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APPLICATIONS OF A SMALL, WIDE-RANGE GAMMA DETECTOR

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October 1955

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ABSTRACT

A small gamma probe operable between 100 mr/hr and 10^3 r/hr was built to measure gamma ray intensities near a large nonuniform source or in a large nonuniform field. The sensitive element, a thallium-activated sodium iodide crystal, is observed by a phototube. Four applications of the unit are described.

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INTRODUCTION

Local measurements of gamma ray intensities are frequently needed near a large nonuniform source or in a large nonuniform field. For example, it may be necessary to know the variation of gamma intensity over a large radioactive object. For many cases a gamma shield having a window exposing only a small portion of the object is impractical. However, a detector that has a volume of only a few cubic centimeters can give good resolution when it is placed close to the surface of the object.

An ionization chamber meeting the "point detector" requirement would be rather complicated to build because several atmospheres of gas pressure would be required to obtain measurable currents in the mr/hr range. The requirement can be met more easily by a small gamma-sensitive crystal, after the method of Maxwell[1], in which the crystal is coupled to a phototube and the average phototube current is measured.

SUMMARY

"Point detector" gamma probes were built that operate on the principle of measuring the average output current of a phototube looking at a scintillating crystal. Crystals as small as 3.6 cubic centimeters in volume were used with standard multiplier-type phototubes.

The success of the "point detector" feature results from the high sensitivity of the phototubes to light pulses from the crystal. The current from the photocathode of a phototube having an end window 1.25 inches in diameter is 10^{-10} ampere per r/hr per cm^3 of sodium iodide crystal. By contrast, an ionization chamber of similar size filled with nitrogen to one atmosphere pressure has an approximate sensitivity of only 3×10^{-13} ampere per r/hr per cm^3.

The normal threshold of the scintillation detector is 1 r/hr when the photocathode current is measured directly. This threshold can be lowered to 1 mr/hr by a special assembly technique in which the surface-leakage currents are reduced, or, at the expense of losing constancy of calibration, by the use of several stages of dynode multiplication.

The response of the detector is linear up to at least 10^3 r/hr. Operation at higher intensities is not recommended because the life of the instrument is limited to about 10^5r by radiation damage to the crystal window and to the phototube.

When short response times of the order of minutes are required, the range of the instrument is limited by phosphorescence to about two decades below the highest reading.

DISCUSSION

METHOD

Gamma radiation may be measured with a scintillation crystal and phototube either by counting pulses or by measuring the average current. The counting method is in common use but requires complicated electronic systems when the counting rate is high. To measure the average current, the simple electrical circuit shown in Figure 1 is satisfactory. The electrometer measures the voltage that the phototube current develops across the reference resistor.

The continuous-current method has the added advantage of indicating a quantity that is a function of the total gamma energy absorbed per unit volume, or of the "dose-rate," rather than indicating gamma flux. The phototube current is directly proportional to the light output of the crystal and increases with the energy of the photons bombarding the crystal. The latter relation is not quite proportional, however, because the absorption coefficient of the crystal decreases with increasing gamma ray energy. Data taken on this point by Paul[2] for NaI(Tl) crystals are reproduced in Figure 2.

End-window multiplier phototubes were used to obtain high sensitivity. The combination of a large photocathode surface and good optical coupling between the crystal and phototube gave a high conversion efficiency.

The sensitivity at the photocathode was found to be about 300 times greater than that of an ionization chamber. A cylindrical NaI(Tl) crystal 1/2 inch long and 3/4 inch in diameter, attached to an end-window phototube 1-1/4 inches in diameter, was exposed to 1 r/hr of gamma radiation. The photocathode current was about 10^{-10} ampere per cm^3 of crystal. For nitrogen-filled chambers at atmospheric pressure, the corresponding sensitivity is only about 3×10^{-13} ampere per cm^3.

Owing to the high sensitivity of the crystal detector, the photocathode current may be measured directly without being amplified by the photomultiplier dynodes. Bypassing the dynodes permits connecting the phototube to a positive input micromicroammeter. A positive-input micromicroammeter is one in which the current being measured tends to produce a positive potential with respect to ground on the input terminal. This is an advantage because some current detectors, such as the Beckman Model V micromicroammeter must be modified to measure currents that require a negative input with respect to ground. For precision gamma monitoring there is the additional advantage that the inherent fluctuations in the gain of the multiplier dynodes are not a problem.

When the photocathode current is measured directly, the gamma threshold is about 1 r/hr unless special precautions are taken. Leakage currents at the base of the photomultiplier tube prevent operation at lower levels. To lower the threshold to about 100 mr/hr, the tube base was removed and the collecting voltage was reduced. Figure 3 shows that a linear response to radiation was obtained down to 100 mr/hr with a collecting potential of 20 volts. Berman and Harris[3] further lowered the threshold to 1 mr/hr by guarding the leads at the glass seals with "Aquadag."

The scintillation probe should not be used to measure radiation intensities much over 10^3 r/hr. Radiation damage to the glass that seals the crystal and to the photocathode limits the life of the probe to about 10^5 r.

The NaI(Tl) crystals phosphoresce. This effect limits the use of the detector in applications where a fast response is required. Response times in the order of minutes limit the range to within two decades below the highest reading. The phosphorescence decays at approximately one decade per hour.

Four practical applications were developed for this type of scintillation device. Their descriptions follow.

APPLICATIONS

Storage Basin Monitor

The "Storage Basin Monitor" surveys irradiated materials under water. A cylindrical NaI(Tl) crystal which is 1/2 inch long and 3/4 inch in diameter is used. It is coupled to either the Type 6291 or Type 6199 multiplier phototube. The instrument is mounted in a water-tight enclosure. The disassembled unit is shown in Figure 4.

The photocathode current is measured directly with the circuit shown in Figure 1. The voltage developed across the reference resistor is read with a Keithley Model 200A electrometer. The sensitivity is 3×10^{-10} ampere per r/hr.

A total range from 0.1 r/hr to 10^5 r/hr is achieved by the use of reference resistors between 3×10^5 and 3×10^{10} ohms. Radiation damage limits the normal use to intensities less than 10^3 r/hr. The base of the phototube can be removed to reach the threshold of 0.1 r/hr.

High Level Cave Probe

The "High Level Cave Probe" is used for measuring the radiation intensity inside high level caves, during operation or before the caves are opened. Its principal application is to determine whether it is safe for an operator to enter the cave.

The probe consists of a cylindrical crystal, 1/2 inch long and 3/4 inch in diameter, which is taped to a Type 6291 photomultiplier. The probe housing is made of stainless steel with aluminum end caps and is tight to both air and light. Electrical connections are provided by a 25-foot triaxial cable which enters the housing through a compression fitting. Figure 5 is a photograph of the instrument.

In the assembly of the probe, great care was taken to cut down leakage currents. The base of the tube was removed and connections were made directly from the triax cable to the bulb leads. The inner parts of the probe were washed in acetone before assembly and a small amount of desiccant was placed in the probe to take up any moisture present after the probe was closed.

The probe has a sensitivity of 4.3×10^{-10} ampere per r/hr when used with a 200-volt collecting potential and 4.1×10^{-10} ampere per r/hr when used with 20 volts. With 200 volts the lower radiation limit is about 1 r/hr.

The current detector used with the probe is a Beckman Model V micromicroammeter. This micromicroammeter has a range from 3×10^{-13} to 3×10^{-7} ampere and provides a 200-volt power source for the probe.

Wire-Monitor Probe

The "Wire Monitor Probe" is used to monitor a moving irradiated wire. The range of the probe is from 100 mr/hr to 10^3 r/hr. The instrument responds fast enough to follow variations in intensity of two per cent while scanning a three-inch sample of wire moving at the rate of 5 ft/min.

Except for a different phototube and crystal the construction of the probe is identical to that of the high level cave probe. The phototube is a 6292 and the NaI(Tl) crystal is 1-3/8 inches in diameter and 1/2 inch thick. The current detector is a Beckman Model V micromicroammeter.

The probe has a sensitivity of 1.12×10^{-9} ampere per r/hr and a lower limit of about 100 mr/hr. A photograph of the probe appears in Figure 6.

Fishpole Probe

A "Fishpole Probe" ten feet long was constructed. It has a range from 1 r/hr to 1000 r/hr. Such a probe is of value in Health Physics work for monitoring highly active sources from safe distances.

The probe consists of a cylindrical crystal 1/2 inch long and 3/4 inch in diameter taped to a miniature photomultiplier tube Type K1211. The crystal and tube are encased in a stainless steel can at the end of a ten-foot aluminum pole. A photograph of the probe is shown in Figure 7. At the other end of the pole is a box containing a micromicroammeter which is a mechanically modified Keithley Model 200A electrometer circuit. A photograph of the control box appears in Figure 8.

The probe has a sensitivity of about 0.8 x 10^{-10} ampere per r/hr and a low sensitivity limit of about 1 r/hr. The probe was linear up to 30 r/hr, a limit which was set by the strength of the available source.

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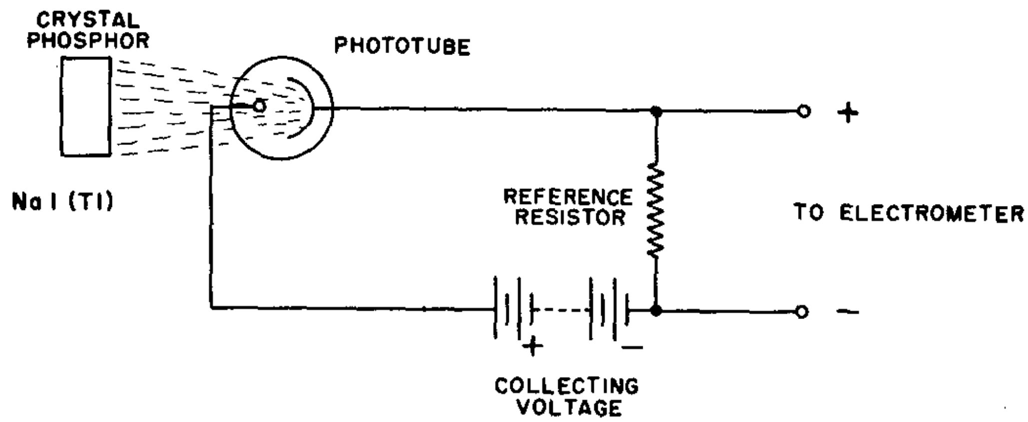
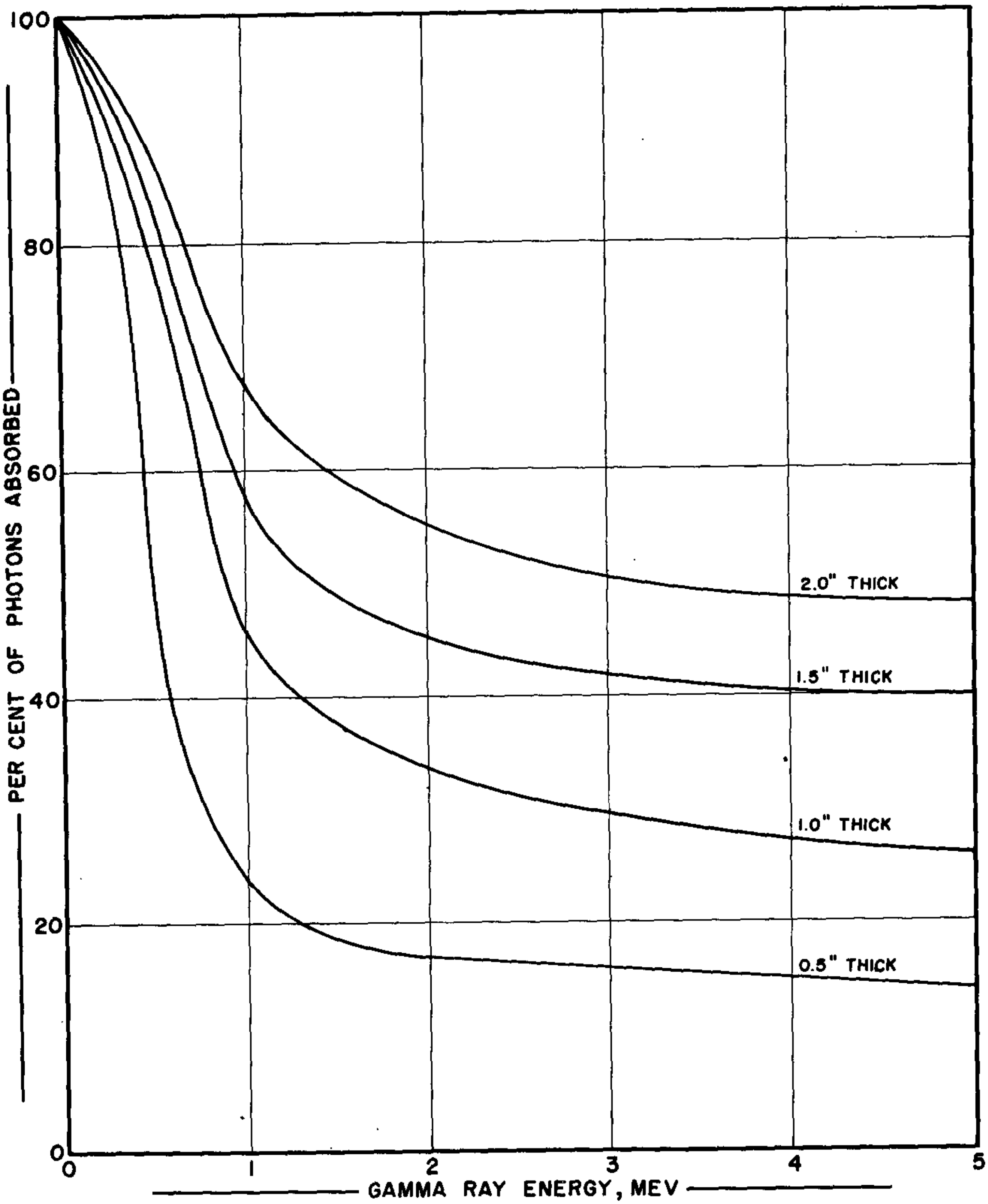
3. Berman, A. I. and Harris, J. N. "Precision Measurement of Uniformity of Materials by Gamma Ray Transmission." Rev. of Sci. Inst. 25, pp. 21-29 (1954).

FIGURE 1



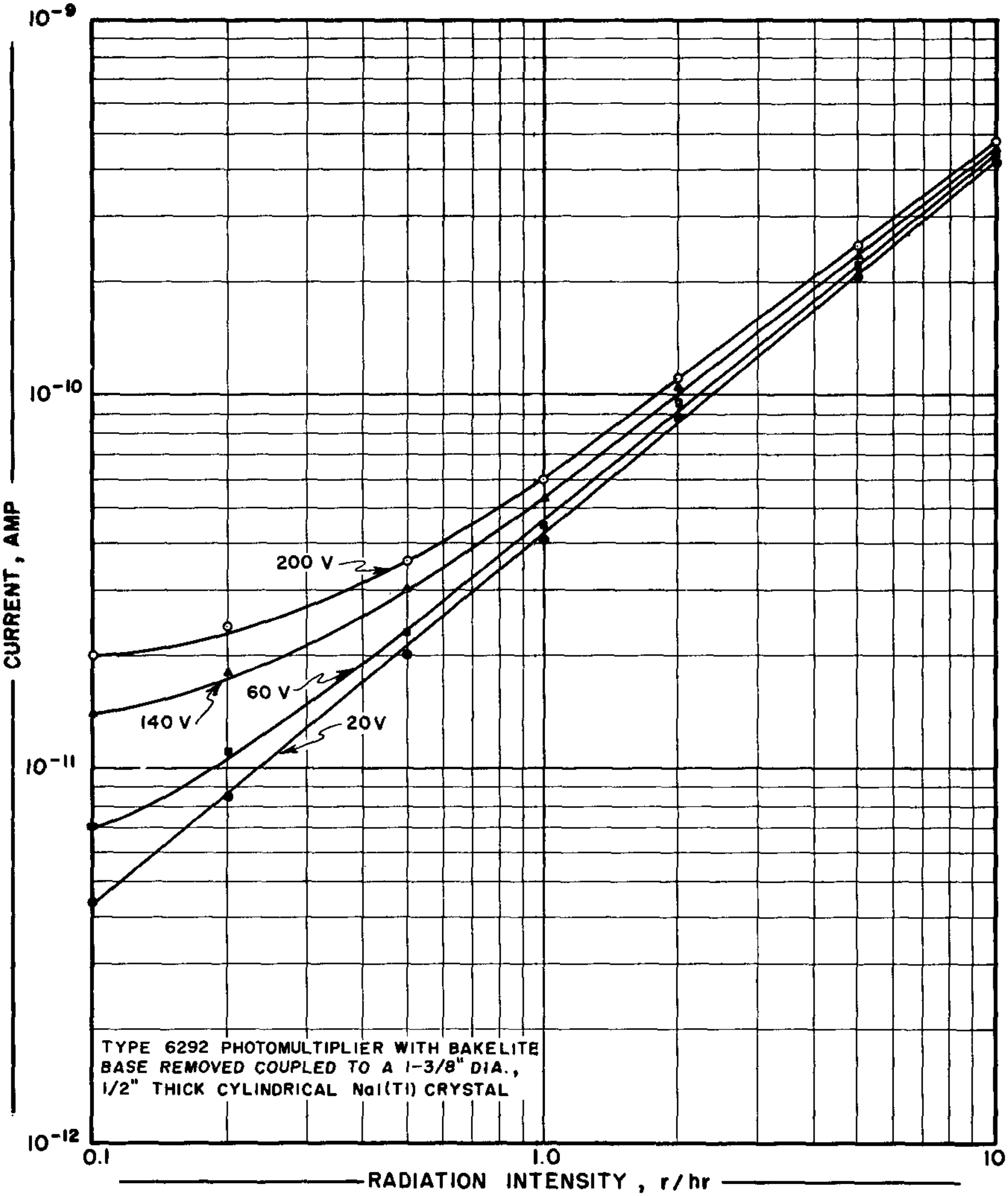
SCHEMATIC WIRING DIAGRAM OF TYPICAL DETECTOR

FIGURE 2



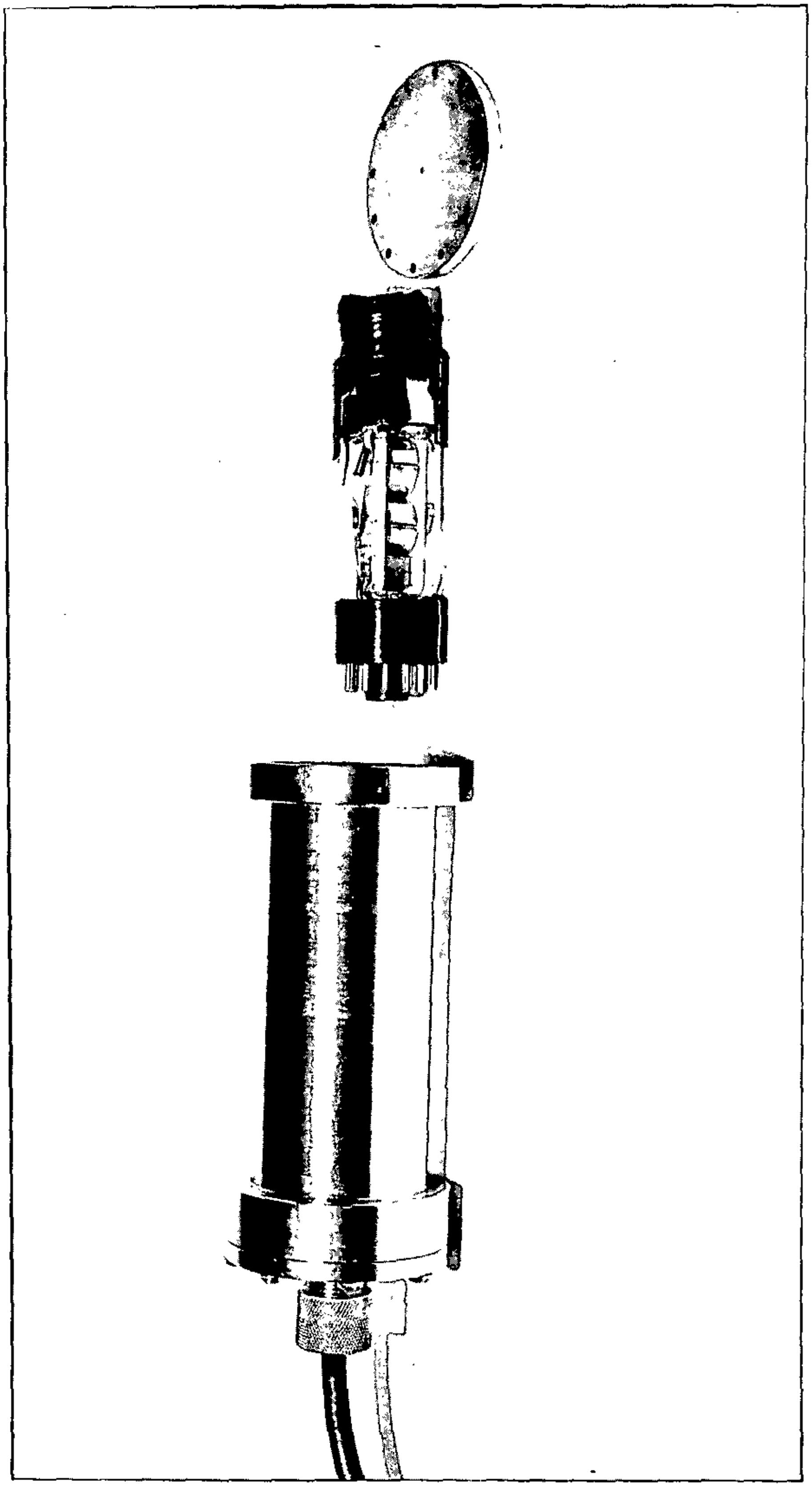
GAMMA RAY ABSORPTIONS IN NaI (Tl) CRYSTALS FOR VARIOUS GAMMA RAY ENERGIES AND CRYSTAL THICKNESSES

FIGURE 3



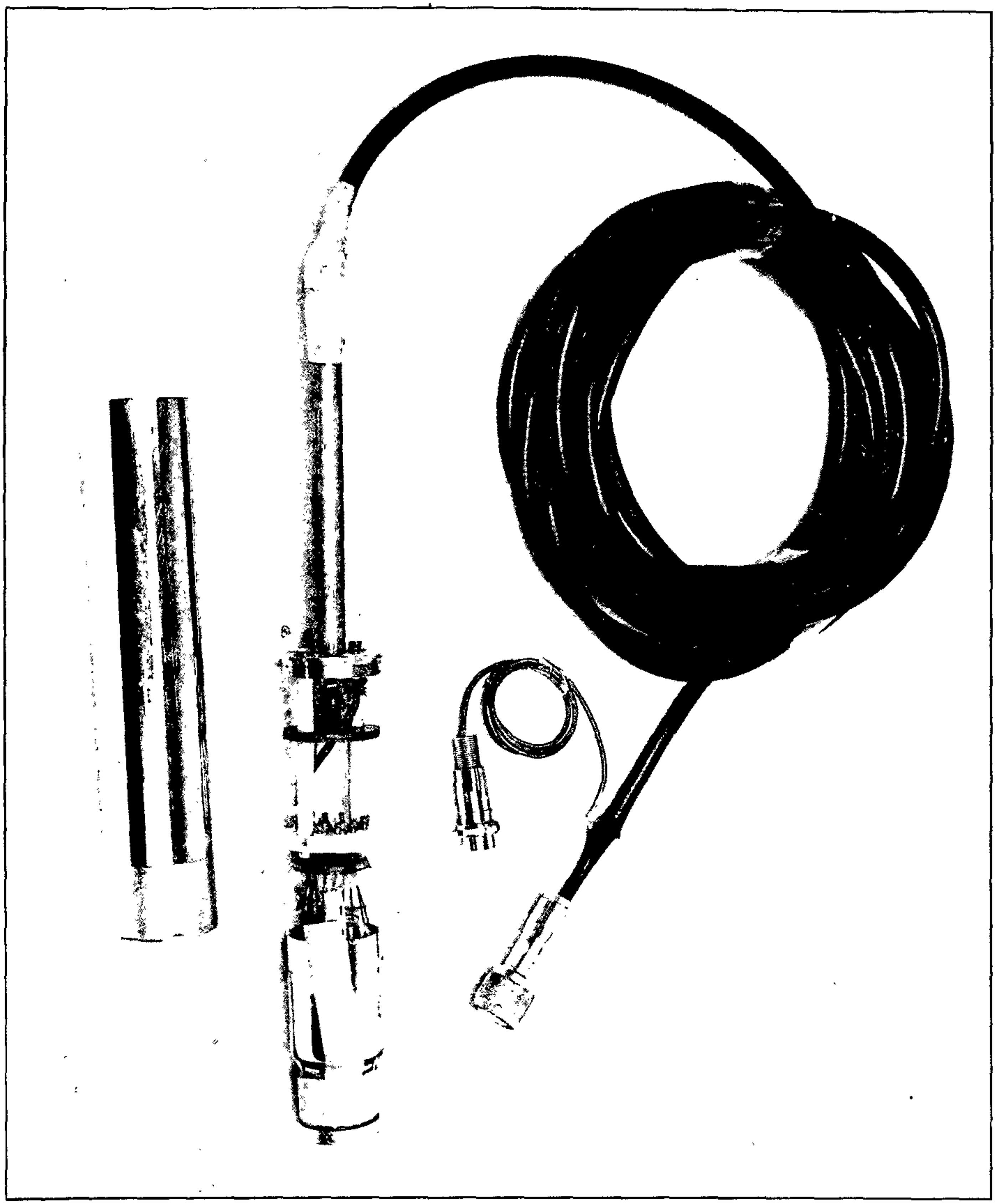
CURRENT vs. RADIATION INTENSITY AT VARIOUS FIRST DYNODE VOLTAGES

FIGURE 4



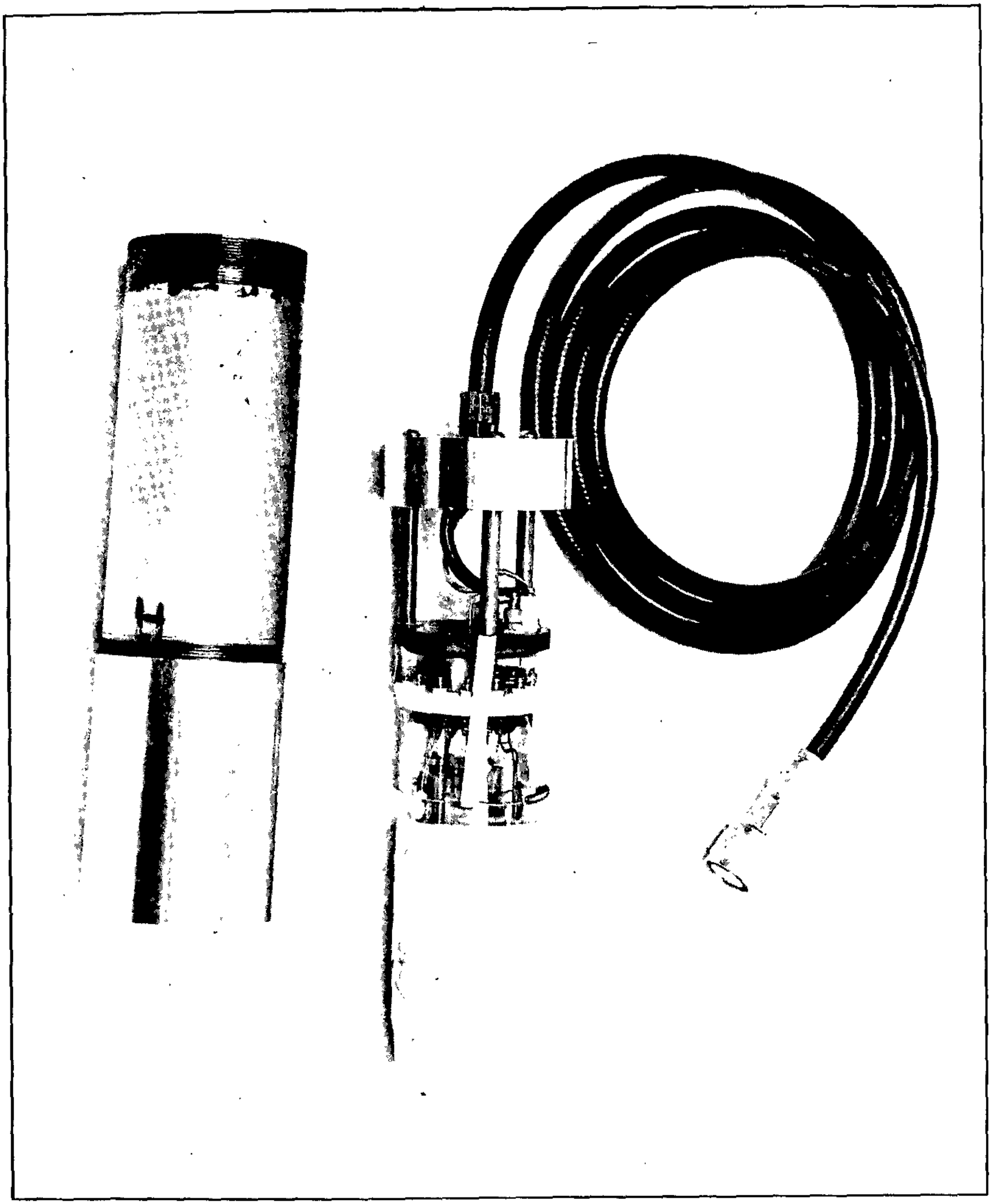
DISASSEMBLED PROBE OF THE STORAGE BASIN MONITOR

FIGURE 5



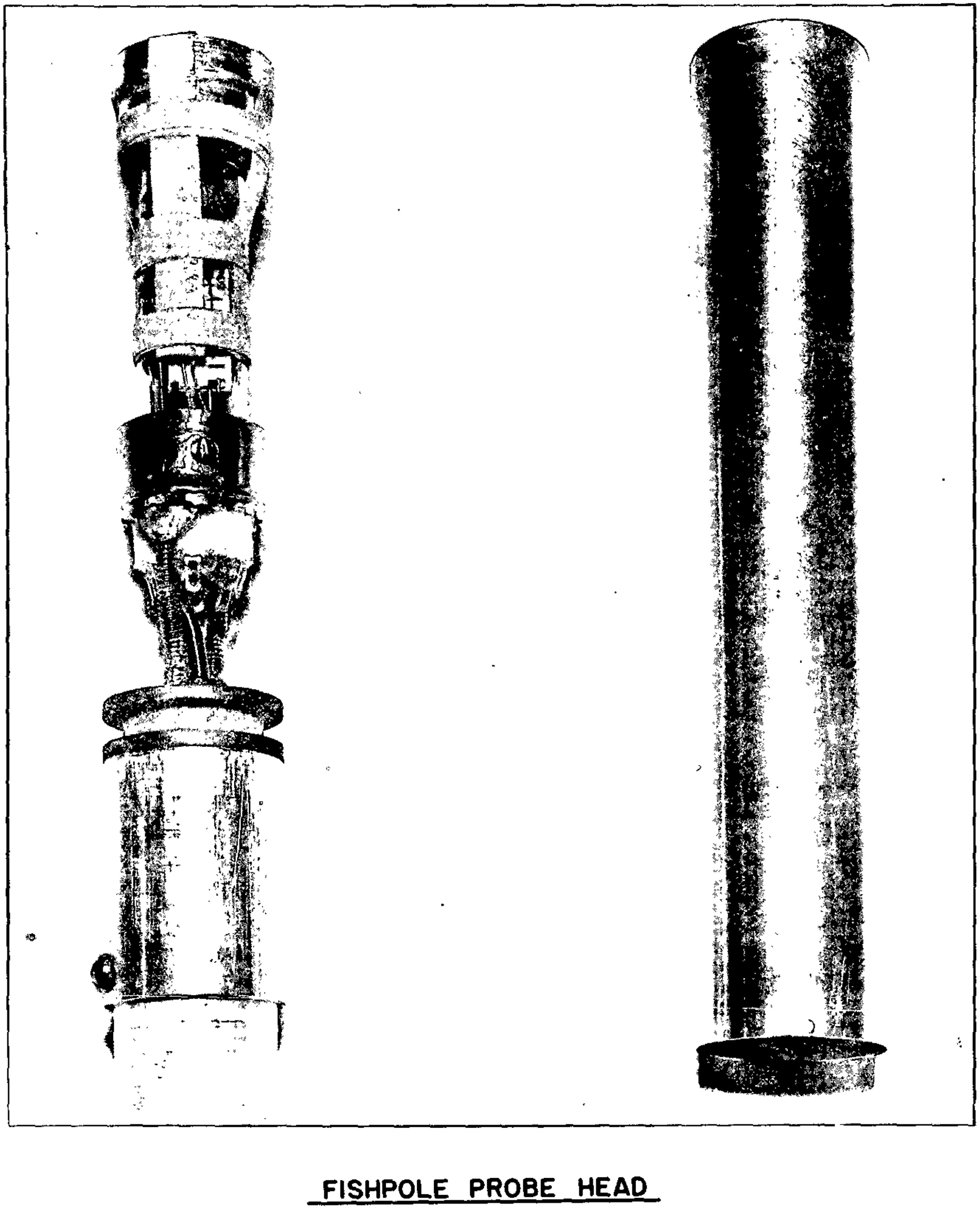
HIGH LEVEL CAVE PROBE

FIGURE 6



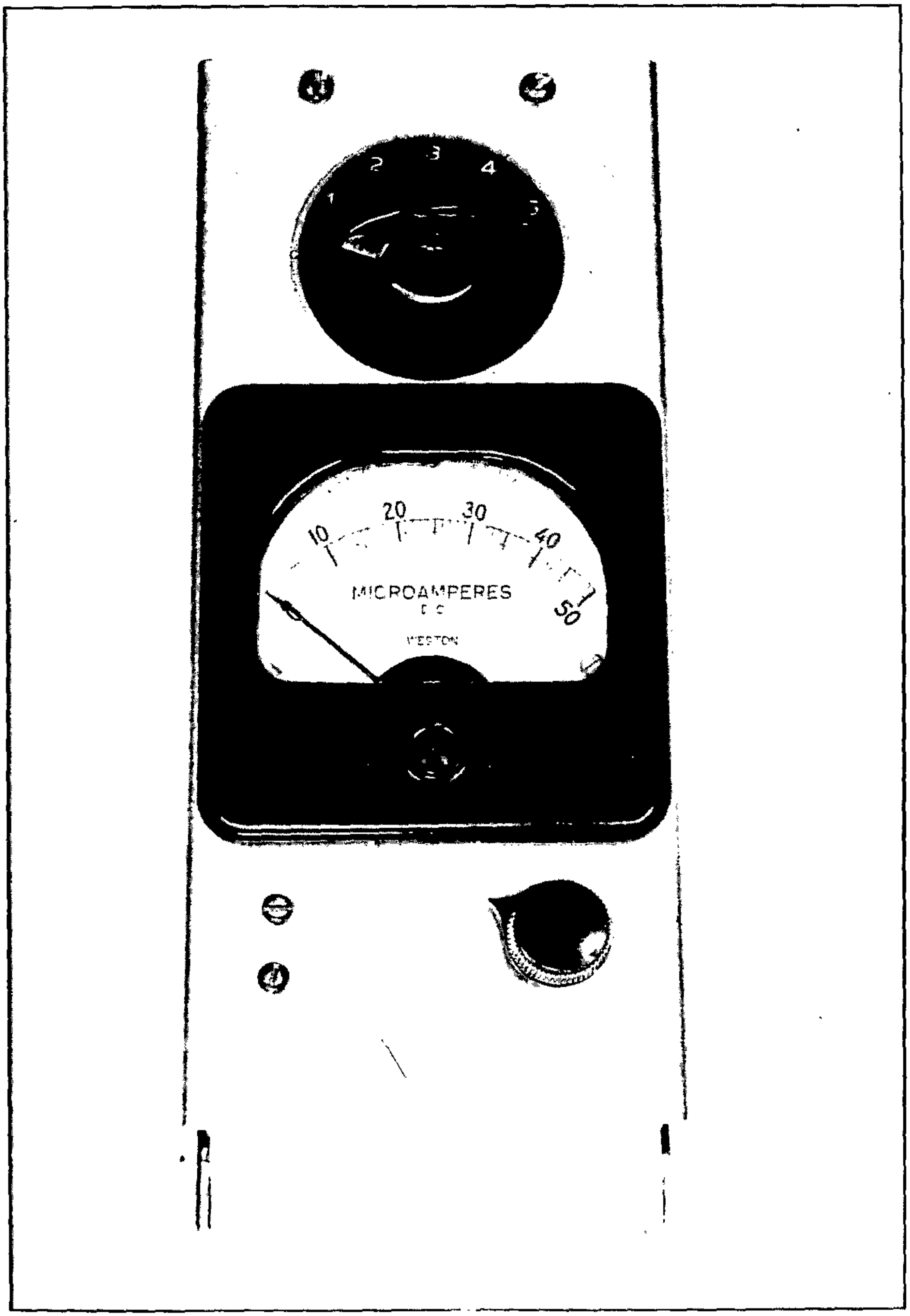
WIRE MONITOR PROBE

FIGURE 7



FISHPOLE PROBE HEAD

FIGURE 8



CONTROL BOX FOR FISHPOLE PROBE