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Cb-1Zr PUMPED SODIUM LOOP

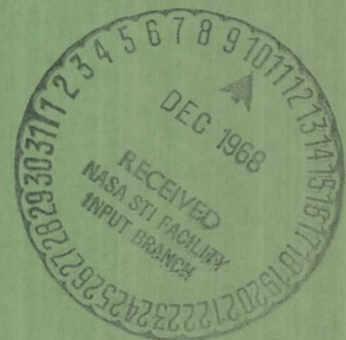
by E. E. Hoffman and J. Holowach

Prepared by

GENERAL ELECTRIC COMPANY

Cincinnati, Ohio

for Lewis Research Center



Cb-1Zr PUMPED SODIUM LOOP

By E. E. Hoffman and J. Holowach

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Prepared under Contract No. NAS 3-2547 by
GENERAL ELECTRIC COMPANY
Cincinnati, Ohio

for Lewis Research Center

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FOREWORD

The work described herein was performed by the General Electric Company under NASA Contract NAS 3-2547. The primary purpose was to develop a Cb-1Zr Rankine system corrosion test loop for the evaluation of refractory alloys in boiling and condensing potassium environments which simulate projected space electric power systems. The experiment described in this report, the Cb-1Zr pumped sodium loop test, was conducted to evaluate the numerous loop components, including the EM pump, metering and isolation valves, pressure transducers, EM flowmeter and instrumentation techniques. Mr. T. A. Moss and Mr. R. L. Davies, Space Power Systems Division, NASA-Lewis Research Center, were the Project Managers for the National Aeronautics and Space Administration. The report was originally issued as General Electric Report R67SD3015.

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ABSTRACT

A forced circulation Cb-1Zr Pumped Sodium Loop was operated for 2650 hours at a maximum circuit temperature of 2065°F. The single phase sodium test was conducted to evaluate a number of components and test procedures prior to the construction and operation of the Cb-1Zr Rankine System Corrosion Test Loop, a two-loop Cb-1Zr facility in which sodium was circulated in the primary or heater circuit and potassium was boiled and circulated in a two-phase secondary loop.

Notable among the components evaluated was the electromagnetic helical induction pump which operated at 1980°F for the full term of the test with no change in performance. Other components which were evaluated included metering and isolation valves, slack diaphragm and stressed diaphragm pressure transducers, I²R heater, and electrical feedthroughs.

Detailed chemical and metallurgical evaluations revealed no evidence of corrosion or significant contamination, either from the sodium or the vacuum chamber environment. The specifications, procedures, fabrication techniques, and testing methods employed for the Cb-1Zr Pumped Sodium Loop test were confirmed to be adequate for the Cb-1Zr Rankine System Corrosion Test Loop test system.

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Cb-lZr PUMPED SODIUM LOOP

I. INTRODUCTION

This report describes the design, fabrication, instrumentation, operation and evaluation of a Cb-lZr forced circulation loop through which liquid sodium was pumped for 2650 hours at a maximum temperature of 2065°F. This loop experiment was the second in a series of three which were included in this program. The primary purpose of the Potassium Corrosion Test Loop Development Program was to develop a prototype corrosion test loop system for the evaluation of various refractory alloys in boiling and condensing potassium under conditions which simulate the environments in projected Rankine systems.

The Cb-lZr Rankine System Corrosion Test Loop experiment, which will be described in the next and last topical report in this series,^(a) was specified to consist of a two-loop Cb-lZr facility in which liquid sodium was circulated in the primary or heater circuit and potassium was boiled and circulated in a two-phase secondary loop. The required operational conditions initially specified for the potassium circuit of the Rankine System Corrosion Test Loop are listed below:

- a. Boiling temperature - 1900°F
- b. Superheat temperature - 2000°F
- c. Condensing temperature - 1350°F
- d. Subcooling temperature - 800°F
- e. Mass flow rate - 20 to 40 lb/hr
- f. Vapor impingement velocity on blades - 1,000 ft/sec
- g. Test duration - 2,500 hr^(b)

(a) Previously issued topical reports for this program are listed in Section XIV.

(b) Test duration subsequently was extended to 5,000 hours.

The method chosen to heat the boiler of the Rankine System Corrosion Test Loop was the use of a primary or heater loop in which $I^2R^{(a)}$ heated sodium was to be pumped through the outer annulus of a tube-in-tube counterflow boiler where the required heat was to be transferred to the potassium in the secondary, two-phase circuit. One of the principal goals of this test program was to incorporate as many components in the Rankine System Corrosion Test Loop as required to assure an accurate determination of the test conditions and thereby minimize the possibility of undetected test variations, e.g., high frequency boiling instabilities, which might compromise loop operation or the post-test compatibility evaluation.

In order to assure the optimum performance and reliability of the individual components of the Rankine System Corrosion Test Loop, a plan was established to evaluate as many of the critical loop components as was practical in two preliminary loop tests. These test loops, namely, the Cb-1Zr Sodium Thermal Convection Loop⁽¹⁾ and the Cb-1Zr Pumped Sodium Loop described in this report, were designed and operated in a manner to evaluate primarily the critical components associated with the all-liquid heater circuit. Several of the reasons for this approach are listed below:

1. The higher operating temperatures and electrical power requirements of the sodium heater circuit might result in malfunction or degradation of critical components such as the EM Pump.
2. Many of the components required for the potassium circuit, e.g., valves, pressure transducers, could be adequately evaluated in the single phase sodium systems.

The Cb-1Zr Sodium Thermal Convection Loop was operated for 1,000 hours at a maximum temperature of 2380°F with a calculated mass flow of 11 pounds per hour which is equivalent to a flow velocity of 1.3 feet per minute.

(a) I^2R will be used to designate the self-resistance heater in this report.

(1) Hoffman, E. E. and Holowach, J., Cb-1Zr Thermal Convection Loop, Potassium Corrosion Test Loop Development Topical Report No. 5, R67SD3014, General Electric Company, Cincinnati, Ohio, June 15, 1967

This earlier test was conducted to obtain a preliminary evaluation of the electrical resistivity characteristics of the heater segment, the method of attaching the heater electrodes, the electrical power vacuum feedthroughs, thermocouple materials and procedures, and the performance of selected thermal and electrical insulation materials.

The Cb-1Zr Pumped Sodium Loop described in the current report was considerably more complex than the thermal convection loop described above and was designed to operate at a pump temperature of approximately 2000°F. In addition to evaluating the helical induction EM pump at this relatively high temperature to simulate the requirements of the heater circuit of the Cb-1Zr Rankine System Corrosion Test Loop, this loop was also required to evaluate both slack diaphragm and stressed diaphragm pressure transducers and refractory alloy metering and isolation valves. Although the pressure transducers and valves were required only for the potassium circuit of the Rankine System Loop, it was concluded that these components could be suitably evaluated in the Pumped Sodium Loop.

The Cb-1Zr alloy was chosen by NASA as the primary containment material for the entire Potassium Corrosion Test Loop Development Program based on its advanced state of commercial development and the indicated corrosion resistance of this alloy to high purity alkali metal environments. It was anticipated that subsequent to this program, refractory metal alloys having considerably greater high temperature strengths than Cb-1Zr could be evaluated in the Rankine System Corrosion Test Loop developed by this program.

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II. LOOP DESIGN

The primary design objective of the Cb-1Zr Pumped Sodium Loop was to evaluate proposed components of the Cb-1Zr Rankine System Corrosion Test Loop at their operating conditions. The Cb-1Zr Sodium Thermal Convection Test Loop, which preceded the test presented in this report, was used to evaluate several of the components of the Rankine System Corrosion Test Loop and the results of this experiment were presented in an earlier report.⁽²⁾ The basic design of the Rankine System Corrosion Test Loop showing the variety of components included in the system is illustrated in Figure 1. The components which were included in the preliminary Cb-1Zr Pumped Sodium Loop Test described in this report are indicated. These components include the EM pump, flowmeter, sodium heater, metering and isolation valves, the stressed diaphragm pressure transducer and the slack diaphragm pressure transducer. The electrical resistance sodium heater had previously been successfully tested in the Cb-1Zr Sodium Thermal Convection Loop.

The features of the loop are illustrated in Figure 2. The engineering drawings for the Cb-1Zr Pumped Sodium Loop are included in Appendix A of this report. The main flow circuit of the loop is as follows: sodium is circulated around the loop by an EM pump located at the lower end of the loop. The sodium, after being discharged from the pump, enters the electrical resistance heater that consists of two 4-inch diameter helical coils in series. The sodium flows upward through the heater past the slack diaphragm pressure transducer and into the heat rejection tube. The sodium flow rate is measured by a permanent magnet flowmeter and then returns to the inlet side of the EM pump. The main circuit of the loop operates in the 1950°F to 2050°F temperature range.

(2) Hoffman, E. E. and Holowach, J., Cb-1Zr Thermal Convection Loop, Potassium Corrosion Test Loop Development Topical Report No. 5, R67SD3014, General Electric Company, Cincinnati, Ohio, June 15, 1967,

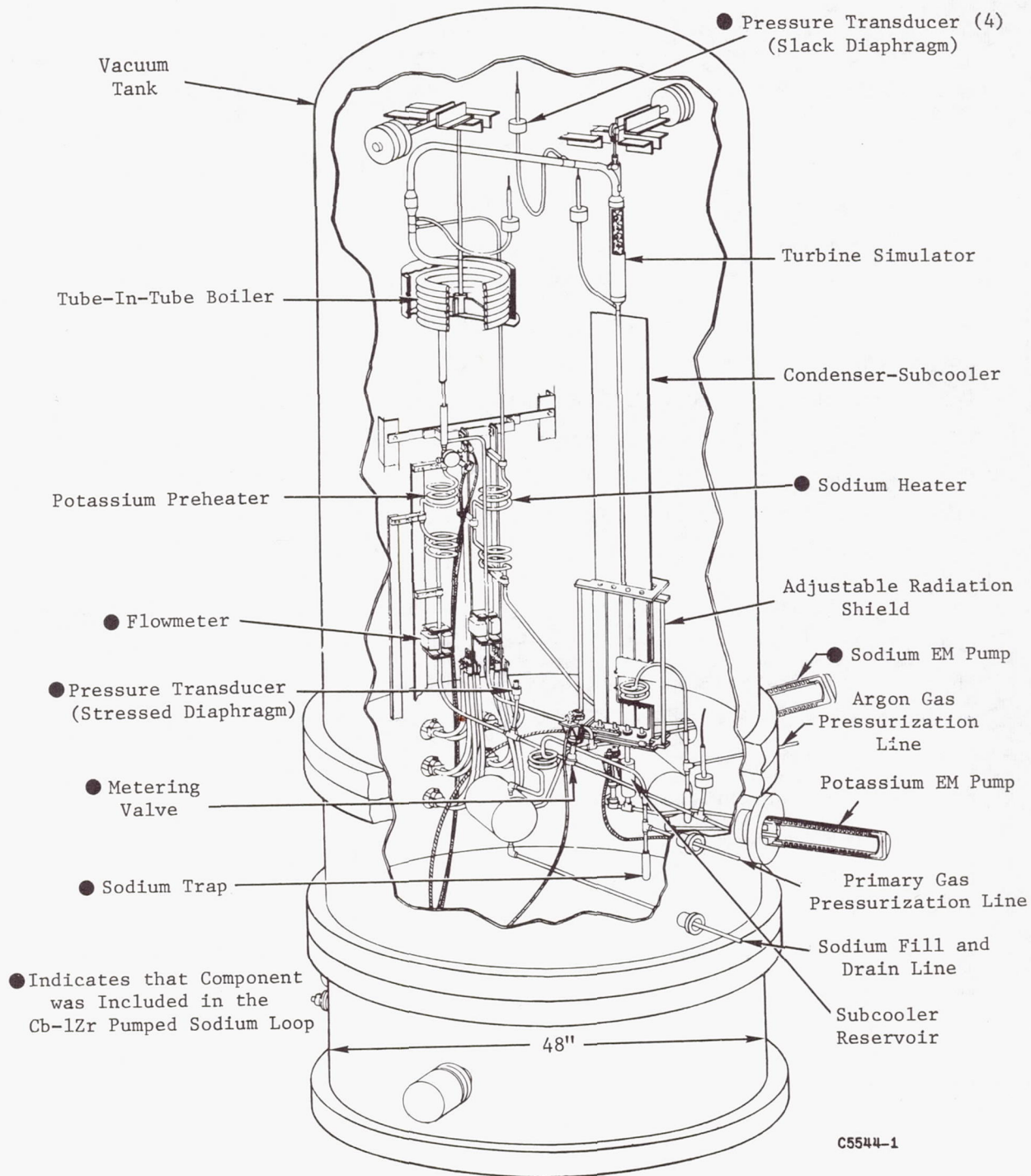


Figure 1. Isometric Drawing of the Cb-1Zr Rankine System Corrosion Test Loop. Components Included in the Cb-1Zr Pumped Sodium Loop for Evaluation are Indicated. (Orig. C65081345)

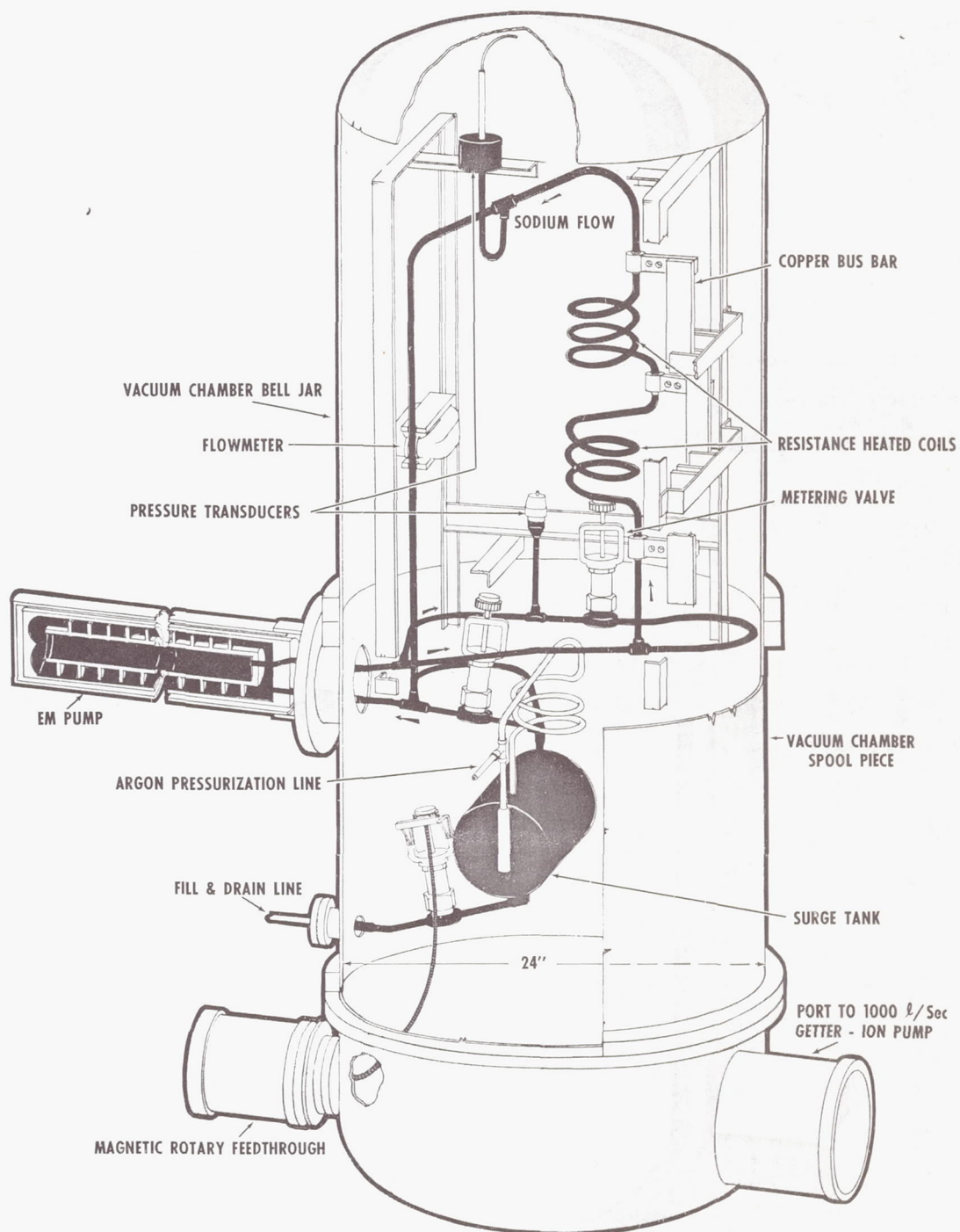


Figure 2. Cb-1Zr Pumped Sodium Loop.

C5544-2

A bypass line was added to the main loop between the EM pump and the sodium heater to test the metering valve and the stressed diaphragm pressure transducer since these components will operate at only 800°F in the Cb-lZr Rankine System Corrosion Test Loop. The temperature of the bypass line is controlled by regulating the mass flow rate of sodium through the bypass by adjustment of the metering valve. The bypass line was made sufficiently long so that the effective radiation heat transfer area of the bypass line would lower the sodium temperature from 1975°F, the pump outlet and bypass line inlet temperature, to 800°F, the desired valve test temperature.

A 6-inch diameter by 10-inch long Cb-lZr surge tank was located at the bottom of the loop and connected to the EM pump inlet. An isolation valve was added between the surge tank and the loop to determine if bonding would occur between the Mo-TZM valve plug and the Cb-lZr valve seat. This valve was added only for the bonding test and was not required for loop operation. A bypass loop around the valve was required to allow excess sodium to flow back into the surge tank as a result of the expansion of the sodium while increasing the loop temperature to the design conditions.

An inert gas pressurization line was attached to the surge tank and was used during loop operation to maintain the pressure in the loop above the saturation pressure of the sodium to prevent localized boiling in the heater. Boiling in the heater section was undesirable since it would result in unstable loop operation because of the rapid changes in the overall electrical resistance of the heater associated with sodium vapor formation. Rapid changes in the resistance of the heater coils would result in severe power fluctuations. The change in density of sodium liquid to vapor would also influence the flow rate and contribute to loop instability.

The design calculations used to predict the sodium flow rate, loop temperatures, power requirements, electrical characteristics of the I^2R heater and the internal pressure stresses in the loop are given in Appendix B. The design data for the Cb-lZr Pumped Sodium Loop resulting from this analysis are given in the second column of Table I. A listing of the design

TABLE I

COMPARISON OF THE DESIGN DATA FOR THE Cb-1Zr SODIUM THERMAL CONVECTION LOOP, Cb-1Zr PUMPED SODIUM LOOP, AND THE SODIUM CIRCUIT OF THE Cb-1Zr RANKINE SYSTEM CORROSION TEST LOOP

	Cb-1Zr Sodium Thermal Convection Loop	Cb-1Zr Pumped Sodium Loop	Sodium Heater Circuit of the Cb-1Zr Rankine System Corr. Test Loop
<u>Structural</u>			
Material	Cb-1Zr	Cb-1Zr	Cb-1Zr
Tube diameter	0.375 inch	0.375 inch	0.375 inch*
Wall thickness	0.065 inch ₂	0.065 inch ₂	0.065 inch*
Flow area	0.00033 ft ²	0.00033 ft ²	0.00033 ft ²
<u>Fluid Flow</u>			
Coolant	Sodium	Sodium	Sodium
Flow rate	16 lb/hr	440 lb/hr	824 lb/hr
Velocity in 0.25-inch ID tubing	0.3 ft/sec	8.5 ft/sec	16 ft/sec
Reynolds no.	3,100	85,000	159,000
Friction factor	0.012	0.0055	0.0048
Pressure loss, total	0.01 psi	4 psi	15 psi
<u>Heat Transfer - Heater</u>			
Heater length	73 inch	73 inch	73 inch
Geometry	4 in. dia. coil	4 in. dia. coil	4 in. dia. coil
Temperature in	1700°F	1950°F	1950°F
Temperature out	2200°F	2050°F	2100°F
Power input	0.7 KW	4.2 KW	9 KW
<u>Electrical</u>			
Current	650 amp	1200 amp	2000 amp
Potential	2.7 volts	4.5 volts	6 volts
Power	1.75 KW	5.4 KW	12 KW
<u>Stress</u>			
Internal pressure	190 psi	150 psi	190 psi
Max. internal pressure stress	370 psi	370 psi	370 psi

* Boiler portion of the sodium circuit, 1-inch OD x 0.1-inch wall thickness tubing.

data of the Cb-1Zr Sodium Thermal Convection Loop and the sodium circuit of the Cb-1Zr Rankine System Corrosion Test Loop are also given in Table I for purpose of comparison.

A. HELICAL INDUCTION ELECTROMAGNETIC PUMP

The helical induction electromagnetic pump was designed by the Atomic Products Section of the Large Generator and Motor Department of the General Electric Company. The pump, shown in Figure 3, operates on the principle of the induction motor where three phase 60 cycle power in the stator windings produce a 2-pole magnetic field revolving at 60 revolutions per second. A pressure head is developed by the interaction of the magnetic field and current which flows as a result of the voltage induced in the liquid metal contained in the pump. The pump duct consists of an outer can and an inner tube with machined helical passages so that the fluid passing through the pump is constrained to flow in a spiral path. The tangential force on the fluid is thus converted into a developed head. The pump will operate in either direction but it is designed for the fluid to enter the helical annulus and return through the central passage of the inner tube. The outer Cb-1Zr can is shrink-fitted on the inner Cb-1Zr tube to prevent leakage between flow passages. Since the inlet and discharge tubes are on the same end of the duct, the pump duct can freely expand into the thermal insulation assembly. The stainless steel can containing the Cb-1Zr alloy reflective foil, which insulates the pump duct from the stator windings, also serves as the vacuum envelope which is welded to the main vacuum chamber. The flow rate and pressure head are controlled by varying the applied voltage to the pump winding. The power input and developed pressure at a particular flow vary approximately as the square of the applied voltage.

Cooling air is supplied to the center of the stator bore and around the stainless steel pump can. Each stator tooth has ventilating passages which permits axial flow of cooling air from the center duct through the stator core and into the end turn region. The cooling air passes through the end turns and out the pump to ventilating ports at each end of the pump. Two copper-constantan thermocouples are located in the end windings to provide a

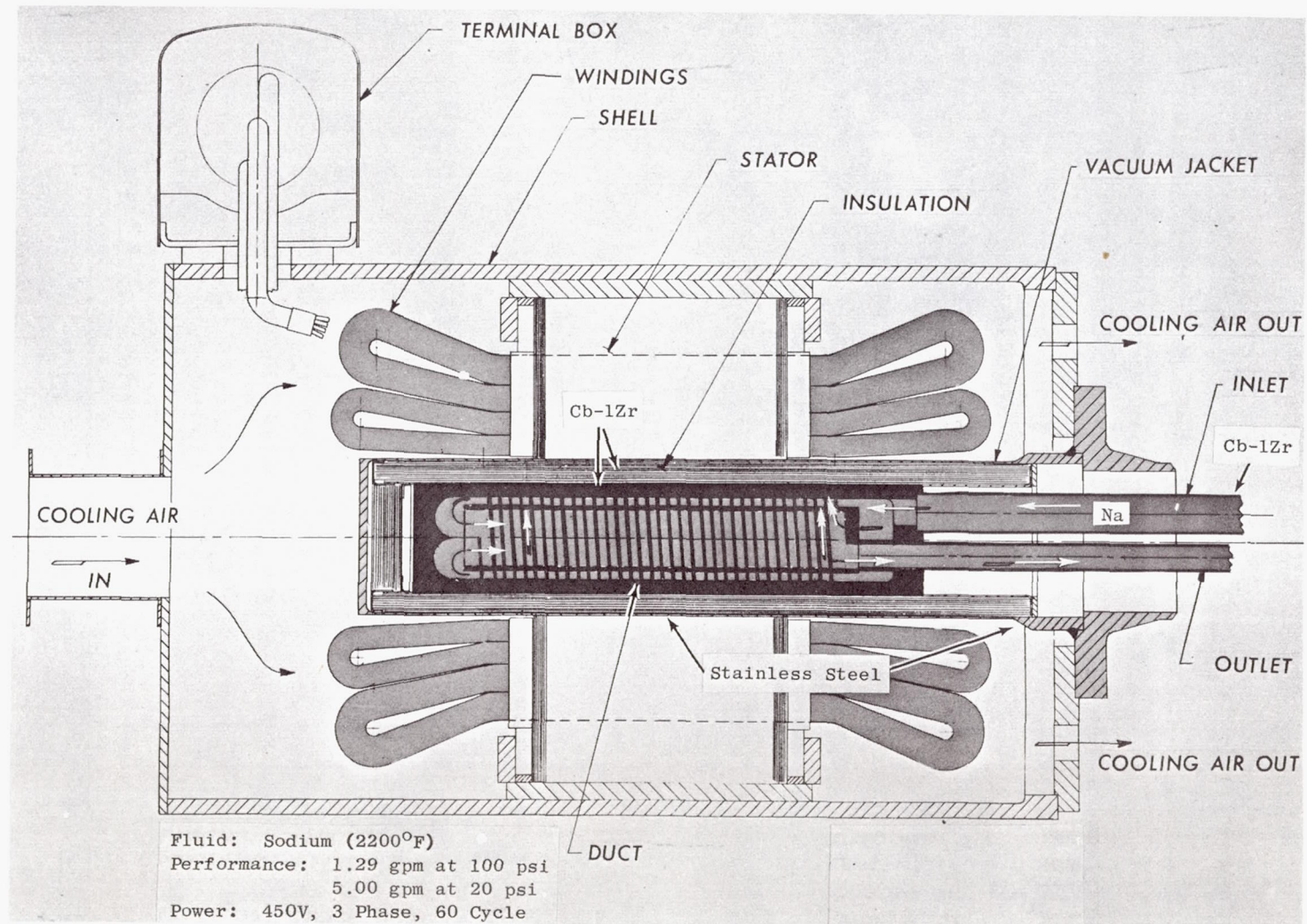


Figure 3. Helical Induction Electromagnetic Pump. (C65041501)

C5544-3

means of monitoring the pump winding temperature during operation. The winding insulation system is Class H which is suitable for operation at temperatures to 400°F.

The general information on the pump including the pump rating, coolant requirements and the design characteristics are shown in Table II. The calculated pump performance of the loop is shown in Figure 4.

B. SODIUM FLOWMETER

A permanent magnet flowmeter was selected for measuring the sodium and potassium flow rates in the Cb-lZr Corrosion Test Loop because of its simplicity, reliability and accuracy. A schematic diagram of a typical permanent magnet flowmeter is shown in Figure 5. Its operation is similar in principle to that of a d-c generator. A d-c output voltage is generated across the flow tube by the conducting fluid moving through the pipe at right angle to the magnetic field established across the pipe by the permanent magnet.

The output voltage is expressed by Faraday's law for induced voltage, i.e.,

$$E = BlV \times 10^{-8}$$

where

E = Output voltage

B = Flux density, gauss

l = Length of conductor, cm

V = Velocity of conductor, cm/sec

Certain practical effects result in differences from the ideal case given above, and they must be accounted for if accurate measurements are to be obtained. These effects and their contributions have been presented previously by R. Affel and coworkers.⁽³⁾

(3) Affel, R. G., Burger, G. H., and Pearce, C. L., Calibration and Testing of 2- and 3 1/2-in. Magnetic Flowmeters for High-Temperature NaK Service, ORNL-2793.

TABLE II

GENERAL INFORMATION ON HELICAL INDUCTION
ELECTROMAGNETIC PUMP, GENERAL ELECTRIC MODEL NO. SKY414PB2

Pump Rating

Fluid	Sodium	2200°F Max.
Flow		1.29/5 gpm
Developed Pressure		100/20 psi
Power Supply	480 volts, 3 phase, 60 cycle	
Power Input		8.2/9.5 kw
Efficiency		.68/.46 %
Power Factor	Pump System	10.7/10.4 % 95 %

Coolant Requirements

Coolant	Air
Coolant Flow	0.5 pounds per second (400 CFM)
Coolant Inlet Temperature	40°C, Max.

Design Characteristics

Pressure	335 psig
Number of Poles	2
Duty Rating	Continuous
Hot Spot Temperature (Insulation)	400°F
Weight, Less Duct	530 lbs

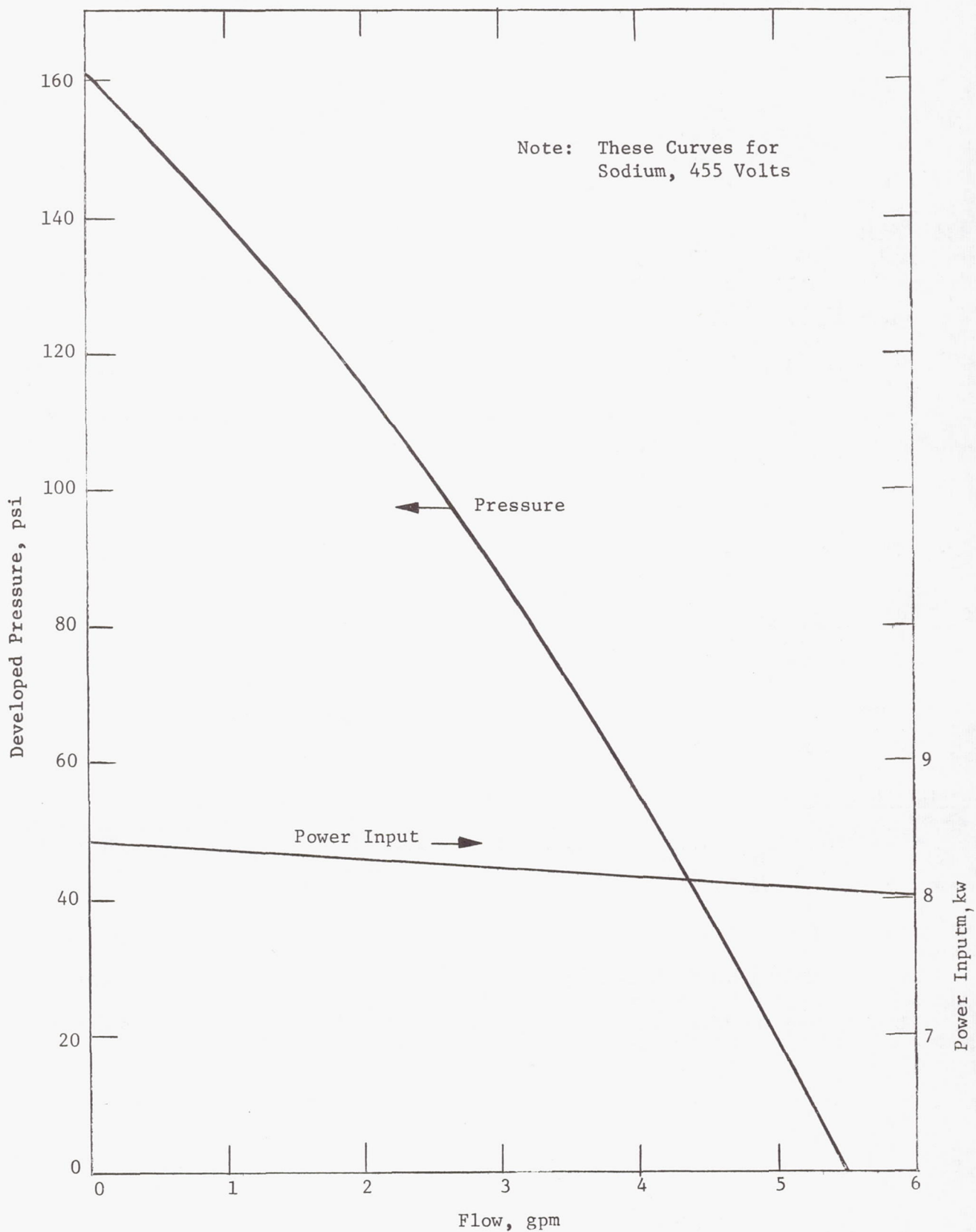
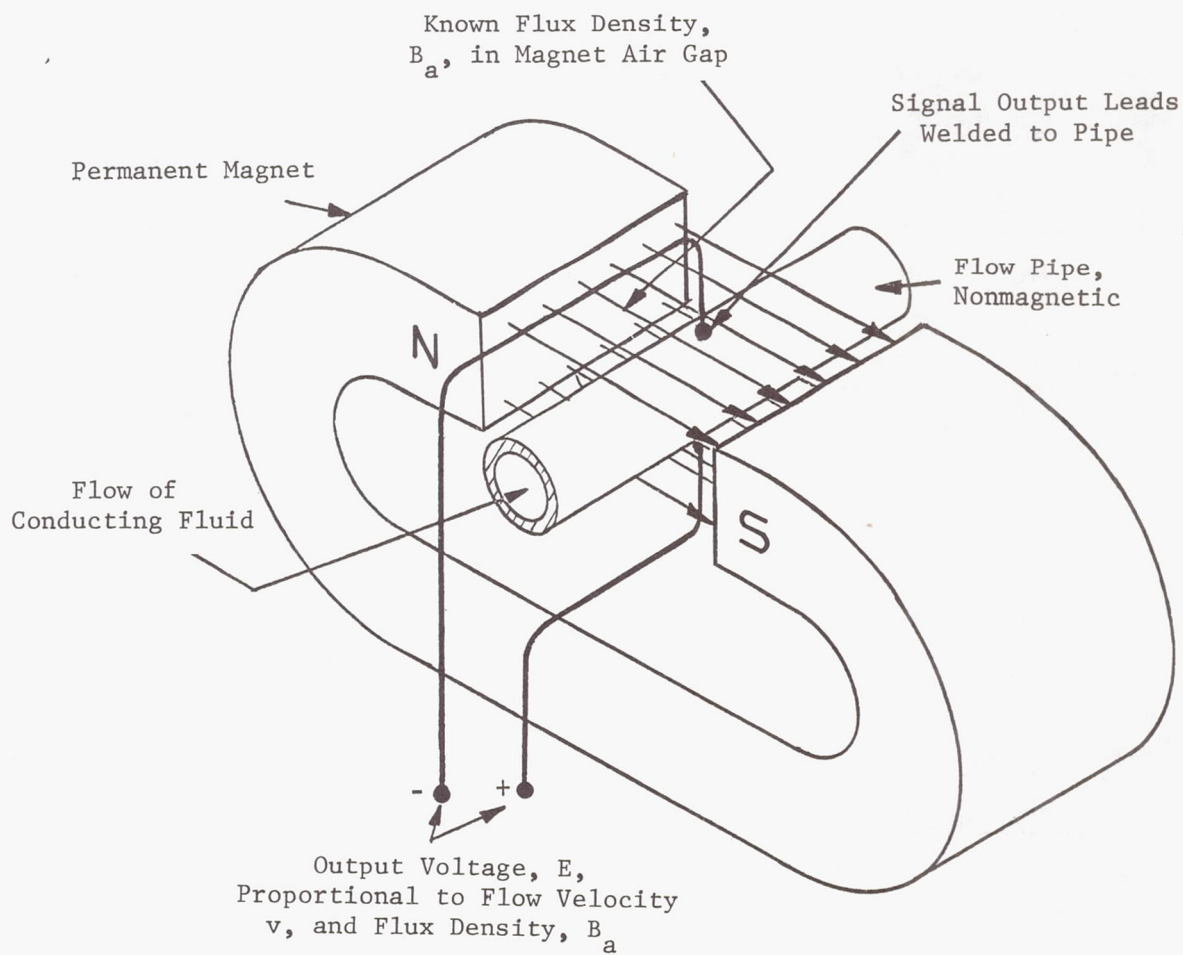


Figure 4. Calculated Pump Performance of General Electric Helical Induction EM Pump Model SKY414PB2.



C5544-5

Figure 5. Magnetic Flowmeter Principle.

The actual design of the flowmeter was limited to the selection of a commercially available Alnico V magnet with a gap between pole faces having adequate clearance for a 0.375-inch OD Cb-lZr tube and a magnetic flux density high enough to produce a millivolt output that could be easily recorded by a standard recording potentiometer. The magnet selected was a cast Alnico V magnet assembly Type MA39^(a) with a nominal 3000 gauss magnetic flux in a 3/4-inch gap with a specified maximum variation of the flux density less than 10% between the 1 1/2-inch diameter pole faces.

The magnet was stabilized by repeated thermal cycling between room temperature and 900°F which is approximately 200°F higher than the anticipated magnet temperature during loop operation. The magnetic flux as a function of temperature is shown in Table III in the room temperature to 900°F range. These values are used in calculating the sodium flow rate at the operating temperature.

The flow tube is fabricated from a 0.375-inch OD Cb-lZr tube with 0.065-inch wall. The electrodes are 0.062-inch diameter Cb-lZr wire which was purchased to the same chemistry specifications as the tube to minimize the spurious thermal emf which could result from dissimilar materials at operating temperatures. A calculated output voltage as a function of flow rate for the loop flowmeter is shown in Figure 6.

C. METERING AND ISOLATION VALVES

Refractory alloy, bellows sealed valves are not commercially available because of the limited demand for refractory valves. The procurement of refractory valves even on special order is a complex process since commercial valve manufacturers are not familiar with refractory metal properties and technology and do not have the special welding and heat treating facilities required in joining refractory alloy parts. However, arrangements can be made with several valve manufacturers to design and machine all necessary valve components with the welding, heat treating and material control being done by the customer.

The design of the metering and isolation valves was subcontracted to Hoke, Inc., Cresskill, New Jersey; a commercial valve manufacturer with an

(a) Magnetic Materials Section, General Electric Company, Edmore, Michigan.

TABLE III

MAGNETIC FLUX VS TEMPERATURE OF THE ALNICO V FLOWMETER
MAGNET AFTER THERMAL STABILIZATION AND PRIOR TO THE LOOP TEST

Magnet Temp., °F	Magnetic Flux, Gauss		
	Run #1	Run #2	Run #3
70	2675	2675	2675
200	2675	2675	2675
400	2675	2675	2675
500	2675	2675	2675
600	2675	2610	2675
700	2675	2610	2675
800	2610	2610	2675
900	2610	2610	2610

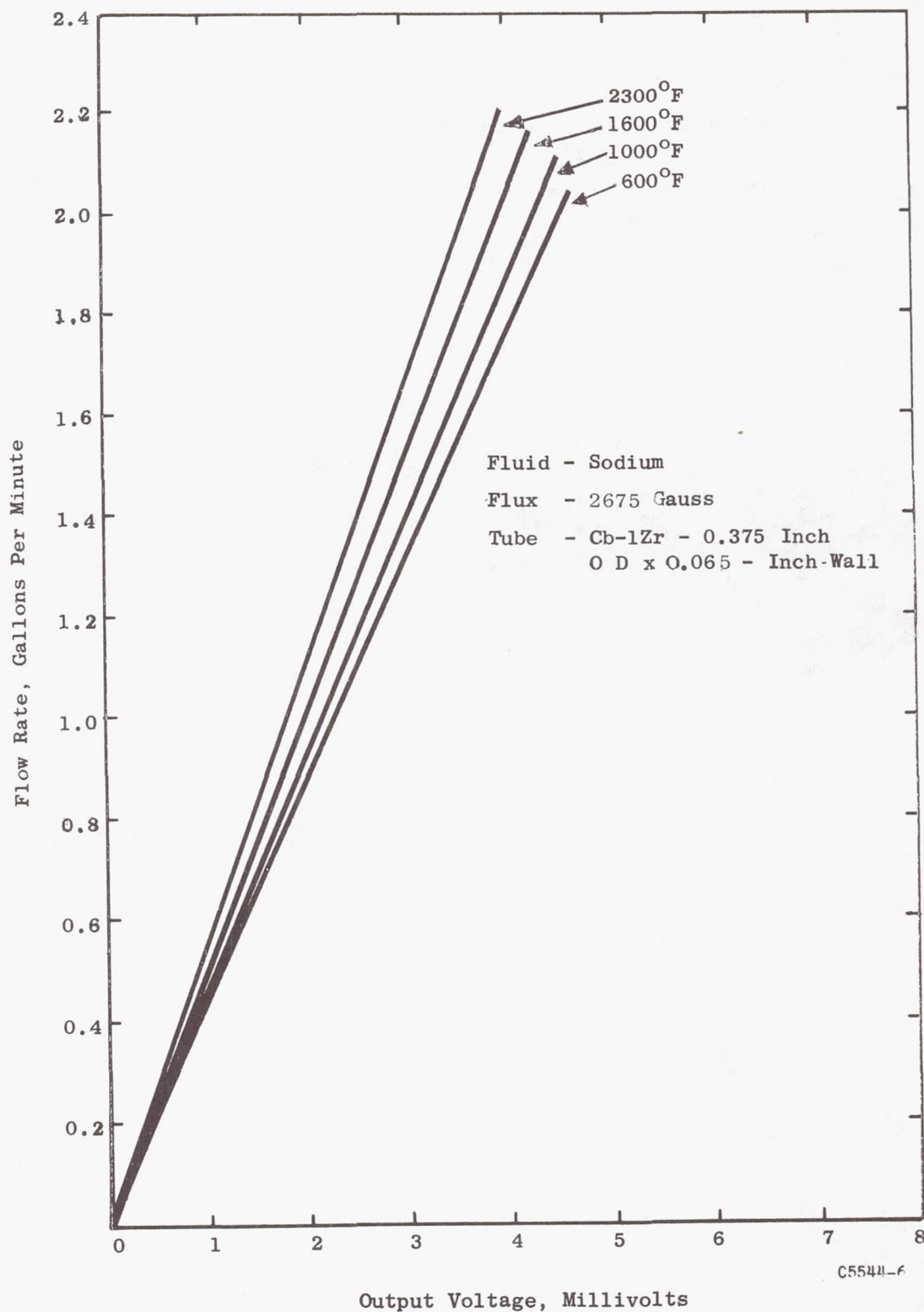


Figure 6. Calculated Output Voltage Versus Flow Rate for the Cb-1Zr Pumped Sodium Loop Permanent Magnet Flowmeter.

established reputation in manufacturing stainless steel valves for alkali metal systems. The general design specifications submitted to Hoke, Inc. were as follows:

Type: Bellows seal, manually operated

Maximum Body Temperature: 1800°F

Maximum Pressure: 200 psia

Flow Rate: 0.25 gpm

Fluid: Potassium or sodium

Materials: All parts in contact with process fluid to be Cb-1Zr
except a molybdenum-TZM alloy plug and plug pin

Connections: 0.375-inch x 0.065-inch wall Cb-1Zr tube

Environment: 1×10^{-8} torr

The results of the design effort by Hoke, Inc. was the Type CB-442 valve shown in Figure 7. An outline drawing of the valve giving rating and specification information is included in Appendix A. GE-SPPS's main effort in the design of the valve was in the specification and procurement of materials, and the detail design of the welded joints especially the bellows assembly. Bellows fabrication and associated heat treatments as well as the quality assurance tests performed on this component are described in Section IV, Loop Fabrication.

The valve design was modified by GE-SPPS so that the valve could be manually operated from outside the vacuum chamber. The actuation system consisted of an ultra-high vacuum, rotary, magnetic feedthrough connected by a flexible stainless steel shaft to a 3-to-1 right angle gear drive mounted on the valve yoke. The right angle gear drive is required to eliminate a compound bend in the flexible shaft since the rotary feedthrough is located below the valve. The magnetic rotary feedthrough for both the metering and isolation valve is shown in Figure 8. This feedthrough transmits torque into a vacuum chamber by magnetic coupling between an external multi-pole magnet and an internal rotor having the same number of poles. The thin-walled rotor housing of nonmagnetic stainless steel constitutes an all-metal, leak-tight vacuum wall. Both the rotor and the external magnet are mounted on ball bearings for low friction operation.

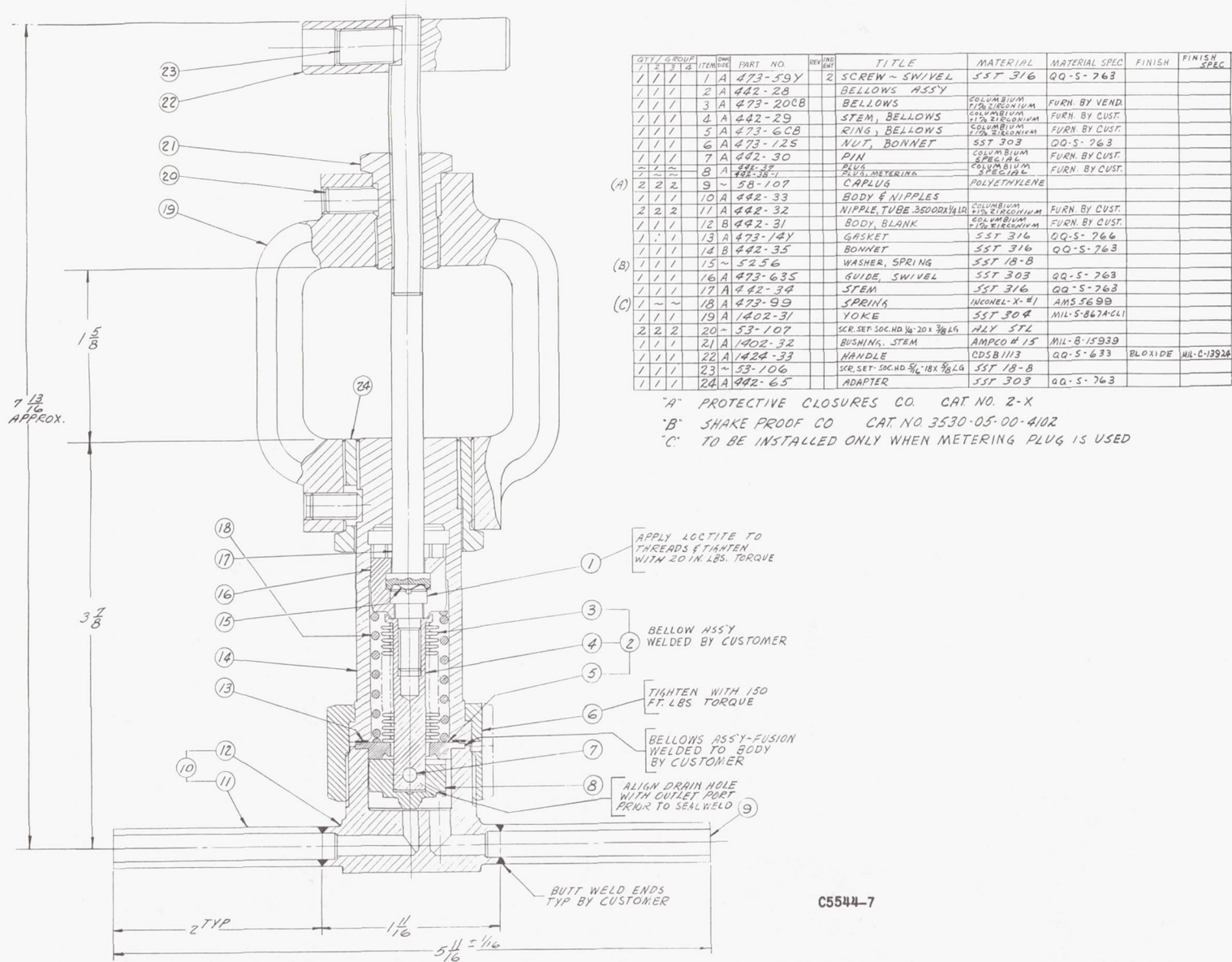


Figure 7. Manual Valve for Metering and Isolating Sodium in the Cb-1Zr Pumped Sodium Loop.

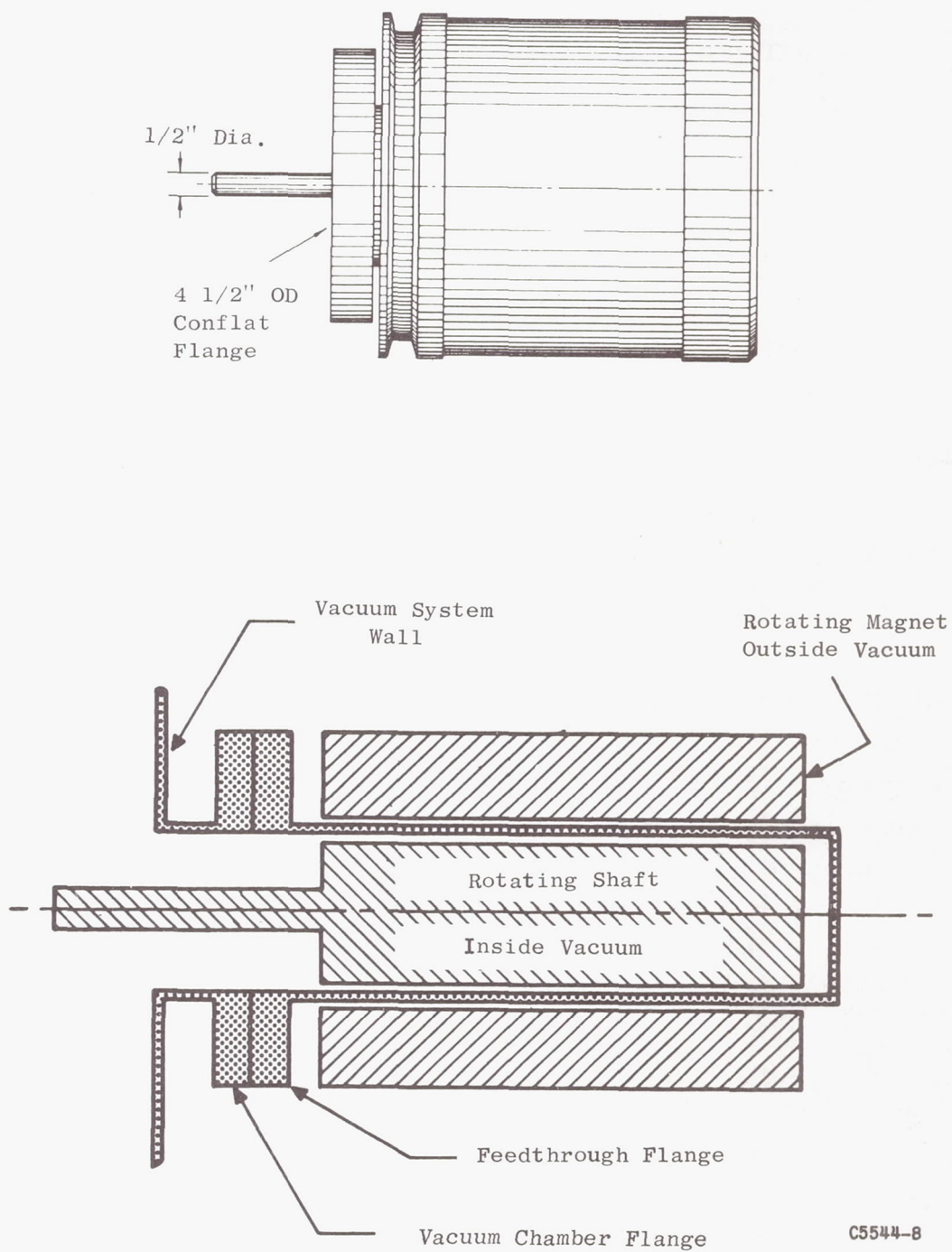


Figure 8. Outline Drawing and Schematic Drawing of Magnetic Rotary Feedthrough. Varian Associates Model No. 954-5039

D. SLACK DIAPHRAGM PRESSURE TRANSDUCER

The most commonly used alkali metal pressure measuring device in high temperature alkali metal test loops is the stainless steel slack diaphragm pressure transducer manufactured by Taylor Instrument Companies, Rochester, New York. The basic transducer shown in Figure 9 consists of a 2.5-inch OD diaphragm housing containing a 0.005-inch thick diaphragm which separates the process fluid from the NaK filled capillary tube. The complete pressure measuring system as received from Taylor Instrument Companies prior to attachment to the loop is shown in Figure 10. The pressure of the process fluid is transmitted across the Cb-1Zr slack diaphragm through the NaK filled capillary tube to a bourdon tube. The deflection in the bourdon tube controls the position of the indicating pointer and at the same time moves a core in a linear variable differential transformer. The output of the differential transformer is fed to a solid state transmitter amplifier giving a 1 to 5 ma DC output.

A refractory alloy pressure transducer is not available from Taylor Instrument Companies since they do not have the special welding and heat treating facilities required in joining refractory parts. However, arrangements were made with Taylor for this firm to design and fabricate all non-refractory parts with GE-SPPS supplying all refractory materials and performing all welding and heat treatment of refractory alloy weldments. Taylor was required to fill and seal the NaK capillary tube, supply a sample of the NaK used to fill the capillary tube in a specially designed sampler, and to calibrate each transducer before final shipment to GE-SPPS.

The general specifications for the slack diaphragm pressure transducer were as follows:

Pressure Range: 0-150 psia

Response: Approximately 1 cycle per second

Maximum Operating Temperature: 2000°F

Calibration Accuracy: 1% of full scale.

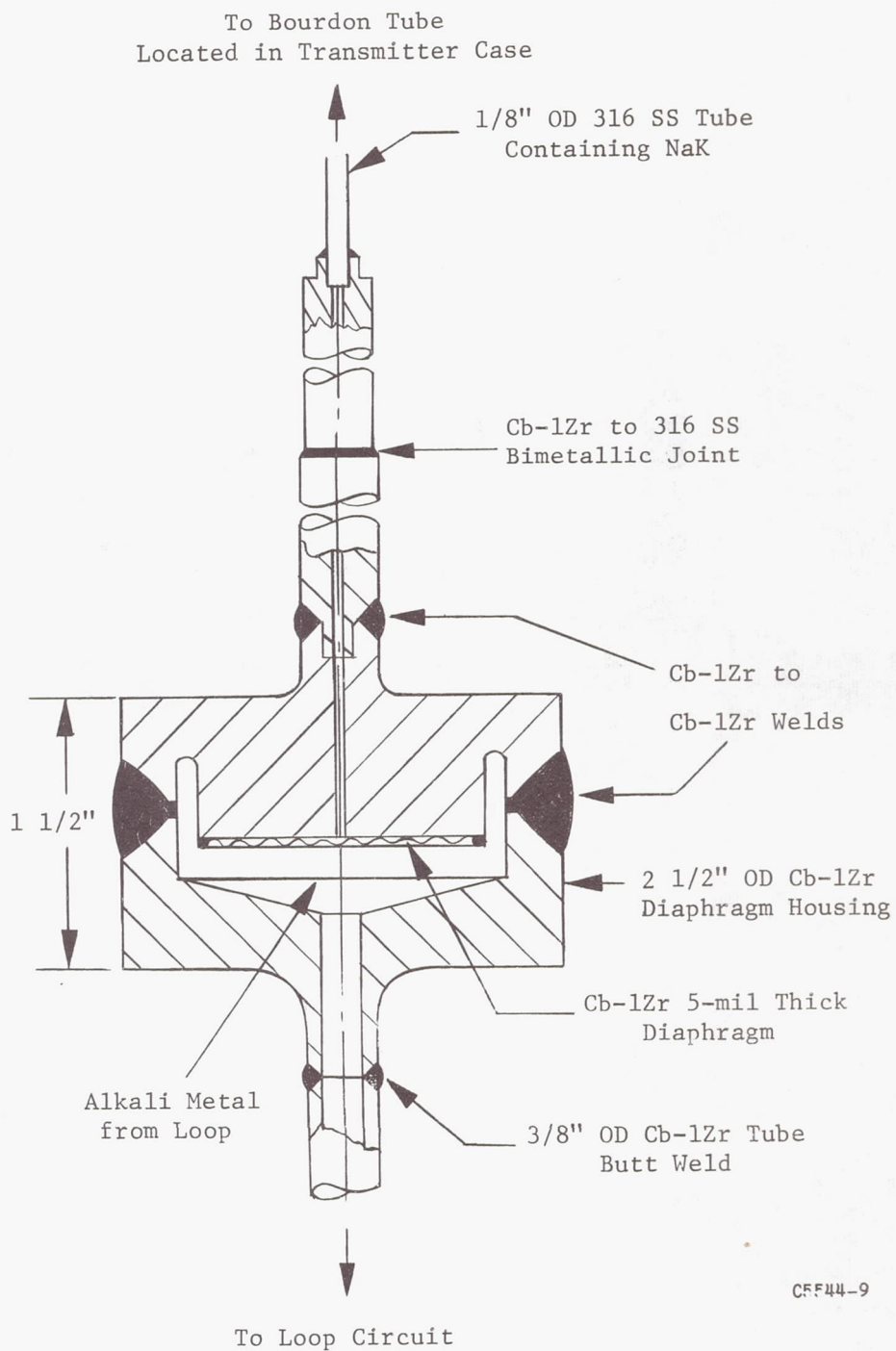
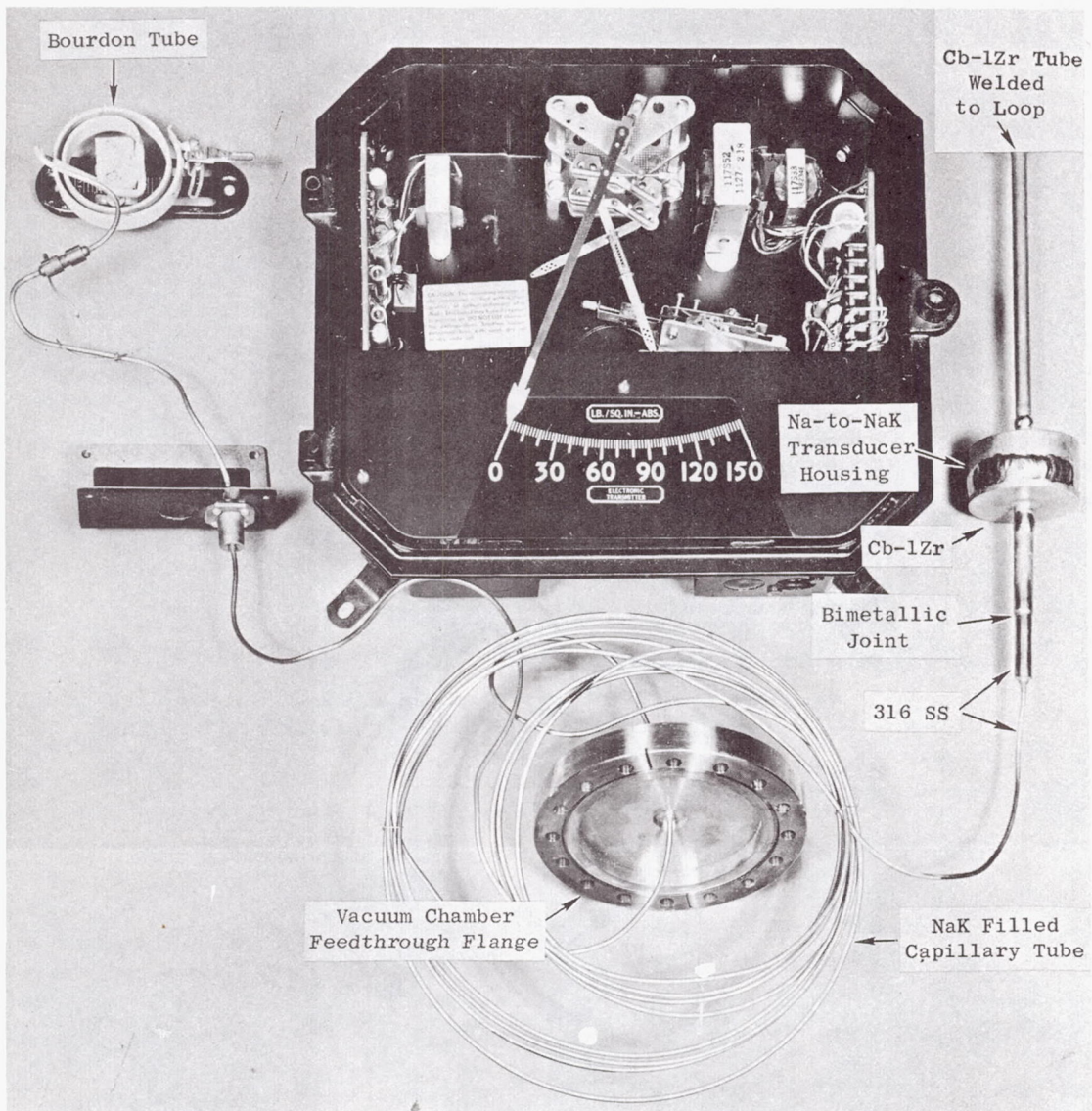


Figure 9. Slack Diaphragm Pressure Transducer from Taylor Instrument Companies, Drawing No. SK14427.



C5544-10

Figure 10. Components of the Slack Diaphragm Pressure Measuring System.
(C66021409)

The major design change was the substitution of Cb-1Zr for stainless steel in the diaphragm and diaphragm housing. The transition from the Cb-1Zr transmitter to the stainless steel capillary tube was made with a Cb-1Zr to stainless steel brazed bimetallic joint. The high vacuum feedthrough flange shown in Figure 10 was welded to the capillary tube approximately mid-way between the bourdon tube and the diaphragm housing so that the bourdon tube and associated readout equipment could be located outside of the vacuum chamber since the transmitter is limited to an ambient temperature range of -20 to +150°F.

E. STRESSED DIAPHRAGM PRESSURE TRANSDUCER

A high frequency response pressure transducer was required to measure the frequency and amplitude of the pressure fluctuations in the potassium boiler of the Cb-1Zr Rankine System Corrosion Test Loop. A stainless steel absolute pressure transducer with high frequency response (0.2 to 2 milliseconds) was commercially available from the Consolidated Control Corporation, Bethel, Conn. and had been successfully operated on several liquid metal test loops at GE-SPPS.⁽⁴⁾ A redesign of the transducer to substitute refractory alloys was undertaken in cooperation with Consolidated Controls Corporation. The standard model of this transducer has a stainless steel housing and an Inconel X stressed diaphragm. Because of the limited corrosion resistance of the conventional superalloys it was desired to change both the diaphragm and the diaphragm housing materials to refractory alloys. The tantalum alloy, T-111,^(a) was chosen in preference to the more widely used Cb-1Zr composition because of the superior creep strength of the tantalum alloy.

(a) Nominal Composition: Ta-8W-2Hf

(4) Alkali Metals Boiling and Condensing Investigations, Vol. 1 - Experimental Program, Edited by R. D. Brooks, NASA CR-54050, June 1, 1964, p. 170.

The basic parts of the stressed diaphragm pressure transmitter are illustrated schematically in Figure 11. They include a pressure sensing element (stressed diaphragm), a rod with one end joined to the diaphragm and a slug attached to its free end and a differential transformer. Any deflection of the diaphragm moves the rod with the slug within the differential transformer. The basic design change was limited to the pressure transmitter; the differential transformer and the sensing circuit were retained from the original design and were purchased from Consolidated Controls Corporation.

The 1.0-inch diameter x 0.015-inch thick flat T-111 stressed diaphragm is welded to a **heavy** wall housing to form the liquid metal seal. T-111 tantalum alloy was also selected for the housing to minimize warping of the diaphragm during welding and to eliminate thermal stresses in the diaphragm during loop operation. The detail drawings of the stressed diaphragm pressure transducer are included in Appendix A.

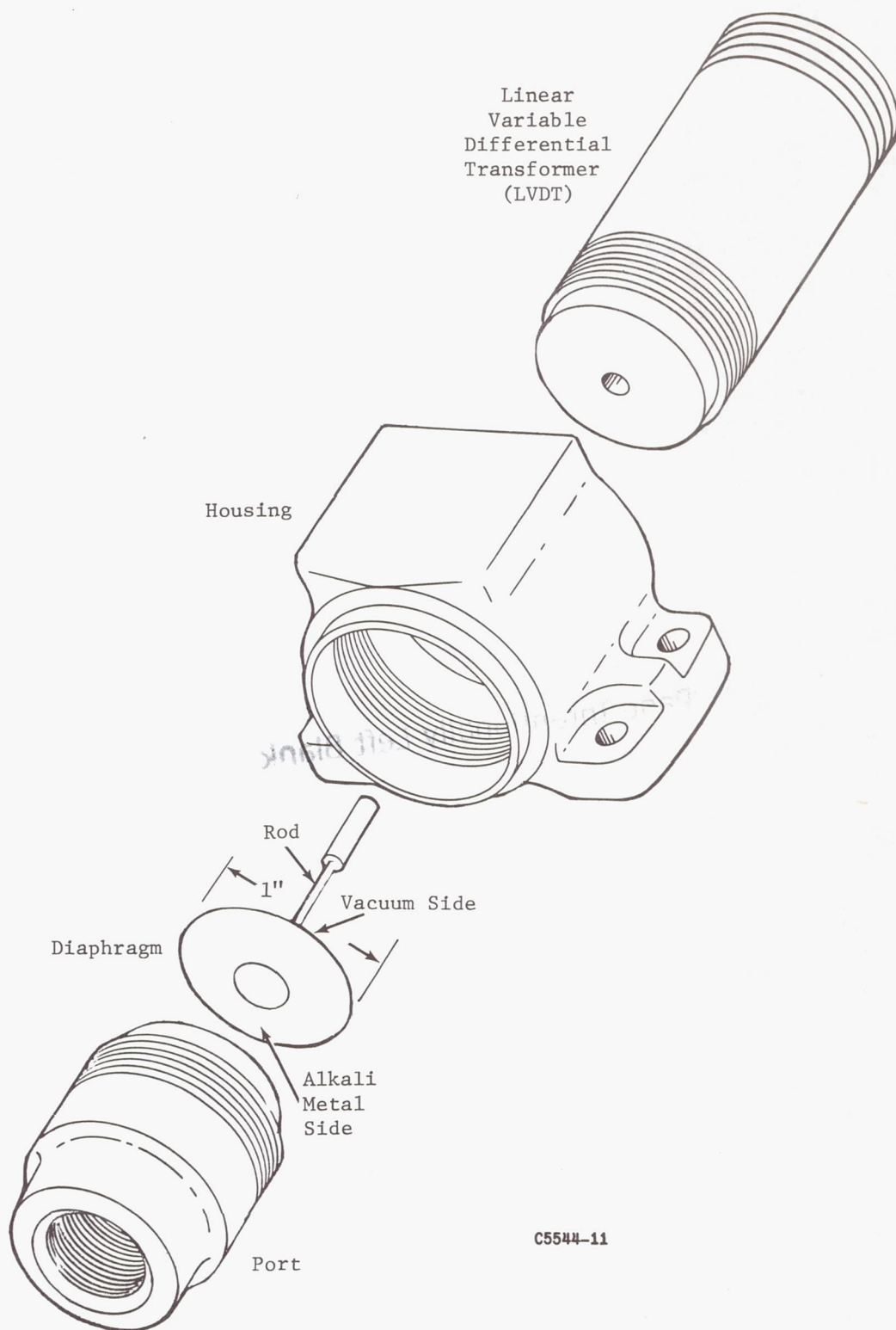


Figure 11. Exploded View of the Stressed Diaphragm Pressure Transducer, Consolidated Control Corporation, Bethel, Connecticut.

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III. MATERIAL PROCUREMENT

The procedures and specifications utilized on this program to obtain the highest quality refractory alloy materials commensurate with the existing technology were described in detail in an earlier topical report⁽⁵⁾ in this series. General Electric-SPPS specifications cited in this report may be found in the referenced report.⁽⁵⁾

A quality assurance program was established to provide adequate identification and documentation of the quality of the refractory alloys used in the construction of the test loops. In addition, the information acquired in the quality assurance program fulfilled the material documentation required for the test history of the loop components.

The majority of the quality assurance measures utilized to evaluate incoming material were performed by the materials producers, and check tests performed by the General Electric Company generally were limited to chemical analyses to determine the concentration of the interstitial elements, metallographic examination, hardness measurements, and visual inspection.

Upon receipt of material from the material producers, a Material Control Number (MCN) was assigned to each homogeneous lot of material. A homogeneous lot included all material of the same size, shape, condition, and finish from one heat of material and which had received the same processing, had been annealed in the same vacuum annealing charge, and had been processed in the same manner in all operations in which the processing temperatures exceeded 500°F.

(5) Frank, R. G.. et al., Material and Process Specifications for Refractory Alloy and Alkali Metals - Potassium Corrosion Test Loop Development Topical Report No. 2, R66SD3007, December 13, 1965, General Electric Company, Cincinnati, Ohio.

A listing of the refractory alloy mill products procured for the program, the specifications to which they were procured, and the results of the quality assurance tests was presented in the earlier report.⁽⁵⁾ Appendix C, Loop Component and Materials List, of this report lists the material information pertinent to the Cb-1Zr Pumped Sodium Loop. The part name, part drawing number and Material Control Number of the various materials used to fabricate each component are given.

One product, the 3/8-inch OD x 0.008-inch wall thickness Cb-1Zr tube (MCN-410), had to be procured on an "aim for" basis because of a lack of background data and experience to ensure the vendor of meeting the specification. The resulting product was higher in oxygen concentration (approximately 800 ppm) than desired. This tubing was used to fabricate bellows for the alkali metal metering and isolation valves of the loop. Although these bellows performed without difficulty in both the Cb-1Zr Pumped Sodium Loop and the Cb-1Zr Rankine System Corrosion Test Loop, which will be described in Topical Report No. 7 of this series, some apprehension was associated with the use of thin walled material of this oxygen concentration. Subsequent to the fabrication and testing of the bellows sealed valves cited above an additional procurement effort succeeded in obtaining thin walled Cb-1Zr tubing having less than 350 ppm oxygen and this tubing can be used in fabricating bellows for valves in future tests.

In summary, high quality mill products were obtained for the fabrication of the Cb-1Zr Pumped Sodium Loop.

IV. LOOP FABRICATION

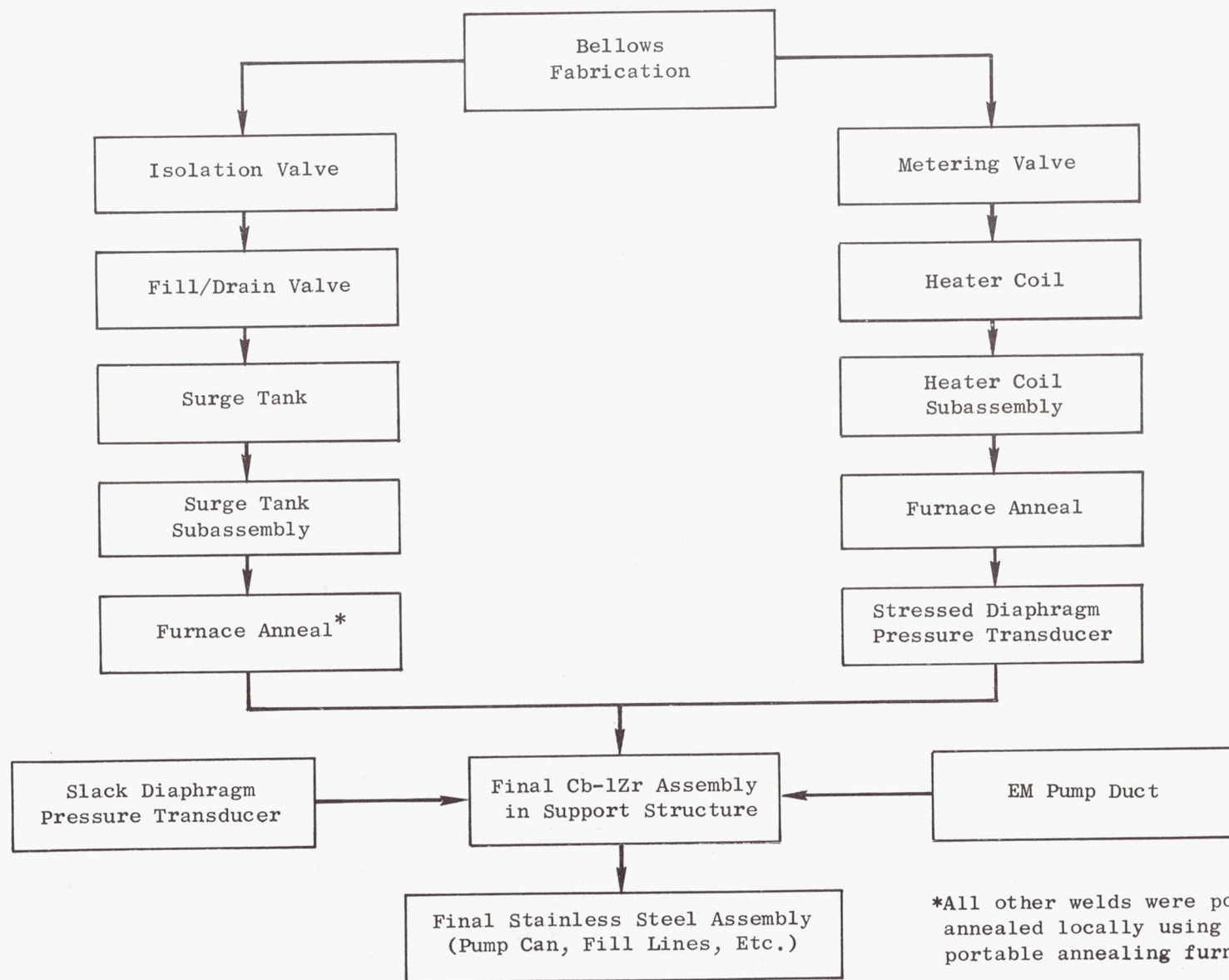
The overall fabrication sequence for the Pumped Sodium Loop is illustrated in Figure 12. Loop assembly required two subassemblies, the surge tank and the heater coil. Postweld annealing of these subassemblies was done at 2200°F for 1 hour in a vacuum furnace. Subsequently, these subassemblies were joined and the stressed diaphragm transducer was welded into the heater coil subassembly. The Cb-1Zr components were then assembled in the support structure and vacuum chamber spool section for welding of the EM pump duct and the slack diaphragm pressure transducer. Postweld annealing of these welds was done locally using a small refractory metal annealing furnace positioned over the weld joint.

The Pumped Sodium Loop components as delineated in Figure 12 were the surge tank, heater coil, three bellows sealed valves, a stressed diaphragm pressure transducer, EM pump, and a slack diaphragm pressure transducer. Each component and the welding procedures employed will be discussed individually below.

A. GENERAL WELDING PROCEDURES

Prior to the welding of the Pumped Sodium Loop components, a preliminary qualification test of the welding equipment was conducted according to requirements defined in Specification SPPS-3C. This specification requires that the inert gas be purified to contain less than 1 ppm active impurities by volume and that the contamination of the weld metal be held to less than 50 ppm oxygen, 50 ppm nitrogen, 10 ppm carbon, and 5 ppm hydrogen. The mass spectrometer helium analysis system, which was used to monitor the gas purity during the welding of the Cb-1Zr Rankine System Corrosion Test Loop and is described in an earlier report,⁽⁶⁾ was not yet in operation. Preliminary monitoring of the purified helium used to

(6) Lyon, T. F., Purification and Analysis of Helium for the Welding Chamber, Potassium Corrosion Test Loop Development Topical Report No. 1, NASA CR-54168, General Electric Company, Cincinnati, Ohio, July 1, 1965.



C5544-12

Figure 12. Fabrication Sequence of the Cb-1Zr Pumped Sodium Loop.

back-fill the chamber was conducted using a Brady apparatus to determine the oxygen concentration and a dewpoint cup to determine the moisture concentration. For the qualification test, the chamber was evacuated to less than 1×10^{-5} torr and had a leak rate of 2.3 microns per hour prior to filling with helium (99.99% purity) which was passed through the Linde Type 13X molecular sieve. Hot trapping and analysis of the helium was not conducted for this equipment qualification test. The results of chemical analyses of the weld metal and postweld annealed specimens satisfied the requirements of Specification SPPS-3C and are compared with the base material and filler wire in Table IV.

The welding chamber in which these tests were conducted and in which the Pumped Sodium Loop was constructed is shown in Figures 13 and 14. No field welds were used in the fabrication of this loop. The large welding tank volume required to accommodate the loop during final assembly was provided by the 8-foot diameter extension tank shown in Figure 14.

B. BELLOWS SEALED METERING AND ISOLATION VALVES

Three Cb-1Zr bellows sealed valves, one Hoke Modified Model 3B with a metering plug and two of the Hoke modified Model 3A valves with isolation plugs were required. The sequence of manufacturing operations was bellows fabrication (Standard-Thomson, Inc), welding of the bellows assembly (General Electric), final machining and fit-up of plugs and valve bodies (Hoke, Inc) and the welding of the bellows assembly to the valve body (General Electric).

The bellows fabrication utilized Cb-1Zr tubing with interstitial element contents as compiled in Table V. The analysis of the Cb-1Zr material during the various stages of the fabrication are listed. The oxygen concentration, although higher than desired was representative of available thin-walled tube technology at the time as discussed in Section III, Materials Procurement. Further vendor liaison is indicated to improve the quality of both as-received tube and vacuum heat treating facilities. As may be noted in Table V, the bulk of the oxygen contamination of the bellows occurred during the fabrication of the thin wall tubing.

TABLE IV
RESULTS OF PRELIMINARY WELDING AND ANNEALING
QUALIFICATION TESTS^(a) WITH THE Cb-1Zr ALLOY

	Chemical Analysis, ppm			
	<u>O</u>	<u>N</u>	<u>H</u>	<u>C</u>
1. Base metal ^(b) analysis by vendor	130	85	1	50
2. Base metal analysis by General Electric	142	22	2	30, 40
3. Filler wire	59	25	1	40
4. Weld metal of this Qualification Test	106, 112	34, 41	2, 3	40
5. Base metal heat treated 1 hour at 2200°F in vacuum ^(c)	138	44	2	10, 20

(a) Welding and annealing in accordance to Specification SPPS-3C with the exception of the helium purification and analysis procedure.

(b) 0.040-inch thick Cb-1Zr sheet, MCN-417.

(c) Vacuum annealed in the Brew Model 424B furnace.

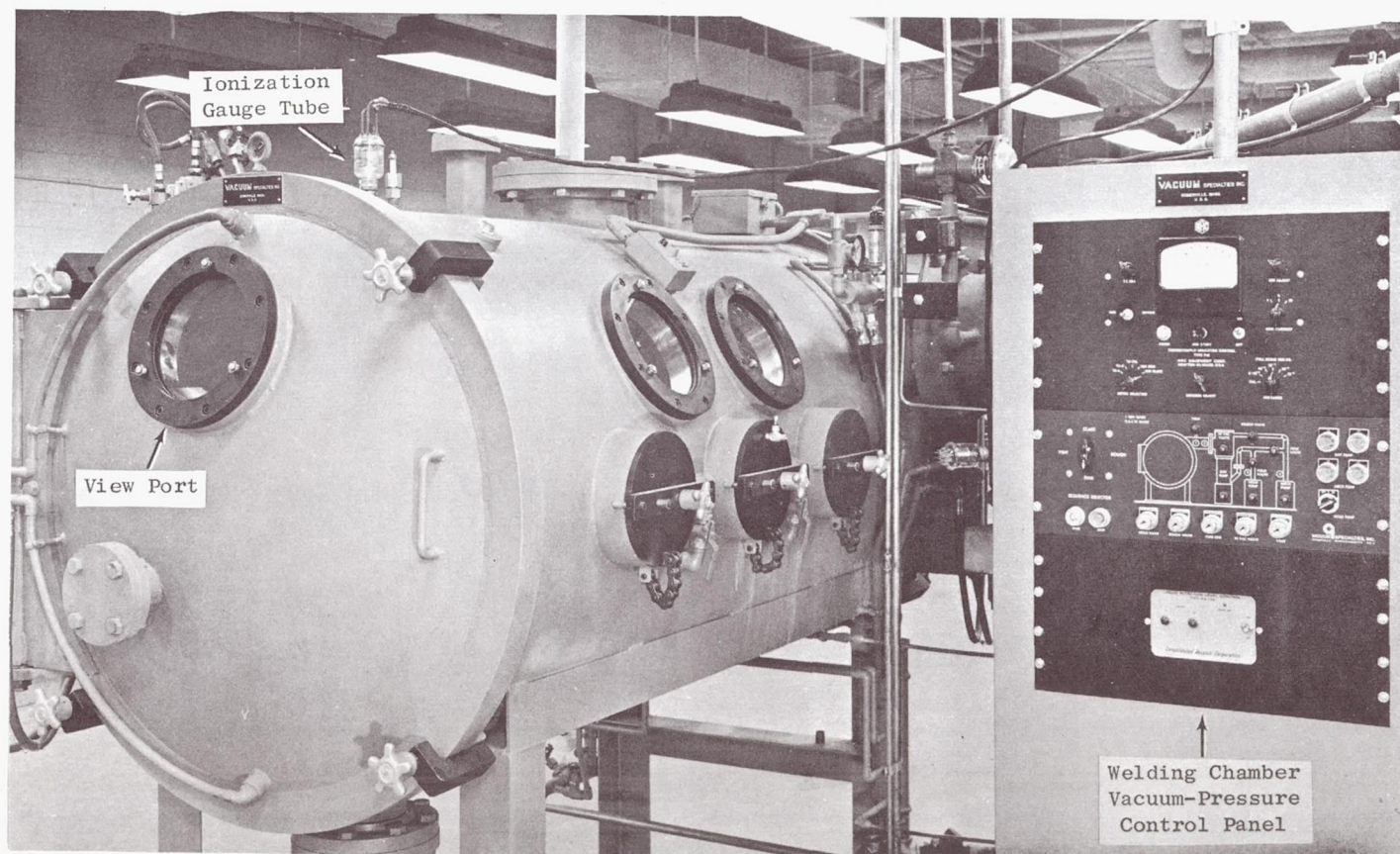
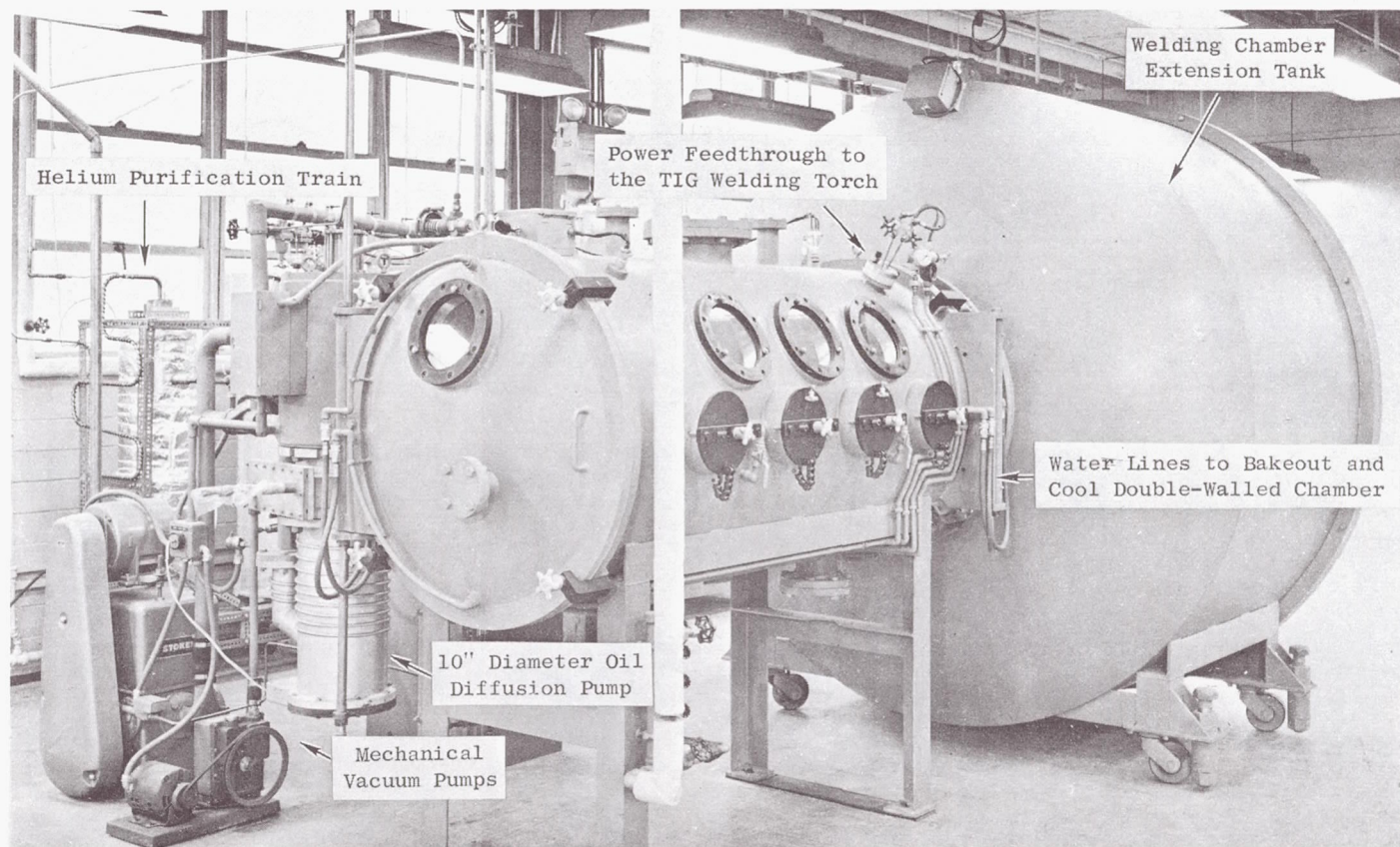


Figure 13. Vacuum-Purge, Controlled Atmosphere Welding Chamber, 3 Feet in Diameter x 6 Feet Long, Equipped with a 10-Inch Diameter Oil Diffusion Pump Capable of Attaining a Pumping Speed of 4100 l/sec at a Pressure of 1×10^{-5} Torr. (C63120630)

C5544-13



C5544-14

Figure 14. Overall View of the Vacuum-Purge, Controlled Atmosphere Welding Chamber with the Chamber Extension Tank (8 Feet in Diameter x 6 Feet Long) in Place. (C63120631)

TABLE V

RESULTS OF CHEMICAL ANALYSES BEFORE AND DURING BELLOWS FABRICATION

	Chemical Analysis, ppm			
	<u>C</u>	<u>O</u>	<u>N</u>	<u>H</u>
1. Ingot analysis (Superior Tube)	110	250	60	3
2. Target analysis ^(a)	200 (max)	500 (max)	300 (max)	50 (max)
3. Tube, as-shipped ^(b) (Superior Tube)	210	660	72	9
4. Tube, as-received (General Electric)	190, 220	868, 880	102, 104	7, 13
5. Tube after 1st vacuum heat treatment, 1 hour- 2300°F (Stellite Division, UCC)	140, 160	826, 828	106	1, 2
6. Tube after 1st forming and second heat treatment, 1 hour-2300°F (Stellite Division, UCC)	-----	1180, 1230	119, 87	1, 1

(a) Target analysis based on vendor experience. Material procured on a "best efforts" basis.

(b) Tube size: 0.375-inch OD x 0.008-inch wall.

This oxygen increase is attributed to in-process annealing which was considered to be proprietary information by the tubing vendor. The apparent oxygen increase during the final heat treatment is attributed to a large scatter in the oxygen concentration of the as-received tubing since the last anneal was supervised by General Electric using procedures which normally resulted in oxygen increases of less than 50 ppm.

The bellows fabrication by Standard-Thomson, Inc was done in two forming operations. The first forming operation produced the deformation illustrated in Figure 15. After intermediate heat treatment, at 2300°F for one hour, the second, more severe, forming was completed. After several trials, reduction of the hydraulic pressure and adjustment of other forming variables resulted in the production of high quality bellows, as indicated by the bellows cross section illustrated in Figure 16. The maximum thickness variation was approximately ten percent.

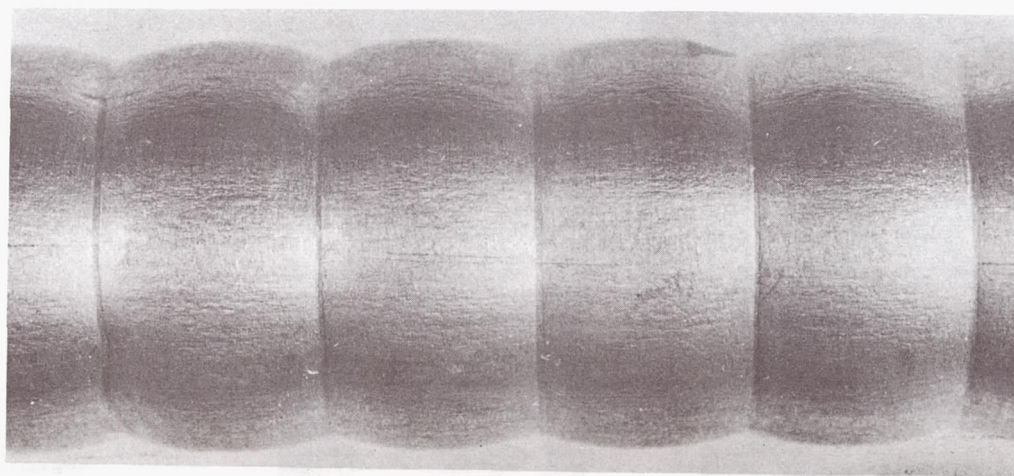
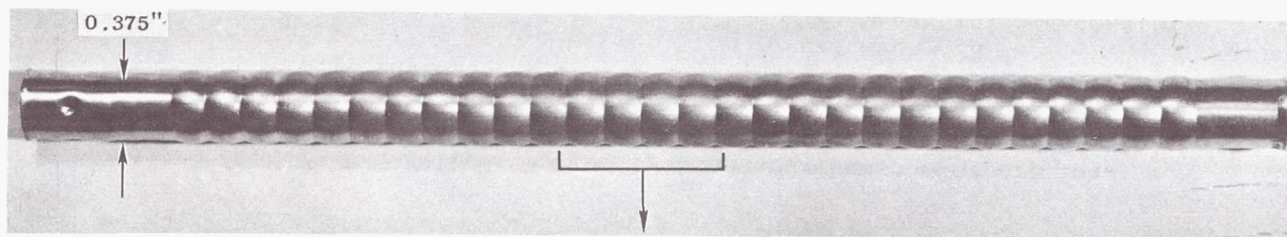
A total of 94 Cb-1Zr bellows were processed to assure that a minimum of 10 good bellows were obtained for making the required valves. Three processing paths were followed and the results are summarized in Table VI.

The completed bellows were delivered to Hoke, Inc for fitting to the bellows assembly. Two electron beam welds illustrated in Figure 17 were required to seal the bellows to the stem and valve ring. The completed bellows assembly and plug are shown in Figure 18 along with the valve body.

Final fabrication required only a seal weld between the bellows assembly and the valve body. To avoid any possible distortion of the valve, the electron beam welding process was utilized. A finished valve without the stainless steel components is shown in Figure 19. These components are illustrated in Figure 20 and shown assembled with the valve actuation system in Figure 21.

C. SLACK DIAPHRAGM PRESSURE TRANSDUCERS

Two Taylor Instrument Companies pressure transducers were fabricated, one being required for the Pumped Sodium Loop. Each transducer is comprised of upper and lower flanges, the slack convoluted diaphragm, process tube and



C5544-15

Figure 15. Cb-1Zr Alloy Bellows Following First Stage of Fabrication of Standard-Thomson, Inc. Starting Dimensions of Tube Blank = 0.375-Inch OD x 0.008-Inch Wall x 7-Inch Long.

(Top) Mag: 1.2X (C63122037)

(Bottom) Mag: 7X (C63122038)

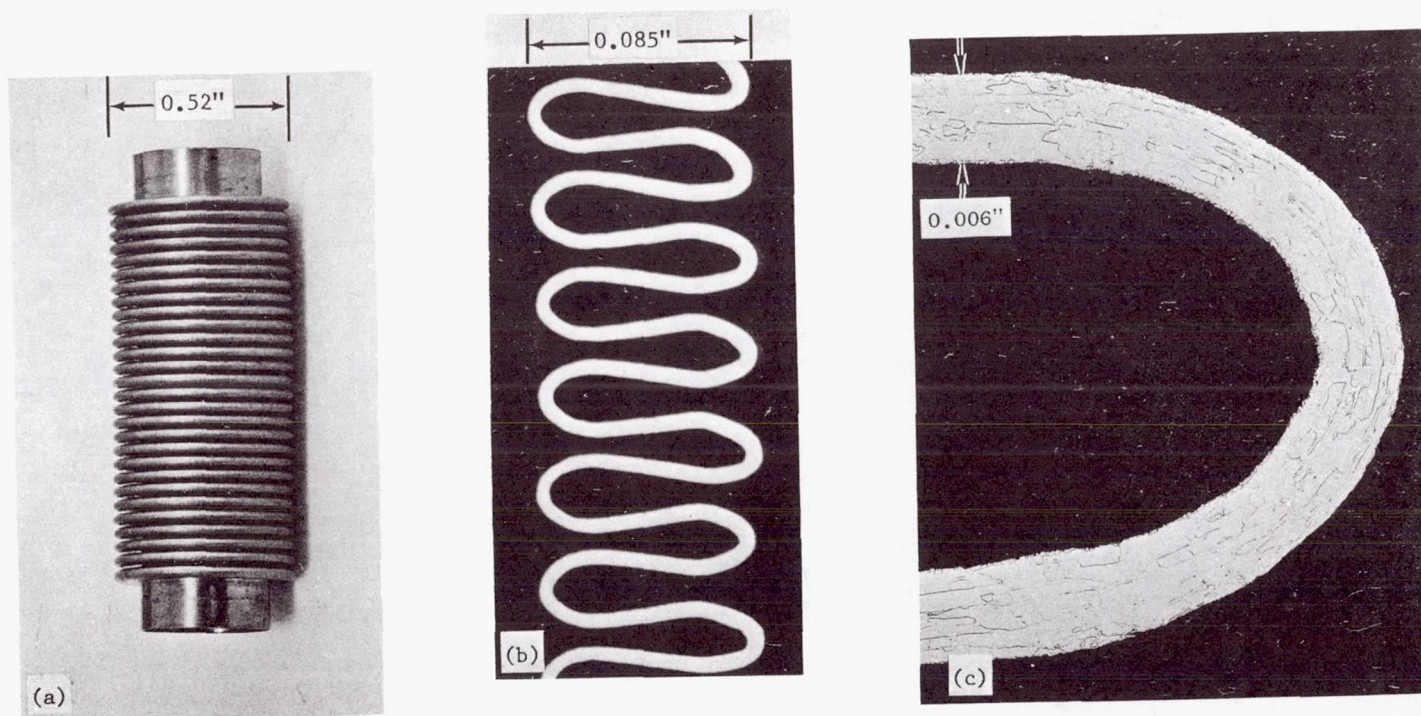


Figure 16. Cb-1Zr Bellows Formed by Standard-Thomson Corporation. Overall View of Bellows (a) and Cross Sections at Low (b) and High Magnification (c) Illustrate the Uniformity of the Convolutions and the Wall Thickness.

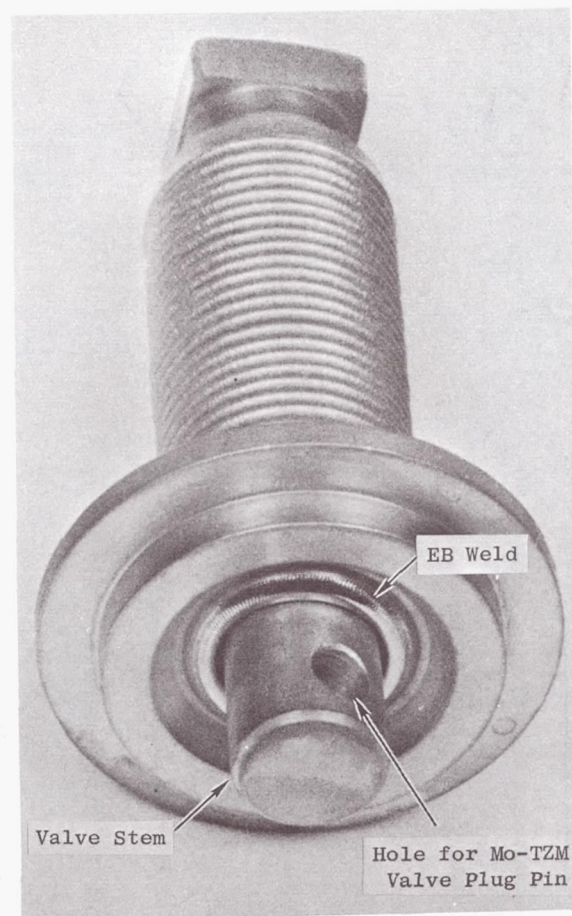
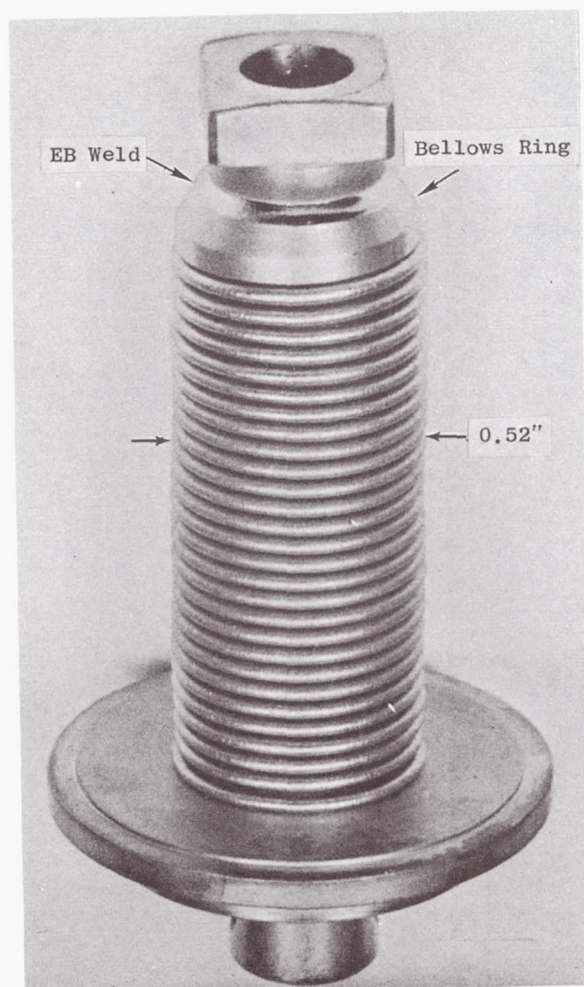
- a) Mag: 2X
- b) Mag: 14X (C64022123)
- c) Mag: 100X (K249)

TABLE VI

FABRICATION RESULTS OF Cb-1Zr BELLOWS

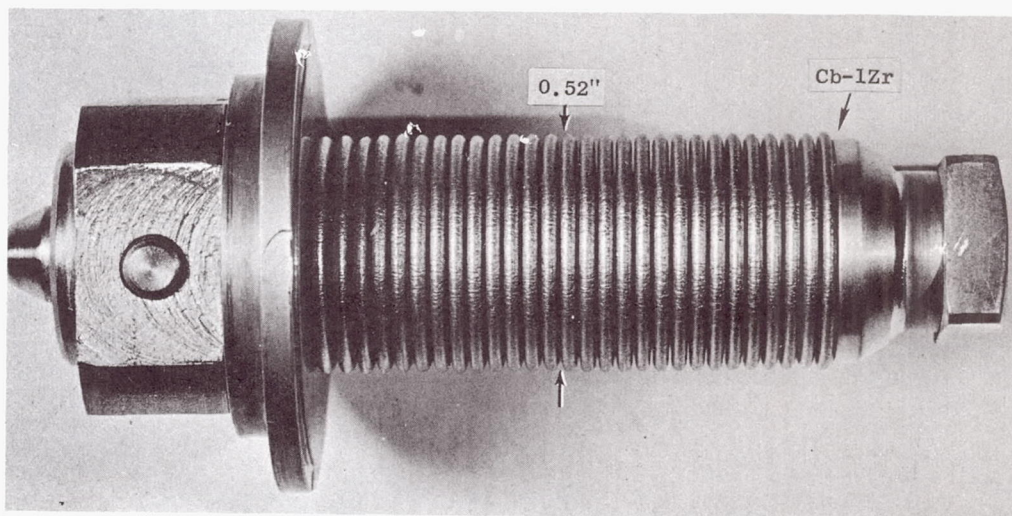
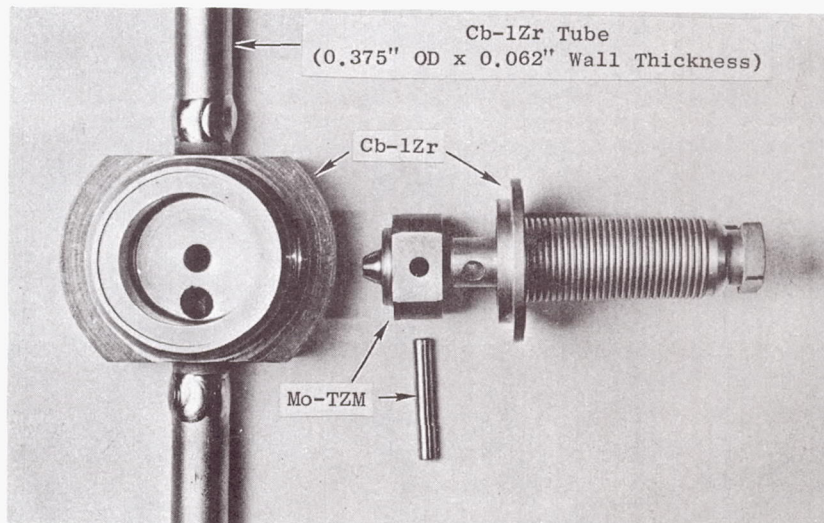
<u>Bellows History</u>	<u>Results</u>
1. a) Tube blanks annealed 1 hour-2300°F b) Initial forming operation at S-T ^(a) c) Annealed 1 hour-2300°F d) Final forming operation at S-T	Thirty-five of seventy-one bellows were tested and found to be helium leak tight by both S-T and G.E. Twenty of the thirty-five bellows were determined to be free of major surface defects as determined by microscopic examination at 30X.
2. a) Tube blanks annealed 1 hour-2300°F b) Initial forming operation at S-T c) Final forming operation at S-T	Two of seven bellows were helium leak tight.
3. a) Tube blanks annealed 1 hour-2300°F b) Final forming operation at S-T, no initial forming operation.	Three of sixteen bellows were helium leak tight.

(a) Standard-Thomson, Incorporated



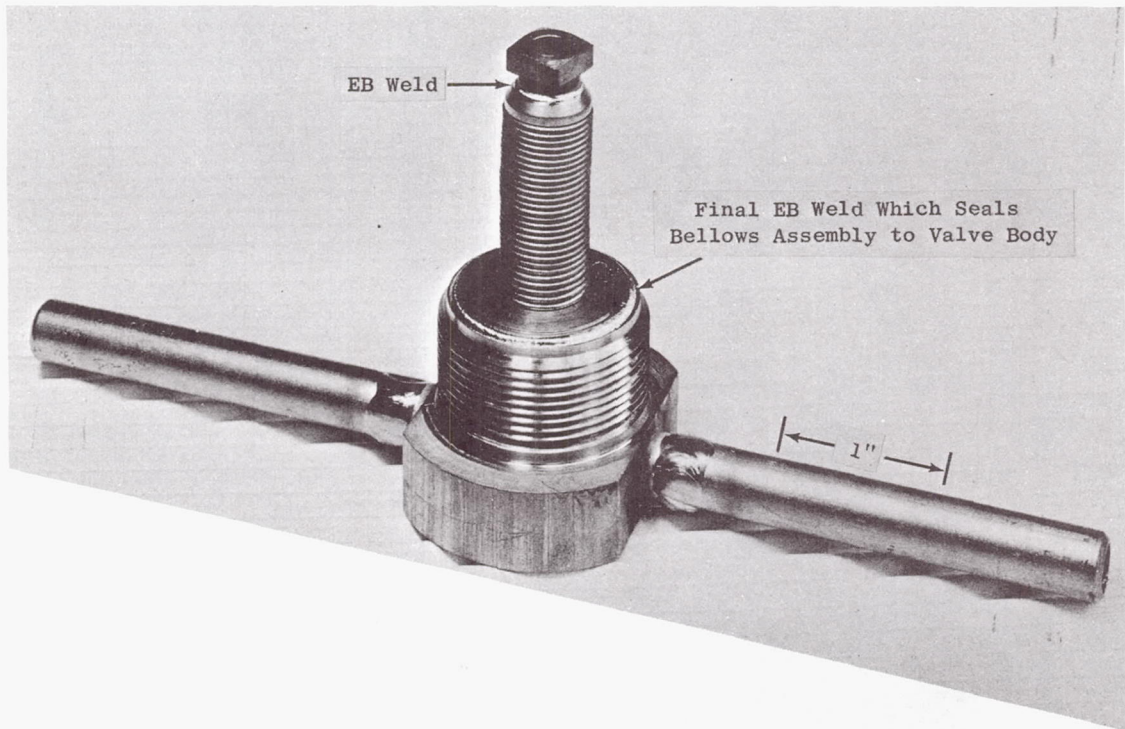
C5544-17

Figure 17. Cb-1Zr Bellows Assembly Showing Location of Electron Beam Welds. (C64030245)



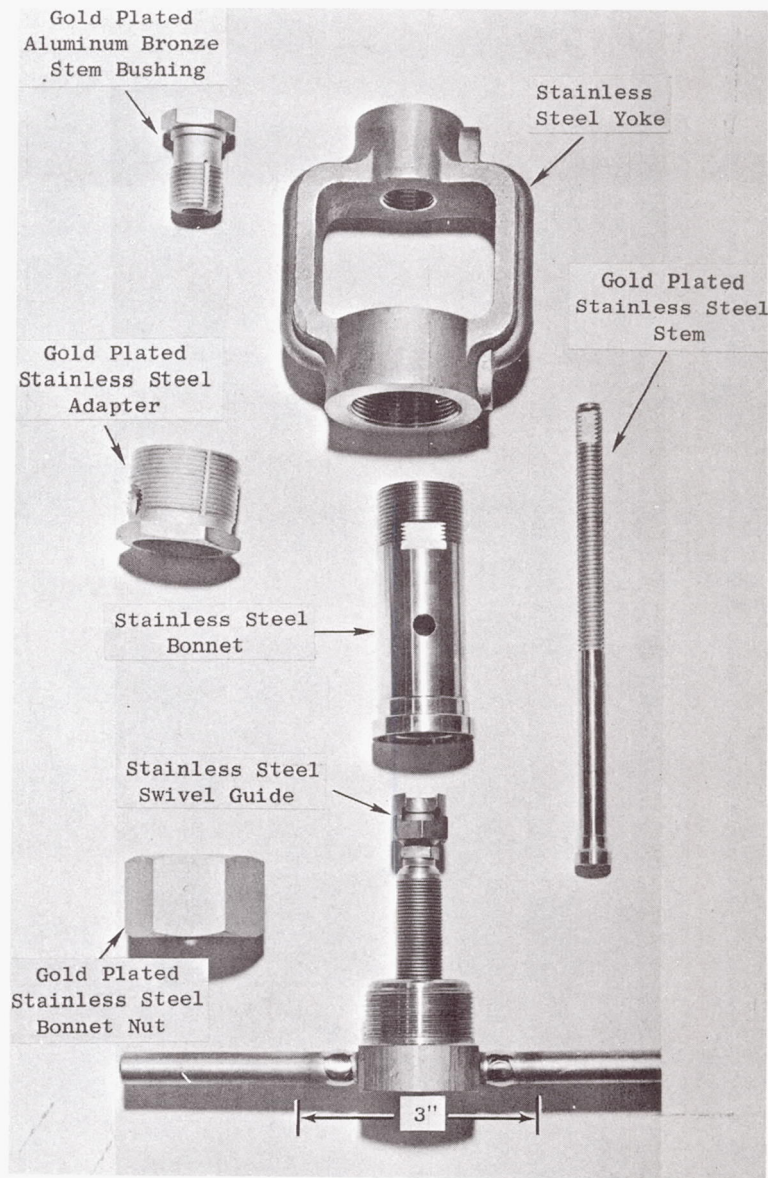
C5544-18

Figure 18. Modified Hoke Valve Prior to EB Welding of the Cb-1Zr Bellows Assembly to the Cb-1Zr Valve Body. (Orig. C64040205, C64040908)



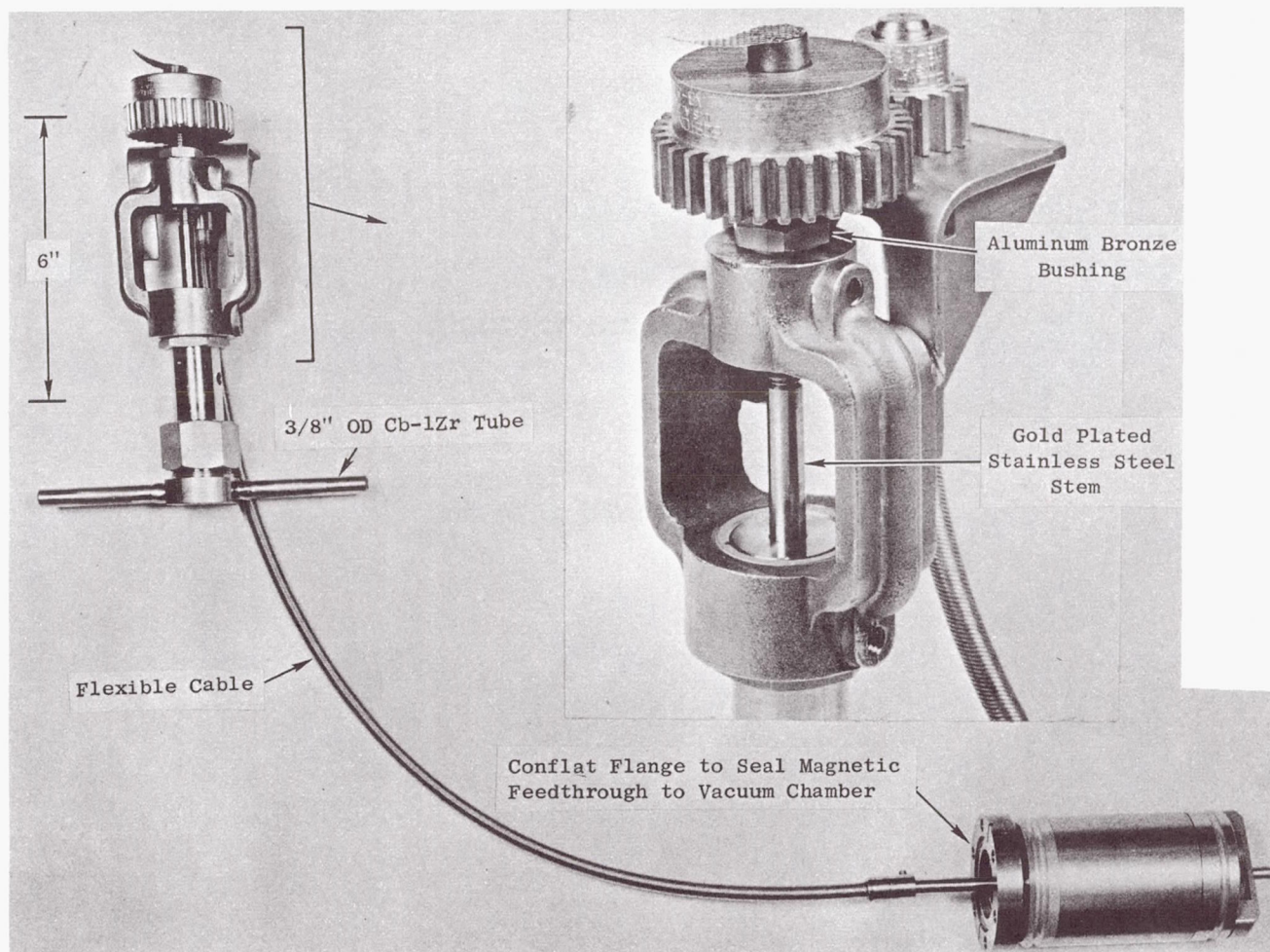
C5544-19

Figure 19. Modified Hoke Cb-1Zr Valve Body and Bellows Assembly.
(Orig. C64041328)



C5544-20

Figure 20. Exploded View of the Modified Hoke Valve. (Orig. C64060420)



C5544-21

Figure 21. Assembled Valve and Actuation System Including Flexible Stainless Steel Cable and Magnetic Rotary Feedthrough.
(Orig. C64090427, C64090426)

a bimetallic joint between Cb-1Zr and stainless steel. This joint of the brazed tongue-in-groove design, provided for attachment of the stainless steel capillary tubing by Taylor Instrument Companies.

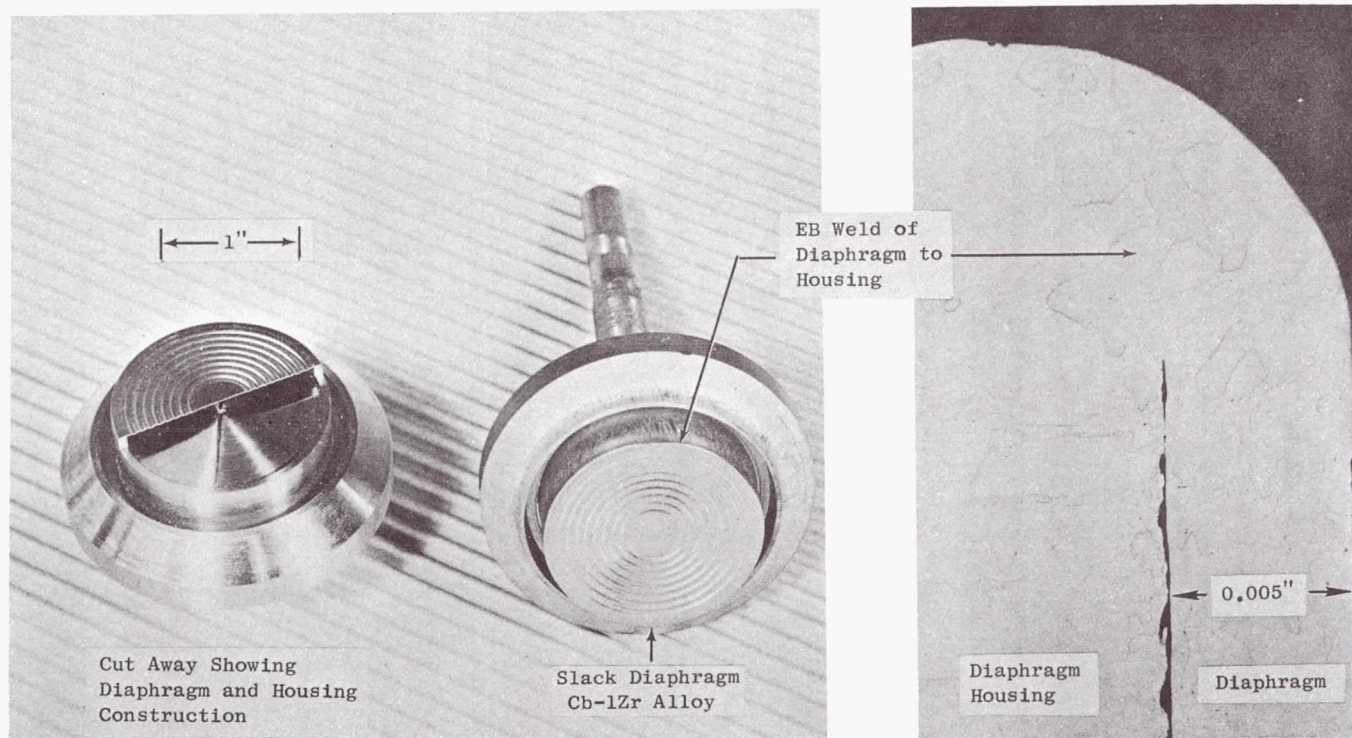
The weld between the diaphragm and upper flange was made by the electron beam process. Tungsten inert gas welding was used to join the process tube to the lower flange, the bimetallic joint assembly to the upper flange, and the final weld between the upper and lower flanges. The electron beam diaphragm weld is illustrated in Figure 22. A trial electron beam weld is shown on the left (22a) and the completed upper flange in the middle (22b). A metallographic cross section of this weld is shown in Figure 22c. The tungsten inert gas welding of the transducer housing is illustrated in Figure 23. Radiographic inspection, heat treatment, and mass spectrometer leak tests were performed successfully.

Two transducers were shipped to Taylor Instrument Companies for filling of the pressure transmitting capillary with NaK. Commercial purity NaK was used for filling since considerable program delay would have resulted if high purity NaK had been specified. A sample of the NaK used to fill the transducers was obtained using the sampler tube shown in Figure 24. Subsequent oxygen analysis by the amalgamation method indicated an acceptable 5 ppm oxygen level.

One of the completed slack diaphragm pressure transducer systems ready for joining to the loop was shown in Section II, Figure 10, of this report. Approximately twenty-five feet of NaK capillary tubing has been attached to the Cb-1Zr component to provide readout outside the vacuum chamber.

D. STRESSED DIAPHRAGM PRESSURE TRANSDUCER

The components of the stressed diaphragm transducer are shown in Figure 25. The 0.015-inch thick T-111 alloy (Ta-8W-2Hf) diaphragm is welded to a T-111 alloy housing which is, in turn, welded to a Cb-1Zr alloy body and process tube. A T-111 alloy probe mount is welded to the center of the diaphragm. The magnetic probe assembly is then brazed to the probe mount to complete the assembly.



C5544-22

Figure 22. Slack Diaphragm Pressure Transducer Diaphragm and Housing Following EB Welding.

a) and b): (Orig. C64021713)
 c) Etched: $20\text{HF}-20\text{HNO}_3-60\text{H}_2\text{O}$
 (Orig. K-492)



C5544-23

Figure 23. Photograph Taken Through the View Port of the Welding Chamber During the TIG Welding of the Slack Diaphragm Pressure Transducer Housings. (Orig. C64013149)

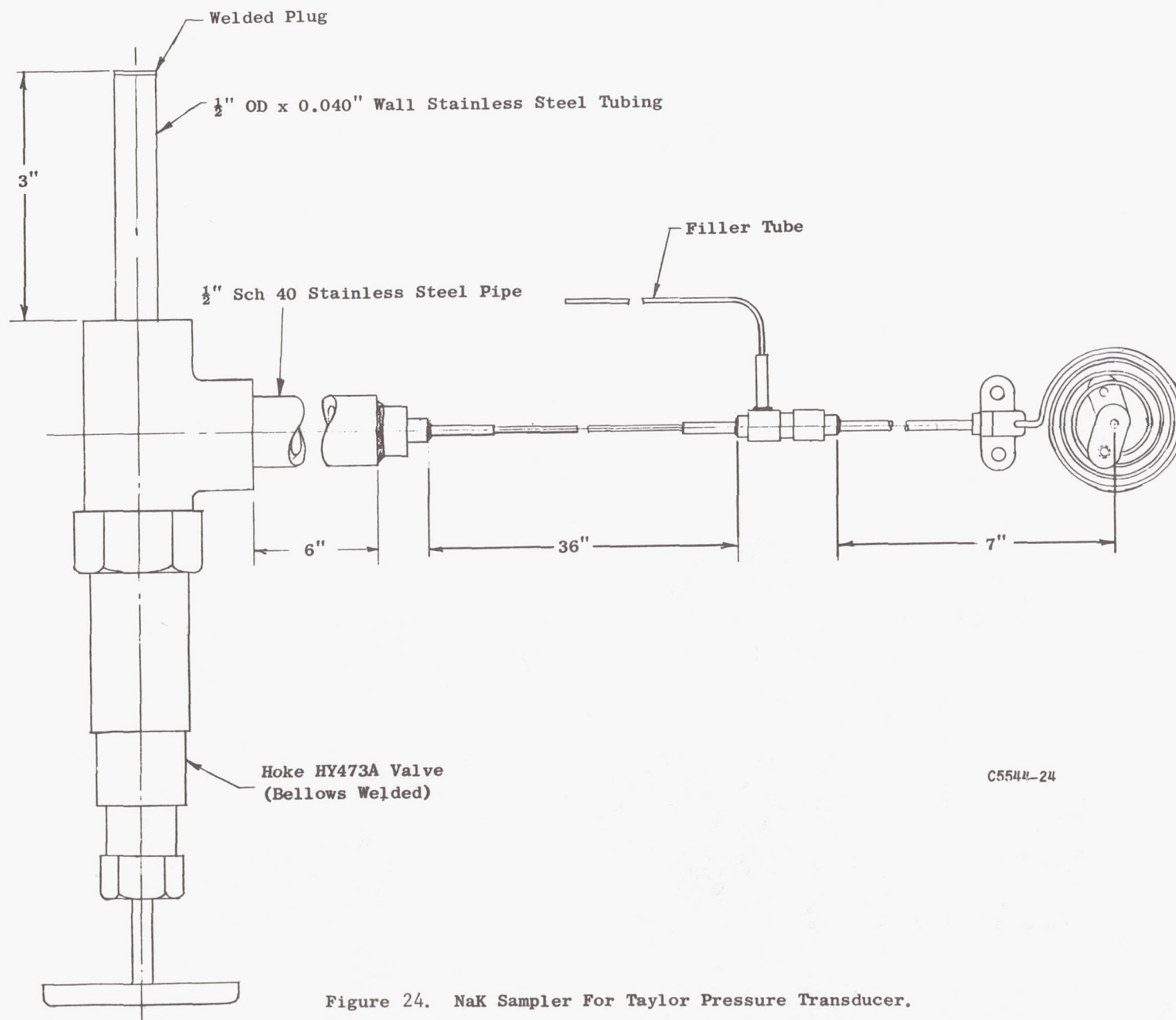
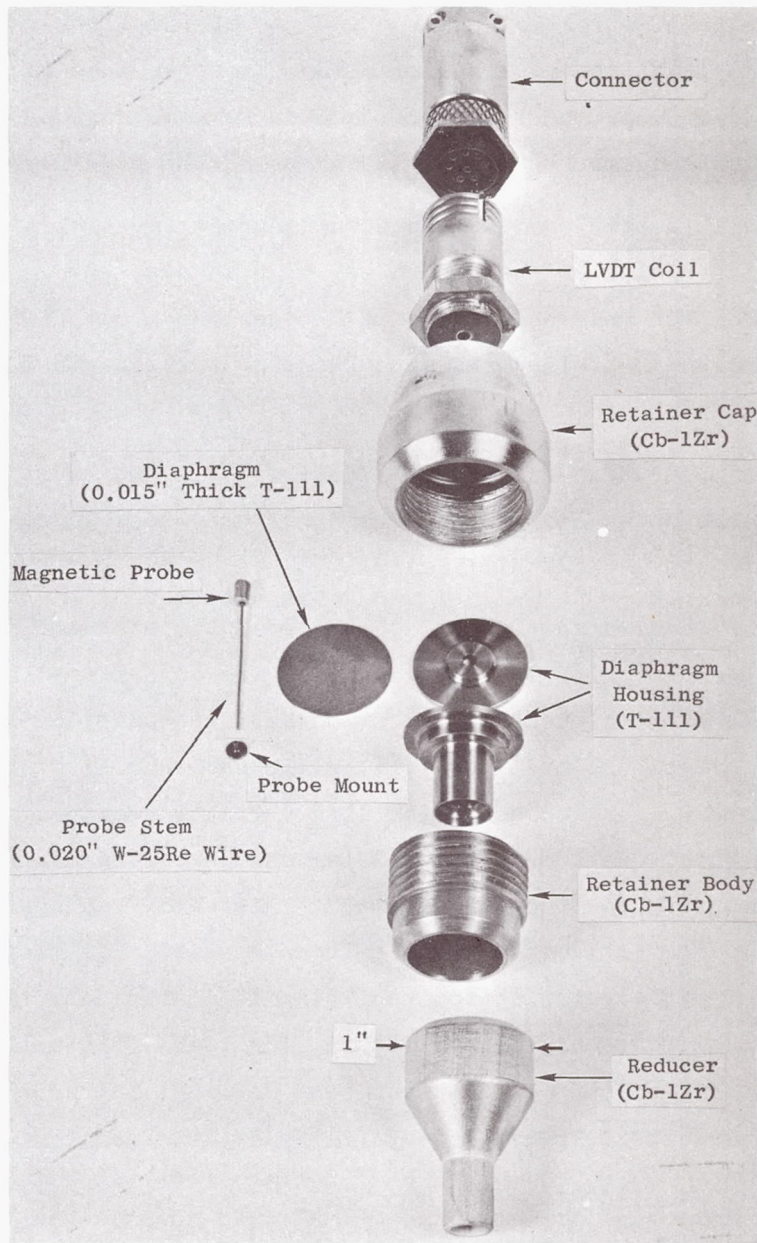


Figure 24. NaK Sampler For Taylor Pressure Transducer.



C5544-25

Figure 25. Exploded View of the Stress Diaphragm Pressure Transducer Prior to Welding. (Orig. C64122910)

Two sets of hardware were processed to develop the electron beam welding technique required for this assembly. The electron beam welds for the diaphragm assembly were produced without difficulty. However, the joint between the T-111 alloy housing and the Cb-1Zr alloy resulted in cracking of the T-111 alloy. This cracking was attributed to the highly localized heat input of the electron beam in combination with a slight joint gap introduced by metal removal during the pickling operation.

To eliminate this problem, the tungsten-inert gas welding process was used to produce this joint on the second set of hardware. As an added precaution, an electron beam weld was made between these components on the outside diameter, thus effecting a double seal between the T-111 and the Cb-1Zr alloy components.

The electron beam welds between the T-111 alloy probe mount and diaphragm, and between the diaphragm and housing were repeated on the second set of hardware without difficulty.

The final fabrication step was the brazing of the magnetic probe assembly to the probe mount. The configuration was a socket joint in which an 0.020-inch diameter W-25Re wire from the magnetic probe was inserted into a suitable hole in the T-111 alloy probe mount. Brazing was accomplished using localized heating with a graphite-tipped, heater probe, under high-purity helium in the welding chamber. The brazing alloy selected was Premabraz-615 (62Ag-24Cu-14In). This alloy was applied to the joint manually in wire form. The completed assembly was mass spectrometer leak tested successfully and submitted to instrumentation for room temperature calibration. In the future, the probe wire will be joined to the diaphragm mount by electron beam welding, rather than brazing, to increase the temperature capability of this joint.

E. ELECTRON BEAM WELDING

The above components required electron beam welding which was performed in accordance with Specification SPPS-14. Chemical analyses of the weld metal for welds made in Cb-1Zr sheet before and after each

sequence of component welds are reported in Table VII. The oxygen, nitrogen, and hydrogen contents indicated no contamination. The carbon content exceeded the 10 ppm increase specified for the Hoke valves "before weld" samples. These values were somewhat questionable because of the small sample size necessitated by the relatively narrow electron beam weld. Duplicate analyses of the same sample indicated variations greater than plus or minus 10 ppm, which was the analytical variance anticipated per Specification SPPS-14.

F. ELECTROMAGNETIC HELICAL INDUCTION PUMP DUCT

The fabrication of the EM pump duct presented some difficulty when the first attempt to produce the interference fit between the helical duct and outer duct shown in Figure 26 was unsuccessful. The procedure used involved heating of the outer duct to 1200°F in high-purity helium. After temperature stabilization, the cool finned duct was inserted, using a "vee" fixture for alignment. Although this procedure was successful in previous instances, in this case seizing of the finned duct occurred at approximately the mid-point of the outer duct.

Subsequently, the outer duct was cut off at the end of the interference fit, re-machined for weld preparation, and a second interference fit attempted from the other end of the finned duct. For this interference fit, the one-half length of the outer duct was heated to 500°F in air while the finned duct was immersed in liquid nitrogen. No difficulty was encountered in producing the interference fit using this procedure.

One additional circumferential weld at the mid-point of the EM pump duct was then required. Since this weld was in contact with the finned duct, special precautions were taken to avoid any blockage in the alkali metal flow channel. The root weld pass was radiographed extensively with no indication of excessive weld drop-through. An air flow pressure drop test was then made which indicated satisfactory performance. This test was repeated after the final weld passes, and the results of this test showed no significant increase in the overall pressure drop.

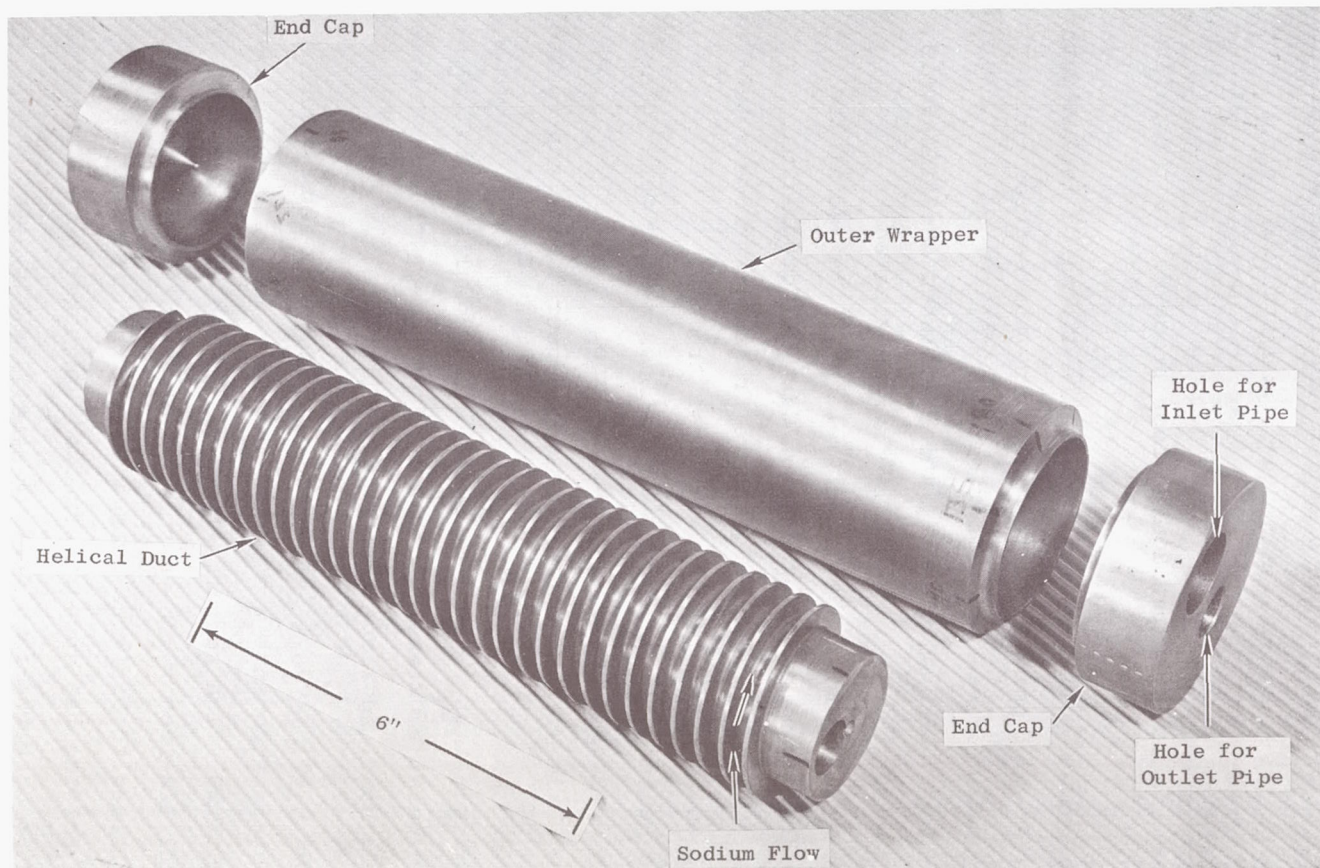
TABLE VII
RESULTS OF CHEMICAL ANALYSES OF ELECTRON BEAM
WELDMENTS PER SPECIFICATION SPPS-14

(a)	Chemical Analysis, ppm			
	<u>O</u>	<u>N</u>	<u>H</u>	<u>C</u>
Base metal analysis by vendor	130	85	1	50
Base metal analysis by General Electric	142	22	2	30, 40
Hoke valve bellows assembly welds				
Sample weld ^(b) before ^(c)	94	53	< 1	100, 70
Sample weld after	104	55	< 1	40, 60
Hoke valve bellows assembly to body weld				
Sample weld before	96	56	3	40, 70
Sample weld after	110	57	3	0, 20
Slack diaphragm pressure transducer to upper flange weld				
Sample weld before	107	43	2	10, 20
Sample weld after			Not determined	
Stressed diaphragm pressure transducer housing to Cb-1Zr retainer body				
Sample weld ^(b) before	107	53	3	40
Sample weld after	102	50	3	30
Stressed diaphragm pressure transducer diaphragm to probe mount				
Sample weld before	142	47	7	30
Sample weld after	108	51	2	40

(a) 0.040-inch thick Cb-1Zr sheet, MCN-417.

(b) All weld metal analyses are on welds made on the Cb-1Zr base material listed above, before and after welding of components listed.

(c) All welds made at a pressure of less than $< 5 \times 10^{-5}$ torr.



C5544-26

Figure 26. Cb-1Zr Alloy Pump Duct Components of the Helical Induction Electromagnetic Sodium Pump for the Cb-1Zr Pumped Sodium Loop. (Orig. C64021714)

G. SURGE TANK

The Pumped Sodium Loop surge tank is shown in Figure 27 prior to welding the end caps in position. The dip leg shown inside the tank was welded on the inside diameter of the tank as well as the outside for maximum reliability. The 6-inch diameter tank cylinder was rolled from 0.125-inch thick sheet and was joined by a longitudinal weld.

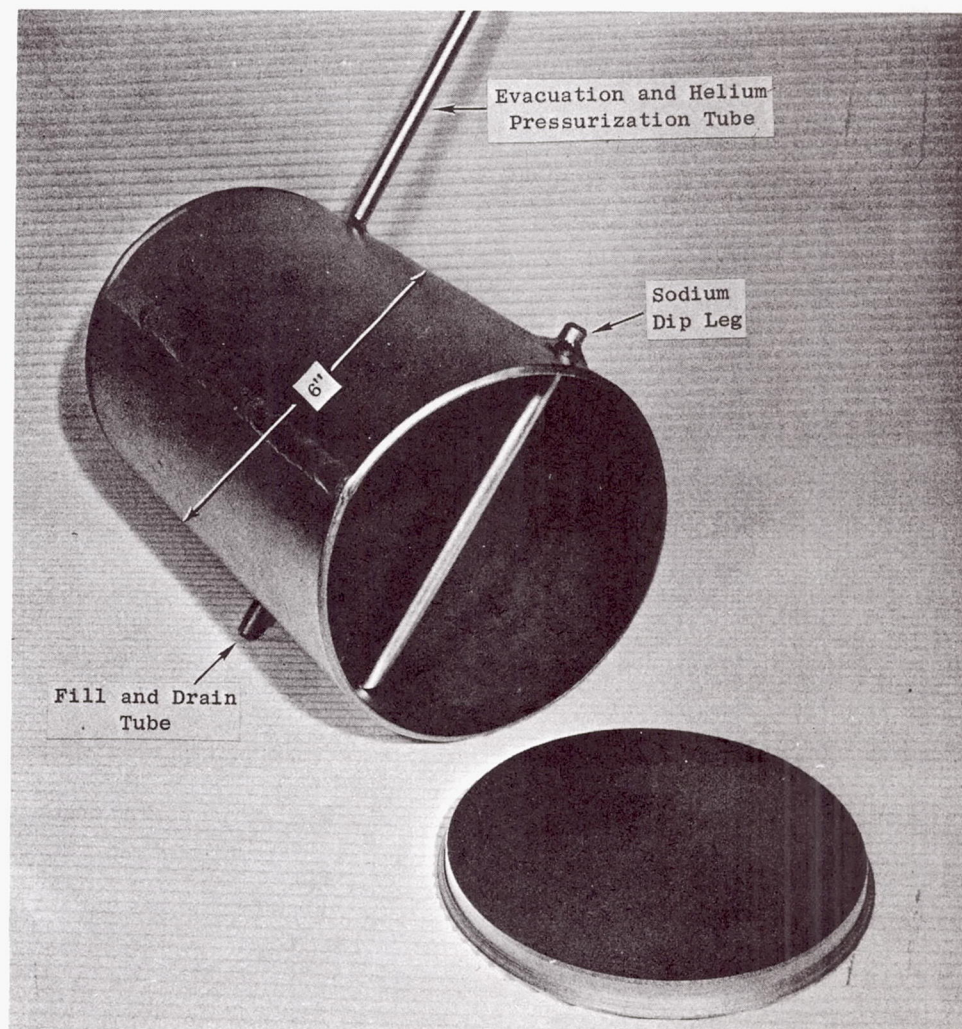
H. FINAL ASSEMBLY

The assembly of the Pumped Sodium Loop proceeded in the following sequence:

1. The heater coil subassembly, Figure 28, which included the heater coil portion of the loop plus the section containing the metering valve was fabricated.
2. The surge tank subassembly which included the fill/drain valve and the isolation valve was fabricated.
3. These subassemblies were postweld heat treated at the Stellite Division of the Union Carbide Corporation.
4. The stressed diaphragm pressure transducer process tube was welded in place and postweld heat treated.
5. The heater coil and surge tank subassemblies were joined.
6. The EM pump duct was welded in place.
7. The slack diaphragm pressure transducer was welded to the loop.

The joining of the latter two components was accomplished in the eight-foot diameter welding extension chamber after integration of the loop, vacuum chamber spool section, and support structure.

Following completion of fabrication of the loop subassemblies, these refractory metal components were mounted on the loop support structure shown in Figure 29. The support structure, which was fabricated from 1 1/2-inch x 1 1/2-inch x 1/8-inch Type 304 stainless steel angles, was carefully polished to minimize outgassing during test operation. All nuts used in bolting the support structure together were slotted with a 0.031-inch wide by 0.062-inch deep axial saw cut, and each washer was cut



C5544-27

Figure 27. Cb-1Zr Sodium Surge Tank Prior to Welding of the End Caps.
(Orig. C64040910)

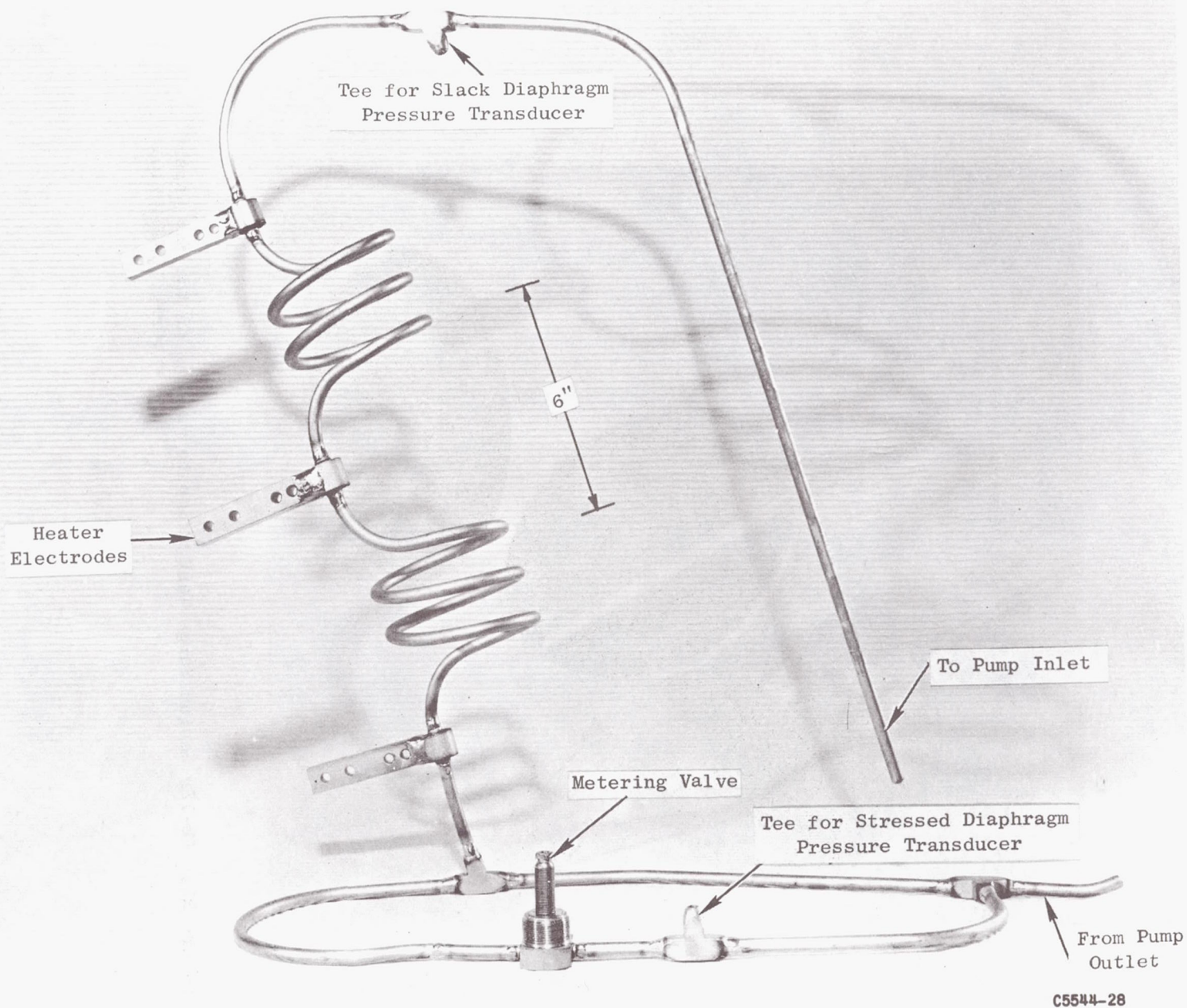
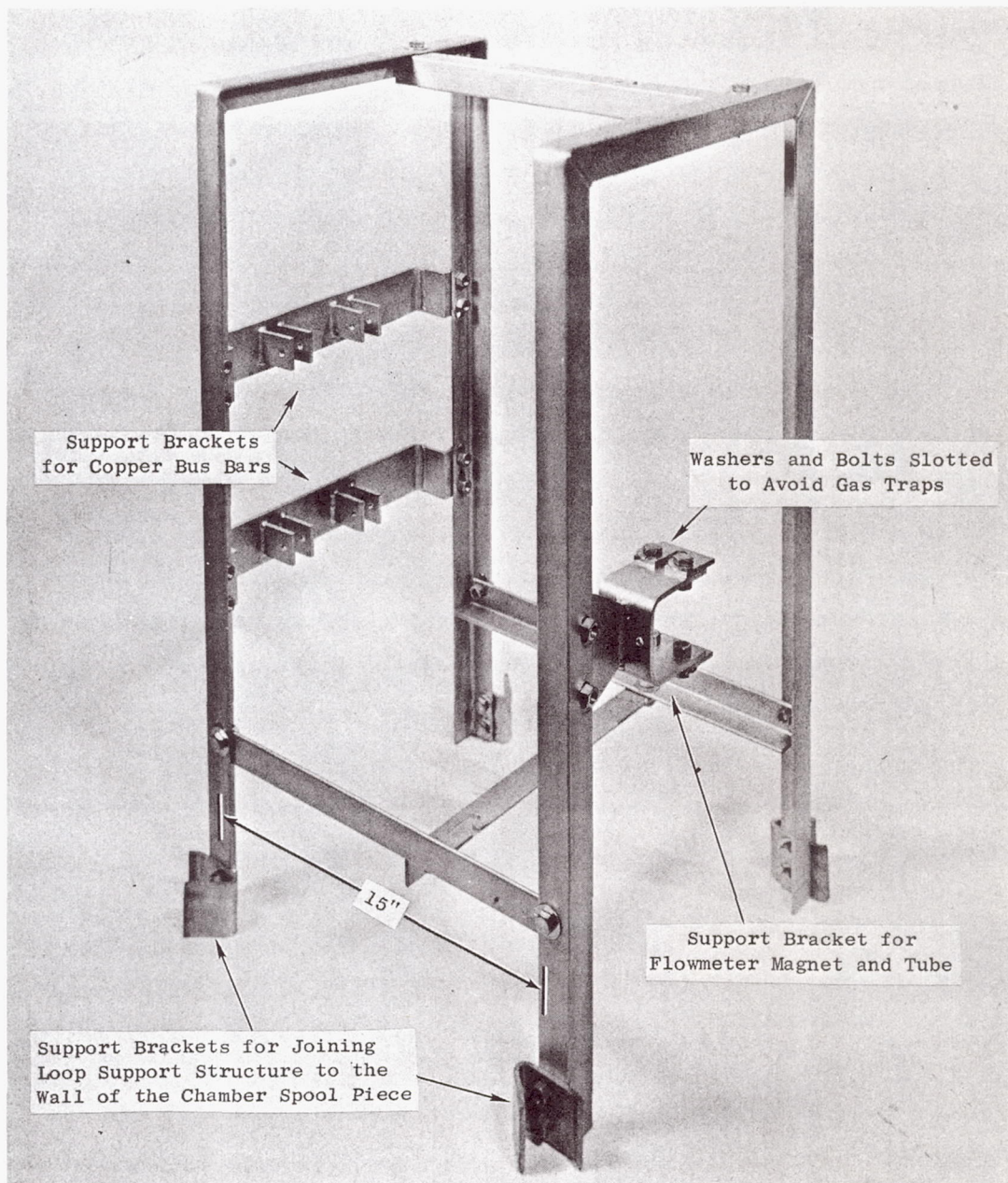


Figure 28. Component Evaluation Loop II Partially Assembled.



C5544-29

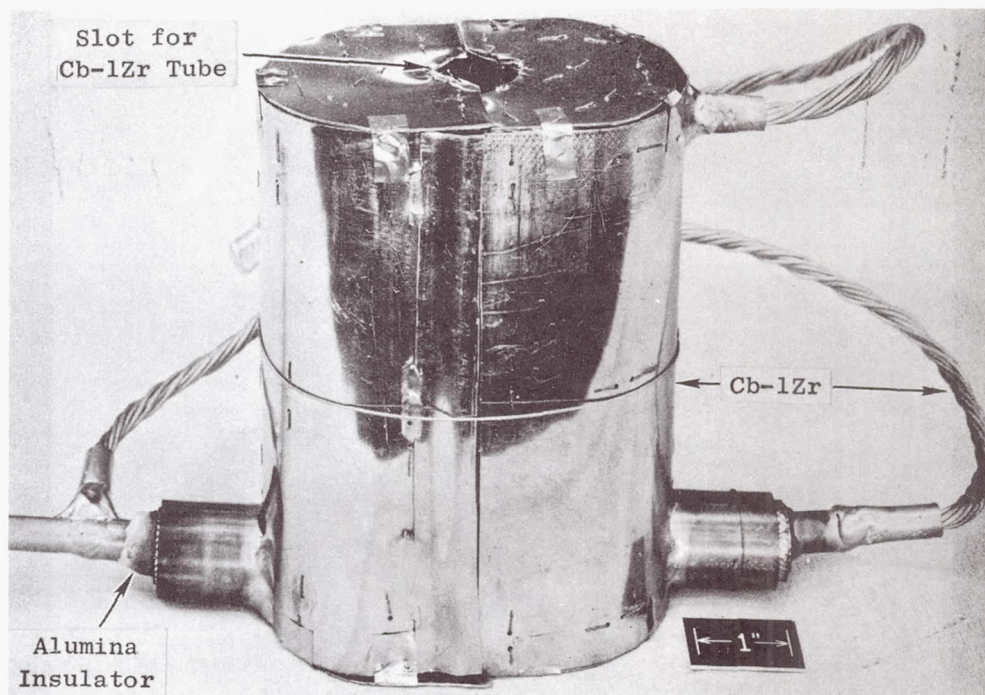
Figure 29. Type 304L Stainless Steel Support Structure for the Cb-1Zr Pumped Sodium Loop. (Orig. C64050114)

radially to eliminate virtual leaks from trapped gas pockets which could lengthen the pump-down time required to achieve a 1×10^{-8} torr operating pressure.

All the latter postweld anneals of Cb-1Zr were conducted in the welding vacuum chamber, using the small refractory metal heater shown in Figure 30, which provided localized heating of the welded joint. The setup for one of the final heat treatments in the welding chamber is illustrated in Figure 31 which also provides a prospective view of the welding position. The refractory metal heater in this case was positioned around the welds attaching the EM pump duct to the loop. Power for the heater was supplied by the welding power supply, and the temperature was monitored by two Pt/Pt-10Rh thermocouples attached to the weld. A total of eight weldments in the Pumped Sodium Loop were annealed locally in the welding chamber.

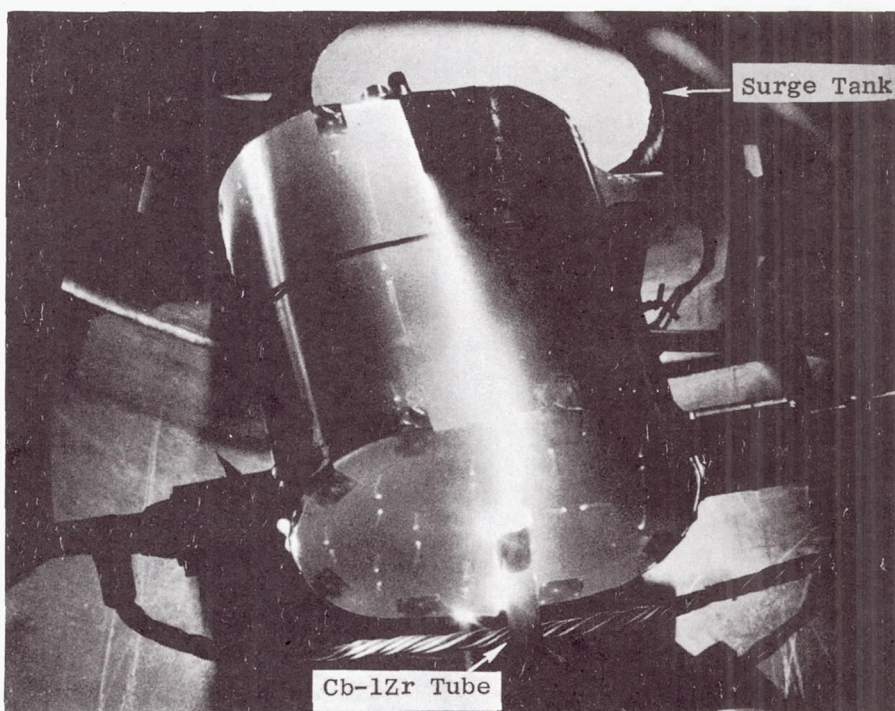
The stainless steel vacuum components were added to the spool section of the vacuum chamber in the final assembly operation. Two vacuum seal welds were required on the entry ports for the sodium fill line and inert gas line. The outer can for the EM pump duct and its support flange were also welded in position.

Welding of the Cb-1Zr alloy component required for final assembly resulted in several minor deviations from Specification SPPS-3C. Although the welding chamber with the extension attached had been previously evacuated to less than 1×10^{-5} torr, the addition of the spool section resulted in slower pumping speed and slightly higher ultimate vacua. Back-filling with purified helium was, therefore, conducted after evacuation to 1.9×10^{-5} torr and 2.6×10^{-5} torr for the EM pump and slack diaphragm pressure transducer welds, respectively. Another deviation occurred during heat treatment of the EM pump duct attachment welds. In this case the heater shorted externally after operation for fifteen minutes at 2200°F. Review of the aging reactions of Cb-1Zr weldments indicated that this time at temperature was sufficient to avoid subsequent aging reactions. Therefore, no further annealing was performed.



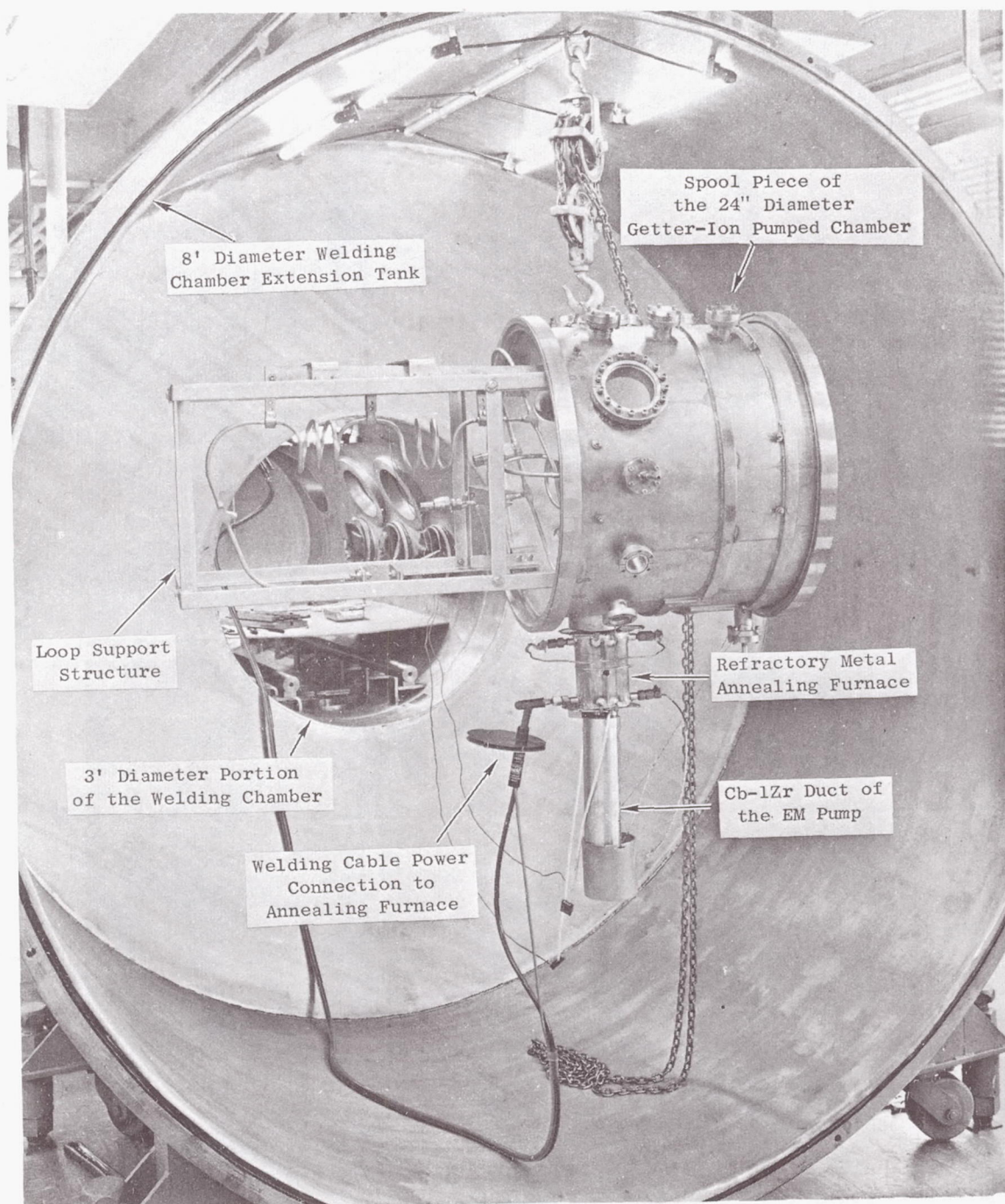
Internal Components:

Heater Elements, 0.050-inch W wire
 Heater Electrodes, Ta
 Foil Insulation, Ta



C5544-30

Figure 30. Refractory Metal Furnace Used for Vacuum Annealing of Cb-1Zr Loop Weldments in the Vacuum-Purge Welding Chamber. Top View Shows Furnace Prior to Mounting for Annealing. Lower Photograph was Taken Through the Chamber View Port During a 2200°F Anneal.
 (Orig. C65032922, C65032301)



C5544-31

Figure 31. Cb-1Zr Pumped Sodium Loop Mounted in the Test Chamber Spool Piece Prior to Annealing of the Cb-1Zr Weldments. Used to Join the EM Pump Duct to the Loop. (Orig. C64060134)

I. POSTWELD VACUUM FURNACE ANNEALING

The qualification of the vacuum furnaces used for postweld annealing treatments was conducted in accordance with Specification SPPS-3C. Results of chemical analyses are reported in Table VIII. Bend tests performed in accordance with Specification SPPS-3C indicated full bend ductility in all cases.

A deviation from Specification SPPS-3C occurred in the degree of vacuum attainable during heat treatment. It was found necessary, due to furnace limitations, to set the upper limit of pressure at 5×10^{-5} torr rather than the 1×10^{-5} torr specified. This upper limit on pressure was considered acceptable since qualification runs which preceded the actual parts were acceptable under these conditions. As an added precaution, two layers of 0.002-inch thick Cb-1Zr foil were used to wrap the loop and components to further minimize the chances for contamination.

TABLE VIII

RESULTS OF CHEMICAL ANALYSES OF Cb-1Zr WELDS FOR HEAT TREATMENT QUALIFICATION

	Pressure, torr		Chemical Analysis, ppm			
	<u>Start of Run</u>	<u>End of Run</u>	<u>O</u>	<u>N</u>	<u>H</u>	<u>C</u>
Base metal ^(a) analysis by vendor			130	85	1	50
Base metal analysis by General Electric			142	22	2	30,40
Weld metal after 2200°F/one hour in R.D. Brew vacuum furnace (Model 424-B, 4 1/2-inch diameter x 7-inch) at General Electric (unwrapped)	3.6×10^{-5}	1.2×10^{-5}	129	56	5	60
Weld metal after 2200°F/one hour local anneal in the VASCO welding chamber at General Electric (unwrapped)	4.9×10^{-5}	1.7×10^{-5}	199	53	7	30
Weld metal after 2200°F/one hour in the C. I. Hayes, Inc. furnace (Model PS-107, 20-inch dia. x 36-inch) at Stellite Division, UCC (wrapped) ^(b)	5.0×10^{-5}	2.5×10^{-5}	123	46	3	--
Weld metal after 2200°F/one hour in General Electric vacuum furnace (G.E. Catalog No. 221L804G1, 6-inch dia. x 10-inch) at General Electric (wrapped)	5.0×10^{-5}	1.0×10^{-5}	151	38	1	70

(a) 0.040-inch thick Cb-1Zr sheet, MCN-417.

(b) Specimens wrapped with one overlapped layer of 0.002-inch x 0.5-inch Cb-1Zr foil. All components were wrapped with two layers of this foil during heat treatment.

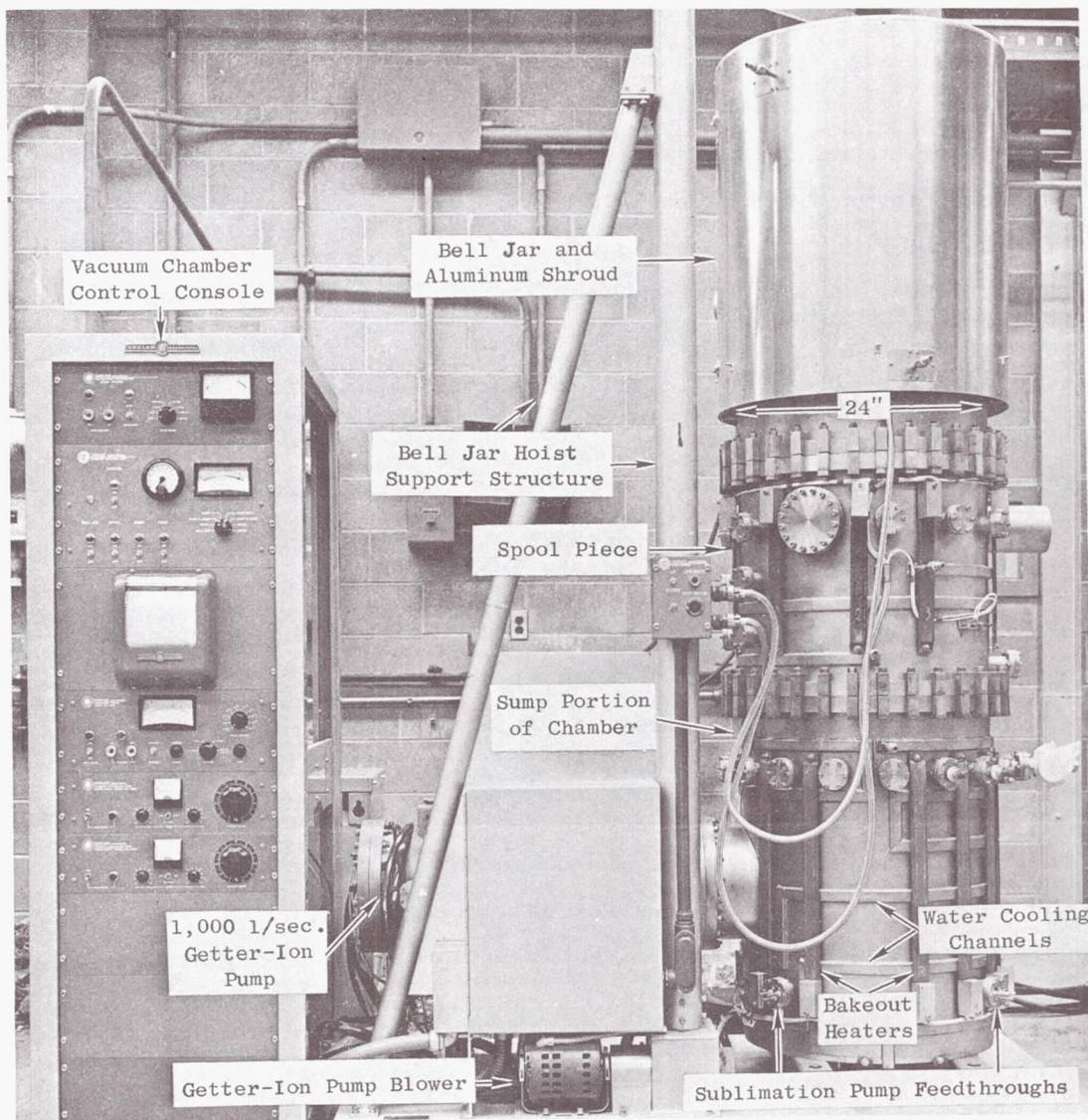
V. TEST EQUIPMENT

A. VACUUM SYSTEMS

The 24-inch diameter by 90-inch high vacuum chamber, shown in Figure 32, consists of a stainless steel bell jar, a spool piece and a sump fabricated by Varian Associates, Palo Alto, California. The three sections are joined together with Wheeler^(a) flanges which use a 0.125-inch diameter copper wire gasket. Electrical resistance strip heaters are attached to the chamber wall to permit continuous bakeout of the chamber to 500°F. The chamber is covered with an aluminum shroud which thermally insulates the chamber, results in more uniform heating, and provides maximum safety to operating personnel. The chamber has water cooling channels welded to the wall which are capable of removing approximately 25 KW of heat during test operation.

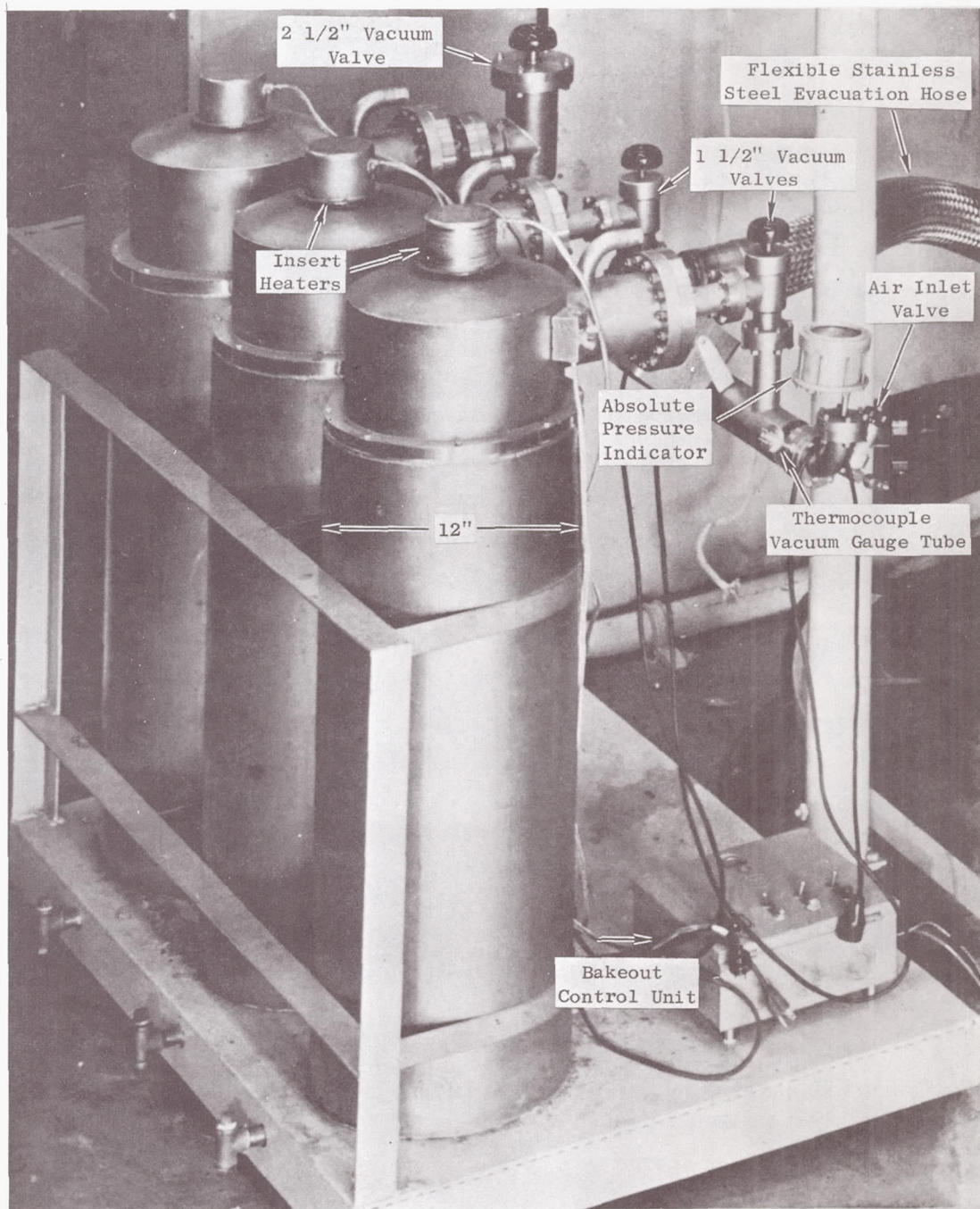
The rough pumping system for the vacuum chamber shown in Figure 33 was a special Vac Sorb^(a) sorption pump station (Varian Associates Drawing No. 610609) which consisted of three sorption pump assemblies mounted on a roughing pump cart and connected to a common pumping manifold. Each sorption pumping unit was filled with highly porous, Type 5A, molecular sieve, a synthetic zeolite material, with sieve pores 5 Angstroms in diameter. The sorption pumps are equipped with an integral liquid nitrogen center sump which is used to prechill the pumps before use. Prior to chilling, the sorption pumps are baked out to reactivate them. Heating of the sorption pumps to 450°F after use accelerates the release of previously pumped gases from the molecular sieve to the atmosphere and readies them for the next pump-down cycle. A thermocouple gauge located on the sorption pump manifold is used to indicate the chamber pressure during sorption pumping. Systems of this type have the capability of reaching a base pressure of 1×10^{-3} torr. After rough pumping the system to less than 10 microns, the bakeable stainless steel valve which isolates the sorption pumps from the chamber proper is closed.

(a) Trademark, Varian Associates



C5544-32

Figure 32. The 24-Inch Diameter by 90-Inch High Getter-Ion Pumped Vacuum Chamber and Associated Equipment Used for Testing the Cb-1Zr Pumped Sodium Loop. (Orig. C64011410)



C5544-33

Figure 33. Sorption Pumping System Used to Evacuate the Test Chamber for the Cb-1Zr Pumped Sodium Loop Test Prior to the Initiation of Getter-Ion Pumping. (Orig. C67112716)

The rough pumping system shown in Figure 33 was designed to evacuate systems of 500 liters volume from atmospheric pressure to 10 microns. This capability was needed to pump down the 4-foot diameter chamber scheduled for use in testing the Cb-lZr Rankine System Corrosion Test Loop and was more than adequate for the 24-inch diameter chamber (volume approximately 750 liters) used to test the Cb-lZr Pumped Sodium Loop.

The high vacuum pumping system utilizes the Varian Associates Model 912-5460 getter-ion pump with a rated pumping speed of 1000 liters per second of air. The pump operates on the principal of ion sputtering and requires a high DC voltage and a strong magnetic field. A magnetic field of more than 1800 gauss is provided by permanent magnets attached externally to the pump. Barrington⁽⁷⁾ has described the operating characteristics of this type of pump and the pumping mechanism for the various gases in detail. The getter-ion pump includes an internal bakeout heater and an external centrifugal air blower to cool the ion pump after bakeout is completed.

The pumping speed characteristics of the Varian getter-ion pump are given below. The pumping speeds for various gases are relative to nitrogen taken as unity.

	<u>Pumping Speed</u>
Nitrogen	1.00
Oxygen	0.57
Argon, Krypton, Xenon	0.01
Hydrogen	2.7
Deuterium	1.9
Helium	0.10
Neon	0.05
Carbon Dioxide, Water Vapor, Carbon Monoxide	1.0
Light Hydrocarbons	0.90-1.60

(7) Barrington, Alfred A., High Vacuum Engineering, Prentice-Hall, Inc., Englewood Cliffs, N. J., 1963.

In addition to the getter-ion pump, four titanium sublimation pumps^(a) are available for use during periods of high outgassing. The location of two of the four sublimation pump feedthroughs is indicated in Figure 32. The high speed pumping of these units is accomplished by titanium filament sublimation and deposition on the chamber surfaces. The pumping action depends on forming titanium compounds with active gases. This method can be used during the entire pressure range of 15 microns to the 10^{-11} torr. The recommended duty cycle (or on time) for the sublimation pumps decreases from 100% down to a pressure of 10^{-6} torr to 25% in the 10^{-7} to 10^{-8} torr pressure range. The variable duty cycle is aimed at conserving the titanium filament life while maintaining a fresh "gettering" surface to obtain optimum pumping speeds. Two to four hours of continuous operation are possible with each of the three filaments per pump when operated at the highest recommended deposition rate.

The components of the vacuum chamber control console are illustrated in Figure 34. A duplicate set of sublimation pump controls is included which permits the simultaneous operation of two of these units, if desired.

The bell jar section of the chamber is raised and lowered by a motor driven screw jack. Two 4-inch diameter bakeable pyrex glass viewing ports are mounted in the wall of the bell jar. These view ports made it possible to observe loop components and to obtain photographs of them during loop operation.

The spool section has the following wall penetrations:

- a. One - 4-inch diameter flange for EM pump
- b. Two - 4-inch diameter flanges for rotary motion magnetic drive feedthroughs
- c. Six - 2 3/4-inch diameter flanges with 1000 ampere power feedthroughs
- d. Eight - 2 3/4-inch flanges for thermocouple feedthroughs, and ion gauge.

(a) Varian Associates: Power Supply Model No. 922-0006; Filament Cartridge, Model No. 956-0030; and Titanium Filament, Model No. 956-0010.

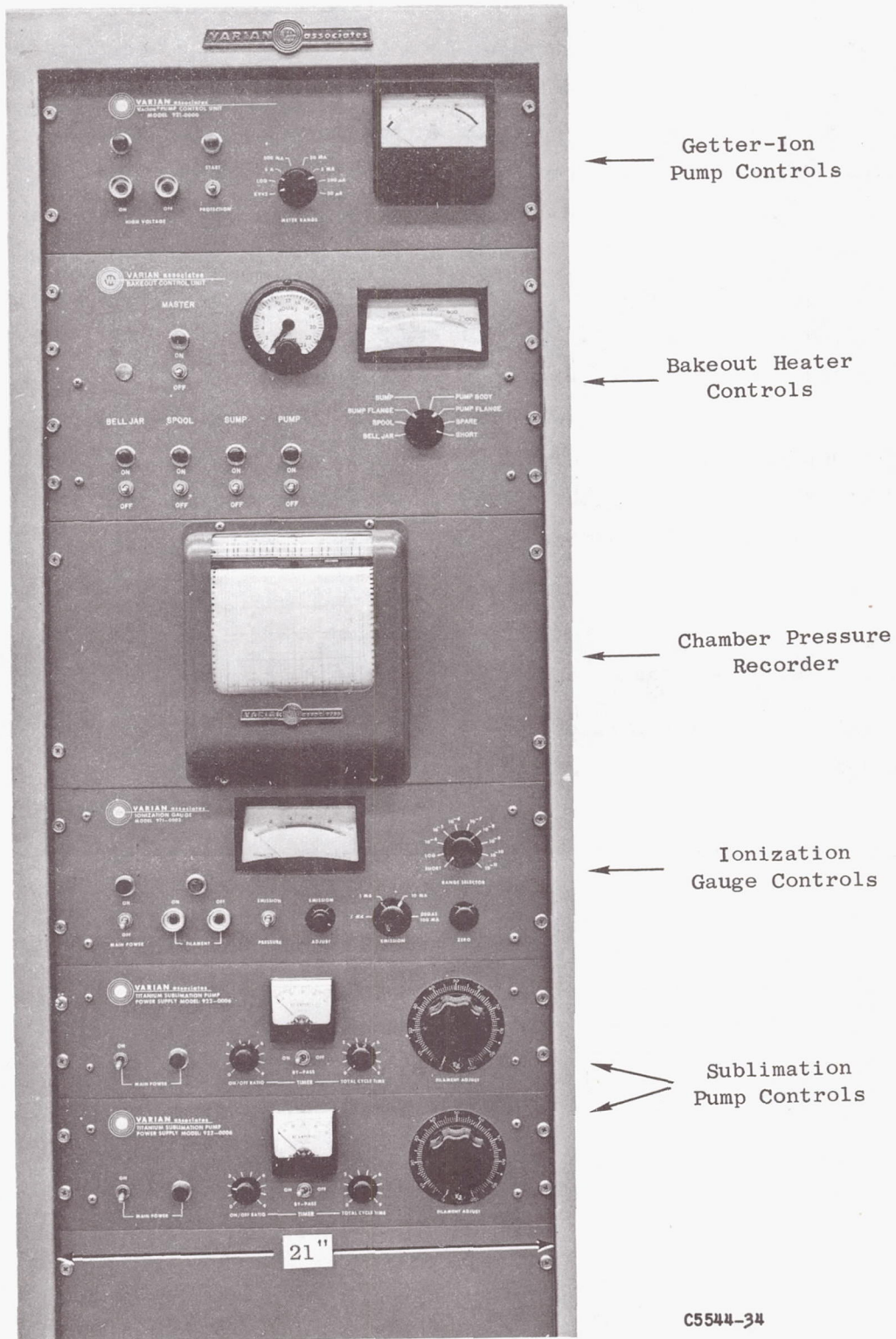


Figure 34. Vacuum Chamber Control Console.

(Orig. C64011411)

In addition to the feedthroughs on the spool section, sixteen 2 3/4-inch diameter flanges are available on the sump for additional instrumentation and feedthrough requirements as well as four 2 3/4-inch diameter flanges for the titanium sublimation pumps. A photograph of the water cooled, electrical power feedthrough is shown in Figure 35. All flanges are sealed with flat OFHC copper gaskets and are capable of withstanding prolonged bakeout to 800°F.

A qualification test on the 24-inch diameter vacuum chamber was performed at Varian Associates prior to shipment to General Electric. The results of this test which called for a 10-hour bakeout are given in Table IX. An ion gauge pressure of 4.1×10^{-10} torr was reached on cool down following bakeout. This pressure was achieved 22 1/2 hours after the sorption pumps were opened to initiate evacuation of the system.

Following installation of the vacuum chamber at General Electric an acceptance test was performed. A pressure of 1×10^{-9} torr was obtained in less than 24 hours including a 10-hour bakeout, without the use of the titanium sublimation pumps. The system reached a pressure of 2.4×10^{-10} torr in 48 hours and 1.5×10^{-10} torr after four days of pumping.

B. CHAMBER PRESSURE MEASUREMENT

The pressure inside the vacuum chamber is measured and recorded during the entire cycle. In the sorption rough pumping system, a thermocouple gauge is used to measure the pressure in the range from atmospheric to 1×10^{-3} torr.

Vacuum chamber pressures in the range 10^{-4} to 10^{-10} torr were measured using a Varian Type UHV-12 calibrated hot cathode ionization gauge. The gauge was calibrated with its control unit at Varian Associates, Palo Alto, California, using an accurately known pumping speed (s) with a measurement of flow rate (2) to establish a calibrated pressure, $P = q/a$. The maximum error of this technique with the equipment is $\pm 6\%$. The calibration data for the ionization gauge used to measure chamber pressure during the Cb-1Zr Pumped Sodium Loop Test are given in Table X. A detailed description of

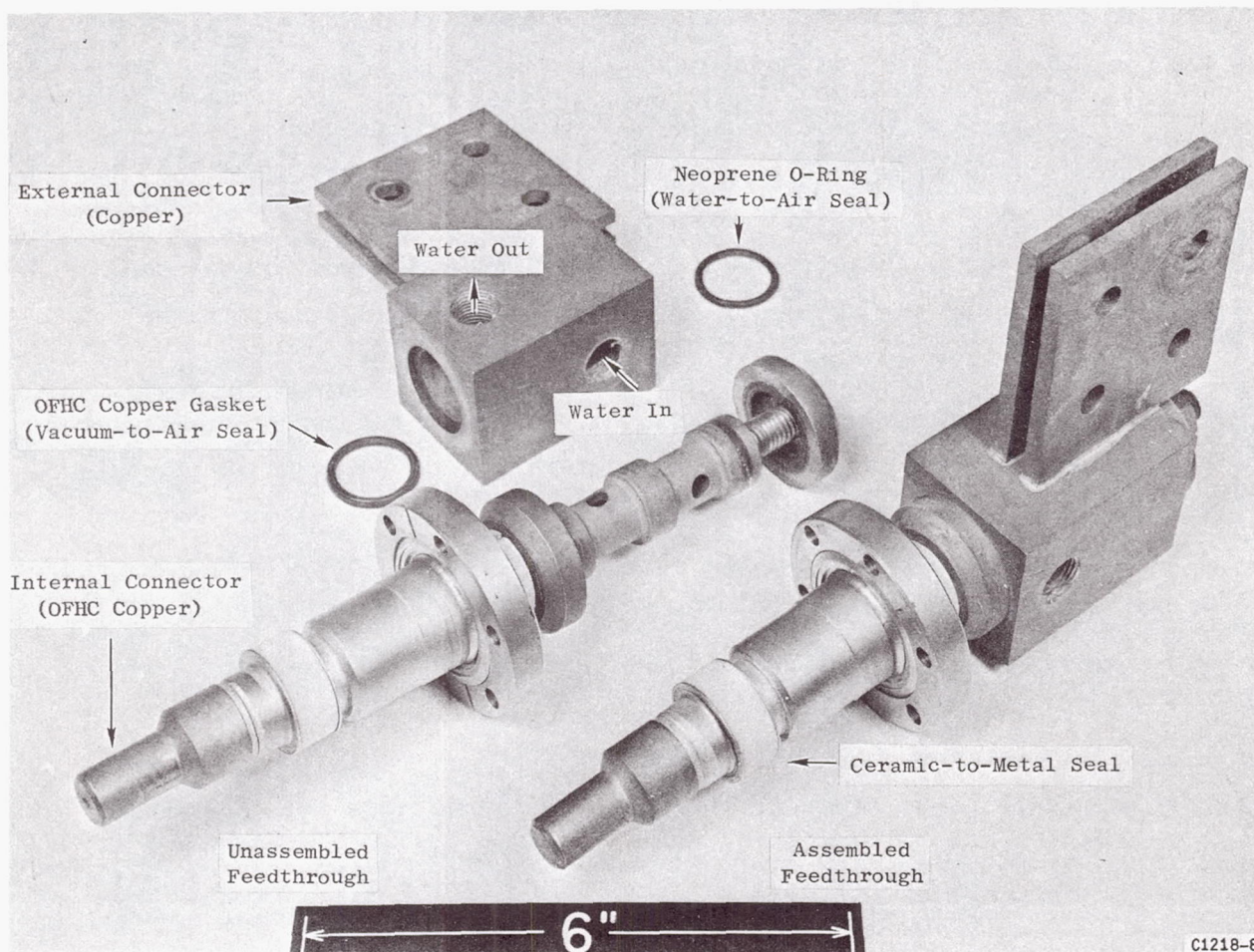


Figure 35. Water Cooled, 1000-Ampere Electrical Power Feedthrough.
(Orig. C67041801)

TABLE IX

PERFORMANCE TEST OF THE 24-INCH DIAMETER BY
90-INCH HIGH PUMPED VACUUM CHAMBER AT VARIAN ASSOCIATES

<u>Elapsed Time</u> <u>Minutes</u>	<u>Remarks</u>	<u>Pressure</u> <u>Torr</u>
0	Sorption pumping started	Atmospheric
45	Ion pump started	6×10^{-3}
47	Valved out sorption pump	---
54	Ion pump confined	6×10^{-6}
60	Pumping	8×10^{-7}
90	Start of 10 hour bakeout	5×10^{-7}
427	Pumping, bakeout on	7.7×10^{-7}
690	Bakeout off	---
1005	Air blower to cool ion pump turned on	2.6×10^{-9}
1350	Final pressure	4.1×10^{-10}

TABLE X

IONIZATION GAUGE CALIBRATION DATA

Calibration date	22 November 1963
Gauge type and number	Varian UHV-12, No. G-24
Ionization gauge control unit type and number	Varian Model No. 971-0003, Unit No. 666
Test gas	Nitrogen
Emission current	4 ma
Degas method and power	Electron bombardment - 40 watts

<u>Pg, Gauge Pressure Indicated on the Ionization Gauge Control, torr</u>	<u>Pa, Absolute Calibration Pressure, torr</u>	<u>Pa/Pg, Correc- tion Factor, torr</u>
5.86×10^{-7}	5.63×10^{-7}	0.96
9.35×10^{-7}	8.40×10^{-7}	0.90
0.90×10^{-6}	8.40×10^{-7}	0.93
3.59×10^{-6}	3.53×10^{-6}	0.98
6.10×10^{-6}	6.07×10^{-6}	0.99
9.10×10^{-6}	9.30×10^{-6}	1.02
0.90×10^{-5}	9.30×10^{-6}	1.03
2.26×10^{-5}	2.64×10^{-5}	1.17
4.76×10^{-5}	6.56×10^{-5}	1.37
7.00×10^{-5}	1.04×10^{-4}	1.48
9.15×10^{-5}	1.60×10^{-4}	1.74

calibration procedure used has been described in a paper by Hayward and Jepsen.⁽⁸⁾

The ionization gauge pressure reading can be checked by measuring the current of getter ion pump on the ion pump control unit meter and converting this current to an equivalent pump pressure by means of the vendor supplied pressure - current chart for this pump illustrated in Figure 36. The ion pump control unit also has a logarithmic pressure scale as shown in the top panel illustrated in Figure 34, which indicates the pressure directly in the 10^{-4} to 10^{-8} torr range.

C. PARTIAL PRESSURE GAS ANALYZER

A partial pressure gas analyzer^(a) was used to monitor the concentration of the residual gases in the test chamber. The analyzer tube^(b) consists of a Nier-type, electron bombardment ion source, a 90-degree sector magnetic analyzer with a 5-cm radius of curvature, and a 10-stage electron multiplier ion detector entirely enclosed in a Type 304 stainless steel envelope with metal-ceramic electrical lead-ins. The metal tube permits bakeout temperatures to 800°F. The electron multiplier ion detector allows the use of a conventional low current amplifier to read the output signal. The analyzer tube is magnetically focused with a 3 kilogauss bakeable permanent magnet mounted on the analyzer tube to achieve ion beam peak separation over the 2 to 50 AMU (atomic mass units) range. The metal tube is designed to operate at total pressures up to 10^{-5} torr and to detect partial pressures of 10^{-14} torr. A discussion of the calibrations performed on the analyzer is given in Appendix D.

D. HEATER POWER SUPPLY

The heater power supply consisted of a combined temperature controller and stepless power regulator system with a stepdown current transformer.

(8) Hayward, W. H. and Jepsen, R. L., "A Simple High Vacuum Gauge Calibration System", Transactions of the American Vacuum Society, 1962.

(a) General Electric Partial Pressure Analyzer, Model 22PC110

(b) General Electric Partial Pressure Analyzer Tube, Model 22PT110

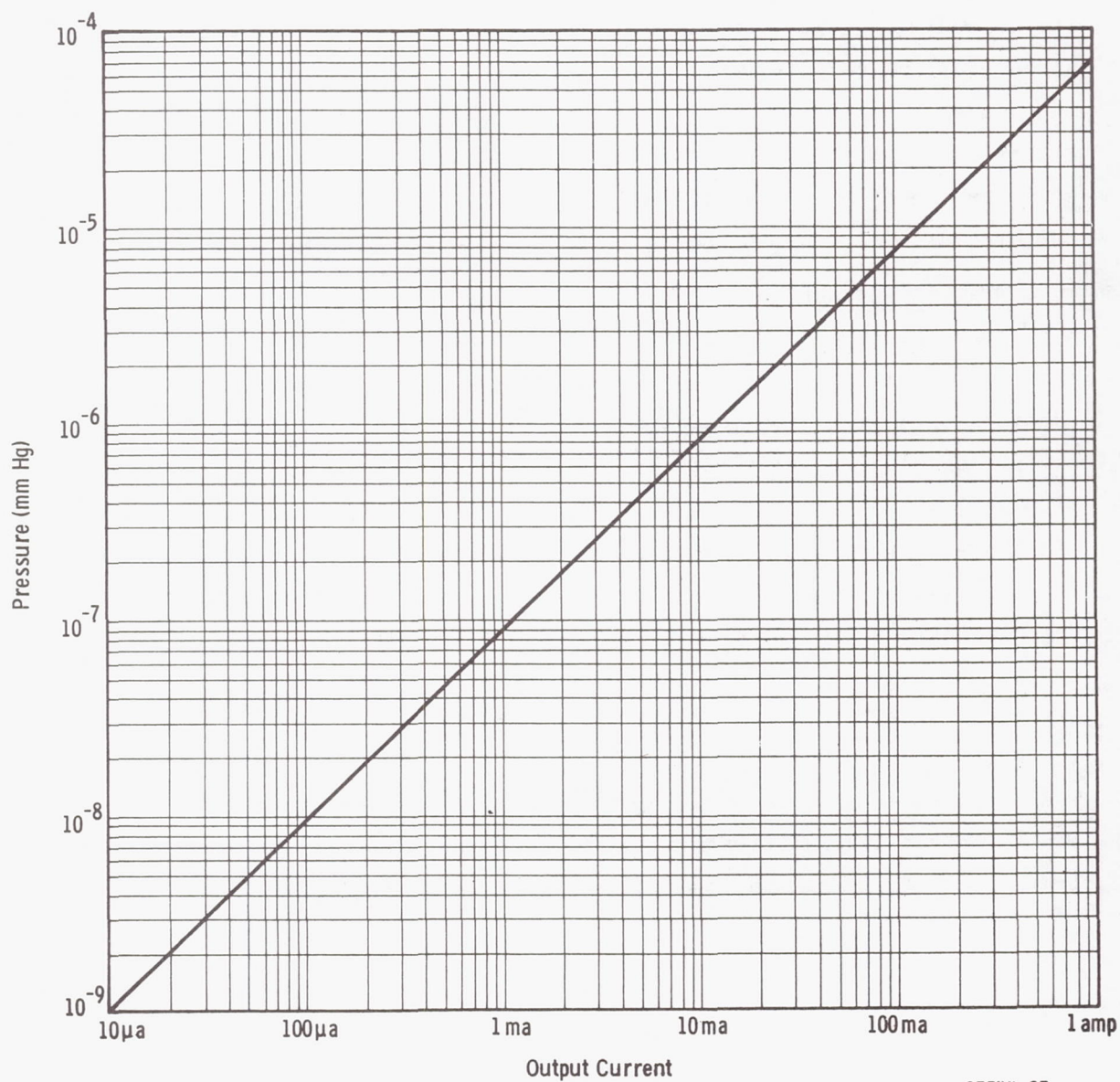


Figure 36. Pressure vs Pump Current for the 1000 Liter per Second Varian Associated Getter-Ion Pump. (Mode. 912-1420)

The system had a continuous power rating of 20 KW with an input power of single phase 440 volt AC. The combined temperature controller and power regulator include:

1. A manual power adjustment
2. Automatic set point control
3. Current limiter control

The system included a single pen, 1/4 percent, null balance, servo operated recording potentiometer with a General Electric Model 524 controller (3-mode proportional control with rate action and automatic reset) and an amplistat plus a saturable core reactor and current transformer. The system functioned as follows:

An input signal to the recorder is obtained from the heater control thermocouple and is measured by the recorder. This input signal is compared to a known voltage developed across the measurement slidewire. The slidewire is part of a bridge circuit, the other part of which is located in the 3-mode controller. The output of the controller is directly proportional to the unbalance of the bridge circuit and provides a DC control signal to an amplistat. The control signal is amplified by the amplistat to a sufficient level to operate a saturable reactor. The output of the saturable reactor is connected to a stepdown transformer rated at 5,000 amperes continuous duty. The high current is fed through the vacuum chamber to the loop heaters by water-cooled 1,000-ampere feedthroughs of the type shown earlier in Figure 35.

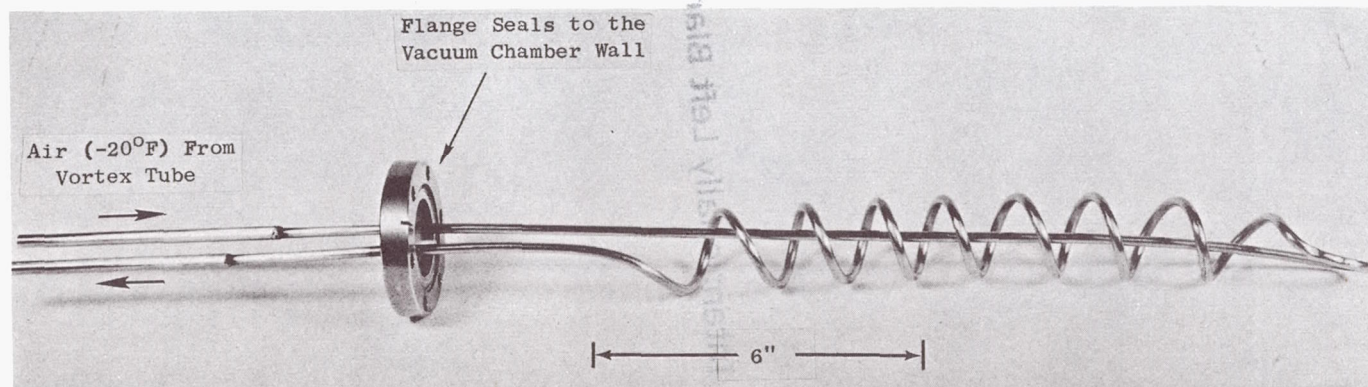
E. AIR COOLED METAL VAPOR COLLECTOR

During the operation of alkali metal test loops in vacuum chambers it is desirable to be able to collect and concentrate metal vapors which may be present in the system. These metal vapors might arise either from the inadvertent use of materials such as commercial copper containing small but volatile concentrations of zinc and lead⁽⁹⁾ or from alkali metal in the event of an alkali metal leak in the system. If a leak in the loop

(9) Hoffman, E. E. and Holowach, J., Cb-1Zr Thermal Convection Loop, Potassium Corrosion Test Loop Development Topical Report No. 5, R67SD3014, June 15, 1967, General Electric Company, Cincinnati, Ohio p.63

should occur it would be possible by use of the collector coil to decontaminate the loop and chamber components before exposing the system to the atmosphere. The collector tube assembly is shown in Figure 37. It consists of a 16-inch long coil of 1/4-inch stainless steel tubing mounted on a 2 3/4-inch flange. When in use the inlet air to the coil is cooled to approximately -20°F by passing it through a Ranque-Hilsch Vortex tube. (a)

(a) Fulton Cryogenics, Cincinnati, Ohio.



C5544-36

Figure 37. Flanged Cooling Coil Insert used to Collect Alkali Metal in the Vacuum Chamber in the Event of a Leak. (Orig, C64122907)

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VI. SODIUM PURIFICATION AND TRANSFER SYSTEM

An earlier topical report⁽¹⁰⁾ in this series included a detailed presentation of the procedures and equipment used to purify, transfer, sample, and analyze the sodium for the Cb-1Zr Pumped Sodium Loop Test. Only a limited review of this portion of the test program will be given in this report.

A. SODIUM PURIFICATION

Reactor grade sodium was purchased from U.S. Industrial Chemical (USI) for use in the Cb-1Zr Pumped Sodium Loop Test. A 15-pound capacity sodium hot trap was designed and fabricated for use in purifying sodium for the loop. The components of the unit are shown in Figure 38 prior to making the final closure weld. All parts of the system designed to run hot during the purification treatment were Types 304 or 316 stainless steel except the titanium liner and the zirconium getter bundle. The in-line filter located in the dip leg line near the dip leg valve was sintered, Type 316 stainless steel with an average pore size of 5 microns. The 15-pound hot trap was equipped with a charge pot of known volume for adding the desired amount of sodium to the loop surge tank. The ratio of the quantity of sodium to the zirconium surface area was 2.7 grams/inch². The hot trap was outgassed in the temperature range 400° to 600°F for about 100 hours to achieve a system pressure of less than 10⁻⁶ torr. A quantity of sodium weighing 12.8 pounds was added to the hot trap and gettered for 100 hours at 1300° to 1400°F. The analyses obtained on the purified product is included in that portion of Section VIII, Pretest Operations, which describes the filling of the loop.

(10) Dotson, L. E. and Hand, R. B., Purification, Analysis and Handling of Sodium and Potassium - Potassium Corrosion Test Loop Development Topical Report No. 4, R66SD3012, General Electric Company, Cincinnati, Ohio, June 13, 1966, P. 15.

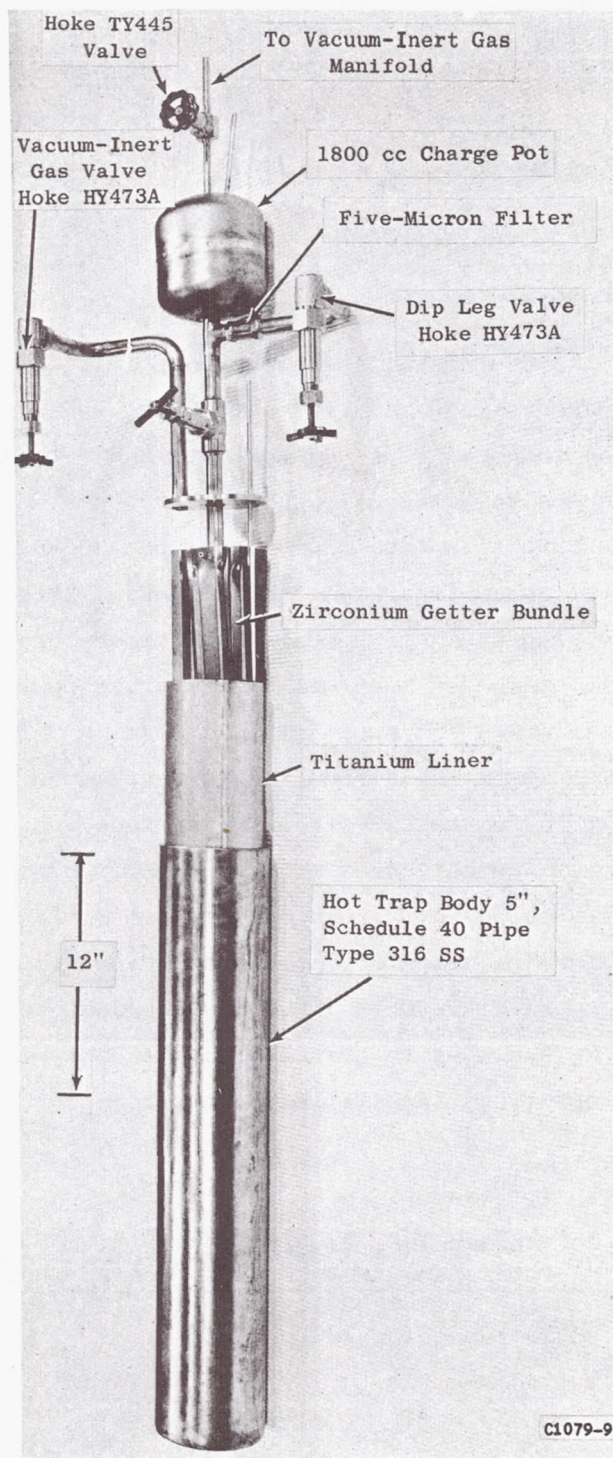


Figure 38. Fifteen-Pound Capacity Sodium Hot Trap with Charge Pot.
(Orig. C64041327)

B. SODIUM TRANSFER SYSTEM

The transfer of the sodium from the 15-pound hot trap into the Pumped Sodium Loop involved a more complex system than that used for the Cb-1Zr Sodium Thermal Convection Loop.⁽¹¹⁾ The apparatus used consisted of a purification system dolly which was portable and a stationary transfer - sampling - disposal system which was connected directly to the loop. Figure 39 shows a schematic diagram of the components of the loop fill system. The vacuum-argon manifold and the hot trap were enclosed in a portable dolly with an oven where the hot trap was located. The transfer section of the fill system contained a by-pass sampling section, a disposal tank, the necessary transfer lines and an oven heater; and was entirely enclosed by insulated walls, making an oven of the entire section enclosure. Figures 40 and 41 show the hot trap dolly and transfer sections, respectively, prior to the filling operation. All items in the systems which contacted sodium were of austenitic stainless steel. All connections were TIG welded except referring to Figure 39, between valves L and S, valves D and E and valves I and J, where Conoseal^(a) tube unions were used.

(a) Aeroquip Corporation, Marmen Division, Los Angeles, California

(11) Hoffman, E. E. and Holowach, J., Cb-1Zr Thermal Convection Loop, Potassium Corrosion Test Loop Development Topical Report No. 5, R67SD3014, General Electric Company, Cincinnati, Ohio, June 15, 1967
p. 30

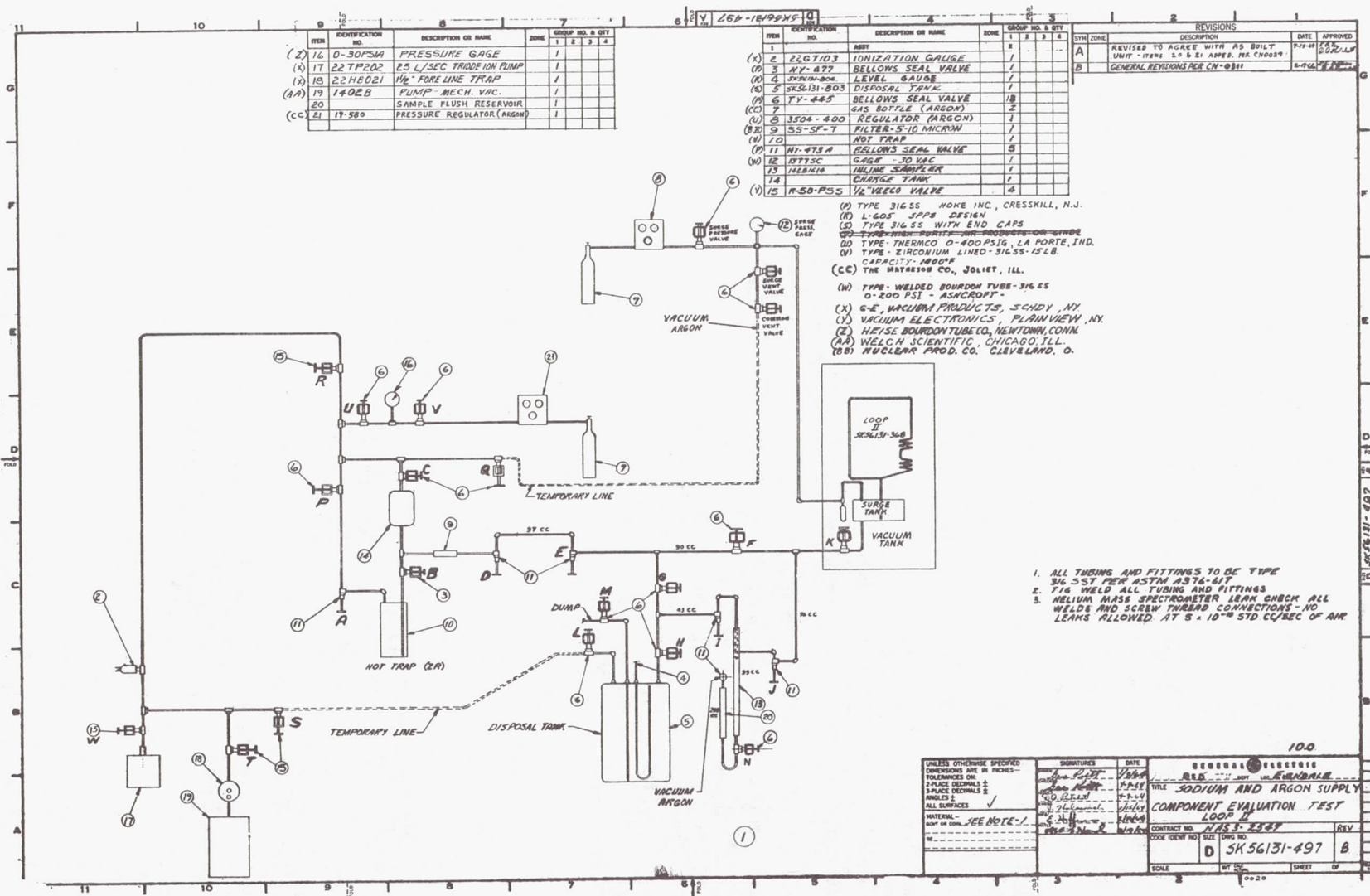


Figure 39. Sodium and Argon Supply for the Cb-1Zr Pumped Sodium Loop Test.

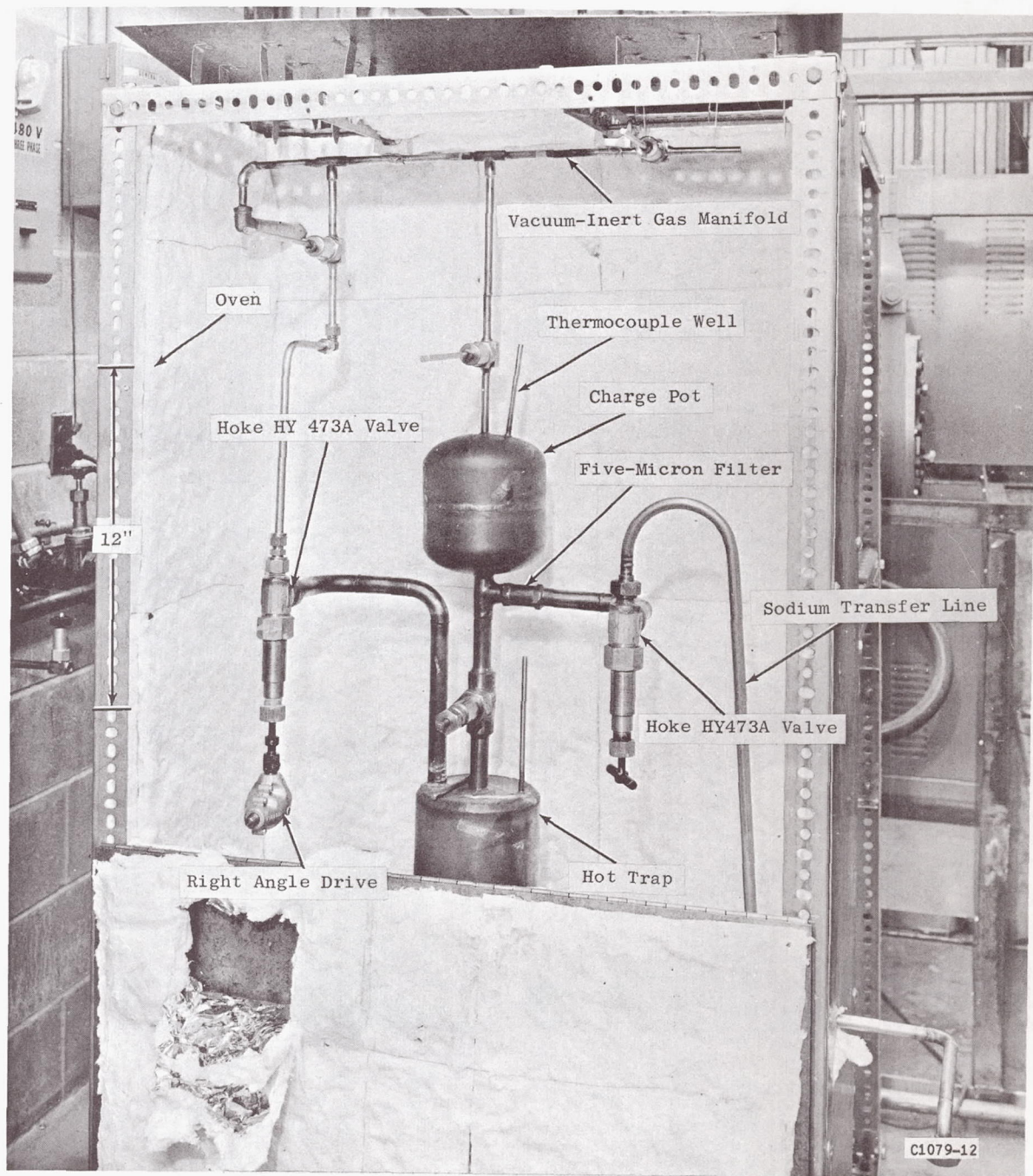


Figure 40. Sodium Purification System.

(Orig. C64061828)

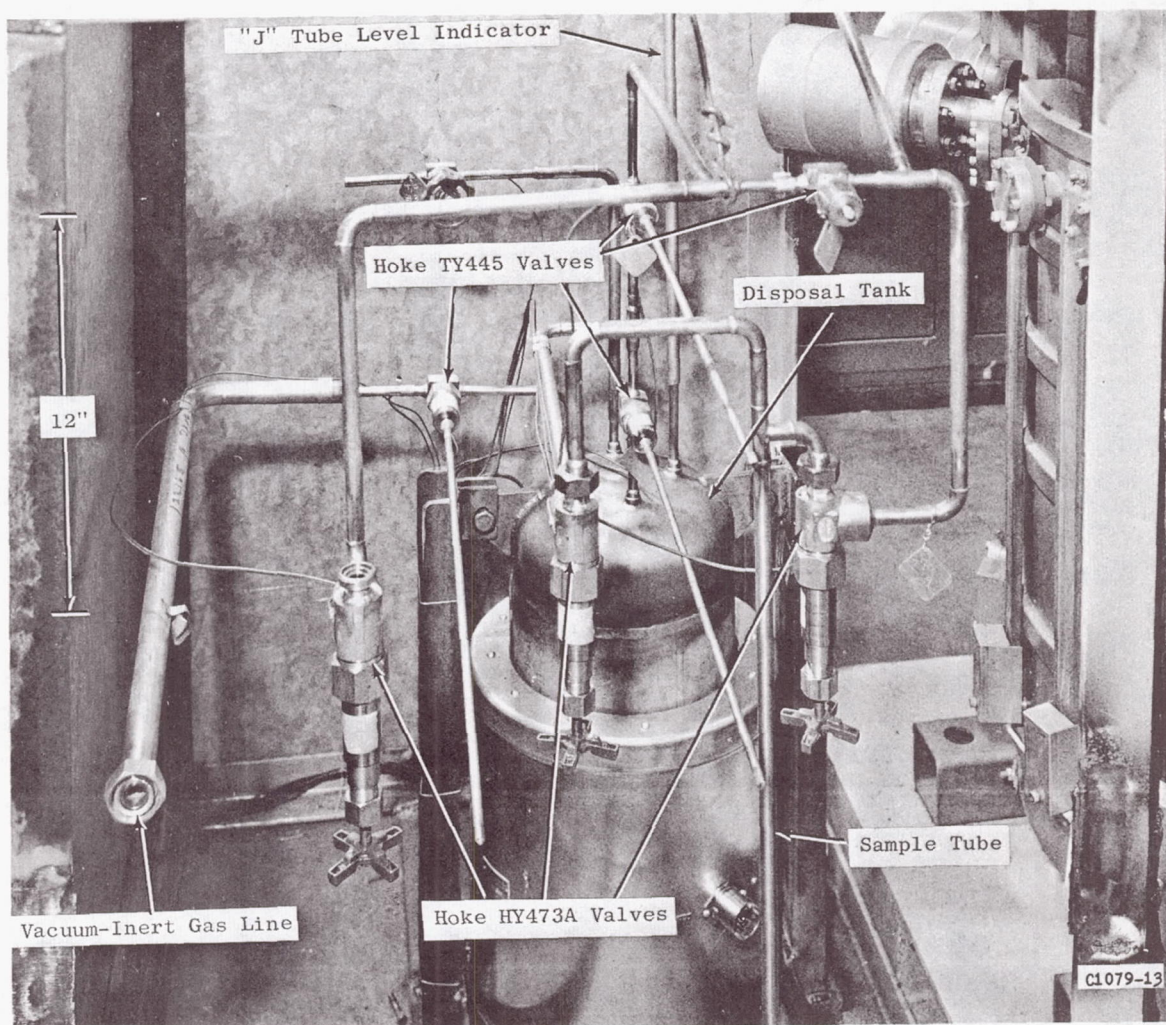


Figure 41. Sodium Transfer System. Located Adjacent to the Cb-1Zr Pumped Sodium Loop Vacuum Chamber. (Orig. C64061825)

VII. LOOP INSTALLATION AND INSTRUMENTATION

Upon completion of the welding and heat treating of the Cb-1Zr Pumped Sodium Loop assembly, a final helium mass spectrometer leak check of the assembly was made. No leaks were detected using a helium mass spectrometer having a sensitivity of 5×10^{-10} standard cc of air per second. The loop, mounted in the test chamber spool piece, was then transferred from the fabrication area to a portable air shelter in the test area for the installation of components, the attachment of loop thermocouples, and the application of Cb-1Zr foil thermal insulation.

A. INSTALLATION AND INSTRUMENTATION ENCLOSURE

The reinforced polyethylene 15-foot diameter air shelter used to house the loop and spool piece during installation and instrumentation is shown in Figure 42. A constant supply of filtered air is forced into the shelter by a blower which maintains an internal pressure of 0.2 psig to support the entire weight of the polyethylene hemisphere. The walls of the air shelter are sealed to the concrete floor by sand bags resting on a reinforced apron and resist the upward force of the internal air pressure. A semirigid steel-framed air lock is attached to the main room to permit personnel movement into and out of the air shelter without releasing the supporting air pressure. The interlock area is also used as a change room by the technicians entering the air shelter. All personnel engaged in instrumenting the loop were required to wear lint-free, white shoe covers, coveralls, and gloves. All loop components were vacuum cleaned, then washed with ethyl alcohol, and vacuum cleaned again to remove any dust or foreign material that could have accumulated during the fabrication or final shipment of the loop to the test area.

B. INSTALLATION OF COMPONENTS

Following placement of the loop and spool piece in the air shelter, the temporary supports used in the fabrication and transfer of the loop to the test site were removed and permanent supports and brackets were installed. The loop is primarily supported by the sodium heater electrodes which are

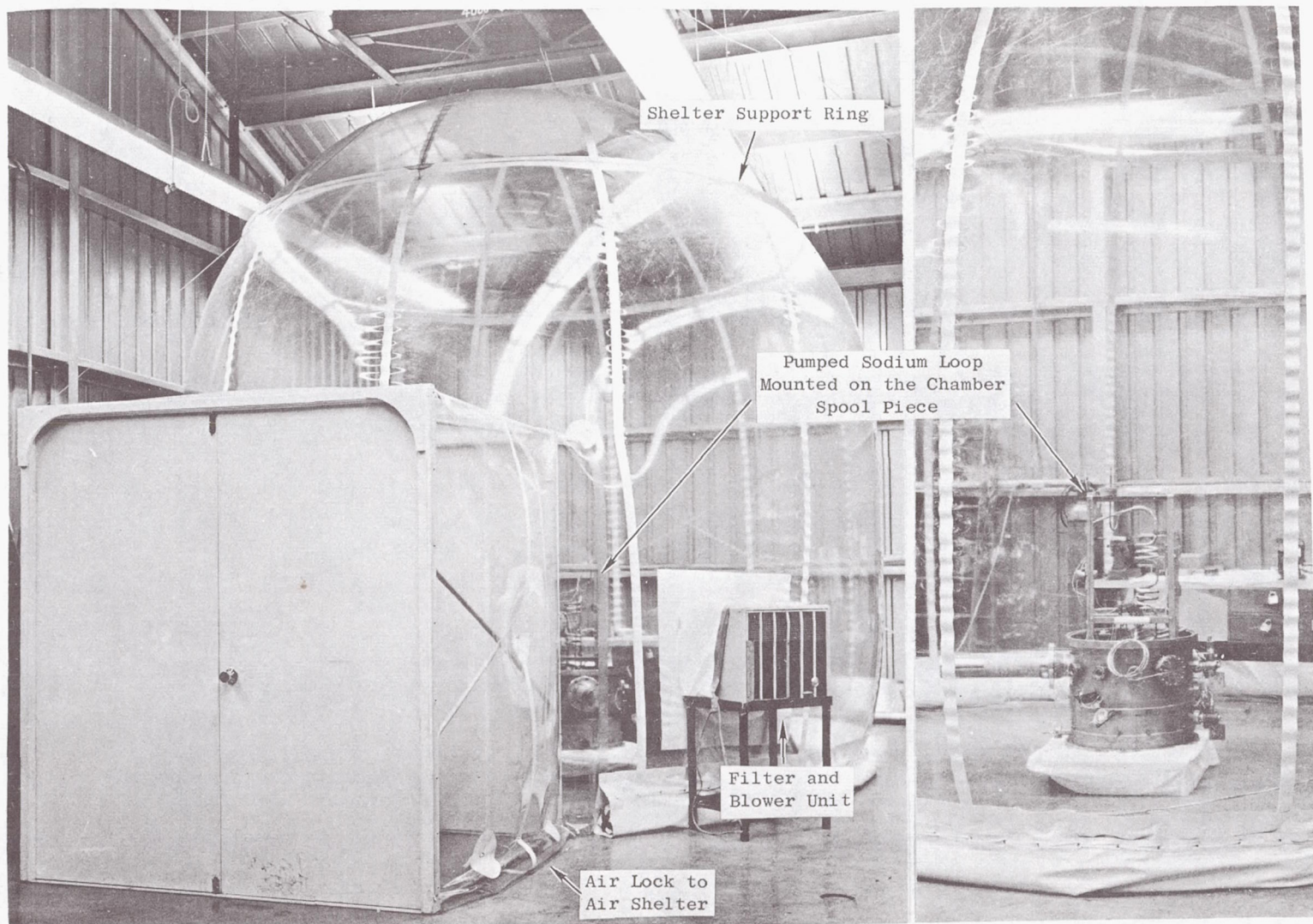


Figure 42. Two Views of the Reinforced Polyethylene Air Shelter Used During the Instrumentation of the Cb-1Zr Pumped Sodium Loop.
(Orig. C64041102, C64041101)

bolted to 2-inch wide by 0.25-inch thick OFHC copper bus bars which are fastened to the support structure. The bus bars are electrically insulated from the support structure by 99.7% alumina insulators. Additional fixed supports were used for the slack diaphragm and stressed diaphragm pressure transducers, the permanent magnet flowmeter, and the surge tank. The differential thermal expansion between the loop and the support structure was accommodated by expansion coils and generous radii designed into the loop for this purpose.

Prior to installing the permanent magnet of the flowmeter on the support bracket surrounding the Cb-1Zr flowmeter tube, the magnet was thermally stabilized. This magnet is in close proximity to the Cb-1Zr tube which is designed to operate at temperatures as high as 2200°F, and it is, therefore, necessary to stabilize the magnet prior to use to avoid an apparent decrease drift in the flowmeter indication during the endurance test due to thermally induced diminution of the magnet flux. The magnet was stabilized by repeated thermal cycling from room temperature to 900°F. The magnetic flux as a function of temperature after thermal stabilization was found to be quite stable as indicated earlier in Table III of Section II, Loop Design. The values obtained were used in calculating the sodium flow rate at the design temperature shown previously in Figure 6. The small effect of magnet temperature on the flux measured was significantly lower than published data for Alnico V which shows a 1.1% loss in flux per 100°F temperature rise up to 600°F. During the Pumped Sodium Loop test, the temperature of this magnet will not exceed 700°F.

The final step in the installation of the loop was the assembly of the valves. An assembled valve with the gear train and the flexible drive cable attached to the pinion gear was illustrated earlier in Figure 21 of this report. One end of the flexible cable was attached to the rotary vacuum feedthrough mounted on the vacuum chamber wall. Prior bench tests of the valve assembly in air in the arrangement required for operation of the Pumped Sodium Loop showed that less than 2 inch-lbs of torque applied to the rotary vacuum feedthrough was sufficient to operate the valve with

100 psi internal pressure. Rotary feedthroughs rated at 4-inch pounds are used to drive the valves.

C. THERMAL INSULATION

Dimpled foil made from 0.002-inch thick by 0.5-inch wide Cb-1Zr strip was selected as the reflective insulating material for the Cb-1Zr Pumped Sodium Loop. This approach was chosen for the following reasons:

1. The narrow strip could easily be wrapped around components of odd shapes and sizes, e.g., heater coils, to give any desired number of layers of insulation.
2. The dimpled foil with its self-spacing feature and minimum thermal conductive path (point contact between successive layers) yielded an insulation assembly of minimum mass and surface area which, in turn, reduced outgassing loads and radiation losses.

The dimpling of the foil was accomplished by passing the foil through the manually operated rolls shown in Figure 43. The Cb-1Zr foil and a sheet of plasticized polyvinylchloride^(a) were passed through the rolls together. The hardened steel, coarse knurled roller embossed the foil with the indentations which spaced the successive layers of foil during subsequent application on the loop components. As the foil was removed from the rolls, it was thoroughly cleaned with ethyl alcohol. Dimpling the foil increased its thickness from 0.002 inch to approximately 0.010 inch.

The number of layers of foil selected was determined by a consideration of the allowable heat loss. For the heater coils, it was necessary to consider both the allowable heat loss and the allowable decrease in electrical resistivity. The six layers of foil on the heater coils shown in Figure 44 provide additional current flow paths, but this is not enough to significantly lower the resistance because of the relatively high resistance of the point contact path through the layers of foil.

(a) Kayflex L-10; Source: S&C Mfg. Company, Cincinnati, Ohio.

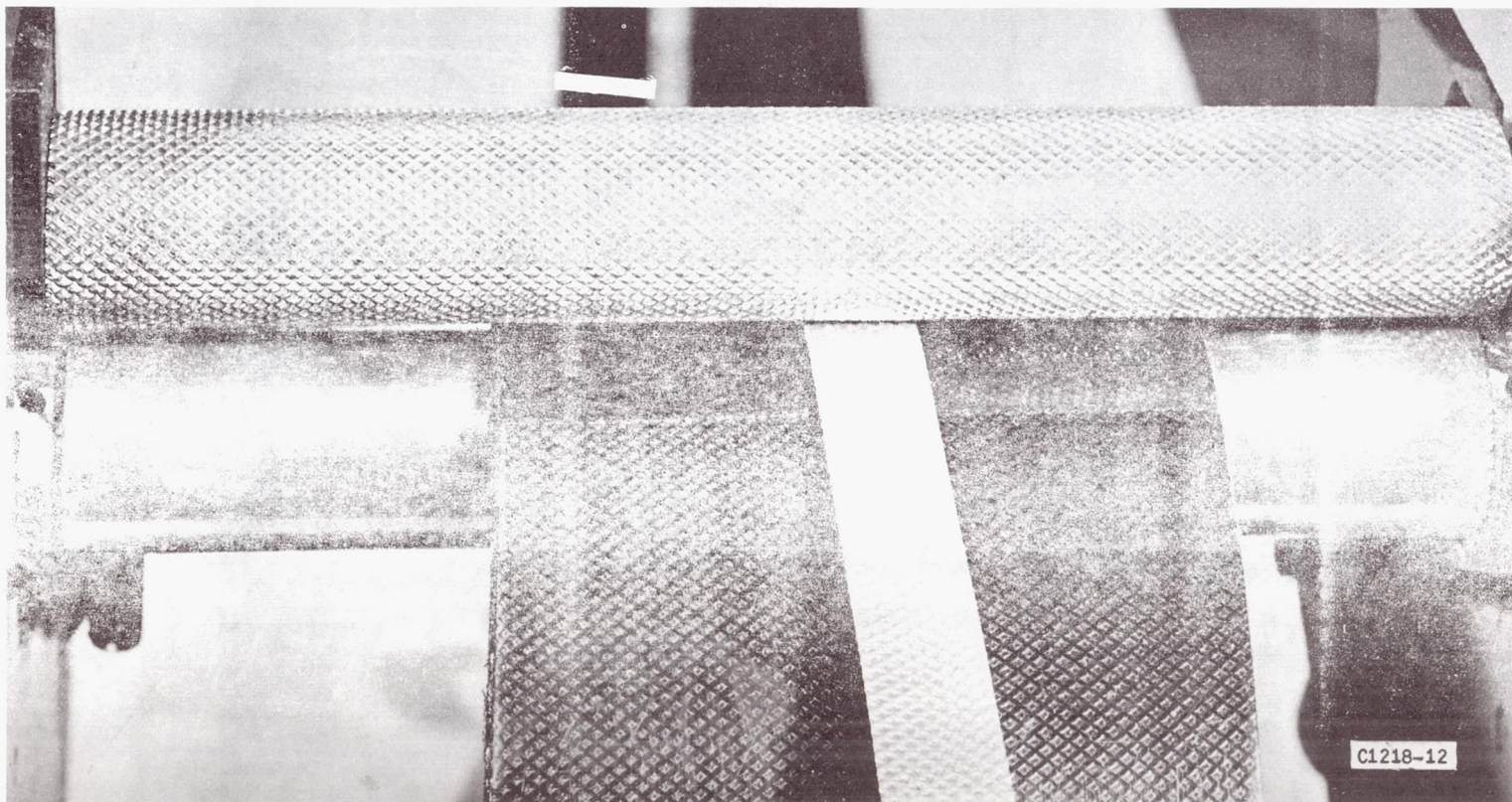
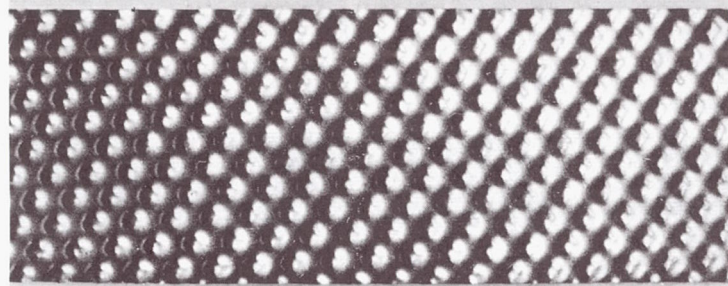
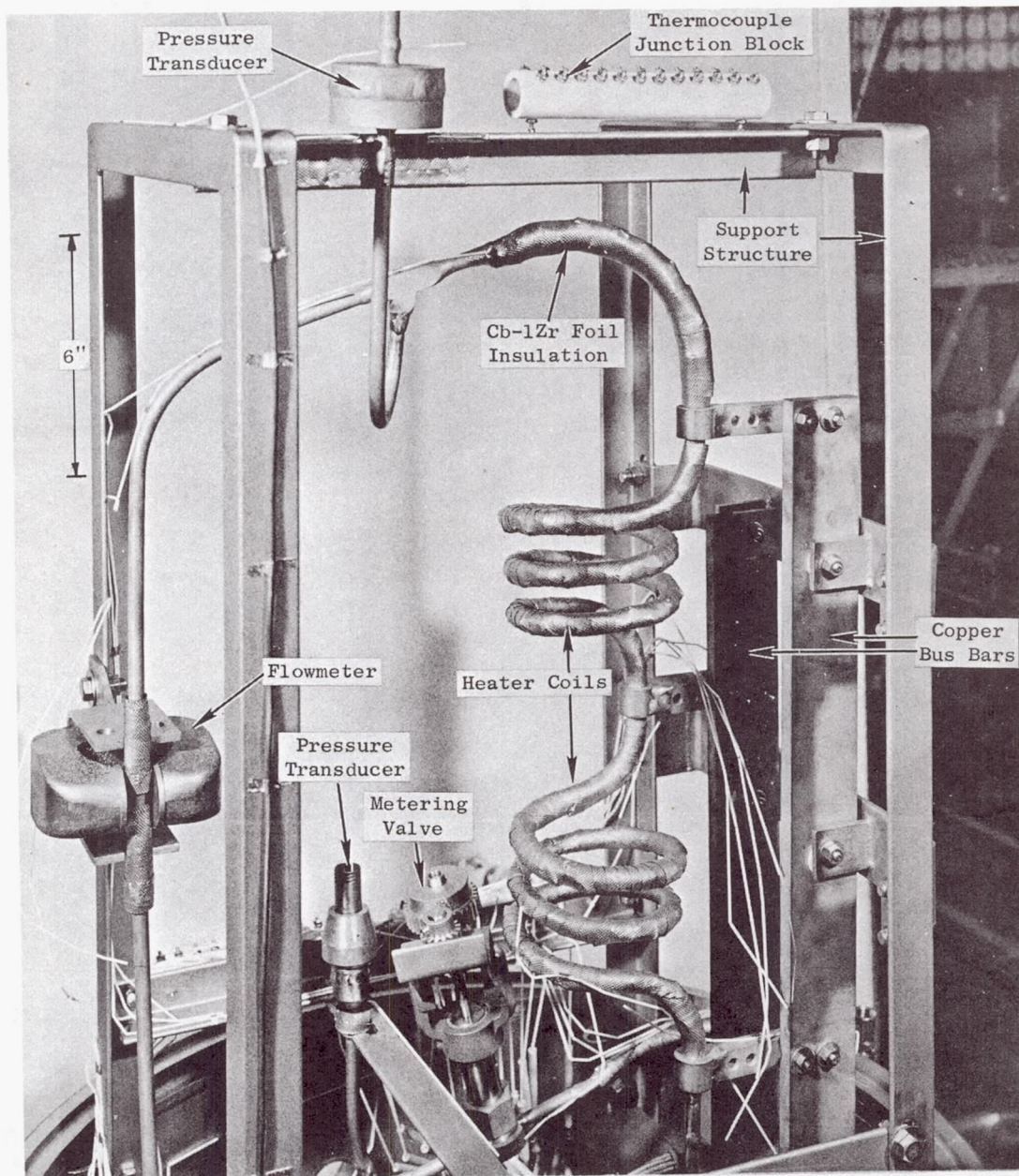


Figure 43. Dimpling of 0.5-Inch Wide x 0.002-Inch Thick Cb-1Zr Foil for use in Insulating Loop Components. Enlarged View of Dimpled Foil Shown. (Orig. C64102722, C64102101)



C5544-38

Figure 44. Cb-1Zr Pumped Sodium Loop Mounted on Chamber Spool Piece in Air Shelter Near Completion of Instrumentation. (Orig. C64061106)

The foil was applied to the tubing by continuously wrapping the strip on the tube in a spiral manner with approximately 10% (0.050-inch) overlap. The foil was fixed to the tube and to itself by spot welds made under a flowing argon atmosphere to prevent atmospheric contamination on the refractory alloy. Great care was taken in applying the foil over the thermocouple attached directly to the tube walls to minimize the possibility of foil-to-thermocouple wire contact during test which might result from slight movement of either material. The approach used is further described in the section below covering the thermocouple installation procedures used.

D. INSTRUMENTATION

The temperature of the loop was measured by 28 W-3Re/W-25Re thermocouples. The basic thermocouple alloy combination selected for instrumenting the three alkali metal loops in the Potassium Corrosion Test Loop Program was W-3Re/W-25Re. The selection was based on its compatibility with the test loop alloy, Cb-1Zr, its high and fairly linear thermal emf, and its reported excellent stability over extended periods of time in vacuum at elevated temperatures.⁽¹²⁾

The W-3Re leg was selected in preference to the pure tungsten leg because of its superior handling properties, i.e., less breakage during installation and operation. Even with the increased ductility of the W-3Re wire over unalloyed tungsten wire, fractures of the W-3Re leg of thermocouples, particularly near the brazed joint between the thermocouple wire and the nickel vacuum feedthrough tube, were one of the chief sources of thermocouple difficulties.

Although various tungsten-rhenium alloy combinations have been used for a number of years, a national standard has not as yet been adopted. Matched tungsten-rhenium thermocouple wire of various alloy combinations, however, can be purchased with a specified accuracy to tentative calibration tables adopted by the thermocouple wire suppliers. The policy adopted

(12) Hendricks, J. W., and Mc Elroy, D. L., High-Temperature High-Vacuum Thermocouple Drift Tests, ORNL-TM-833, August 1964.

for this program was to purchase wire to a chemical or material specification and conduct calibration tests at General Electric on the thermocouple wire in accordance with the overall quality control plan. The W-3Re wire was purchased from the Lamp Metals Components Department of the General Electric Company, Cleveland, Ohio, and the W-25Re wire was purchased from Hoskins Manufacturing Company, Detroit, Michigan. All thermocouple wire used in a specific loop test is from one matched lot with its own calibration.

The results of the calibration of the thermocouple wire used to instrument the loop are shown in Figure 45. The calibration test was originally run in an argon atmosphere at 5 psig using a certified Pt/Pt-10Rh thermocouple as the calibration standard. (Subsequent thermocouple calibrations for other loop tests of this program were performed in a high-vacuum thermocouple test facility which will be described in Topical Report No. 7 of this series.)

The location of the 28 loop thermocouples is shown in Figure 46. Starting at the hot junction of the thermocouple, the wires were routed along the support structure through a thermocouple vacuum feedthrough to a 150°F thermocouple reference junction compensator.^(a) At the reference junction, a transition from the W-Re thermocouple wire to copper lead wire was made which connected to the 24-point recording potentiometer. This thermocouple circuit was illustrated in Figure 15 of the topical report describing the Cb-1Zr Thermal Convection Loop Test.⁽¹³⁾

The thermocouple wires inside the chamber were electrically insulated with high-purity, 99.5% two-hole alumina insulators to the point of contact with the Cb-1Zr tubing. Beryllium oxide insulators (99.5%) were used in contact with the regions of the loop designed to operate at temperatures in excess of 2000°F. The insulators are supported at frequent intervals by small straps of Cb-1Zr foil spot welded to the support structure. A foil strap near the junction is required to remove all possible strain on the spot-welded junction.

(a) Research Inc, Minneapolis, Minn., Model No. RJ 4081.

(13) Hoffman, E. E. and Holowach, J., Cb-1Zr Thermal Convection Loop, Potassium Corrosion Test Loop Development Topical Report No. 5, R67SD3014, General Electric Company, Cincinnati, Ohio, June 15, 1967, p. 40

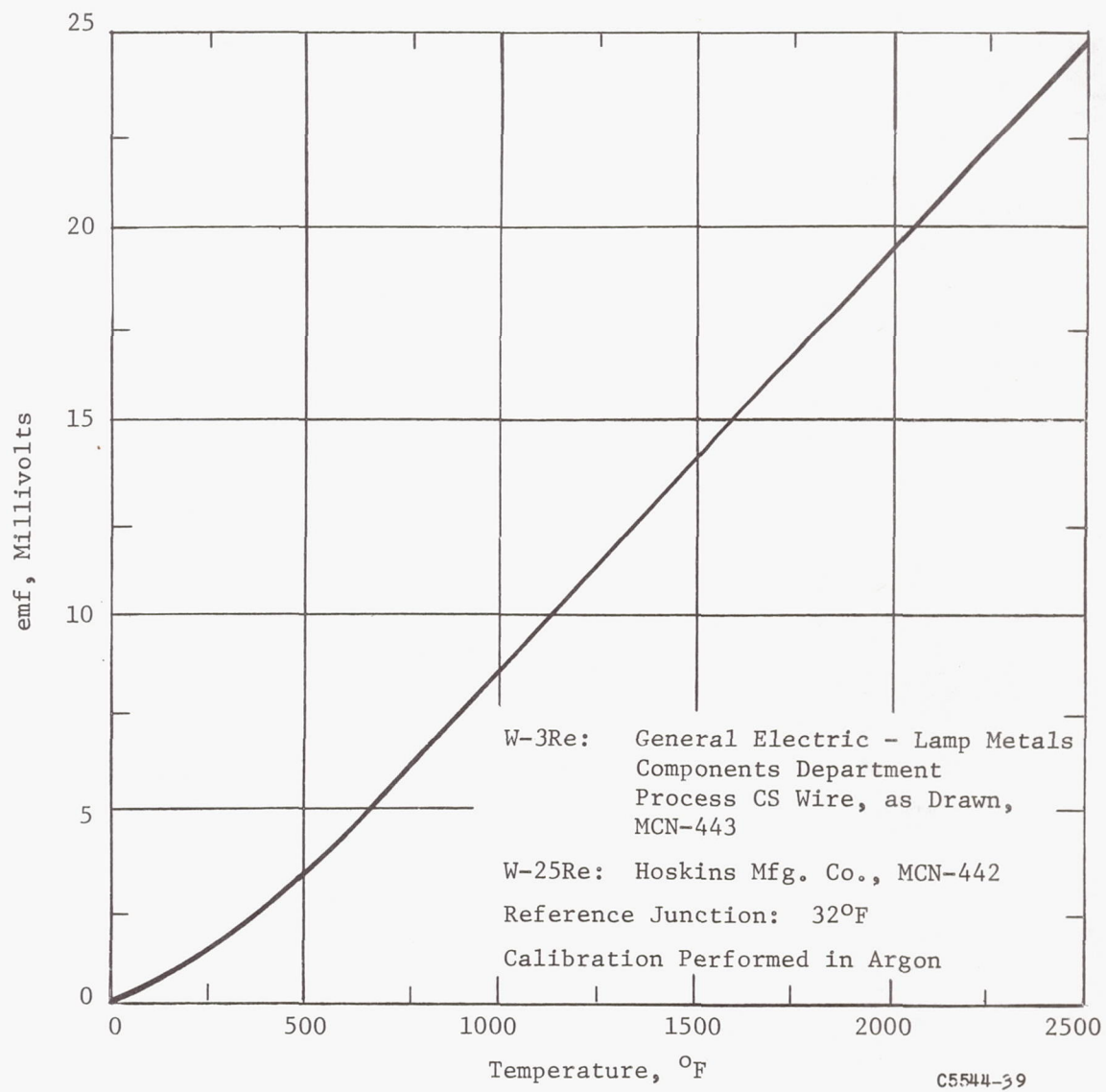


Figure 45. Thermal emf of the W-3Re/W-25Re Thermocouple Wire
Used in Instrument the Cb-1Zr Pumped Sodium Loop.

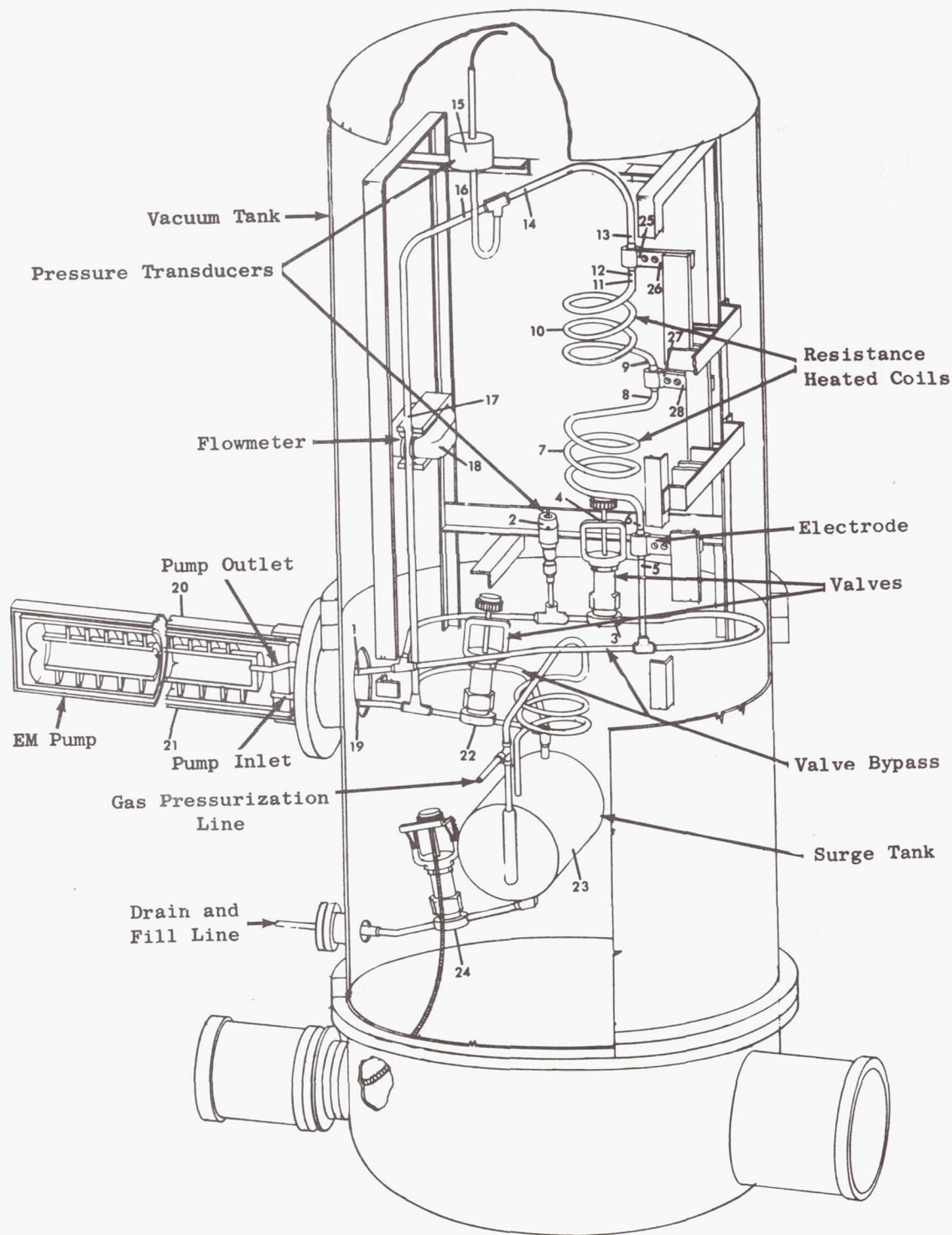


Figure 46. Cb-1Zr Pumped Sodium Loop Showing the Location of W-3Re/W-25 Re Thermocouples (Indicated by Numbers) Used to Instrument the System. (Orig. C64061705)

A typical split spot-welded thermocouple junction is shown in Figure 47. Each wire is laid parallel to the other, approximately 0.10 inch apart. Two consecutive spot welds are applied to each wire so that in the event the first spot weld breaks away from the surface without breakage of the wire, the thermocouple will continue to function. The active spot weld connection nearest to the measuring instrument will always be the actual hot junction. A small thermal shield is fixed around the junction to reduce heat radiation losses from the junction and to prevent thermocouple wire shorts when foil insulation is wrapped on the tube.

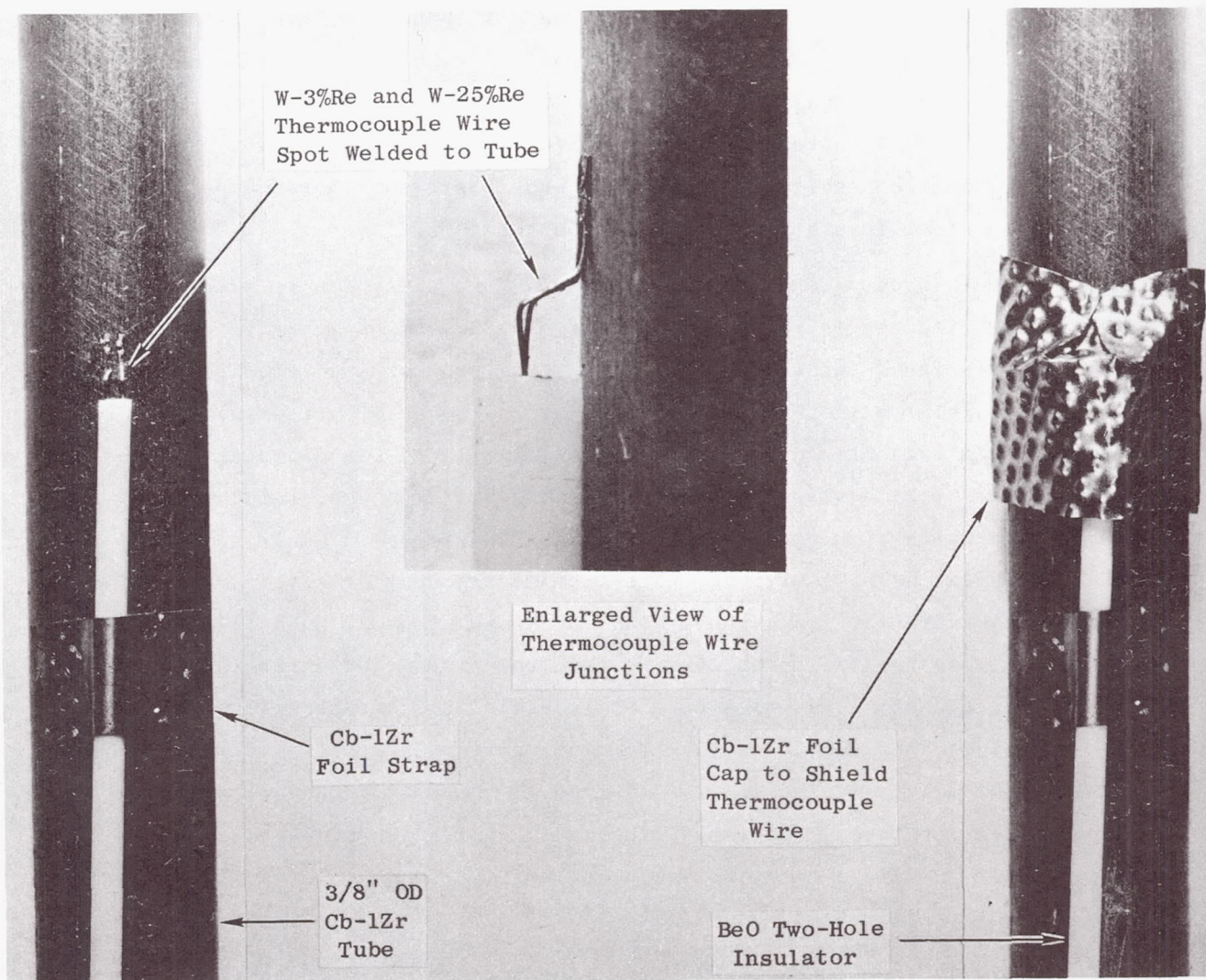
The method used to install the W-3Re/W-25Re thermocouple wires in the feedthrough flanges is illustrated in Figure 48. By using a flanged cross^(a) with an octal tube feedthrough^(b) on each of three arms of the flanged cross, it was possible to install twelve pairs of thermocouple wires through a single 2 3/4-inch flange in the chamber wall. The 5-mil diameter thermocouple wires were sealed to the 0.050-inch diameter nickel feedthrough tubes by brazing with Premabraz 615 (62Ag-24Cu-14In) in an argon atmosphere using a local electrical resistance heat source. As shown in the sketch in Figure 48, single-hole alumina insulators were used to electrically insulate the thermocouple wire from the nickel tube near the brazed seal. Teflon tubing was also used to insulate the thermocouple wires from the nickel feedthrough tubes to eliminate spurious thermal emfs which would result from multiple electrical junctions if the wires touched the nickel tubes. The feedthrough assembly flanges shown in Figure 48 are sealed using flat copper gaskets and may be baked out at 500°F.

E. CHAMBER INSTALLATION

Figure 49 shows the loop mounted in the spool section shortly before completion of the loop insulation and instrumentation. The unit was then transferred from the air shelter and mounted on the sump section of the

(a) Varian Associates Model No. 952-5051.

(b) Varian Associates Model No. 954-0055.



C1218-16

Figure 47. Method Used to Install W-3 Re/W-25 Re Thermocouple Wires on Cb-1Zr Alloy Tubing.

(Orig. C65020803)

(Orig. C65020804)

(Orig. C65020801)

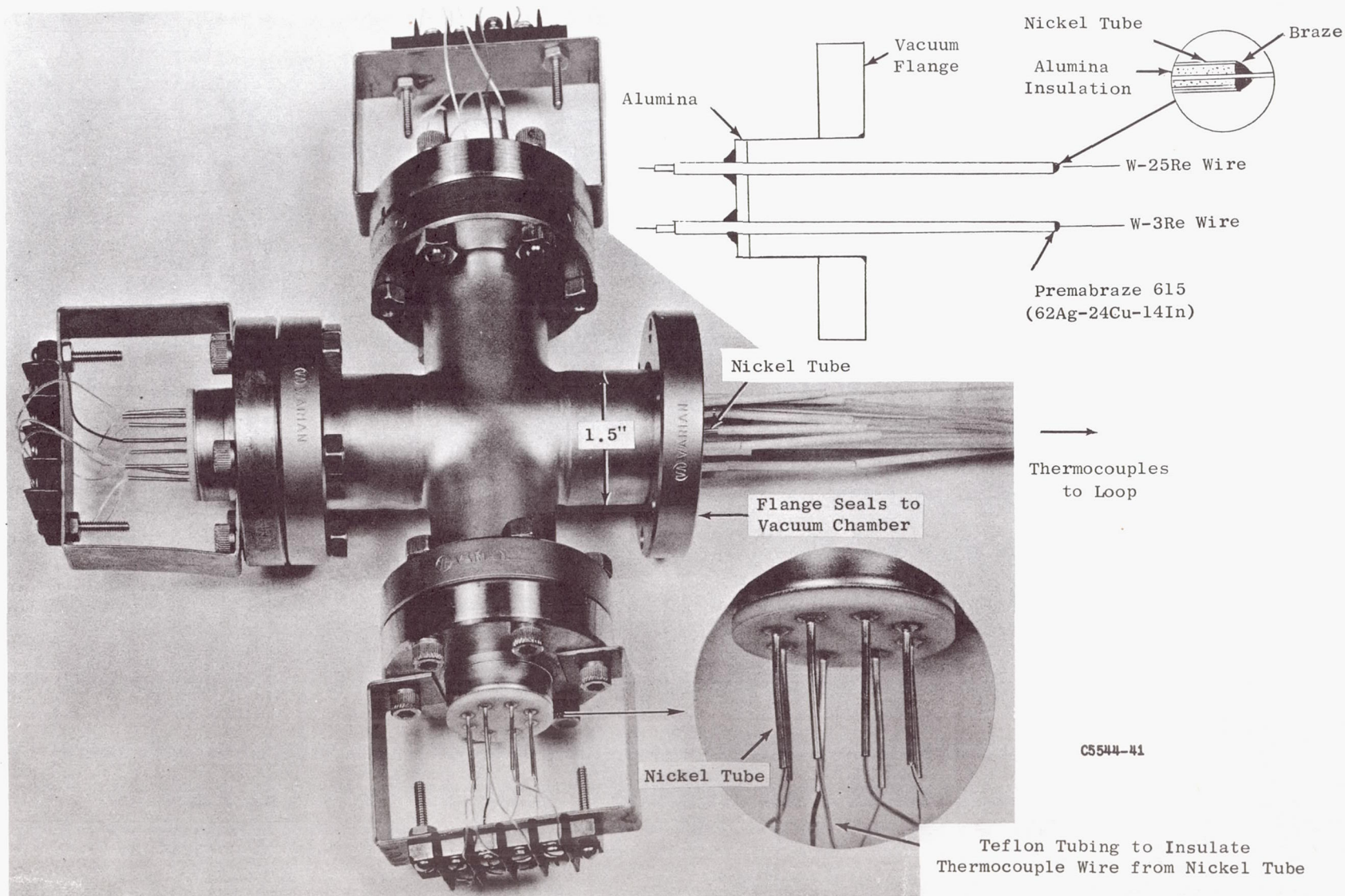
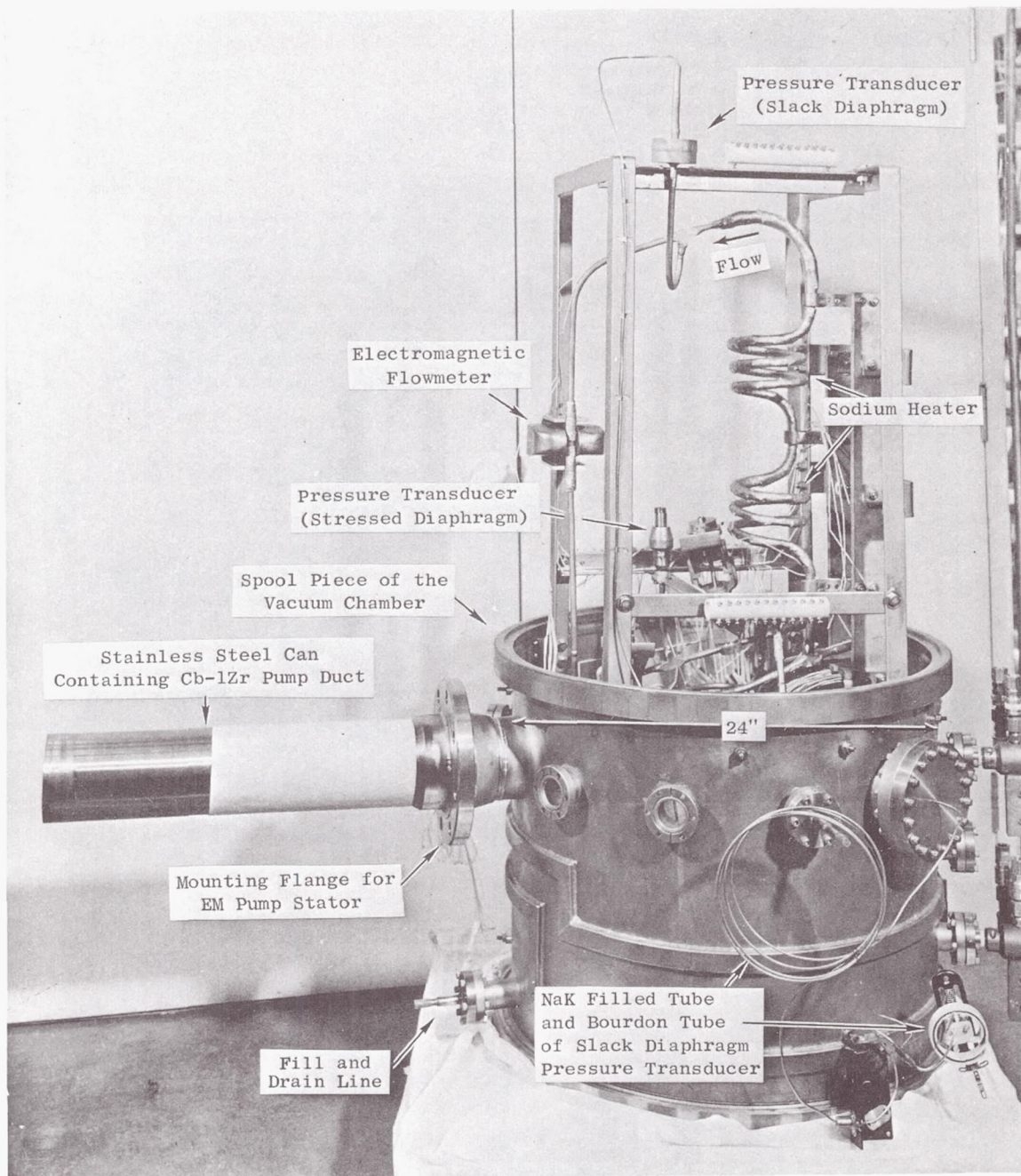


Figure 48. Method Used to Install W-3Re/W-25Re Thermocouple Wires in Vacuum Feedthrough Flanged Cross.

(Orig. C64110504)
(Orig. C64110505)
(Orig. C65051111)



C5544-42

Figure 49. Cb-1Zr Pumped Sodium Loop Near Completion of Installation and Instrumentation. (Orig. C64061105)

24-inch diameter vacuum chamber. The final connections joining the loop proper to the auxiliary test equipment and the control console were then made and these are listed below.

1. The loop pressurization line was connected to an argon gas supply. The external argon gas supply system was of all welded stainless steel construction with bellows-sealed valves and a metal diaphragm pressure regulator.^(a) The argon system was used to pressurize the sodium and thereby, prevent boiling in the heater coils during loop operation. The entire system was helium leak checked after assembly and all components were baked out at 300°F under vacuum.

The argon gas supply used for pressurization of the loop analyzed^(b) as follows:

Ar	-	99.997%	CO	-	1 ppm
O ₂	-	5 ppm	CO ₂	-	1 ppm
N ₂	-	5 ppm	H ₂	-	0.25 ppm
CH ₄	-	0.2 ppm	H ₂ O	-	4.5 ppm

2. The sodium fill and drain line was welded to the sodium transfer system, helium leak checked, and baked out at 300°F under vacuum to remove adsorbed gases from the inner wall surface of the sodium fill tube.
3. The EM pump stator was slipped over the pump duct insulation can and bolted to a fixed flange on the vacuum chamber. A compressed air supply was attached to the stator housing for cooling the insulation can and the stator windings.
4. The thermocouple leads were connected to the reference junction and resistance, and continuity checks were repeated on all thermocouples from the loop to the recorder. The flowmeter and

(a) Thermco Company, LaPorte, Indiana, 0-400 psig.

(b) Vendor Analysis - Matheson Company, Inc.

the pressure transducers connections to the recording potentiometers were completed at this time.

5. The loop safety circuits were checked out and these are listed below:

- a) An overtemperature thermocouple which turns off heater power to the loop if the loop temperature exceeds the control temperature by 200°F.
- b) An explosive valve argon flooding system which is actuated by the getter-ion pump current if the pump current exceeds 700 m.a. (equivalent to a pressure of 5×10^{-5} torr).
- c) A relay in the ionization gauge control which shuts off the loop heater power and the EM pump if the pressure rises to above 1.5×10^{-7} torr.

A closeup view of the loop after completion of the installation is shown in Figure 50. An overall view of the complete Cb-1Zr Pumped Sodium Loop test system just prior to the sealing of the chamber in preparation for the initial pumpdown, bakeout, and sodium filling is given in Figure 51. The control console showing the variety of instrumentation used to control and monitor loop operation is shown in Figure 52.

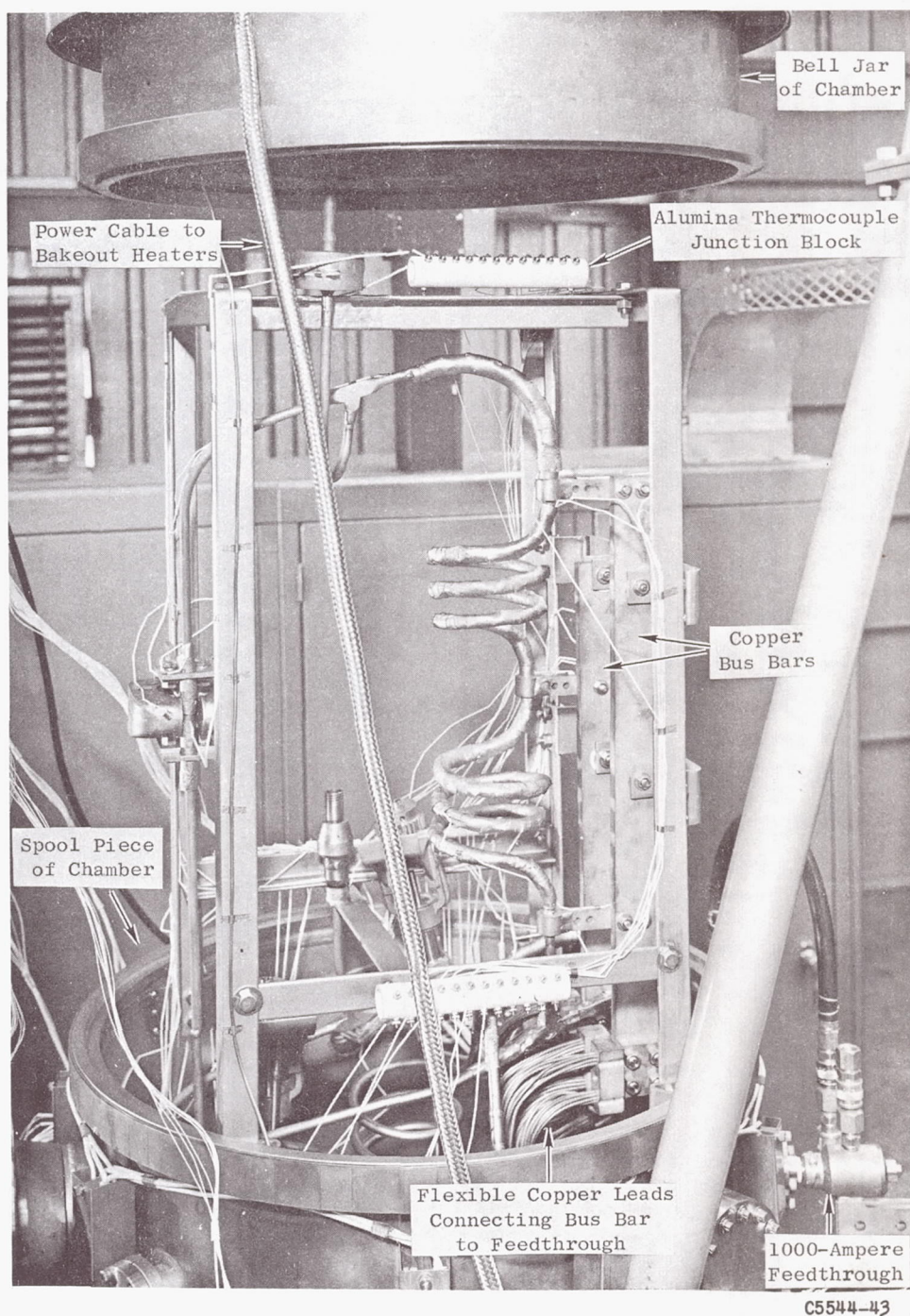
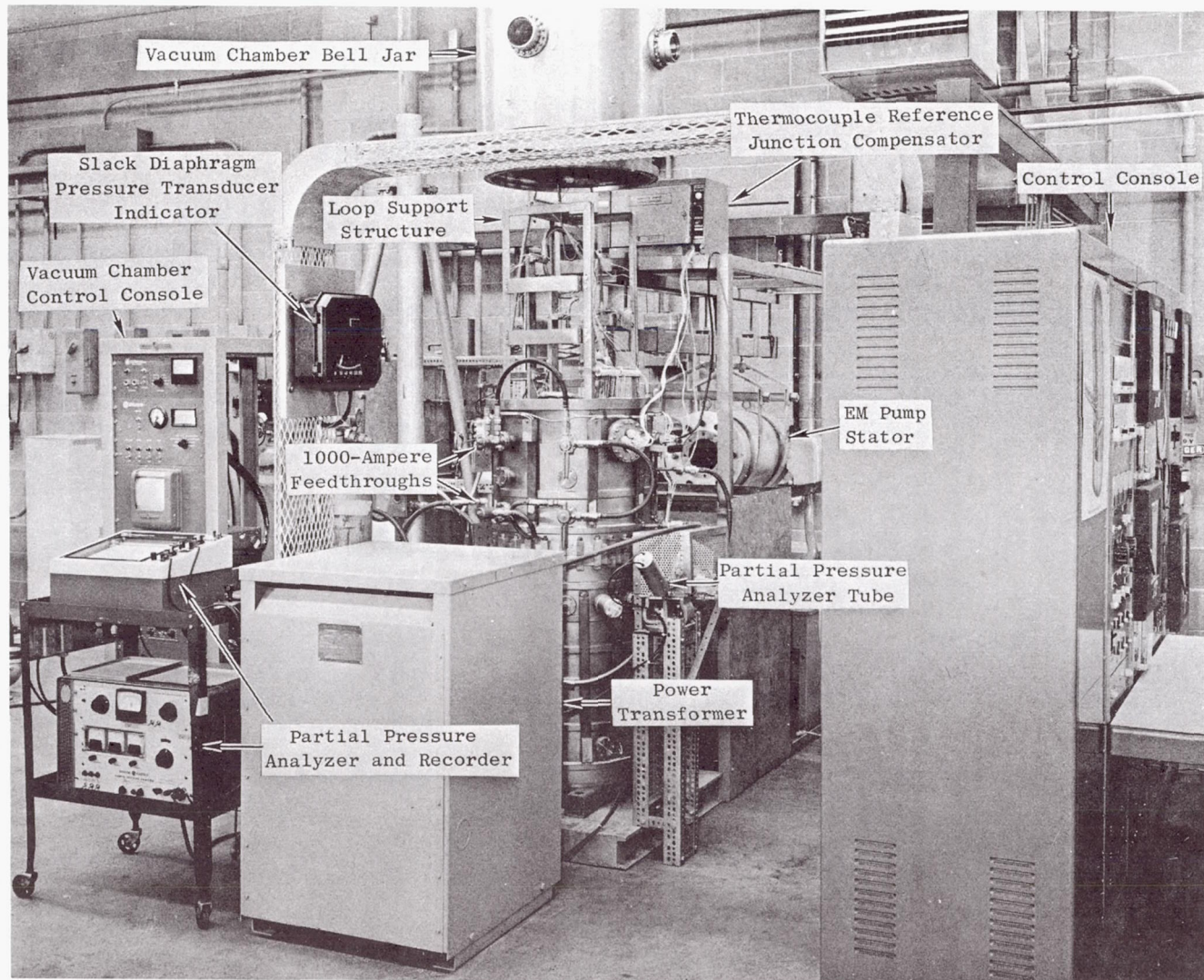
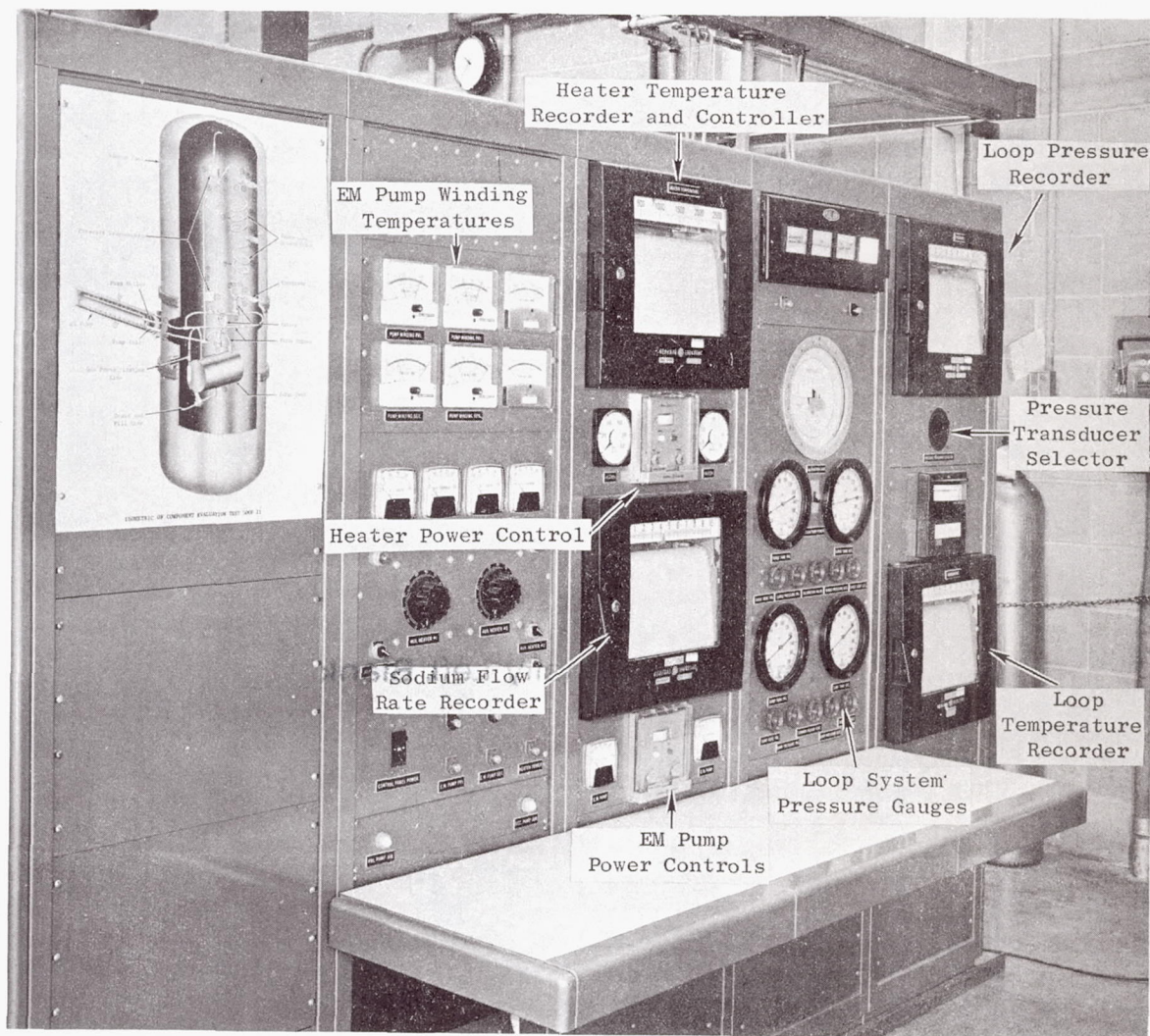


Figure 50. Cb-1Zr Pumped Sodium Loop in Test Chamber Following Completion of Instrumentation Just Prior to Sealing of the Chamber.
(Orig. C64061827)



C5544-44

Figure 51. Cb-1Zr Pumped Sodium Loop and Auxiliary Test Equipment Just Prior to the Sealing of the Test Chamber. (Orig. C64061829)



C5544-45

Figure 52. Control Console of the Cb-1Zr Pumped Sodium Loop. (Orig. C64061831)

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VIII. PRETEST OPERATIONS

The portion of the test program of the Cb-1Zr Pumped Sodium Loop presented in this section describes the pretest activities from the initial sealing of the test chamber following installation of the loop and spool piece until the loop reached the operating conditions and began logging hours on the 2500-hour endurance test.

A. PUMPDOWN AND BAKEOUT OF THE VACUUM CHAMBER

After the loop was installed in the 24-inch diameter x 90-inch high vacuum chamber, the bell jar was lowered and bolted to the spool flange on June 20, 1964. The vacuum chamber was rough pumped to 10⁶ microns with liquid nitrogen chilled sorption pumps before the 1000 liter per second ion pump was turned on. After the pressure had reached the 10⁻⁶ torr range, the sublimation pumps were turned on maximum power to outgas the titanium filaments. Flexible heating tapes were used to bakeout the partial pressure gas analyzer tube and the stainless steel EM pump can which contained a large quantity of Cb-1Zr foil insulation.

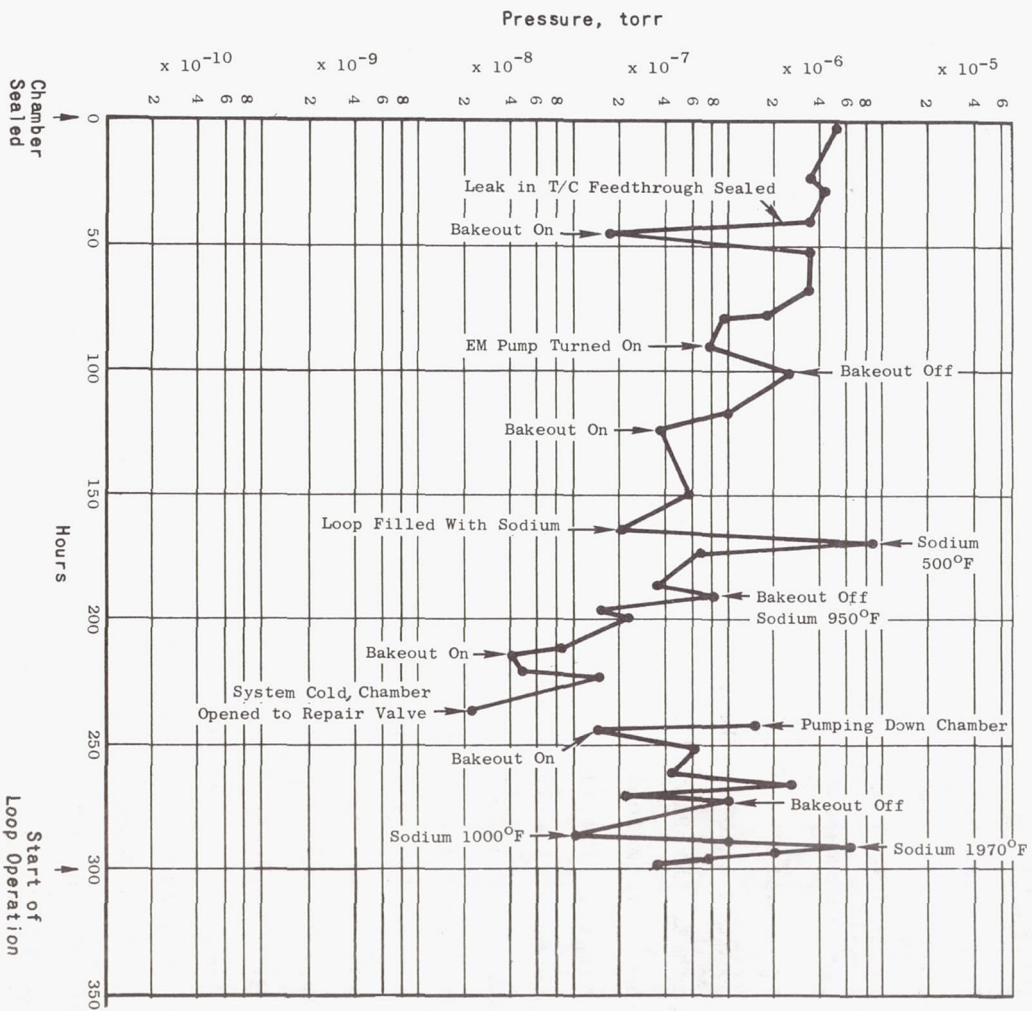
The bakeout heaters on the vacuum chamber are regulated by an on-off controller actuated by a thermal switch mounted on the vacuum chamber wall. An overpressure relay, which is part of the ion pump control circuit, can over-ride the heater control circuit if the pressure in the chamber exceeds 4×10^{-5} torr. This procedure is used to prevent the ion pump from being overloaded by the outgassing. However, during the start of the outgassing, the rate of rise in the pressure together with the large thermal capacity of the heating system can overshoot the overpressure set point and overload the ion pump. For this reason an adjustable set point temperature controller would be a desirable feature for vacuum test chambers which have large outgassing rates. To circumvent the above outgassing problem the bakeout was restricted initially to the individual sections of the chamber. The steady state temperatures of the various loop and vacuum components varied from a minimum of 250°F to 525°F with all bakeout heaters on.

Although the loop system proper was helium leak checked on numerous occasions during fabrication and following final assembly, an additional scheduled leak check was performed in the test chamber which assured that there were no leaks in the loop. This final leak test of the loop was performed by scanning for argon with the partial pressure analyzer while pressurizing the inside of the loop with argon. The loop was found to be leak tight. This result and the indicated leak tightness of the test chamber itself confirmed that outgassing was the principal source of the chamber pressure and the bakeout was continued.

The chamber pressure during the bakeout and pretest operation period is plotted in Figure 53. After 40 hours of bakeout, the vacuum chamber was helium leak checked using the partial pressure gas analyzer. A leak in the thermocouple feedthrough was found and sealed. The pressure immediately dropped from 4×10^{-6} torr to 2×10^{-7} torr. The chamber was again leak checked but no other leaks were detected and the still relatively high pressure was concluded to be the result of outgassing of the loop and vacuum chamber walls. As the bakeout was continued the pressure decreased, reaching a value of 2×10^{-7} torr with the system on bakeout. This pressure was achieved 165 hours after the chamber was sealed and just prior to filling the loop with sodium. The total pressure and partial pressures of the various residual gases during the period when the loop temperature was being increased to the required operating conditions is discussed in Part G of this section describing Pretest Operations.

B. CALIBRATION OF THE FAST RESPONSE PRESSURE TRANSDUCER

On June 29, 1964 with the loop filled with sodium and the chamber on bakeout the fast response pressure transducer was calibrated. This calibration followed two earlier calibrations, one performed after initial fabrication of the component and a second prior to filling the loop with sodium. This "hot" calibration, with the transducer at 480°F, required slightly over an hour. A net zero shift of approximately 12% of the span which varied 26% was observed. The zero shift was always an increase in absolute level and the span shift was not consistent. Because of the many



CS544-46

Figure 53. Vacuum Chamber Pressure During the Pretest Bakeout and Low Temperature Operation of the Cb-12r Pumped Sodium Loop.

and complex operational difficulties experienced with the fast response pressure transducer a complete discussion of the performance of this component will be covered in Section XII, Evaluation of Component Performance and Installation Procedures.

C. FILLING OF THE LOOP WITH SODIUM

The sodium purification and transfer equipment and procedures were presented in Section VI of this report. Since the filling operation was covered in detail in an earlier report⁽¹⁴⁾, only a brief summary will be given in this report.

After hot trapping, the hot-trap and charge-pot assembly were incorporated into the loop filling, sampling and dumping plumbing system adjacent to the Pumped Sodium Loop Test Chamber. The assembled system was then helium leak checked and found to be free of leaks at room temperature. The transfer system was outgassed at 250° to 300°F until the pressure rise rate was reduced to 0.95 micron-liters per minute. A pressure of 1×10^{-5} torr was obtained in the system prior to flushing the stainless steel transfer system with three pounds of hot trapped sodium. Following oxygen analysis of the sodium sample taken during the flushing operation, the loop surge tank was filled with 4.5 pounds of sodium. This operation was performed 165 hours after the chamber was sealed. The surge tank was pressurized to 100 psia with high-purity argon to fill the loop, and sodium was pumped through the loop at 500°F for one hour. The loop surge tank was then evacuated, causing the sodium to drain back into the surge tank. A sodium sample was subsequently taken from the surge tank and analyzed to determine if the oxygen level of the initial charge was sufficiently low to start the test.

The analytical results obtained on the sodium samples taken after hot trapping, after flushing the transfer system, and after filling and flushing the loop are given in Figure 54. Statistical analysis of these

(14) Dotson, L. E., and Hand, R. B., Purification, Analysis and Handling of Sodium and Potassium, Potassium Corrosion Test Loop Development Topical Report No. 4, R66SD3012, p. 19 and p. 55.

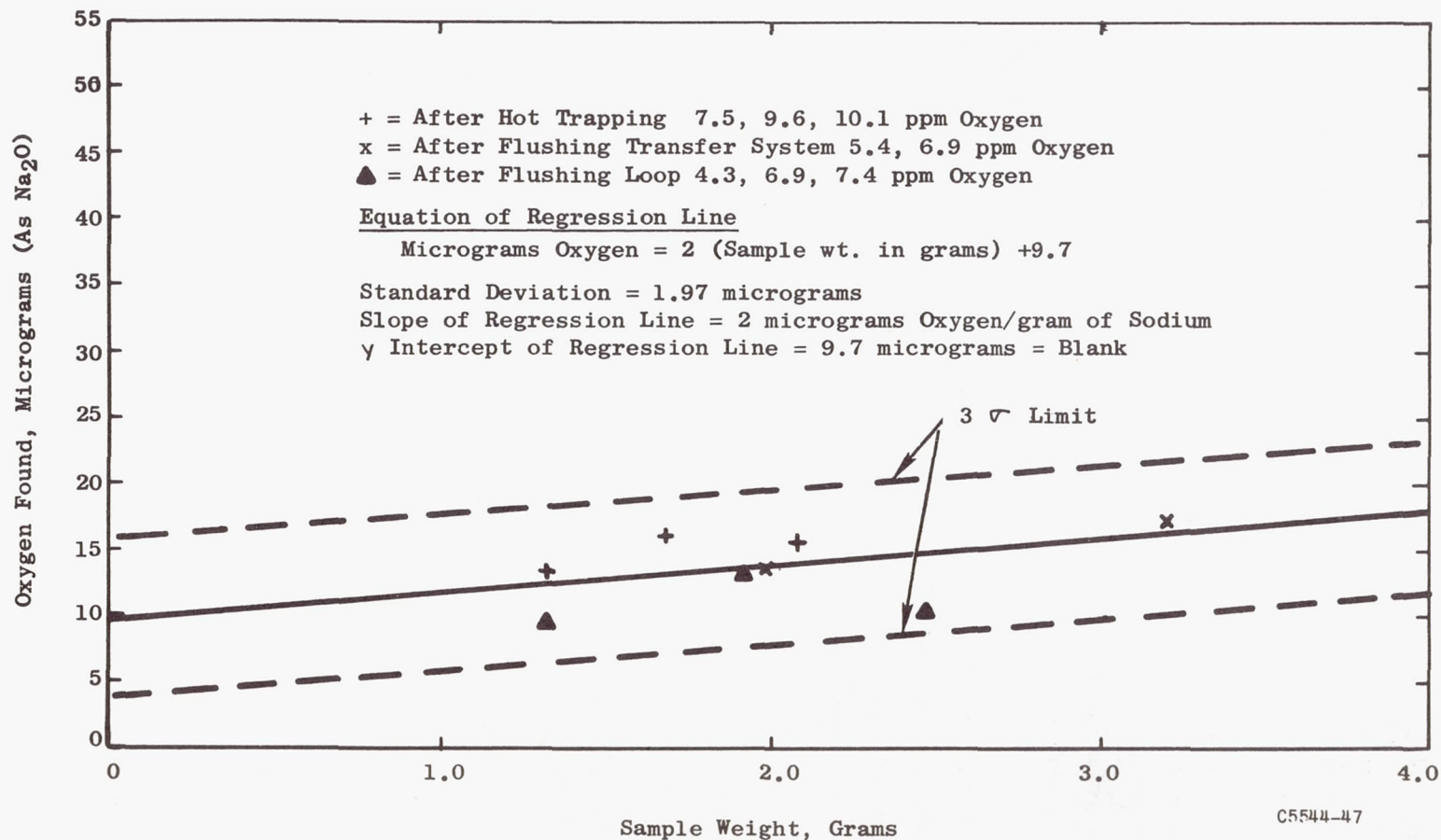


Figure 54. Oxygen Analyses of Sodium Following Purification and Filling of the Cb-1Zr Pumped Sodium Loop.

data indicate an oxygen concentration of 2 ppm, a 9.7 microgram oxygen blank for the analytical technique, and a 3σ value of 5.9 micrograms. Metallic analyses on the hot trapped sodium and the loop flush sodium are shown in Table XI.. Essentially no change in metallic constituents was indicated.

D. CALIBRATION OF THE PARTIAL PRESSURE ANALYZER

After approximately 200 hours of chamber bakeout and with the loop temperatures in the range 850° to 950°F, a calibration of the partial pressure analyzer was performed. An earlier and more complete calibration of the analyzer had already been performed before the loop was assembled in the vacuum chamber. This second calibration was conducted to determine whether the response of the analyzer had changed due to actual instability of the analyzer system with time or to some other factor such as accidental movement of the analyzer tube relative to the magnet. A base pressure of 3×10^{-8} torr was obtained and calibrations were made for helium and nitrogen at pressures as high as 8×10^{-7} torr. A detailed discussion of the calibration technique and results used to obtain the partial pressure data presented in this report are given in Appendix D of this report.

E. LOOP VALVE ACTUATION TEST

During the bakeout, it was found that the metering valve operation was extremely erratic and required a higher input torque to operate the valve after each adjustment. After 237 hours at bakeout temperature, it was decided to replace the 4 inch-pound torque rotary feedthrough^(a) with a 6 foot-pound unit^(b), to overcome the increased friction in the valve drive unit. The valve had been repeatedly bench tested in air without deterioration and had required less than 2 inch-pounds to operate the valve. The galling action between the threaded gold plated bushing and the gold plated valve stem operating in vacuum at bakeout temperature was

(a) Varian Associates Model No. 954-5026

(b) Varian Associates Model No. 954-5039

TABLE XI

METALLIC ANALYSES OF THE SODIUM FOR THE Cb-12r PUMPED SODIUM LOOP

	Chemical Analysis, ppm										
	<u>Fe</u>	<u>B</u>	<u>Co</u>	<u>Mn</u>	<u>Al</u>	<u>Hg</u>	<u>Zn</u>	<u>Sn</u>	<u>Cu</u>	<u>Pb</u>	<u>Cr</u>
After Hot Trapping	1	<5	<5	<1	<1	<1	<50	<5	<1	<5	<1
After Loop Flush	1	<5	<5	<1	3	1	<50	<5	<1	<5	<1

	Chemical Analysis, ppm											
	<u>Si</u>	<u>Ti</u>	<u>Ni</u>	<u>Mo</u>	<u>V</u>	<u>Be</u>	<u>Ag</u>	<u>Zr</u>	<u>Sr</u>	<u>Ba</u>	<u>Ca</u>	<u>K</u>
After Hot Trapping	<10	<5	<1	<5	<1	<1	<1	<10	<1	<3	<1	75
After Loop Flush	<10	<5	<1	<5	<1	<1	<1	<10	<1	<3	3	40

responsible for the increased friction. The changeover to the 6 foot-pound torque rotary feedthrough was made and the chamber bakeout continued.

F. CHECK OF THE LOOP SAFETY CIRCUITS

A low temperature check out of the controls and instrumentation was repeated in preparation for the endurance run. The loop safety circuits were also re-checked and activated. The safety circuits checked included the following:

1. An overtemperature thermocouple which turns off heater power to the loop if the loop temperature exceeds the control temperature by 200°F.
2. An explosive valve argon flooding system which is actuated by the getter-ion pump current if the pump current exceeds 700 m.a. (equivalent to a pressure of 4×10^{-5} torr).
3. A relay in the ionization gauge control which shuts off the loop heater power and the EM pump if the pressure rises to above 1.5×10^{-7} torr.

G. HEATING TO THE LOOP OPERATING CONDITIONS

As indicated earlier in Figure 53, a chamber pressure of 2×10^{-7} torr was achieved, with the bakeout on, 165 hours after the chamber was sealed. At this time the loop was filled with sodium and the flushing and sampling operations described in Part C of this section were performed. As shown in Figure 53, the loop temperature increased to 500°F when the loop was filled with sodium and the chamber pressure increased to 8.6×10^{-6} torr. At this pressure level, which persisted for less than one hour, hydrogen and mass/charge-28 (N_2 or CO) made up 22% and 36% respectively of the total pressure of the system. Hydrogen became the principal gas present when the sodium was circulated and the loop reached a temperature of 950°F. The increase in the temperature of the sodium was due entirely to the heat added by the EM pump. At this time (192 hours), the total pressure was 8.0×10^{-7} torr and the hydrogen accounted for 42% of the total pressure.

The bakeout was interrupted 237 hours after the sealing of the chamber to repair and modify the metering valve drive actuation system.

A chamber pressure of 2.2×10^{-8} torr was achieved with the system at room temperature just prior to opening the chamber. The chamber was resealed following the change of the rotary motion magnetic feedthrough and the loop startup operation was continued.

During the period from 288 to 292 hours when the sodium temperature was being increased from 1000° to 1970°F, the pressure increased to 6.5×10^{-6} torr but dropped to less than 1×10^{-6} torr in three hours. The titanium sublimation pumps were effective in reducing the pressure in the system during the peak gas load period associated with startup of the test. The rapid pressure reduction noted between 295 and 300 hours in Figure 53, 6.5×10^{-6} torr to 3.5×10^{-7} torr, is attributed to the combined effects of sublimation pumping and diminution of the outgassing load.

The chamber pressure at various times during the final heatup of the system to the operating conditions is given in Table XII. During the time period from 0830 to 0930 on July 2 the chamber pressure increased from 9.5×10^{-8} to 6.7×10^{-6} torr while the loop temperature was being increased from 1010° to 1880°F. Although the test system had been on bakeout for a total of approximately 170 hours between the initial sealing of the chamber and test startup, a considerable gas load remained which was released when the temperature of the components was increased to levels required during operation.

TABLE XII

PRESSURE IN THE TEST CHAMBER DURING THE HEATING UP OF THE Cb-1Zr
PUMPED SODIUM LOOP TO THE OPERATING CONDITIONS ON JULY 2, 1964

<u>Hour</u>	<u>Heater Temperature °F</u>	<u>Chamber Pressure torr</u>
0830	1010	9.5×10^{-8}
0840	1120	1.4×10^{-7}
0850	1280	3.0×10^{-7}
0855	1360	5.5×10^{-7}
0902 ^(a)	1440	1.0×10^{-6}
0917 ^(a)	1760	4.9×10^{-6}
0930 ^(a)	1880	6.7×10^{-6}
1005 ^(a)	1950	4.5×10^{-6}

(a) Titanium sublimation pumps on

IX. TEST LOOP OPERATION

The pretest activities which preceded the attainment of the operating conditions required for Cb-1Zr Pumped Sodium Loop were described in the previous section. A detailed discussion of the total pressure and partial pressure measurements made during the 2650-hour endurance test will be presented in Part C of this section following the presentation of the other aspects of loop operation.

A. LOOP OPERATION DURING THE 2500-HOUR ENDURANCE TEST

The logging of test time began at 1000 on July 2, 1964 and the test conditions after steady state operation was reached are given below:

Heater outlet temperature - 2050°F

Pump inlet temperature - 1985°F

Metering valve temperature - 650° - 800°F

Loop pressure - 144 psia

Sodium flow rate - 415 lb/hr

Electrical power input - 6.75 KW

During the first 100 hours of loop operation the chamber pressure decreased from the low 10^{-7} torr range to the high 10^{-8} torr range and had reached a level of 4×10^{-8} torr after 200 hours of operation. The chamber pressure with the loop at the operating conditions decreased slowly throughout the test. As indicated above, a detailed discussion of the total pressure and partial pressures will be deferred to Part C of this section.

The first unscheduled shutdown of the loop occurred at 1130 July 19 after 409 hours of operation, due to the over-temperature of a thermal overload relay in the EM pump power supply. The over-temperature of the thermal relay occurred on an excessively hot day when the ambient temperature of the test cell, where the EM pump power supply is located, exceeded 100°F. The thermal relay was adjusted to its maximum temperature setting to permit higher ambient operating temperatures, and a large capacity exhaust fan was installed to increase the laboratory ventilation and prevent thermal overloading of the relay.

A scheduled shutdown of the loop was made at 0800 August 3 after 734 hours of operation, to determine and correct the cause of progressive deterioration in the metering valve actuation system and to identify and locate the source of a dark deposit which had accumulated on the colder regions of the test chamber wall.

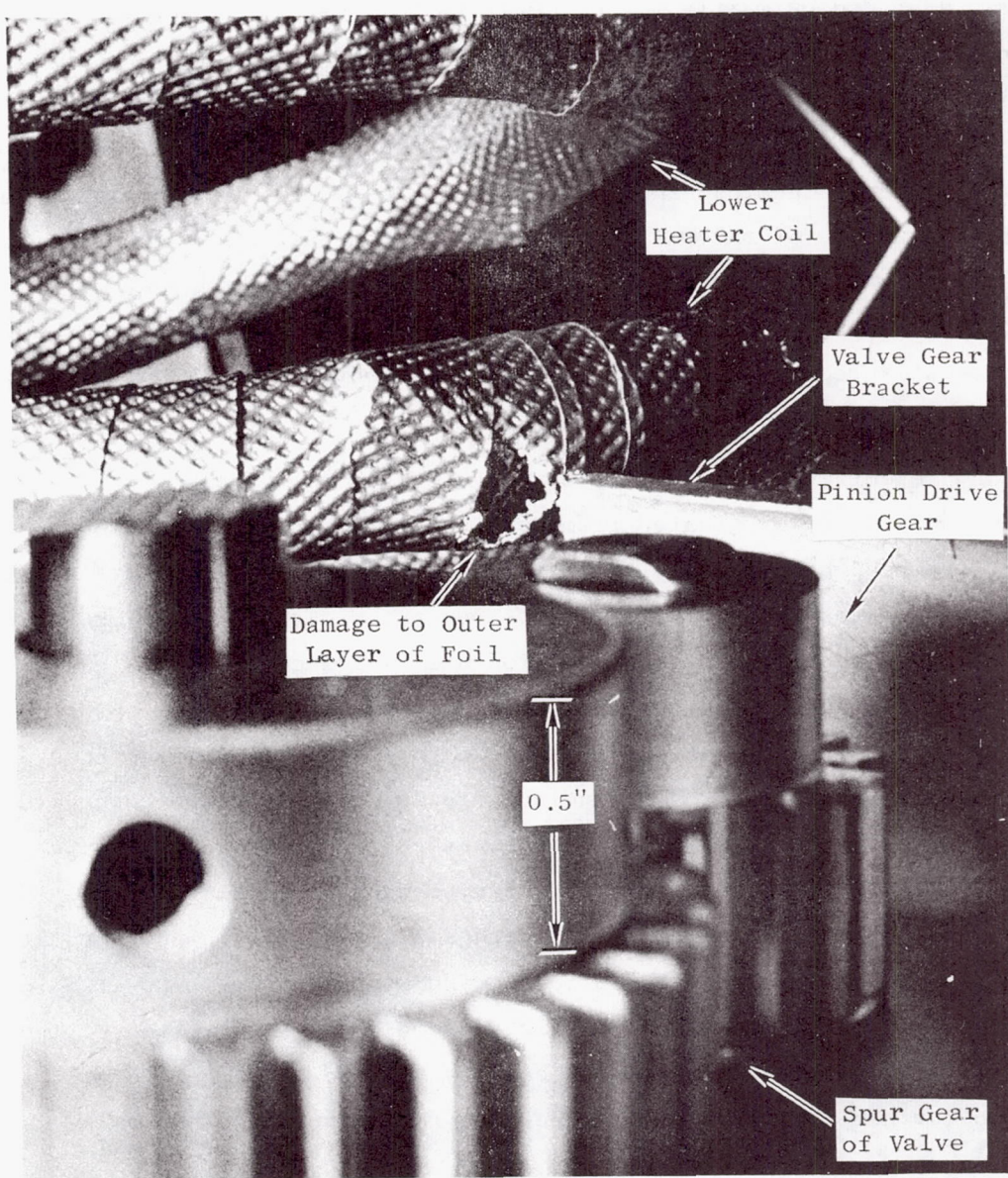
The dark deposit had concentrated in bands which traced the path of the water cooling channels. Darkening appeared to increase slowly to a maximum intensity during the first 200 to 300 hours of the test and then remain relatively constant. During the bakeout following the unscheduled shutdown of July 19, the deposits completely disappeared from the heated chamber walls but reappeared during the subsequent steady state operation in the exact location of the water cooling channels of the vacuum chamber. The tendency of the deposit to migrate in the chamber indicated that the material had a relatively high vapor pressure at the chamber bakeout temperature of 400° - 500°F. During the scheduled shutdown of August 3, the loop temperature was decreased to 1000°F and the chamber walls were heated to approximately 500°F to allow the deposit to concentrate on an air-cooled coil which was located near the center of the vacuum tank. This coil was installed initially so that it might be used to collect sodium in the event that a leak developed in the loop. This coil was previously described in Section V, Test Equipment, and illustrated in Figure 37. The inlet air to the coil was cooled to approximately -20°F by passing it through a Ranque-Hilsch Vortex Tube. The substance deposited on the collector coil was identified as cadmium. The minute amount of the deposit and the fact that it rapidly migrated to the coolest areas of the chamber made it of little consequence in affecting loop operation or contamination. The major interest was to hopefully identify the source and thereby remove it from future loop test systems, but checks of numerous types of nuts, bolts, washers, etc, for cadmium coatings did not reveal the source.

Visual examination of the loop in the region of the metering valve revealed that the valve body had apparently rotated during attempts to operate the valve and this movement resulted in momentary contact of the

bracket with the Cb-1Zr foil insulation on the lower loop heater coil. Arcing from the electrically charged heater to the grounded stainless steel gear bracket resulted. Fortunately, the damage as shown in Figure 55 was confined primarily to the metallic foil used to insulate the heater thermally, and only two small pits less than 0.010 inch in diameter and less than 0.002 inch deep were found on the surface of the heater tube. The pits were easily removed by light polishing of the tube wall with alumina paper. Chemical analyses performed on acid smear samples taken from the surface of the polished area indicated that no stainless steel constituents were present on the Cb-1Zr tube. Restraining bars were subsequently welded from the support structure to the gear bracket assembly to prevent a recurrence of this type of movement.

During this period of loop inspection following the August 3 test shutdown, examination of the valve actuation system revealed that the actuation problem originated from galling in the threaded section of the valve stem and bushing. Prior to the test shutdown, up to 6 ft-lbs of torque had been required at times to open and close the metering valve. In bench tests prior to loop operation only 1-2 inch-lbs of torque was sufficient to operate the valve. Self-welding of the highly stressed threads was initially considered to be a potential problem and both the stainless steel stem and the aluminum bronze^(a) bushing had been gold plated to avoid this problem. Upon disassembly of the valve, it was observed that the valve stem and bushing had bonded and, after the initial break-away, could be operated only with a significantly higher operating torque than had been required prior to the start of the test. The increased operating torque in turn resulted in extremely rough operation of the gear drive assembly which exhibited a tendency to bind at higher torque levels and so further increased the torque required to actuate the valve.

(a) Nominal Composition: Cu-9Al-3Fe



C5544-48

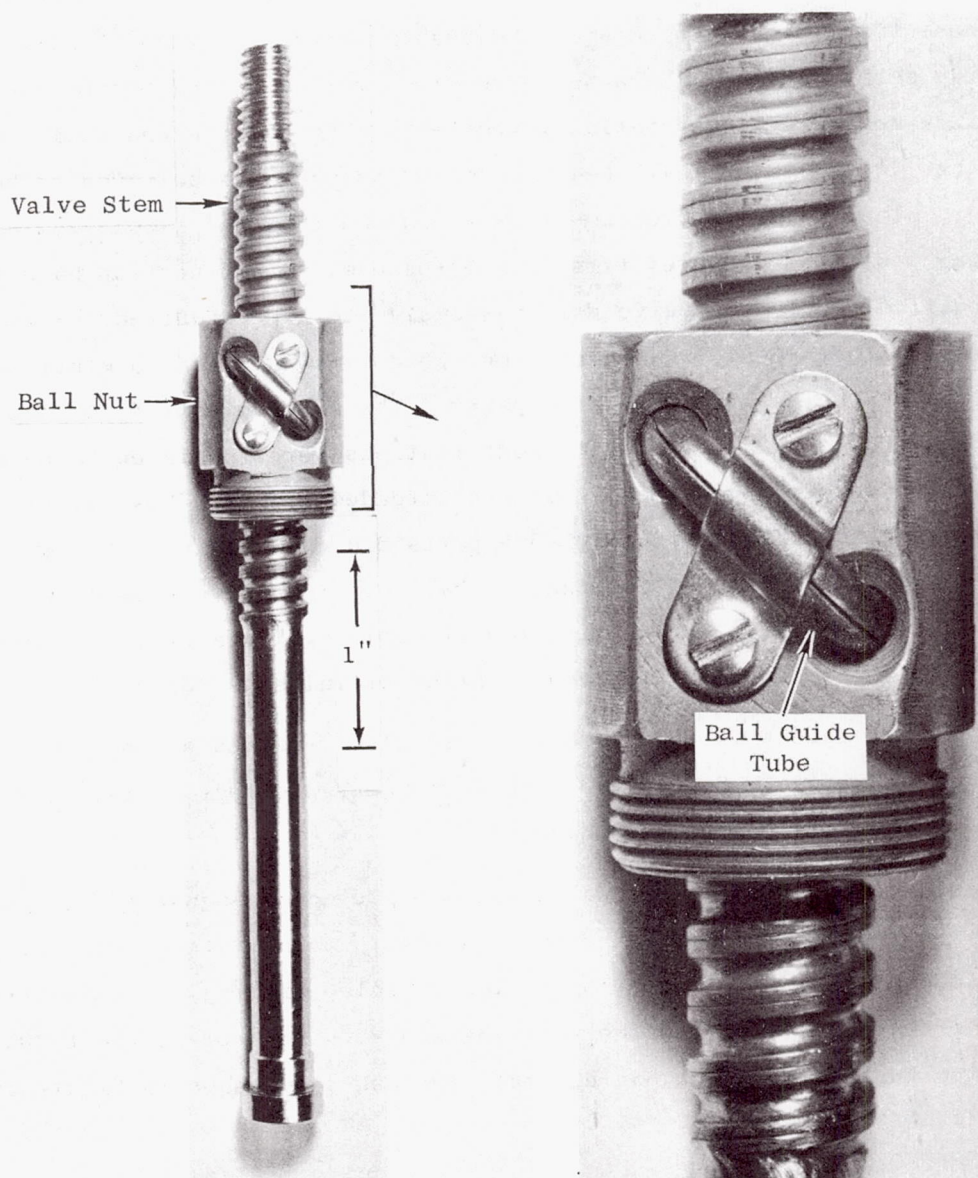
Figure 55. Damage to the Outer Layer of Cb-1Zr Foil Insulation on the Lower Heater Coil Caused by Electrical Arcing to the Valve Gear Bracket. (Orig. C64080513)

Two approaches were initiated to eliminate the valve actuation problem. The first approach was simply to replace the gold-plated stainless steel stem and aluminum bronze bushing with similar L-605 (Co-base alloy) parts. The second approach considered was the replacement of the entire threaded stem and stem bushing with a Saginaw^(a) ball bearing screw assembly which would require less operating torque and possibly minimize the operational problem due to galling and self-welding. Although the ball bearing screw approach was believed to be the better solution of the problem, it was decided that the L-605 stem and bushing would be evaluated first since these materials were on hand and no modification to the valve drive assembly would be required. Following machining, the L-605 threaded surfaces were work hardened to minimize the galling tendencies of these valve parts. The procurement of the Saginaw ball bearing screw and the valve modifications were initiated to be available as immediate replacements for the threaded stem and bushing in the event that the substitution of L-605 parts did not eliminate the problem. A recognized advantage of the Saginaw ball bearing valve stem drive approach was the ease of substitution of commercially available cermet or ceramic balls for the standard hardened stainless steel balls.

Several defective thermocouples were also repaired during the August 3-17 test shutdown. Shorts and breaks in the W-3Re legs of the thermocouples were the principal problem.

All modifications and repairs were completed on August 18 and the chamber was evacuated and baked out. Attempts to operate the metering valve during loop temperature operation revealed binding in the metering valve actuation system and the test was shutdown to replace the L-605 stem and stem bushing with the Saginaw ball nut and stem shown in Figure 56.

(a) Saginaw Steering Gear Division, General Motors Corp., Saginaw, Michigan.



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Figure 56. Saginaw Ball Nut and Valve Stem Assembly Used in the Modification of the Cb-1Zr Pumped Sodium Loop Metering Valve. (Orig. C64092401, C64092402)

On August 21 the chamber was evacuated and baked out, and on the following day the test was resumed. The metering valve performed satisfactorily with the Saginaw ball bearing screw assembly.

During the August 21-22 test startup, flow instabilities were noted. These temporary instabilities had also been detected at certain periods during prior loop operation. Local boiling of the sodium in the heater coils was considered to be a possibility, but unlikely, due to the substantial overpressure of argon on the sodium in the surge tank. Hot spot temperatures several hundred degrees Fahrenheit higher than the highest measured heater temperatures would have been required. Low flow as compared to that obtained during earlier loop operation was also noted. Reversing the electrical power leads to the pump to obtain reverse flow resulted in normal flow for a given pump power setting. Returning the pump leads to the normal connections also gave the normal flow. Dumping the sodium to the surge tank and then refilling the loop also eliminated the sodium flow problems. All of these observations were quite confusing at the time. Subsequent experiments during the post-test operation period together with the results of the post-test chemical and metallurgical evaluations, which revealed no plugging or corrosion, indicated that entrapped argon gas in the loop was responsible for the anomalies discussed above. Additional discussion of this problem is presented in Part B of this section.

On August 23, after 757 hours of accumulated test time, the test was shutdown by activation of the argon flooding safety circuit which is triggered by an increase in the getter-ion pump current. A check of the vacuum chamber showed that one of the four pump cells had developed a short which increased the ion pump current and closed an overpressure relay which fired the explosive valve, flooding the chamber with argon gas. The rapid rise in chamber pressure resulting from the argon flooding turns off the ion gauge filament and an accessory 110-volt outlet which activates a relay that shuts off the power to the loop heater and the EM pump.

The temperatures of various regions of the loop during the cool down period following actuation of the protective argon flooding system are given in Table XIII. All of the loop components, with the exception of the fairly massive EM pump (23 pounds of Cb-1Zr), cooled to a temperature of less than 1000°F in less than 4 minutes.

The test was resumed on August 24 by pumping with the three sound pump cells after electrically isolating the defective getter-ion pump cell. An argon instability occurred in the getter-ion pump at 1930 on August 24. The resultant surge in getter-ion pump current (equivalent to a pump pressure of 5×10^{-5} torr) was sufficient to activate the associated safety circuits and shutdown the test. While restarting the test on August 25, surges in the getter-ion pump current were noted and simultaneous partial pressure scans for argon confirmed that rapid releases of argon from the pump were responsible for the pressure excursions in the system. Instabilities of this type are not uncommon in diode-type getter-ion pumped systems.⁽¹⁵⁾ Calibration of the partial pressure analyzer with argon and flooding of the test chamber with argon as cited above, no doubt, contributed to the instabilities noted on several occasions during loop operation. Additional comment on the argon instability problem in getter-ion pumped systems will be presented in Part C of this section.

Loop test conditions were obtained on August 25 and the test continued. During the 400 hours of uninterrupted loop operation, the metering valve continued to show an apparent plugging tendency. This valve was operated repeatedly during the test to increase the flow in the bypass line of the loop in an attempt to maintain the valve temperature at 800°F. Despite the repeated adjustments to increase the flow rate, the valve temperature slowly decayed from the initial temperature of 800°-900°F to 640°F in several days, which is essentially the equilibrium temperature of loop components

(15) Barrington, Alfred E., High Vacuum Engineering, Prentice-Hall, Inc, Englewood Cliffs, N. J., 1963, p. 101.

TABLE XIII

TEMPERATURES OF VARIOUS COMPONENTS OF THE Cb-1Zr PUMPED
SODIUM LOOP FOLLOWING ACTUATION OF PROTECTIVE ARGON FLOODING SYSTEM

Time Minutes	Temperature, °F			
	EM Pump Outlet	Bottom Heater Coil	Heater Outlet	EM Pump Inlet
0	1930	1840	2000	1957
1	1692	1390	1408	1426
2	1627	1123	1242	1114
3	1563	1011	1077	993
4	1508	947	965	900
5	1472	909	871	823
10	1344	919	634	603
20	1077	725	561	485
30	890	603	452	402

not in contact with the 1900°-2000°F liquid metal in the main loop. The 640°F temperature is indicative of very low or no flow in the bypass line. The exact cause of the temperature decay has not been established although the effect has been repeatedly observed. A typical temperature decay of the valve temperature after an adjustment is shown in Figure 57. The valve temperature was permitted to exceed the 800°F design test temperature to more clearly demonstrate the decay. Within approximately 48 hours following adjustment of the metering valve, the valve temperature had dropped to 700°F, indicating essentially no flow in the bypass line.

A typical valve adjustment showing the relative movement between the plug and the valve seat as the stem is rotated is shown in Figure 58. The valve in its initial position with the plug firmly seated and with no flow in the bypass line is at an equilibrium temperature of 640°F. The valve stem is then rotated 17° in the second position which moves the valve plug 0.006 inch and withdraws the cylindrical section of the plug between the metering cone surface and the seating surface of the plug from the valve orifice. In this position the flow area is essentially zero and the valve temperature remains unchanged. In the third position, the valve stem is rotated an additional 28° which raises the plug an additional 0.008 inch for a total lift off of 0.014 inch from the initial off position. The gap between the plug and seat is 0.0043 inch which is equivalent to a flow area of 0.002 square inch and allows sufficient sodium flow through the bypass line to raise the temperature of the valve body from 630° to 1175°F. The drop in valve temperature after various time periods following opening of the metering valve is also given in Figure 58.

A rapid rise in chamber pressure resulting from another argon instability caused activation of the chamber safety circuits and a test shutdown. The test was restarted on September 10 and continued, uninterrupted, for the remainder of the 2500 hour test.

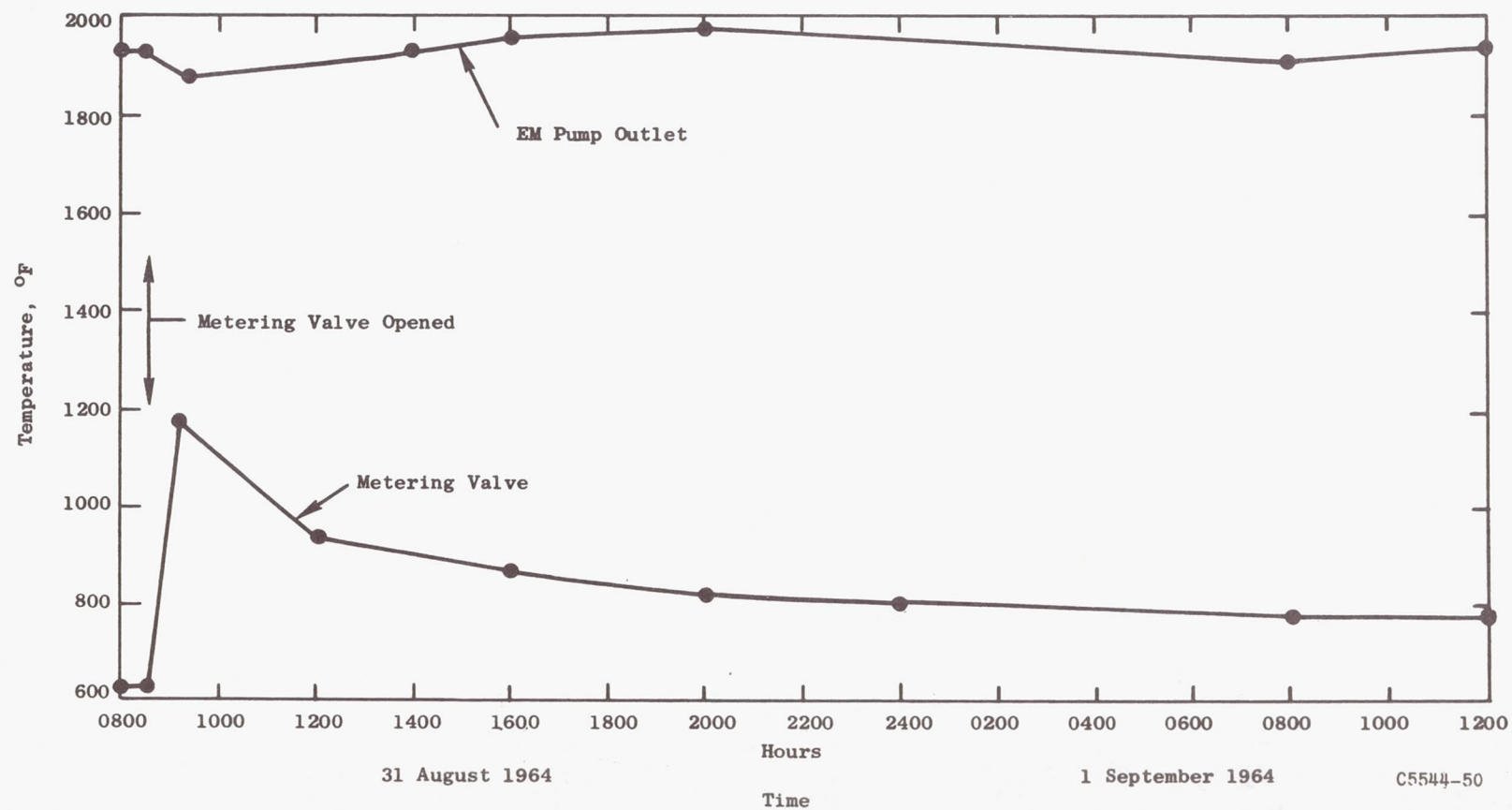
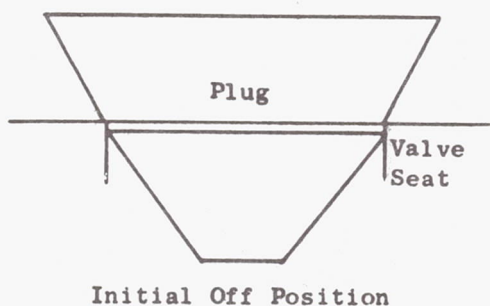
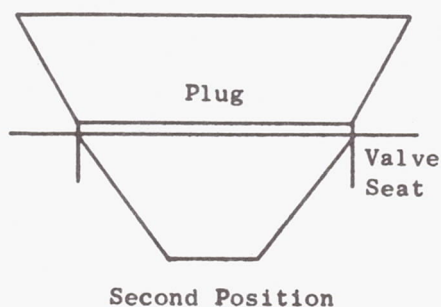


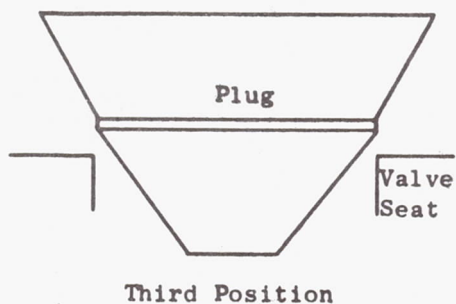
Figure 57. Temperature Decay of Cb-1Zr Pumped Sodium Loop Metering Valve After a Valve Adjustment During Steady State Operation.



Plug Position - Fully Closed Valve
Temperature - 640°F



Stem Rotation - 17°
Plug Position - 0.006 in. Axial Lift
Flow Gap - Zero
Flow Area - Zero
Valve Temperature: 640°F



Stem Rotation = Additional 28°, Total of 45°
Plug Position = 0.014 in. Axial Lift
Flow Gap = 0.0043-Inch
Flow Area = 0.002-Inch²

Valve Temperature °F	Time, Hours
1175	0
930	4
800	16
780	24
770	32
744	56
693	80
671	104
644	148

Figure 58. Summary of a Typical Adjustment of the Cb-1Zr Pumped Sodium Loop Metering Valve in an Attempt to Maintain Valve Body Temperature at 800°F During 2000°F Steady State Operation.

The nominal loop temperatures during the 2500 hour endurance test are given in Figure 59. A number of the thermocouples were not recording at the end of the 2500 hour test; however, with the exception of the variations in the temperature of the bypass line containing the metering valve discussed above, all loop temperatures were extremely stable during the test with no indications of corrosion or plugging in the system.

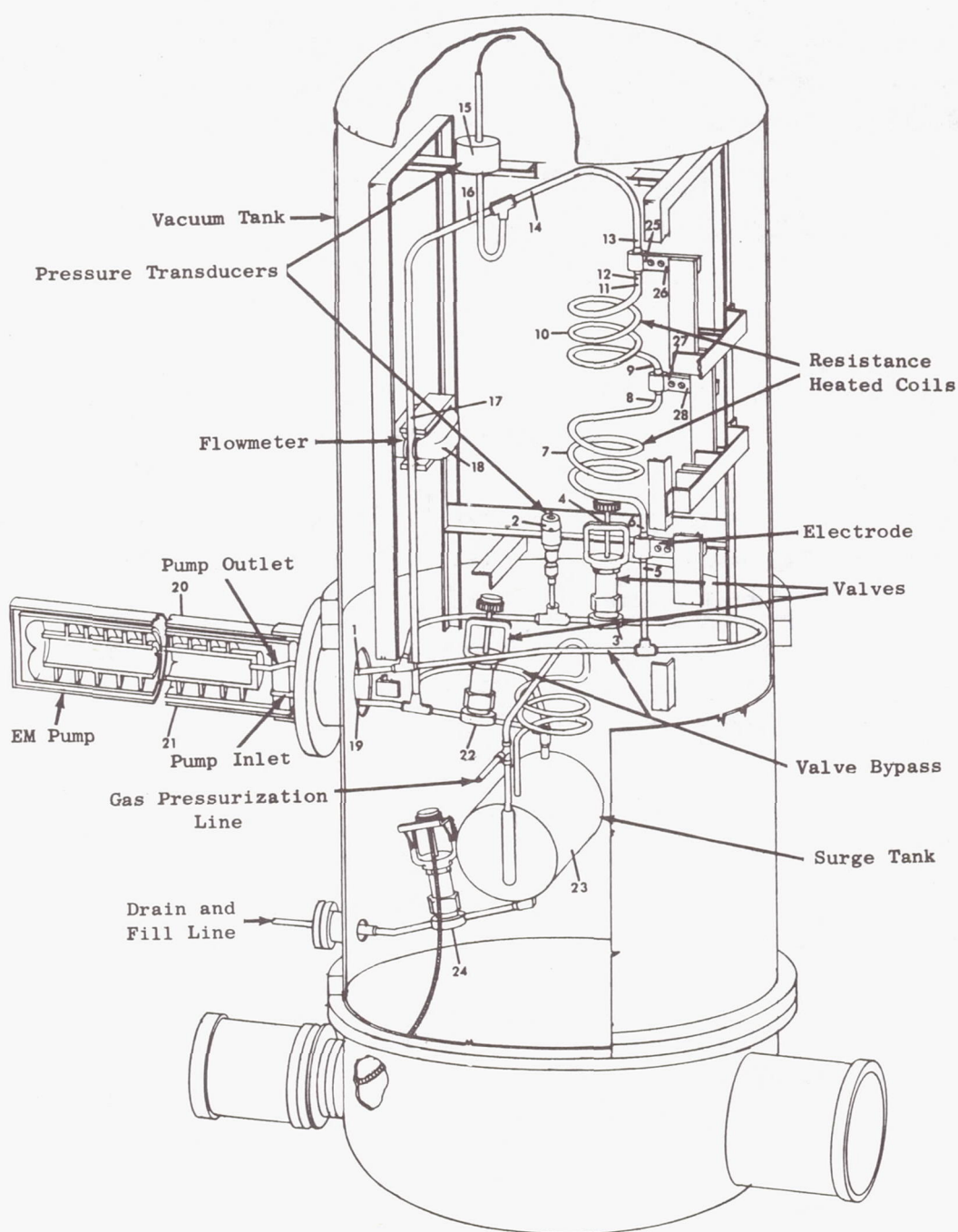
B. POST-TEST LOOP OPERATION

In addition to the 2500-hour endurance run, the Cb-1Zr Pumped Sodium Loop was operated at the design test conditions for an additional 150 hours to evaluate:

1. A new gear assembly for the metering valve.
2. Relocation of the thermocouple reference junction block inside the vacuum chamber.
3. A new type of high vacuum thermocouple feedthrough with W-3Re and W-25Re thermocouple wires with ceramic-to-metal seals replacing the nickel feedthrough tubes used during prior loop operations.
4. Replacement of the copper lead wires on the stressed diaphragm pressure transducer with stainless steel lead wires.
5. A 15 KW Hall effect wattmeter used to measure accurately the electric power input to the sodium heater.

Although the loop was filled (from the surge tank) and flow was established on November 23 without difficulty, large fluctuations in both the flow rate and loop pressure were observed before power was applied to the loop. The fluctuations increased in amplitude as the loop temperature was increased and continued during the entire 100-hour test. These fluctuations were similar to those discussed earlier during the review of the 2500-hour endurance run.

During the test, repeated operation of the metering valve showed that the new gear assembly was a significant improvement over the previous design. The new gear bracket not only provided a more accurate alignment



Loop
Temperatures

T/C No.	°F
1	1975
2	585
3	800
4	580
5	1965
6	1950
7	1985
8	2020
9	2000
10	2035
11	2065
12	2065
13	2050
14	2045
15	650
16	2030
17	2015
18	670
19	1985
20	1880
21	1850
22	505
23	475
24	455
25	1655
26	1575
27	1720
28	1580

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Figure 59. Temperatures of the Various Components of the Cb-1Zr Pumped Sodium Loop During the 2500 Hour Test. (C65083107)

of the gears but permitted the installation of a tungsten carbide bushing that eliminated the galling problem encountered in the 2500-hour endurance run. The new design was subsequently used in both the isolation and the metering valves of the Cb-1Zr Rankine System Corrosion Test Loop to be discussed in Topical Report No. 7 of this series.

The relocation of the thermocouple reference junction block from a constant temperature (150°F) reference junction outside of the vacuum chamber, as shown in Figure 51, to a reference junction inside of the chamber was made to eliminate the problems which have been encountered in obtaining helium leak tight brazed joints between the W-Re thermocouple wires and the nickel tubes of the high-vacuum feedthroughs. Failure of the W-3Re wire near the braze joint during the fabrication and installation of the thermocouples was responsible for a large number of thermocouple failures in both the Cb-1Zr Sodium Thermal Convection Loop and the Cb-1Zr Pumped Sodium Loop Tests.

The new reference junction block consists of a high-purity alumina terminal strip mounted on a 1/4-inch copper plate attached to the chamber wall. Tantalum foil thermal shields were used to reduce the radiation heat flux from the test loop and to maintain the junction block at a temperature of less than 200°F and as isothermal as possible during loop operation. The temperature of the reference junction which is required to correct the indicated loop temperature is measured by three copper-constantan thermocouples.

The relocation of the reference junction inside the chamber and the use of the brazed copper leads eliminated a major portion of the thermocouple failure troubles experienced in the past. The copper wire leads were more ductile and the routing of the wires both inside and outside of the vacuum chamber was facilitated. Not all of the braze joints between the copper wires and the nickel tubes of the vacuum feedthrough were helium leak tight following the first brazing operation in the argon-filled chamber; however, the problem encountered is far simpler to solve than the brazing of W-Re wires into the nickel tubulations. This is due primarily to superior

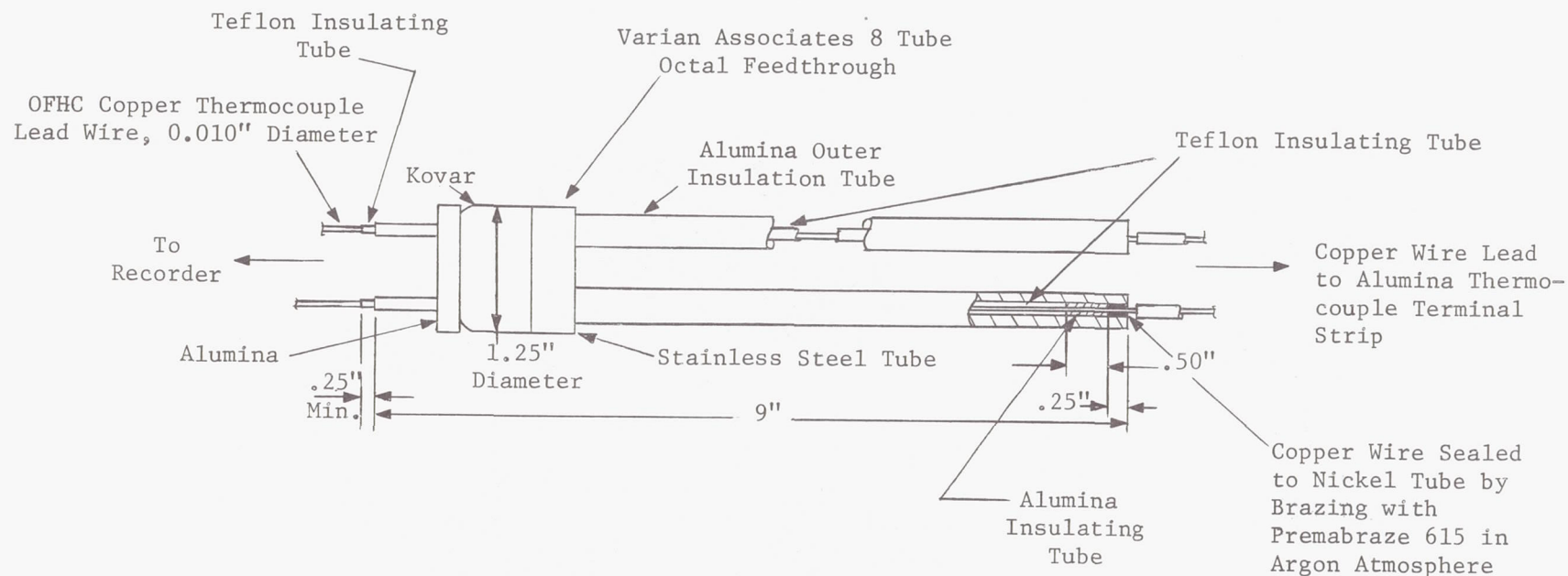
brazing characteristics of the copper wire/nickel tube combination compared to the W-Re wire/nickel tube combination. A sketch illustrating the technique used to install the copper lead wire in the octal feedthroughs is shown in Figure 60.

The new type of thermocouple feedthrough, which consists of W-3Re and W-25Re wire brazed with a copper-gold alloy into an alumina disk, was also evaluated in the 100-hour run following completion of the scheduled 2500-hour test, is shown in Figure 61. This feedthrough^(a) has W-Re thermocouple wire penetrations in lieu of the standard nickel tubulations to minimize the possibility of spurious thermal emf's generated from dissimilar metal contacts. No difficulties were experienced in the installation and the seals proved reliable and remained leak free during the 500°F bakeout and the subsequent loop operation. The use of this type of feedthrough requires the use of an external thermocouple junction.

A 15 KW Hall effect wattmeter^(b) was installed in the heater power supply of the Pumped Sodium Loop after an initial calibration at the factory. The wattmeter has a 0-1.5 KW, 0-4.5 KW and 0-15 KW range selector switch with a $\pm 1\%$ accuracy. The input power calculated from the potential and current measured at the primary to the 20 KVA transformer was approximately 10% higher than the output power measured with the wattmeter. However, when the transformer core losses were accounted for, the agreement was within 5%. The wattmeter will be used for accurate power measurements in calibrating the primary and secondary flowmeters of the Cb-1Zr Rankine System Corrosion Test Loop by calorimetric measurements. Although precise power measurements were not required for the operation of the Pumped Sodium Loop, the installation of the wattmeter at this time was made to checkout the equipment and familiarize program personnel with the operation of this unit before using it for the Cb-1Zr Rankine System Corrosion Test Loop.

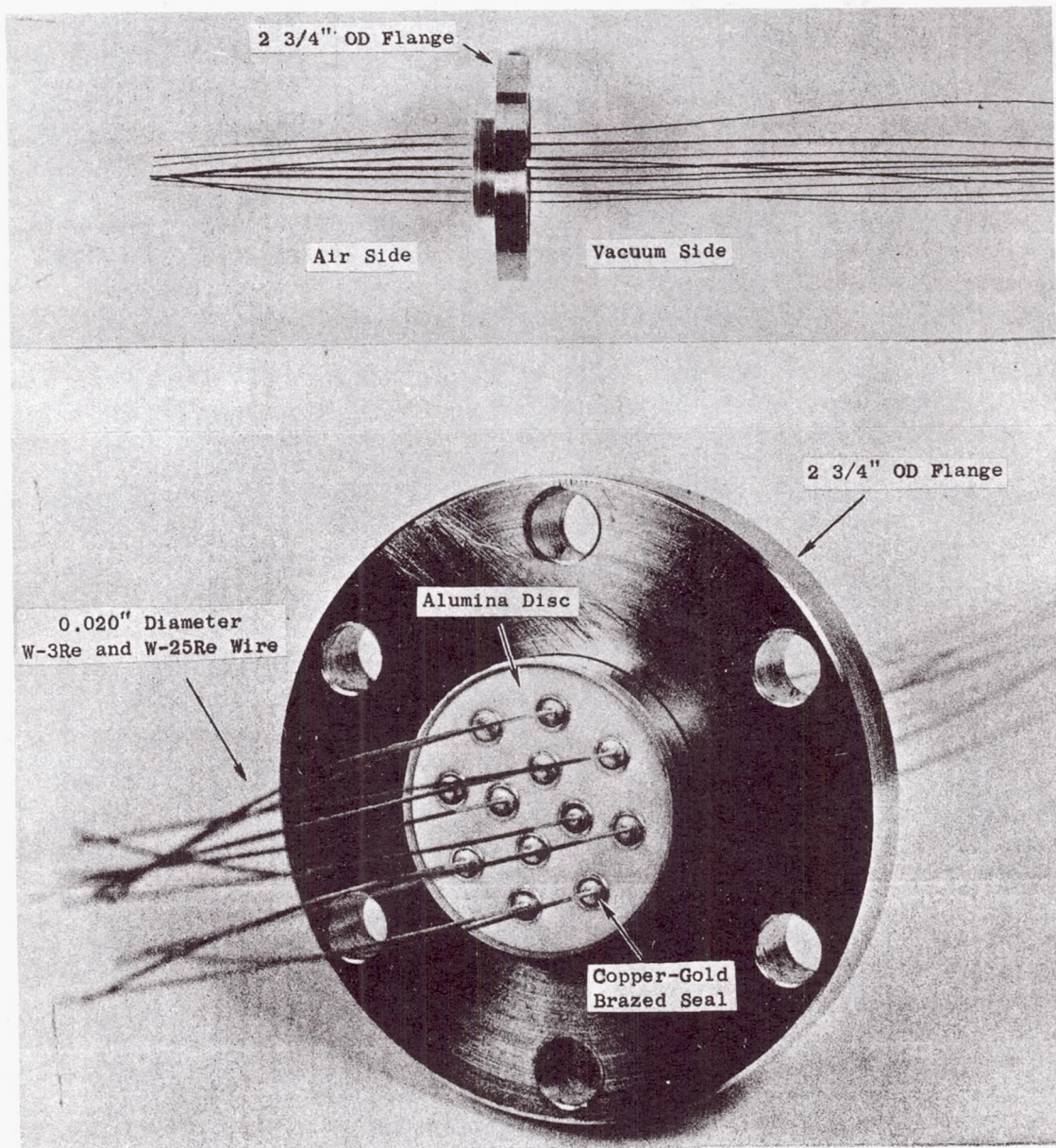
(a) General Electric Vacuum Products Operation, Schenectady, New York, (Model 22HNO20).

(b) Columbus Scientific, Inc, Columbus, Ohio, (Model 150C61-YM).



C5544-52

Figure 60. Technique Used to Install OFHC Copper Thermocouple Lead Wires in Varian Associates Octal Feedthrough, Model No. 954-5055. The Stainless Steel Tube Section is Subsequently Sealed to a Stainless Steel Flange by Welding.



C5544-53

Figure 61. Overall and Closeup View of the Twelve Wire General Electric W-3Re/W-25Re Thermocouple Feedthrough that was Evaluated During the Last 150 Hours of Operation of the Cb-1Zr Pumped Sodium Loop. (Orig. C64111837, C64111836)

Upon completion of the 100-hour period of post-test operation, the sodium was allowed to freeze in the loop and radiographic examination of the loop revealed spherical shaped void areas in both the vertical and horizontal pipe sections of the loop. These voids were believed to be accumulations of argon gas which entered the flow circuit via the surge tank and dip leg.

The test was continued for an additional 50-hour period to study the frequency and magnitude of the instability in the loop due to the apparent gas accumulation and possible corrective action which would be effective in future loop operations. The unstable operation could be observed and measured on the flow rate recording and simultaneous perturbations were recorded for the heater temperature and loop pressure. These perturbations were similar to those encountered during the 2500-hour endurance run. The maximum temperature fluctuations during the test were approximately $\pm 25^{\circ}\text{F}$ with an average frequency of 6 cycles per second. The loop operation could be stabilized by reversing the flow as was noted in earlier operation. It is possible that the improved stability was due to a more favorable geometry at the pump inlet for trapping gas in the pump cavity when the flow was reversed.

In order to attempt to remove the argon from the flow circuit, the sodium was dumped from the loop to the surge tank by evacuating the surge tank through the pressurization and evacuation line. The sodium was held in the surge tank under vacuum for several hours at 450°F and then pressurized back into the loop. No flow or temperature fluctuations were detectable when the loop was restored to the test conditions with both normal and reversed flow indicating that the procedure outlined above had removed the argon from the flow circuit.

As a result of these experiments and a review of the previous occasions when flow instabilities were observed, it has been concluded that the argon was introduced into the loop during the filling operation. The standard procedure used to fill the loop was to pressurize the surge tank to 50 psia and then melt the sodium in the surge tank by turning on the

chamber bakeout heaters. It now appears that localized melting of the sodium in the vicinity of the dip line, which extends to the bottom of the surge tank, could have allowed both sodium and argon to enter the loop.

The loop filling procedure for the Cb-lZr Corrosion Test Loop was modified to avoid argon entrainment during the filling of the primary and secondary circuits. A vacuum will be maintained above the sodium and potassium in the surge tanks until the alkali metal is molten. The surge tanks will then be pressurized with argon to force the alkali metal into the loop.

The log summarizing the major activities during the 2650 hours of operation of the Cb-lZr Pumped Sodium Loop are given in Table XIV.

C. TOTAL PRESSURE AND PARTIAL PRESSURES IN THE VACUUM CHAMBER

In order to minimize the possibility of significant contamination of the refractory alloy components of the Cb-lZr Pumped Sodium Loop, great care was taken in the selection of the vacuum chamber components and in the procedures used in assembling and operating the test loop. The beneficial effect of the extensive bakeout of the chamber and loop components was discussed in Section VIII, Pretest Operations. Information regarding the partial pressures of the residual gases in the vacuum environment is also needed in order to relate refractory alloy contamination, as revealed by post-test evaluation, with the concentration of the individual gases in the test environment.

The various topics related to the test environment which are discussed below include total chamber pressure, partial pressures of the residual gases, pressure rise tests and argon instability in the getter-ion pump.

1. Total Pressure Measurements. As indicated previously in Section V, Test Equipment, a calibrated hot cathode ionization gauge, Varian Type UHV-12, was used to measure the pressure in the vacuum chamber. Measurements were made twice a day as a minimum, during periods of routine operation and more frequently during the early portions of the test and following test restarts. A plot of the vacuum chamber pressure during the 2500-hour

TABLE XIV

Cb-1Zr PUMPED SODIUM LOOP - OPERATION HISTORY JULY 2 - DECEMBER 2, 1964

<u>Time</u>	<u>Date</u>	<u>Test Hours</u>	<u>Remarks</u>
1000	July 2	0	Loop start-up
1130	July 19	409	Unscheduled shutdown - overtemperature of EM pump thermal overload relay
1330	July 20		Resume test
0800	August 3	734	Scheduled shutdown - metering valve modified by substituting L-605 bushing and stem for original parts - chamber wall deposits analyzed - thermocouples repaired
	August 18	734	Attempt to resume test - metering valve and flow difficulties
	August 18	734	Scheduled shutdown - Saginaw ball nut and stem substituted for L-605 stem and stem bushing in metering valve
1300	August 22		Resume test
0610	August 23	757	Unscheduled shutdown - defective ion-pump cell
1300	August 24		Resume test
1930	August 24	763	Unscheduled shutdown - argon instability in ion pump
1430	August 25		Resume test
0900	September 10	1154	Unscheduled shutdown - argon instability in ion pump
2000	September 10		Resume test
1000	November 6	2500	Scheduled 2500 hour test completed
0900	November 24		Start of post-test operation
1600	November 27	2600	End of scheduled 100-hour run
1100	November 30		Start of 50-hour flow instability study
1030	December 2	2650	Test terminated

endurance run is given in Figure 62. It may be noted in this plot that approximately 80 percent of the endurance run operation was at a pressure of approximately 1×10^{-8} torr and that, while at temperature, the loop was exposed to pressures in excess of 5×10^{-7} torr for only very brief periods.

The product of pressure and time, torr-hours, is an important quantity in evaluating the exposure of refractory alloy components at elevated temperature to vacuum environments. Calculation of this value for the Cb-1Zr Pumped Sodium Loop during the 2650 hours of total operation yielded a value of approximately 2.3×10^{-4} torr-hours. The importance of minimizing the exposure of hot components for even relatively short times to high pressures is apparent, since 100 hours at a pressure of 10^{-6} torr would result in 1×10^{-4} torr-hours of exposure. By utilization of extensive bakeout times and slow test startups the torr-hours during this phase of test operation was limited to a value of less than 0.1×10^{-4} . Torr-hours based on total pressure is, of course, only a qualitative indicator of the contamination potential of a vacuum environment since the information regarding the torr-hours of the contaminating species is necessary to attempt to obtain a quantitative relationship.

2. Partial Pressure of the Residual Gases. A total of 160 partial pressure scans were made during the 2650 hours of testing of the Cb-1Zr Pumped Sodium Loop. The analyzer tube, control and recorder were described in Section V, Test Equipment. A complete description of the procedures used to calibrate the analyzer system is given in Appendix D of this report.

The results of a typical partial pressure scan during early loop operation is given in Figure 63. In examining this spectrum, the ion current multiplier setting should be carefully noted. Thus, while the peak height at mass/charge ratio (m/e) = 4 is greater than that at m/e = 2, the actual ion current at m/e = 2 is nearly a factor of 10 greater than that at m/e = 4. Similarly, the peak m/e = 55 which at first glance appears to be a major peak, is actually comparable to the peak at m/e = 25. The presence of hydrocarbons in the system is evidenced by the characteristic

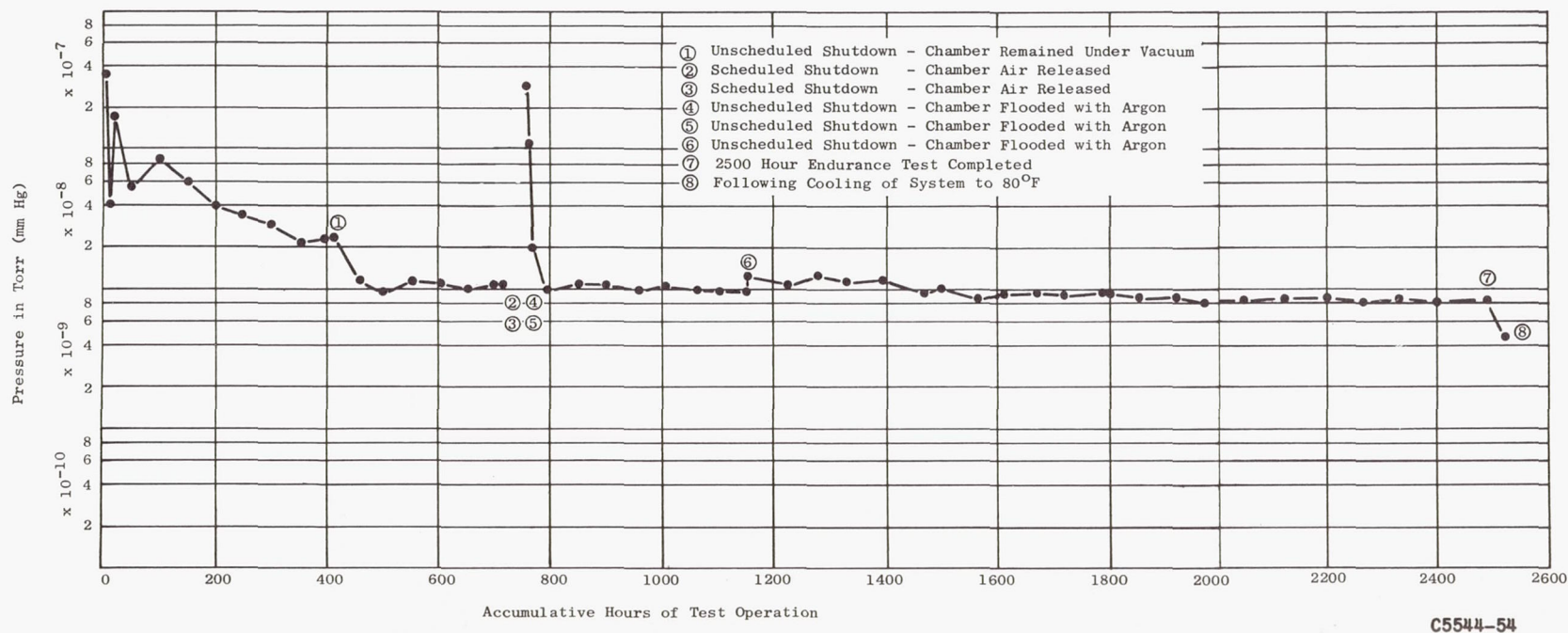


Figure 62. Total Pressure in the Test Chamber During the 2500 Hour Test.

Figure 63. Mass Spectrum of Residual Gases in the Cb-1Zr Pumped Sodium Loop Vacuum Chamber Following 174 Hours of Operation. Maximum Loop Temperature = 2065°F. (C65051104)

grouping of peaks in certain mass ranges. The CH_4 group between masses 16 and 12 is due to ions CH_4^+ , CH_3^+ , CH_2^+ , CH^+ , and C^+ . Similarly, the C_2H_6 group contributes peaks between masses 30 and 24; the C_3H_8 group between 44 and 36; the C_4H_{10} group between 58 and 48; the C_5H_{12} group between 72 and 60; the C_6H_{14} group between 86 and 72; the C_7H_{16} group between 100 and 84; and the C_8H_{18} group between 114 and 96. It may be seen in Figure 63 that the analyzer gives good resolution of adjacent peaks up to about $m/e \approx 50$. The origin of these hydrocarbon peaks has not been determined, but they probably arise from heavier molecules which are cracked in high temperature regions of the loop, or perhaps in the analyzer itself. The concentration of the hydrocarbons above mass/charge -50 in the chamber is quite low since the most sensitive current settings were used to detect these peaks.

The change in the true partial pressures of the various residual gases in the vacuum chamber during the first several hundred hours of loop operation may be noted in Table XV which lists the pressures after 166 and 310 hours of test operation. It is apparent from these data that hydrogen is the major gas and that nearly all of the pressure decrease observed during this period resulted from the decrease in hydrogen pressure.

A plot of the partial pressures of the residual gases in the chamber during the 2500 hours of loop operation is given in Figure 64. It may be noted that during the heating up of the loop to the operating conditions and the first several hundred hours of loop operation that hydrogen was the major constituent of the residual pressure in the chamber. During the last 1500 hours of the 2500-hour endurance test, N_2 or $\text{CO}(m/e=28)$, $\text{Ar}(m/e=40)$, $\text{H}_2\text{O}(m/e=18)$, and possibly H_2 ($m/e=2$) are the principal species present. Unfortunately, a malfunction in the ion source of the partial pressure analyzer at high accelerating voltages prevented scanning for hydrogen during the last 2000 hours of loop operation. However, comparison of the sum of the partial pressures with the total pressure before and after this malfunction indicates that the hydrogen pressure during the last several hundred hours of operation was in the range $1-4 \times 10^{-9}$ torr.

TABLE XV

RESULTS OF PARTIAL PRESSURE ANALYZER SCANS
DURING THE OPERATION OF THE Cb-1Zr PUMPED SODIUM LOOP

Mass/Charge	Gas	Hours of Loop Operation	
		166	310
		True Pressure, Torr	True Pressure, Torr
2	H ₂	3.00×10^{-8}	0.70×10^{-8}
4	He	0.34×10^{-8}	0.46×10^{-8}
16	CH ₄	0.08×10^{-8}	0.01×10^{-8}
18	H ₂ O	0.24×10^{-8}	0.34×10^{-8}
28	N ₂ or CO	0.61×10^{-8}	0.62×10^{-8}
32	O ₂	(a)	(a)
40	Ar	0.15×10^{-8}	0.17×10^{-8}
44	CO ₂	0.10×10^{-8}	0.07×10^{-8}
Total True Pressure		4.52×10^{-8}	2.37×10^{-8}
Indicated Ionization Gauge Pressure		5.1×10^{-8}	2.8×10^{-8}

(a) Mass/charge -32 (oxygen) less than 1×10^{-10} torr

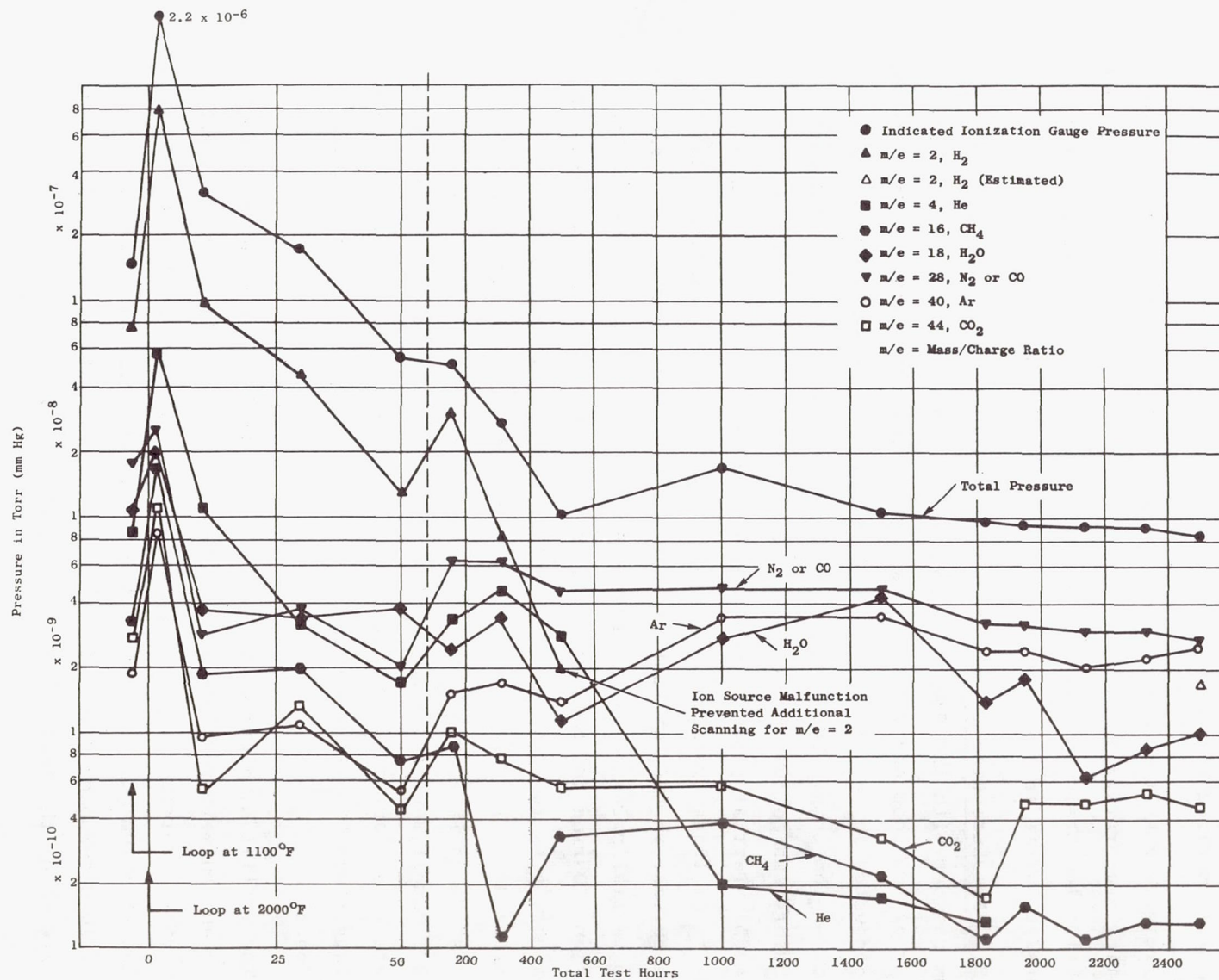


Figure 64. Indicated Ionization Gauge Pressure and Partial Pressures of the Various Gaseous Species in the Cb-1Zr Pumped Sodium Loop Test Chamber vs Total Hours of Loop Operation.

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The relative high and constant argon concentration in the test environment is attributed to the low pumping speed for this gas by the diode-type, getter-ion pump and the periodic releases of argon (argon instability) which will be discussed in more detail later in this section.

Pressure rise tests were conducted both with the test system at the operating temperature and at room temperature near the end of the 2650 hours of testing to obtain information regarding the possible sources of the residual pressure in the system and these are discussed below.

3. Pressure Rise Tests. Pressure rise tests were conducted on the vacuum chamber with the Pumped Sodium Loop at temperature and following cooling of the loop and the test chamber to room temperature. These tests were conducted for a time period of 45 minutes following turning off of the getter-ion pump. The results of the pressure rise tests conducted just before and following the 2650 hours of loop operation are plotted in Figure 65. Partial pressure scans were made before and 30 minutes after the start of these pressure rise tests. These results indicated that the major increase in the hot test pressure with time was caused by increases in the partial pressure of hydrogen, methane and the inert gases, helium and argon. During the cold pressure rise test the pressure increase was due primarily to increases in the partial pressure of hydrogen and methane. As indicated earlier, it was not possible to monitor the hydrogen partial pressure during this period because of a malfunction in the ion source. However, comparison of the sum of the partial pressures and the ion gauge pressure before and after 30 minutes of the pressure rise tests indicated that large increases in hydrogen pressure occurred during the pressure rise tests.

The initial high pressure rise rate in the first 10 minutes of both the hot and room temperature tests shown in Figure 65 is attributed primarily to the release of gases, particularly the inert gases and hydrogen, from the titanium pump elements. Pumping of the very small gas load by the hot loop components is believed to be responsible for the zero pressure rise rate after the first 10-15 minutes of the hot test. The very low

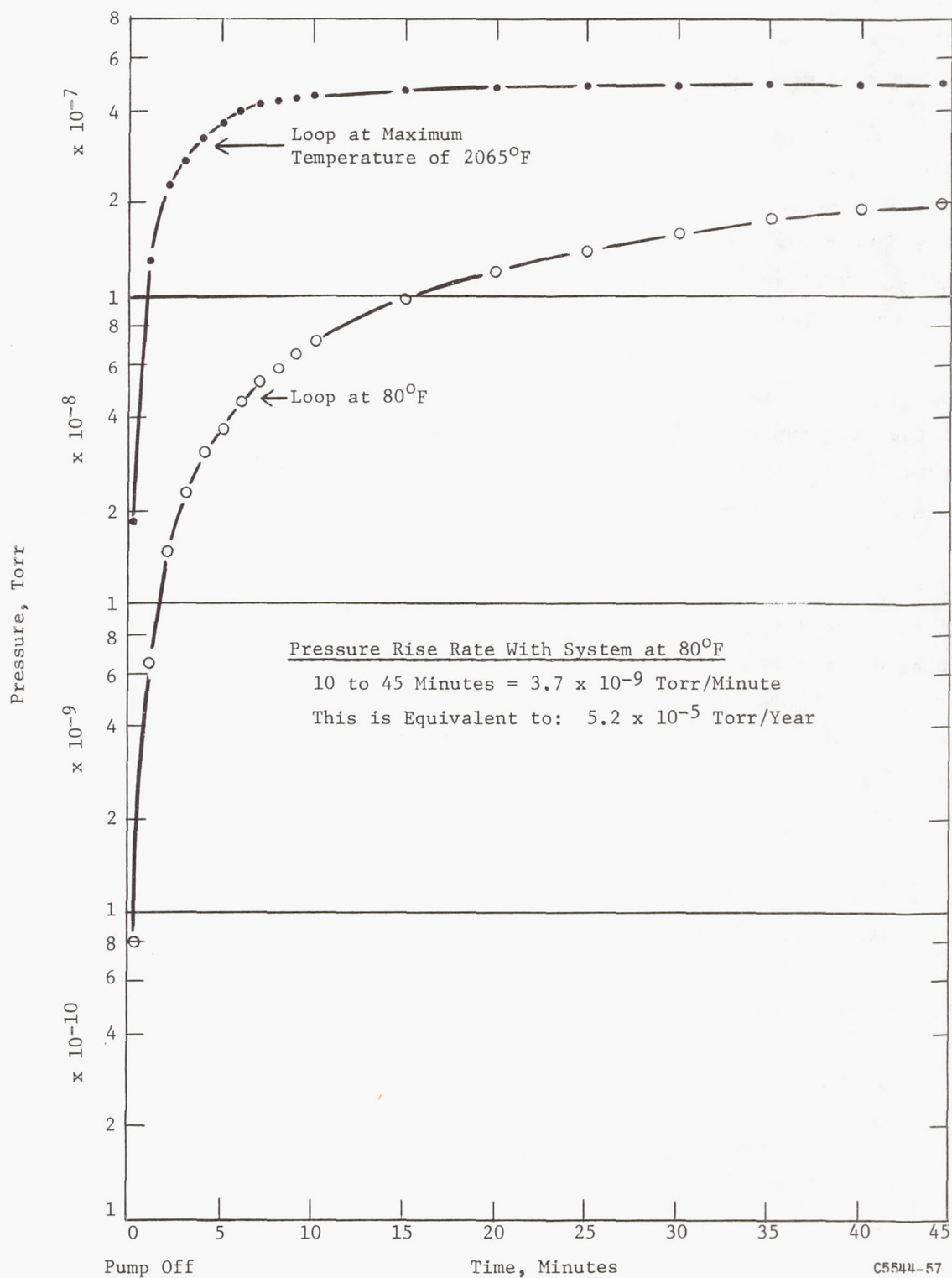
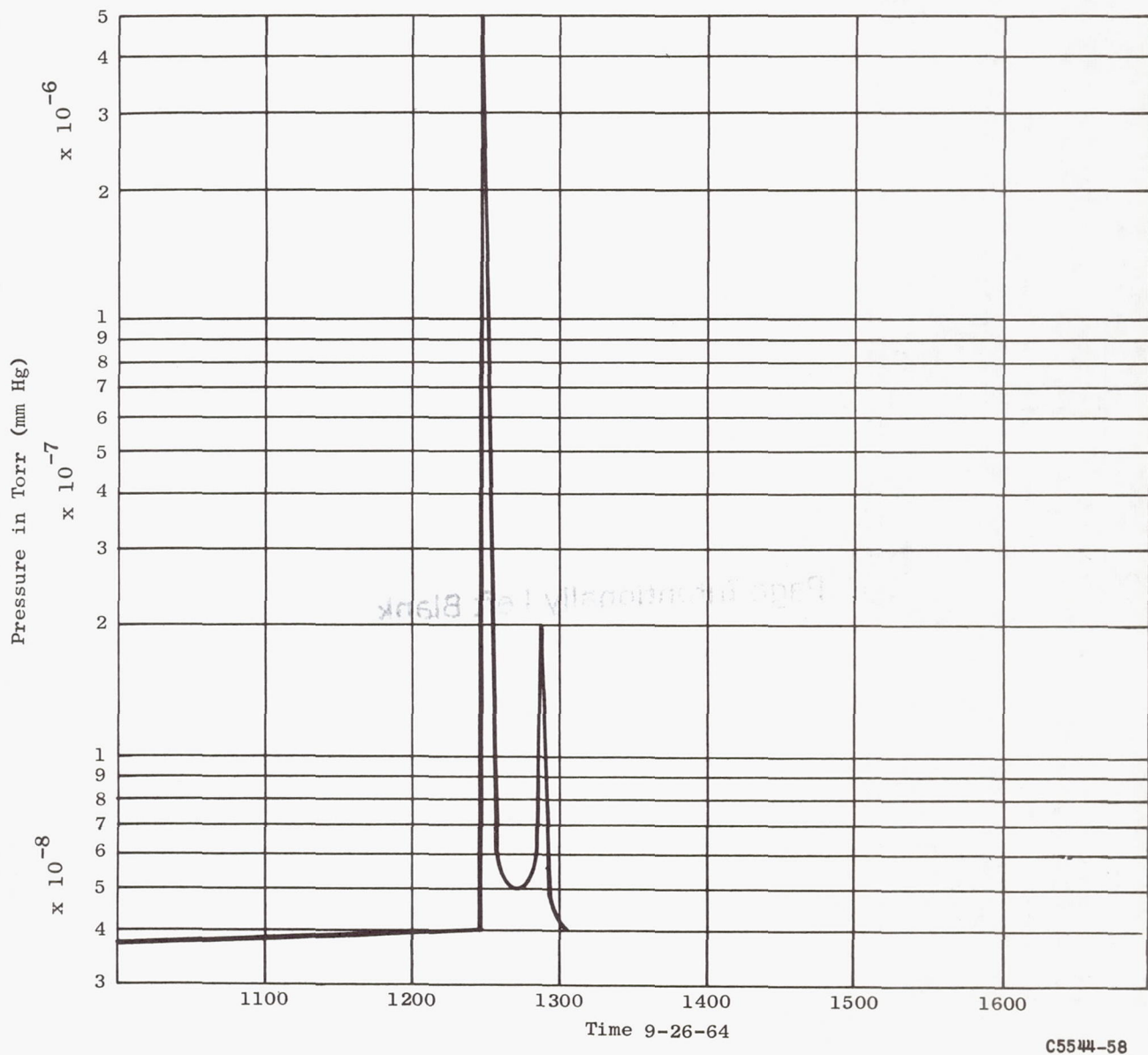


Figure 65. Pressure Rate Tests on Vacuum Chamber With Cb-1Zr Pumped Sodium Loop at Temperature and Following Cooling to Room Temperature.

pressure rise rate observed in the room temperature test in the 10-45 minute period indicates that the system was free of any significant leaks or sources of outgassing.

4. Argon Instability. It was indicated during the discussion of loop operation that on a number of occasions rapid increases in the vacuum chamber pressure were noted. Generally the pressure decreased to the former low value in a few minutes and test operation was not affected. However, on two occasions, as indicated in Table XIV, the test system safety circuits were activated by rapid pressure increases to values in excess of 5×10^{-5} torr and the test was automatically shut-down. The rapid increase in pressure is due to the release of argon from the titanium pump elements. This phenomena is known as "argon instability". A detailed discussion of the argon instability problem is presented in a paper by Jepsen and coworkers.⁽¹⁶⁾ An argon instability recorded during the operation of the Cb-1Zr Pumped Sodium Loop is shown in Figure 66. The two pressure rises recorded occurred during a 30-minute period. Normally an argon instability is of little consequence in the testing of refractory metals in vacuum chambers; however, with safety circuits which are actuated by pressure increases, unnecessary test shut-downs can result. Measures which have been or could be employed to reduce or eliminate this problem include, a) the use of triode-type getter-ion pumps which are relatively free of this problem, b) use of a special type of diode-type getter-ion pump element which is designed to cope with this problem and c) minimizing the argon inventory in the system by eliminating air leaks, since air contains approximately one per cent argon.

(16) Jepsen, R. L., et al., "Stabilized Air Pumping with Diode-Type Getter-Ion Pumps", 1960 Seventh National Symposium on Vacuum Technology Transactions, Pergamon Press, Inc., New York, 1961, pp. 45-50.



C5544-58

Figure 66. Typical Rapid Changes in the Vacuum Chamber Pressure Resulting from Argon Instabilities in the Getter-Ion Pump.

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X. DRAINING, DISTILLING AND DISASSEMBLY OF THE LOOP

The operations performed to remove sodium from the loop and to obtain sodium samples for post-test chemical evaluation are described in this section. Following removal of sodium from the loop by draining and distilling, the various components were disassembled for chemical and metallurgical evaluation. The room temperature pressure rise test described in the previous section was performed following the draining of sodium from the loop and prior to opening the chamber to install the distillation heaters.

A. DRAINING OF SODIUM FROM THE LOOP

Following completion of the 2650 hours of loop testing the sodium was transferred to the stainless steel disposal tank located outside the vacuum chamber. This disposal tank was previously shown in Figure 41. A sodium sample was collected using a stainless steel sampling tube arrangement similar to the one illustrated in Figure 39, the schematic diagram of the loop system.

A 5-micron Type 316 stainless steel filter, 3/4-inch diameter by 1/8-inch thick, was installed in the dump line in order to collect any particulate matter which might be present in the sodium. It was planned to filter the sodium with a pressure drop across the filter of 13-15 psi to avoid breaking or blowing out the filter. However, the loop dumped suddenly at about 1000°F when the sodium in one of the transfer lines melted. It was determined that a by-pass valve around the filter was partially open and very little sodium passed through the filter. The analyses of the sodium sample obtained during the dump are in Table XVI and indicate oxygen at the 5 ppm level and a very low concentration of other elements. Although only a portion of the sodium went through the 5-micron stainless steel filter when the loop was emptied, the filter assembly was removed and vacuum distilled until free of residual sodium. Examination of the filter at a magnification of 30X revealed no mass transfer particles and spectrographic analysis of metal scraped from the face of the filter showed only the normal stainless steel elements.

TABLE XVI

ANALYSIS OF SODIUM OBTAINED FROM THE
Cb-1Zr PUMPED SODIUM LOOP AFTER 2650 HOURS OF OPERATION

Oxygen Analysis

	Sample Wgt. <u>gms</u>	ppm O as Na ₂ O By Mercury <u>Amalgamation Method</u>
Sample No. 149-192	4.543	4.9
	2.180	5.8

Spectrographic Analysis

<u>Element</u>	<u>GE</u> <u>ppm of NaCl</u>	<u>NUMEC</u> <u>ppm of NaCl</u>
Fe	< 5	3
Al	1 or less	1
Ag	< 1	<1
B	< 25	<5
Be	< 1	<1
Ca	< 1-15	4
Cb	< 1	<10
Co	< 1	<5
Cr	< 1	<1
Mg	< 1	<1
Mn	< 1	<1
Mo	< 1	<5
Ni	< 1	<1
K	--	60
Si	< 1	<10
Sn	< 1	<5
Ti	< 1	<5
V	< 25	<1
Zr	< 1	<10
Pb	< 1	<5
Cu	< 1	<1

NUMEC = Nuclear Materials & Equipment Corporation,
Apollo, Pennsylvania

Several attempts were made to determine the post-test oxygen concentration of the sodium by the neutron activation method using 14 Mev neutrons. Oxygen concentrations of several hundred ppm were reported originally by General Atomic where these analyses were performed. However, subsequent studies at General Atomic revealed that there are major difficulties in the application of the fast neutron activation method for determining the oxygen concentration of sodium. The results of the mercury amalgamation analyses for oxygen previously given are considered to be accurate.

B. DISTILLATION OF RESIDUAL SODIUM FROM THE LOOP

Following the dumping of the sodium from the loop, the test chamber was opened and modifications were made in order to distill residual sodium from the loop. Six tantalum coil heaters with a total heat capacity of 2 KW were installed on the loop support structure and a stainless steel thermal radiation shield was added between the loop heaters and the vacuum chamber wall to reduce the heat losses. The chamber was resealed and evacuated to the 10^{-7} torr range. The tantalum heaters and the chamber bakeout heaters were then turned on and the power input was increased slowly for several hours until the minimum loop temperature was 800°F. Power was also supplied to the heater coil and the EM pump and their temperatures were maintained at 1000°F. The distillation was continued for over 200 hours during which time the sodium was periodically drained from a small collection tank into the disposal tank.

In order to establish if any particulate matter from the loop had been missed in the dumping procedure outlined above, the sodium in the disposal tank was filtered during transfer from the disposal tank to another storage container. The 5-micron stainless steel filter assembly used was removed, distilled free of residual sodium, and subsequently inspected. Several dark areas were detected on the face of the filter. These areas were scraped with a metal spatula, and the particles were removed and analyzed. Only the constituents of stainless steel were recovered. Sodium samples for additional oxygen determinations were collected during the

transfer from the disposal tank to the storage container. Duplicate analyses on this sample produced oxygen values of 5.3 and 7.6 ppm which are in good agreement with the values of 4.9 and 5.8 ppm given in Table XVI. No significant concentration of columbium, zirconium or other metallic elements was detected in the analysis of a spectrographic sample.

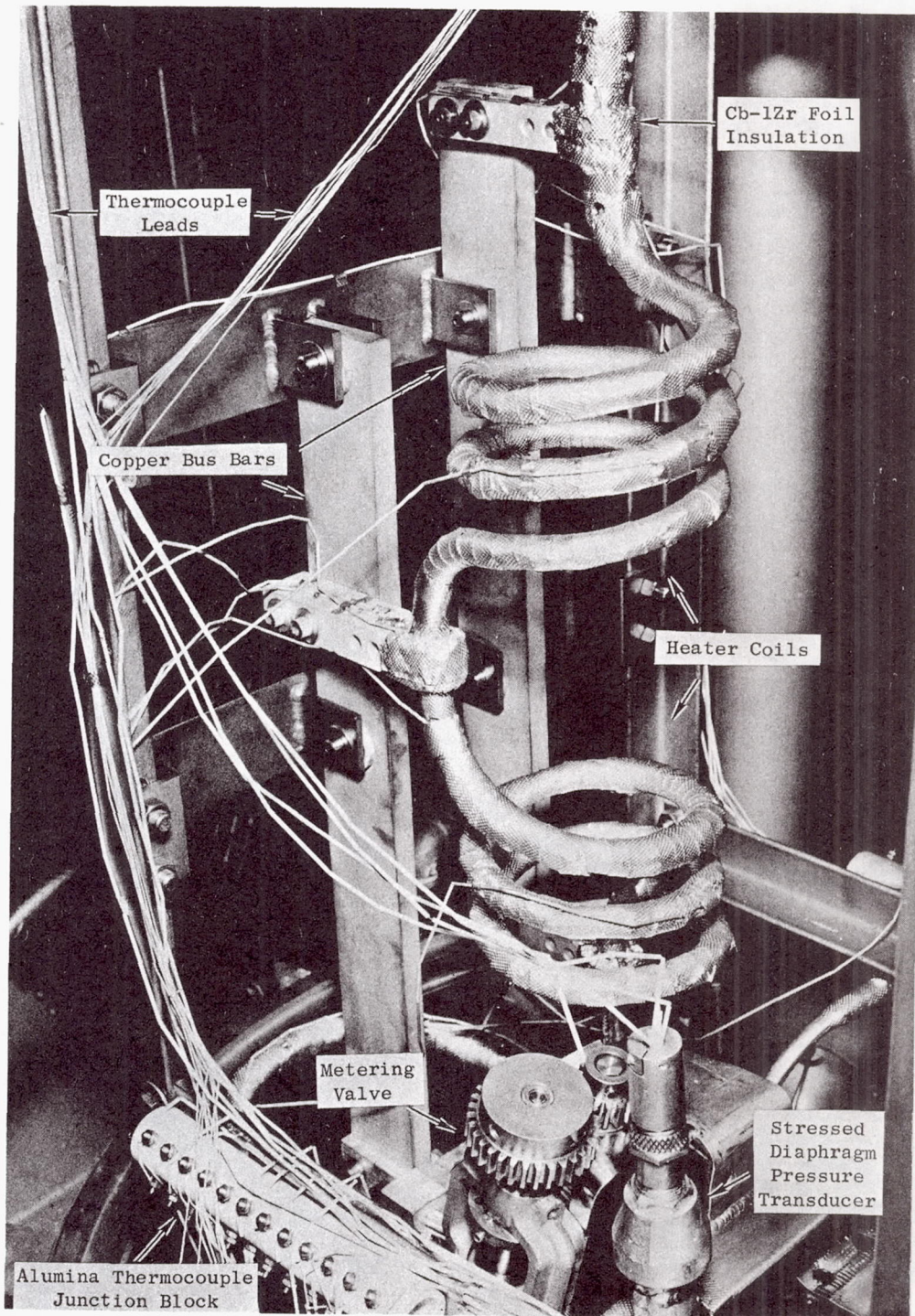
C. DISASSEMBLY AND CLEANING OF LOOP COMPONENTS

The excellent appearance of the various loop components following completion of the 2650 hours of testing is illustrated in Figure 67. Specimens of the 2-mil thick Cb-1Zr foil insulation were removed from the loop and checked for contamination and embrittlement, since this very thin material would be a sensitive indicator of contamination. All the foil specimens checked had the appearance and ductility of the pretest foil as determined by reverse bending to fracture. The results of the chemical analysis of the various specimens of foil are given in Section XI of this report.

The first step in removing actual loop components was to cut through the stainless steel can which formed the vacuum enclosure for the EM pump. In cutting up the loop proper, a procedure was used which permitted the maintenance of gas-tight seals of each section removed from the loop. This was accomplished by means of a cold-weld pinch-off device^(a) which has a remote hydraulically actuated head which could be conveniently positioned in the many restricted areas where "cuts" were desired. Figure 68 shows the two models of the pinch-off device which were used and a typical cold-weld seal in small diameter Cb-1Zr tubing. This technique not only gave helium leak tight seals which prevented reaction of the atmosphere with possible corrosion products but also precluded the possibility of introducing metallic particles into the loop, such as would have been the case if a hack saw had been used.

The sealed segments of the loop were then placed in the vacuum/purge welding chamber, where the pinch sealed ends were cut off under argon with

(a) Kane Engineering Laboratories, Palo Alto, California.



C5544-59

Figure 67. Cb-1Zr Pumped Sodium Loop Components Following Completion of the 2650-Hour Test. (Orig. C64111327)

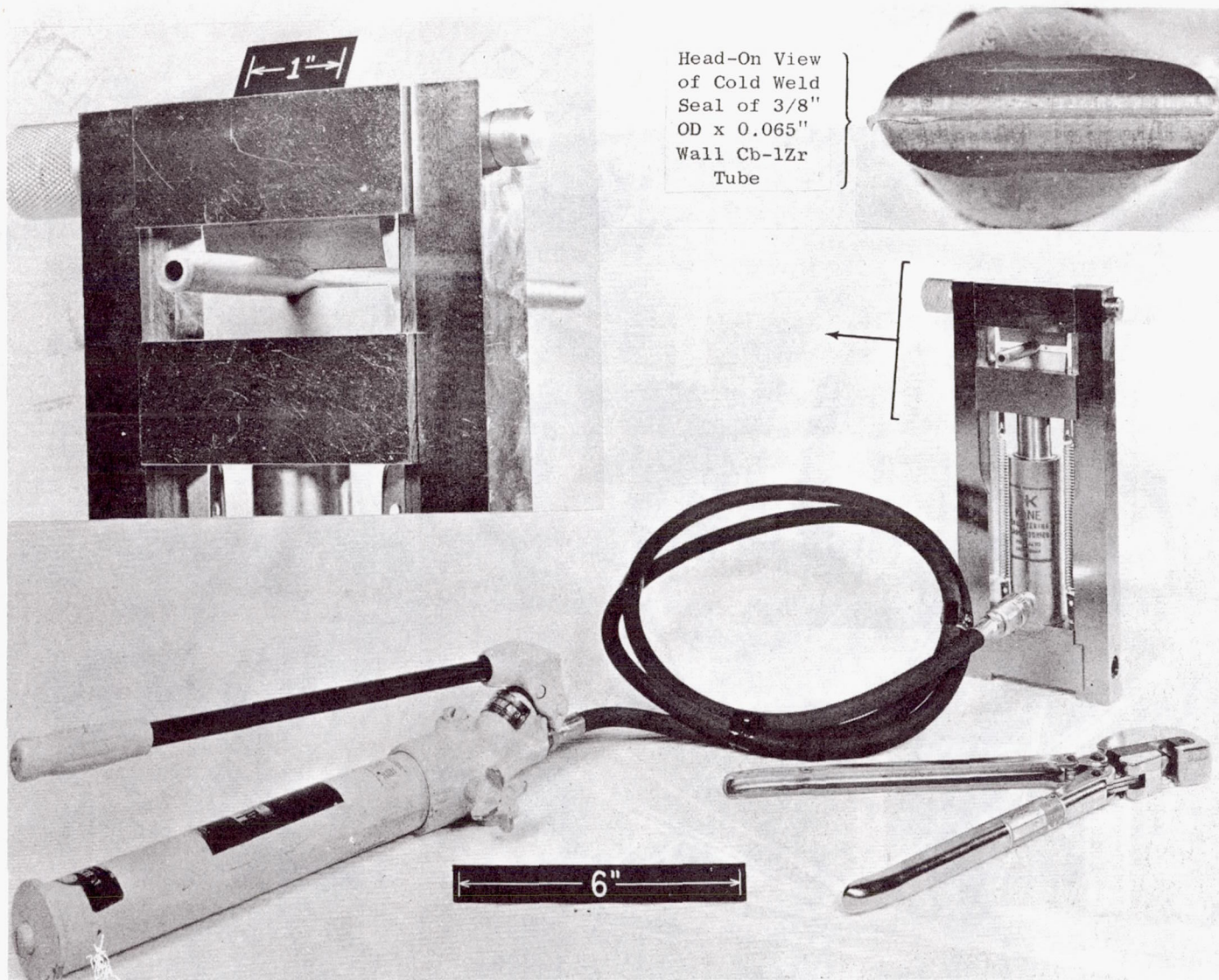
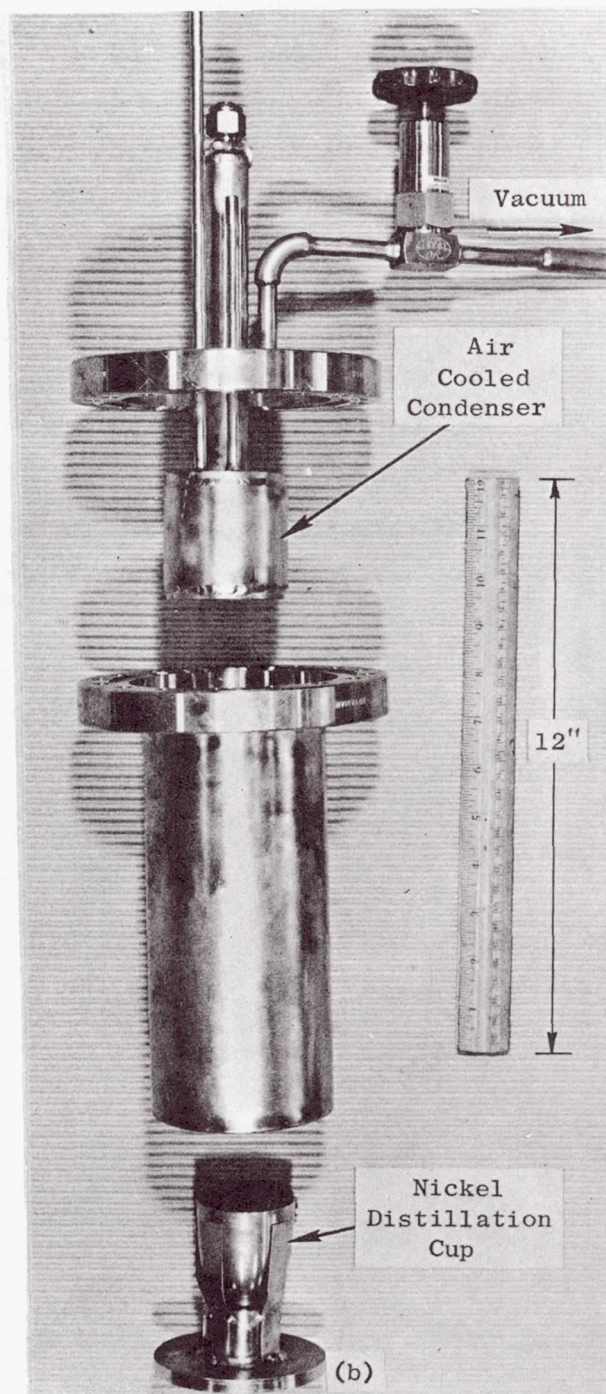
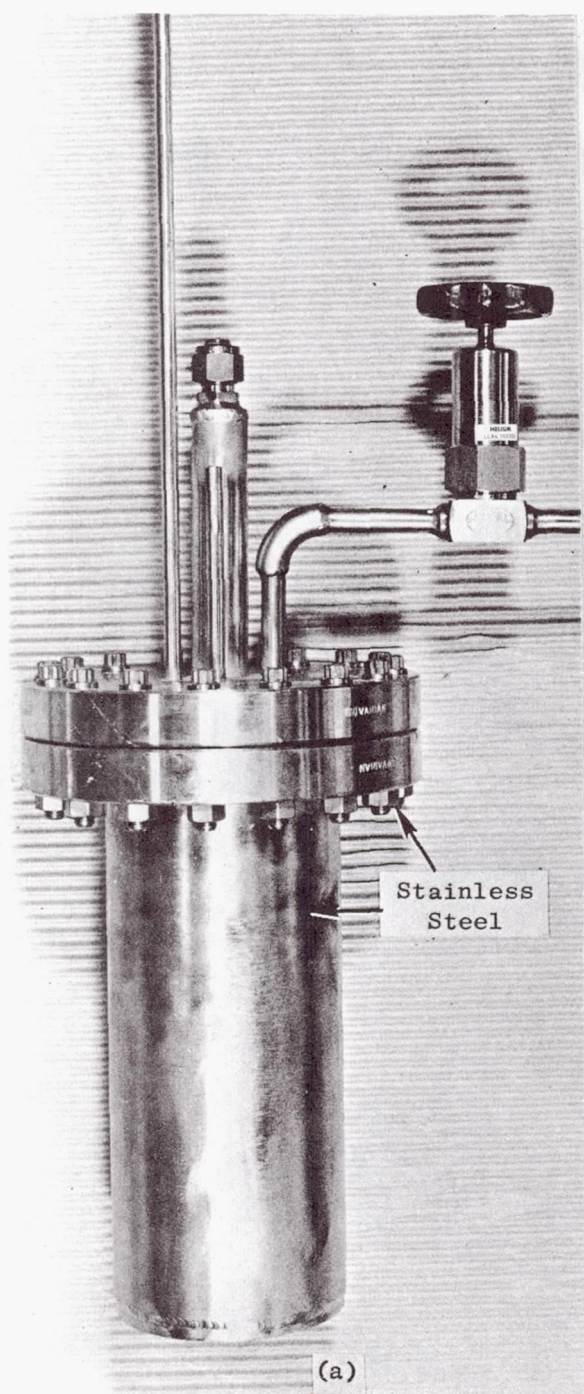


Figure 68. Manual and Hydraulic Cold Weld Pinch-Off Devices Used to Seal Cb-1Zr Alloy Tubing During Sectioning of Corrosion Test Loops. (Orig. C650621104)

a tubing cutter, and each section was examined to determine if any corrosion products or residual sodium were present. Examination of all the loop components indicated that the initial distillation of sodium from the loop while still in place in the test chamber was quite successful with only a small amount of sodium remaining in the inlet and outlet tee fittings to the EM pump. Those sections which showed evidence of residual sodium were placed in the vacuum distillation unit under the protective helium gas cover of the welding chamber for additional cleaning. The distillation unit used is shown in Figure 69. The tube segments which contained a sodium residue were heated under vacuum in this unit to 800°F and the sodium which vaporized was collected on the surfaces of the air-cooled condenser.

Following final cleaning in the distillation unit, all sections of the loop were carefully examined for evidence of mass transfer or corrosion and none was found.



C5544-61

Figure 69. High Vacuum Distillation Unit Used to Distill Residual Alkali Metal from Corrosion Test Components. Assembled Unit Shown in (a) and an Exploded View of the Components Shown in (b).

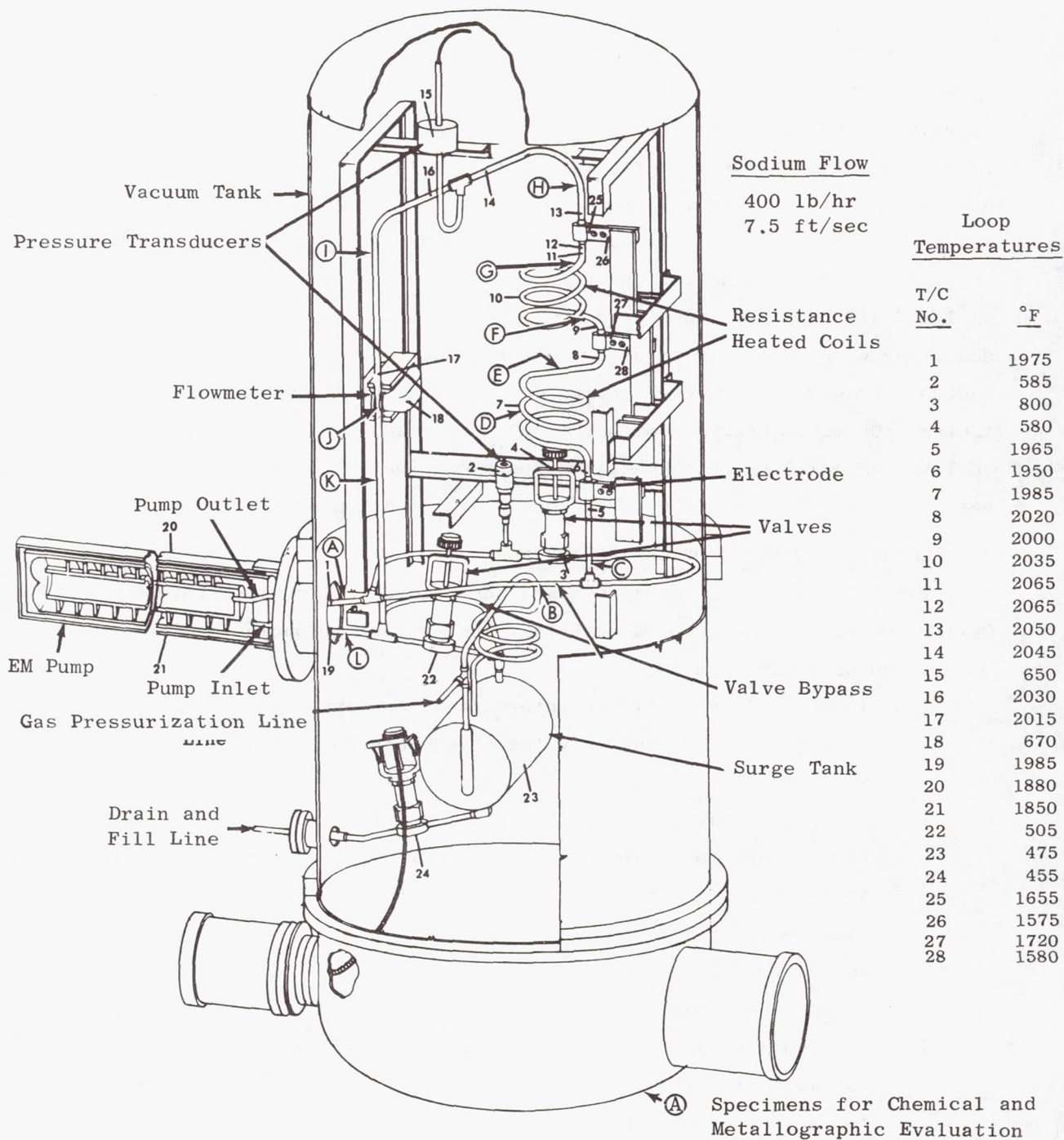
XI. CHEMICAL AND METALLURGICAL EVALUATION OF THE Cb-1Zr TUBING

As indicated in the previous section, the loop was cut into a number of small segments using the pinch-off device. The sealed ends of these segments were subsequently removed with a tubing cutter and each segment inspected for evidence of corrosion or mass transfer. A total of 25 metallographic specimens, 17 bend specimens, and 13 specimens for chemical analysis were taken from the various regions of the loop. The locations and temperatures of the various portions of the loop tubing which were analyzed are indicated in Figure 70. The post-test evaluations to be described were performed in order to determine the effects of both the sodium exposure and the test chamber environment on the Cb-1Zr loop tubing. Chemical analyses of both whole wall samples and gradient analyses of wall segments, metallographic examination, bend tests and hardness surveys were employed during this evaluation.

A. CHEMICAL ANALYSIS OF Cb-1Zr TUBING

The results of these analyses and the before test analysis of the Cb-1Zr tubing are given in Table XVII. The following conclusions may be made based on these results:

1. In general, very little interstitial contamination occurred during the test, and only the oxygen concentration varied significantly.
2. Analyses obtained on the lowest temperature region (1965°F) and the highest temperature regions (2050° and 2065°F) indicate a transfer of oxygen from the high to the low temperature sections.
3. Maximum wall contamination (approximately 250 ppm O) occurred in the 2015°F heat rejection area (sample J) not protected with Cb-1Zr foil wrap.
4. Gradient analyses obtained indicate that all of the oxygen contamination from the vacuum chamber environment was confined to the outer portions of the tube wall.



C5544-62

Figure 70. Cb-1Zr Pumped Sodium Loop Showing Loop Temperatures and Locations of Specimens for Chemical and Metallographic Evaluation.

TABLE XVII

RESULTS OF CHEMICAL ANALYSIS^(a) OF SPECIMENS OF TUBING^(b)
 FROM THE Cb-1Zr PUMPED SODIUM LOOP WHICH CIRCULATED SODIUM
 AT A MAXIMUM TEMPERATURE OF 2065°F FOR 2650 HOURS

Sample Location ^(c) and Description	Chemical Analysis, ppm ^(d)			
	O	N	H	C
(A) Pump Outlet (1970°F)	254	25	3	--
Inner 1/3 of Wall	350	33	18	--
(C) Heater Inlet (1965°F) - <u>No Foil Wrap</u>	383	58	2	80
(E) End of First Heater Coil (2020°F)	163	42	1	50
(G) End of Second Heater Coil (2065°F)	101	38	2	120
(H) 2 Inches Past Heater Coil (2050°F)	87	41	1	60
Following Removal of 0.010 Inch of Outer Surface of Tube Wall	59	36	3	--
(J) Middle of Cold Leg - <u>No Foil Wrap</u> (2015°F)	404	61	5	110
Outer 1/3 of Wall	569	43	1	80
Middle 1/3 of Wall	188	77	3	100
Inner 1/3 of Wall	146	55	1	80
(K) Middle of Cold Leg (2015°F)	219	53	4	80
Outer 1/3 of Wall	428	50	6	105
Middle 1/3 of Wall	393	84	4	70
Inner 1/3 of Wall	171	68	3	50
(L) Pump Inlet (1985°F)	207	46	7	60
Before Test Analysis	159	29	5	60

(a) Analysis given is for total wall thickness unless otherwise indicated.
 All tube specimens covered with Cb-1Zr foil during test unless otherwise indicated. Average of duplicate analyses given in table.

(b) 0.375-inch OD x 0.065-inch wall.

(c) Location of the specimens indicated in Figure 70.

(d) Analytical methods: O, N and H; Vacuum Fusion
 C; Combustion Conductometric

A plot illustrating the relationship between the oxygen concentration of various regions of the loop is given in Figure 71. Comparison of the total wall oxygen concentrations of the samples from areas wrapped with Cb-1Zr foil insulation suggests that oxygen may have been transferred by the sodium from the highest temperature regions to the lower temperature regions. The analyses of the inner portions of the tube walls from the 1970° and 2050°F regions revealed wall gradients consistent with this hypothesis. Results obtained during the evaluation of the Cb-1Zr Sodium Thermal Convection Loop also indicated that oxygen was transferred through the sodium from the high to low temperature regions. (17)

During the disassembly of the loop, four layers of the 0.002-inch thick Cb-1Zr alloy foil from the hottest region (2065°F) of the loop were removed and analyzed in order to obtain a sensitive indication of the quality of the vacuum chamber test environment during the 2650-hour test. With a half thickness of only 1 mil, even small amounts of oxygen pickup may readily be detected. The results of these analyses are given in Table XVIII. The maximum oxygen increase (approximately 380 ppm) was detected in the outer foil as one would predict. A slight amount of nitrogen contamination of the outer foil is also apparent. As indicated in Section X, the foil ductility was not affected by the test exposure.

B. METALLOGRAPHIC EXAMINATION OF Cb-1Zr COMPONENTS

A total of 25 metallographic specimens were prepared from samples of Cb-1Zr tubing taken from various regions of the loop. As indicated previously in Section III, Material Procurement, the tubing received a final annealing heat treatment of one hour at 2200°F in vacuum. The recrystallized grain size of the tubing before the loop test was ASTM Number 7, and no significant change was noted as a result of the 2650 hour test. The lower maximum loop temperature in the Pumped Sodium Loop as compared to the earlier Cb-1Zr Sodium Thermal Convection Loop, as well as minor differences in interstitial chemistry of the two heats of tubing, contributed to the lack of significant grain growth in the heater coils of the Pumped Sodium Loop.

(17) Hoffman, E. E. and Holowach, J., Cb-1Zr Thermal Convection Loop, Potassium Corrosion Test Loop Development Topical Report No. 5, R67SD3014, General Electric Company, Cincinnati, Ohio, June 15, 1967, p. 69

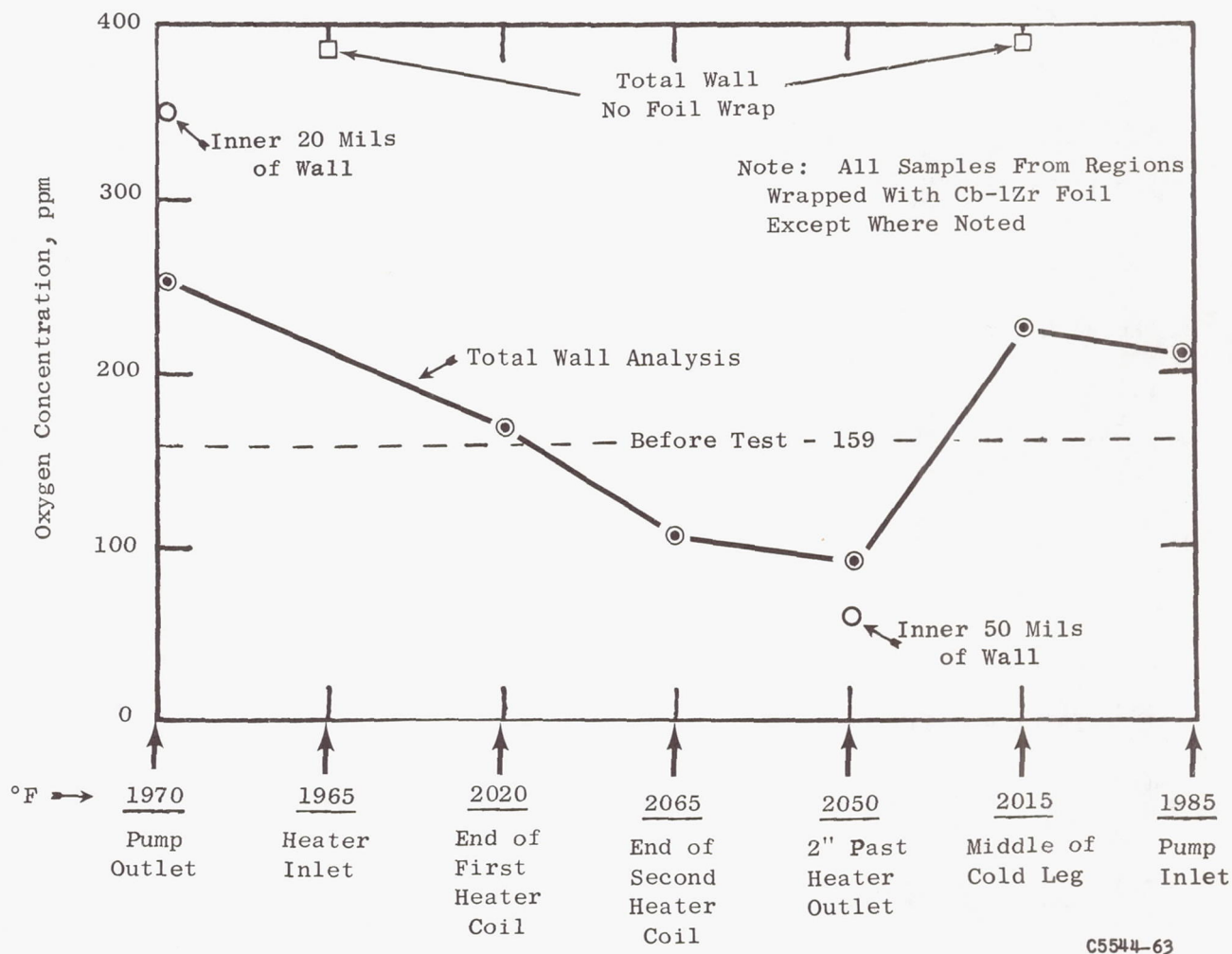


Figure 71. Oxygen Concentration of the Cb-1Zr Tubing (0.375-Inch OD x 0.065-Inch Wall) From Various Regions of the Cb-1Zr Pumped Sodium Loop. Analyses of Inner Portions of the Tube Wall Illustrate the Effect of Operating Temperature on the Oxygen Gradient in Wall.

TABLE XVIII

CHEMICAL ANALYSES RESULTS OBTAINED ON THE FOUR LAYERS OF
 Cb-1Zr FOIL^(a) USED TO INSULATE THE TOP HEATER COIL OF THE
 Cb-1Zr PUMPED SODIUM LOOP DURING 2650-HOUR TEST IN 10^{-8} TORR ENVIRONMENT

<u>Foil Location</u>	<u>Approximate Temperature, °F^(b)</u>	<u>Analysis, ppm^(c)</u>		
		<u>O</u>	<u>N</u>	<u>H</u>
Fourth Layer (Outer)	1220	720	64	10
Third Layer	1540	510	34	8
Second Layer	1780	521	25	8
First Layer (Inner)	1930	465	30	6
Before Test	--	338	28	12

(a) Material Control Number 401, 0.002-inch thick by 0.5-inch wide.

(b) Temperature of foil calculated using an emittance value of 0.2 and a tube wall temperature of 2065°F.

(c) Analytical Methods: O, N and H; Vacuum Fusion
 C; Combustion Conductometric

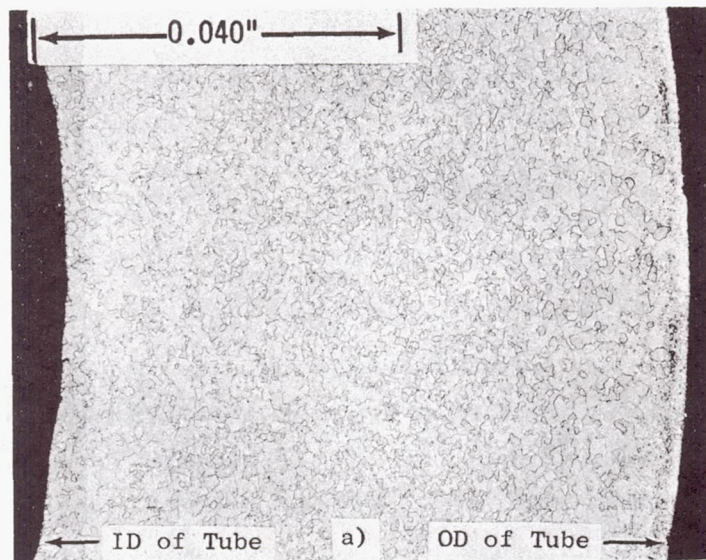
The appearance of the Cb-1Zr tubing before test is illustrated in Figure 72. The typical ID surface had smooth, shallow irregularities with a maximum depth of less than 1/2 mil. This surface condition is the result of the final cleaning operation prior to loop fabrication in which 0.2 to 0.4 mil of the surface is removed by pickling in a solution of $60\text{H}_2\text{O}-20\text{Hf}-20\text{HNO}_3$ (percent by volume). The pickling was performed in accordance with SPPS Specification 03-0010-00-B, "Chemical Cleaning of Columbium and Columbium Alloy Products".

Metallographic examination was performed on both longitudinal and transverse specimens. Figures 73 through 78 are arranged in an order which traces the loop circuit from the heater inlet around the loop to the inlet region of the EM pump. A thorough examination of all specimens at magnifications up to 1000X revealed no evidence of mass transfer deposits or corrosion. The subtle differences in metallographic appearance are attributed to the thermal history and minor variations in the etching characteristics of the various specimens. A number of the Cb-1Zr weldments were examined and the appearance of the surface of welds following exposure to sodium is typified by the structures shown in Figures 74 and 78. There was no evidence of any attack in any of the weldments.

The post-test ductility of seventeen 1/2-inch long tube sections from various regions of the loop was checked by flattening the tubes using a strip of 0.060-inch thick sheet as an internal support. Measurement of the specimens following flattening indicated a bend radius of 0.030 inch (one-half the tube wall thickness) for these specimens. Metallographic examination of polished cross sections at 500X was performed on the bend specimens. No cracks were observed on the OD surfaces of any of the specimens following this very severe deformation. Several small cracks to a depth of less than 4 mils were found on the ID surface subjected to severe compressive strain, however, this effect was also observed in before test specimens.

C. MICROHARDNESS OF Cb-1Zr TUBING

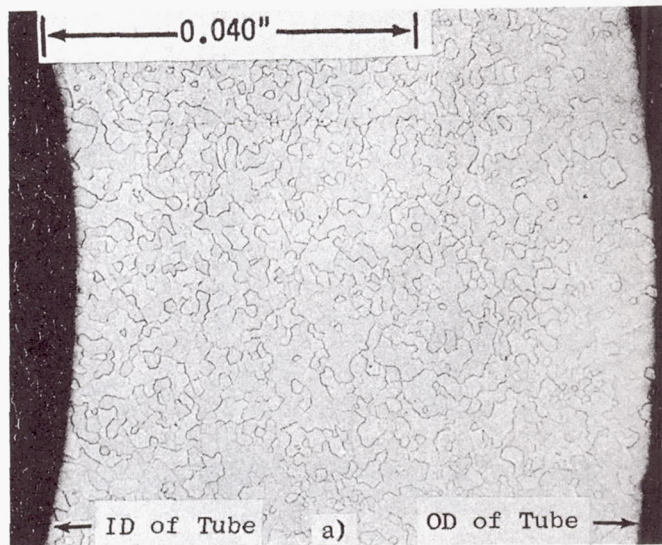
Microhardness surveys across the tube wall of Cb-1Zr specimens from various regions of the loop were conducted. Two traverses were made



C5544-64

Figure 72 Microstructure of a Typical Cross Section of the Sodium - Cb-1Zr Pump Tubing (0.375" OD x 0.065" Wall) Before Test.
Etchant: 60 ml Glycerine - 20 ml Hf - 20 ml HNO_3

- a) Mag: 50X (A310111)
- b) Mag: 500X (A020111)

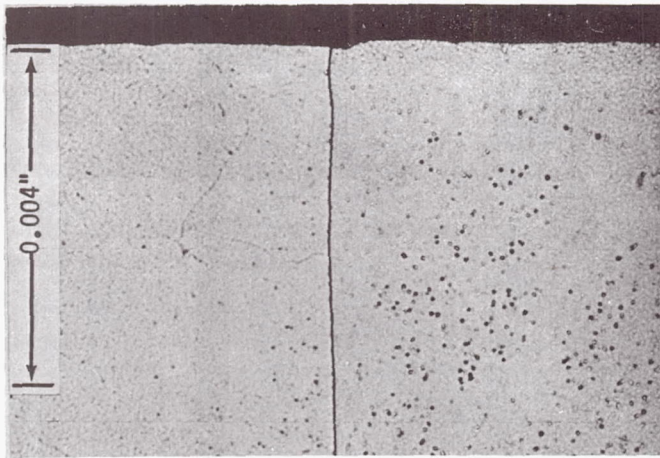


C5544-65

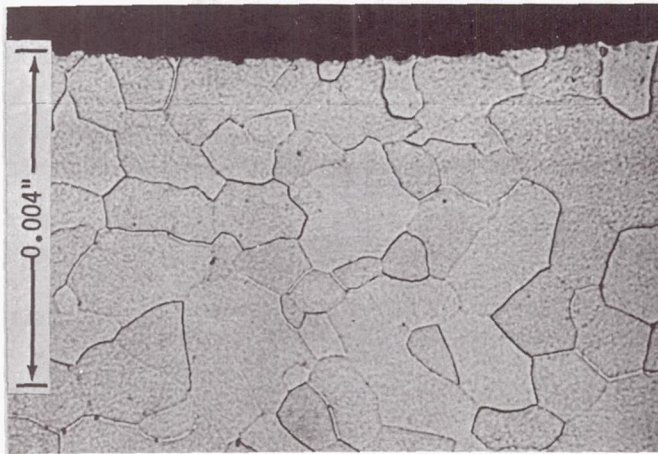
Figure 73 Microstructure of a Cross Section of the Cb-1Zr Tube From the Region Six Inches Below Lower Heater Electrode, Region C in Figure 70, 1965°F.

Etchant: 60 ml Glycerine - 20 ml Hf - 20 ml HNO_3

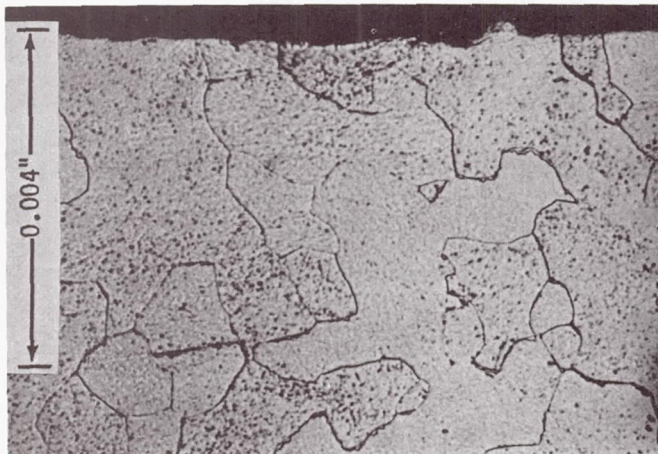
- a) Mag: 50X (A180712)
- b) Mag: 500X (A180713)



a) Butt Weld, 6" Below
Lower Heater Electrode
(Region C, 1965°F)



b) Middle of Lower
Heater Coil
(Region D, 1985°F)



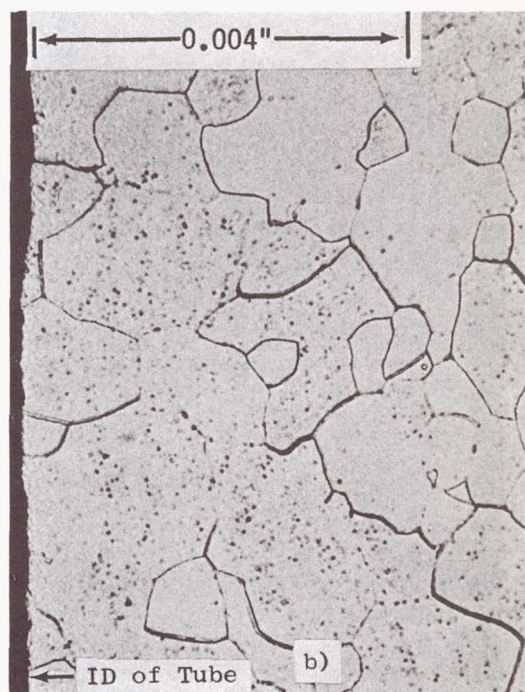
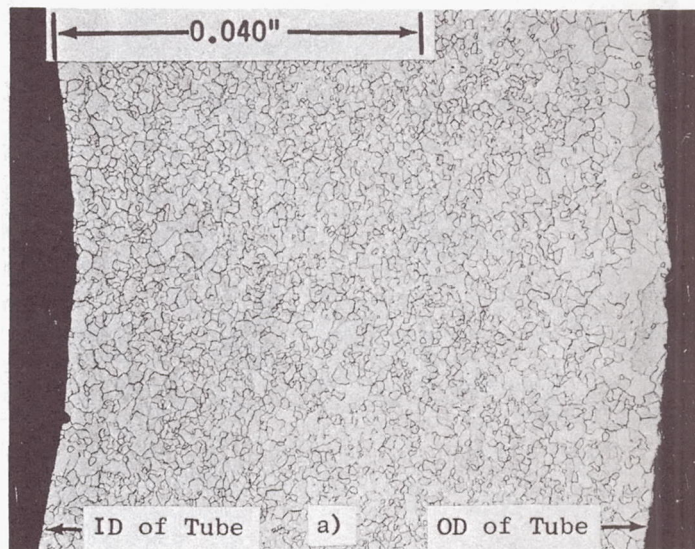
c) 2" Below Middle
Heater Electrode
(Region E, 2020°F)

C5544-66

Figure 74 Microstructures of the ID Surfaces of Cross Sections of the Cb-1Zr Tubing. Specimen Locations Given in Figure 70.

Etchant: 60 ml Glycerine - 20 ml Hf - 20 ml HNO₃

- a) Mag: 500X (A181313)
- b) Mag: 500X (A181411)
- c) Mag: 500X (A090212)



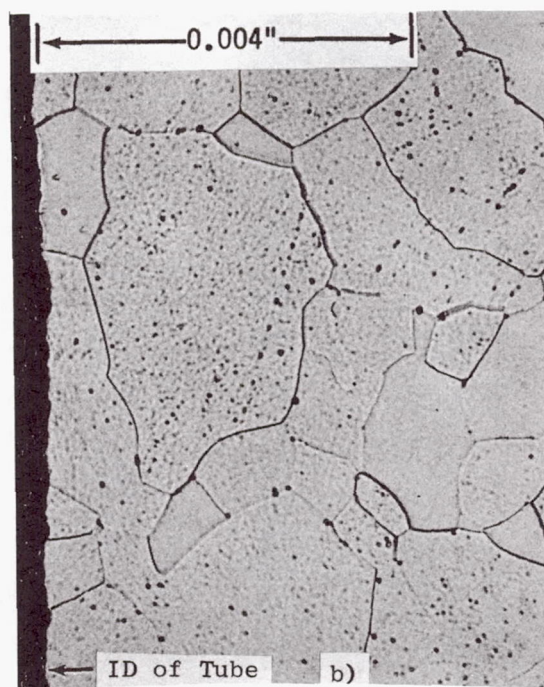
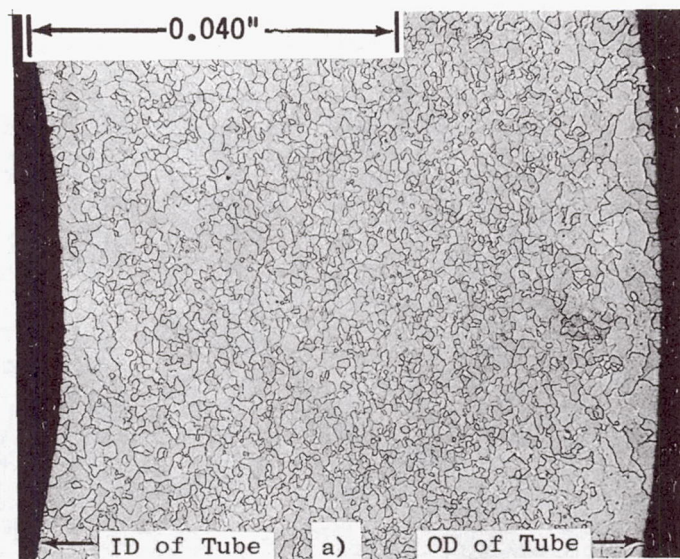
C5544-67

Figure 75 Microstructure of a Cross Section of the Cb-1Zr Tube From the Region One Inch Above Middle Heater Electrode, Region F in Figure 70, 2000°F.

Etchant: 60 ml Glycerine - 20 ml Hf - 20 ml HNO_3

a) Mag: 50X (A180912)

b) Mag: 500X (A180911)

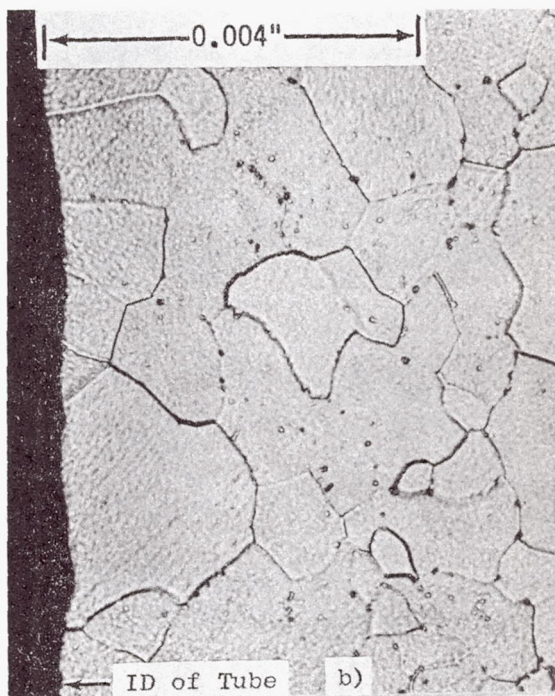
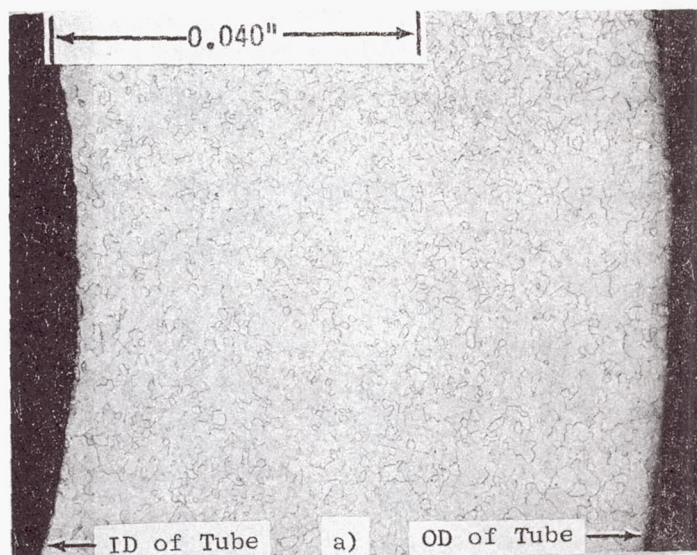


C5544-68

Figure 76 Microstructure of a Cross Section of the Cb-1Zr Tube From the Region One Inch Below the Top Heater Electrode, Region G in Figure 70, 2065°F.

Etchant: 60 ml Glycerine - 20 ml Hf - 20 ml HNO_3

- a) Mag: 50X (A181011)
- b) Mag: 500X (A181012)

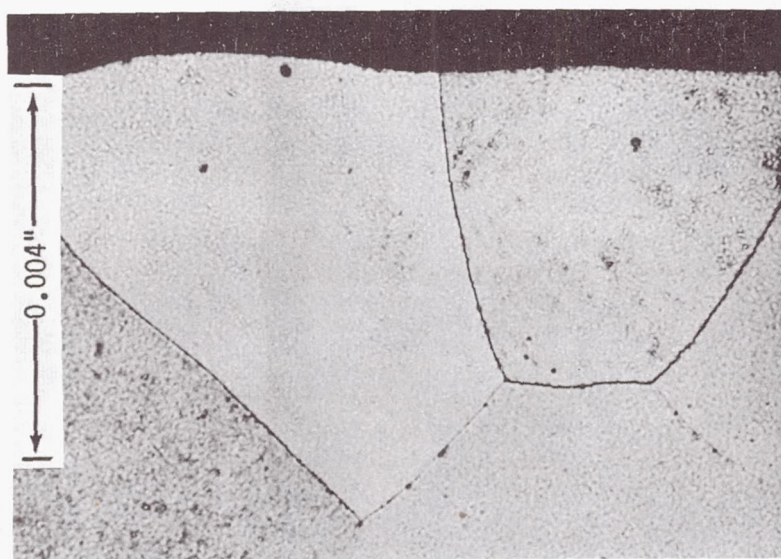


C5544-69

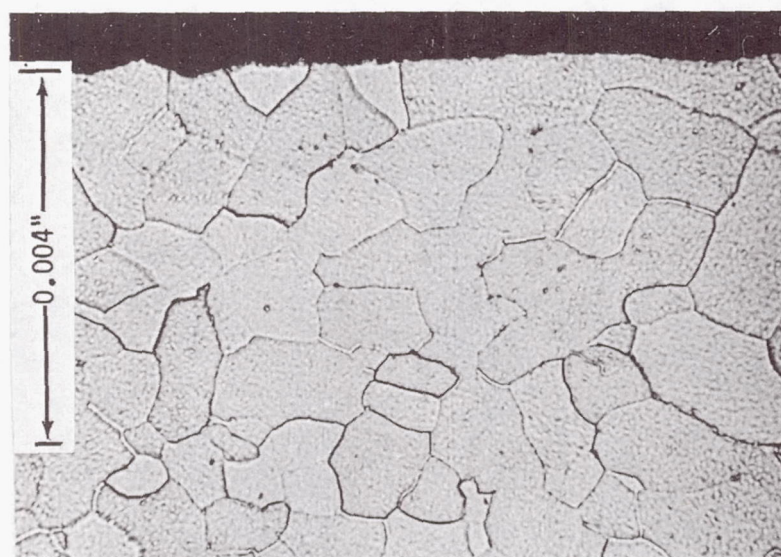
Figure 77 Microstructure of a Cross Section of the Cb-1Zr Tube From the Region Above the Flowmeter, Region I in Figure 70, 2020°F.

Etchant: 60 ml Glycerine - 20 ml Hf - 20 ml HNO₃

- a) Mag: 50X (A090413)
- b) Mag: 500X (A181211)



a) Butt Weld, 6" Below
Flowmeter
(Region K, 2010°F)



b) Inlet Tube to EM Pump
(Region L, 1985°F)

C5544-70

Figure 78 Microstructures of the ID Surfaces of Cross Sections of the Tubing. Specimen Locations Given in Figure 70.

Etchant: 60 ml Glycerine - 20 ml Hf - 20 ml HNO_3

- a) Mag: 500X (A180211)
- b) Mag: 500X (A180311)

across metallographic cross sections of the tube wall with hardness readings made every three mils near the ID and OD surfaces and every ten mils in the central regions of the wall. The results of the micro-hardness survey are listed in Table XIX. A plot of the data obtained was not made because there were no detectable hardness gradients across the 0.065-inch thick tube walls. The operating temperature, post-test oxygen concentration of the wall, and whether or not the tube was covered with Cb-1Zr foil insulation is also indicated. The lack of any significant hardening of the Cb-1Zr tubing is in agreement with the results obtained for the tubing of the Cb-1Zr Sodium Thermal Convection Loop⁽¹⁸⁾ and is consistent with the completely ductile behavior demonstrated by the bend tests on the tubing cited previously.

(18) Hoffman, E. E. and Holowach, J., Cb-1Zr Thermal Convection Loop, Potassium Corrosion Test Loop Development Topical Report No. 5, R67SD3014, General Electric Company, Cincinnati, Ohio, June 15, 1967, p. 84.

TABLE XIX

RESULTS OF MICROHARDNESS SURVEYS OF THE
Cb-1Zr TUBING FOLLOWING THE 2650 HOURS OF EXPOSURE TO SODIUM

Specimen ^(a) Location	Operating Temp., °F	Insulated With Cb-1Zr Foil	Oxygen Concentration of Wall, ppm	Knoop Hardness Number, 100 g load, Range (Average)
C	1965	No	383	97-105(102)
H	2050	Yes	87	99-119(112)
J	2015	No	404	115-124(120)
K	2015	Yes	219	91-105(95)
Tubing before Test			159	95-105(100)

(a) Specimen location indicated in Figure 70.

XII. EVALUATION OF COMPONENT PERFORMANCE

The main objective of the Cb-1Zr Sodium Pumped Loop was to evaluate a number of the key components of the Cb-1Zr Rankine Cycle Corrosion Loop. These included the sodium EM pump, the metering and isolation valve, and the slack and stressed diaphragm pressure transducers and thermocouples. An earlier and considerably simpler thermal convection loop was tested for 1000 hours to evaluate principally the method of loop heating and high amperage electrical feedthroughs. (19)

A. METERING AND ISOLATION VALVES

The metering and isolation valves proved to be the most troublesome components in the loop operation. Bench tests of the valves in air at room temperature indicated that the valves could easily be operated with the 4 inch-pound torque rotary feedthrough. However, after a short time exposure in the high vacuum environment at the 500°F bakeout temperature, the valve drive system was plagued with operating problems associated with the galling and self-welding of the threaded or rubbing surfaces. Gold plating of the threads or use of work hardened L-605 alloy parts was not successful in solving the problem; however, the replacement of the threaded stem and bushing with a ball bearing screw eliminated the problem completely and resulted in a more efficient valve design due to the low friction of the ball bearing screw. Use of the ball bearing screw permits the use of a variety of commercially available ball bearing materials. The WC-6Co balls selected for use in these valves performed in an excellent manner. It should be mentioned that sapphire balls which were evaluated were easily fragmented and are considered to be inferior to the carbide balls for this application.

(19) Hoffman, E. E. and Holowach, J., Cb-1Zr Thermal Convection Loop, Potassium Corrosion Test Loop Development Topical Report No. 5, R67SD3014, General Electric Company, Cincinnati, Ohio, June 15, 1967, p. 87.

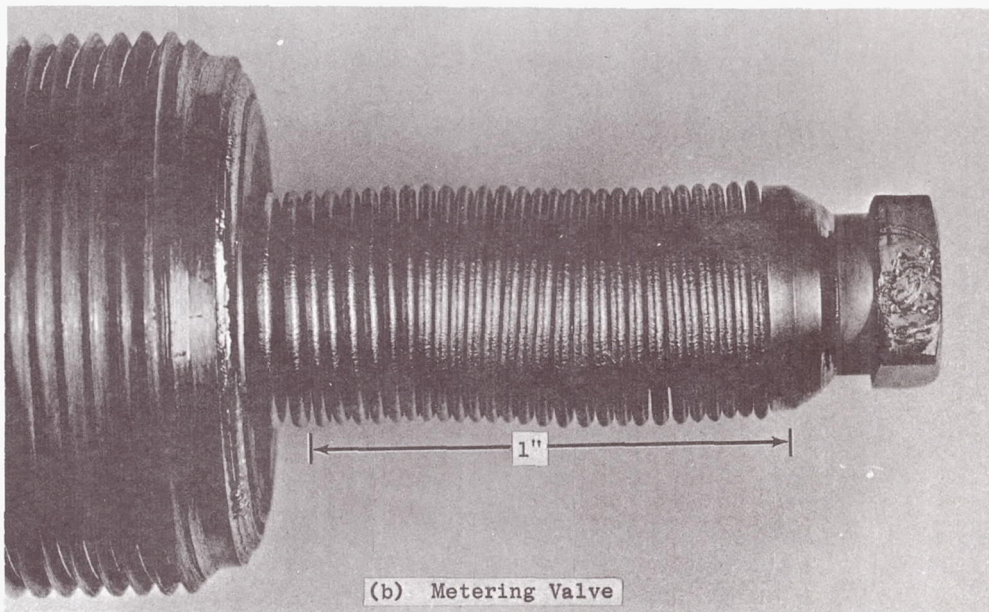
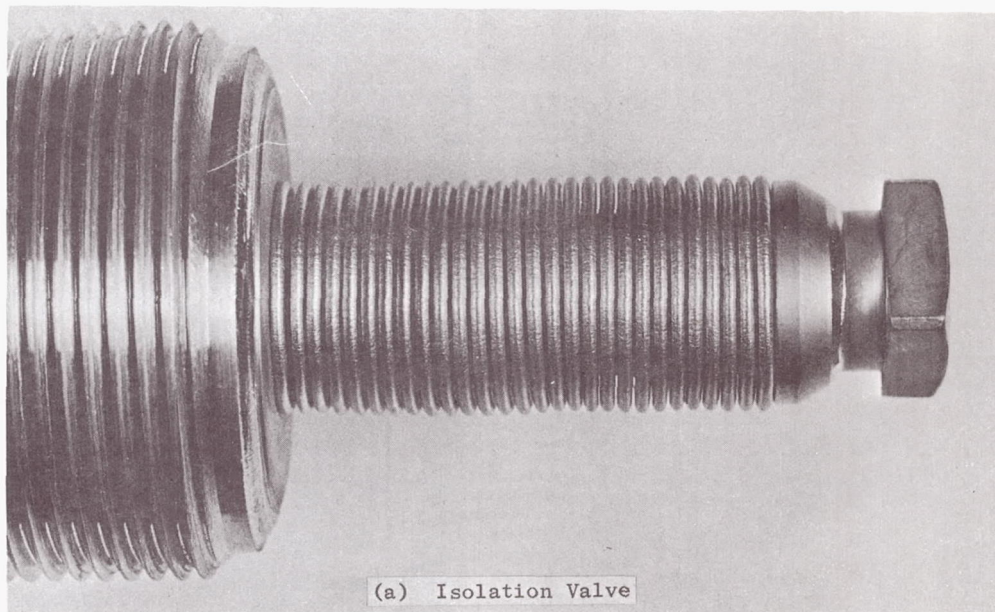
The Cb-1Zr bellows of the isolation and metering valve were in excellent condition following the 2650-hour test. Photographs of these bellows are shown in Figure 79. The slight distortion of the metering valve bellows is apparent but it is not considered to have impaired the reliability of this component. As indicated in Section III, Material Procurement, of this report, some concern existed prior to the loop test because of the high oxygen content of the bellows (approximately 800 ppm). The high quality of vacuum chamber environment maintained during the test prevented loss of ductility of the thin-walled bellows.

No bonding of the Mo-TZM valve plug to the Cb-1Zr seat was observed at any time indicating that a safe service temperature of 800°F can be specified for this material combination in sodium. The post-test appearance of the Mo-TZM plug from the metering valve is illustrated in Figure 80. The surface of the Mo-TZM plug was discolored slightly as compared to the pretest appearance but no corrosion or mechanical damage due to seating in the Cb-1Zr valve body could be detected.

The flexible stainless steel shaft used to actuate the valve resulted in some springback in operating the valve which was observed especially on small valve adjustments when high torque was required due to galling. However, with the lower torque required after the substitution of the ball bearing screw, the springback was extremely small and did not interfere with the valve operation.

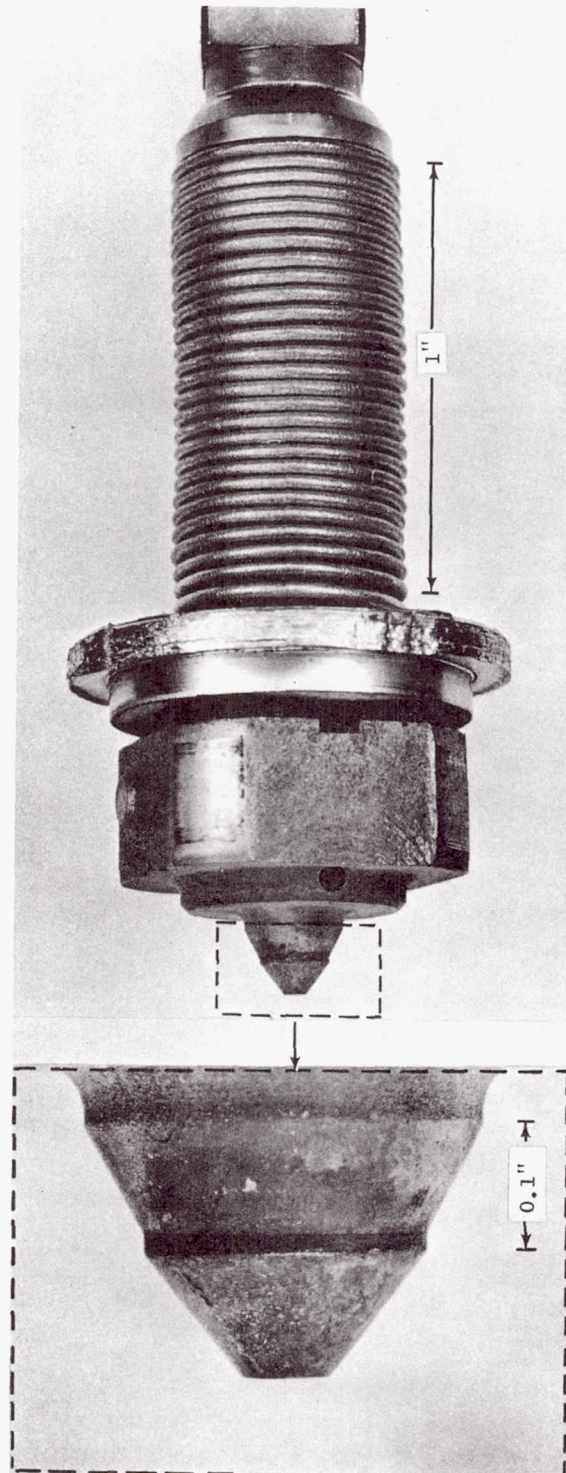
B. HELICAL INDUCTION ELECTROMAGNETIC PUMP

The sodium EM pump performed reliably without any deterioration of performance during the 2650-hour operation. The loop was not instrumented for obtaining experimental pump performance data so a direct comparison with the calculated pump performance shown in Figure 4 can not be made. The pump operated at inlet and outlet temperatures of 1985° and 1975°F, respectively, during the entire test with a flow rate of 440 lbs/hr and an estimated pressure head of 5 psi. The design flow rate of the loop was reached with an applied voltage of only 125V which is far below the design voltage of 450V. Since the power input and the developed head at a



C5544-71

Figure 79. Cb-1Zr Bellows of Modified Hoke Valves Following Completion of the Cb-1Zr Pumped Sodium Loop Test. Isolation Valve Bellows (a) Unchanged During Test. Metering Valve Bellows (b) Shows Evidence of Some Distortion. (Orig. C65041260, C65041259)



C5544-72

Figure 80. Cb-1Zr Bellows and Mo-TZM Alloy Plug of the Cb-1Zr Pumped Sodium Loop Metering Valve Following Disassembly of the Valve. (Orig. C65051405, C65051406)

particular flow rate vary approximately as the square of the applied voltage, the actual power input was only $(125/450)^2$ or less than 10% of the rated pump power. The pump capacity will therefore meet the pumping requirements of the Cb-1Zr Rankine System Corrosion Test Loop of 824 lb/hr at 15 psi pressure head with sufficient excess capacity for off-design test runs.

A desirable feature of the EM pump was the ability to preheat the pump duct without an auxiliary heater before the initial sodium fill. The pump was also used to heat the sodium in the loop during the pretest operation up to 1000°F for outgassing the loop components and for near isothermal runs to calibrate the loop thermocouples before the start of the test.

An air pressure drop test was conducted on the EM pump duct before and after the 2650 hour test and the results indicated that no change had occurred which was in agreement with the lack of any significant corrosion of test components as described in Section XI.

C. SODIUM FLOWMETER

The sodium flow rate was measured by a permanent magnet flowmeter designed to operate at a liquid metal temperature of 2200°F. Prior to the test it was estimated that the Alnico V magnet would operate at a temperature of approximately 700°F. In order to stabilize the magnet prior to test, it had been thermally cycled repeatedly from room temperature to 900°F. As indicated previously in Table III, a stable flux density of 2675 gauss at 700°F was obtained. The flux density measurement was repeated after completion of the 2650-hour loop test. During loop operation the magnet temperature was 670°F as measured by a thermocouple attached directly to the magnet. The pretest and post-test flux densities as a function of temperature are shown in Figure 81. Although no detectable change in the flux density at room temperature was measured, the magnet after test showed a greater sensitivity to temperature than indicated by the pretest measurement. The decrease of approximately 10% noted in the flux density at room temperature following the thermal

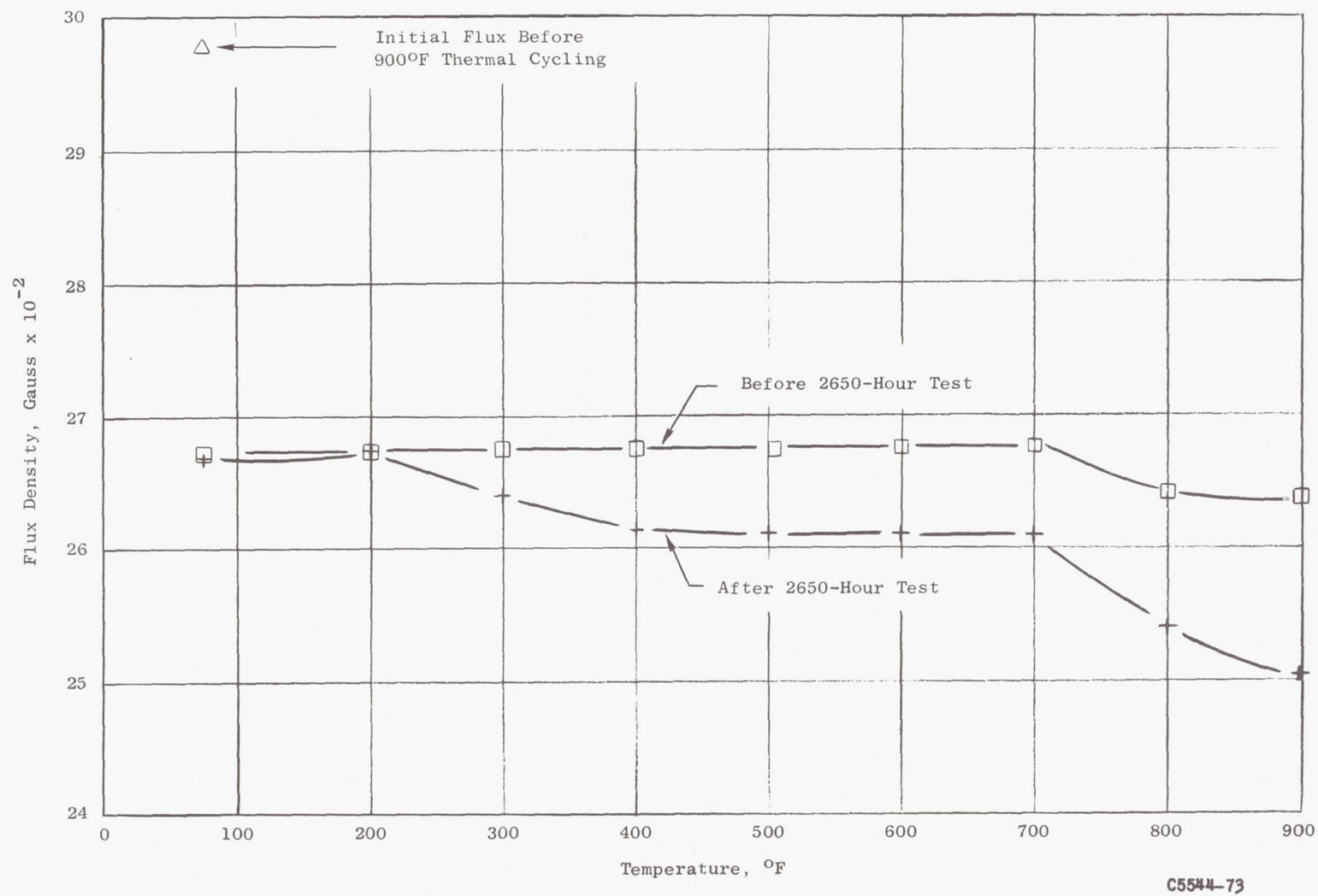


Figure 81. Magnet Flux Density Versus Temperature of the Cb-1Zr Pumped Sodium Loop Flowmeter Magnet Before and After 2650-Hour Test.

stabilization treatment before test emphasizes the necessity for this pretest operation. The decrease in the flux density of the magnetic at its operation temperature during the loop test would result in an error in the calculated flow of less than three percent.

D. SLACK DIAPHRAGM PRESSURE TRANSDUCER

The Cb-1Zr slack diaphragm pressure transducer described in Section II and illustrated in Figures 9 and 10 proved to be as reliable as the commercial stainless steel models commonly used in liquid metal loops. The pressure transducer met the sensitivity and response characteristics specified by the vendor and showed no zero drift during the entire operation. The slack diaphragm pressure transducer once again proved its usefulness in measuring absolute pressure and low frequency pressure fluctuations in alkali metal systems.

E. STRESSED DIAPHRAGM PRESSURE TRANSDUCER

The stressed diaphragm pressure transducer, shown in Figures 11 and 25, which has a response of up to 100 cps was designed and fabricated for evaluation in the Cb-1Zr Pumped Sodium Loop to supplement the low frequency response (1 cps) of slack diaphragm pressure transducers in measuring pressure fluctuation during periods of unstable boiling and condensing which may be encountered in the potassium circuit of the Cb-1Zr Rankine System Corrosion Test Loop. The stressed diaphragm transducer consists of a pressure housing with a 0.015-inch thick T-111 alloy diaphragm which serves as a stressed member. Deflection of this diaphragm, which is a function of the pressure on it, is the measured quantity.

An initial calibration was performed on the diaphragm assembly before the 2200°F heat treatment of the assembly welds. During the annealing of the Cb-1Zr process tube, the stressed diaphragm pressure transducer was located outside the annealing furnace and did not exceed 1500°F during this annealing treatment. The results of this calibration indicated that the diaphragm operated satisfactorily over the full pressure range of 0-150 psia and was repeatable within 0.5% over four full scale pressure cycles. The net change in the output level for a 0-150 psia change in pressure was approximately 100 millivolts.

A second calibration was made with the transducer installed in the loop, but prior to filling the loop with sodium. The calibration which was made with argon gas at room temperature showed that the net change in output for the 0-150 psia change in pressure was 52 millivolts which was repeatable to within 0.53% over four complete pressure cycles or approximately one-half of the output measured in the initial calibration of the same pressure range. The decrease in output can probably be attributed to a change in the diaphragm deflection characteristics during the heat treating of the Cb-1Zr assembly welds after the initial calibration. During the 1-hour 2200°F annealing treatment, the temperature of the diaphragm housing did not exceed 1500°F, as indicated previously.

A third calibration was performed with the loop filled with sodium during the bakeout period with the transducer temperature at 480°F. During this calibration, there was a net zero shift of approximately 12% of the span. During loop operation, a continued zero shift in the positive direction was observed, indicating creep in the diaphragm, although the slope of the output characteristic curve remained unchanged. During the shutdown of August 3 after 784 hours of operation, the output changed from 290.5 mv to 219.9 mv in reducing the loop pressure from 150 psia to 0 psia, or a net change of 70.6 mv compared to 52 mv for the calibration before test operation.

On August 26 after 800 hours of test operation, the transducer failed to respond to pressure changes in the loop. A post-test inspection after the 2500-hour endurance run showed three of the six copper electrical leads to the transducer were open about 4 inches from the LVDT connection. The failure was due to mechanical fatigue caused by induced vibrations from the AC heater power supply. The failures occurred in the thermal expansion loop in the copper wire leads which had been provided to accommodate the differential thermal growth between the support structure and the loop and permitted large amplitude swings.

The six copper electrical lead wires were replaced by Type 302 stainless steel wires for the 150-hour post-test operation to increase the mechanical strength of the leads. This also eliminated any possible thermoelectric potential due to a dissimilar metal junction between the lead wire and the Type 302 stainless steel head pin of the coil.

During the pump down of the vacuum chamber before restoring the loop to the test conditions, the pressure transducer behaved normally during the roughing operation when sorption pumps were used to evacuate the chamber to approximately 5 microns. When the getter-ion pump was turned on, the transducer output became very unstable and could be observed to be associated with the electrical arcing in the chamber during the glow discharge period prior to confinement of the ion pump. Upon confinement of the ion pump, the transducer output again became stable although the zero level was displaced from the original zero by approximately 200 millivolts. The transducer output in response to a change in pressure level remained normal and showed a 60 millivolt change for a 127 psi change in pressure during a subsequent calibration.

During the pump down of the vacuum chamber for the distillation of the residual sodium from the loop after completion of 2650-hour test, it was observed that 300 volt D.C. potential appeared on several non-grounded conductors during the ion pump startup. The effect of this D.C. voltage on the electronic circuitry may be responsible for the erratic behavior and zero shift observed during the 2500-hour test. If the zero shift observed resulted from a permanent change in the electrical characteristics of the excitation circuitry incurred during the ion pump starting period, this problem can be eliminated in future tests by disconnecting the electronic circuitry during the pump down cycle.

Post-test calibration of the transducers at room temperature using argon gas indicated a net output change of 40 millivolts for a 150 psi change in pressure with a sensitivity of 6 psi per millivolt at the 150 psi level. The excitation-demodulation circuit was then connected to a second previously calibrated transducer, and a negative zero shift of

170 millivolts was observed. Since no change in the transducer had occurred since the first calibration, it must be assumed that the zero shift was caused by a change in the electronic circuitry and probably due to the high voltage arcing observed during the ion pump startup described above. The extreme change in calibration and zero shift of the stressed diaphragm pressure transducer limits its usefulness to measuring the frequency and amplitude of pressure fluctuations. Absolute pressure measurements with the stressed diaphragm pressure transducer are not accurate and would require considerable development effort on both the transducer and the electrical sensing system for a reliable, accurate system. It is therefore recommended that the stressed diaphragm pressure transducer be used to measure the frequency and amplitude of pressure fluctuations in the range of 0 to 100 cps and the slack diaphragm pressure transducer for 0 to 1 cps pressure fluctuations and the absolute operating pressure of the loop.

F. TEMPERATURE MEASUREMENT

Reliable temperature measurements proved to be a problem area in both the installation and operation of the loop. During the 2500-hour run, 13 of the 28 thermocouples had failed. Of the 13 failed thermocouples, five thermocouples were open at the vacuum feedthrough and seven thermocouples were shorted near the vacuum feedthrough. For the 100-hour post-test operation following completion of the 2500-hour endurance test, the reference junction was relocated to inside the vacuum chamber and copper wire was used from the reference junction through the thermocouple feedthrough to the recorder. The technique used is shown in Figure 60 in Section IX of this report. The copper wire leads were more ductile and the routing of the wires both inside and outside of the vacuum chamber was facilitated. Not all of the braze joints between the copper wires and the nickel tubes of the vacuum feedthrough were helium leak tight following the first brazing operation in the argon-filled chamber; however, the problem was far simpler to solve than the brazing of W-Re wire into nickel tubulations. This is primarily due to the brazing characteristics of the copper wire/nickel tube combination compared to the W-Re/nickel tube

combination. The relocation of the reference junction block to inside the vacuum chamber eliminated the major thermocouple problems encountered in the installation and operation of the loop.

The twelve-wire W-Re thermocouple vacuum feedthrough shown earlier in Figure 61, was evaluated during the post-test operation. This approach eliminated the standard nickel tubulations and minimized the possibility of spurious thermal emf's generated from dissimilar metal contacts. No difficulties were experienced in the 150 hour post-test operation and the seals proved reliable and remained leak free during the 500°F bakeout and the subsequent loop operation. However, the use of the W-Re thermocouple vacuum feedthrough requires an external thermocouple junction with the associated problem of handling brittle W-Re wire. Additional disadvantages of this type of thermocouple feedthrough include the danger of overstressing the brazed seal between the wire and the alumina disc by movement of the relatively strong W-Re wire. The high cost of this type of feedthrough compared to the more widely used nickel tube feedthroughs is an additional factor. For these reasons, the recommended procedure for future loop instrumentation is to use the internal reference junction with the nickel tubulation thermocouple feedthrough.

G. PARTIAL PRESSURE GAS ANALYZER

The results obtained with the partial pressure residual gas analyzer during the 2650 hour test were presented in Section IX, Test Loop Operation. An instrument of this type is considered to be an integral part of any high vacuum system used to test refractory metal in order to determine the concentration of contaminating gases in the vacuum environment. The partial pressure analyzer is also of great utility in the identifying outgassing sources and leaks in the system. A metal analyzer tube was used for the Cb-1Zr Pumped Sodium Loop test and this change from the glass analyzer tube used during the Cb-1Zr Sodium Thermal Convection Loop test improved the reliability of the test chamber and permitted bakeout of this component at a higher temperature than possible with the glass envelope.

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XIII. SUMMARY AND CONCLUSIONS

The prime purpose of conducting the Cb-lZr Pumped Sodium Loop, which was to evaluate a number of the critical components required for the subsequent Cb-lZr Rankine System Corrosion Test Loop, was accomplished. In addition to the specific components and test results cited below, a multitude of specification and procedures for such operations as material procurement, alkali metal purification and sampling, welding, and annealing were developed and confirmed to be adequate for the program requirements.

The modifications of the conventional Hoke, Inc. stainless steel valve to refractory alloy construction was successful. Difficulties during test operation were encountered only with the normal items of valve construction which were not in contact with sodium and which were not modified in the original redesign. Replacement of the threaded stem bushing with the ball bearing nut and the use of a carbide insert bushing in the drive gear support plate solved the galling problems encountered initially. The remote valve actuation system performed satisfactorily following solution of the galling problems in the valve.

Fabrication and operation of the Cb-lZr helical induction electromagnetic pump was completely successful and trouble free, with the exception of a slight problem during assembly of the duct, which was easily solved. The pump exceeded the performance requirements and post-test evaluation indicated no significant corrosion or mass transfer as a result of the 2650 hours of operation at 1980°F.

Results of tests to determine the temperature dependence of the magnetic flux of the Alnico V flowmeter magnet after pretest thermal stabilization and following loop operation indicate that these measurements are required to improve the accuracy of the flow measurement.

Operation of the slack diaphragm pressure transducer was completely trouble free and no alterations in the accuracy or response of this

component were detected. The stressed diaphragm pressure transducer, which was evaluated primarily as a sensor of high frequency pressure oscillations, proved adequate in this respect. However, many factors in the design and operation of this component make it unsuitable as an absolute pressure indicator without extensive redesign.

Some difficulties were encountered with the use of the W-3Re/W-25Re thermocouples. The chief area of difficulty was associated with the fragile nature of the 5-mil W-Re wires near the brazed feedthrough seals. This problem was eliminated by the use of an internal thermal junction block and copper lead wire from this block through the feedthrough flanges.

Chemical and metallographic evaluation of the various loop components indicated no significant contamination or corrosion by either the sodium or vacuum chamber environments. Total wall and gradient sample analysis of the Cb-1Zr tubing from various regions indicated migration of oxygen from the high temperature regions of the loop to lower temperature regions. No loss of ductility was detected in the tubing as a result of the 2650 hour test.

XIV. PUBLISHED REPORTS

Quarterly Progress Reports	For Quarter Ending
Report No. 1 (No NASA No.)	October 15, 1963
Report No. 2 (NASA-CR-54008)	January 15, 1964
Report No. 3 (NASA-CR-54081)	April 15, 1964
Report No. 4 (NASA-CR-54167)	July 15, 1964
Report No. 5 (NASA-CR-54269)	October 15, 1964
Report No. 6 (NASA-CR-54344)	January 15, 1965
Report No. 7 (NASA-CR-54735)	April 15, 1965
Report No. 8 (NASA-CR-54843)	July 15, 1965
Report No. 9 (NASA-CR-54912)	October 15, 1965
Report No. 10 (NASA-CR-54990)	January 15, 1966
Report No. 11 (NASA-CR-72042)	April 15, 1966

Topical Reports

- Report No. 1 - "Purification and Analysis of Helium for the Welding Chamber" by T. F. Lyon, NASA-CR-54158, July 1, 1965.
- Report No. 2 - "Materials and Process Specifications for Refractory Alloy and Alkali Metals" by R. G. Frank, D. N. Miketta, W. H. Kearns, W. R. Young and R. B. Hand, R66SD3007, December 13, 1965.
- Report No. 3 - "Materials Specifications for Advanced Refractory Alloys" by D. N. Miketta and R. G. Frank, NASA-CR-54761, October 1, 1965.
- Report No. 4 - "Purification, Analysis and Handling of Sodium and Potassium" by L. E. Dotson and R. B. Hand, R66SD3012, June 13, 1966.
- Report No. 5 - "Cb-1Zr Sodium Thermal Convection Loop" by E. E. Hoffman and J. Holowach, R67SD3014, June 15, 1967.

APPENDIX A

DRAWING LIST AND MAJOR DRAWINGS OF THE Cb-1Zr PUMPED SODIUM LOOP

<u>Figure No.</u>	<u>Title</u>	<u>GE-SPPS Drawing No.</u>
82	Assembly, Cb-1Zr Pumped Sodium Loop	SK56131-369 Rev. J
83	Manual Metering Valve	SK56131-425 Rev. B
--	Manual Isolation Valve	SK56131-238 Rev. B
84	Slack Diaphragm Pressure Transducer, Taylor Instrument Co. Dwg. No. 14427	SK56131-356 Rev. D
85	Assembly, Stressed Diaphragm Pressure Transducer	119C2835 Rev. C
86	Body Assembly, Stressed Diaphragm Pressure Transducer	119C2837 Rev. C
87	Retainer Body, Stressed Diaphragm Pressure Transducer	142B1737 Rev. D
88	Diaphragm Assembly, Stressed Diaphragm Pressure Transducer	142B1738 Rev. C
89	Housing, Stressed Diaphragm Pressure Transducer	142B1739 Rev. C
90	Retainer Cap, Stressed Diaphragm Pressure Transducer	119C2836 Rev. B
--	Housing Cap, Stressed Diaphragm Pressure Transducer	142B1740 Rev. B
--	Reducer, Stressed Diaphragm Pressure Transducer	119C2838 Rev. B
91	Heater Coil	SK56131-802 Rev. B
92	Heater Electrode	SK56131-801 Rev. A
93	Reducer, EM Pump Inlet	SK56131-366 Rev. D
--	Reducer, EM Pump Outlet	SK56131-367 Rev. C
94	Heater Coil Installation	SK56131-368 Rev. A
95	Loop Support Structure Assembly	SK56131-370 Rev. D
--	Copper Bus Bar	SK56131-354 Rev. B

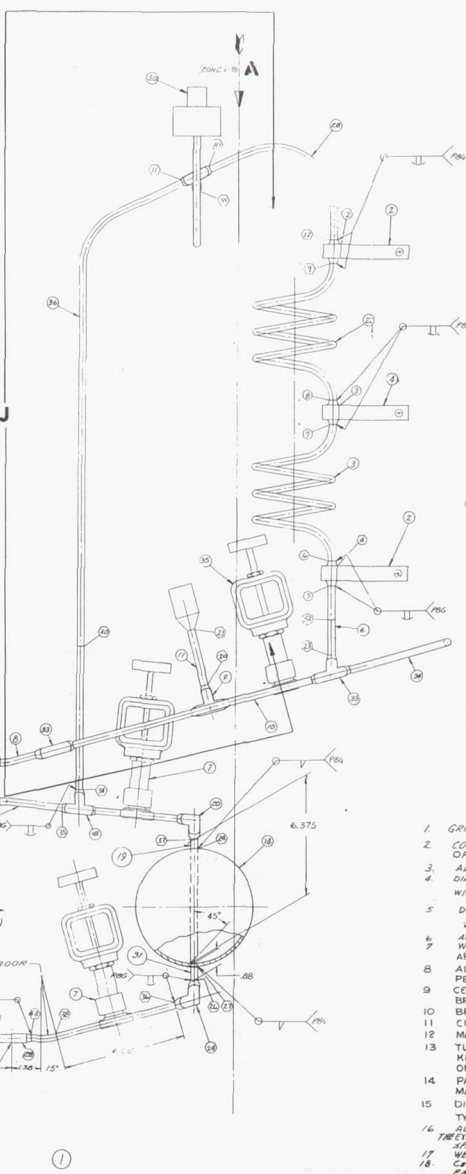
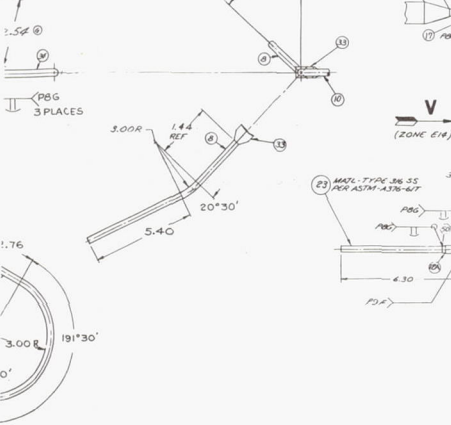
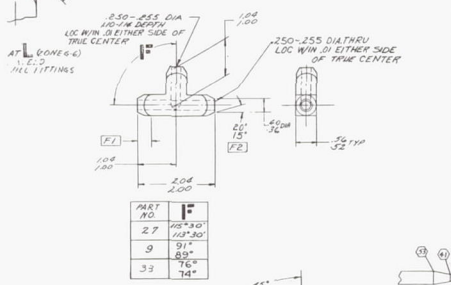
APPENDIX A (Continued)

<u>Figure No.</u>	<u>Title</u>	<u>GE-SPPS Drawing No.</u>
--	Alumina Insulating Sleeve	SK56131-332
--	Alumina Insulating Washer	SK56131-333
96	Copper Cable Connector	142B1649
--	Copper Cable Connector	142B1650
97	Vacuum Chamber Spool Section Assembly	SK56131-337
98	Electrical Feedthrough	SK56131-326
--	Argon/Sodium Feedthrough Flange	SK56131-372 Rev. B
99	Sodium and Argon Supply	SK56131-497 Rev. B
100	Sodium Purification System	246R806 Rev. B
101	Sodium Fill System	246R807

VENDOR DRAWINGS

<u>Title</u>	<u>Vendor</u>	<u>Drawing No.</u>
Pump Duct Assembly	Large Generator and Motor Dept.	588C476 Rev. 5
Sodium EM Pump Duct	General Electric Company	
for Model 5KY414PB2	Schenectady, N. Y.	
Helical Induction		
Electromagnetic Pump		
Pressure Transducer	Taylor Instrument Companies	14427
	Rochester, N. Y.	
Manual Metering Valve	Hoke, Inc., Cresskill, N. J.	CB442, Mod. 3B
Manual Isolation Valve	Hoke, Inc., Cresskill, N. J.	CB442, Mod. 3A





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DATE	BY	REVISIONS	DATE	BY	REVISIONS
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3-4	B	NOTE A-ADDED ULTRAS SONIC OR X-RAY INSPECTION	7-26	A	2.0000
2-6	C	ADDED TRIP (K&J&J)-621 UNINS 2.0-4	11-6-6	A	2.0000
		W/ 35-5610-228 P/26			
010	D	1. DELETED ITEM 2.67	11-6-6	B	2.0000
		UNINS 2.0-4			
010	D	UNINS 1245-30			
010	E	UNINS 1245-30 UNINS 1245-30	11-6-6	B	2.0000
010	E	UNINS 30-07			
010	F	UNINS 32-16			
010	F	UNINS 32-16			
010	G	WAS 3.56-PE CNOV001	11-6-6	A	2.0000
010	H	ADDED COLL P/13-PEKNOV000	11-6-6	A	2.0000
010	H	ADDED COLL P/13-PEKNOV000	11-6-6	A	2.0000
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2		COFFEE	B-3	
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4	SK-6145-10-AP	ELECTRIC	B-3	
5	SK-6145-10-AP	PIPE 3750' 0.05 WALL	D-1	
6		PIPE 3750' 0.65 WALL	F-1	
7		PIPE 3750' 0.65 WALL	F-1	
8	SK-6145-10-AP	PIPE 3750' 0.65 WALL	C-1	
9		PIPE 3750' 0.65 WALL	D-1	
10		PIPE 3750' 0.65 WALL	D-1	
11	UT-2385(S)	TRANSFORMER, 1000 VA	A-2	
12		TRANSFORMER, 1000 VA	A-2	
13		TRANSFORMER, 1000 VA	A-2	
14		TRANSFORMER, 1000 VA	A-2	
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76		PIPE 3750' 0.05 WALL	C-1	
77		PIPE 3750' 0.05 WALL	C-1	
78		PIPE 3750' 0.05 WALL	C-1	
79		PIPE 3750' 0.05 WALL	C-1	
80		PIPE 3750' 0.05 WALL	C-1	
81		PIPE 3750' 0.05 WALL	C-1	
82		PIPE 3750' 0.05 WALL	C-1	
83		PIPE 3750' 0.05 WALL	C-1	
84		PIPE 3750' 0.05 WALL	C-1	
85		PIPE 3750' 0.05 WALL	C-1	
86		PIPE 3750' 0.05 WALL	C-1	
87		PIPE 3750' 0.05 WALL	C-1	
88		PIPE 3750' 0.05 WALL	C-1	
89		PIPE 3750' 0.05 WALL	C-1	
90		PIPE 3750' 0.05 WALL	C-1	
91		PIPE 3750' 0.05 WALL	C-1	
92		PIPE 3750' 0.05 WALL	C-1	
93		PIPE 3750' 0.05 WALL	C-1	
94		PIPE 3750' 0.05 WALL	C-1	
95		PIPE 3750' 0.05 WALL	C-1	
96		PIPE 3750' 0.05 WALL	C-1	
97		PIPE 3750' 0.05 WALL	C-1	
98		PIPE 3750' 0.05 WALL	C-1	
99		PIPE 3750' 0.05 WALL	C-1	
100		PIPE 3750' 0.05 WALL	C-1	

- (A) PART NO. 20 HOKE INC.
CRIESSKILL, NEW JERSEY
- (B) PART NO. 25 SSP FITTING CORP.
BEDFORD, OHIO
- (C) PART NO. 30 TAYLOR INSTRUMENT CO.
ROCHESTER, N.Y.

- 1 GWT BLAS AREA J FOR HIGH EMITTANCE PER SP5 SPEC 15
2 CONTOUR OF TUBING COMPONENTS MUST BE WITHIN 0.6
3 OF DEFINED TUBE SHAPE
4 ALL SEAMLESS TUBING PER SP5 SPEC 16 WITHIN 0.004 IN 4
5 DOWNSIDE PART OF J ARE TO BE 0.8 CONCENTRIC
6 WITH M N WITHIN 0.02 FIR
7 DIA 5/8 T PART (ZONE AD) TO BE CONCENTRIC
8 WITH DIA 5/8 T PART WITHIN 0.02 FIR
9 ALL BAR STOCK PER SP5 SPEC 16 WITHIN 0.004 IN 4
10 ALL BAR STOCK PER SP5 SPEC 16 WITHIN 0.004 IN 4
11 ALL BAR STOCK PER SP5 SPEC 16 WITHIN 0.004 IN 4
12 ALL CB-1Z R WELDS ARE TO BE X-RAY INSPECTED
13 PER SP5 SPEC 16
14 CERTIFY OPERATORS FOR HIGH VACUUM FURNACE
15 BRAZE PER SP5 SPEC 16
16 BRAZE PER SP5 SPEC 16
17 CLEAN CB-1Z R PER SP5 SPEC 16
18 MASS SPECTROMETER LEAK TEST PER 101-271B
19 TUBING TO BE INSPECTED FOR CRACKS, FREES OF ALL
20 KINKS & ABRASIONS , ONLY BENDING SPECIFIED
21 ON DWG ALLOWED
22 TUBES TO BE 100% MUST BE BAGGED OR TAGGED AS A
23 MATCHED ASSY- SERIAL NO. & PART NO. REQ
24 DIA X TO BE CONCENTRIC WITH DIA Y WITHIN 0.004 FIR,
25 TYP ALL FITTING
26 ALL TUBING PARTS TO BE ULTRASONIC OR RAY INSPECTED PER
27 TUBING SURFACES WILL BE PERMANENT INSPECTED PER
28 WELDING WIRE 0.004 DIA PER SP5 SPEC 16
29 PART 1.3.3

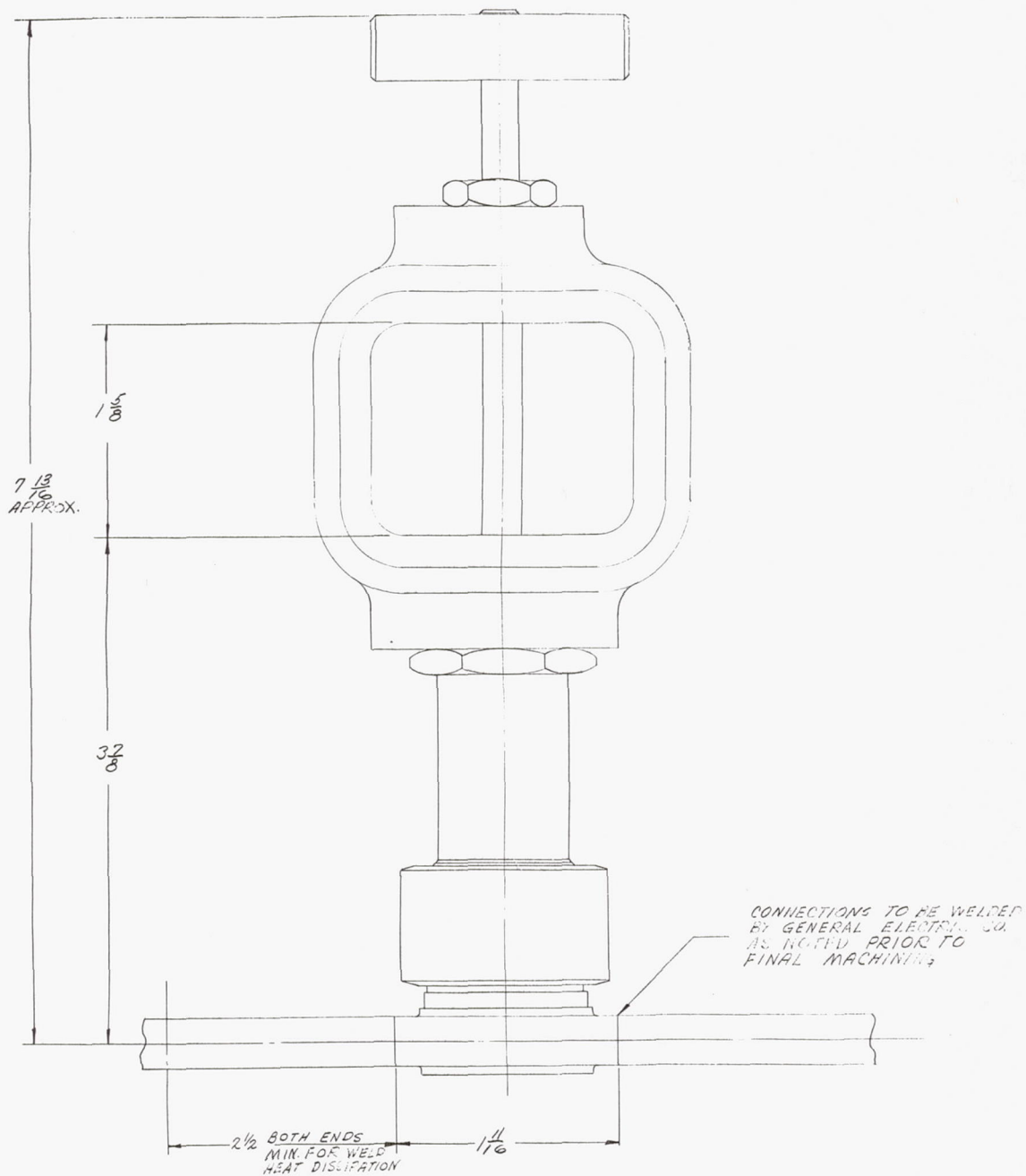


Figure 83. Manual Metering Valve.

REVISIONS				
SYM	ZONE	DESCRIPTION	DATE	APPROVED
A		NOTE 10-ADDED AMEND 1-4 CHG SPPS 15T TO SPPS 15 NOTE 14-ADDED ULTRA-SONIC OR X-RAY INSPECTION NOTE 16-CHG 3 BELLOWS TO 2 BELLOWS	1-2-64	<i>[Signature]</i>
B		TITLE WAS "MOD 2"		<i>[Signature]</i>

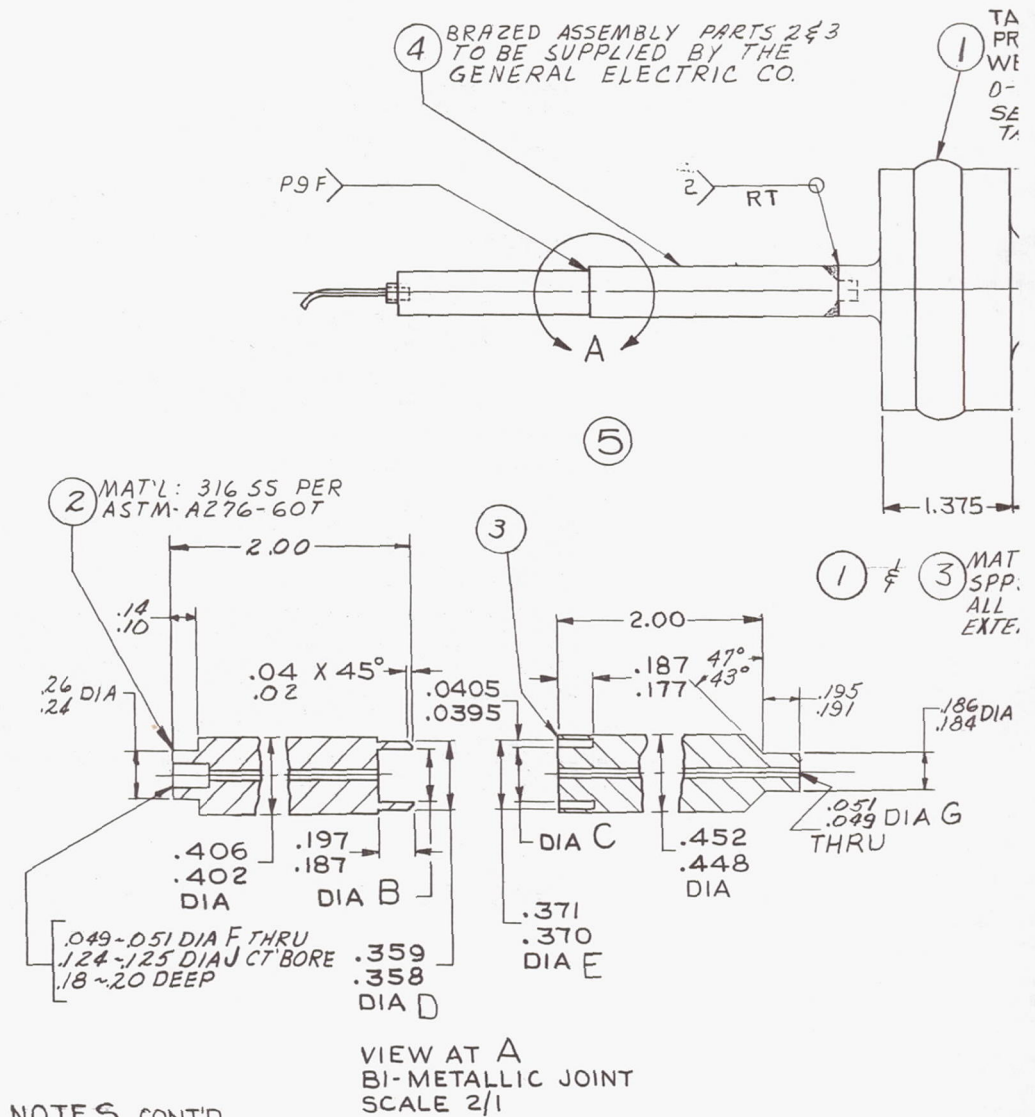
SPECIFICATION AND RATING

- 1 SERVICE ~ MANUAL, METERING
- 2 FLUID ~ LIQUID POTASSIUM OR SODIUM
- 3 TEMPERATURE ~ 1200°F
- 4 PRESSURE ~ 200 PSIA
- 5 FLOW RATE ~
FULLY OPEN ~ .256 GPM AT 10 PSI PRESSURE DROP
HALF OPEN ~ .126 GPM AT 5 PSI PRESSURE DROP
FULLY CLOSED ~ ZERO FLOW AT 100 PSI PRESSURE DROP
- 6 ENDURANCE ~ 10,000 HOURS AND 1000 CYCLES AT OPERATING CONDITIONS
- 7 LEAKAGE ~
EXTERNAL ~
NO LEAKAGE ALLOWED THAT CAN BE DETECTED
BY A HELIUM MASS SPECTROMETER WITH
1X10⁻⁹ CC/SEC CAPABILITIES
INTERNAL ~ WATER CHECK
NO LEAKAGE ALLOWED IN EXCESS OF .01 GPM
WITH VALVE FULLY CLOSED AND A PRESSURE DIFFERENTIAL
OF 10 PSI AT ROOM TEMPERATURE
- 8 PORTS ~ NOMINAL 5/32 DIA.
- 9 CONNECTION ~ 3/8 O.D. X 1/4 I.D.
- 10 MATERIAL ~ ALL COMPONENTS IN CONTACT WITH PROCESS
FLUID WITH THE EXCEPTION OF THE VALVE PLUG AND PIN WILL
BE CB-1Zr PER SPPS-18 AMEND 1-4 & 2B AMEND 1-4 AS SUPPLIED BY
GENERAL ELECTRIC CO. PLUG & PIN TO BE TZM PER
SPPS SPEC 15
- 11 ALL CB-1Zr WELDING TO BE DONE BY THE GENERAL ELECTRIC
CO. PER SPPS-3C
- 12 FINISHED VALVE MUST BE ACETONE CLEANED AND
FREE OF ALL DIRT GRIT AND ORGANIC MATERIALS
- 13 PRIOR TO INSTALLATION, OPERATE VALVE TO LIMITS OF STEM
TRAVEL, 5 CYCLES AT 200 PSIG AND REPEAT HELIUM MASS
SPECTROMETER LEAK TEST. NO EXTERNAL LEAKS ALLOWED
- 14 ALL CB-1Zr MACHINED PARTS TO BE ULTRA-SONIC OR X-RAY INSPECTED AND
EXTERNAL SURFACES WILL BE PENETRANT INSPECTED PER SPPS 18 AMEND. 1-4
- 15 NO HEAT TREATING OR ACID PICKLING WILL BE PERFORMED
BY THE VENDOR
- 16 BELLOWS STOCK THICKNESS TO BE .004 MIN AS DETERMINED BY
20 MEASUREMENTS ON 2 BELLOWS SELECTED AT RANDOM
FROM THE BELLOWS LOT

SPECIFICATION CONTROL

NO CHANGE SHALL BE MADE TO THE DESIGN, CONFIGURATION,
MATERIAL, PARTS, OR MANUFACTURING PROCESSES, WITHOUT
PRIOR WRITTEN APPROVAL OF THE PURCHASING DEPARTMENT
(SPPS)

ITEM	IDENTIFICATION NO.	DES.
1	SK56131-356PI	PRESSL
2		P2 TUBE
3		P3 TUBE
4		P4 BI-MET/
5		G5 ASSE



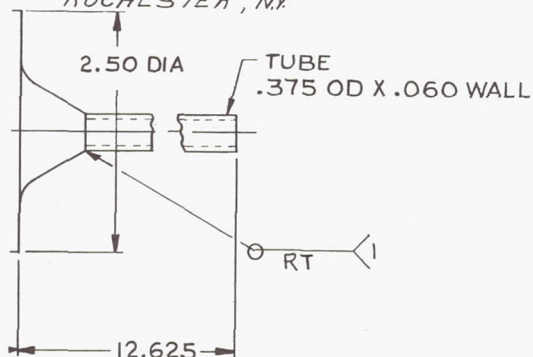
NOTES CONT'D

- 9 UNLESS OTHERWISE SPECIFIED SYMBOL FOR WELD TEST & NO. DESIGNATION PER MIL-STD-23A & AWS A2.2-58

Figure 84. Slack Diaphragm Pressu
Drawing No. 14427. (D)

DESCRIPTION OR NAME	ZONE	GROUP NO. & QTY				REVISIONS		SIZE	CONT ON SHEET	SH NO.	REV.
		1	2	3	4						
PRESSURE TRANSDUCER		1				C-4	A	ADDED AMEND. 1-4 ADDED ULTRA-SONIC OR X-RAY INSPECTION		1-2-64	b. Papp
			1				B	1) ADDED MATL CALLOUT FOR ITEM 1		2-3-64	b. Papp
TALLIG JOINT		1	X				C	1) ADDED PARTS LIST 2) CLARIFIED DELINEATION DROO16 , CNOO32		8-28-64	b. Papp g. H. Howard D.O. Burtch
EMBLY		X				C3	D	1) WAS "...TO BE PENETRANT INSP PER SPPS 1B" CNO115		2-3-65	b. Papp D.O. Burtch
TAYLOR VOLUMETRIC PRESSURE ELEMENT											

TAYLOR VOLUMETRIC
PRESSURE ELEMENT
WELDING TYPE, NAK FILLED, 1000°F TO 2000°F,
1-150 PSI, 1 CYCLE/SEC RESPONSE TIME
SEE DRAWING NUMBER 14427
TAYLOR INSTRUMENT CO.
ROCHESTER, NY



T/L: CB-1ZR PER (A)
25 SPEC IB AMEND. 1-4 & 2B
MACHINED PARTS WILL BE ULTRA-SONIC OR X-RAY INSPECTED AND THE
EXTERNAL SURFACES TO BE DYE PENETRANT INSP PER AMS 2646. NO INDICATIONS
NOTES (DI) INTERPRETED AS CRACKS ALLOWED

- 1 DIA B TO FIT AT ASSY WITH DIA C - SNUG FIT REQD
- 2 DIA B & DIA C .0005 MAX OUT OF ROUNDNESS
- 3 DIA B, D & J ARE TO BE CONCENTRIC WITH DIA F WITHIN .002 FIR
- 4 DIA C, E & H ARE TO BE CONCENTRIC WITH DIA G WITHIN .002 FIR
- 5 CERTIFY OPERATORS FOR HIGH VACUUM FURNACE
BRAZE PER SPPS SPEC NO. 10
- 6 BRAZE BI-METALLIC JOINT PER SPPS SPEC NO. 9A
- 7 CLEAN CB-1ZR PER SPPS SPEC NO. 11A
- 8 PARTS 2 & 3 TO BE TAGGED OR BAGGED AS A
MATCHED ASSEMBLY

SPECIFICATION CONTROL

NO CHANGES SHALL BE MADE TO THE DESIGN, CONFIGURATION,
MATERIAL, PARTS OR MANUFACTURING PROCESSES
WITHOUT PRIOR WRITTEN APPROVAL OF THE
PURCHASING DEPARTMENT (SPPS)

Pressure Transducer, Taylor Instrument Co.
Drawing No. SK56131-356 Rev. D)

ITEM	IDENTIFICATION NO.	DESCRIPTION OR NAME	ZONE	GROUP NO. & QTY				REVISIONS			
				1	2	3	4	ZONE	SYM	DESCRIPTION	DATE
1	119C2835 G1	ASSY		X				A	1) DELETED ITEM 4	10-5-64	C. P. ... S. C. ...
2	119C2836 P1	CAP. RETAINER		/	/				2) ADDED ITEM 5		
3	119C2837 G1	BODY ASSY		/					3) ADDED NOTE 4		
4	119C2838 P1	REDUCER		/					CN0058		
5	142B1839 P1	LVDT COIL		/	/			B	1) WAS: "SEE NOTE 4, LVDT ASSY"	12-18-64	C. P. ... D. G. ...
6	119C2835 G2	ASSY			/				2) DELETED NOTE 4		
7	119C2837 G2	ASSY - BODY			/				CN 0093		
								C	ADDED GROUP 2	2-2-65	J. Post D. G. ...
									PER C/N 0113		

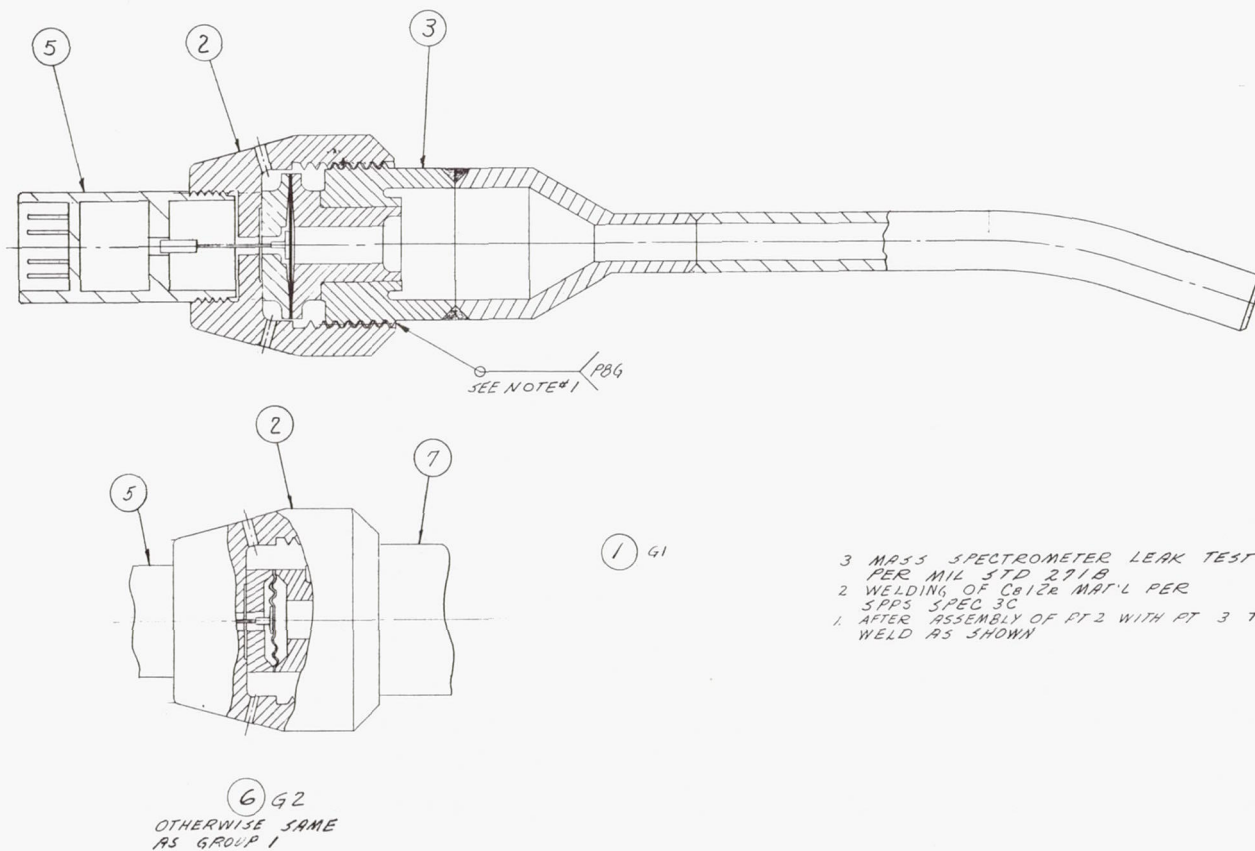


Figure 85. Assembly, Stressed Diaphragm Pressure Transducer.
(Drawing No. 119C2835 Rev. C)

ITEM	IDENTIFICATION NO.	DESCRIPTION OR NAME	ZONE	GROUP NO. & QTY				REVISIONS		
				1	2	3	4	SYM	ZONE	DESCRIPTION
1	119C2837-G1	ASSY	B6	X				A		1) TITLE WAS "BODY ASSEMBLY" CN 0032
2	142B1737	RETAINER BODY	D5	1				B		1) ADDED ITEMS 6 & 7
3	142B1738	DIAPHRAGM ASSY	D6	1				B		2) ADDED NOTE 6
4	142B1740	HOUSING CAP	D6	1				B		3) NOTE 5 ADDED "OMITTING SECTION 3.5"
5	142B1739	HOUSING	D5	1						CNO058
6	119C2838P1	REDUCER	D3	1	1			C	A7	ADDED GROUP 2 PER 9/N 0113
7	142B1804P1	TUBE	D2	1	1					
8	119C2837-G2	ASSY	A7	X						
9	142B1739 P2	HOUSING	B6	1						
10	142B1740 P2	CAP- HOUSING	B7	1						
11	142B1863G1	ASSY - DIAPHRAGM	B7	1						

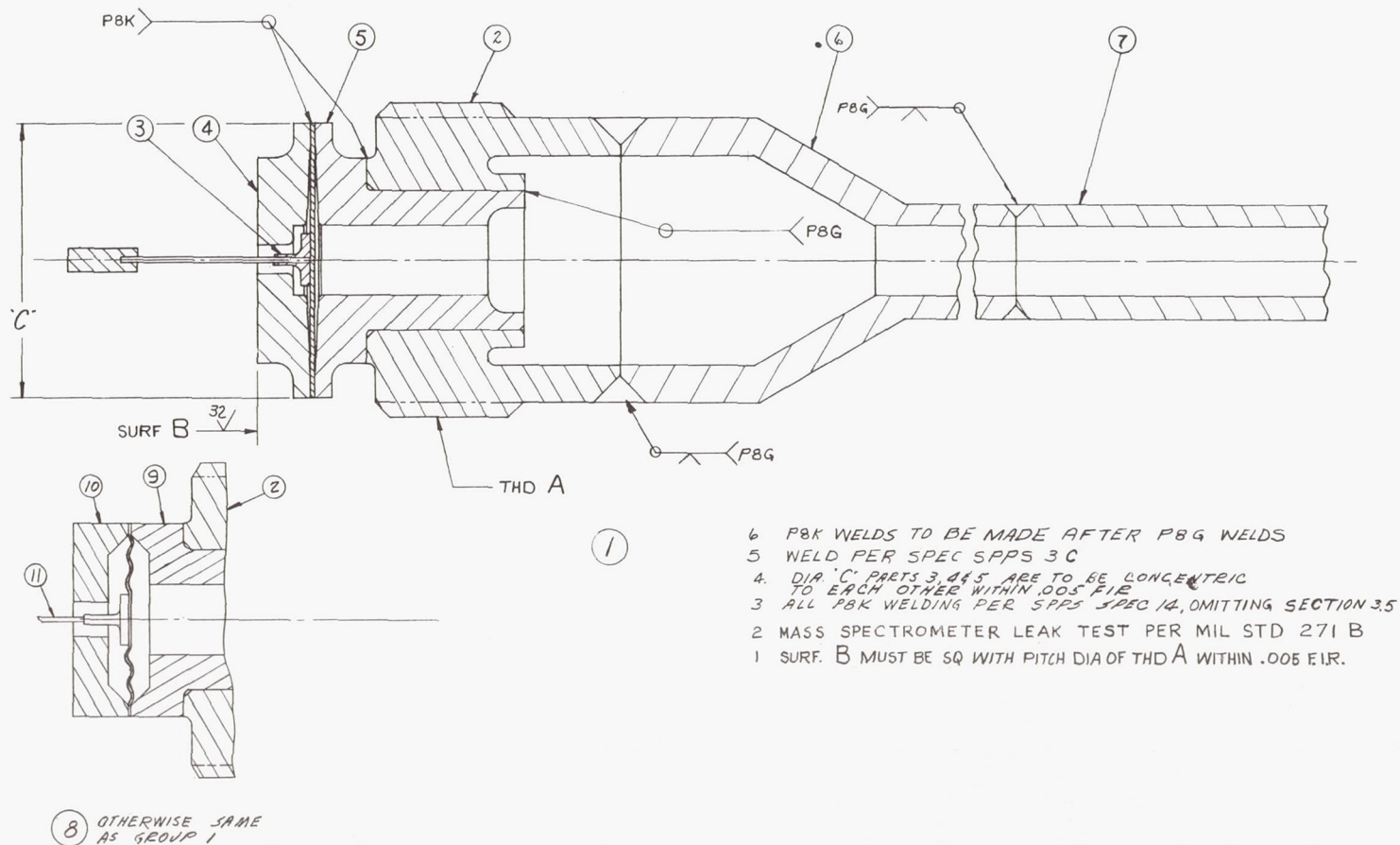
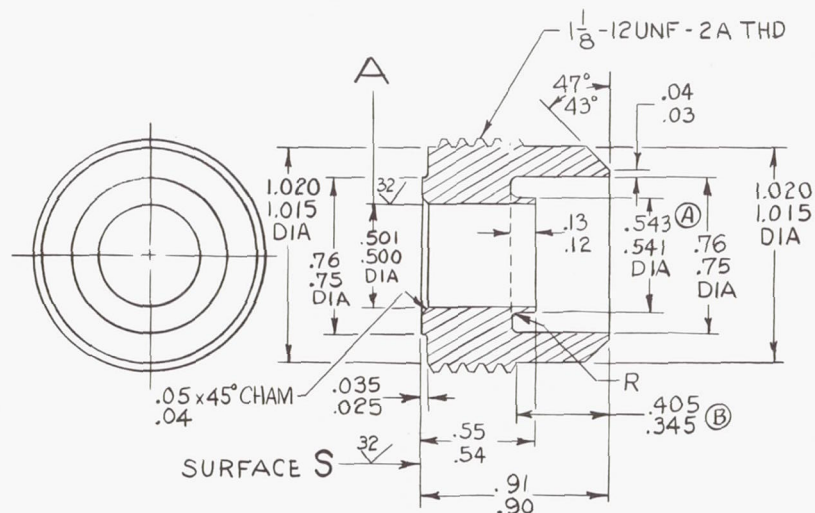


Figure 86. Body Assembly, Stressed Diaphragm Pressure Transducer.
(Drawing No. 119C2837 Rev. C)

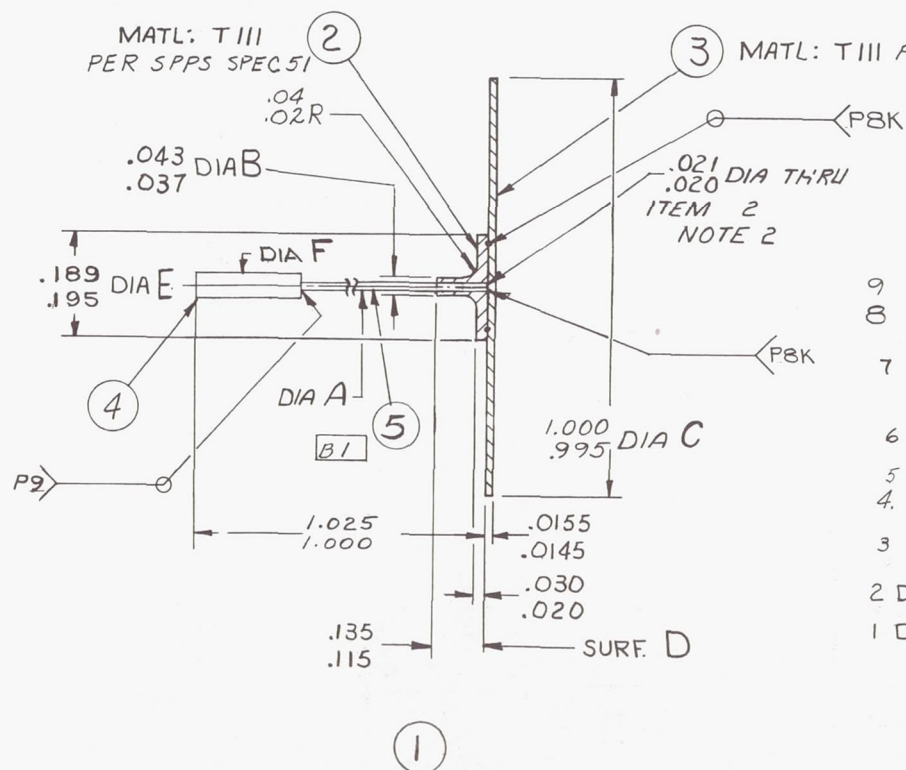


REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED
	A	WAS .63-.62	4-22-64	G. PUTT
	B	ADDED .405-.345	4-22-64	G. PUTT
	C	NOTE 4 WAS FLUORESCENT PENETRANT INSP. CNO115	2-3-65	D.P. BONNETT D.A. PRITCHETT
	D	RETRACED NO CHANGE PER DOP	10-31-66	S.G. RUTLAND

4. DYE PENETRANT INSP PER AMS 2646. NO INDICATIONS INTERPRETED AS CRACKS ALLOWED
3. BORE **A** AND O.D. OF $\frac{1}{8}$ THREAD TO BE SQUARE WITH SURFACE **S** WITHIN .002 FULL INDICATOR READING
2. PITCH DIA OF $\frac{1}{8}$ THREAD TO BE CONCENTRIC WITH DIA **A** WITHIN .002 FULL INDICATOR READING
1. BAR, ROD, SHEET, PLATE AND STRIP: COLUMBIUM-1% ZIRCONIUM ALLOY PER SPEC SPPS-1B INCLUDING AMENDMENTS 1 THRU 4

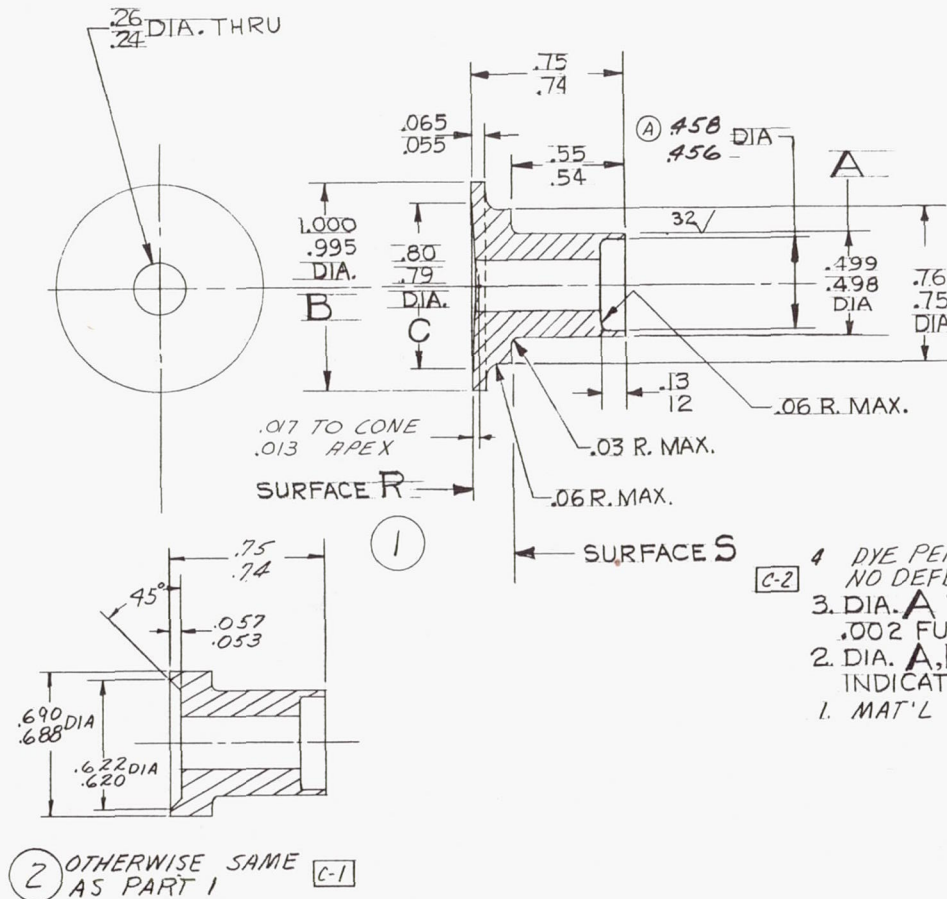
Figure 87. Retainer Body, Stressed Diaphragm Pressure Transducer.
(Drawing No. 142B1737 Rev. D)

ITEM	IDENTIFICATION NO.	DESCRIPTION OR NAME	ZONE	GROUP NO. & QTY				REVISIONS			
				1	2	3	4	SYM	DESCRIPTION	DATE	APPROVED
1		ASSY		X				A	1) WAS "BRAZE IN COMM. GRADE ARGON..."	8-28-64	D. C. Bickel
2	142B1738P2	PROBE MOUNT		1					CN0032		
3	142B1738P3	DIAPHRAGM		1				B	1) ADDED ITEM 5	10-5-64	D. C. Bickel
4	SEE NOTE 4	MAGNETIC PROBE		1					2) ADDED NOTE 8 & 9		
5	SEE NOTE 8	.020 DIA W-25%Re WIRE		1					CN 0058		
								C	NOTE 3 WAS FLUORESCENT PENETRANT INSP.	2-3-65	D. C. Bickel
									CN0115		



- 9 ITEM 5 TO BE .005 BELOW SURF D AFTER WELD
- 8 MECHANICAL GRADE WIRE
HOSKINS MANUFACTURING CO. DETROIT, MICH
- 7 BRAZE IN HIGH PURITY ARGON IN PURGED CHAMBER
USING LOCALIZED RESISTANCE HEAT SOURCE
WITH MANUAL FILLER APPLICATION
- 6 BRAZE FILLER METAL - HANDY AND HARMON
BT ALLOY
- 5 ALL PBK WELDING PER SPPS SPEC 14
4. FROM MODEL NO 411M14-300 PRESS. TRANSDUCER
CONSOLIDATED CONTROLS CORP
- 3 DYE-PENETRANT INSP PER AMS 2646. NO INDICATIONS
INTERPRETED AS CRACKS ALLOWED
- 2 DIA A & F MUST BE SQ WITH SURF. D WITHIN .005 F.I.R.
- 1 DIA'S A, B & E MUST BE CONC WITH DIA C WITHIN .005 F.I.R.

Figure 88. Diaphragm Assembly, Stressed Diaphragm Pressure Transducer.
(Drawing No. 142B1738 Rev. C)



REVISIONS			
SYM	DESCRIPTION	DATE	APPROVED
A	WAS .38 ~ .36	8-22-64	J. J. Pitt
B	TITLE WAS "HOUSING" CNOO 32	8-31-64	D. G. R. [Signature]
C	1) ADDED PART 2 2) NOTE 4 WAS FLUORESCENT PENETRANT INSPECT PER AMS 2645 PER C/N 0113	2-2-65	D. G. R. [Signature]

- [C-2] 4 DYE PENETRANT INSPECT PER AMS 2646
NO DEFECTS INTERPRETED AS CRACKS ALLOWED
3. DIA. A TO BE SQUARE WITH SURFACES R AND S WITHIN .002 FULL INDICATOR READING
2. DIA. A, B & C TO BE CONCENTRIC WITHIN .002 FULL INDICATOR READING
1. MAT'L TIII PER SPPS SPEC 51

Figure 89. Housing, Stressed Diaphragm Pressure Transducer.
(Drawing No. 142B1739 Rev. C)

REVISIONS			
SYM	ZONE	DESCRIPTION	DATE APPROVED
A	D-4	WAS 1.40 ~ 1.38	4-20-60 J. D. H.
B	B-3	(1) NOTE 4 WAS FLUORESCENT PENETRANT INSPECT PER AMS 2645 PER C/N 0113	2-2-65 J. D. H. D. G. H.

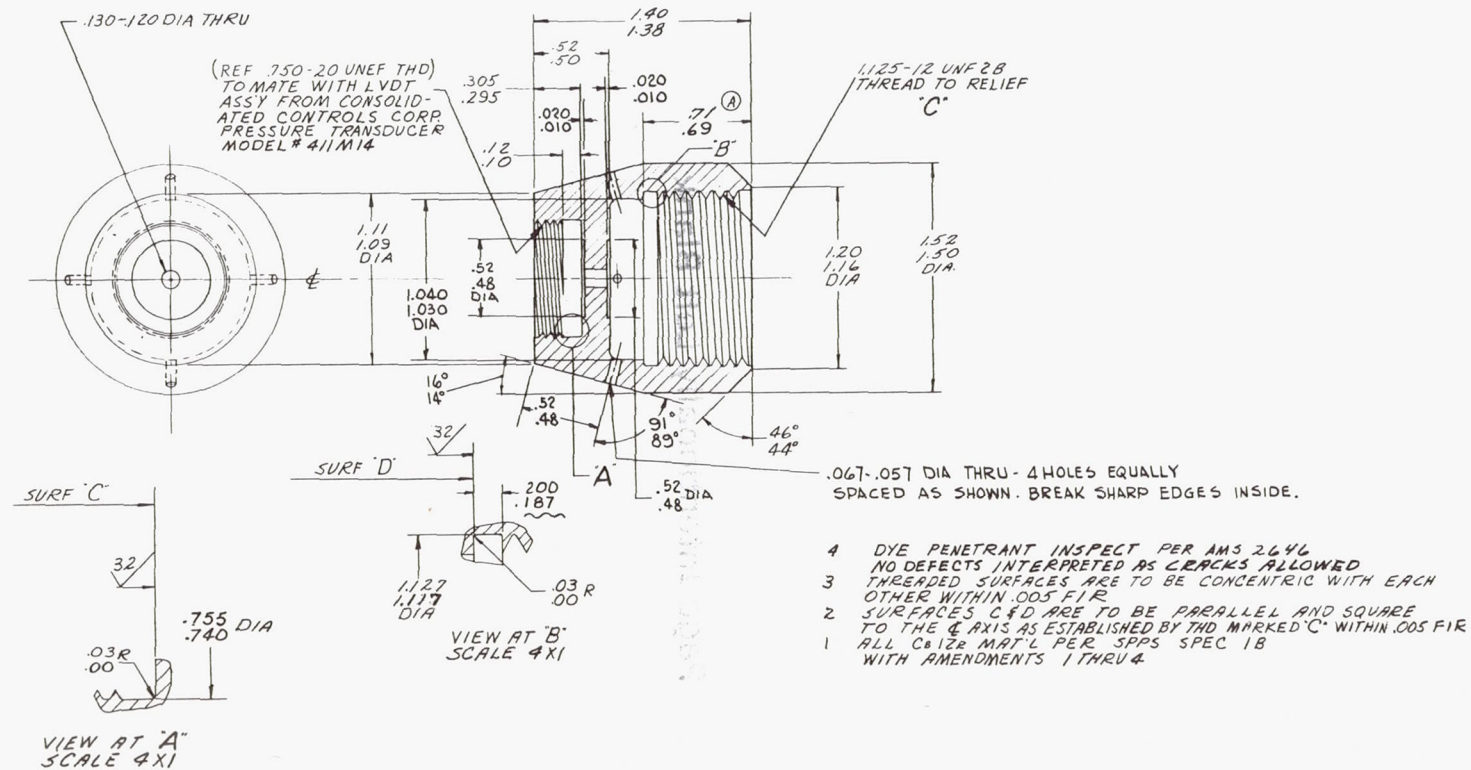
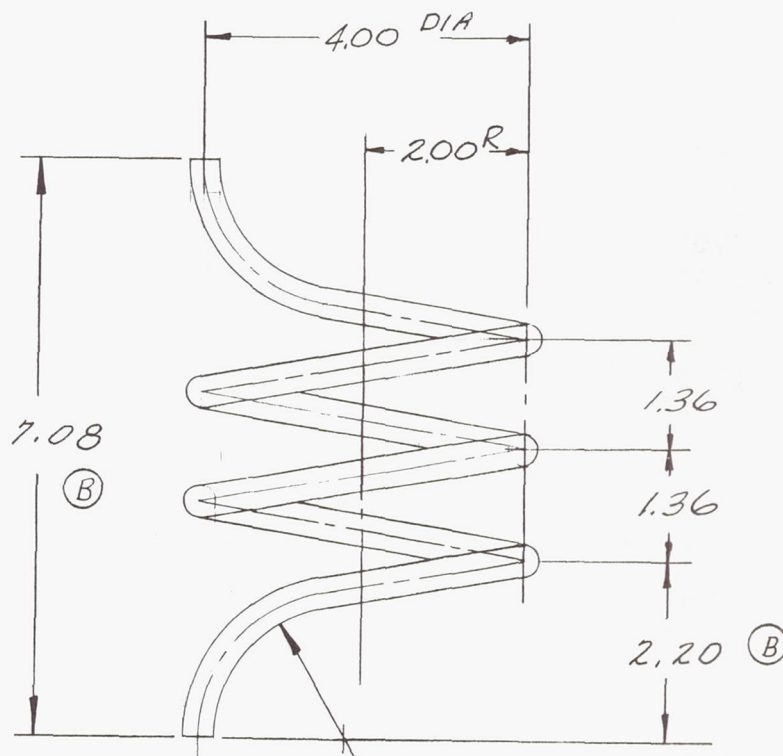


Figure 90. Retainer Cap, Stressed Diaphragm Pressure Transducer.
(Drawing No. 119C2836 Rev. B)

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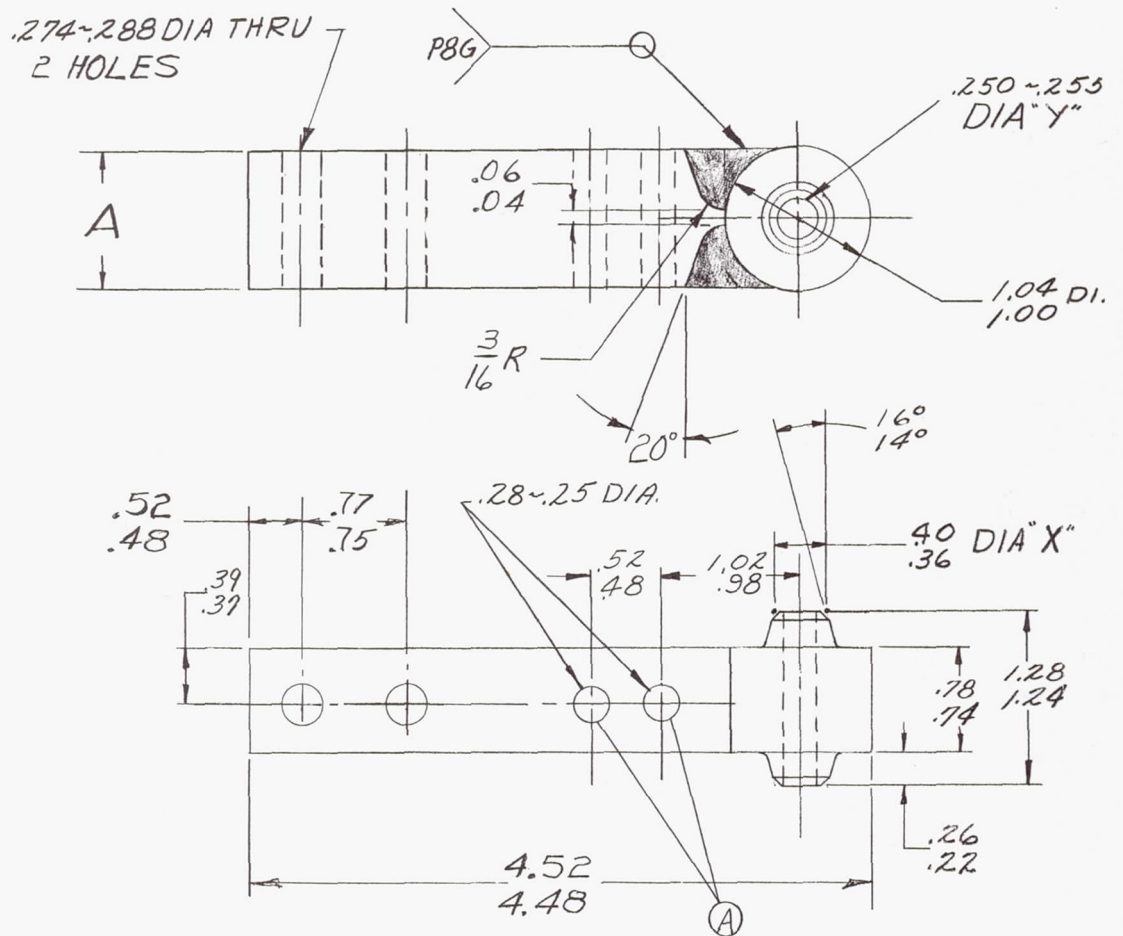
1 TUBE - RH COIL
 .375 O.D. X .065 WALL
 MAT'L - CB-12R

2 TUBE - LH COIL
 .375 O.D. X .065 WALL
 MAT'L - CB-12R

CONTOUR OF TUBE TO BE WITHIN .06 OF
 DEFINED TRUE SHAPE
 ALL SEAMLESS TUBING PER SPPS SPEC 2 B
 BAG OR TAG WITH PART IDENT. NO. & SERIAL NO.

REVISIONS			
SYM	DESCRIPTION	DATE	APPROVED
A	ALTERED TUBE SHAPE		
B	WAS 6.28 - ADDED 2.20	4-16-64	B. Rott

Figure 91. Heater Coil. (Drawing No. SK56131-802 Rev. B)



PART NUMBER	A
1	1.00~1.04
2	.50~.52

Figure 92. Heater

REVISIONS			
SYM	DESCRIPTION	DATE	APPROVED
A	ADDED TWO HOLES	4-7-68	B. Ruff

.255 DIA THRU
"Y"

4 DIA.
O

1. ALL CB-12R MACHINED PARTS TO BE ULTRA-SONIC OR X-RAY AND THE EXTERNAL SURFACES WILL BE PENETRANT INSPECTED PER SPPS SPEC 1B ~ AMEND 1-4
2. ALL BAR STOCK PER SPPS SPEC 1B WITH AMEND 1-4
3. WELD METHOD FOR CB-12R - INERT GAS TUNGSTEN ARC PER SPPS SPEC 3C
4. CLEAN CB-12R PER SPPS SPEC 11A
5. DIA'S "X" AND "Y" ARE TO BE CONCENTRIC WITHIN .010 FIR
6. WELDING WIRE PER SPPS SPEC 1B WITH AMEND 1-4
7. BAG OR TAG WITH PART IDENT. NO & SERIAL NO.
8. GRIT BLAST FOR HIGH EMITTANCE PER SPPS SPEC 12

Electrode. (Drawing No. SK56131-801 Rev. A)

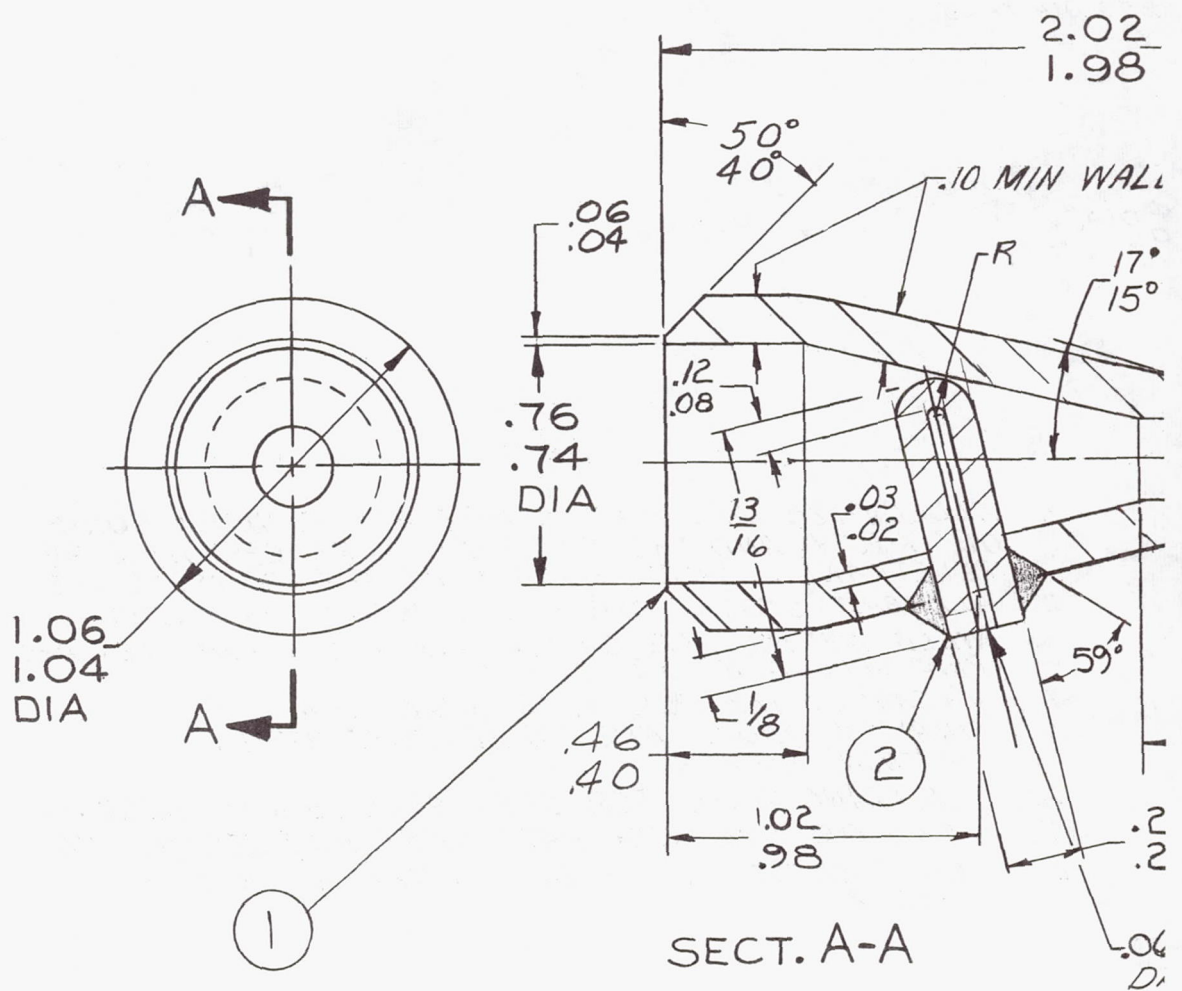
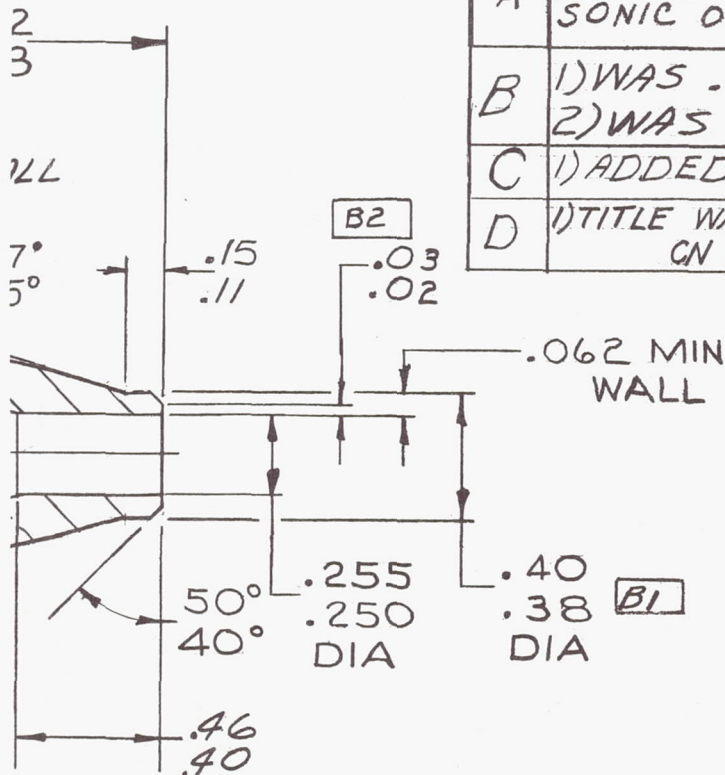


Figure 93. Reducer, EM Pump Inlet.

REVISIONS			
SYM	DESCRIPTION	DATE	APPROVED
A	NOTE 2 ~ ADDED AMEND. 1-4 NOTE 3 ~ ADDED ULTRA-SONIC OR X-RAY INSPECTION	1-2-64	b Patti
B	1) WAS .56-60 DIA 2) WAS .04-.06	1-31-64 1-31-64	<i>[Signature]</i> J.P. Patti
C	1) ADDED ITEM 2	3-2-64	<i>[Signature]</i> b Patti
D	1) TITLE WAS "REDUCER" CN 0032	8-28-64	<i>[Signature]</i> J.C. Patti



26 DIA
25

1/63 DIA
2R/LL

1. BAG OR TAG WITH PART NO. & SERIAL NO.
2. MAT'L CB-1Zr PER SPPS 1B AMEND. 1-4
3. ALL CB-1Zr MACHINED PARTS WILL BE ULTRA-SONIC OR X-RAY INSPECTED AND THE EXTERNAL SURFACES WILL BE PENETRANT INSPECTED PER SPPS SPEC-1B WITH AMEND. 1-4
4. WELD PER SPPS SPEC 3B
5. MASS SPECTROMETER LEAK TEST PER MIL-STD-271B

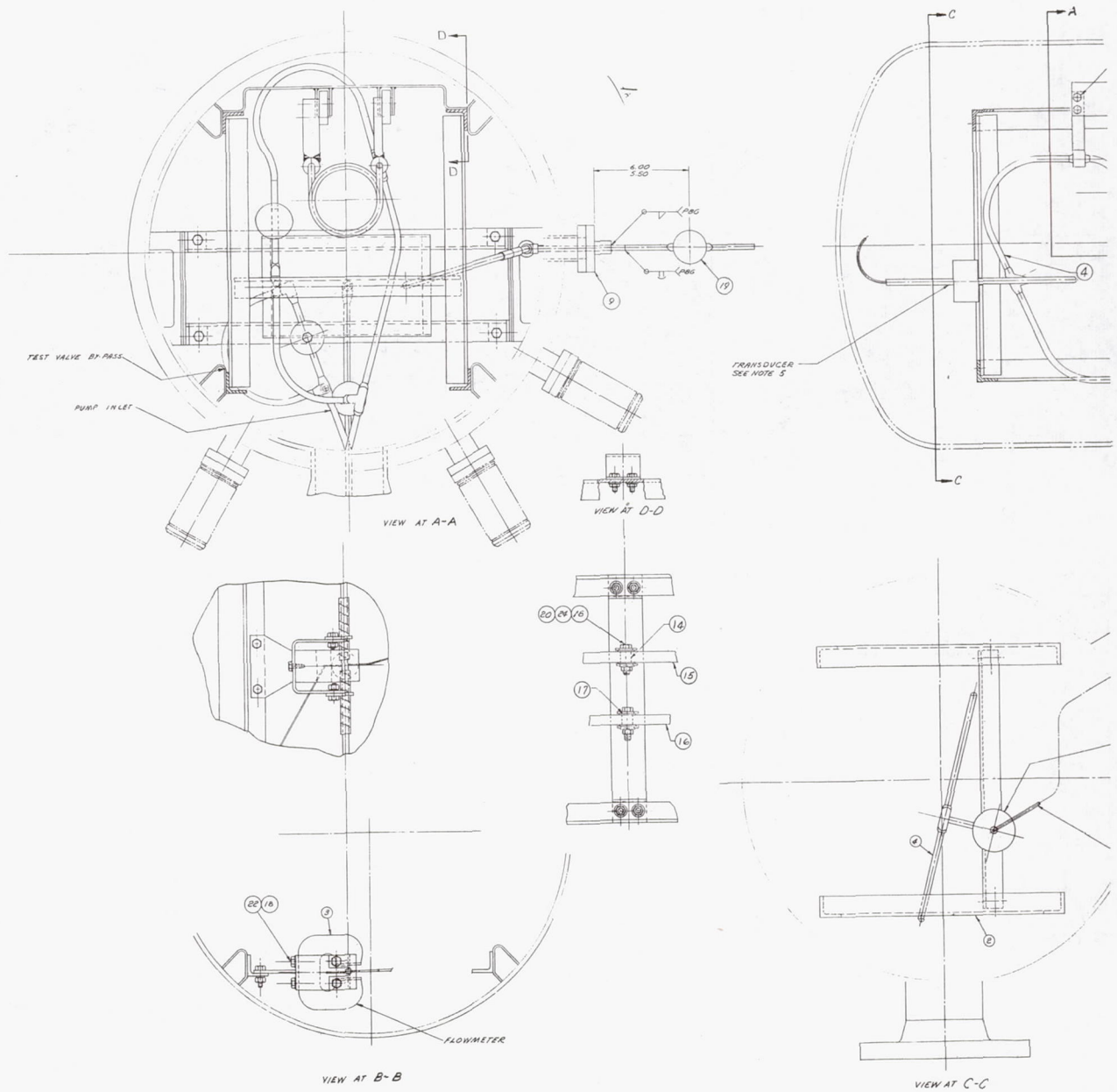
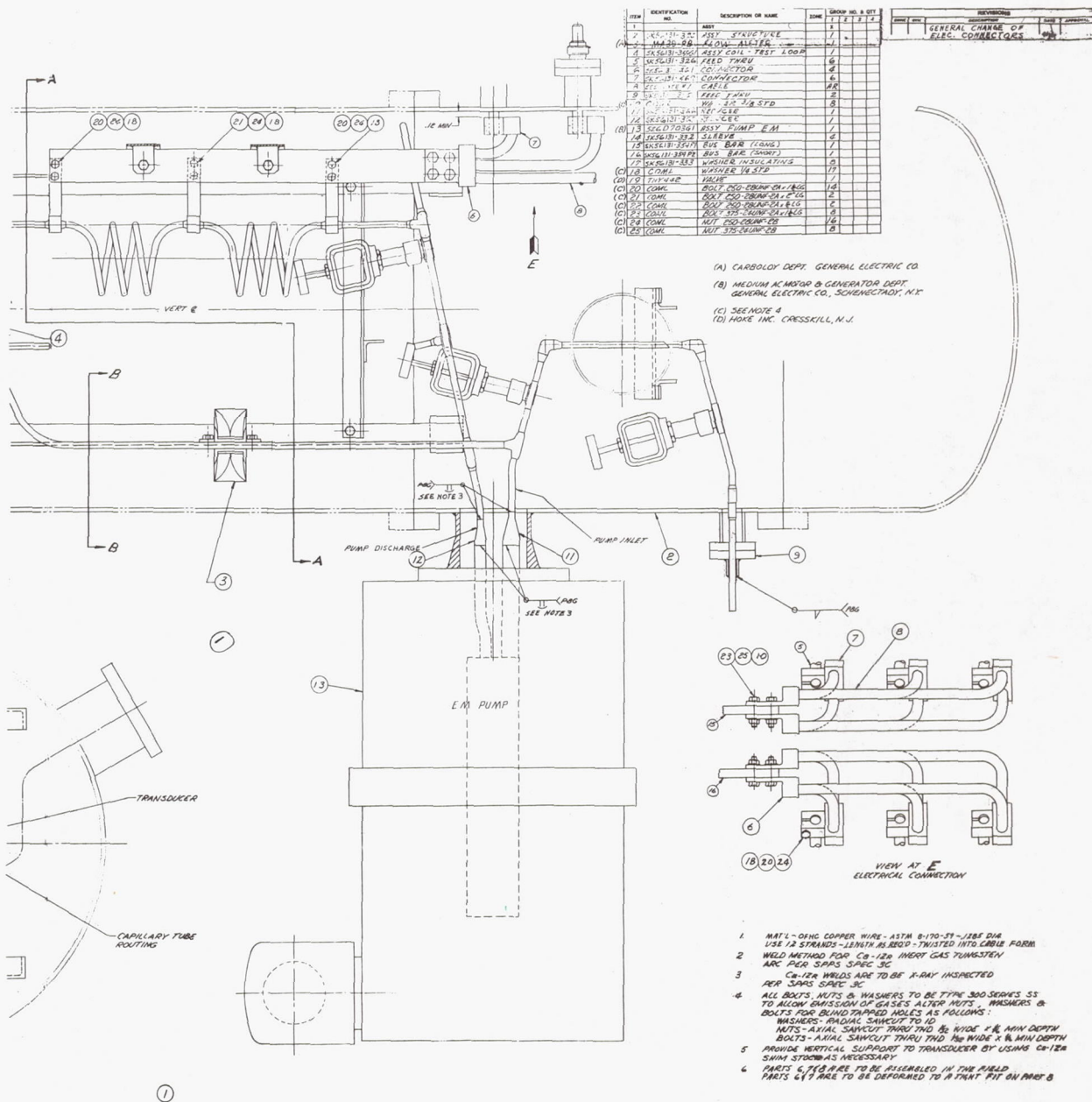
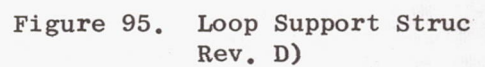
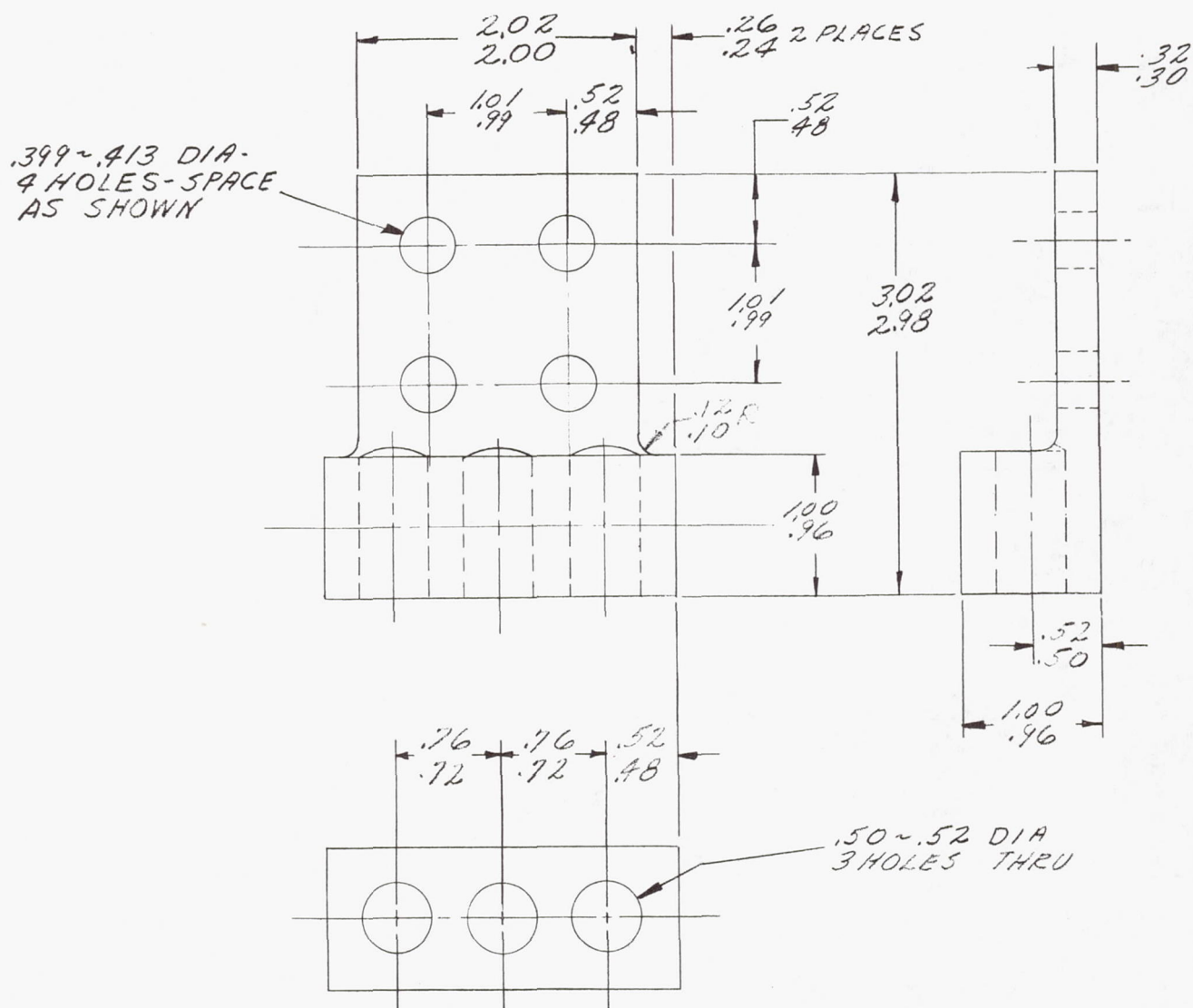


Figure 94. Heater Coil Installation.



(Drawing No. SK56131-368 Rev. A)





2. BAG OR TAG WITH PART IDENT. NO. & SERIAL NO.
1. CLEAN WITH ACETONE

Figure 96. Copper Cable Connector. (Drawing No. 142B1649)

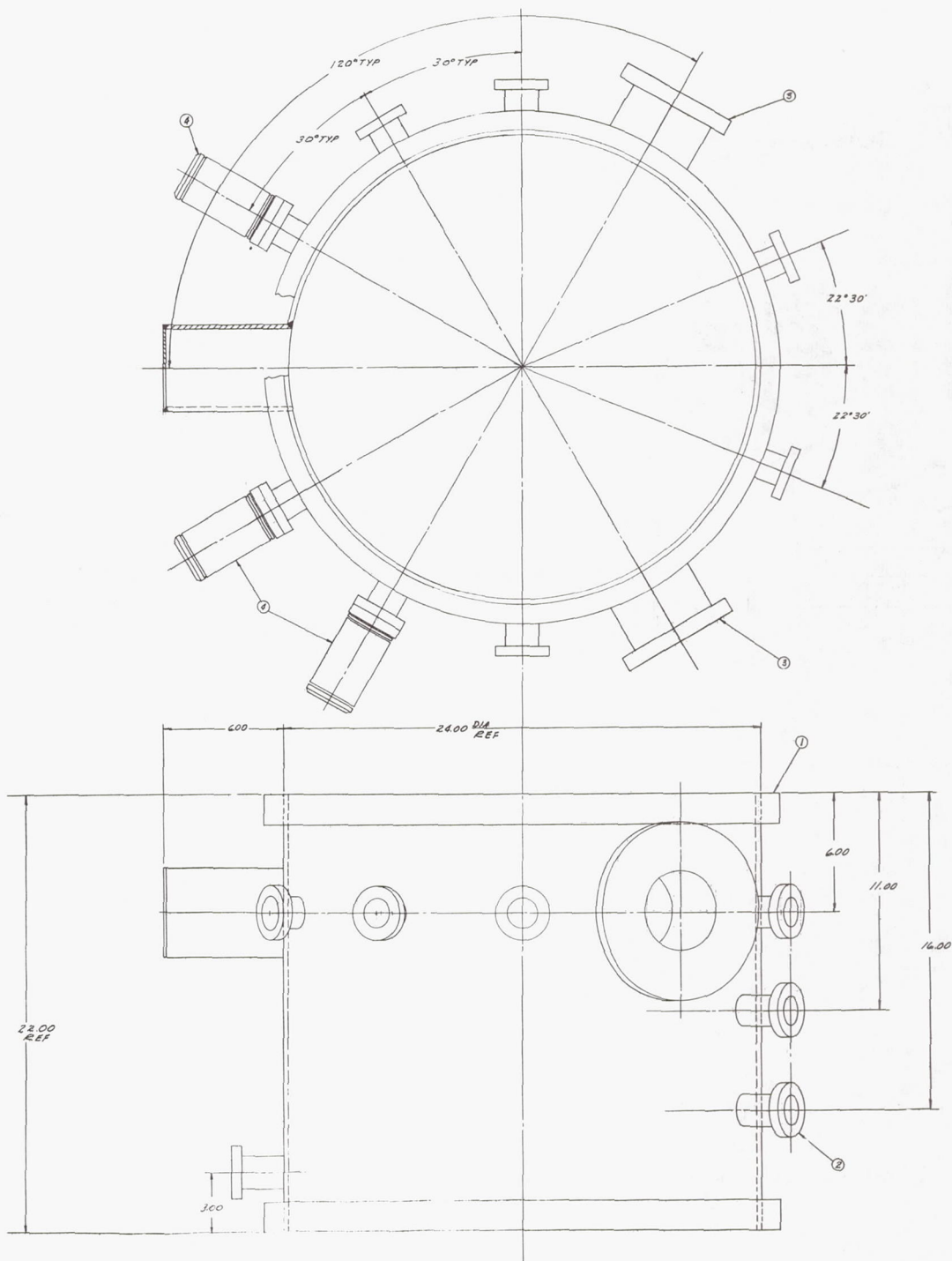


Figure 97. Vacuum Chamber Spool Section Assembly. (Drawing No. SK56131-337)

* RATING-
1000 AMPS
110 VOLTS

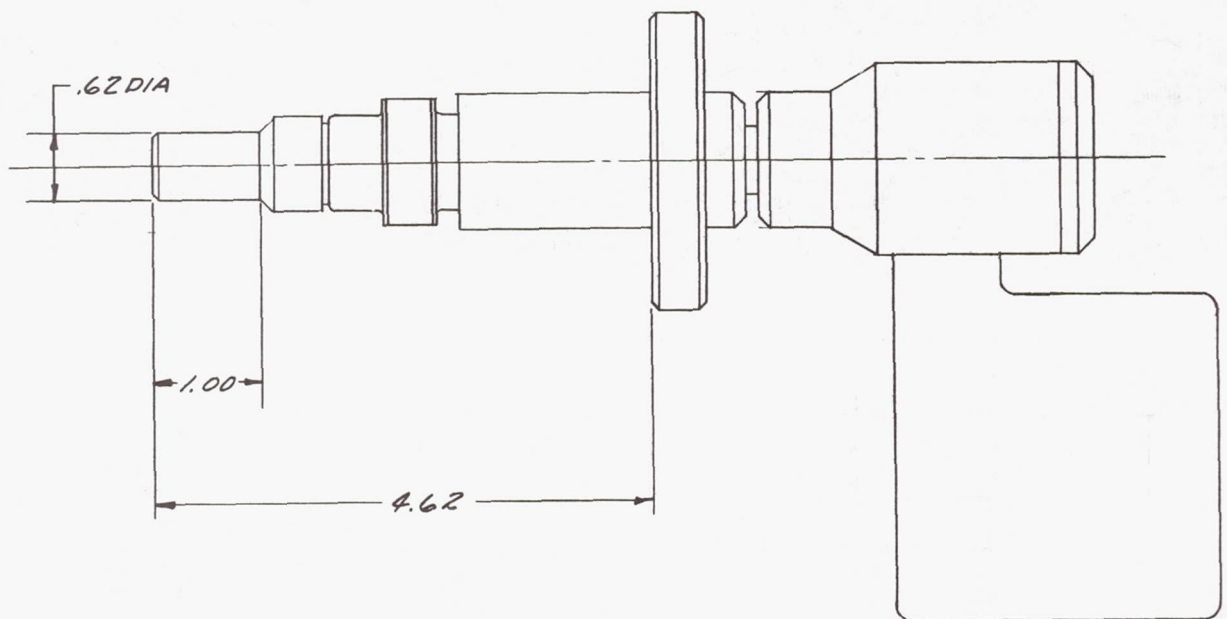


Figure 98. Electrical Feedthrough. (Drawing No. SK56131-326)

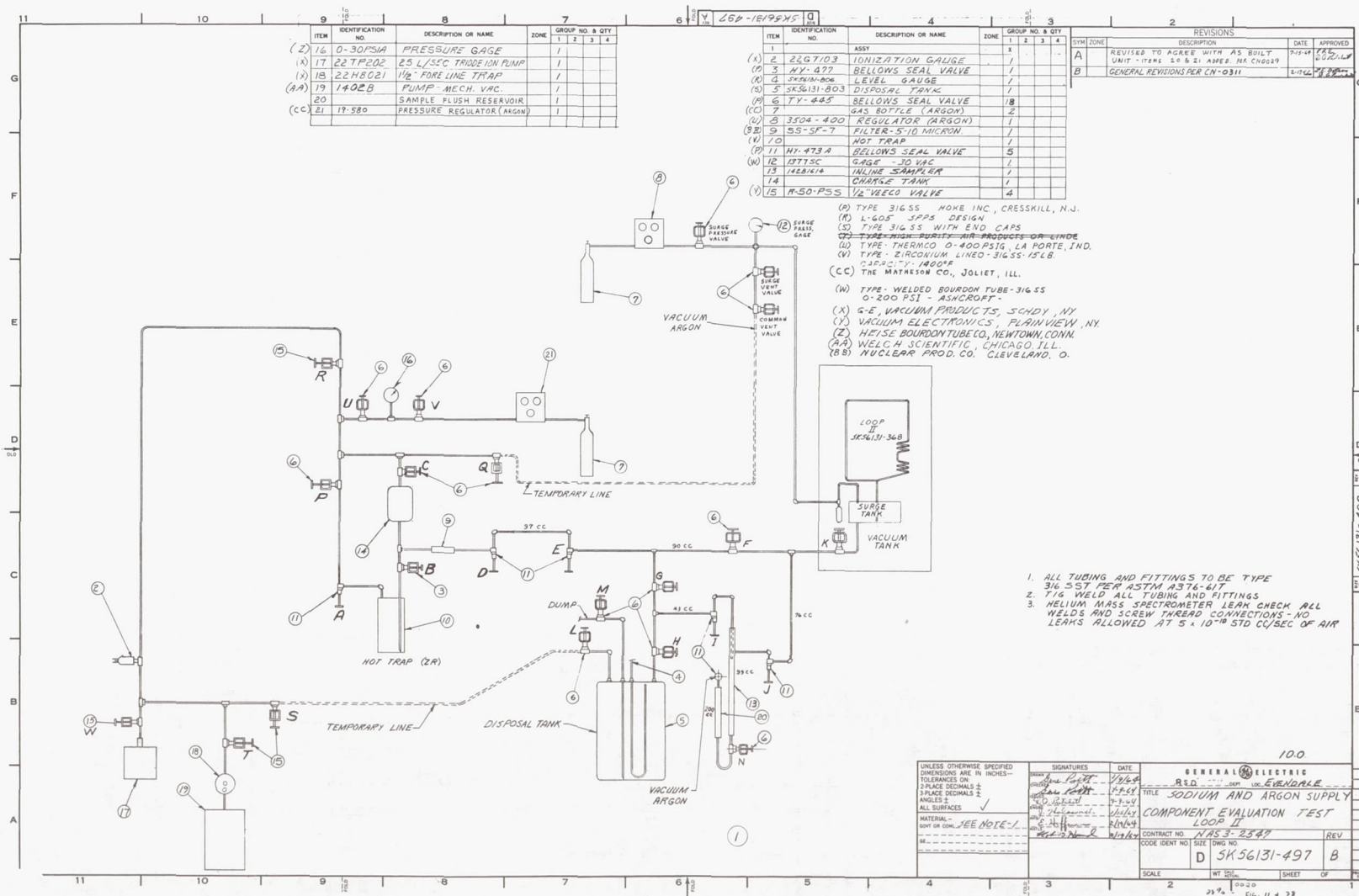
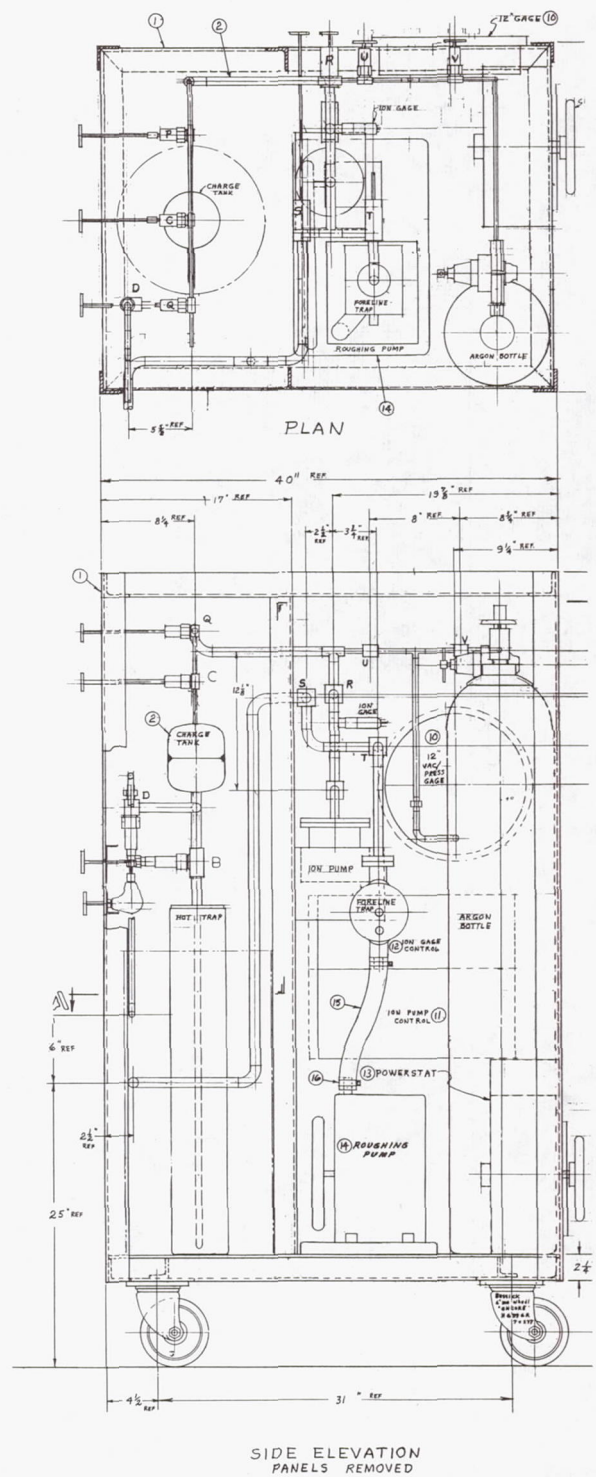
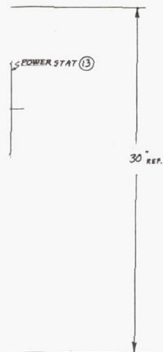


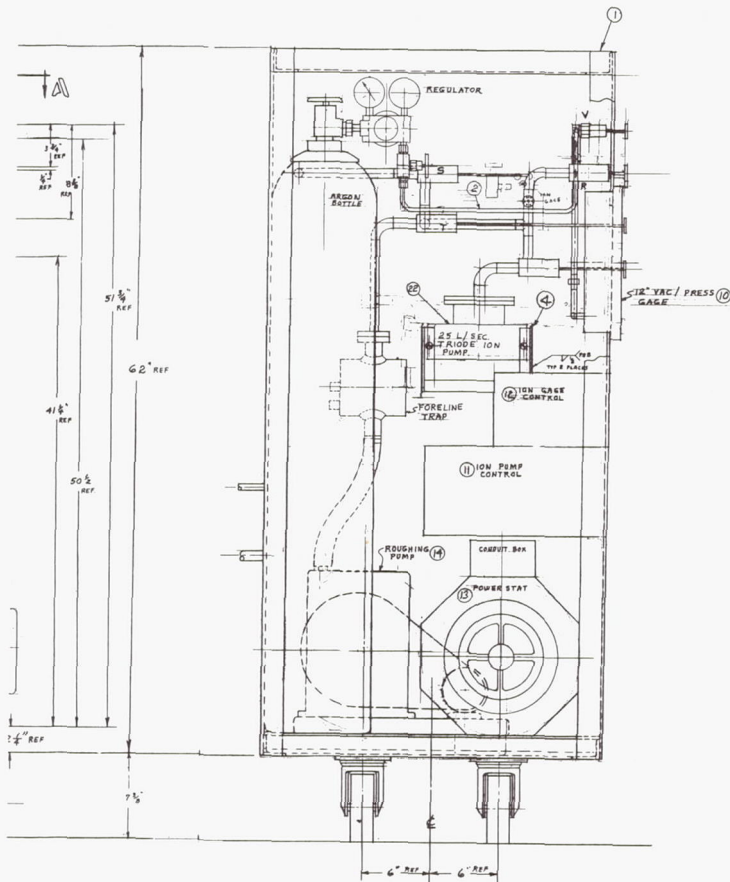
Figure 99. Sodium and Argon Supply. (Drawing No. SK56131-497 Rev. B)



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ITEM	IDENTIFICATION NO.	DESCRIPTION OR NAME	QTY	GROUP NO. & REV.	REVISIONS			
					REV.	DESCRIPTION	DATE	BY
1		ABST	1	1	A	TITLE CHANGE	D.O.P.	1-24-52 B.E.C.
2	246R806 G	DOLLY ASSEMBLY	1		B	ITEM 11 ADDED #22TC01	1-24-52	B.E.C.
3	223E517 G	PIPING ASSEMBLY	1			ITEM 12 ADDED #220C100	1-24-52	B.E.C.
4	119C 2717 G	BRACKET	1			ADDED ITEM 22	1-24-52	B.E.C.
5	(SEE NOTE 1)	HEATER TYPE OV CAT# OV-22	1					
6		BOLT 1/4" X 3" LG - HEI. 22	4					
7		NUT - HEI. 1/4" X 3"	4					
8		HEATER	2					
9	(SEE NOTE 2)	INSULATION - FIBERGLASS TYPE ESUF	AS REQD					
10	(SEE NOTE 3)	1/2" THICK WITH POL. BACKING						
11	(SEE NOTE 4)	G-ROSE - FLYER MOUNTED - SIZE 12	1					
12	(SEE NOTE 4)	ION PUMP CONTROL - RACK MOUNT	1					
13	(SEE NOTE 4)	ION GAGE CONTROL - RACK MOUNT	1					
14	(SEE NOTE 5)	POWERSTAT MODEL 1854 D	1					
15	(SEE NOTE 5)	25 AMP. 0-250 VOLT	1					
16	(SEE NOTE 5)	ROCKING PUMP # 1402	1					
17	(SEE NOTE 5)	VACUUM HOSE 1/4" ID.	AS REQD.					
18	(SEE NOTE 6)	CLAMP	2					
19	(SEE NOTE 6)	POWERSTAT TYPE 3P WIRL	1					
20	(SEE NOTE 7)	1/4" SO. DIA. RACK # 247	1					
21	" " "	" " " CHUCK RACK # 875	1					
22	" " "	" " " HARDY BEL. RACK # 005	2					
23	" " "	" " " OVER. RACK # 1201	2					
24	(SEE NOTE 8)	TRIODE ION PUMP # EETP02	1					

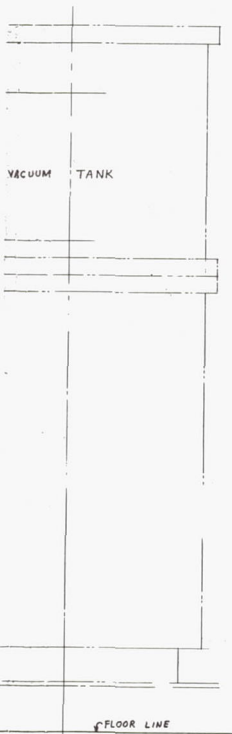


REAR VIEW
PANEL REMOVED

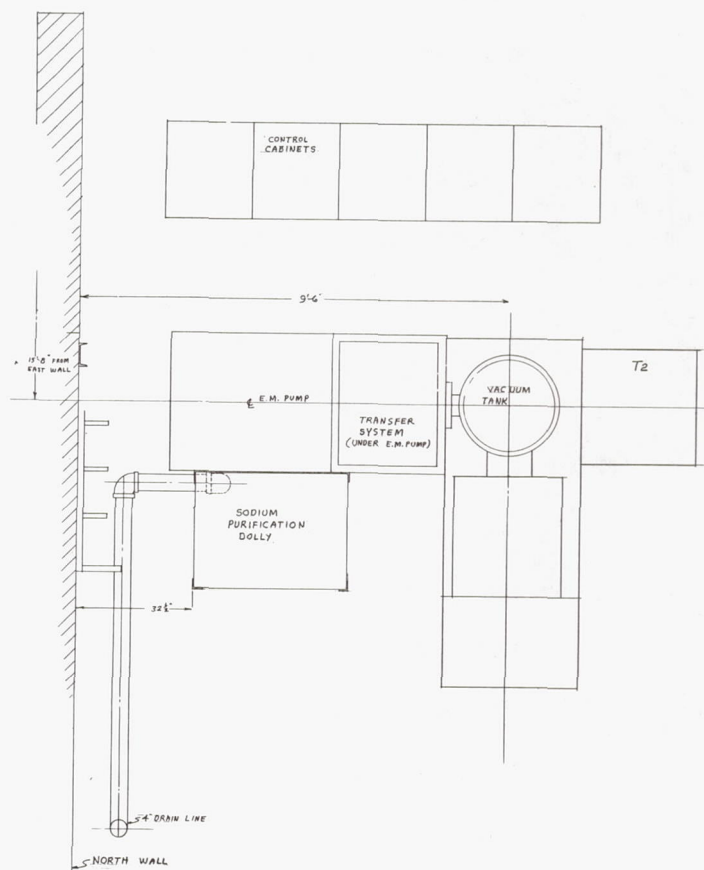
NOTES:

- 1- CHROMALOX HEATERS - EDWIN L. WIEGAND CO., PITTSBURG 8, PA. OR EQUAL
- 2- CARBORUNDUM CO. NIAGARA FALLS, N.Y. OR EQUAL
- 3- HEISE BURDON TUBE CO. INC., NEW TOWN, CONN., OR EQUAL
- 4- VACUUM PRODUCTS OPERATION, GENERAL ELECTRIC CO., SCENECTADY 5, N.Y.
- 5- WELSH CHICAGO ILL. OR EQUAL
- 6- SUPERIOR ELECTRIC CO. BRISTOL, CONN. OR EQUAL
- 7- GENERAL ELECTRIC SUPPLY CO. CINTI, OHIO

System. (Drawing No. 246R806 Rev. B)



ITEM	IDENTIFICATION NO.	DESCRIPTION OR NAME	ZONE	GROUP NO. 1				
				1	2	3	4	5
1		ASST						
2	246R805	LOOP II SODIUM TRANSFER SYSTEM						
3	246R806	LOOP II SODIUM PURIFICATION SYSTEM						
		SYSTEM						



LOCATION PLAN
LOOP II BLD. 314
CELL I

No. 246R807)

APPENDIX B

LOOP DESIGN

1. Nomenclature

Simple Latin Letter Symbols

<u>Symbol</u>	<u>Quantity</u>	<u>Unit</u>
A	Area	ft ²
C	Specific heat	BTU/lb _m -°F
D	Diameter	ft, inch
E	Electric potential	Volts
f	Fanning friction factor	Dimensionless
g	Conversion factor	lb _m /ft ² -sec
I	Electric current	Ampere
k	Thermal conductivity	BTU-ft/ft ² -hr-°F
L	Generalized length parameter, $l \sqrt{\frac{\alpha_E}{kt} \left(\frac{T_o}{1000} \right)^3}$	ft, inch
l	Length	ft, inch
N	Number of shields	Dimensionless
P	Power input	KW
Q	Rate of heat flow	BTU/sec, BTU/hr
S	Perimeter	ft, inch
T	Temperature	°F
t	Thickness	ft, inch
W	Mass flow rate	lb _m /sec
X	Distance	ft, inch
Z	Elevation	ft, inch

Composite Latin Letter Symbols

P_f	Frictional pressure	lb_f/ft^2 , psi
P_B	Buoyancy pressure	lb_f/ft^2 , psi
N_{Re}	Reynolds number DG/μ	Dimensionless
Q_{loss}	Net heat loss from electrode	BTU/sec, BTU/hr
Q_{net}	Net heat rejected from heater	BTU/sec, BTU/hr
Q_o	Heat rejected from uninsulated electrode	BTU/sec, BTU/hr
Q_{Rej}	Heat rejected from hot leg	BTU/sec, BTU/hr
T_{end}	Electrode end temperature	$^{\circ}\text{R}$
T_{in}	Sodium temperature at heater inlet	$^{\circ}\text{R}$
T_{Na}	Sodium temperature	$^{\circ}\text{R}$
T_o	Electrode base temperature	$^{\circ}\text{R}$
T_{out}	Sodium temperature at heater outlet	$^{\circ}\text{R}$
T_e	Surface temperature at length,	$^{\circ}\text{R}$
T_s	Surface temperature	$^{\circ}\text{R}$
T_s^*	Equivalent sink temperature of environment	$^{\circ}\text{R}$
T_w	Vacuum chamber wall temperature	$^{\circ}\text{R}$
T_x	Temperature at any distance X	$^{\circ}\text{R}$

Greek Letter Symbols

σ	Stefan-Boltzman constant	$0.173 \times 10^{-8} \text{ BTU/hr-ft}^2\text{R}^4$
ϵ	Total emissivity	Dimensionless
μ	Dynamic viscosity	$\text{lb}_m/\text{ft-sec}$
ρ_L	Average sodium density in cold leg	lb/ft^3
ρ_H	Average sodium density in hot leg	lb/ft^3
η	Fin Radiating Efficiency	Dimensionless

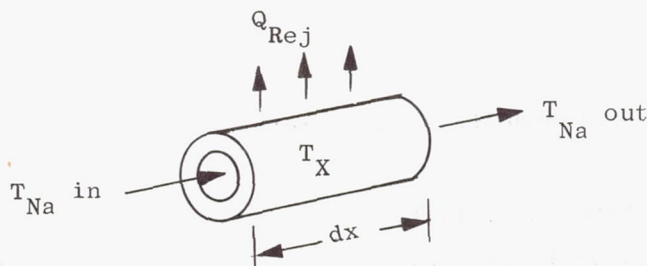
2. FLOW RATE AND TEMPERATURE DISTRIBUTION

A thermal analysis of the Cb-1Zr Pumped Sodium Loop was completed prior to the design of the loop to insure that the loop would meet its primary design objective which was to evaluate Cb-1Zr Rankine System Corrosion Test Loop components at their design operating conditions. These design conditions include liquid sodium operation in the 800°F to 2050°F temperature range for 10,000 hours in a 1×10^{-8} torr vacuum.

A schematic diagram of the loop is shown in Figure 102. The loop is fabricated from 0.375-inch OD Cb-1Zr tubing which is the tube size used extensively in the Rankine System Corrosion Test Loop in both the sodium and potassium circuits.

The sodium flow rate and power level of the loop is a function of the heat rejection capacity of the 0.375-inch diameter tube used for the cold leg which is limited in length by the available space in the 24-inch diameter vacuum chamber. The outer surface of the cold leg tube was grit blasted to raise the surface emittance from 0.2 to 0.5 to increase the heat rejection capability of the loop.

The sodium flow rate can be calculated by solving the equations relating the heat rejection rate of the cold leg and the heat balance in the system. The heat rejected by radiation from a small increment, dx , of the cooling leg is shown in the sketch below and is given by equation (1a).



$$Q_{\text{Rej}} = \sigma \epsilon A (T_S^4 - T_w^4) \quad (1a)$$

where:

T_s = temperature of tube wall

T_w = temperature of chamber wall

for $T_s^4 \gg T_w^4$

$$Q_{\text{Rej}} \approx \sigma \epsilon A T_s^4 \quad (1b)$$

Differentiating equation (1b), we find that the heat rejection rate for an incremental radiating area, dA , is equal to

$$dQ_{\text{Rej}} = \sigma \epsilon T_s^4 dA \quad (1c)$$

$$\text{For a tube, } dA = \pi D dx \quad (1d)$$

and substituting for dA in equation (1c), we obtain

$$dQ_{\text{Rej}} = \sigma \epsilon T_s^4 \pi D dx \quad (1e)$$

During steady state conditions, the heat rejected from the incremental area, dA , is also equal to the heat loss of the sodium in passing through the incremental length, dx .

$$dQ_{\text{Na}} = dQ_{\text{Rej}} = WC dT_{\text{Na}} \quad (1f)$$

Equating equations (1e) and (1f), we obtain

$$WC dT = \sigma \epsilon T_s^4 \pi D dx \quad (1g)$$

which can be rearranged to

$$\frac{dT}{T_s^4} = \frac{\pi \sigma \epsilon D}{WC} dx \quad (1h)$$

Upon integrating the equation (1h), we obtain

$$\frac{1}{T^3} = \frac{3 \sigma \epsilon \pi D}{WC} x + \text{const} \quad (1i)$$

Upon evaluating equation (1i) between limits $x = 0$, $T = T_1$, $x = 0$, and $T = T_2$, $x = 1$, we obtain

$$\frac{1}{T_2^3} - \frac{1}{T_1^3} = \frac{3 \sigma \epsilon \pi D}{WC} \quad (1j)$$

where:

$$\begin{aligned}
 T_1 &= \text{temperature at } x = 0, 2510^\circ\text{R} \\
 T_2 &= \text{temperature at } x = 1, 2410^\circ\text{R} \\
 l &= \text{distance along cooling leg, ft} \\
 W &= \text{flow rate, lb/hr} \\
 D &= \text{OD of tube} = 0.0313 \text{ ft} \\
 C &= \text{specific heat of Na} = 0.324 \frac{\text{BTU}}{\text{lb}^\circ\text{F}} \text{ at } 2000^\circ\text{F} \text{ (average} \\
 &\quad \text{temperature assumed for heat rejection section)} \\
 \epsilon &= \text{total hemispherical emissivity} = 0.5 \text{ (grit blasted)}^{(20)} \\
 \sigma &= \text{Stefan-Boltzman constant} = 0.481 \times 10^{-12} \frac{\text{BTU}}{\text{sec-ft}^2\text{-R}^4}
 \end{aligned}$$

Substituting the above values in equation (1j) we calculate the sodium flow rate as a function of the tube length, l , for an inlet temperature of 2510°R and an exit temperature of 2410°R . A plot of the flow rate and the heat rejection rate as a function of the tube length is shown in Figure 103. For an estimate design tube length of 55 inches the sodium flow is 440 lbs per hour and a heat rejection capability of 4.17 KW.

3. POWER REQUIREMENTS

Net Power Input - The net power input for the loop can now be computed on the basis of the calculated flow rate of 0.122 lb/sec (440 lbs/hr) and a temperature rise of 100°F .

$$\begin{aligned}
 Q_{\text{net}} &= W C \Delta T & (2a) \\
 Q_{\text{net}} &= 0.122 \frac{\text{lb}}{\text{sec}} \times 0.324 \frac{\text{BTU}}{\text{lb}^\circ\text{F}} \times 100^\circ\text{F} \\
 Q_{\text{net}} &= 3.96 \text{ BTU/sec} \\
 Q_{\text{net}} &= 4.17 \text{ KW}
 \end{aligned}$$

(20) Dotson, L. E., "Emittance Coating Studies on Cb-1Zr Alloy," General Electric Company Report, R61FPD571, March 15, 1962.

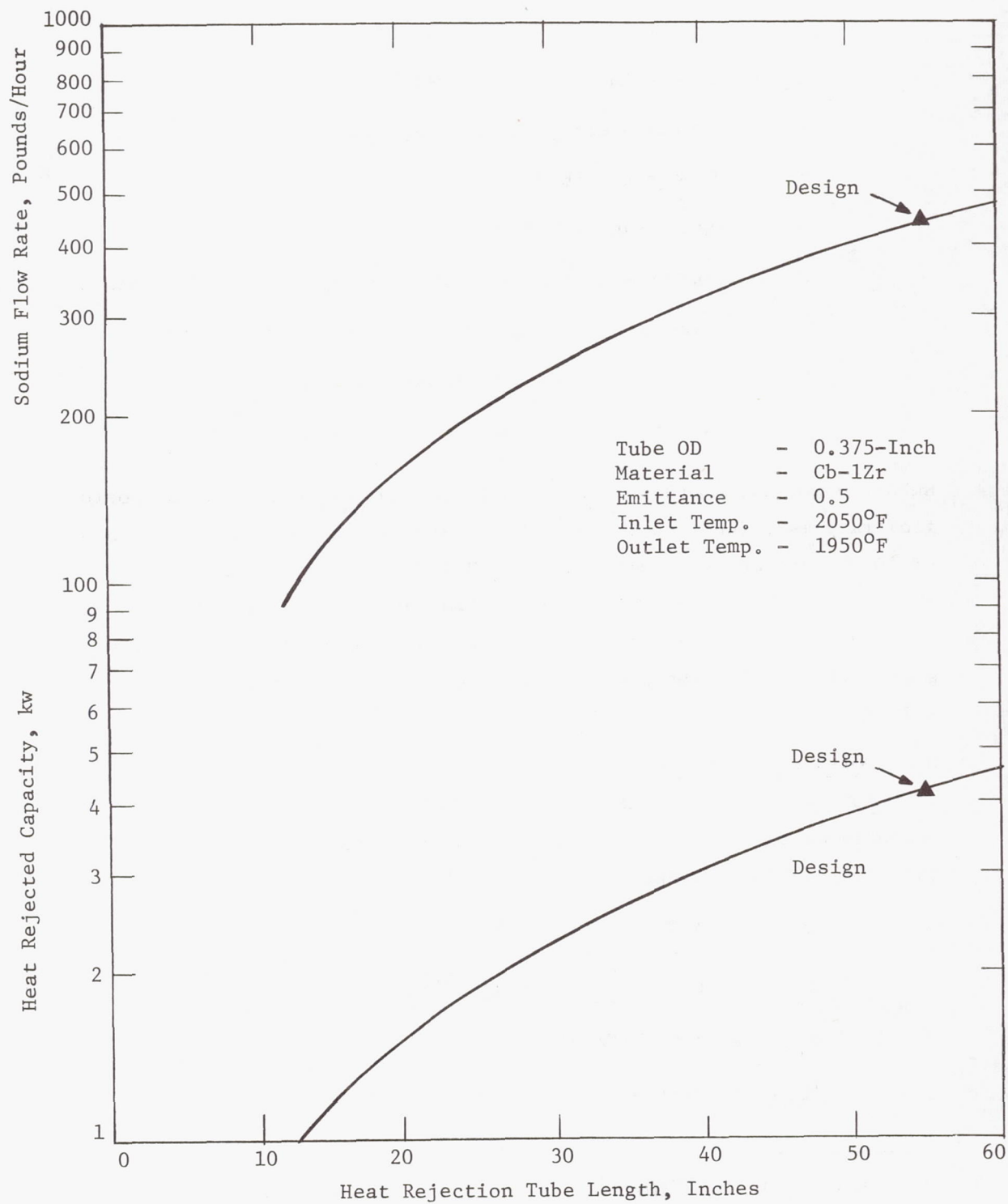


Figure 103. Calculated Radiation Heat Rejection Rate and Sodium Flow Rate as a Function of Tube Length for Cb-1Zr Pumped Sodium Loop.

In addition to the net heat input to the sodium, the heat losses from the heater and the electrodes must be added to give the gross electrical power input.

Heater Losses - The longitudinal temperature distribution in the heater for uniform power generation is a linear rise equal to

$$T_x = (T_{out} - T_{in}) \frac{x}{L} + T_{in} \quad (2b)$$

where:

L = total heater length, 73 inches

T_{out} = sodium temperature out, 2050°F

T_{in} = sodium temperature in, 1950°F

$$T_x = \left(\frac{2050 - 1950}{73/12} \right) x + 1950^\circ\text{F}$$

or differentiating

$$dT = 16.4 \, dx \quad (2c)$$

The heat loss from the uninsulated or bare heater can be estimated by

$$dQ_o = \epsilon \sigma T_s^4 \pi D \, dx \quad (2d)$$

Substituting equation (2c) into equation (2d), we obtain

$$dQ_o = \epsilon \sigma T_s^4 \pi D \frac{dT_s}{16.4} \quad (2e)$$

Integrating (2d) and evaluating, we obtain

$$Q_o = \left[\frac{\sigma \epsilon D T_x^5}{16.4 \times 5} \right]_{2410^\circ\text{R}}^{2510^\circ\text{R}}$$

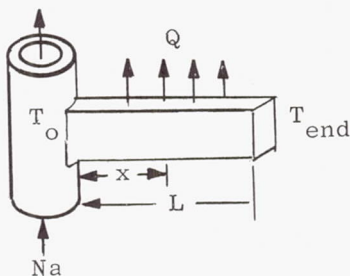
$$Q_o = 1.70 \text{ BTU/sec for } \epsilon = 0.2^{(20)} \text{ (polished Cb-lZr)}$$

The most effective type of insulation used in vacuum is a highly reflective, multiple shield assembly. For closely wound layers of dimpled foil with the same emittance as the heat source, the effectiveness of the assembly will be inversely proportional to one plus the number of shields.

Therefore, the heat loss for the heater with six layers of columbium foil will be:

$$\begin{aligned} Q_{\text{loss}} &= \frac{Q_o}{N+1} \\ Q_{\text{loss}} &\approx \frac{1.70}{6+1} \\ Q_{\text{loss}} &\approx 0.24 \text{ BTU/sec} \end{aligned} \tag{2f}$$

Electrode Temperature Distribution and Heat loss



Assuming the electrode acts as a finite fin with one dimensional heat conduction along the length; then for an element of length, dx , the change in the heat conducted along the fin can be expressed as

$$dQ_{\text{cond}} = \left[-k A \left(\frac{dT}{dx} \right)^2 \right] dx \tag{3a}$$

where A = cross section area.

The heat rejected from the surface of the incremental length, dx , is

$$dQ_{\text{rad}} = \sigma \epsilon S (T_o^4 - T_s^4) dx \tag{3b}$$

where S = circumference of electrode

Equating (3a) and (3b), we obtain

$$k A \left(\frac{dT}{dx} \right)^2 dx = \sigma \epsilon S (T_s^4 - T_w^4) dx \tag{3c}$$

or

$$\frac{d^2T}{dx^2} = \frac{\sigma \epsilon S}{k A} (T_s^4 - T_w^4) \tag{3d}$$

Equation (3d) is the same equation that is solved by Lieblein⁽²¹⁾ with $\frac{\epsilon S}{A}$ instead of $\frac{\epsilon}{t}$ for the generalized length parameter

$$L = 1 \sqrt{\frac{\sigma \epsilon}{kt} (10^9) \left(\frac{T_o}{1000} \right)^3}$$

Using equation (3d) and Figures 104 and 105, the following end temperatures and heat losses were calculated for the electrodes:

Electrode	T_o	T_{end}	L	η	Q Loss
Top 3/4" x 1/2" x 5" LG	2050°F	940°F	2.42	0.25	0.20 BTU/sec
Center 3/4" x 1" x 5" LG	2000°F	1030°F	1.96	0.30	0.32 BTU/sec
Bottom 3/4" x 1/2" x 5" LG	1950°F	930°F	2.28	0.27	0.19 BTU/sec

Total Power Input Required - The total thermal input to the loop heater may be determined by summation of the net heat input to the sodium and the heat loss from the electrodes and the heater.

Heater input to sodium	3.99 BTU/sec
Heat loss from electrodes	0.71 BTU/sec
Heat loss from heater	<u>0.23 BTU/sec</u>
Total Power	4.93 BTU/sec
Total Power	5.15 KW

4. ELECTRICAL CHARACTERISTICS OF THE I^2R HEATER

The heat input to the thermal convection loop is by electrical resistance heating of the hot leg of the loop. Heat generation occurs in both the tube and the sodium as a function of local temperature and geometry. The heater consists of two coils in series with a common center electrode and both ends grounded. The difference in the power generated between the upper and lower coil as a result of the difference in average electrical resistance which is a function of the temperature, will be neglected. It will be assumed that each coil dissipates one-half of the total power input.

(21) Lieblein, S., "Analysis of Temperature Distribution and Radiant Heat Transfer Along a Rectangular Fin of Constant Thickness," TND-196, NASA, November 1959.

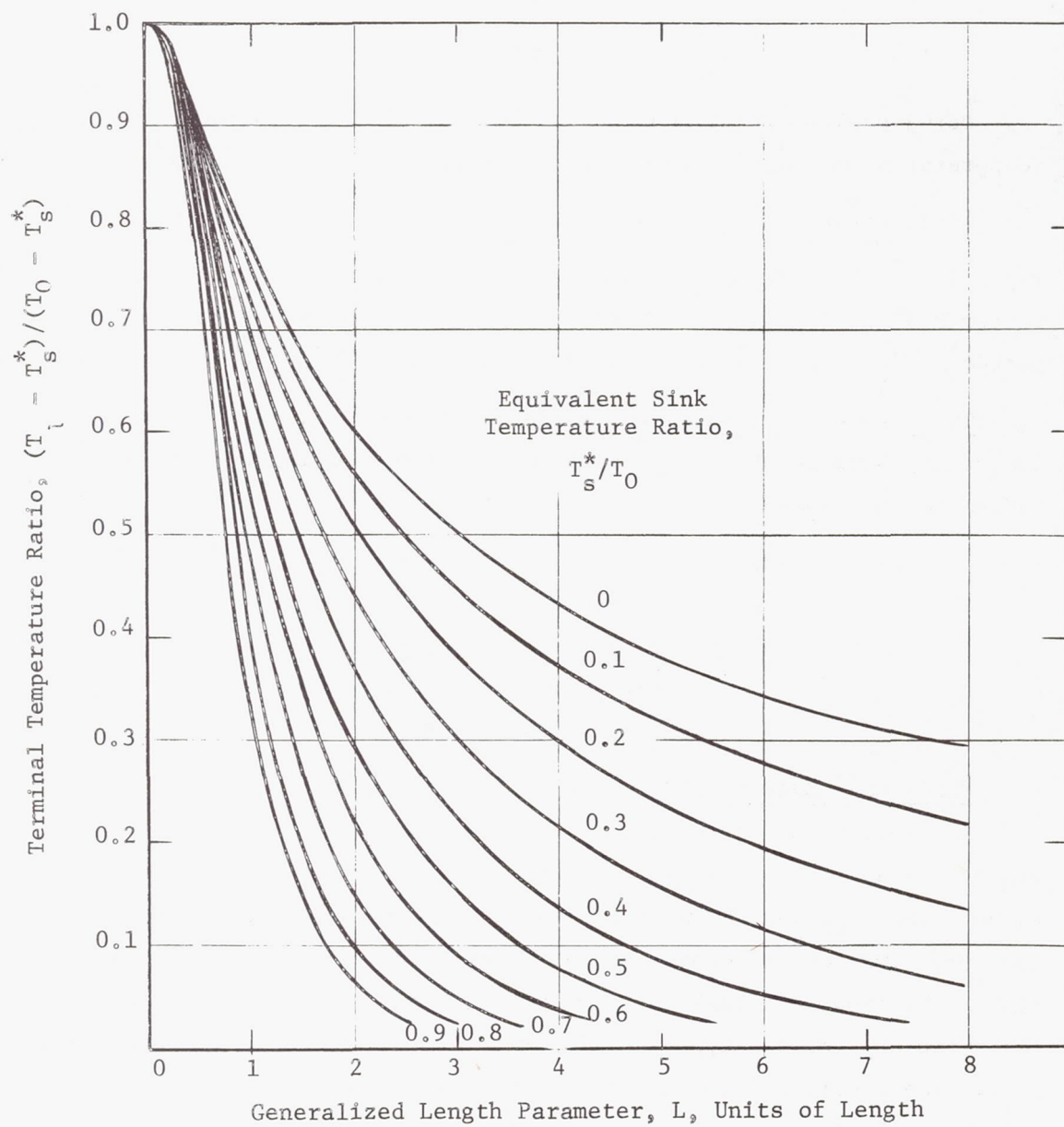


Figure 104. Variation of Terminal Temperature Ratio with Fin Plate Length.

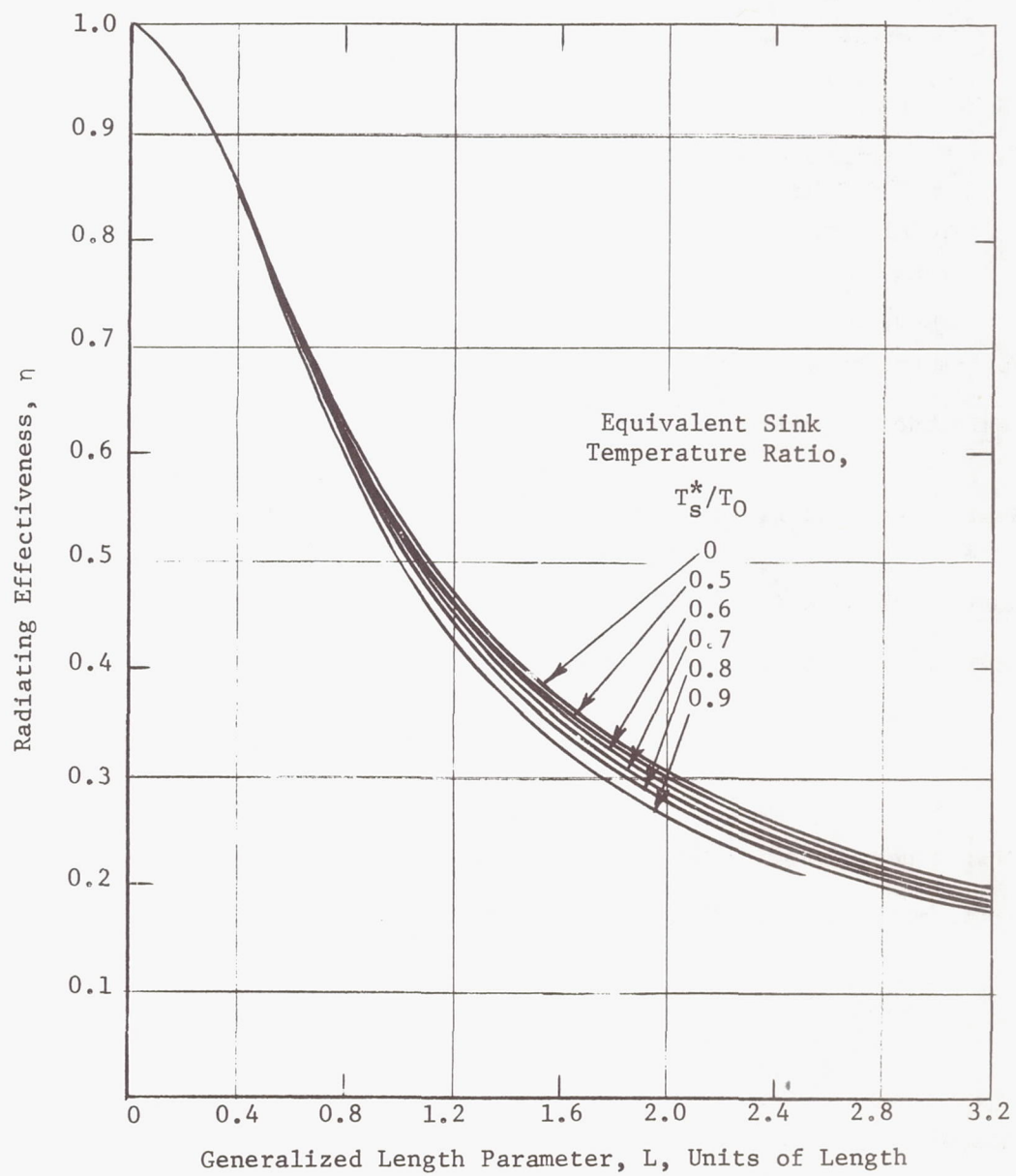


Figure 105. Variation of Radiating Effectiveness with Fin Plate Length.

Sodium heater

No. of coils	2
Material	Cb-1Zr
Electrical resistivity of Cb-1Zr	56×10^{-6} ohms-cm @ 2050°F
Electrical resistivity of sodium	74.8×10^{-6} ohms-cm @ 2050°F
Total length	73 inches
Tube ID	0.375 inch
Tube OD	0.245 inch

Resistance of one coil (tube only)

$$\text{Resistance of coil} = 1/2 \left(\frac{\rho L}{A} \right) \quad (4a)$$

$$\text{Resistance of coil} = 1/2 \left(\frac{56 \times 10^{-6} \times 73}{\frac{\pi}{4} (0.375^2 - 0.245^2) \times 2.54} \right)$$

Resistance of coil = 0.0126 ohms

$$\text{Resistance of sodium in one coil} = 1/2 \frac{\rho L}{A} \quad (4b)$$

$$= 1/2 \left(\frac{74.8 \times 10^{-6} \times 73}{\frac{\pi}{4} 0.245^2 \times 2.54} \right)$$

Resistance of sodium in one coil = 0.0229 ohms

$$\begin{aligned} \text{Total resistance of each coil} &= \frac{1}{\frac{1}{R_{\text{Na}}} + \frac{1}{R_{\text{Cb}}}} \quad (4c) \\ &= \frac{1}{\frac{1}{0.0229} + \frac{1}{0.0126}} = 0.00815 \text{ ohms} \end{aligned}$$

Assuming each coil will contribute 1/2 of the 5.15 kilowatts required, the current in each coil will be

$$I = \sqrt{\frac{P}{R}} \quad (4d)$$

$$I = \sqrt{\frac{2575 \text{ watts}}{0.00815 \text{ ohms}}}$$

$$I = 562 \text{ amps}$$

The voltage drop across each leg will be

$$\begin{aligned} E &= IR \\ E &= 562 \text{ amps} \times 0.00815 \text{ ohms} \\ E &= 4.57 \text{ volts} \end{aligned} \tag{4e}$$

The total input current to the heater will be

$$I_{\text{Tot}} = 2 I = 1124 \text{ amps} \tag{4f}$$

5. INTERNAL PRESSURE STRESS

The maximum pressure stress in the loop system is in the loop tubing.

$$S_H = \frac{P}{t} (r_i + 0.6 t) \tag{5a}$$

where

$$\begin{aligned} P &= \text{internal pressure, 150 psia} \\ D &= \text{inside tube diameter, 0.25 inch} \\ t &= \text{wall thickness, 0.065 inch} \\ r_i &= \text{inside tube radius, 0.122 inch} \\ S_H &= \frac{150}{0.065} [0.122 + 0.6(0.065)] \\ S_H &= 292 \text{ psi} \end{aligned}$$

The stress required to produce 1% creep in 10,000 hours at 2200°F is reported to be approximately 1500 psi. ⁽²²⁾

6. Cb-1Zr VALVE BELLOWS

The Cb-1Zr valve bellows used in the Cb-1Zr Pumped Sodium Loop were fabricated by Standard-Thomson to the following general specifications:

Material	Cb-1Zr
OD	0.520 Inch
ID	0.375 Inch
No. of Convolutions	28
Travel	0.125 Inch
Maximum Rated Internal Pressure	3,600 psi
Blank Thickness	0.0075 Inch

(22) Moss, Thomas A., "Materials Technology Presently Available for Advanced Rankine Systems," Nuclear Applications, Volume 3, No. 2, February 1967, p 74.

Operating Stress - The range of stress in the bellows during loop operation can be approximated by:

$$S_R = \frac{1.5 E T \Delta}{h 0.5 W^{1.5} N_d} + \frac{P_w^2}{2t} \quad (23)$$

where

- S_R = range of stress due to expansion and pressure, psi
- Δ = total movement range, extension or compression, inch
- E = Modulus of elasticity, psi
- W = bellows width, inch
- N_d = number of half corrugations
- P = internal pressure, psi
- D = mean bellows diameter

The equation for the stress range consists of two terms; the first term reflects the stress due to the bellows travel and the second term refers to the stress due to internal pressure. For a deflection of 0.100 inch at 150 psi internal pressure; the bellows stresses are approximately 80,000 psi for the deflection term and 11,700 psi due to the internal pressure. The stresses due to pressure should be kept within the 10,000 hour 1% creep value at the design temperature. Based on the 10,000-hour 1% creep value of Cb-1Zr, the maximum rated temperature of the valve bellows is 1500°F.

Spring Rate - The axial deflection of the Cb-1Zr bellows as a function of load was experimentally measured and is presented in Figure 106. The bellows spring rate at room temperature is 118 pounds per inch or 3300 lbs/inch per convolution. The force required to deflect the bellows 0.10-inch which is the normal travel range of the metering valve is 11.8 pounds compared to a calculated value of 14.6 pounds based on the equation:

$$F = \frac{4 E D t^3}{3 h 0.5 W^{2.5} N_d}$$

(23) Design of Piping Systems, p. 121, John Wiley & Sons, New York, 1956.

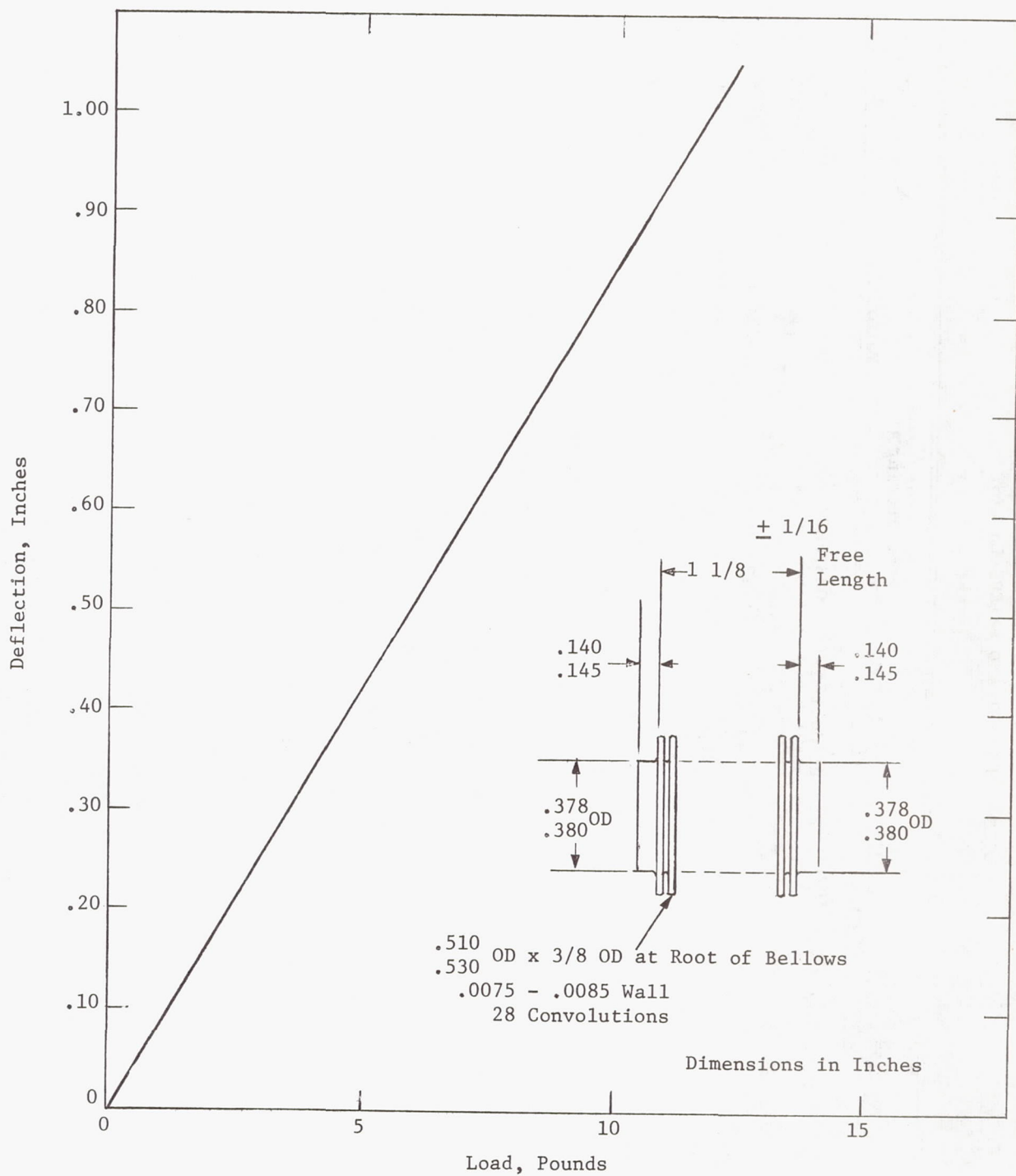


Figure 106. Deflection Versus Load for Cb-1Zr Valve Bellows for Cb-1Zr Sodium Pumped Loop. Bellows Formed by Standard Thomson.

APPENDIX C

LOOP COMPONENT AND MATERIALS LIST

<u>Component</u>	<u>Drawing No.</u>	<u>Part</u>	<u>Part Drawing No.</u>	<u>Material</u>	<u>Material Control No. (MCN-)</u>
Pump duct assembly	588C476, Rev. 5 ^(a)	Finned duct	923B838 ^(a)	Cb-1Zr tube	301
				Cb-1Zr bar	200
		Duct cap	149A2193	Cb-1Zr bar	200
		Duct pipe	149A2192	Cb-1Zr pipe	300
		Connector	149A2194	Cb-1Zr bar	413
		Discharge pipe	149A2195	Cb-1Zr tube	306
		Inlet pipe	149A2196	Cb-1Zr pipe	310
		Filler metal	(Spec. SPPS-3C)	Cb-1Zr wire	429,430
Slack diaphragm	SK56131, Rev. D	Diaphragm	14427A-P(a) ^(b)	Cb-1Zr foil	402
		Lower flange	14427A-P1(b)	Cb-1Zr bar	405
		Upper flange	14427A-P1(c)	Cb-1Zr bar	405
		Bimetallic tube	14427A-P2	316 SS tube	100
		Bimetallic tube	14427A-P3	Cb-1Zr tube	422
		Process tube	14427D	Cb-1Zr tube	404
Manual metering valve	SK56131-425, Rev. B	Tube nipple	442-32 ^(c)	Cb-1Zr tube	404
		Body	442-31	Cb-1Zr bar	425
		Metering plug	442-42-1	Mo-TZM bar	434
		Pin	442-30	Mo-TZM bar	433
		Bellows ring	473-6CB	Cb-1Zr	428
		Bellows stem	442-29	Cb-1Zr bar	422
		Bellows	473-20CB	Cb-1Zr tube	410
		Backup ring	442-45CB	Cb-1Zr bar	422
		Bellows sleeve	442-10CB	Cb-1Zr bar	422

<u>Component</u>	<u>Drawing No.</u>	<u>Part</u>	<u>Part Drawing No.</u>	<u>Material</u>	<u>Material Control No. (MCN-)</u>
Manual isolation valve	SK56131-238, Rev. B	All parts same as Manual metering valve except Isolation plug	442-43 ^(c)	Mo-TZM bar	434
Surge tank	SK56131-369, Rev. J	Tube	SK56131-369, P17	Cb-1Zr tube	437
		Fitting	SK56131-369, P18	Cb-1Zr bar	412
		Fill/drain valve	SK56131-238, Rev B	--	---
		Isolation valve	SK56131-238, Rev B	--	---
		Elbow	SK56131-369, P20	Cb-1Zr bar	412
		Tube	SK56131-369, P21	Cb-1Zr tube	437
		Tube	SK56131-369, P19	Cb-1Zr tube	404
		Surge tank	SK56131-369, P14	Cb-1Zr sheet	415
				Cb-1Zr plate	414
		Tube	SK56131-369, P31	Cb-1Zr tube	404
		Elbow	SK56131-369, P24	Cb-1Zr plate	416
		Tube	SK56131-369, P36A	Cb-1Zr tube	437
		Coil	SK56131-369, P3	Cb-1Zr tube	437
EM pump inlet reducer	SK56131-366, Rev. D	Reducer	SK56131-366, P1	Cb-1Zr bar	412
		Thermocouple well	SK56131-366, P2	Cb-1Zr bar	422
Bimetallic joint subassemblies	SK56131-369, Rev. J	Bimetallic tube	SK56131-369, P12A	316 SS tube	108
		Bimetallic tube	SK56131-369, P12B	Cb-1Zr bar	422
		Tube	SK56131-369, P5A	Cb-1Zr tube	405
		Tube	SK56131-369, P39	Cb-1Zr tube	404

<u>Component</u>	<u>Drawing No.</u>	<u>Part</u>	<u>Part Drawing No.</u>	<u>Material</u>	<u>Material Control No. (MCN-)</u>
Stressed diaphragm pressure transducer	119C2835	Reducer	119C2838, Rev. B	Cb-1Zr bar	423
		Retainer body	142B1737, Rev. D	Cb-1Zr bar	428
		Housing	142B1739, Rev. C	T-111 bar	449
		Housing cap	142B1740, Rev. B	Cb-1Zr bar	424
		Diaphragm	142B1738, Rev. C, P3	T-111 strip	450
		Probe mount	142B1739, Rev. C, P2	T-111 bar	448
		Magnetic probe assembly	(From Consolidated Controls Corp. Model No. 411M14- 300 Pressure Trans- ducer)	--	---
Heater coil subassembly	SK56131-369, Rev. J	Electrode	SK56131-801, P2	Cb-1Zr bar	423, 426
		Electrode	SK56131-801, P1	Cb-1Zr bar	423, 427
		Heater coil R.H.	SK56131-802, P1	Cb-1Zr tube	437
		Heater coil L.H.	SK56131-802, P2	Cb-1Zr tube	437
		Tubes	SK56131-369, P28 36, 8, 10, 34, 32, 6	Cb-1Zr tube	437
		Tee fittings	SK56131-369, P27, 33, 9	Cb-1Zr plate	416
		Metering valve	SK56131-425, Rev. B	--	---
		Cap	SK56131-369, P6	Cb-1Zr bar	422

<u>Component</u>	<u>Drawing No.</u>	<u>Part</u>	<u>Part Drawing No.</u>	<u>Material</u>	<u>Material Contr No. (MCN-)</u>
Final assembly	SK56131-369	Heater coil subassembly	SK56131-369, P6	--	---
		Surge tank subassembly	SK56131-369, P7	--	---
		Stressed diaphragm pressure trans- ducer	119C2835	--	---
		Pump duct subassembly	588C476	--	---
		Slack diaphragm pressure trans- ducer	SK56131-356	--	---
		Tubes	SK56131-369, P13, 15, 16, 23	316 SS tubes	452

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- (a) General Electric Company, Large Generator and Motor Department, Schenectady, New York.
- (b) Taylor Instrument Companies, Rochester, New York.
- (c) Hoke, Incorporated, Cresskill, New Jersey.

APPENDIX D

CALIBRATION OF THE PARTIAL PRESSURE ANALYZER

During the operation of the Cb-1Zr Pumped Sodium Loop, a General Electric Company Model 514 Partial Pressure Analyzer was used to monitor the composition of the residual gases in the vacuum chamber. The analyzer tube, control unit and scan recorder are described and illustrated in Section V, Test Equipment, in the body of this report. In order to obtain quantitative data, the analyzer was calibrated by admitting pure gases into the system through a variable leak valve and noting the partial pressure analyzer ion current for various chamber pressures, as indicated by the ionization gauge.

During the actual calibrations of the analyzer on the 24-inch diameter x 90-inch high vacuum chamber it was noted that following the introduction of a pure gas into the system there was an appreciable increase in the concentration of practically every residual gas in the system. This effect was most pronounced when the inert gases, argon and helium, were admitted. In one particular case, upon introducing argon into the system, the helium ion current was actually greater than the argon ion current. More typically, the ion current due to the gas admitted was about 75% of the total ion current when inert gases were admitted, and about 90% of the total for the more active gases, with considerable variation from these typical values. This effect is most probably due to evolution of previously pumped gases from the ion pump. Because of this effect, it was necessary in the data reduction procedure to first estimate the response of the analyzer to each of the residual gases in the system, and then to correct the ionization gauge reading for the presence of all species which had concentrations sufficient to affect the ion gauge indication.

Two separate calibrations of the partial pressure analyzer have been made. The first and more complete calibration was performed before the loop was assembled in the vacuum chamber. Base pressure for these tests

were about 2×10^{-10} torr and calibrations were made for the pure gases H_2 , He, N_2 , A, and CO_2 at pressures generally between 5×10^{-7} and 5×10^{-9} torr as indicated by the ion gauge.

The second calibration was performed after the loop had been installed in the chamber but before actual operation of the loop. The vacuum chamber and loop had been baked out for 200 hours and sodium was being circulated through the loop at approximately 800°F. This check was made to determine whether the response of the analyzer had changed due to actual instability of the analyzer system with time or to some other factor such as accidental movement of the analyzer tube relative to the magnet. For the second calibration base pressures of about 3×10^{-8} torr were obtained and calibrations were made for He and N_2 at pressures as high as 8×10^{-7} torr.

The results of these two calibrations are shown in Figure 107 where the ratio of the partial pressure analyzer ion current to the indicated ion gauge pressure is plotted against mass of the calibrating gas. As may be seen from Figure 107, there is relatively little mass discrimination in the analyzer system; that is, the response of the analyzer to high mass species is the same (within a factor of 2) as the response to the low masses. Apparently some small change in the response of the analyzer occurred between the two calibrations. The data from the second calibration were used to calculate the partial pressure during the Cb-1Zr Pumped Sodium Loop Test.

For a particular residual gas in the system, the data of Figure 107 may be used directly to obtain the indicated ion gauge pressure. In order to obtain the true partial pressure, one must divide the indicated ion gauge pressure by the relative response of the ion gauge. In Table XX are given the various factors necessary to convert the partial pressure analyzer ion current to either indicated pressure or to the true pressure. These factors were used in calculating the indicated and true pressure data presented in Section IX, Test Loop Operation, of this report.

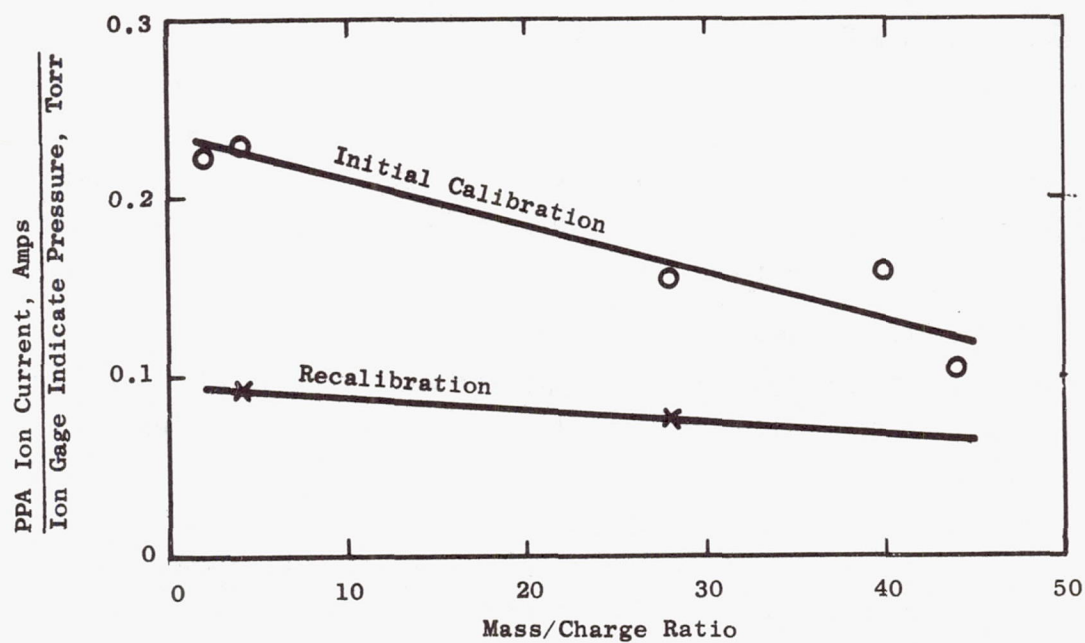


Figure 107. Calibration of Partial Pressure Analyzer.

TABLE XX

CONVERSION FACTORS OBTAINED FROM
RECALIBRATION OF THE PARTIAL PRESSURE ANALYZER

Gas	Mass	Ion Gauge Sens. Relative to N ₂	To Obtain Indicated Pressure	To Obtain True Pressure
			Multiply PPA Ion Current By	
H ₂	2	0.42	10.6	25.2
He	4	0.19	10.8	56.8
CH ₄	16	1.07	11.8	11.0
H ₂ O	18	0.89	12.1	13.6
N ₂ or CO	28	1.00	13.2	13.2
O ₂	32	0.85	13.7	16.1
Ar	40	1.56	14.7	9.4
CO ₂	44	1.37	15.4	11.2

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