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"CUTIE PIE," A PORTABLE RADIATION INSTRUMENT

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ABSTRACT

A portable beta and gamma radiation meter of exceedingly small dimensions and weight has been developed. User acceptance has been more enthusiastic than any previous instrument of its type.

The circuit, using one Victoreen V-32 tube, is the simplest electronic circuit possible for radiation work and gives high sensitivity.

Stability exceeds anything of comparable sensitivity which has come to our attention. The short term stability is due to a circuit which prevents emission before the cathode reaches operating temperature. Long term stability has been improved by evacuating the tube enclosure and switch.

The complete, one unit instrument, weighs four pounds two ounces, and is carried with a pistol grip. Exclusive of chamber and handle, its dimensions are 3" wide, $6\frac{1}{2}$" long, and 5" high.

The case is formed of aluminum and is designed to give excellent visibility of the meter.

Three ranges of approximately 50, 500 and 5000 mr/hr have been incorporated in the instruments.

The instrument has been named "Cutie Pie" due to its diminutive size.

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I PROBLEM

Instability and failure to hold calibration have given portable electronic radiation survey instruments an undersirable reputation with field users of this type of equipment.

Opinions obtained from field users of such instruments have resulted in the following tabulation of what a satisfactory instrument should be:

1. Ability to zero the instrument at all times regardless of humidity conditions. Humidity conditions at Clinton run at saturation during the night. Depending upon weather conditions, it may remain at saturation during the day or may drop as low as 30%. During summer periods instruments have shown particularly bad characteristics due to this severe humidity shift.

2. Inasmuch as each instrument is radiation calibrated, linearity of response is not a major consideration, although it is desirable.

3. The instrument must dependably hold calibration within at least 10%.

4. The range, which can be conveniently read, should be from 10 to 25 mr/hr up to about 5000 mr/hr.

5. The instrument must be free from spurious response. That is: the tube and its associated grid circuit should not collect ions or electrons when the instrument is subjected to radiation.

6. The instrument should be of one unit construction and have a chamber not exceeding three or three and one-half inches in diameter.

7. The instrument must be reasonably free from instability or short time drift after a short warm-up period.

The instrument about to be described has fulfilled all the above requirements with the exception of paragraph three. The overall effect of humidity and battery voltage changes are, after two months operation, not fully known.

II CIRCUIT THEORY

If only one tube could be used as a current amplifier, a marked reduction in battery supply requirements would result. Provided that the circuit and tube were reasonably stable, such an arrangement appeared unusually attractive.

The Victoreen V-32 triodes are rated at 140 micro-mhos conductance, and 10^{14} ohms cold input resistance.

An experimental set-up was made and a realizable gain of 80 micro-mhos resulted. An increment of .25 volt grid potential gave 20 microamperes plate current increment with an 1800 ohm microammeter in the plate circuit.

$$G_m = \frac{\delta\, i_p}{\delta\, e_g}$$

$$G_m = \frac{20 \times 10^{-6}}{.25} = 80 \times 10^{-6} \text{ mhos}$$

Electrode potentials were the same as those given on the appended circuit diagram.

After numerous changes, the circuit given was established as the simplest possible and incorporated the following desirable features:

1. It establishes a constant plate current. In this case it is approximately 125 microamperes. The G_m of the tube remains more constant with this arrangement than with fixed grid voltage and variable plate current as is common to other zero setting circuits.

   With the elimination of variable leakage paths, the required balancing range has been restricted to such an extent that any marked drop of battery voltages prevents zero setting. Thus, the tube must work within very restricted conditions and the G_m should remain quite constant.

2. The switch, connected in the zero setting and grid bias circuit at the filament end, imparts unusual benefits.

When the amplifier is turned on, plate and cathode potentials are simultaneously applied to the tube. With normal operating grid potentials, the tube operates under emission limited conditions until the cathode reaches normal temperature. This has been shown to be the cause of de-stabilization of the cathode and resultant amplifier instability.[1]

However, with this circuit when the amplifier is off, the grid is at $-7\frac{1}{2}$ volts potential due to the location of the balancing current switch. Immediately after turning the amplifier on, the grid remains at comparatively high bias due to the time constant of the grid resistor

1. Victoreen Instrument Co. Technical report No. 5, 2/15/45. "Stabilization of tubes having oxide coated cathodes."

and the distributed capacity of the grid circuit. This space charge limits the space current until the cathode is at operating temperature. The tube has a mu of 1.75. Consequently, with $7\frac{1}{2}$ volts applied to the plate, the plate current is cut-off until the grid drifts to ~ 4.3 volts, which requires several seconds with a 10^{11} grid resistor.

III GRID CURRENT AND LEAKAGE

After completion and satisfactory tests, four instruments were placed in field use. Immediately after being placed in service a protracted period of high humidity was experienced which caused instability and inability to zero set the instruments. They further displayed spurious response, which was of sufficient magnitude as to make readings taken by the instrument questionable. The first four instruments made did not utilize the vacuum compartment to be described later. Instead, the tube, input resistors and switch were placed in a shield which was carried at bias potential.

By drying the instruments with heat, the instability and zero setting characteristics were restored to normal. The spurious response remained, however.

The spurious response, which had been observed on previous instruments, was annoying. Considerable time spent on this problem yielded results which answered problems that had been vexing for sometime. A check of all components used, finally revealed that the tube leakage, instead of being 10^{14} ohms, was in extreme cases less than 10^{11} ohms. Most of this leakage existed between the grid and plate.

The net result was, that due to this grid to plate leakage, the potential of the grid was made more positive than the bias voltage, by an amount which was proportional to the grid resistor and leakage resistance. This permitted electron collection of ionized air by the grid circuit.

Inasmuch as the troubles above referred to are common to practically all electronic instruments of this type, methods for eliminating these troubles were sought.

IV VACUUM COMPARTMENT

The use of desiccant was attempted and was satisfactory for about four days, at which time the desiccant became saturated. The replacement of the desiccant at such short intervals was out of the question. The only practical approach to the leakage problem appeared to be enclosing the circuit in a vacuum.

Inasmuch as the cabinet and chamber design were received with more enthusiasm than anything previously offered, it seemed advisable to design a vacuum compartment which could be installed in the already designed cabinet.

The greatest stumbling block to such design was a vacuum seal for the rotating switch shaft in such space as was available.

Suggestions offered by W. A. Adcock led to the present design, in which one end of a short length of neoprene tubing was secured vacuum tight to the rotating shaft. The other end of the tube was secured vacuum tight to a bushing which communicated with the vacuum compartment. Thus, the neoprene tube was flexed in torsion and a vacuum tight seal effected.

The enclosure of the circuit in a vacuum has accomplished the following two results:

1. It has eliminated variations in electrical leakage which have in the past contributed to unsatisfactory performance.

2. It has eliminated spurious response due to ionization of air in a chamber, composed of an enclosure and any circuit elements which might be at potentials different from the enclosure, and associated with the input circuit.

Although the enclosure is 54 volts positive with respect to the grid, a 10 mg Ra source placed directly against the enclosure produces no reading on the meter with a vacuum of 29″ Hg. A curve of pressure vs. instrument reading is linear, giving 20 microamperes deflection at 16 inches vacuum with the 10 mg source. Thus, a reliable check of vacuum can be made by switching the input switch to zero set and exposing the instrument to a strong gamma source.

Provisions have been made for pumping the chamber down after air leakage has occurred. The valve which is of very simple construction is so placed that a vacuum line can be connected to it through a 3/8″ hole in the bottom of the cabinet. The construction of this valve is such that only a moderate vacuum can be obtained. Consequently, the unit should not be connected to a system in which high vacuums are intended. Lubricating the valve screw with heavy Apezion or Silicone grease is required to obtain 29″. However, after the valve is closed, it is vacuum tight.

V CHAMBER AND SENSITIVITY

A 2″ meter can be read with some degree of confidence at 1/4 scale. Consequently, it was decided that the instrument, to fulfill the requirement of paragraph four, should read between 50 and 100 mr/hr full-scale. The maximum value of grid resistance, unless excessive time constants can be tolerated, is 10^{11} ohms.

Chamber design must therefore be such that approximately 4 x 10^{-12} amperes are produced with 50 mr/hr radiation.

The current from an ion chamber is expressed by:

$$\text{Ion current} = \frac{V \times R}{K} \times 10^{-12}$$

where

V = Volume in c.c.

R = Radiation in Roentgens per 8 hrs.

K = 86.4

With the above given values, the volume of the chamber required is 864 c.c. for 50 mr/hr.

Chamber dimensions of 3″ diameter and 5 1/4″ length were selected and gives a volume of 662 c.c. This volume is less than the computed value. However, the Dentalab resistors used ran from 1.1 to 1.4 x 10^{11} ohms so the sensitivity was satisfactory.

The chamber has a .001″ nylon window in the front for beta measurements. This window can be covered with a hinged 1/4″ bakelite door for gamma measurements in the presence of betas.

With 54 volts applied to the chamber, lack of saturation begins to appear at about 2000 mr/hr. Future instruments will be equipped with the new Type 412 Mini-Max $22\frac{1}{2}$ volt batteries. These batteries will permit 90 volts of chamber supply in the same space as the present 45 volt hearing aid batteries.

VI PERFORMANCE

The B battery has a useful life of well over 600 hours, and the A battery over 100 hours.

Stability is many, many times better than any previous instruments. For example, before enclosing the circuit in a vacuum the drift after 16 hours was more than 20 microamperes. After vacuum enclosure, the 16 hour drift is only 3/4 microampere. After turning the amplifier on, a slow but steady drift occurs. With new batteries, the drift is negligible after 15 seconds. As batteries age this time increases.

Radiation sensitivity at full-scale is between 40 and 70 mr/hr up to 5,000 mr/hr and is dependent upon the grid resistors.

Calibration is not linear, but does not deviate from linearity sufficiently to prevent approximate interpolation.

No guard circuit has been used on the Kovar or Amphenol 93-C connector. If these critical areas are thoroughly and completely cleaned, leakage sufficient to affect the instrument is absent. Leakage trouble in previous instruments has no doubt occurred in areas which have not or cannot be thoroughly cleaned after assembling the parts into a unit.

ACKNOWLEDGMENTS

Acknowledgments are hereby made to G. W. Parker for suggestions leading to the case design and also to D. R. Luster for chamber design, and to W. A. Adcock for suggesting the vacuum seal used on the switch shaft.

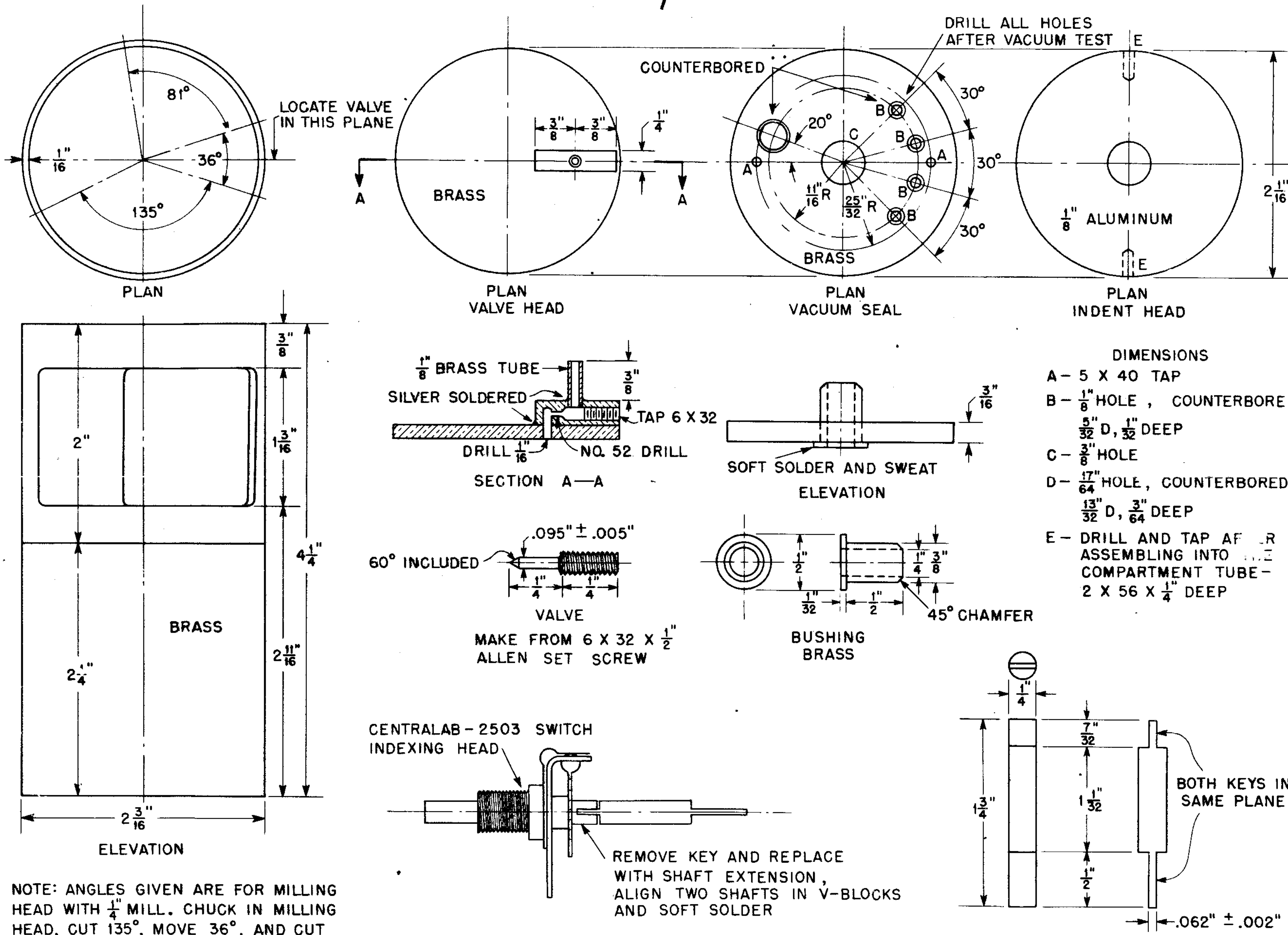
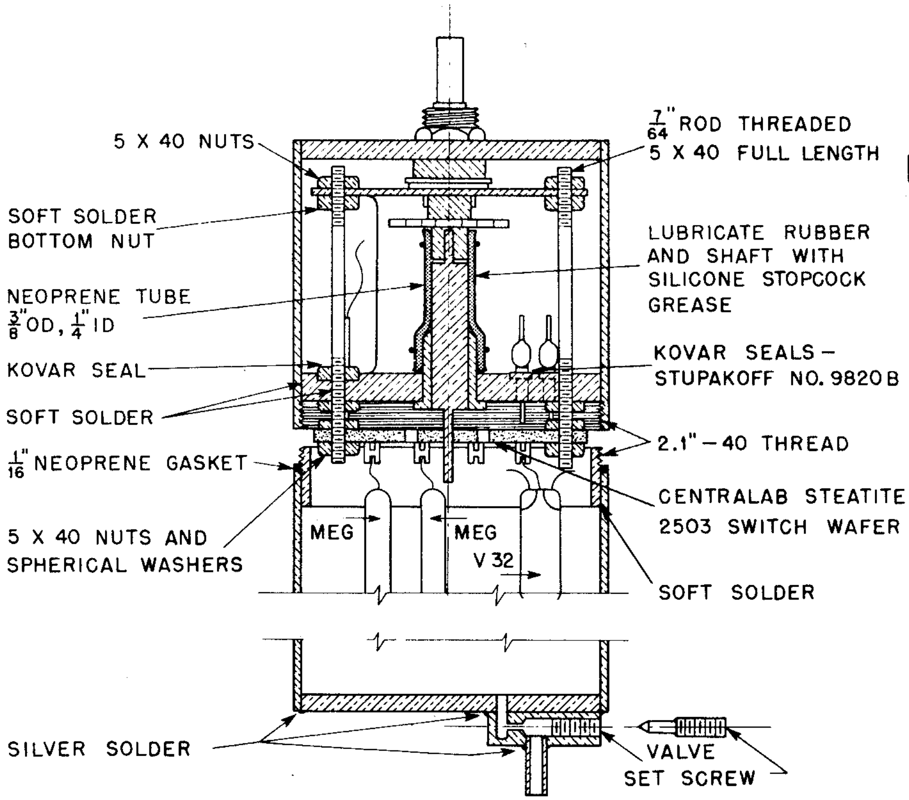
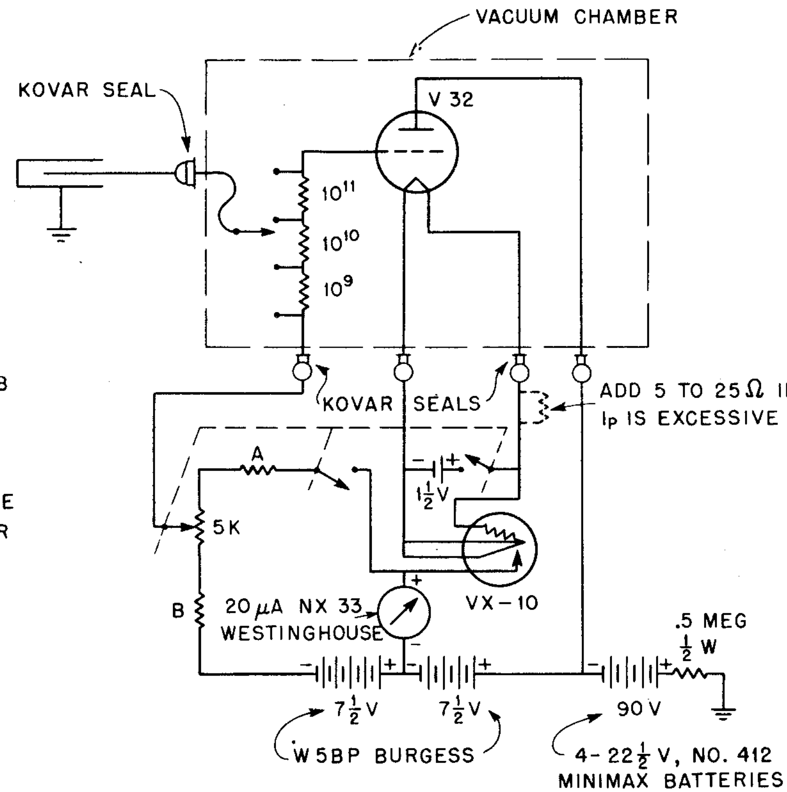


Figure 1. "Cutie Pie" circuit and vacuum unit.



VACUUM UNIT ASSEMBLY
SHOWN AT SECTION A–A

NOTE: SOFT SOLDER AND THOROUGHLY SWEAT ALL METAL PARTS PASSING THRU VACUUM SEAL
MATERIAL: BRASS TUBING, $2\frac{1}{4}$" OD – $\frac{1}{8}$" WALL
BRASS TUBING, $2\frac{1}{4}$" OD – $\frac{1}{4}$" WALL



CUTIE PIE CIRCUIT

NOTE: A – 10 K, $\frac{1}{2}$ WATT
B – 50 K, $\frac{1}{2}$ WATT
IF PLATE CIRCUIT IS TOO LOW
MAKE A – 12.5 K, $\frac{1}{2}$ WATT
B – 65 K, $\frac{1}{2}$ WATT

Figure 1. (Continued).

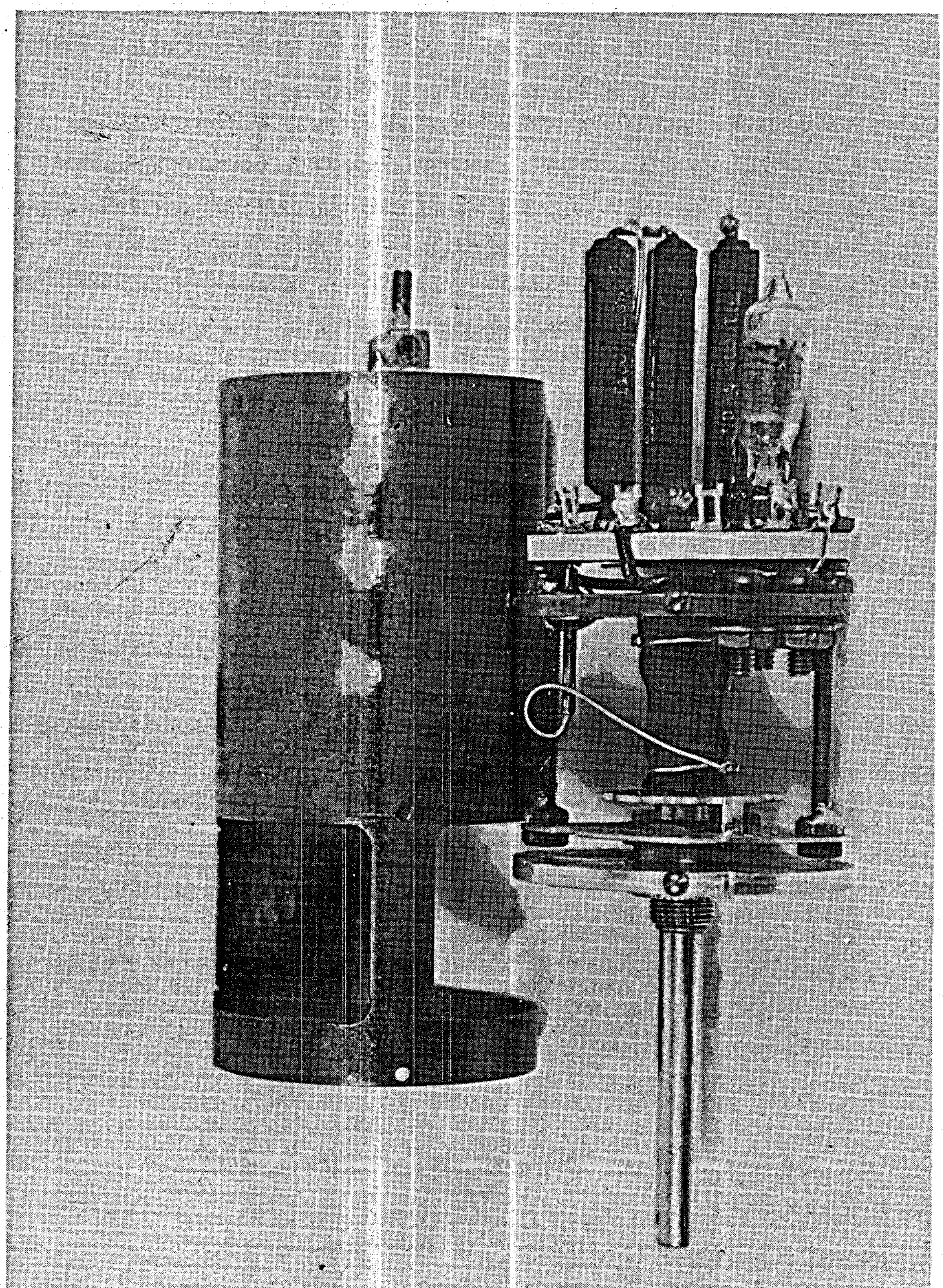


Figure 2.

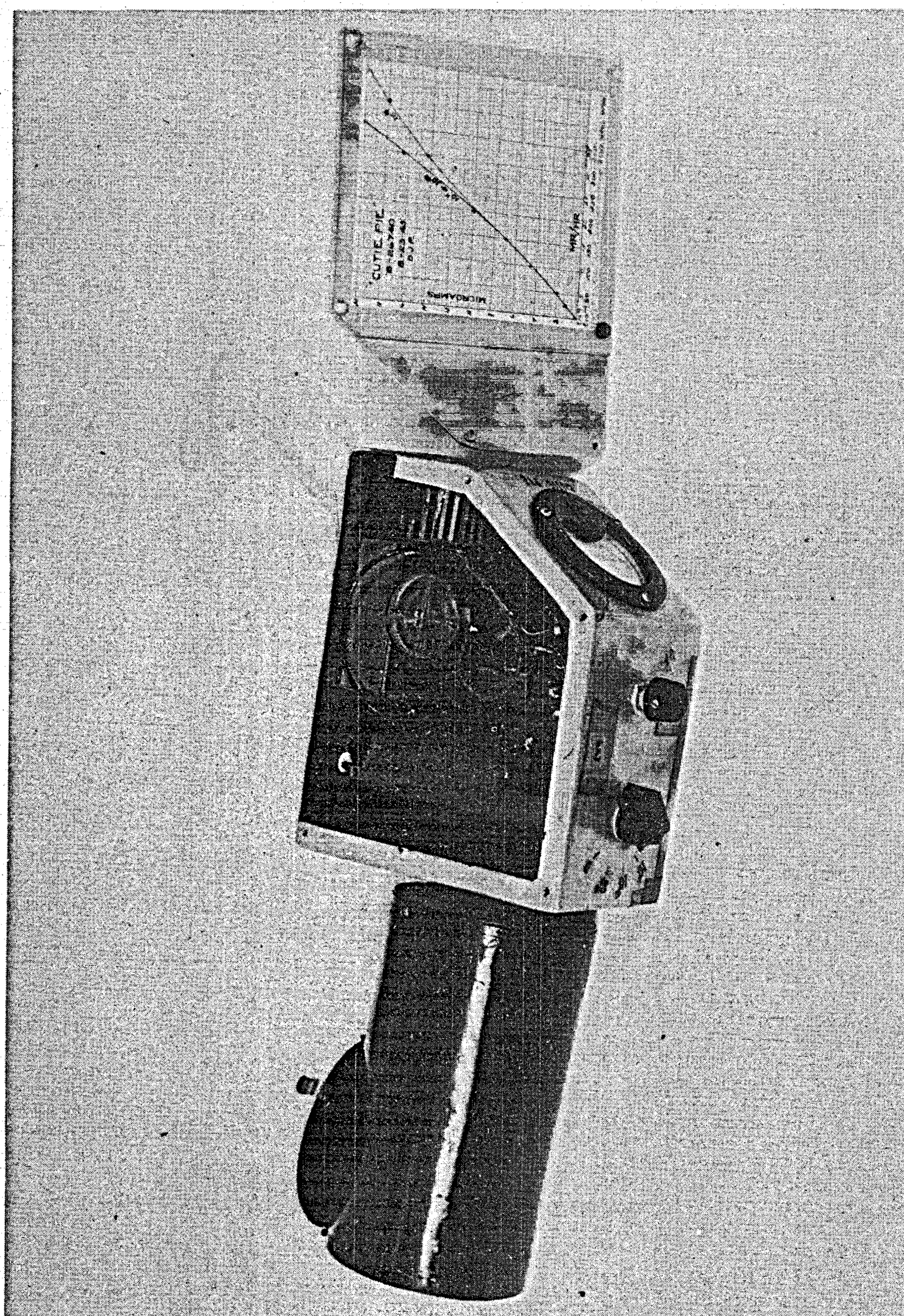


Figure 3.

2 " AND
1-10