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WR15 Microwave Calorimeter and Bolometer Unit

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WR15 Microwave Calorimeter and Bolometer Unit

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WR15

MICROWAVE CALORIMETER

AND

BOLOMETER UNIT

by

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ABSTRACT

A microwave calorimeter which serves as the National Bureau of Standards (NBS) standard for power measurements in the frequency range 50 to 75 GHz has been completed and evaluated recently. Included here are descriptions of the principal changes in the calorimeter and bolometer unit from the WR28 models which are of similar design. Also included are construction details, accessory equipment, operation procedure, and error analysis. An improved thermal isolating waveguide section and calorimeter flange are features of this calorimeter.

A careful error analysis permits the determination of the effective efficiency of a standard bolometer unit to estimated limits of systematic uncertainty of ± 0.23%. The estimated 3σ limit of random uncertainty is 0.05%.

Key words: Calorimeter; microwave; power; standard.

1. INTRODUCTION

The National Bureau of Standards (NBS) standards for microwave power consist of a series of calorimeters and standard bolometer units which evolved from a design by Macpherson and Kerns [1][1]. Refinements and modifications to the original design have been made by Engen [2]. The calorimeters are used to determine the effective efficiencies of bolometer units which are used as transfer standards. This paper describes the latest of the NBS calorimeters and bolometer units (fig. 1) which are designed for use in the frequency band 50 to 75 GHz (WR15).

Presented here is a description of the principal changes from earlier WR28 designs of the standard bolometer units and the calorimeters [3]; directions for construction, operating procedures, and an error analysis. The error analysis includes a correction for systematic errors, and an estimate of the total limits of uncertainty in the effective efficiencies of the standard bolometer units.

1.1. Changes in Electroformed Isolation Section

The principal difference of the WR15 calorimeter from the WR28 calorimeter is in the construction of the thin-walled waveguide thermal isolation section. This section of waveguide had previously been folded from one thousandth-inch thick copper but now is electroformed. It proved difficult to terminate the thin-walled section to provide a flange surface having the same loss as the flange of a precision

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[1] Figures in brackets indicate literature references.

section of waveguide. (Ideally the flange loss should be the same when the mount is calibrated in the calorimeter and when the mount is being used.) The electroformed section has several advantages--ease of making a flange surface similar to that of a precision section of waveguide; also the isolation section and flange microwave loss may be evaluated by a sliding short method [4]. The sliding short method provides better accuracy than the previously used fixed short method for evaluation of loss in the isolation section and flange.

1.2. Changes in Bolometer Units

There are two principal differences between the new WR15 bolometer units and the earlier WR28 units. The WR15 commercial block, which contains the thermistor matching structure and microwave bypass for the dc lead, proved to have an inadequate microwave bypass and required more lossy material around the dc lead in the unit than had been previously used. The other difference is that thermal barriers across the waveguide were not used in the WR15 units. Thermal barriers have been used in the units to keep thermal energy from the thermistor from leaving the unit. The justification for omitting the thermal barriers is given in the error analysis.

2. CONSTRUCTION

Details of the fabrication of calorimeter and bolometer unit parts are shown in figures 2, 3, 4, and 5, and a list of commercial products used is given in tables 1 and 2.

2.1. Directions for Assembly of the Calorimeter Lead-in

To start the assembly of the calorimeter lead-in, solder the seal flange to the short end of the J shaped waveguide, and face off the flange. Drill screw clearance holes and alignment holes using a drill jig. Put the conduit fittings in place and flare the conduit ends, (fig. 6). Pass the waveguide and the conduits through the holes in the two conduit spaces and the binding post block and solder on the underside. Solder the calorimeter unit flange; face it off and drill screw holes and alignment holes and tap the screw holes. Install the binding posts. Next pull the thermistor lead and the thermopile lead through the conduits. Attach the thermistor lead to the ungrounded binding post. Install the O rings, waveguide, and conduit seals. The seals are shown in figure 6, and the components are listed in table 3.

2.2. Directions for Assembly of the Calorimeter

Start the assembly of the calorimeter base by removing 1.5 inches (3.8 cm) of the aluminum mandrel from the base flange end of the electroformed waveguide using hot concentrated sodium hydroxide solution. Next, tin, then solder together the electroformed waveguide, calorimeter flange, base flange, and base using 60-40 tin lead solder. The solder must be kept off the thin section of the electroformed waveguide and the surfaces that fit against the spacers. Clean up any flux in this area. Position the spacers. The space between the electroformed waveguide and spacers must be totally filled with low viscosity epoxy resin. Epoxy resin is also used to bind the spacers to the base, calorimeter flange, and reference flange, and the stainless steel inserts in the calorimeter flange. After the epoxy resin has cured, remove the remainder of the mandrel using sodium hydroxide solution. Protect the spacer. Face off the base flange and drill screw and alignment holes using a drill jig. Drill the alignment holes in the calorimeter flange and grind it flat. Put in the trim wires and close the holes in reference ring and base using a pointed punch. Insert the thermopile insulation into the reference flange and calorimeter flange. Wind the thermopile form with 47 evenly spaced turns of constantan wire and secure the ends by looping the wire through the holes in the form. Mask the wires on the top of the form to prevent plating, and copper plate the exposed wire for 30 minutes using a current of 100 milliamperes. Remove the masking material and solder the jacks in place. Press the thermopile into place. Assemble the conduit to the base and add the legs and O-ring. Add the reference ring and connect the thermopile leads. Screw the hanger, calorimeter spacer, stud and cover together. The cover screws are used not only to hold the cover in place but also to remove it.

2.3. Directions for Assembly of the Bolometer Unit

Place the sleeve over the post on the commercial block and solder the dc lead to the post. Solder together the block flange, waveguide section, and unit flange. Face off both flanges, and drill screw and alignment holes, tap the screw holes, in the unit flange. Grind the unit flange flat. Assemble the unit binding post in the block flange. Secure the block to the block flange with screws. Lay the block dc lead in the groove in the block flange. Cut the dc lead to length and solder to the unit binding post. Cover the exposed joint with electrical grade room temperature cure silicon rubber. Fill the groove in the block flange with a mixture of powdered iron and low viscosity epoxy resin. Epoxy resin is also used to hold the cover plates in place. Conducting epoxy resin is used to calk the grooves in the block flange. The block and block flange are covered with aluminized polyester pressure-sensitive tape.

3. CALORIMETER OPERATION

The operation of the calorimeter requires a number of items of equipment. Figure 7 shows the waveguide components used to supply microwave power. The components are listed in table 4 and connections to the components are listed in table 5. The accessory equipment is shown in figure 8 and listed in table 6.

3.1. Measurement Sequence

The sequence followed in determining the effective efficiency of a bolometer unit is as follows:

(1) Install the unit in the calorimeter, and seal the calorimeter.

(2) Place the calorimeter in the water bath.

(3) Connect the appropriate calorimeter leads to the bolometer bridge, the microvolt potentiometer, and microwave WR15 waveguide line.

(4) Time is then allowed for the calorimeter to come to practical equilibrium with the water bath. Practical equilibrium occurs about one and one half hours after the calorimeter is placed in the bath. The need for practical equilibration after the calorimeter is placed in the water bath results from the lack of exact equality of the bolometer unit and thermal reference time constants, and from a difference in temperature between the calorimeter and water bath.

(5) The bolometer bridge is then turned on. If the practical equilibration time is known, the bolometer bridge may be switched on immediately after the calorimeter is placed in the bath, rather than waiting for the thermopile output to reach a low value (i.e. 0.002 μV). The klystron is turned on and locked on frequency. The microwave switch must be open to keep power from the calorimeter.

(6) An interval of about 40 minutes is required for thermal equilibrium between the unit and thermal reference after a change in the power level to the unit.

(7) After equilibration, the thermopile voltage and the voltage across the self-balancing bridge are noted.

(8) The microwave power is switched into the calorimeter, and its level adjusted to give a nominal V_2/V_1 ratio of 0.5. The microwave power stabilizer used has a stability of 10 ppm per hour.

(9) The thermopile voltage increases, with about 40 minutes required to re-establish thermal equilibrium.

(10) The voltage data are taken.

(11) The microwave power is switched off.

(12) The thermopile voltage decreases, with about 40 minutes required for equilibration.

(13) The voltage data are taken.

(14) The data are reduced. Usually there is a small drift (0.06%/Hr.) of the total bias power requirements of the bolometer due to long term drift in the bolometer, therefore the dc data are averaged. This drift does not represent a change in η_e, but only instability in the bolometer element itself.

(15) The calorimeter is taken from the water bath, dried off, the cover opened, and the unit removed.

4. ERROR ANALYSIS

The error analysis presented is similar to that in [3]; except that the flange loss and isolation section microwave loss measurements were made by the moving short method [4] rather than the fixed short method [3].

The equation used to calculate the effective efficiency (η_e) of the bolometer unit is

$$\eta_e = \frac{1 - (V_2/V_1)^2}{e_2[1 + b]/e_1 - (V_2/V_1)^2} \qquad (1)$$

where V is the voltage across the self-balancing bolometer bridge [5] and e is the thermopile voltage. The subscripts 1 and 2 denote respectively conditions of dc only, and dc plus microwave power, absorbed in the thermistor. The term (1 + b) is the correction for systematic errors in e_2, the thermopile voltage. The systematic errors and limits of systematic uncertainty affecting e_2 are listed in table 7.

It is necessary to convert from the values of systematic errors--power absorbed in unit walls, calorimeter flange, thermal isolation section, and by microwave leakage--which are in percentage of microwave power to percentage of e_2. The converting multiplier used is 0.765, which is the ratio of microwave power absorbed in the unit to the total power absorbed in the unit, $[0.75 + 0.75(1 - 0.926)]/[0.75 + 0.25 + 0.75(1 - 0.926)]$, where 0.75 is the microwave power in the thermistor, 0.25 is the dc power in the thermistor, and 0.926 is the effective efficiency. This conversion is necessary because the value of e_2 is a function of total power absorbed in the unit rather than a function of microwave power alone.

4.1. Nonproportionality of the Thermopile Voltage

This is a small error and it is assumed that it will be similar to the values reported in reference [3], which lists a systematic error of + 0.00012 and limits of systematic uncertainty of ± 0.01% of e_2 for the WR28 calorimeter.

4.2. Bolometer Unit Walls

The microwave power absorbed in the waveguide between the unit flange and the thermistor will have a greater effect on the value of e_2 than power absorbed in the thermistor.

The greatest effect is near the flange. This is due to the thermal resistance of the mount walls and the distributed radiative and convective thermal leakage from the unit. The thermopile sensitivity to dc power dissipated in a small temporary test heater located at the flange was determined to be greater than the thermopile sensitivity for dc power absorbed in the thermistor by 1.7% of the latter. The loss in the mount waveguide may be considered as being half way between the flange and thermistor, and the microwave power absorbed in the mount waveguide would thus have 0.85% too great an effect on the thermopile voltage. The loss in the waveguide is 1.5% of the microwave power absorbed in the mount and thermistor. Therefore, the contribution to b is - 0.0001, (0.015 × 0.0085 × 0.765) of e_2 with limits of systematic uncertainty of ± 0.01% of e_2.

4.3. Calorimeter Flange

A portion of the microwave power is absorbed in the waveguide joint consisting of the unit flange and mating calorimeter flange. If the joint loss is the same whether the unit is being calibrated or being used, the joint loss may be considered a part of the effective efficiency and not a systematic error. The measurements made to date do not indicate a significant difference between the calibration and use joint losses. The combined uncertainty for the two joint loss measurements is ± 0.1% of the incident power or ± 0.076% of e_2.

4.4. Thermal Isolation Section

A portion of the microwave power is absorbed in the waveguide lead to the bolometer unit. Only the loss from the center of the thermal isolating waveguide section to the calorimeter flange raises the value of e_2 and constitutes a systematic error [6]. The loss in this section was determined by a moving short method [4]. The loss for this 0.25 inch (0.635 cm) long section is 0.4% of the incident microwave power or 0.306% of e_2. The uncertainty in the length of the section is ± 0.005 inch (± 0.013 cm) and the uncertainty in the value of the loss measurement is ± 0.11% of the incident power. The sum of these uncertainties is ± 0.12% of the incident power or ± 0.092% of e_2.

4.5. Microvolt Potentiometer

The limits of systematic uncertainty for the ratio e_2/e_1 were calculated from calibration data for the microvolt potentiometer, which is used to null and display the e values. This limit is ± 0.0055% of e_2.

4.6. Environment Stability

The nonidentical twin geometry and lack of inner shell increases the demands on the temperature stability of the calorimeter environment. This increased thermal stability is well within the capability of the precision temperature-controlled water bath [7], [8] which has a stability during the measurement of ± 10μK. Based on the calorimeter thermopile output after changing the bath temperature by 1000μK, the change in the thermopile output due to a change of ± 10μK would be ± 0.0004% of a typical e_1 value, which is negligible.

4.7. Lead Thermal Isolation

Although the calorimeter is immersed in a temperature-controlled water bath, its leads extend into the room air. So changes in room temperature can effect the calorimeter through its leads. Measurements made on the WR28 calorimeter showed that the effect is small. A ± 1.5K change in room temperature would produce a calculated change of ± 0.00025% in e_2.

4.8. Error Due to the Bridge and Voltmeter

Analysis of the bridge errors as applied to the calorimeter measurement of η_e shows the errors to be one part per million or smaller and they are neglected.

The principal error in the determination of the dc power in the thermistor is due to errors in the voltmeter used to measure the voltage across the bridge. The worst case error in the ratio V_2/V_1 is 0.0066% of the ratio. To determine the resulting error in η_e, the partial derivative of η_e (equation 1) with respect to V_2/V_1 was taken. Substitution of typical values yielded an uncertainty in η_e of ± 0.0004% which is negligible.

4.9. The Bolometer Units

Any microwave power that leaks from the unit would constitute a systematic error because this leakage power would not be accounted for either in the effective efficiency or the reflected power from the unit. The commercial thermistor block which was used in assembling the bolometer unit had appreciable leakage around the dc lead. Consequently lossy material was placed in the unit around the dc lead to reduce the leakage. A measurement showed the leakage to be 0.01% of the incident power or 0.0076% of e_2, with uncertainty limits of ± 0.0076% of e_2.

Typically, there is some convected and radiated thermal energy transmitted out through the waveguide from the thermistor bead. This thermal energy is not measured by the thermopile, and if its magnitude changed with the addition of microwave energy the change would cause a systematic error. The dc resistance of the thermistor is maintained constant by the self-balancing bolometer bridge. But theoretically, the presence of microwave power can cause some change in the surface temperature distribution of the bead. In previously constructed NBS bolometer units the thermal leakage was confined inside the mount by thermal barriers placed across the waveguide. This eliminated the potential error.

Recent experimental evidence indicates that the change in thermal radiation from a thermistor when microwave power replaces 75% of the dc power in the thermistor is less than 1% of the power in the thermistor. The thermal power leaving the unit through the WR15 waveguide is 0.1% of the thermistor power; which would indicate a possible uncertainty of 0.001%, (0.1 × 0.01) which is negligible, and indicates that thermal barriers are not necessary.

4.10. Imprecision

An estimate of the imprecision in the effective efficiency measurement was made for the WR28 calorimeter [3], and is assumed to be similar for the WR15 calorimeter. The estimated 3σ limits for η_e are ± 0.05% of the effective efficiency.

4.11. Summary

The estimated 3σ limits of the imprecision (random error) in the measurement of the effective efficiency are ± 0.05% of η_e.

The systematic errors and their uncertainties are listed and totaled in table 7. The total estimated systematic error is -0.00296 and the correction (1 + b) to e_2 is 0.99704.

The estimated limits of uncertainty in the above systematic error are ± 0.203% of e_2. To obtain the corresponding estimated limits of systematic uncertainty in the value of η_e, the partial derivative of η_e was taken with respect to (1 + b) and typical values substituted to obtain a multiplier of 1.106. The estimated limits to the systematic uncertainty in the value of η_e are therefore ± 0.23% of η_e. The total uncertainty (systematic + random) is ± 0.28% of η_e.

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Table 1

Commercial Products for Calorimeter

Quantity	Item
1	WR15 copper waveguide bent to J shape
1	Flange UG-385/U
2	Binding posts
1	No. 6 spaghetti tubing, 1/4 in. (0.64 cm) long
1	No. 6 Polyamide washer
2	No. 6 Brass washer
3	6-32 Brass nuts
1	Cable clamp, for 1/8 inch O.D. cable
1	No. 6 Solder lug
31 In.	14 gauge (AWG) stranded copper wire with polytetrafluoroethylene insulation
8 ft.	Polytetrafluoroethylene tubing, size 18,
17 ft.	30 gauge (AWG) insulated magnetic wire
2 oz.	Electrical grade room temperature cure silicone rubber
1	O ring 7/16" OD, 1/16" Dia. cross section, for seal flange
1	O ring 7/8" OD, 1/16" Dia. cross section, for seal flange
3	O ring 3/16" OD, 1/16" Dia. cross section, for lead seals
3	O ring 7/32" OD, 1/16" Dia. cross section, for lead seals
1	O ring 3/4" OD, 090" Dia. cross section, for stud
1	O ring 4 1/2" OD, 3/16" Dia. cross section, for base
4	4-40 Sealing screws with O ring
1 lb.	Sodium hydroxide
1 lb.	Low viscosity (900 cps) epoxy, solvent free, room temperature cure

Table 1 (Continued)

Quantity	Item
6 ft.	30 gauge (AWG) constantan wire (bare)
2	Jack for 0.02 inch Dia. pin, 0.18 inch long. 0.05 inch Dia.
4	0-80 Round head screws, 1/2 inch long
4	2-56 Binding head screws, 1/4 inch long

Table 2

Commercial Products for Bolometer Units

Quantity	Item
2	WR15, copper waveguide, one inch long
2	Commercial block Hitachi*, Model M2521 or equivalent
4	2-56, Flathead brass screw, 1/4 inch long
2	1-72, Round head brass screw, 1/8 inch long
2	24 gauge (AWG), Insulated magnet wire, 2 inch 5 (cm) long
1 oz.	Silver filled conducting epoxy
1 ft.	1 inch (2.5 cm) wide aluminized polyester pressure sensitive tape
1 oz.	Powdered iron
2	Size 18, Tetrafluoroethylene tubing, 0.13 inches (0.33 cm) long

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*At this writing this is the only known broad band commercial block available in WR15 waveguide size. In no case does this identification imply recommendation or endorsement by the National Bureau of Standards, nor does it imply that the component identified is necessarily the best available for the purpose.

Table 3

Components of Lead-in Seals

No. on Figure 6	Component
1	Conduit spacer
2	Thermistor lead
3	Thermopile lead
4	Conduit seals
5	J shaped waveguide
6	Conduits
7	Conduit fittings
8	O rings
9	Waveguide seal
10	Seal flange

Table 4

Components to Supply Microwave Power to WR15 Calorimeter

No. on Figure 7	Component
1	Klystron
2	Water Jacket
3	10 dB Directional Coupler
4	Wavemeter
5	Crystal Detector
6	Isolator
7	Variable Attenuator
8	Power Leveler
9	Switch
10	90° E plane bend
11	Load
12	Waveguide Stands

Table 5

Connections to Microwave Components

A	Klystron Ground
B	To klystron power supply via Pound frequency stablizer
C	To cooling water and drain
D	Crystal current to Pound stabilizer
E	Power leveler current from Type II power bridge
D	Microwave power to Calorimeter

Table 6
Accessory Equipment

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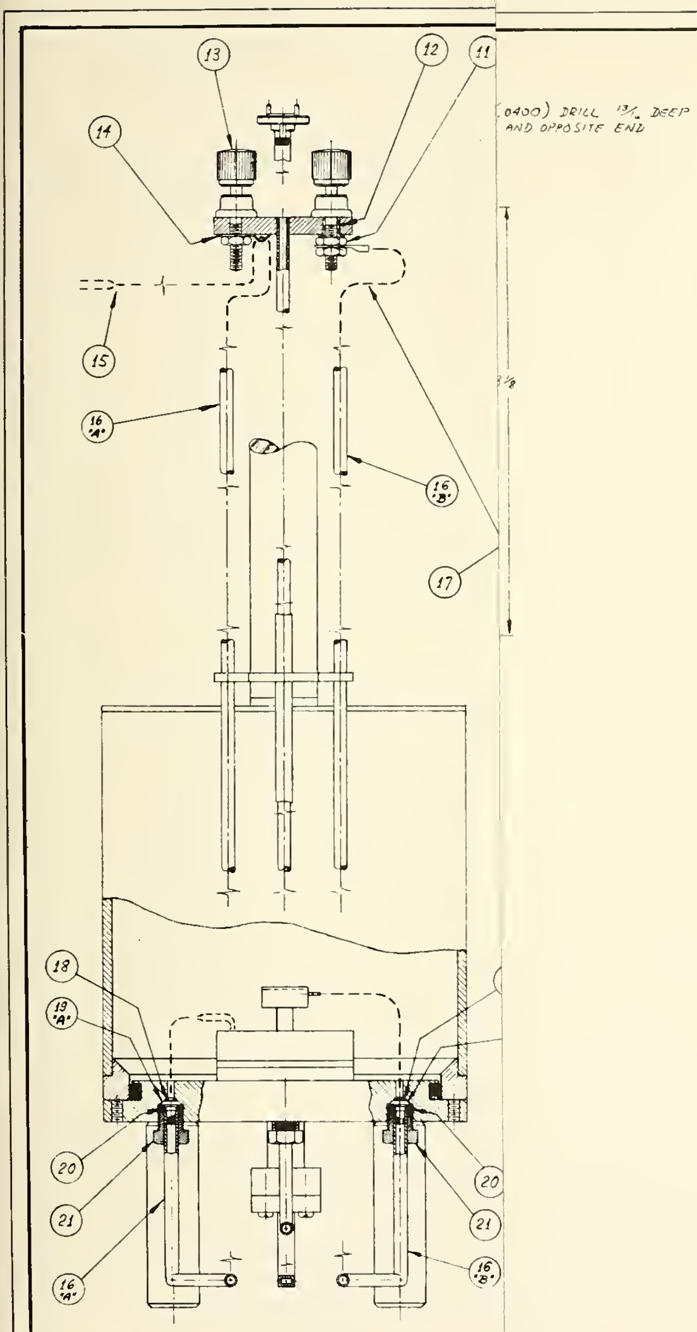
1. Klystron power supply
2 Pound Stablizer
3. Photocell Galvanometer Amplifier
4. Secondary Galvanometer
5. AC Voltmeter
6. NBS Type II Power Measurement System
7. Digital Voltmeter
8. NBS precision temperature-controlled water bath
9. Microvolt potentiometer

Table 7

Systematic Errors and Limits of Systematic Uncertainty

	Systematic Error b	Limits of Systematic Uncertainty % of e_2
Thermopile Nonproportionality	+ 0.00012	± 0.01%
Unit Walls	- 0.0001	± 0.01%
Calorimeter Flange		± 0.076%
Thermal Isolation Section	- 0.00306	± 0.092%
Microvolt Potentiometer		± 0.0055%
Environmental Stability		± 0.0004%
Lead Tempering		± 0.00025%
Microwave Leakage from Bolometer Unit	+ 0.000076	± 0.0076%
Change in Thermal Leakage from the Waveguide		± 0.001%
TOTALS	- 0.00296	± 0.203%

Figure 1. WR15 calorimeter.



ORIGINAL DATE OF DRAWING

REVISIONS

NO.	E. C. N.	CHANGE	DATE
1			
2			
3			
4			

LIST OF PARTS

* STOCK PARTS

PIECE NO	NOMENCLATURE	NO REQ'D
	MANDREL	1
	SUB - ASSEMBLY	1
	SUB - ASSEMBLY	1
32	THERMOPILE FORM MAT'L ~ TETRAFLUORETHYLENE	1
*31	BRASS SCREW, #0-80 UNF ROUND HEAD, 1/2 LONG	4
30	REFERENCE RING MAT'L ~ FREE CUTTING BRASS	1
29	REFERENCE FLANGE W/TRIM WIRES MAT'L ~ TELLURIUM COPPER	1
*28	O-RING, 4 1/2 O.D. 3/16 NOM. WIDTH	1
27	COVER SCREW MAT'L ~ FREE CUTTING BRASS	3
26	LEG MAT'L ~ FREE CUTTING BRASS	4
25	SEAL FLANGE MAT'L ~ FREE CUTTING BRASS	1
*24	BRASS SCREW, # 4-40 UNC HEAD WITH O-RING SEAL, 3/8 LONG	4
*23	O-RING, 7/16 O.D., 1/16 NOM. WIDTH	1
*22	O-RING, 7/8 O.D., 1/16 NOM. WIDTH	1
21	CONDUIT FITTING MAT'L ~ FREE CUTTING BRASS	3
*20	O-RING, 7/32 O.D., 1/16 NOM. WIDTH	3
19 "C"	CONDUIT SEAL MAT'L ~ FREE CUTTING BRASS	1
19 "B"	LEAD SEAL, BOLOMETER DC LEAD MAT'L ~ FREE CUTTING BRASS	1
19 "A"	LEAD SEAL, THERMOPILE LEAD MAT'L ~ FREE CUTTING BRASS	1
*18	O-RING, 1/4 O.D., 1/16 NOM. WIDTH	3
17	BOLOMETER DC LEAD MAT'L ~ SEE DETAIL DWG.	1
*16 "C"	CONDUIT MAT'L ~ BRASS TUBE, 3/16 O.D 1/32 WALL	1
*16 "B"	CONDUIT MAT'L ~ BRASS TUBE, 3/16 O.D., 1/32 WALL	1
*16 "A"	CONDUIT MAT'L ~ BRASS TUBE, 3/16 O.D. 1/32 WALL	1
15	THERMOPILE LEAD MAT'L ~ SEE DETAIL DWG.	1
*14	CABLE CLAMP FOR 1/4" O.D. CABLE	1
*13	COMMERCIAL BINDING POST	2
12	DIELECTRIC BUSHING MAT'L ~ POLYAMIDE	1
*11	BRASS HEX. NUT # 6 - 32 UNC	3
10	WR 15 UNIT FLANGE MAT'L ~ FREE CUTTING BRASS	2
*9	STAINLESS STEEL CAPTIVE SCREW # 4-40 UNC (MIL. STD. FOR WR 15)	4
*8	WR 15 WAVEGUIDE MAT'L ~ OFHC COPPER	1
7	BINDING POST BLOCK MAT'L ~ FREE CUTTING BRASS	1
6	CONDUIT SPACER MAT'L ~ FREE CUTTING BRASS	2
5	HANGER MAT'L ~ FREE CUTTING BRASS	1
4	CALORIMETER SPACER MAT'L ~ POLYAMIDE	1
*3	O-RING, 3/4 O.D. .090 WIDTH	1
2	STUD MAT'L ~ FREE CUTTING BRASS	1
1	COVER MAT'L ~ FREE CUTTING BRASS	1

FIGURE 2

CALORIMETER ASSEMBLY
AND
MANDREL.

DIMENSIONS IN INCHES (Unless otherwise specified) TOLERANCES (Unless otherwise specified) DECIMALS ±.005 FRACTIONS ±.010 ANGLES ±½°	DRAFTSMAN Victor Levinson	CHECKER
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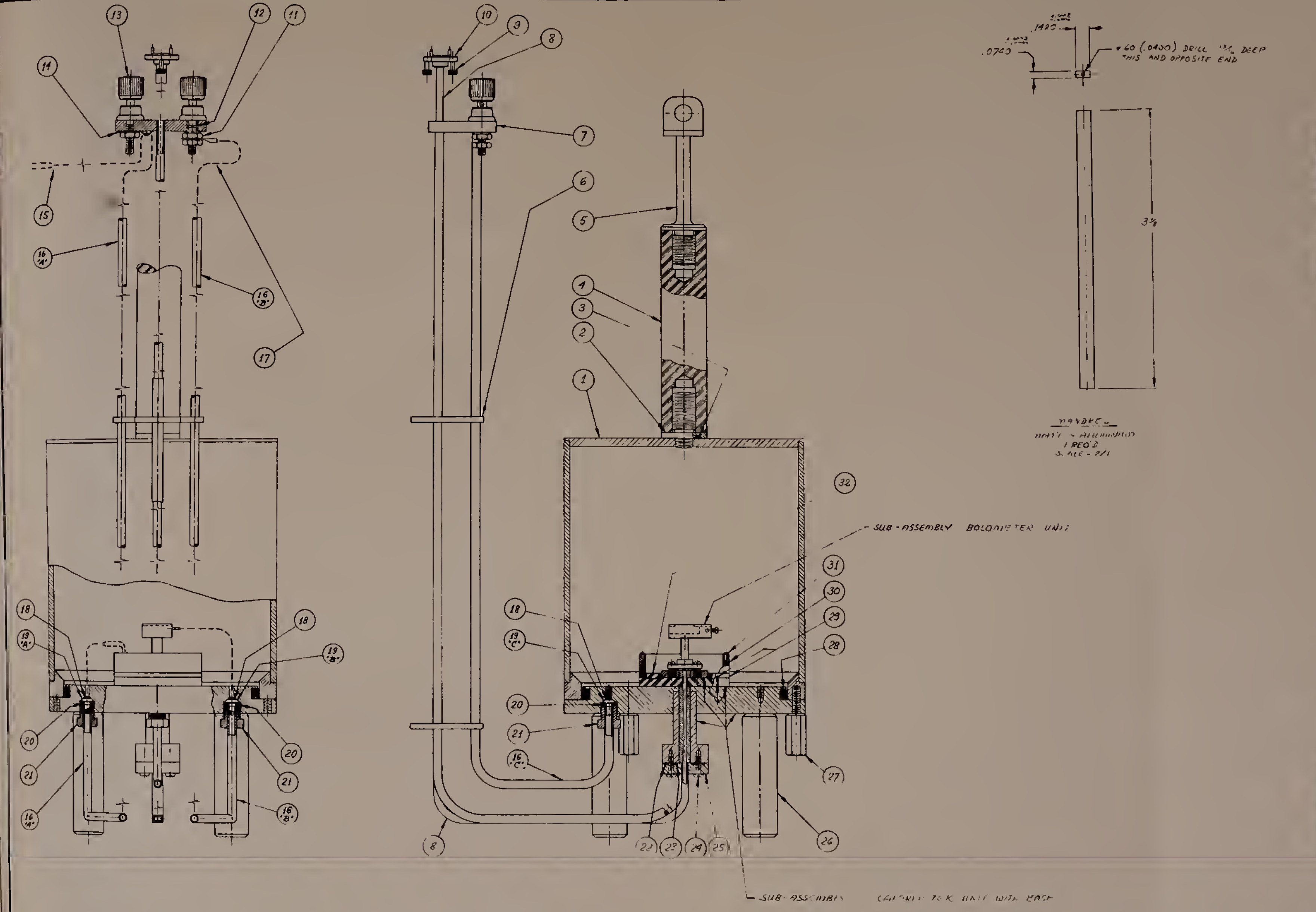

ORIGINAL DATE OF DRAWING

REVISIONS

		CHANGE	DATE
1			
2			
3			
4			

LIST OF PARTS

✱ STOCK PARTS

	NOMENCLATURE	
	MANDREL	1
	SUB-ASSEMBLY	1
	SUB-ASSEMBLY	1
32	THERMOPILE FORM MAT'L - TETRAFLUORETHYLENE	1
✱31	BRASS SCREW, #0-80 UNF ROUND HEAD, ½ LONG	4
30	REFERENCE RING MAT'L - FREE CUTTING BRASS	1
29	REFERENCE FLANGE WITH NIPPLES MAT'L - TELLURIUM COPPER	1
✱28	O-RING, 4⅛ O.D. 1/16 NOM. WIDTH	1
27	COVER SCREW MAT'L - FREE CUTTING BRASS	3
26	LEG MAT'L - FREE CUTTING BRASS	4
25	SEAL FLANGE MAT'L - FREE CUTTING BRASS	1
✱24	BRASS SCREW, #4-40 UNC HEAD WITH O-RING SEAL 3/8 LONG	4
✱23	O-RING, 7/16 O.D. 1/16 NOM. WIDTH	1
✱22	O-RING, 7/8 O.D. 1/16 NOM. WIDTH	1
21	CONDUIT FITTING MAT'L - FREE CUTTING BRASS	3
✱20	O-RING, 7/32 O.D., 1/16 NOM. WIDTH	3
19 'C'	CONDUIT SEAL MAT'L - FREE CUTTING BRASS	1
19 'B'	LEAD SEAL, BOLOMETER DC LEAD MAT'L - FREE CUTTING BRASS	1
19 'A'	LEAD SEAL, THERMOPILE LEAD MAT'L - FREE CUTTING BRASS	1
✱18	O-RING, 1/4 O.D., 1/16 NOM. WIDTH	3
17	BOLOMETER DC LEAD MAT'L - SEE DETAIL DWG.	1
✱16 'C'	CONDUIT MAT'L - BRASS TUBE, 3/16 O.D 1/32 WALL	1
✱16 'B'	CONDUIT MAT'L - BRASS TUBE, 1/4 O.D., 1/32 WALL	1
✱16 'A'	CONDUIT MAT'L - BRASS TUBE, 5/16 O.D. 1/32 WALL	1
15	THERMOPILE LEAD MAT'L - SEE DETAIL DWG.	1
✱14	CABLE CLAMP FOR 1/8" O.D. CABLE	1
✱13	COMMERCIAL BINDING POST	2
12	DIELECTRIC BUSHING MAT'L - POLYAMIDE	1
✱11	BRASS HEX. NUT #6-32 UNC	3
10	WR 15 UNIT FLANGE MAT'L - FREE CUTTING BRASS	2
✱9	STAINLESS STEEL CAPTIVE SCREW #4-40 UNC (MIL. STD. FOR WR 15)	4
✱8	WR 15 WAVEGUIDE MAT'L - OFHC COPPER	1
7	BINDING POST BLOCK MAT'L - FREE CUTTING BRASS	1
6	CONDUIT SPACER MAT'L - FREE CUTTING BRASS	2
5	HANGER MAT'L - FREE CUTTING BRASS	1
4	CALORIMETER SPACER MAT'L - POLYAMIDE	1
✱3	O-RING, 3/4 O.D. .030 WIDTH	1
2	STUD MAT'L - FREE CUTTING BRASS	1
1	COVER MAT'L - FREE CUTTING BRASS	1

FIGURE 2

CALORIMETER ASSEMBLY
AND
MANDREL.

DECIMALS
FRACTIONS
ANGLES

DRAFTSMAN: Victor Lecinsa

D.E. HARVEY

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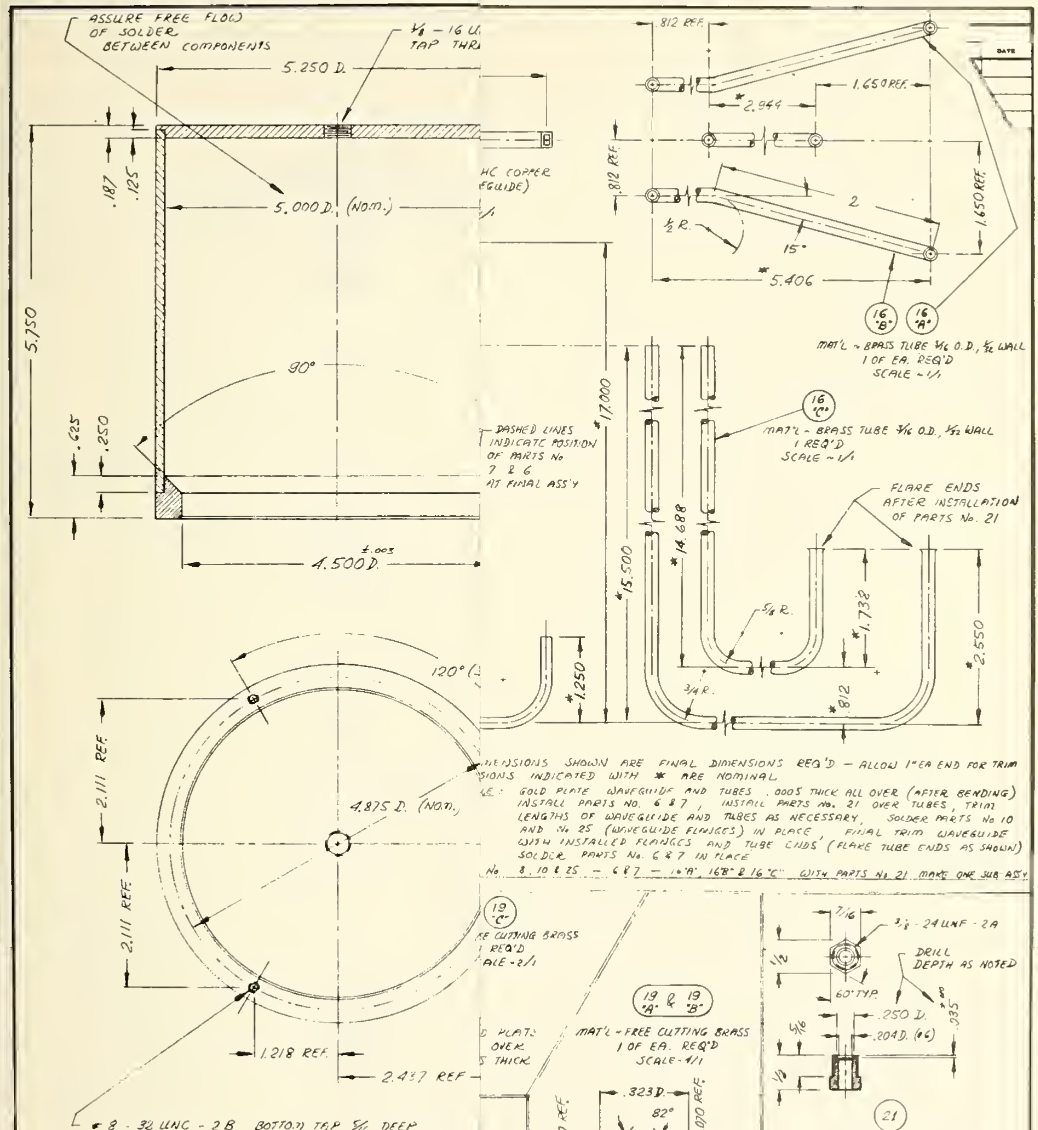
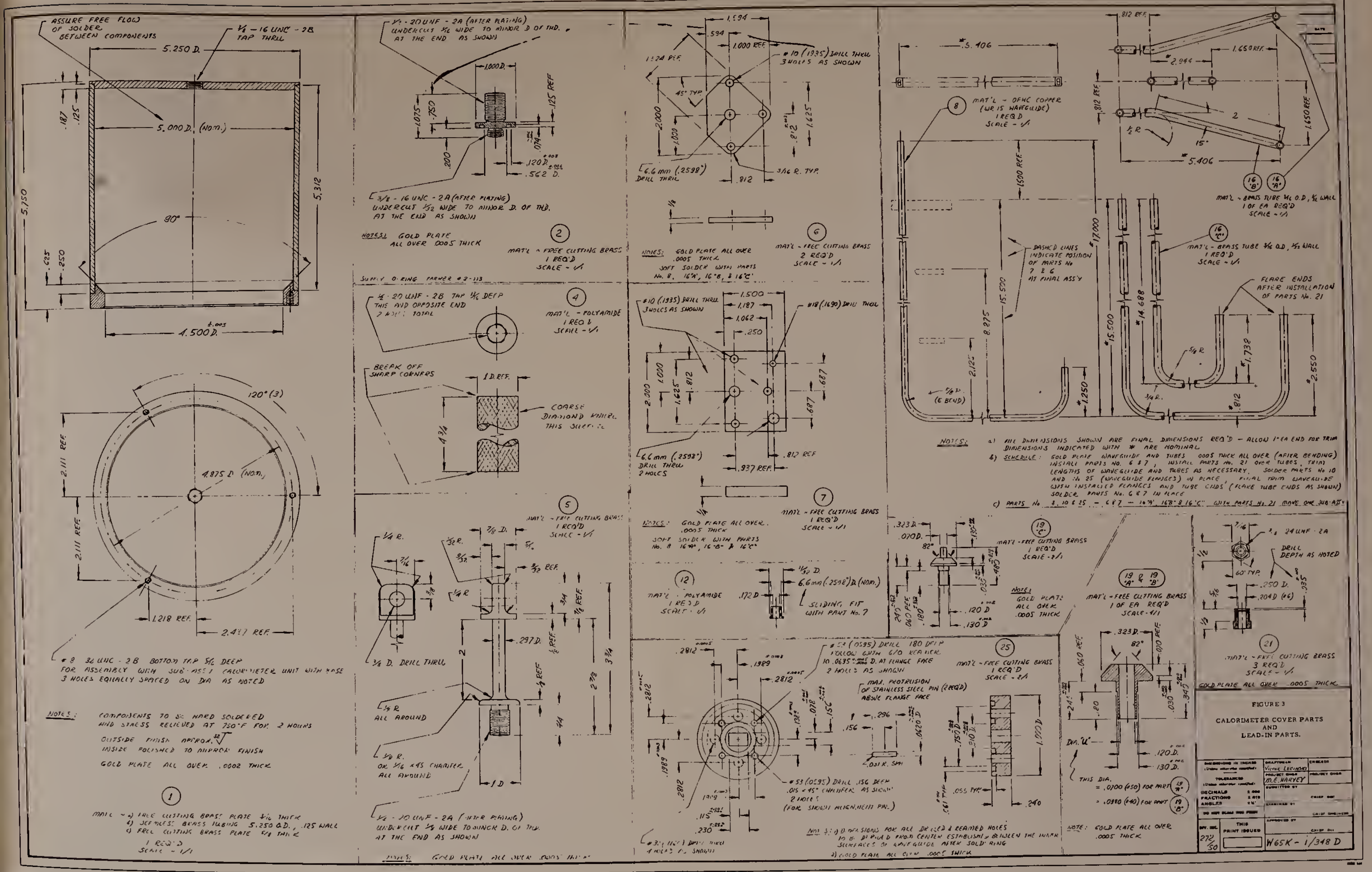


FIGURE 3

CALORIMETER COVER PARTS AND LEAD-IN PARTS.


ASSURE FREE FLOW OF SOLDER BETWEEN COMPONENTS
1/4 - 16 UNC - 2B TAP THRU
5.250 D.
5.000 D. (NOM.)
5.750
5.312
.187
.125
90°
.625
.250
4.500 D.
120° (3)
2.111 REF
4.875 D (NOM.)
1.218 REF.
2.437 REF.
#8 32 UNC - 2B BOTTOM TAP 5/16 DEEP FOR ASSEMBLY WITH SUB-ASSY CALORIMETER UNIT WITH BASE 3 HOLES EQUALLY SPACED ON DIA AS NOTED
NOTES: COMPONENTS TO BE HARD SOLDERED AND STRESS RELIEVED AT 750°F FOR 2 HOURS
OUTSIDE FINISH APPROX. 32
INSIDE POLISHED TO MIRROR FINISH
GOLD PLATE ALL OVER .0002 THICK
1
MAT'L - a) FREE CUTTING BRASS PLATE 1/16 THICK
b) SEAMLESS BRASS TUBING 5.250 O.D., .125 WALL
c) FREE CUTTING BRASS PLATE 5/8 THICK
1 REQ'D
SCALE - 1/1
1/2 - 20 UNF - 2A (AFTER PLATING) UNDERCUT 1/16 WIDE TO MINOR D OF THD. AT THE END AS SHOWN
1.000 D.
1.075
.750
.125 REF
.200
.074
.120 D.
.562 D.
3/8 - 16 UNC - 2A (AFTER PLATING) UNDERCUT 1/32 WIDE TO MINOR D. OF THD. AT THE END AS SHOWN
NOTES: GOLD PLATE ALL OVER .0005 THICK
2
MAT'L - FREE CUTTING BRASS
1 REQ'D
SCALE - 1/1
SUPPLY O-RING PARKER #2-113
1/4 - 20 UNF - 2B TAP 5/16 DEEP THIS AND OPPOSITE END 2 HOLES TOTAL
4
MAT'L - POLYAMIDE
1 REQ'D
SCALE - 1/1
BREAK OFF SHARP CORNERS
1 D. REF.
COARSE DIAMOND KNURL THIS SURFACE
4 3/4
5
MAT'L - FREE CUTTING BRASS
1 REQ'D
SCALE - 1/1
1/4 R.
7/16
3/8
1/4 R
3/8 D. DRILL THRU
7/8 D.
5/8
1/32 R.
5/32
3/32 REF.
3/4
7/8 REF.
.297 D.
1/2 REF.
2
2 7/8
3 3/4
1/2 REF
1/4
1/8 R ALL AROUND
1/8 R. OR 1/16 x 45 CHAMFER ALL AROUND
1 D
1/4 - 20 UNF - 2A (AFTER PLATING) UNDERCUT 1/32 WIDE TO MINOR D. OF THD. AT THE END AS SHOWN
NOTES: GOLD PLATE ALL OVER .0005 THICK
1.594
.594
1.000 REF.
#10 (.1935) DRILL THRU 3 HOLES AS SHOWN
1.124 REF.
45° TYP
2.000
1.000
.812
1.625
6.6 mm (.2598") DRILL THRU
3/16 R. TYP.
.812
1/8
NOTES: GOLD PLATE ALL OVER .0005 THICK
SOFT SOLDER WITH PARTS No. 8, 16"A", 16"B", & 16"C"
6
MAT'L - FREE CUTTING BRASS
2 REQ'D
SCALE - 1/1
#10 (.1935) DRILL THRU 3 HOLES AS SHOWN
1.500
1.187
1.062
.250
#18 (.1695) DRILL THRU
2.000
1.000
1.625
.812
.687
.687
6.6 mm (.2598") DRILL THRU 2 HOLES
.812 REF
.937 REF.
1/4
7
MAT'L - FREE CUTTING BRASS
1 REQ'D
SCALE - 1/1
NOTES: GOLD PLATE ALL OVER .0005 THICK
SOFT SOLDER WITH PARTS No. 8 16"A", 16"B" & 16"C"
12
MAT'L - POLYAMIDE
1 REQ'D
SCALE - 1/1
.172 D
1/32 D
6.6 mm (.2598") D (NOM.)
SLIDING FIT WITH PART No. 7
.2812
.1989
.2812
#53 (.0595) DRILL .180 DEEP FOLLOW WITH 6/0 REAMER TO .0635 D. AT FLANGE FACE 2 HOLES AS SHOWN
MAX. PROTRUSION OF STAINLESS STEEL PIN (REQ'D) ABOVE FLANGE FACE
.296
.156
.0620 D
.031 R. SM
#53 (.0595) DRILL .156 DEEP .015 x 45° CHAMFER AS SHOWN 2 HOLES (FOR SHOWN ALIGNMENT PIN.)
.115
.230
#3 (.1160) DRILL THRU 4 HOLES AS SHOWN
25
MAT'L - FREE CUTTING BRASS
1 REQ'D
SCALE - 2/1
.757 D
.310 D.
1.000 D
.055 TYP.
.240
NOTES: 1) DIMENSIONS FOR ALL DRILLED & REAMED HOLES TO BE DRILLED FROM CENTER ESTABLISHED BETWEEN THE INNER SURFACES OF WAVEGUIDE AFTER SOLD. RING
2) GOLD PLATE ALL OVER .0005 THICK
*5.406
8
MAT'L - OFHC COPPER (WR 15 WAVEGUIDE)
1 REQ'D
SCALE - 1/1
1.500 REF.
17.000
15.500
8.275
2.125
5/8 R. (E BEND)
DASHED LINES INDICATE POSITION OF PARTS No 7 & 6 AT FINAL ASS'Y
.812 EFF.
.812 REF.
2.944
1.650 REF.
1.650 REF.
2
1/2 R.
15°
*5.406
16 "B"
16 "A"
MAT'L - BRASS TUBE 1/4 O.D., 1/32 WALL
1 OF EA REQ'D
SCALE - 1/1
16 "C"
MAT'L - BRASS TUBE 3/16 O.D., 1/32 WALL
1 REQ'D
SCALE - 1/1
FLARE ENDS AFTER INSTALLATION OF PARTS No. 21
*15.500
*14.688
*1.250
5/8 R.
*1.738
3/4 R.
*.812
*2.550
NOTES: a) ALL DIMENSIONS SHOWN ARE FINAL DIMENSIONS REQ'D - ALLOW 1" EA END FOR TRIM DIMENSIONS INDICATED WITH * ARE NOMINAL
b) SCHEDULE: GOLD PLATE WAVEGUIDE AND TUBES .0005 THICK ALL OVER (AFTER BENDING) INSTALL PARTS NO. 6 & 7, INSTALL PARTS No. 21 OVER TUBES, TRIM LENGTHS OF WAVEGUIDE AND TUBES AS NECESSARY. SOLDER PARTS No 10 AND No 25 (WAVEGUIDE FLANGES) IN PLACE - FINAL TRIM WAVEGUIDE WITH INSTALLED FLANGES AND TUBE ENDS (FLARE TUBE ENDS AS SHOWN) SOLDER PARTS No. 6 & 7 IN PLACE
c) PARTS No 8, 10 & 25 - 6 & 7 - 16"A", 16"B" & 16"C" WITH PARTS No. 21 MAKE ONE SUB-ASS'Y
.323 D.
.070 D.
82°
19 "C"
MAT'L - FREE CUTTING BRASS
1 REQ'D
SCALE - 4/1
.120 D
.130 D
NOTE: GOLD PLATE ALL OVER .0005 THICK
19 "A" & 19 "B"
MAT'L - FREE CUTTING BRASS
1 OF EA REQ'D
SCALE - 4/1
.323 D.
82°
.060 REF.
.120 D.
.130 D.
DIA. "C"
THIS DIA. = .0700 (#50) FOR PART 19 "A"
= .0980 (#40) FOR PART 19 "B"
NOTE: GOLD PLATE ALL OVER .0005 THICK
7/16
1/4 - 24 UNF - 2A
DRILL DEPTH AS NOTED
60° TYP.
.250 D.
.204 D (#6)
21
MAT'L - FREE CUTTING BRASS
3 REQ'D
SCALE - 1/1
GOLD PLATE ALL OVER .0005 THICK
FIGURE 3
CALORIMETER COVER PARTS AND LEAD-IN PARTS.
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M.E. HARVEY
27 1/50
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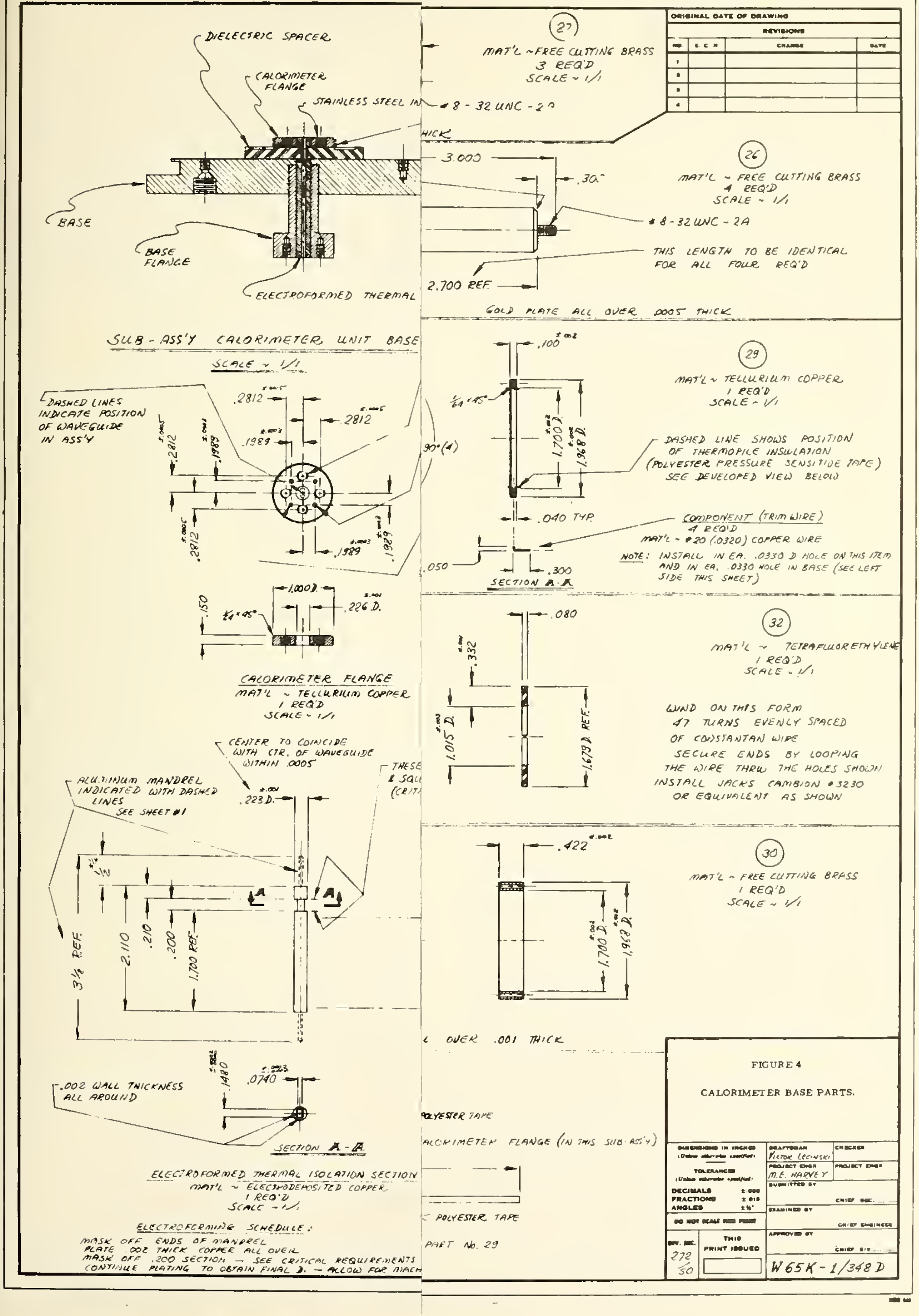

FIGURE 4

CALORIMETER BASE PARTS.

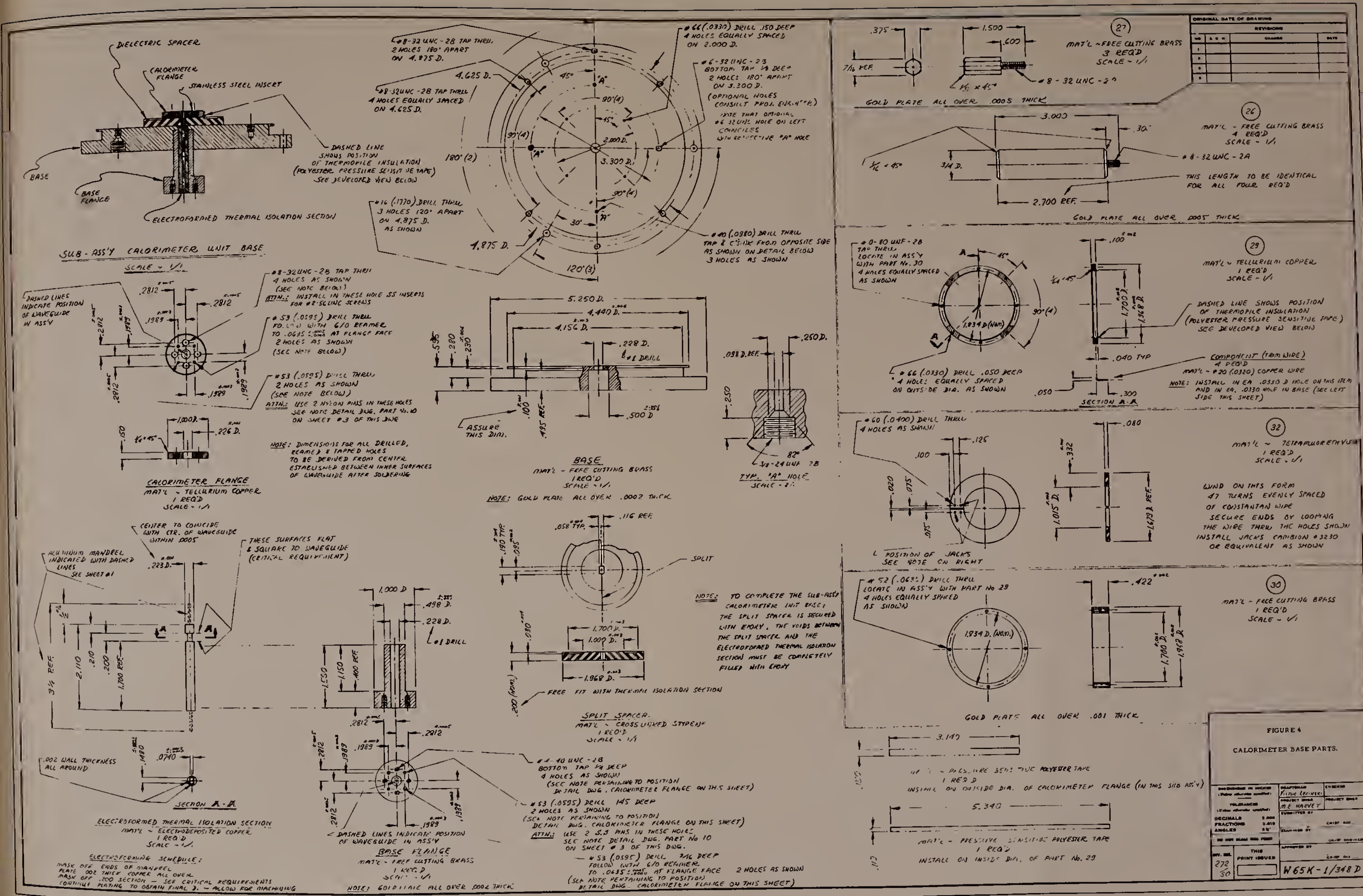

FIGURE 4

CALORIMETER BASE PARTS.

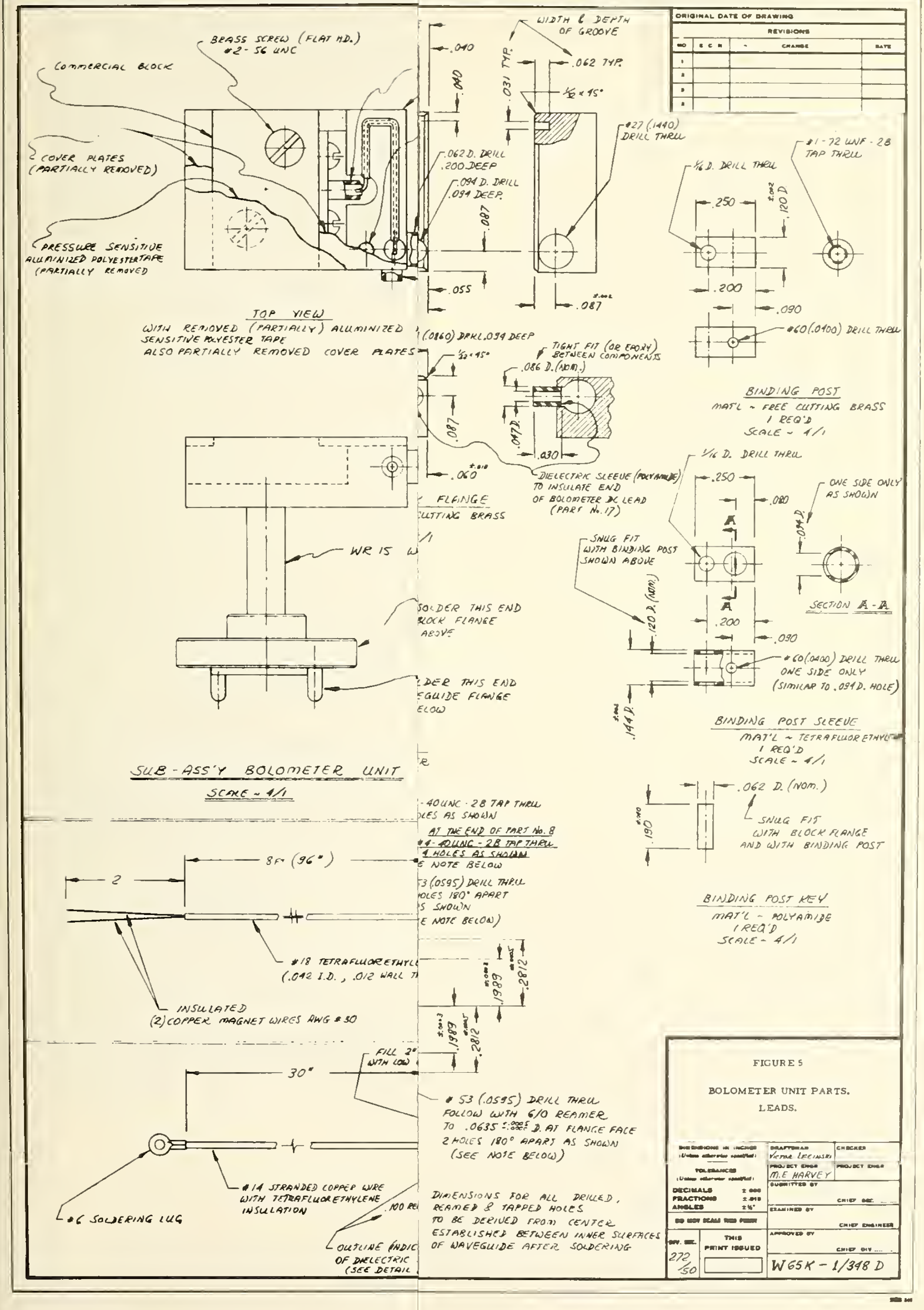

FIGURE 5

BOLOMETER UNIT PARTS.
LEADS.

DIMENSIONS IN INCHES (Unless otherwise specified)
TOLERANCES (Unless otherwise specified)
DECIMALS ± .000
FRACTIONS ± .010
ANGLES ± ½°
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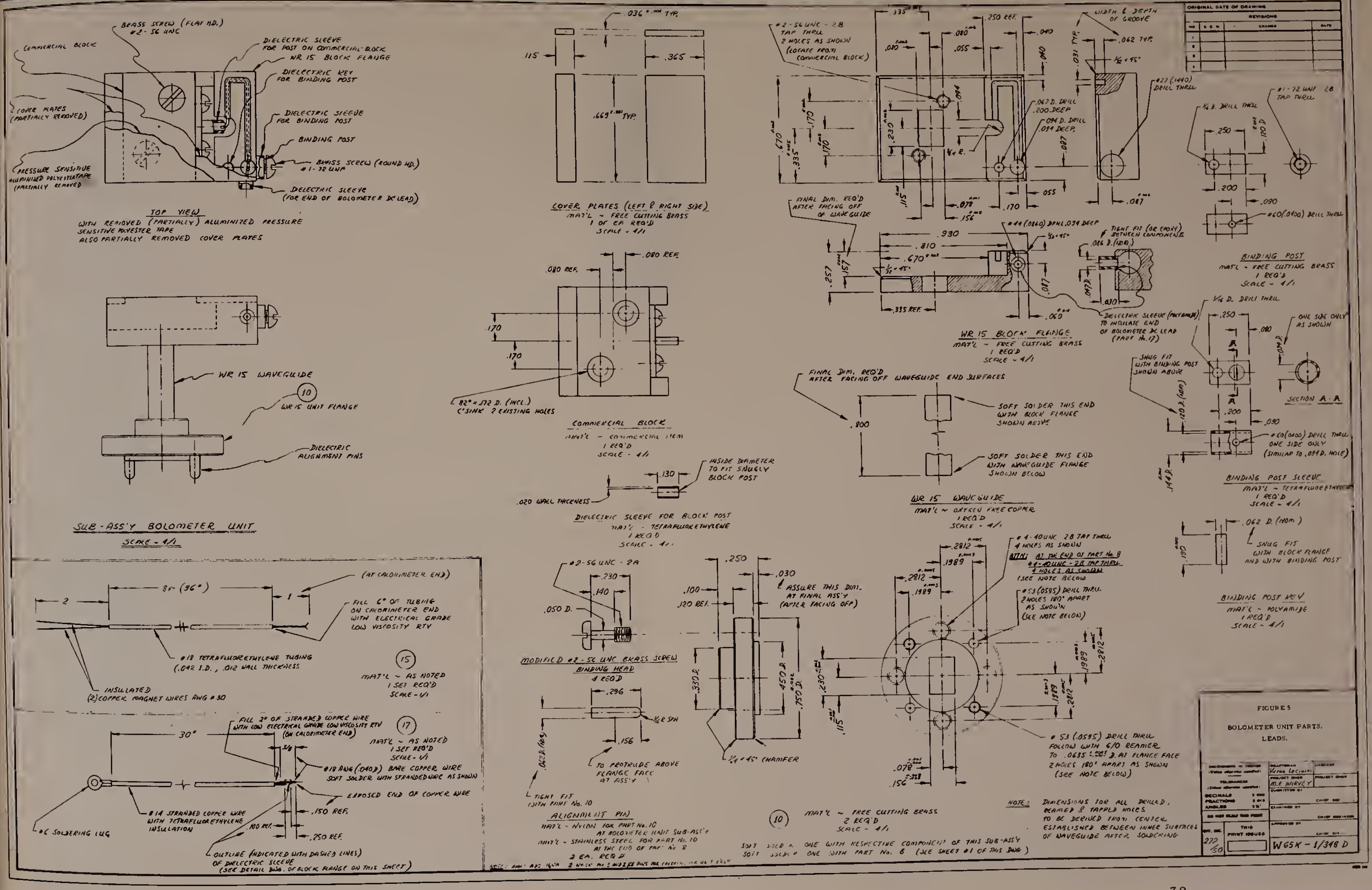

FIGURE 5

BOLOMETER UNIT PARTS. LEADS.

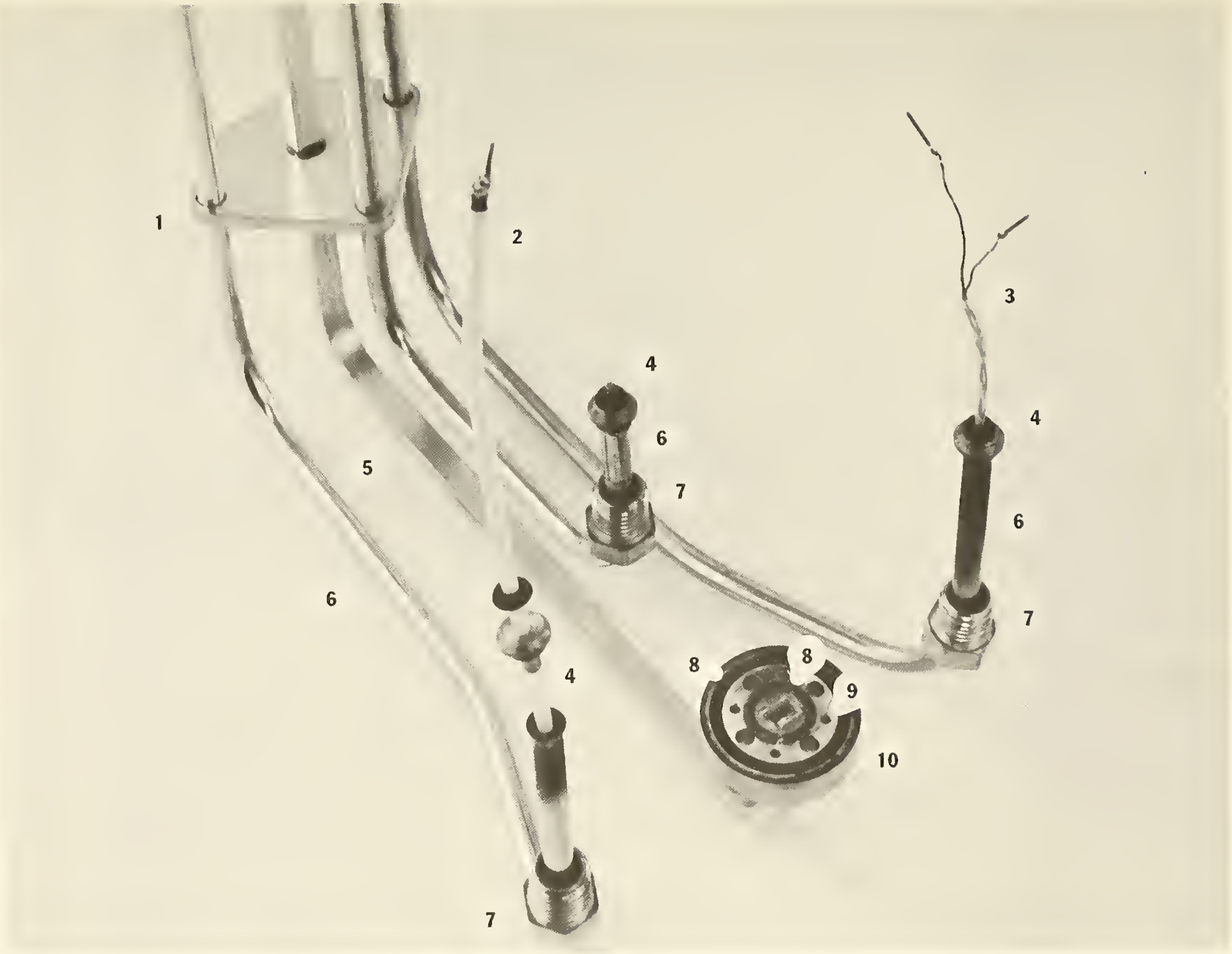

Figure 6. Lead-in seals.

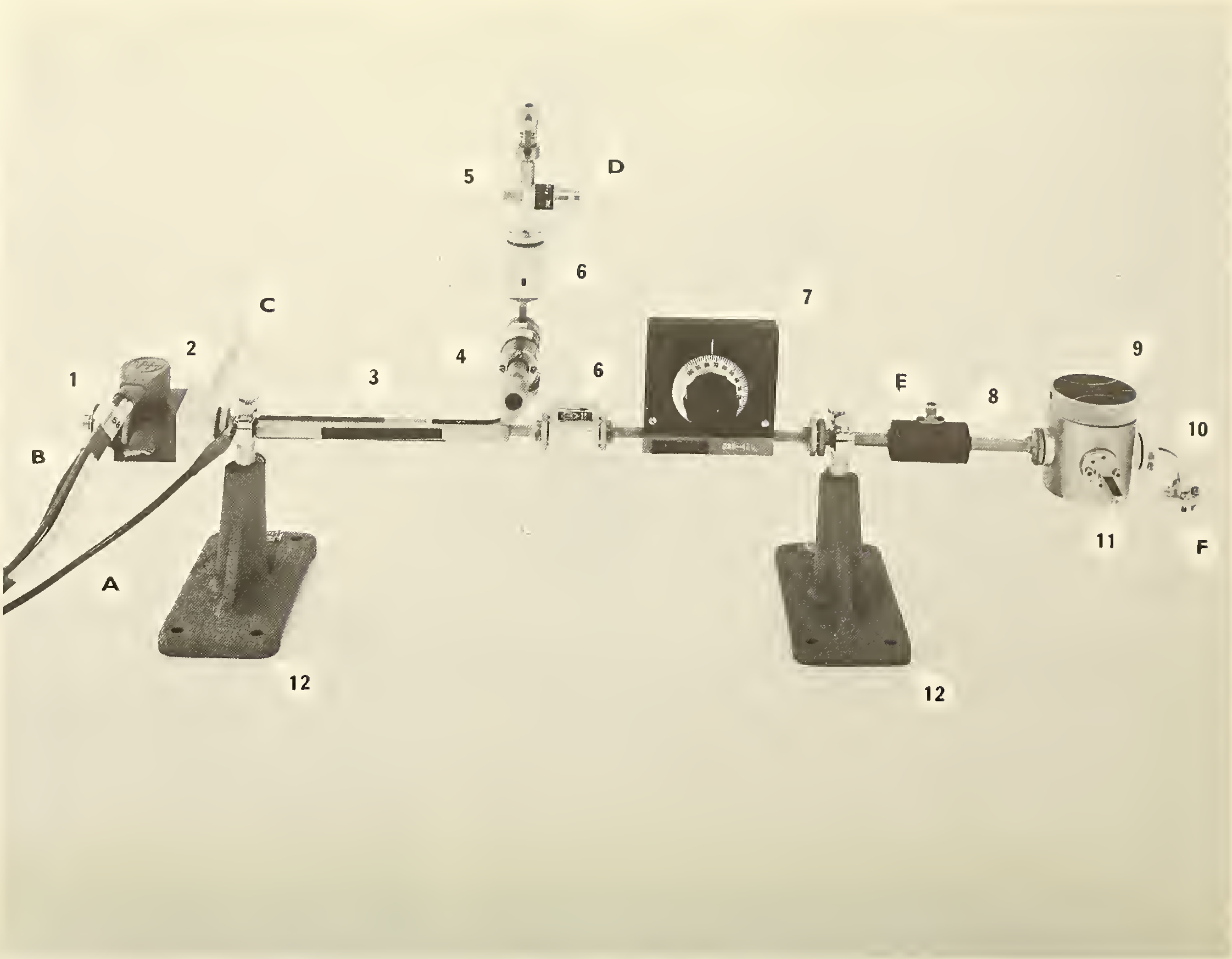

Figure 7. Components to supply microwave power.

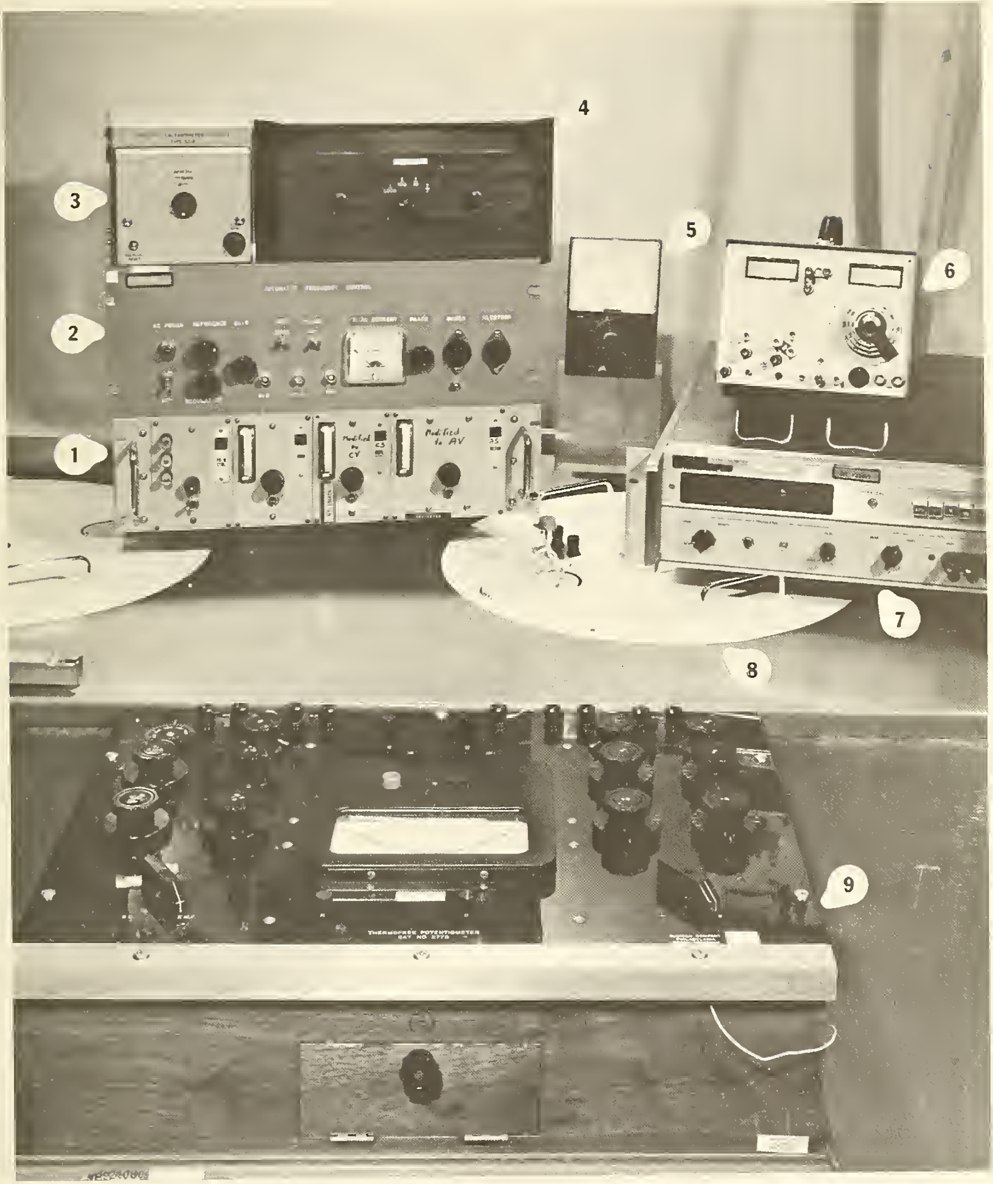

Figure 8. Accessory equipment.

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16. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)

A microwave calorimeter which serves as the National Bureau of Standards (NBS) standard for power measurements in the frequency range 50 to 75 GHz has been completed and evaluated recently. Included here are descriptions of the principal changes in the calorimeter and bolometer unit from the WR28 models which are of similar design. Also included are construction details, accessary equipment, operation procedure, and error analysis. An improved thermal isolating waveguide section and calorimeter flange are features of this calorimeter.

A careful error analysis permits the determination of the effective efficiency of a standard bolometer unit to estimated limits of systematic uncertainty of ± 0.23%. The estimated 3σ limit of random uncertainty is 0.05%.

17. KEY WORDS (Alphabetical order, separated by semicolons)

Calorimeter; microwave; power; standard.

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