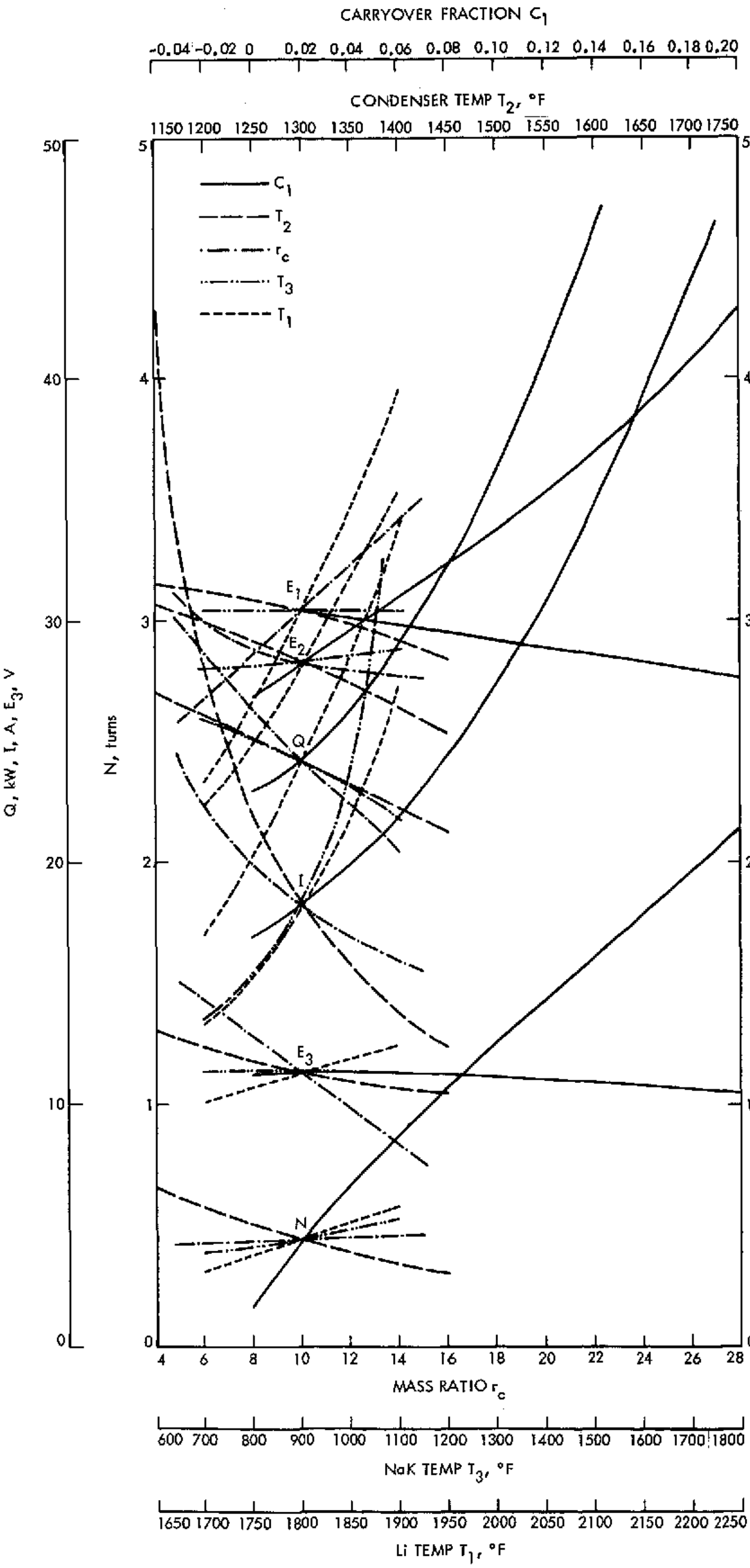


Fig. D-1. Cs-Li loop characteristics

NASA — JPL — Coml., L.A., Calif.