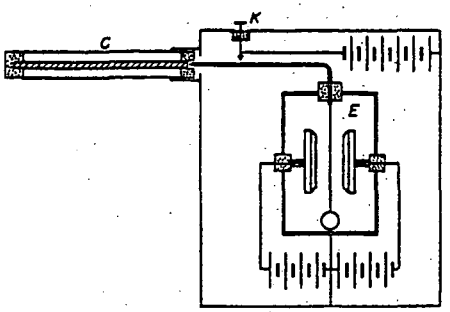

FIG. 3. Schematic diagram of the probable integrating ionization chamber for measurements of exposures to gamma rays and x-rays. *K*—charging key, *C*—detachable ionization chamber, *E*—string electrometer.

of the instrument, and the deflection of the electrometer recorded. The electrometer is so calibrated in connection with the chamber that this final reading gives directly the dose in roentgens. This measurement is based on the assumption that the decrease in voltage of the central electrode of the chamber has been produced entirely by ionization of the air in the chamber during the period of exposure. With care in selection and preparation of the insulators, this assumption can be realized sufficiently for the types of measurements under discussion. Instruments of this type are available commercially, such as the Victoreen minometer, in which all potentials are derived from an ordinary outlet from the lighting circuit.

Use of Geiger-Müller counter. For direct determination of the rate at which a dose is administered, a suitable modification of the Geiger-Müller counter has found extensive use. The principle of this device is illustrated, so far as essential features are concerned, in Figure 4. The sensitive element in this device is the Geiger-Müller counter tube. Its action depends on the release of ions from parts of the tube or gas by the gamma radiation or x-radiation as it traverses the counter. Usually a single pair of such ions produces sufficient ionization to cause a discharge between the cylinder and central wire of the counter tube. This discharge results in a sudden rise of voltage of the central wire. The voltage pulse can be amplified by a suitable vacuum-tube circuit. In Figure 4 the vacuum-tube circuit associated immediately

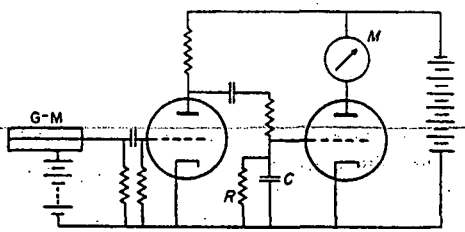

FIG. 4. Simplified diagram of vacuum-tube circuit for use with a Geiger-Müller counter tube to measure the rate of exposure to gamma rays and x-rays. G-M—counter, *M*—indicating meter, *C*—condenser in which received pulses are accumulated, *R*—resistor permitting charge to leak from condenser *C*, so that the potential across this condenser assumes a constant value for a constant rate of pulses.

with the counter serves to level, as well as amplify, the pulse. It may consist of one or several vacuum tubes connected in a variety of ways. For simplicity a single tube is shown for this part of the circuit in the figure. Sufficient rectification is also introduced into this part of the circuit so that the pulses emerging are undirectional when reaching the condenser, *C*. Therefore, a small quantity of charge is added to this

condenser for each pulse. Since the resistor, *R*, is connected across this condenser the value of the potential across the condenser will finally assume a constant value for a constant average rate of pulses. The second vacuum-tube circuit is connected as a voltmeter so that the potential can be read on the condenser by means of the meter, *M*, in the plate circuit. Thus, in a relatively short time, depending on the value of the product *RC*, after the Geiger-Müller counter has been introduced into the field of radiation the meter, *M*, will indicate the intensity of the radiation. This meter may be calibrated in roentgens per day, or some similar unit. In the same way the meter will follow changes in this intensity. This change may occur as a result of alterations in the source of radiation, or of moving the instrument to different positions in relation to the source.

Although the Geiger-Müller counter is most effective as an indicator of the rate of exposure, the circuit represented also may be converted into an integrating instrument by removing the resistor, *R*, from across the condenser. Then, the voltage on the condenser will be proportional to the number of pulses that have arrived since the condenser was last discharged. Electrical circuits associated with Geiger counters are sensitive to electrical disturbances. Therefore, they can be used in connection with x-ray installations only when carefully shielded. They also must be specially constructed and calibrated for use with x-rays of each separate spectral range. These difficulties are not ordinarily encountered in measurements of radioactivity.

Use of photographic film. A very practical method for measuring exposure to gamma rays and x-rays is by use of photographic films. With care in calibration and selection of films, the photographic method is capable of considerable accuracy. Very misleading results are obtained, however, when proper precautions are not observed. The use of x-ray dental films is very convenient, since they may be worn by an operator through a period of work extending to several days and thus provide an over-all integration of the dose received. For proper evaluation of the results, the developed films must be photometered in comparison with films from the same lot which have received known exposures to radiation of the same quality as that under investigation. Figure 5, reproduced from a paper by Fricke and

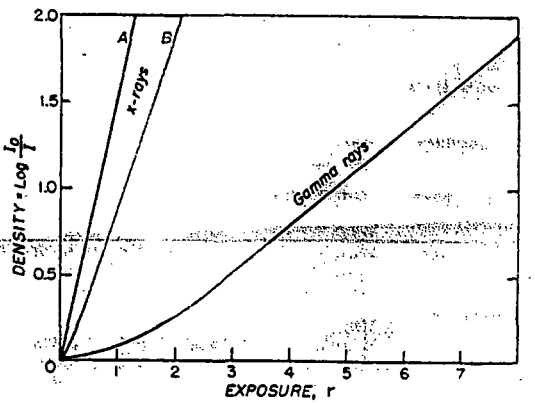

FIG. 5. Curves showing the variation in blackening in the same type of film for equal doses of x-rays and gamma rays. *A*—80 kv. x-rays, no filter, *B*—200 kv. x-rays, filtered by 2 mm. of copper. Gamma rays filtered by 6.8 mm. of gas.