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A Method of Measuring the Quantity of X-Radiation

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This is to certify that, in accordance with the requirements of South Dakota State College for the Master of Science Degree, Mr. J. Norman Cheadle has presented to this committee three bound copies of an acceptable thesis, done in the major field; and has satisfactorily passed a two-hour oral examination on the thesis, the major field, Electrical Engineering, and the minor field, Mathematics.

Advisor

October 1, 1949
Date

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Rep. of Graduate Committee

A METHOD OF MEASURING THE QUANTITY OF X-RADIATION

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A METHOD OF MEASURING THE QUANTITY OF X-RADIATION

I. The Problem

Experimentation at South Dakota State College to determine the mutations in plant life resulting from the exposure of the seeds to X-radiation, made it desirable to be able to measure the quantity of radiation to which the seeds were exposed. Seeds being used in these tests are sorgums, castor beans, sunflowers, and safflowers. The tests will require a group of successive plant generations over a period of years. The purpose of this paper is to present a method by which the quantity of X-radiation, in roentgen units, can be measured.

II. X-Rays--What Are They?

X-rays, or roentgen rays, are radiations of wave-lengths between approximately .01 and 10 Angstroms[1] and having many characteristics similar to light. They move in straight lines, can be reflected and refracted the same as light. Also like light, they are not influenced by magnetic or electric fields. However, X-rays are different in that they are invisible; they are of much shorter wave-length and are capable of penetrating opaque materials.

X-rays are used in medicine for the diagnosis and treatment of disease. In industry they are used for the examination of opaque materials. Both X-ray photography and fluoroscopy are used by the medical profession; industry principally makes use of X-ray photography, which is similar to light photography. Fluoroscopy is the use, in diagnosis, of a fluorescent screen which is activated by the X-rays converting their energy into light. The observer examines the picture as it is formed on the screen; no film is used.

The following tabulation indicates several uses of X-rays and the tube voltages generally used to produce the rays.

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1. An Angstrom is equivalent to 10^{-8} centimeter.

USES	TUBE VOLTAGES
Photography of flowers, insects, fabrics, and paper.	5 to 15 kilovolts.
Crystallography (atomic structure study).	20 to 50 kilovolts.
Medical and industrial fluoroscopy.	30 to 100 kilovolts.
Radiotherapy[2] and ordinary industrial uses.	50 to 200 kilovolts.
Deep therapy and thick-section industrial radiology.[3] (Requires special multi-section tubes.)	200 to 2,000 kilovolts.

When X-rays strike matter, they remove electrons from the orbits of atomic structures; that is, the X-rays cause ionization of the matter. Each of these removed electrons must receive from the X-rays sufficient energy to break away from its parent atom. These electrons are called secondary electrons.

According to the quantum theory of matter, X-rays consist of quanta of energy, called photons. A photon has energy but no mass. It is electrically neutral. When a photon strikes an atom it may give up its whole energy to the atom. Part of the photon energy has been used to remove an electron from the atom and the remainder of the energy goes to increase the kinetic energy of the atom. This kind of collision is called a photo-electric collision (or true absorption) and the removed electron is called a photo-electron. The electron differs from the photon in that it has a definite mass and a negative charge.

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2. "Radiotherapy is the treatment of disease by the application of roentgen rays or the rays from radio-active substances." <u>American Standard Definitions of Electrical Terms</u>, American Institute of Electrical Engineers, 1941.

3. "Radiology is that branch of science which relates to roentgen rays and radium rays." <u>American Standard Definitions of Electrical Terms</u>, <u>op</u>. <u>cit</u>.

Therefore, it has many more chances than the photon to collide with other particles when traveling through the electrical fields of the atoms. The photo-electron, then, produces along its path a series of ions whose number depends upon the original energy of the electron. Even in air, most photo-electrons are stopped within a few centimeters, but along their zig-zag path several thousand ion pairs may be formed.

Another type of collision is the Compton collision or scattering type of collision. Here the photon in knocking an electron out of its orbit around an atom gives up only a part of its energy to the electron. The photon is deviated from its path and proceeds along its new path with a reduced amount of energy. The removed electron is called a recoil electron or a Compton electron. The scattered photon may have a second and even a third Compton collision and in this way remove more recoil electrons from other atoms until its entire energy is used up. Both photo-electrons and recoil electrons are designated as secondary electrons.

As the X-ray tube voltage is increased, the number of recoil electrons increases while the number of photo-electrons decreases. This is readily understandable as the higher tube voltage means increased energy photons which then bounce from one atom to another before all of their energy is spent.

III. X-Rays--How Are They Produced?

It was in 1895 that Wilhelm vonRoentgen discovered an unknown radiation to which he applied the name X-rays. He was experimenting with a Crooke's tube, which is a two electrode type of tube, when he discovered that some of the radiations produced were capable of penetrating opaque materials.

Today X-rays are generated in high-voltage two electrode vacuum tubes in which a heated cathode causes electrons to be emitted. These electrons are drawn at high velocities toward the anode of the tube by the high voltage on the anode. When the electrons strike the face of the anode target, X-rays are produced. The anode proper is usually constructed of copper for greater heat conductivity, while the target, embedded in the face of the anode, is commonly of tungsten. Tungsten has a high atomic number and its comparatively massive molecules cause a more rapid deceleration of the electrons moving from the cathode to anode of the tube and therefore convert a larger portion of their kinetic energy into X-radiation. Even so, only a small percentage of the energy input to the tube is transformed into X-rays--less than one percent for medium-voltage tubes. The balance of the energy must be conducted away from the anode to prevent overheating. Tubes are often oil-filled and circulating water is used to conduct the heat away.

For an X-ray tube of given construction, two quantities greatly affect the X-rays generated. These are the tube current (cathode to anode) and the anode voltage. Increasing the tube current increases the intensity of the resulting rays approximately in direct proportion. Increasing the anode voltage has two effects. First, it increases the intensity of the rays with about the square of the voltage. Second, it increases the penetrating ability, or "hardness", of the rays by shortening their wave-length. The minimum wave-length produced is related to the tube voltage by the following formula.[4]

$$\lambda_{min} = \frac{12,350}{\text{Volts}}$$

λ_{min} is measured in Angstroms. An Angstrom is equal to 10^{-8} centimeter. The maximum energy occurs at a wave-length of about one and one-half times this minimum wave-length.[4]

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4. Bendz, W.I., Electronics for Industry, Wiley Book Co., 1947.

IV. Why is the Measurement of the Quantity of X-Radiation Necessary?

Two factors must be specified to properly describe X-radiation. One is the quality; the other is the quantity. The quality is concerned with the wave-length and penetrating ability of the radiation. A given tube operating at a set anode voltage would produce X-rays of consistant quality.

The American Institute of Electrical Engineers defines the quantity of X-rays as "the product of intensity and time". Also, "intensity is the attribute of a beam of roentgen rays (X-rays) which determines the rate of ionization of air at a given point, under the conditions stipulated in the definition of the roentgen. It is expressed in roentgens per unit of time." The A.I.E.E. definitions offer the further note on the term quantity. "It should be clearly understood that quantity is used here in a sense different from that customary in other fields, such as radiant energy in general. It is not proportional to energy, but rather to the product of energy density and a coefficient expressing the ability to cause ionization." This is a very important fact and should be constantly kept in mind when using the term quantity. If confusion is to be avoided, it is almost essential to eliminate any association of the definitions used in X-ray measurement from terms used in light measurement.

The use of the term exposure in place of quantity might better suggest its true meaning. Exposure is used to describe the radiation to which a place is exposed. It is a property of the radiation only and tells nothing about what happens to the radiation nor what effects it produces. It does not indicate whether the radiation is absorbed or passes on through the region without absorption.

The unit of X-ray exposure (or quantity) used when dealing with the effects of these radiations on living organisms is the roentgen. This unit is based upon the effect of X-rays in ionizing air--that is, in making air electrically conducting. The roentgen is defined as "the quantity of X-radiation which, when the secondary electrons are fully utilized and the wall effect of the chamber is avoided, produces in one cubic centimeter of atmospheric air at zero degree centigrade and 760 mm. of mercury pressure, such a degree of conductivity that one electrostatic unit of charge is measured at saturation current."[5] The mass of one cubic centimeter of dry atmospheric air at zero degree centigrade and 760 mm. of mercury pressure is .001293 gram.

For the ionized medium, air was chosen for two reasons: (a) because X-ray absorption per gram is nearly the same for air, water, and body tissue over a wide range of wave-lengths, and (b) for convenience and ready reproducibility.

Another definition which results in a unit that is exactly equivalent for tube voltages below 200 KV to the unit in the above definition is as follows. "The roentgen shall be the quantity of X-radiation such that the associated corpuscular emission per .001293 gram of air, produces, in air, ions carrying one e.s.u. of quantity of electricity of either sign."[6]

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5. Adopted by the Second International Congress of Radiology in 1928.
6. Adopted by the Radiological Society of North America in 1937.

Although either definition may be used for the work presented in this paper, the first stated will be discussed in detail in a later section.

V. A Method of Measuring the Quantity of X-Radiation.

The problem of measuring the quantity of X-radiation consists of two parts. First, a known mass of air to be ionized must be segregated. Second, the number of ions produced in this mass of air must be determined.

In constructing the free air ionization chamber, aluminum was used because it is a low-atomic-number material. Therefore, any tertiary X-rays caused by secondary X-rays from the main beam striking the walls of the ionization chamber are of such long wave-length as to be quickly absorbed before having an opportunity to produce an appreciable number of ions in the air volume.

The ionization chamber was constructed of two circular aluminum plates. A circular section was cut from the center of one of these plates to form an ion collector and a guard ring. Details of construction are shown in Figure 2.

The completed ionization chamber with other apparatus for measuring the quantity of radiation is shown in Figure 1. A potential of 1200 volts D.C. was maintained between the plate on the left and the guard ring on the right by means of the power supply shown. The guard ring, which was connected to the positive side of the power supply, was earth grounded. It has been found experimentally that the electric field between a pair of parallel plates becomes uniform at a distance from the ends about one and one-half times the plate separation.[7] Therefore, the

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7. Duggar, B.M., Biological Effects of Radiation, McGraw Hill Co., 1936.

radial length of the guard ring was made about one and one-half times the distance between the plate and the guard ring. The electric field lines of force are then parallel in the region between the ion collector and the left plate as shown in Figure 4.

Negative ions produced within the volume abcd by the X-rays passing through this region are drawn along these parallel lines of force to the ion collector. The ion collector will have an effective width greater than its actual width by half the air gap between the collector and the guard ring when the collector is at the same potential as the guard ring. If the collector is at a potential above that of the guard ring, distortion of the electric field will cause the effective width of the ion collector to be less than the above value. If the potential of the collector is below that of the guard ring, then the effective width will be more.

The electroscope connected between the ion collector and the guard ring was used to determine the setting of the potentiometer R necessary to maintain the collector at the same potential as the guard ring. Movement of the gold-leaf of the electroscope was observed through a microscope for greater accuracy.

Trials were made with the guard ring maintained at 120, 165, and 200 volts above ground. It was thought that better accuracy might be obtained by this method. The procedure consisted of connecting the ion collector to the guard ring and adjusting the potentiometer R so that the voltage from the contact on R to ground equaled the voltage of the guard ring with respect to ground. The corresponding reading of the electroscope was taken as the zero reading. X-rays were then passed through the ionization chamber and the potentiometer R continuously adjusted to maintain the above zero reading on the electroscope. This method was abandoned when it was found that equally good results with greater simplicity could be obtained by connecting the guard ring directly to earth ground.

During the time data was being obtained with the guard ring connected to earth ground, the following check on the ion collector potential was made. Before each exposure of the ionization chamber to X-rays a wire was connected from the ion collector to the guard ring to assure that the two were at the same potential. The gold-leaf of the electroscope was then observed to be certain that it was at its zero setting (the hairline of the microscope).

The effective volume of the air ionized was taken as the product of the area A of the aperture through which the X-rays were allowed to pass (as shown in Figure 4) and the effective length of the ion collector along the path of the X-rays. When so considered the quantity of X-radiation is that at the plane of the aperture. The inverse-square law can then be used to determine the quantity at other points along the path of the X-rays.

The above procedure is necessary as the source of the X-rays is not a point source due to the fact that the focal spot on the X-ray tube target is usually at least 8 mm. in diameter. Therefore, after limitation by the lead sheet with the aperture, the X-ray beam consists of a region of uniform flux density and a region of non-uniform flux density. Right at the aperture, however, we have a single region of uniform flux density. All the ions created within the region abcd (Figure 4) are caused by X-rays that have passed through the aperture A.

The resulting ionization current to the ion collector is then a measure of the X-rays passing through the aperture. The only assumption involved is that absorption of the rays by the air between the lead sheet and the region abcd is negligible in comparison to the total flux. This is true except for very soft X-rays (below 60 KV) where a correction must be used. Tube voltages used in this experiment were well above this value; consequently no correction was necessary.

The <u>roentgen</u> has been defined as "the quantity of X-radiation which, when secondary electrons are fully utilized and the wall effect of the chamber is avoided, produces in one cubic centimeter of atmospheric air at zero degree centigrade and 760 mm. of mercury pressure, such a degree of conductivity that one electrostatic unit of charge is measured at saturation current." Let us now further analyze this definition. To insure that "secondary electrons are fully utilized" it is necessary that the spacing between the ion collector and the left plate (see Figure 4) be great enough to allow the secondary electrons to expend their total energy in producing ions before striking the walls (plates) of the ionization chamber. In section II secondary electrons were defined as electrons expelled from atoms by photons of X-ray energy.

The "wall effect of the chamber" refers to secondary ionization due to secondary electrons striking the walls. This is avoided by using aluminum for chamber walls and by providing sufficient space between the ion collector and the left plate. For a narrow (1 cm.) beam of 200 KV (peak) X-rays a spacing of 10 cm. between ion collector and opposite plate of chamber is sufficient.[8] It was convenient to use

8. Duggar, B.M., <u>Biological Effects of Radiation</u>, P.65, McGraw Hill Book Co., 1936.

7.4 cm. spacing on the ionization chamber constructed, and since 110 KV was the maximum tube voltage that was intended to be used, this spacing was deemed sufficient. With a narrow beam and sufficient spacing between plates, the volume abcd in Figure 4 is bounded only by air.

The definition of the roentgen refers to the electrostatic unit of charge (e.s.u.). The unit of charge in the MKS system is the coulomb. One coulomb is equal to approximately $3\ (10)^9$ electrostatic units. A more exact figure is $2.998\ (10)^9$. The first stated figure is satisfactory for the calculations to be made here.

To assure saturation current, it is necessary to have sufficient electric field between the ion collector and the opposite plate of the ionization chamber to pull all the ions to the ion collector or the opposite plate before an appreciable number are lost by recombination (deionization). For most X-ray flux densities encountered in practice, a field strength of about 100 volts per centimeter is sufficient.[9] The 1200 volts used for the 7.4 centimeter spacing meets this requirement and should assure saturation current.

To determine the actual volume of the air, V, being used as the measured volume in this experiment the following formula was used.

$$V = L \times A$$

where, V is the volume of air in cubic cm.

L is the effective length in cm. of the air volume along the path of the X-rays.

A is the cross-sectional area of the aper ture in the lead sheet in cm^2. (See Figure 4.)

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9. Glasser, Quimby, Taylor and Weatherwax, Physical Foundations of Radiology, P.155, Paul Hoeber, Inc., 1944.

L was determined by measurement to be 7.65 cm. and A was found to be 1.27 cm^2. The actual volume of the air was then,

$$V = 7.65 \times 1.27 = 9.72 \text{ cubic cm.}$$

Since the definition of the roentgen is based upon air under standard conditions of zero degree centigrade and 760 mm. of pressure, it is necessary to make use of Charles's and Boyle's laws to reduce the actual volume of air used to an equivalent volume under standard conditions.

$$\frac{V_1}{V_2} = \frac{T_1}{T_2}$$

where, V_1 is the volume at temperature T_1 (degrees absolute).

V_2 is the volume at temperature T_2 (degrees absolute).

The temperature of the chamber was 28 degrees centigrade which is 301 degrees absolute.

Let V_1 be the volume of the air at 273 degrees absolute (zero degree centigrade) and let V_2 be the volume of the air at 301 degrees absolute (28 degrees centigrade).

$$V_1 = V_2 \frac{T_1}{T_2}$$

$$V_1 = 9.72 \times \frac{273}{301}$$

V_1 = 8.82 cubic cm. = the volume of the measured air when corrected to zero degree centigrade.

Next we will reduce the air volume to an equivalent volume at standard pressure of 760 mm. of mercury. According to Boyle's law,

$$\frac{V_1}{V_2} = \frac{P_2}{P_1}$$

where, V_1 is the volume when subjected to pressure P_1.

V_2 is the volume when subjected to pressure P_2.

The atmospheric pressure when the data was taken was 719 mm. of mercury.

Let V_2 be 8.82 cubic cm. which was the volume of the air at 719 mm. pressure when corrected to zero degrees centigrade temperature. Let V_1 be the volume of the air at a pressure of 760 mm. P_2 is 719 mm. and P_1 is 760 mm.

$$V_1 = V_2 \frac{P_2}{P_1}$$

$V_1 = 8.82 \times \frac{719}{760} = 8.34$ cubic cm. = the volume of the measured air when corrected to standard conditions.

We are now ready to determine the number of ions produced in the measured air and from this determine the quantity of X-rays in roentgens. The X-rays in passing between the plates of the ionization chamber produce ions in the air. The negative ions under the influence of the electric field between the left chamber plate (Figure 4) and the ion collector travel against the electric flux lines to the ion collector. We are interested only in those ions in the volume abcd (Figure 4), which are the ions that travel to the ion collector. The ions traveling to the guard ring simply return to the 1200 volt D.C. power supply and do not enter into our calculations.

These ions arriving at the ion collector charge the insulated system consisting of the upper plate of the condenser, the ion collector, and the leaves of the electroscope with a negative charge. If, during the time X-rays are passed through the ionization chamber, the contact on potentiometer R is continuously adjusted to maintain the gold-leaf on the electroscope at its zero reading, then we know that the ion collector and the guard ring have been maintained at the same potential. The electroscope may be considered an electrostatic voltmeter. Since the electroscope is connected across the condenser and potentiometer R connected in series, as the condenser is charged the voltage introduced across R must be equal and opposite to the voltage across the condenser. This must be true if the electroscope continuously reads zero. Therefore, the change in the voltmeter reading V_1 (Figure 4) is equal to the change in voltage across the condenser.

Now the charge on a condenser is equal to the capacitance of the condenser multiplied by the voltage across the condenser. Similarly,

$$\Delta Q = C \Delta V$$

where, ΔQ is the change in charge on the condenser in coulombs,

C is the capacitance in farads,

ΔV is the change in voltage across the condenser.

By the definition of the roentgen, a quantity of X-radiation of one roentgen produces one e.s.u. of charge in one cubic centimeter of air under standard conditions. But one coulomb of charge is equal to $3\,(10)^9$ e.s.u. Therefore,

$$\text{Roentgens} = \frac{3\,(10)^9 \; C \; \Delta V}{\text{Vol.}}$$

where, C is the capacitance of the insulated system consisting of condenser, ion collector, and leaves of electroscope,

ΔV is the change in voltage of the above system,

Vol. is the volume of the measured air in cubic cm. (under standard conditions).

In terms of units: $\text{Roentgens} = \frac{\text{e.s.u.}}{\text{coulombs}} \times \frac{\text{coulombs}}{\text{cubic cm.}} = \frac{\text{e.s.u.}}{\text{cubic cm.}}$

As previously discussed, e.s.u.'s per cubic centimeter is the basis of the definition of the roentgen.

The capacitance of the ion collector, condenser, and leaves of the electroscope to ground was measured as described in Appendix I and found to be .0006422 microfarad.

Using 110 KV on the X-ray tube and 5 MA tube current the following data was obtained.

Time	V_1 (Before X-rays)	V_1 (After X-rays)
15 sec.	0 volts	45 volts
30 "	0 "	80 "
45 "	0 "	115 "
60 "	0 "	155 "
75 "	0 "	185 "
90 "	0 "	230 "
105 "	0 "	260 "
120 "	0 "	310 "

The time was measured by the timer on the control panel of the X-ray equipment. Longer periods of time than 120 seconds were not used as they were considered unnecessary. The process of observing the gold-leaf of the electroscope through a microscope for more than two minutes is tiring and is quite unnecessary as multiplying the X-ray intensity in roentgens per minute by any length of time will give the quantity of X-radiation.

As a sample calculation, data from line four of the tabulation above, which is for the one minute period, is shown substituted into the formula $\text{Roentgens} = \frac{3\,(10)^9\ C\ \Delta V}{\text{Vol.}}$.

$$\text{Roentgens} = \frac{3\,(10)^9 \times .0006422\,(10)^{-6} \times 155}{8.34}$$

Roentgens = 35.8 in 60 seconds time.

This is equivalent to an intensity of 35.8 roentgens per minute. By similar calculations the completed table below was obtained.

Quantity (in roentgens)	Time (in sec.)	Intensity (in roentgens / min.)
10.4	15	41.6
18.5	30	37
26.6	45	35.5
35.8	60	35.8
42.7	75	34.2
53.2	90	35.4
60.1	105	34.3
71.6	120	35.8

The graph of the quantity of radiation in roentgens plotted against time is shown in Figure 5.

The quantity of radiation at points along the X-ray path other than at a distance of 48 cm. from the tube target can be determined by using the inverse-square law. This relationship states that the intensity of the radiation is inversely proportional to the square of the distance from the source of the X-rays.[10] Since the quantity is the product of the intensity and time, the quantity (or exposure) expressed in roentgens varies inversely as the square of the distance from the source.

As an example, let us consider a sample of seeds placed on the floor of the lead-lined housing. The seeds are then 79 cm. from the tube target. With the X-ray generator set for 110 KV and 5 MA we can

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10. Bendz, W.I., Electronics for Industry, P.35, Wiley Book Co., 1947.

expect an intensity of about 35.5 roentgens per minute (Figure 5) at a distance of 48 cm. from the tube target.

$$\frac{Q_1}{Q_2} = \frac{I_1}{I_2} = \frac{D_2^2}{D_1^2}$$

where, Q_1 is the quantity of radiation in the first case (in roentgens),

Q_2 is the quantity of radiation in the second case (in roentgens),

I_1 is the intensity in the first case (in roentgens per minute),

I_2 is the intensity in the second case (in roentgens per minute),

D_2 is the distance from the tube target to point 2 (in cm.),

D_1 is the distance from the tube target to point 1 (in cm.)

Now, if D_2 is taken as the 79 cm. from the target to the seeds, D_1 is the 48 cm. for which Figure 5 holds, and I_1 is 35.5 roentgens per minute, then substitution into the above formula gives the following.

$$I_2 = 35.5 \times \frac{48^2}{79^2}$$

I_2 = 13.1 roentgens per minute = the intensity at a distance of 79 cm. from the tube target.

The quantity of radiation can then be determined for any period of time by multiplying this intensity by the time. For example, if the seeds were subjected to the above exposure rate for 20 minutes, they would be subjected to a total exposure (or quantity of radiation) of 13.1 multiplied by 20 or 262 roentgens.

VI. Summary of the Steps in Measuring the Quantity of Radiation by This Method.

With the apparatus shown in Figure 4, the procedure for obtaining a measurement of the quantity of radiation is as follows.

1. Set contact on R at the grounded end.
2. Connect ion collector to guard ring and adjust hairline of microscope to gold-leaf of electroscope. Then remove connection between collector and ring.
3. Pass X-rays through ionization chamber.
4. While observing gold-leaf through microscope, continuously adjust R to keep gold-leaf at hairline.
5. When timer on control panel of generator turns off X-rays, read voltmeter V_1.
6. Compute quantity using the following formula.

$$\text{Roentgens} = \frac{3\,(10)^9\,C\,\Delta V}{\text{Vol.}} \times \frac{T}{273} \times \frac{760}{P}$$

where, C is the capacitance of the condenser, ion collector, and electroscope leaves in farads,

ΔV is the change in reading of voltmeter V_1 in volts,

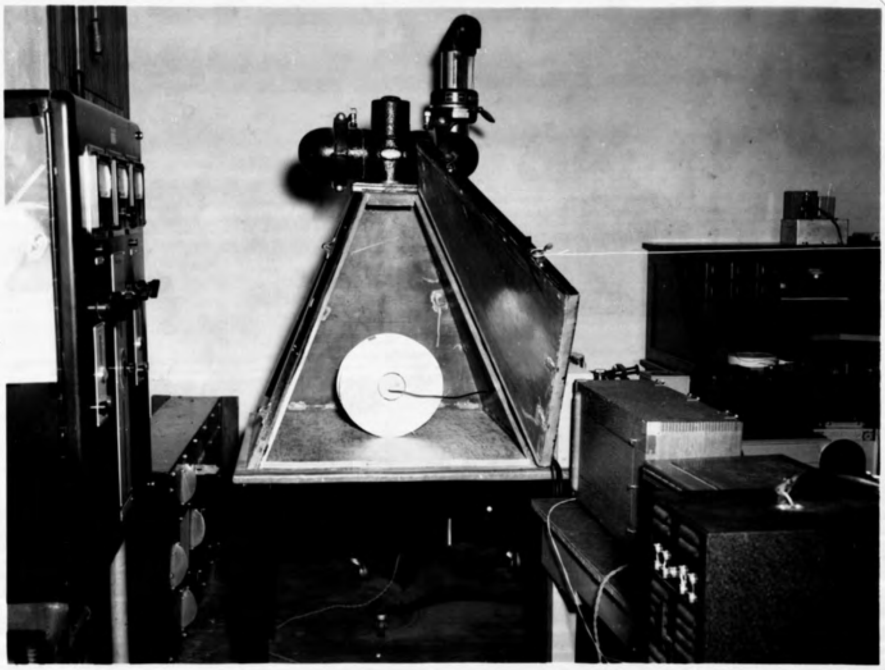
Vol. is the volume of measured air under existing conditions in cubic cm.,

T is the temperature of ionization chamber air in degrees absolute,

P is atmospheric pressure in mm. of mercury.

VII. Conclusions.

The method presented here for the measurement of the quantity of radiation traces back to the basic definition of the unit of quantity, the roentgen. The accuracy of the measurements is limited by the accuracy of the equipment used. For the original purpose of the measurements, to get an idea of the quantity of radiation to which the seeds of sorgum, castor beans, sunflowers, and safflowers were exposed, it is believed that the measurements are entirely satisfactory. Even if these measurements were 10% in error we still have a good approximation of the exposure of the seeds, and it is quite reasonable to expect accuracy well within this value. However, the method is cumbersome due to the equipment used and for that reason it is not recommended for other than occasional use.



Ionization Chamber Shown

Inside Lead-Lined Housing.

FIGURE 1

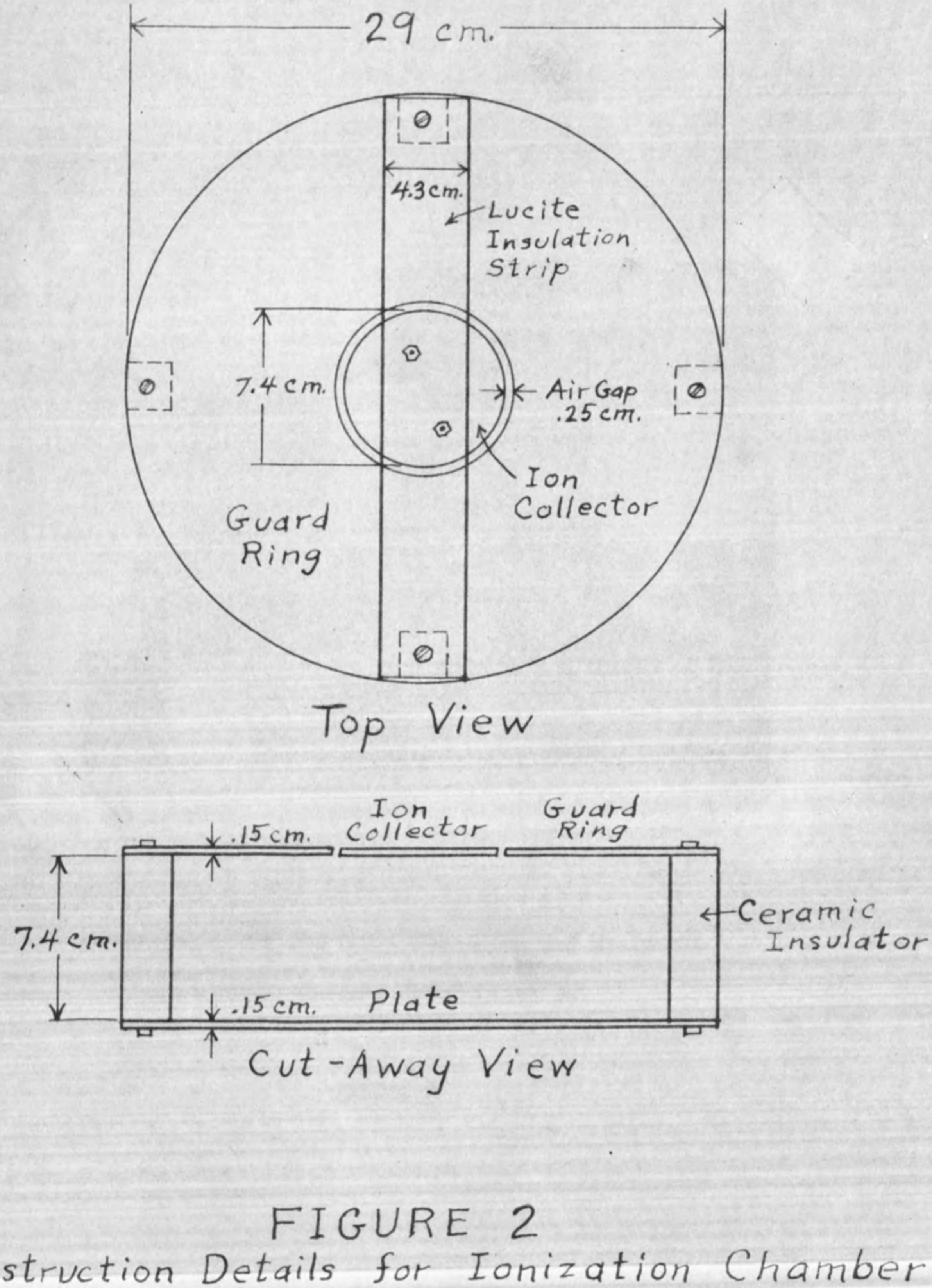
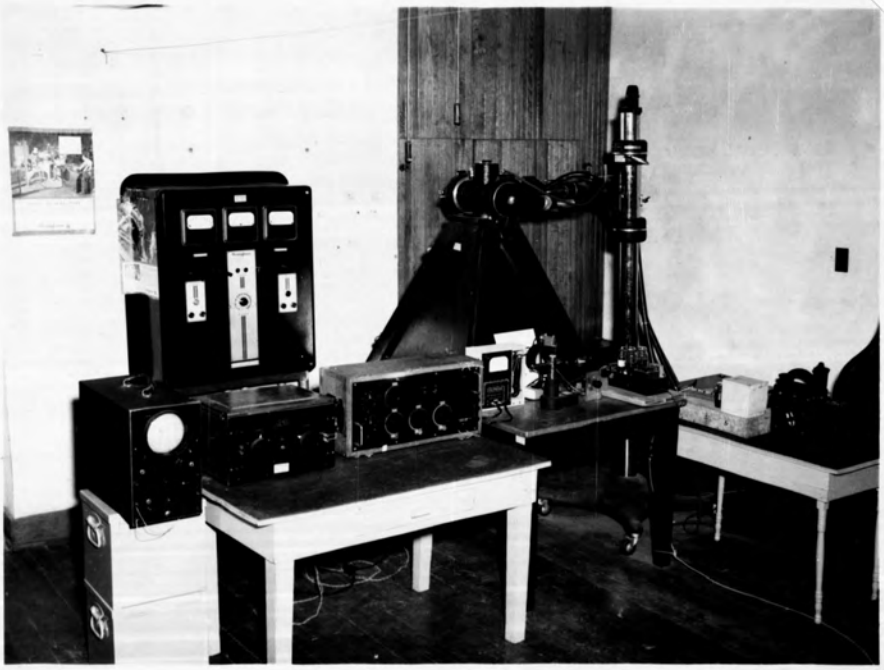


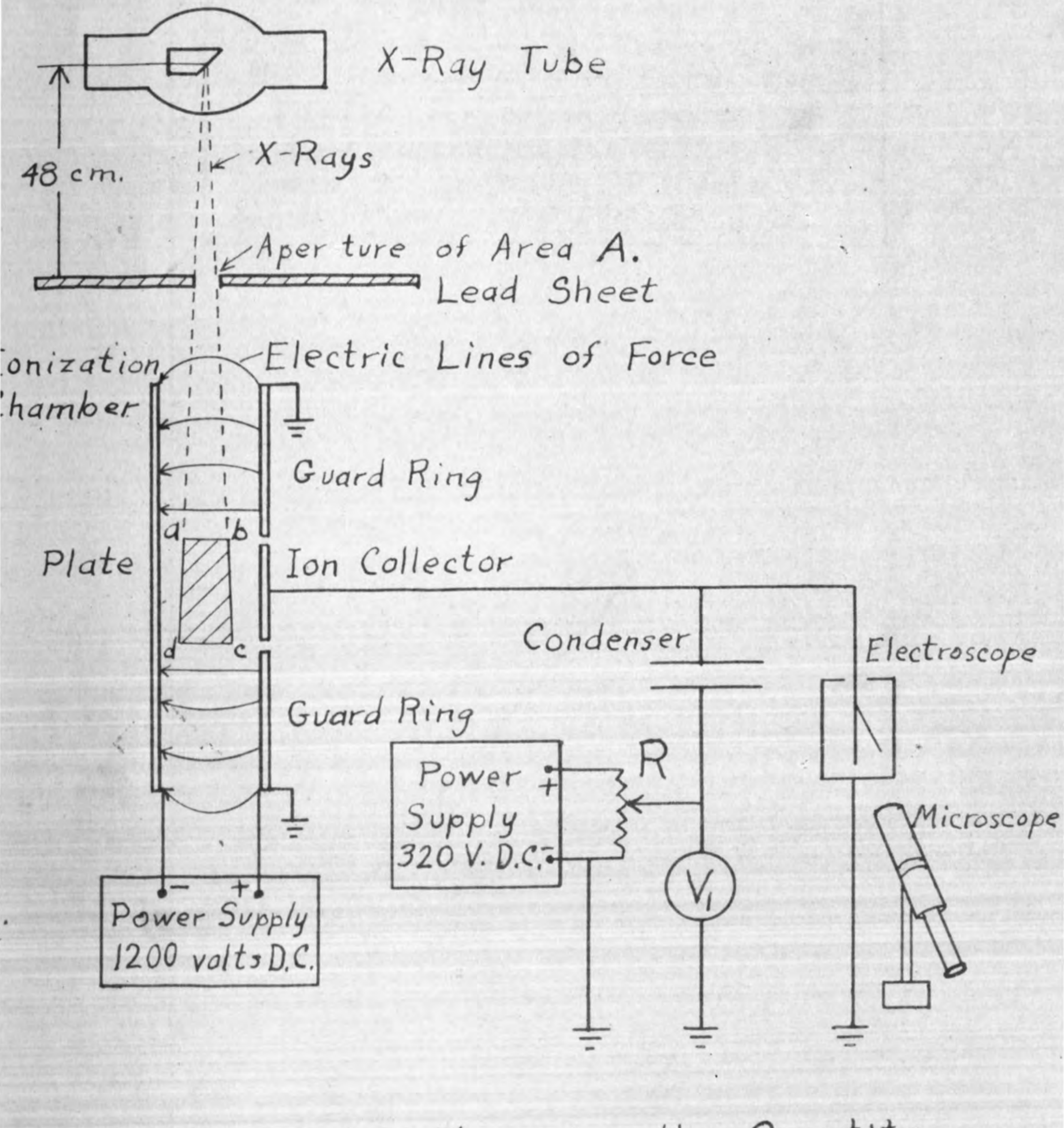
FIGURE 2

Construction Details for Ionization Chamber



Westinghouse 150 KV X-Ray Generator and Equipment
Used to Measure X-Ray Quantity.

FIGURE 3



Apparatus for Measuring the Quantity of X-Radiation in Roentgens

FIGURE 4

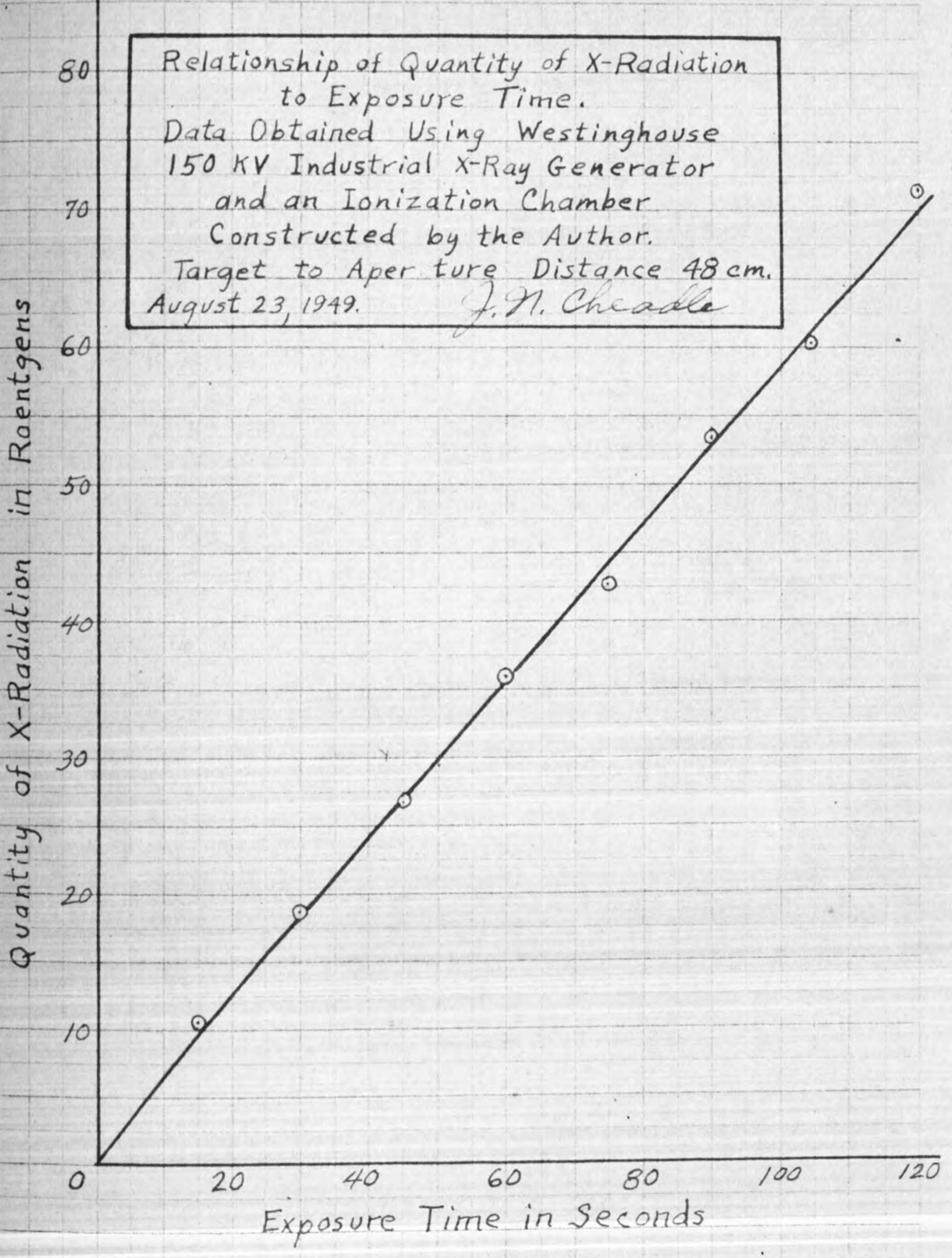
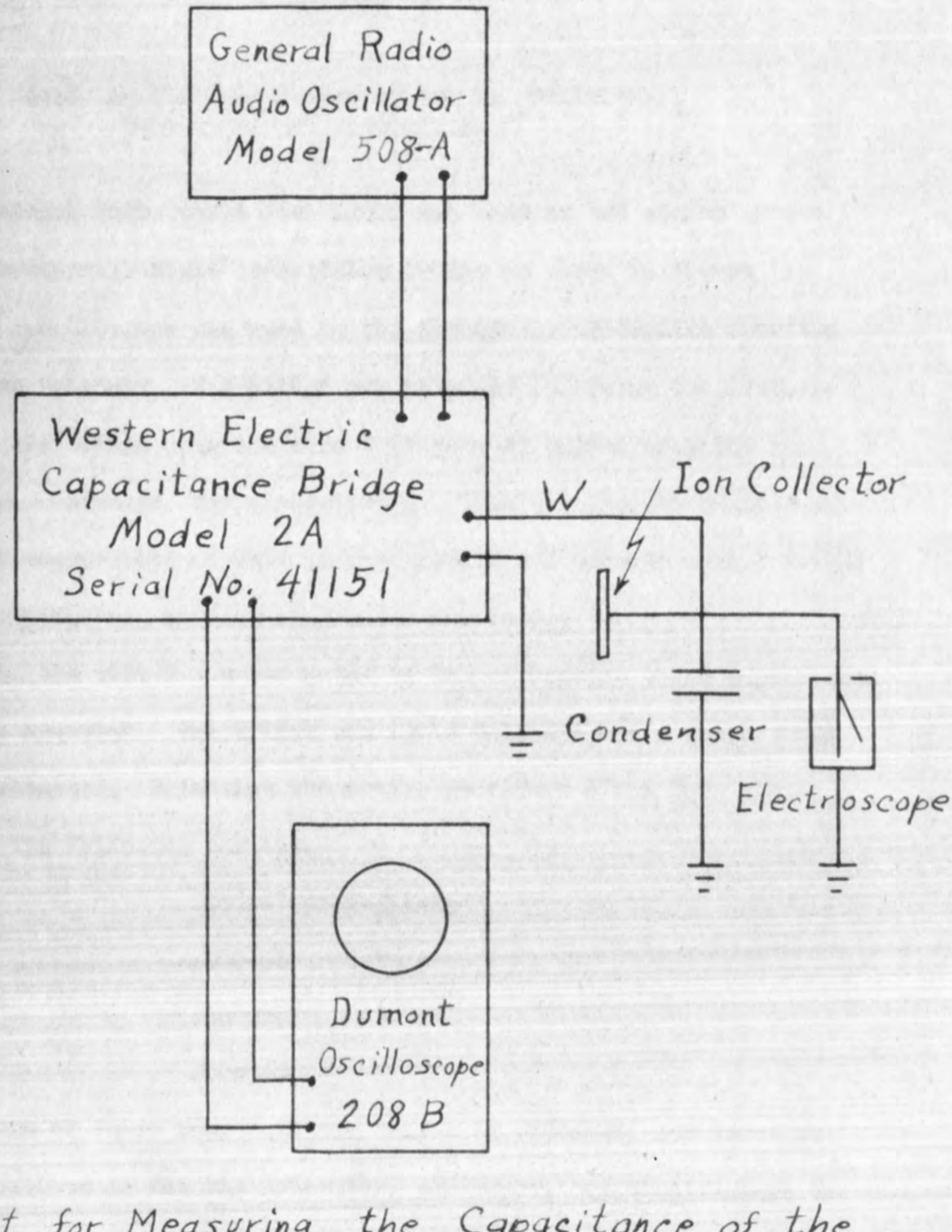

Relationship of Quantity of X-Radiation to Exposure Time.
Data Obtained Using Westinghouse 150 KV Industrial X-Ray Generator and an Ionization Chamber Constructed by the Author.
Target to Aperture Distance 48 cm.
August 23, 1949.
J. N. Cheadle
Quantity of X-Radiation in Roentgens
80
70
60
50
40
30
20
10
0
20
40
60
80
100
120
Exposure Time in Seconds

FIGURE 5



Equipment for Measuring the Capacitance of the Ion Collector, Condenser, and Electroscope.

FIGURE 6

APPENDIX I

Measuring the Capacitance of the Ion Collector, Condenser, and Electroscope.

A General Radio audio oscillator was used as the signal source for the Western Electric capacitance bridge as shown in Figure 6. A Dumont oscilloscope was used as the detector to determine when the bridge was balanced. The bridge was balanced following the instructions on the bridge with the wire W (Figure 6) laying near the ion collector, condenser, and electroscope. This was done to balance out any stray capacitance of this wire to ground and thereby make possible a final capacitance reading of greater accuracy.

Next, the wire W was connected to the components whose capacitance was to be measured. The bridge was again balanced and a capacitance reading obtained. Repeating the entire procedure above four times produced the following results.

.000647 microfarads

.000643 "

.000637 "

.000642 "

The average of these four readings, which is .0006422, was taken as the capacitance of the ion collector, condenser, and electroscope to ground.

APPENDIX II.

Detailed Information on Apparatus Used.

The X-ray generator was a Westinghouse unit which can be readily adjusted to operate at tube voltages from 30 to 150 KV. For continuous operation at 150 KV it is rated at a maximum tube current of 6 MA. Very short time exposures can be made at tube currents up to several times this value. The X-ray tube itself was a Machlett Industrial Thermax type B.

The voltmeter V_1 was a Supreme vacuum-tube voltmeter model 565.

The capacitance bridge used for measuring the capacitance of the condenser, ion collector, and leaves of electroscope was a model 2A Western Electric bridge. The accuracy claimed for this unit is plus or minus .2 of 1% plus or minus .00001 microfarad.

For resistor R a 20,000 ohm, 5 watt, wire wound potentiometer was used.

The condenser was an Aerovox, 3,000 volt, mica condenser with low-loss case.

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