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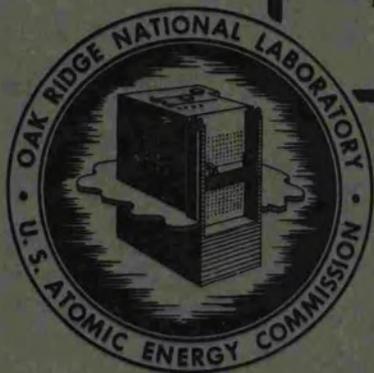
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DOSE RATES OF RADIATION
FROM NATURAL URANIUM

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DOSE RATES OF RADIATION FROM NATURAL URANIUM

by

T. E. Bortner

Physics of Nuclear Radiation
Section of Health Physics Division

Date Issued: **SEP 26 1950**

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DOSE RATES OF RADIATION FROM NATURAL URANIUM

Abstract

Rates of ionization of air at the surface of a thick disk of natural uranium, produced by the radiations from the uranium, were measured with an extrapolation chamber. The measured rate of ionization is a function of the atomic number of the material used as a collecting electrode. Using a carbon collector, the total rate of ionization of the air is 14.4 esu per cc per hr, reduced to standard temperature and pressure. With the alpha radiation filtered out, the rate of ionization due to the residual radiation (principally beta) is 0.24 esu per cc per hr.

The measured values of ionization rates due to the filtered radiation, using seven collecting electrodes ranging in atomic number from that of beryllium to that of lead, were found to range from 0.216 esu per cc per hr to 0.504 esu per cc per hr. The experimental results obtained are such that a logarithmic graph of measured ionization rate versus atomic number of collector material is a straight line.

DOSE RATES OF RADIATION FROM NATURAL URANIUM

Instrumentation

The extrapolation chamber, shown in Figure 1, is essentially the same as that described by Sheppard and Abele, ORNL-265. The collecting electrode and guard ring have respective diameters of 2 cm and 7.5 cm, and are separated by a space of 0.005 inches. Both are threaded so that they screw down tightly to form a single flat surface. Separation and parallelism of the electrodes are determined by means of a micrometer depth gauge.

The dial of the movable shell of the chamber is threaded with a pitch of one millimeter. The circumference is divided, by an engraved scale, into 40 divisions. Inaccuracy of the thread was tested with a micrometer depth gauge and with a cathetometer and was found to be less than one percent in the range used.

Two reed electrometers, built by the Applied Physics Corporation, were used with practically identical results. Resistors of 5×10^{11} ohms and 1×10^{12} ohms were used. These were manufactured by the Victoreen Instrument Company and calibrated by Floyd Glass of the Oak Ridge National Laboratory Instrument Department and by the National Bureau of Standards. Condensers manufactured by John E. Fast Company and chosen to give an RC time constant of five minutes gave very steady operation. The electrometer was used as a null instrument with the output indicated on a recorder. The compensating emf, measured in millivolts on a potentiometer, was used to compute the rate of ionization using the equation,

$$I = 3600 \text{ sec/hr} \times 3 \times 10^9 \text{ esu/coulomb} \times \frac{760 \text{ mm Hg}}{273^\circ \text{ K}} \times \frac{TE}{PRV}$$

where

I = rate of ionization (esu per cc per hour)

P = barometric pressure at time of measurement (mm of Hg),

T = absolute temperature at time of measurement ($^\circ\text{K}$)

E = electrometer potential (volts)

R = resistance of electrometer circuit (ohms), and

V = volume of air from which ions are collected (cc).

Method and Results

The source of radiations was a disk of natural uranium metal three inches in diameter and three-eighths of an inch thick with the surface hand-lapped to a tolerance of 0.0001 inches. In measuring the total rate of ionization of air at the surface, the uranium disk was used as an electrode of the extrapolation chamber. The measurement of the rate of ionization due to the radiation other than alpha was accomplished by filtering out the alpha radiation with a thin sheet of polystyrene coated with aquadag so that it could be used as an electrode. The surface density of the polystyrene was 6.9 mg/cm^2 . This thickness of polystyrene was used because preliminary examination showed that it would exclude all alpha radiation. Calculations indicated that a thinner absorber could be used, but the possibility of microscopic holes or irregularities in thickness made the greater thickness seem advisable. The ionization rate due to beta radiation was not measured separately from that due to gamma radiation, but it is known that the contribution of the gamma radiation is relatively small.

Cyclical reversal of collecting voltage was used in all measurements to compensate for charge carried by radiated particles. Results given are averages of the values thus obtained. For the measurement of the beta-gamma ionization rate, two different electrometers were used each with collecting electrodes of both carbon and polystyrene. All measurements made with these electrometers and electrodes agreed within 0.0005 esu per cc per hr.

Figure 2 is a graph of measured values of electrometer potentials resulting from total radiation plotted against electrode separations. It will be observed that, in the range of separations used, 0.1 mm to 0.5 mm, the experimental points fall on a straight line of which the slope corresponds to a total ionization rate of 14.4 esu per cc per hr. Figure 3 is a similar graph for the beta-gamma radiations, corresponding to an ionization rate of 0.240 esu per cc per hr*. In both cases, greater

*Report CH-930, "Some Physical Aspects of the Effect of Beta Radiation on Tissue," by H. M. Parker. Four mg/cm² cellulose acetate absorber gave a value reported as 0.275 rep/hr.

*Memorandum CF-49-9-136 (Oak Ridge National Laboratory) "The Beta-Gamma Surface Dosage Rate from Natural Uranium", by Ben Kalmon. A value of 0.246 rep/hr was reported, using an aluminum absorber of 6.2 mg/cm².

*Report AECD-2753 "Extrapolation Chamber Determination of Beta Ray Surface Dose Rate from Uranium and Some Uranium Compounds", by H. Bass, H. DiGiovanni, and H. D. Levine. A value of 0.239 rep/hr was reported, using a polystyrene absorber of 7 mg/cm².

electrode separations could have been used without departure from a linear relationship. However, since the linear range for measurements with some of the collecting electrodes of higher atomic number is more limited, all final measurements were made with separations of one mm or less.

Figure 4 gives respective extrapolated values obtained for the beta-gamma ionization rates using collectors and guard rings made of beryllium, carbon, aluminum, copper, cadmium, tantalum, and lead. Except for the materials used for the collecting electrodes and guard rings, all conditions of measurement were the same as those described for carbon. While there is no comprehensive theory covering scattering and energy loss in relation to particles charge and atomic number of scattering material, it is of interest to note that when the extrapolated ionization rates are plotted on logarithmic paper as a function of the atomic number of the collecting electrode, a straight line graph is obtained.

Relationship Between Ionization Rates and Tissue Dosages

The most commonly used unit of measurement of tissue dosage by particulate radiations is the rep, defined in terms of the radiation energy absorbed per unit mass of tissue. In terms of such a unit, the rate of dosage to tissue at the surface of the metal, for a given rate of ionization, will depend both upon the stopping power of the tissue for the radiation involved and upon the energy of radiation absorbed by the air per ion pair produced. Thus the relationship between rate of tissue dosage

and rate of ionization depends upon both the composition of the tissue and the kind of particle. This relationship may be written,

$$D = KNPI$$

where

D is the rate of tissue dosage at the surface of the metal,

I is the rate of ionization per cc of air in the extrapolation chamber,

P is the stopping power of tissue for the kind of particle involved,

N is the average energy of radiation absorbed per ion pair produced in air, and

K is a constant of proportionality.

For beta radiation in average wet body tissue, the values of the physical quantities involved are such that, if the size of the rep is defined as 95 ergs per gram of tissue, KNP is approximately numerically equal to unity*. For alpha radiation in the same tissue, N is greater by the factor $\frac{36 \text{ ev/ip}}{32.5 \text{ ev/ip}}$ and P is greater by the factor 1.06*.

Using these values, the above equation may be written,

$$D_{\beta} = I_{\beta}, \text{ and}$$

$$D_{\alpha} = 1.17 I_{\alpha}$$

In the case of the extrapolation chamber measurements made with a carbon collecting electrode, the approximations in the above equations should be good since scattering by the electrode is not expected to

* ORNL-783, K. Z. Morgan: The Use of Roentgen Equivalent Physical (Rep).

differ greatly from that by tissue. Thus, if the rep is defined as a tissue dosage of 95 ergs per gram, the measured rates of ionization are believed to correspond approximately to rates of dosage to soft tissue in contact with natural uranium metal as follows:

Total radiation, 14.4 esu per cc per hr = 16.9 rep per hr; and beta-gamma radiation, 0.240 esu per cc per hr = 0.240 rep per hr.

Acknowledgements

The author wishes to acknowledge the valuable assistance of the following members of the Health Physics Division in the preparation of this report: E. E. Anderson, P. W. Reinhardt, H. K. Richards, and Forrest Western. The accuracy of the measurements was made possible by skillful construction of the extrapolation chamber by D. M. Walker and other members of the Health Physics Instrument Shop.

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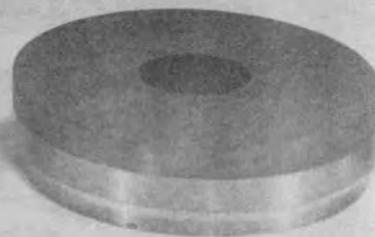
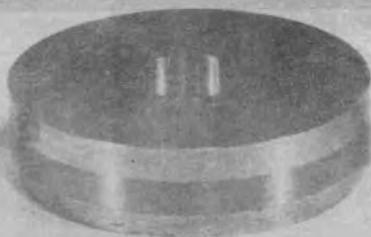
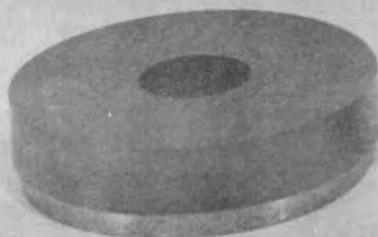
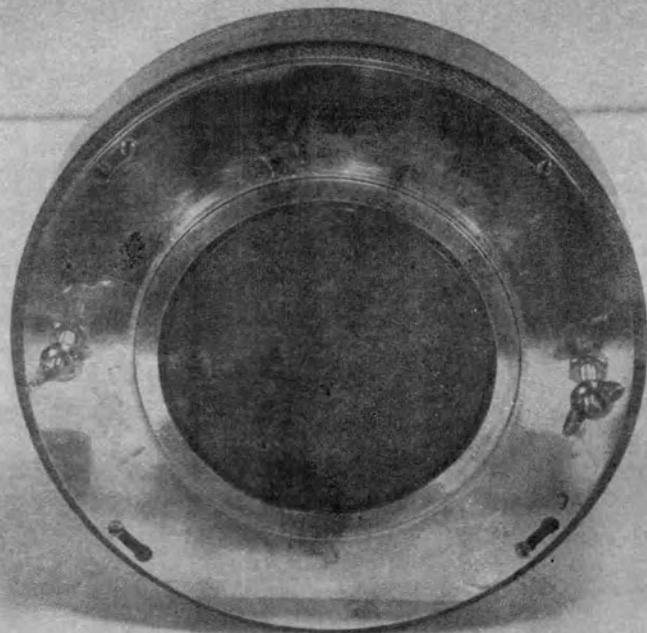
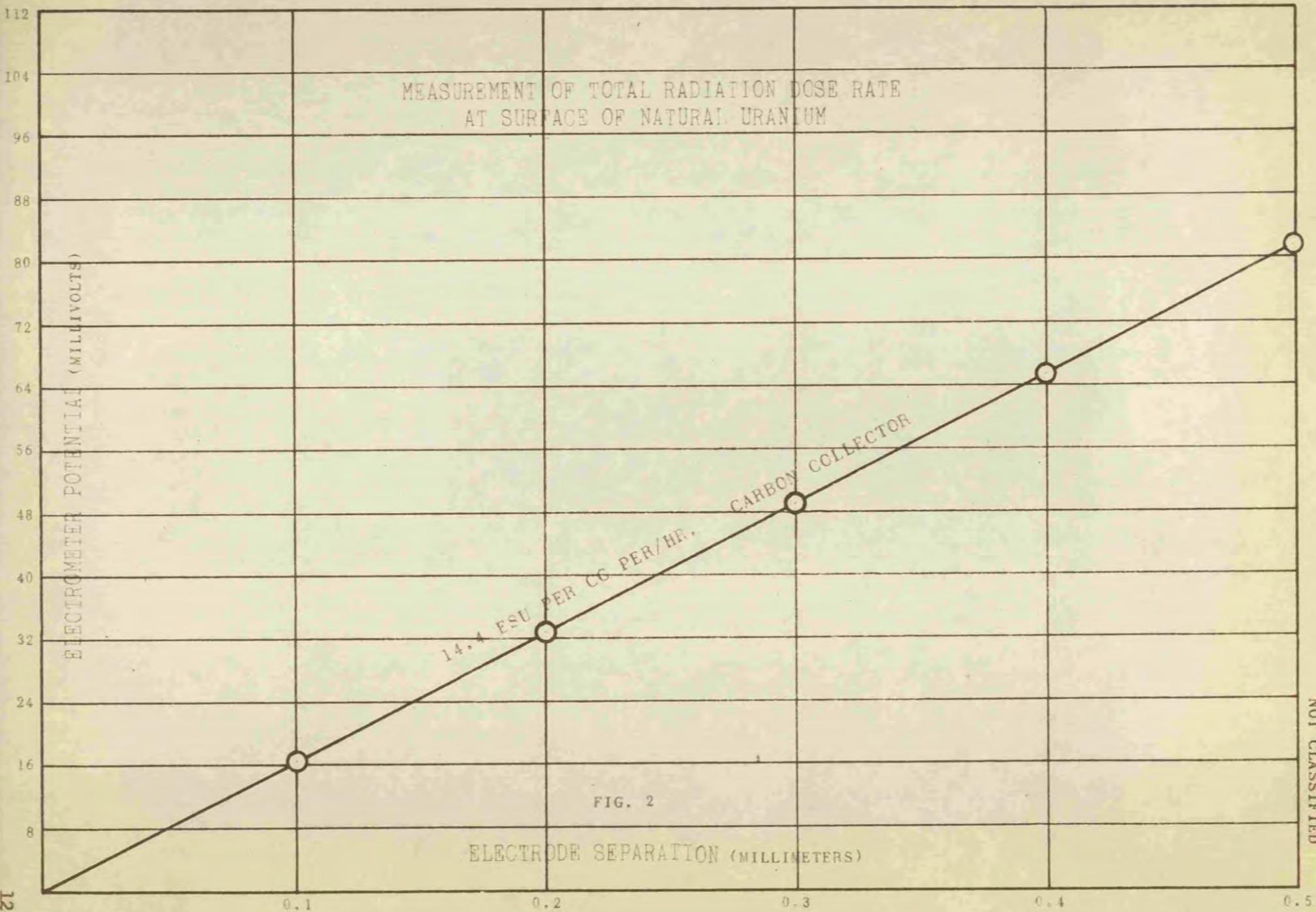


FIG. 1

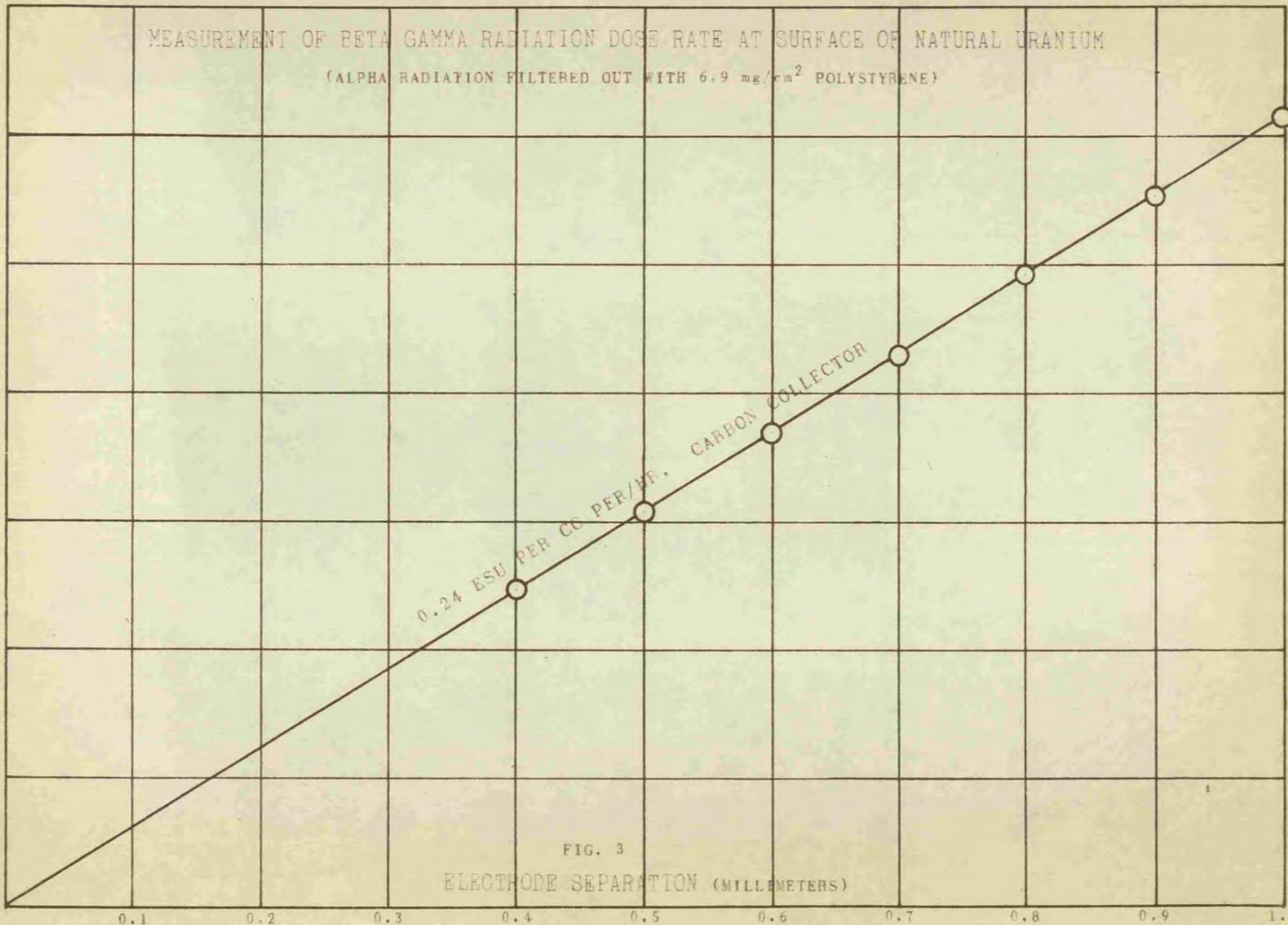


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MEASUREMENT OF BETA GAMMA RADIATION DOSE RATE AT SURFACE OF NATURAL URANIUM
(ALPHA RADIATION FILTERED OUT WITH 6.9 mg/cm² POLYSTYRENE)

0.24 ESU PER CC PER/HR. CARBON COLLECTOR

FIG. 3
ELECTRODE SEPARATION (MILLIMETERS)



MEASUREMENT OF BETA GAMMA DOSE RATES AT THE SURFACE
OF NATURAL URANIUM WITH DIFFERENT ATOMIC NUMBER COLLECTORS.

(ALPHA RADIATION FILTERED OUT WITH 6.9 mg/cm^2 POLYSTYRENE)

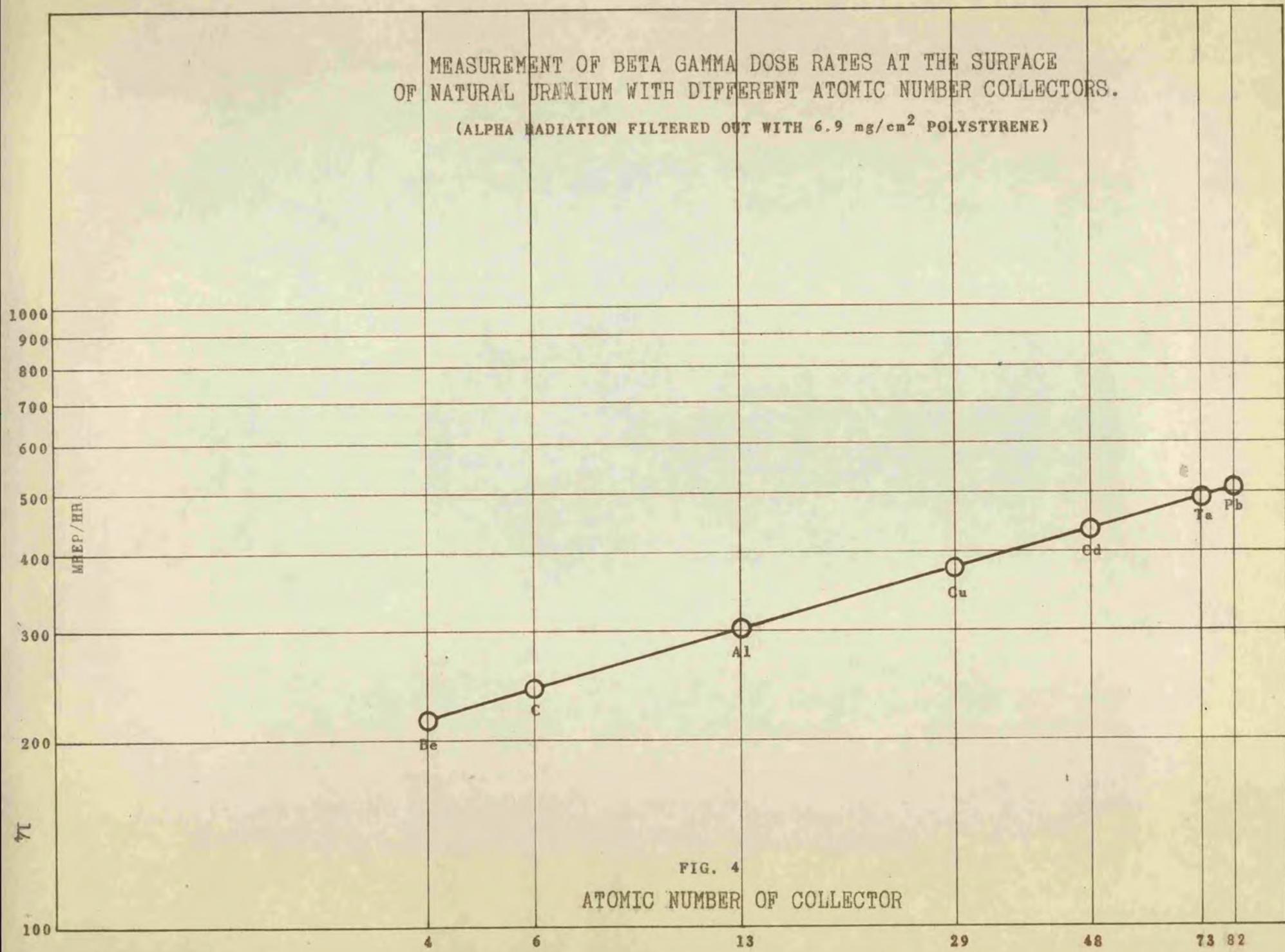


FIG. 4
ATOMIC NUMBER OF COLLECTOR