IONIZATION CHAMBERS FOR RADIOACTIVITY OIL WELL LOGGING

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IONIZATION CHAMBERS FOR RADIOACTIVITY OIL WELL LOGGING

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PREFACE

The author has been engaged for some time in work on radioactivity oil well logging apparatus. A substantial part of this time has been spent testing ionization chambers.

A very extensive investigation has been conducted to determine the characteristics of ionization chambers. From the data obtained it is possible to determine the best type of ionization chamber for a particular survey problem.

The author wishes to acknowledge the contributions of the technical staff of Well Surveys, Inc. The constant help and encouragement of Mr. Gilbert Swift is deeply appreciated. The author expresses his thanks to Well Surveys, Inc. for use of its facilities and for permission to use material and information obtained by the author on regular research projects as a subject for a master thesis.

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CHAPTER I

GAMMA-RAY OIL WELL LOGGING APPARATUS

Well logging is the process of exploring systematically the entire length of the borehole or any portion thereof. To accomplish this process an instrument is used that is capable of measuring physical factors associated with the borehole strata, and producing a graph of the factors as a function of depth. Radioactivity can be considered a measurable property that is directly and permanently associated with a given rock. The radioactivity of a rock can be considered unalterable[1] by temperature, pressure or chemical reaction and it merely decreases in radiation intensity with age.

Radioactivity[2] is the phenomenon of spontaneous disintegration of the atoms of matter, accompanied by the emission of alpha, beta or gamma rays. A packet of gamma radiation sent out as a consequence of a single disintegration is termed a "photon".

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[1] J. Barton Hoag and S. A. Korff, "Electron and Nuclear Physics", D. Van Nostrand Company, Inc., 1948, page 253.

[2] James M. Cork, "Radioactivity and Nuclear Physics", D. Van Nostrand Company, Inc., 1947, page 141.

In gamma ray oil well logging we are concerned only with the gamma rays emitted by the atomic disintegration of the rocks. Gamma rays originate in the excited nuclei of atoms. They represent the energy difference between the initial excited state and a lower energy state. Gamma radiation is a very penetrating high frequency electromagnetic wave, identical in nature to very penetrating X-rays. The measurement of gamma rays is a standard method for determining the radiation intensity of radioactive substances.

A radioactivity well log can be made with an instrument based on a method of measuring the natural gamma radiations emitted into a well borehole by any given succession of strata. This is called a gamma ray log and can be made inside casing pipe due to the penetrating ability of the short wave length gamma rays.

The gamma ray log is a graph of the intensity of natural radioactivity of the various rocks surrounding the well bore, plotted with respect to depth. It is used to differentiate between various types of strata formations and to locate the exact position and thickness of each formation. The thickness of the strata must be considered together with the time of response of the detecting instrument. For accurate measurements of the strata, the response time of the instrument must be of the order of seconds when comparisons are being made between weakly radioactive strata. This is true because of the necessity of indicating statistically a sufficient number of quanta for good accuracy. It is necessary to limit the speed in gamma-ray well logging so that a reasonable length of sample can be attained. The desirable maximum speed is that value which corresponds with a progress of not over one sensitive length of the detector in the time corresponding to the instrument time constant.

A commonly used detector for gamma rays in well logging is an ionization chamber. Figure 1.1 shows the essential components of a gamma ray well logging apparatus that has been in commercial use for several years. The detector is an ionization chamber filled with a dense gas to many atmospheres of pressure.

The subsurface amplifier is a vibrating capacitor type electrometer. The subsurface instrument is connected to the surface equipment by means of a shielded and insulated cable. The surface equipment comprises a hoisting unit with cable drum and slip rings to connect the recording equipment to the subsurface instrument. The recording chart is synchronized with the depth at which the subsurface instrument is located so that the radiation intensity recorded on the chart is a function of depth.

This discussion of the logging equipment will be limited to the ionization chamber and electrometer input circuit with a brief description of the operation of the recording system using a capacitative commutator[3] electrometer with servo feed-back.

Figure 1.2 shows a block diagram of a modulator type electrometer system with a recording type galvanometer and servo feed-back to stabilize its performance. Figure 1.3 shows the schematic diagram of the input coupling arrangement of a modulator of the capacitative commutator type. This represents the fundamental part of the electrometer circuit. It provides a coupling between a d.c. source of potential, or a slowly varying one, and an a.c. amplifier. The capacitative commutator generates an a.c. potential that is proportional at all times to the d.c. input. The capacitative commutator action is obtained by employing a vibration type capacitor formed by a fixed rigid plate and a reed or plate driven harmonically at a fixed frequency by a magnetic driving circuit.

Resistor R_1 serves to isolate the reactive component of the source impedance from the vibrating capacitor. Resistor R_2 is the input resistance across which a voltage is developed by the d.c. input current. R_1 may be small compared to R_2. The RC time constant composed of R_1 plus R_2 and the mean value of the capacity C, must be long compared to the period of vibration of C_1. This is

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[3] S. A. Scherbatskoy, T. H. Gilmartin and Gilbert Swift, "The Capacitative Commutator", The Review of Scientific Instruments, Vol. 18, No. 6, 415-521, June, 1947.

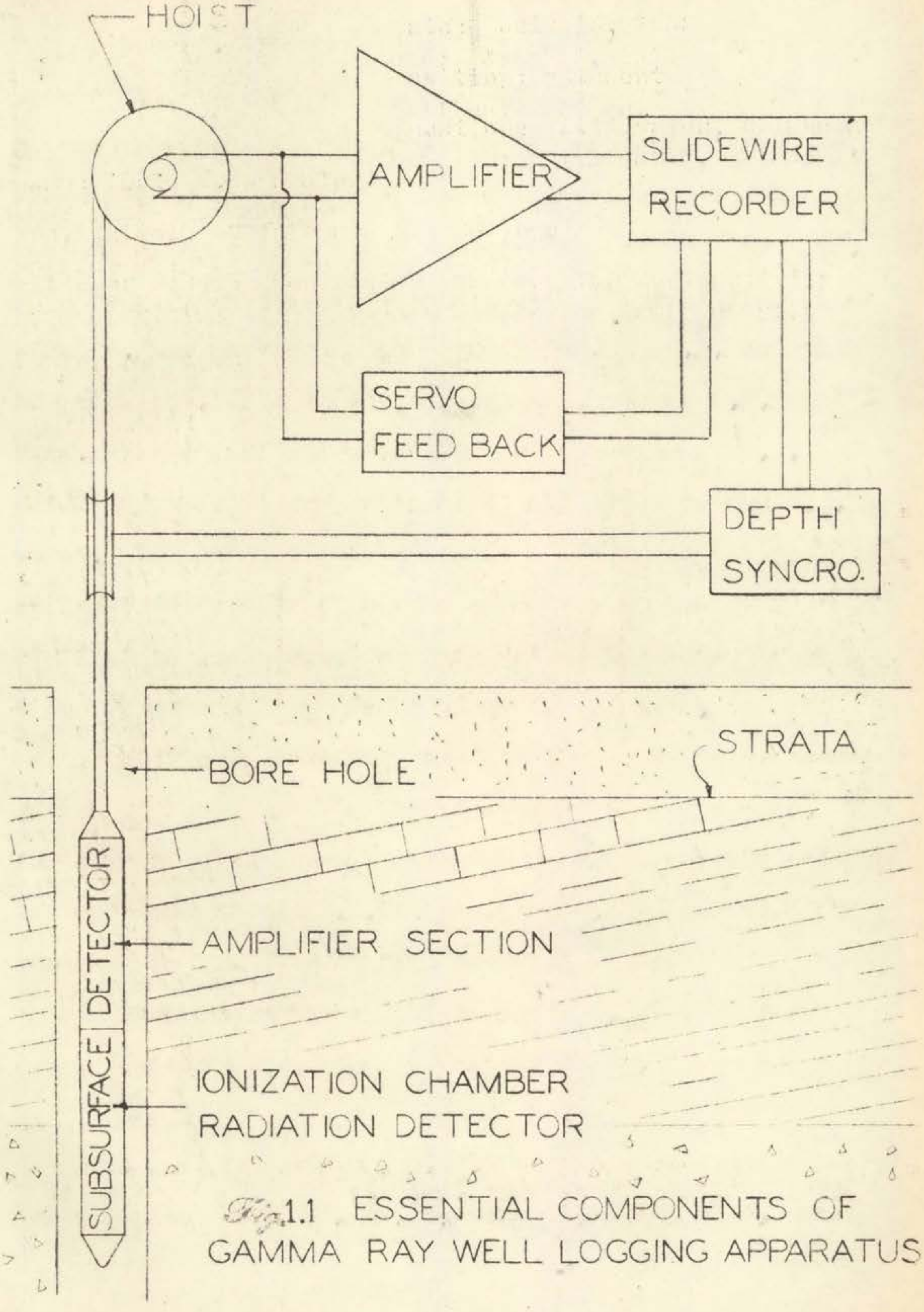

Fig. 1.1 ESSENTIAL COMPONENTS OF GAMMA RAY WELL LOGGING APPARATUS

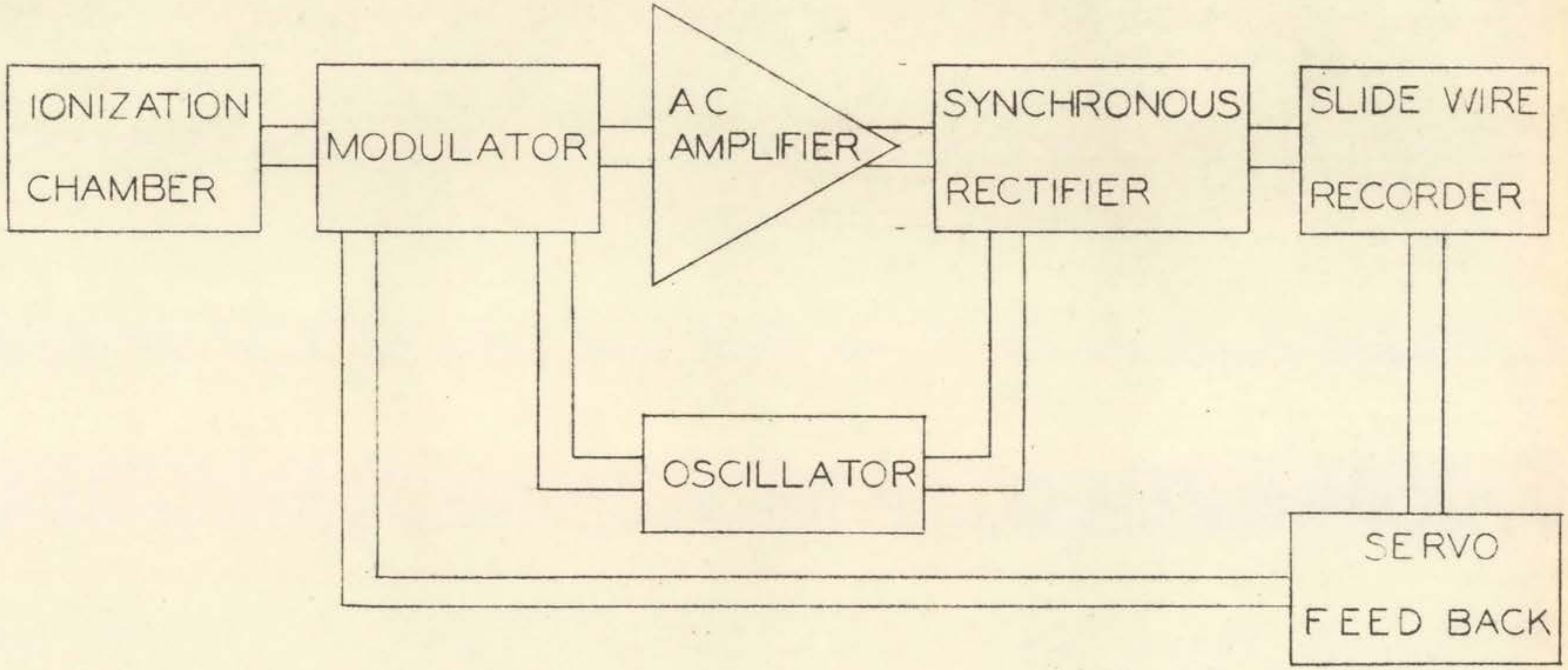

Fig. 1.2 BLOCK DIAGRAM OF A RECORDING RADIO ACTIVITY DETECTOR

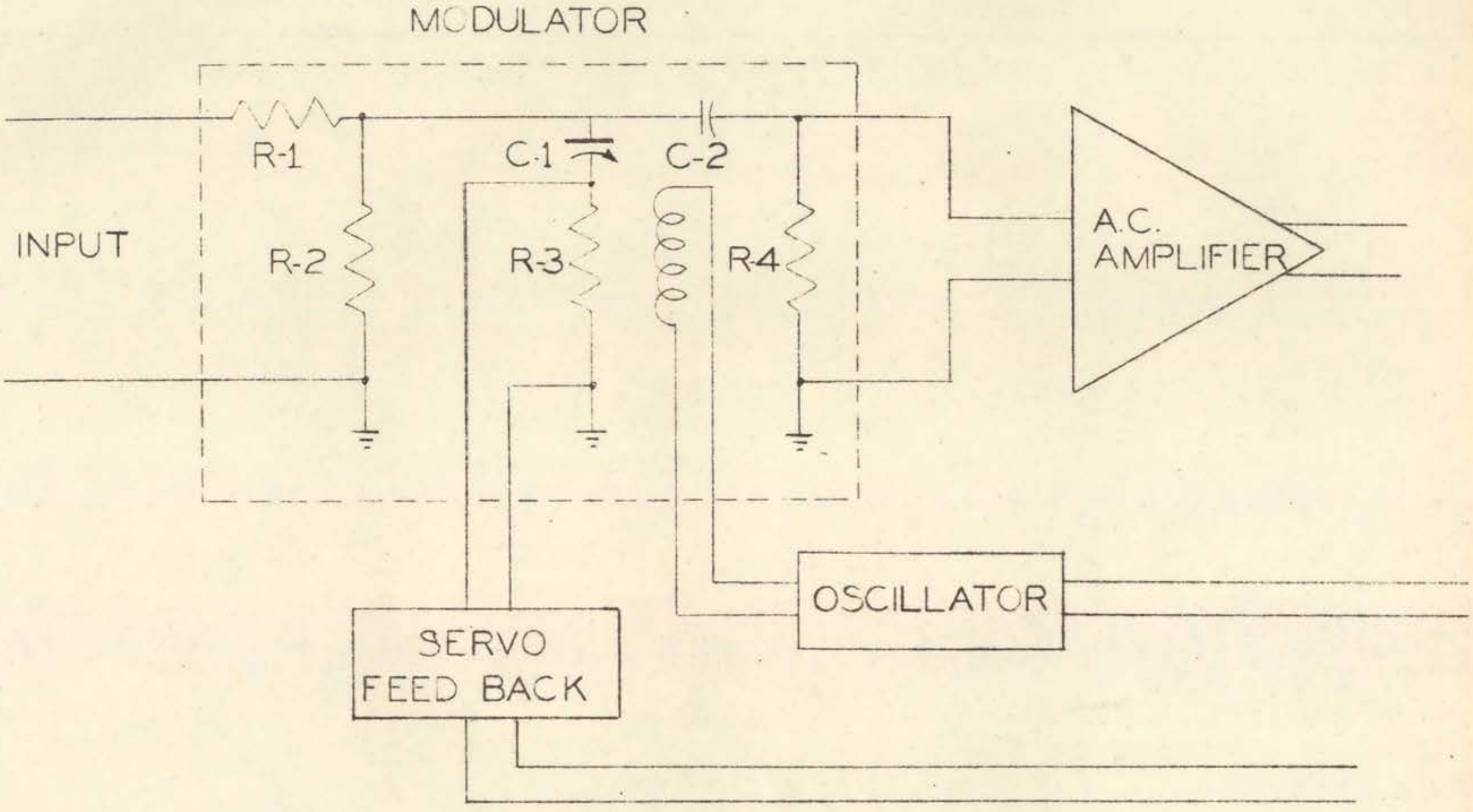

Fig 1.3 SCHEMATIC OF THE CAPACITATIVE COMMUTATOR MODULATOR AS SHOWN IN FIG 1.2

required so that the charge on the vibrating capacitor will remain constant during a period of its vibration. Capacitor C_2 is used to isolate the d.c. input from the a.c. amplifier. The leakage resistance of C_2 and its mounting must be maintained at a value that is high compared with other resistances in the circuit. This prevents any grid current from flowing through the resistor R_2.

An ionization chamber[4] may be defined as an enclosure containing two oppositely charged electrodes in air or some other gas, so arranged that when the gas is ionized, by some radiations such as gamma rays, the resulting ions are drawn to the electrodes. The current through the chamber is then a measure of the intensity of the ionizing rays. The ionization chamber current can be measured by a sensitive electrometer, such as the capacitative commutator electrometer previously described. Figure 1.4 shows the coupling of the electrometer input circuit to an ionization chamber. This is a very satisfactory arrangement for detecting and measuring radioactivity. The ionization chamber is of the coaxial type with the outer case capable of holding pressures up to many atmospheres. The electrodes are insulated from each other and from the outer case, and the space between them must be gas-filled. Argon gas is usually employed for this purpose. The electric field is

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[4] Nelson M. Cooke and John Markus "Electronics Dictionary", McGraw-Hill Book Company, 1945, page 187.

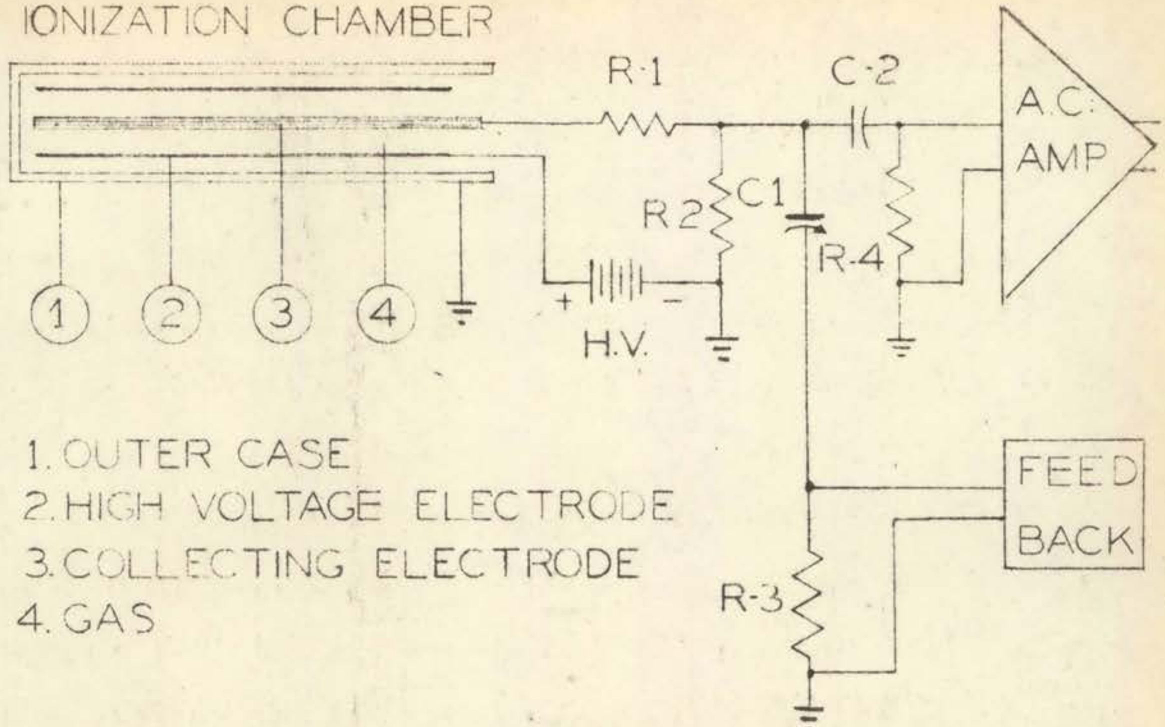


Fig. 1.4 CAPACITATIVE COMMUTATOR ELECTROMETER AND IONIZATION CHAMBER

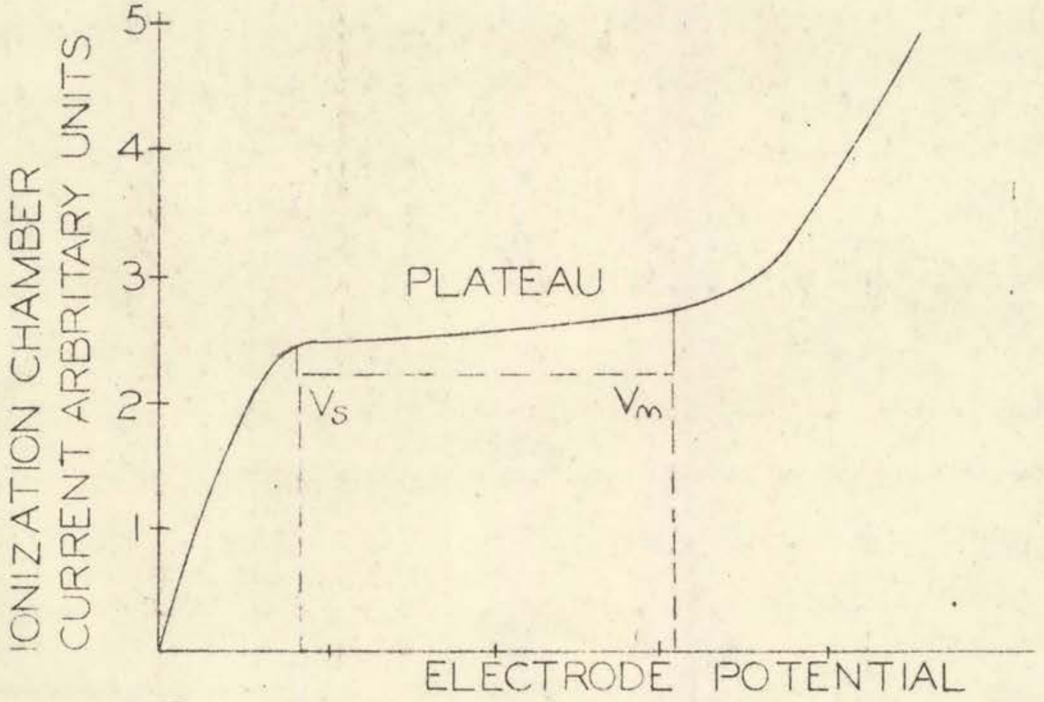
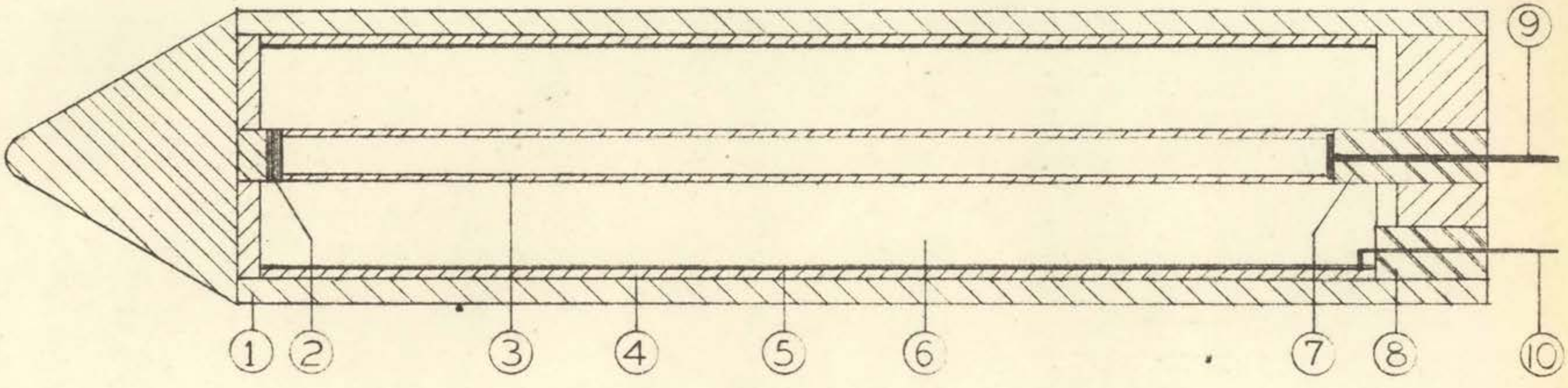


Fig. 1.5 IONIZATION CHAMBER SATURATION CURVE SHOWING THE OPERATING PLATEAU REGION due to the high voltage connected directly to one electrode and through a high value resistor to the collecting electrode. When an ionizing ray passes through the gas in the chamber it will leave a number of positive and negative ions in its wake. The negative ions will move toward the high voltage electrode and the positive ions will move toward the collecting electrode, when the high voltage potential is of the polarity shown in Figure 1.4. The electrode potential must be such that operation will be in the plateau region shown by the saturation curve in Figure 1.5. The voltage, Vs, is necessary to prevent the recombination of the positive and negative ions, and is called the saturation point on the curve of electrode potential vs. ionization current.

CHAPTER II

IONIZATION CHAMBER DETECTORS USED IN OIL WELL LOGGING

The ionization chamber used in oil well logging is of the coaxial type, made with a heavy steel case to withstand the external pressure encountered in deep boreholes. Figure 2.1 shows the construction of a typical ionization chamber used in radioactivity well logging, and Figure 2.2 shows the schematic diagram of the coupling of the ionization chamber to the electrometer and the high voltage supply. The ionization chamber current flows through the high value resistor R_2 and develops a voltage difference between the plates of the vibrating capacitor C_1. Because of its periodic capacitance variation an a.c. voltage is developed across C_1 which is at all times proportional to the d.c. ionization chamber current. The a.c. voltage is amplified and used to drive a slidewire recorder with servo feed-back. The feed-back current through R_3 develops a voltage that tends to balance out the voltage difference across C_1 caused by the ionization chamber current. When the voltage across R_3 is equal to that across R_2, both plates of C_1 are at the same potential and no a.c. voltage is generatred by the vibrating capacitor C_1. The system thus works on the null principal. With servo feed-back the sensitivity is almost completely independent of



1. OUTER STEEL CASE
2. INSULATOR
3. COLLECTING ELECTRODE
4. INSULATION
5. HIGH VOLTAGE ECTRODE
6. GAS
7. INSULATOR PORCELAIN
8. INSULATOR NEOPRENE
9. ELECTRODE CONTACT (COLLECTING)
10. ELECTRODE CONTACT (H. V.)

Fig. 2.1 IONIZATION CHAMBER

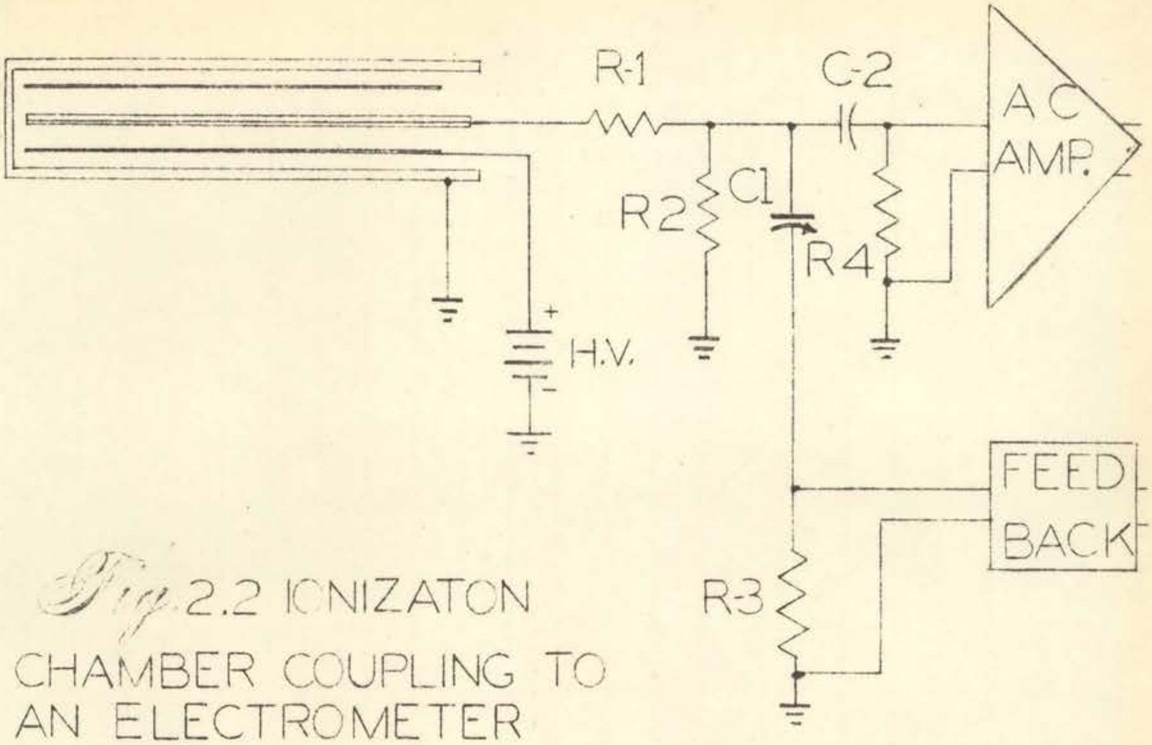


Fig. 2.2 IONIZATON CHAMBER COUPLING TO AN ELECTROMETER

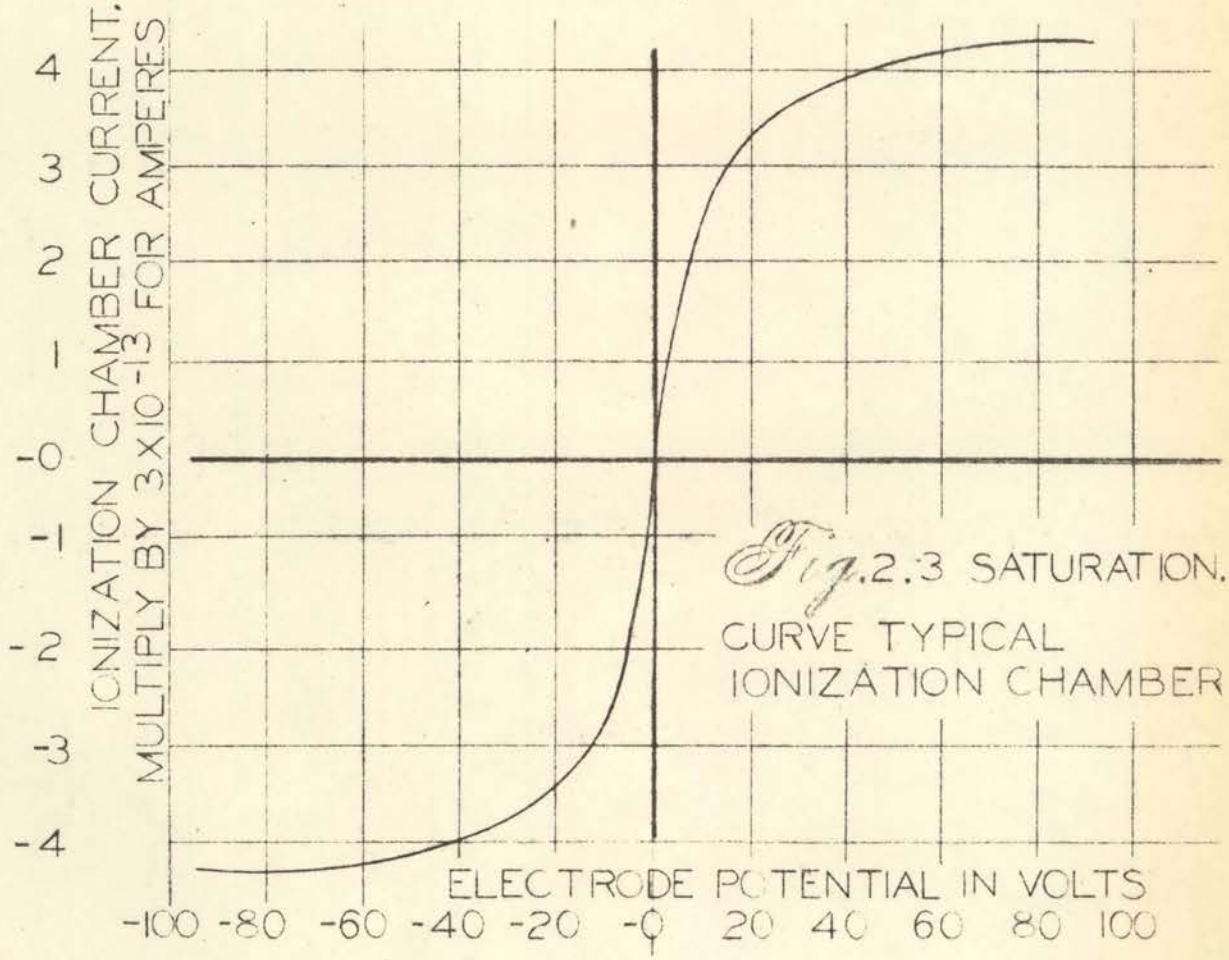


Fig. 2.3 SATURATION. CURVE TYPICAL IONIZATION CHAMBER

variations in the commutator or amplifier gain since the servo-mechanism continuously maintains the input at null. Whenever there is a change of radiation intensity near the ionization chamber the recorder makes a deflection that is proportional to this change.

The natural radioactivity radiations emitted from the borehole strata are in most cases very weak. A sensitive detector is needed to pick up these radiations and register the variation in intensity from one strata to another. The ionization chamber shown in Figure 2.1 is approximately thirty inches in effective length, three and five-eighths inches outside diameter, with a .625 inch diameter center electrode, and is filled with argon gas to a pressure of approximately ninety atmospheres. The recording equipment will register a change in the ionization chamber current of 10^{-15} amperes.

An ionizing particle thru the chamber releases electrons, leaving heavy positive ions. The electrons having a high mobility and will be collected very rapidly if they remain free. In electro-negative gases the electrons are rapidly captured, giving rise to heavy negative ions. The mobility of negative ions in a clean gas is essentially the same as that of positive ions.[1] They tend to have a higher mobility than positive ions in the presence of some

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[1] D. H. Wilkerson, "Ionization Chambers and Counters", Cambridge University Press, 1950, page 29-32.

polar impurities. The time of observation for well logging ionization chambers is usually expressed in terms of their half-time instead of the sixty-three percent time interval indicated by the RC time constant. The half-time observation expedites data taking and provides a practical test for field operations. The half-time is obtained by measuring the time it takes for the recorder to move half of its total excursion when a radiation source is suddenly applied to the ionization chamber. The time constant is 1.45 times the half-time.

Figure 2.3 shows a typical saturation curve of electrode potential vs. ionization chamber current. Saturation is obtained at about 22-1/2 volts electrode potential. The response time of an ionization chamber is dependent on the RC time constant of the chamber and its associated electrical equipment, also on the electrode potential and on the type of gas, its purity and its pressure in the chamber. Figure 2.4 shows the chamber half-time response plotted against the electrode potential for two different instrument time constants. These curves show that the response half-time decreases down to a certain point as the electrode potential increases, and then remains constant as the electrode potential continues to increase. This point is determined by the RC time constant of the circuit, and limits the minimum response time possible for an instrument with a given RC time constant. The operation of this chamber with an electrode potential of 90 volts is slower

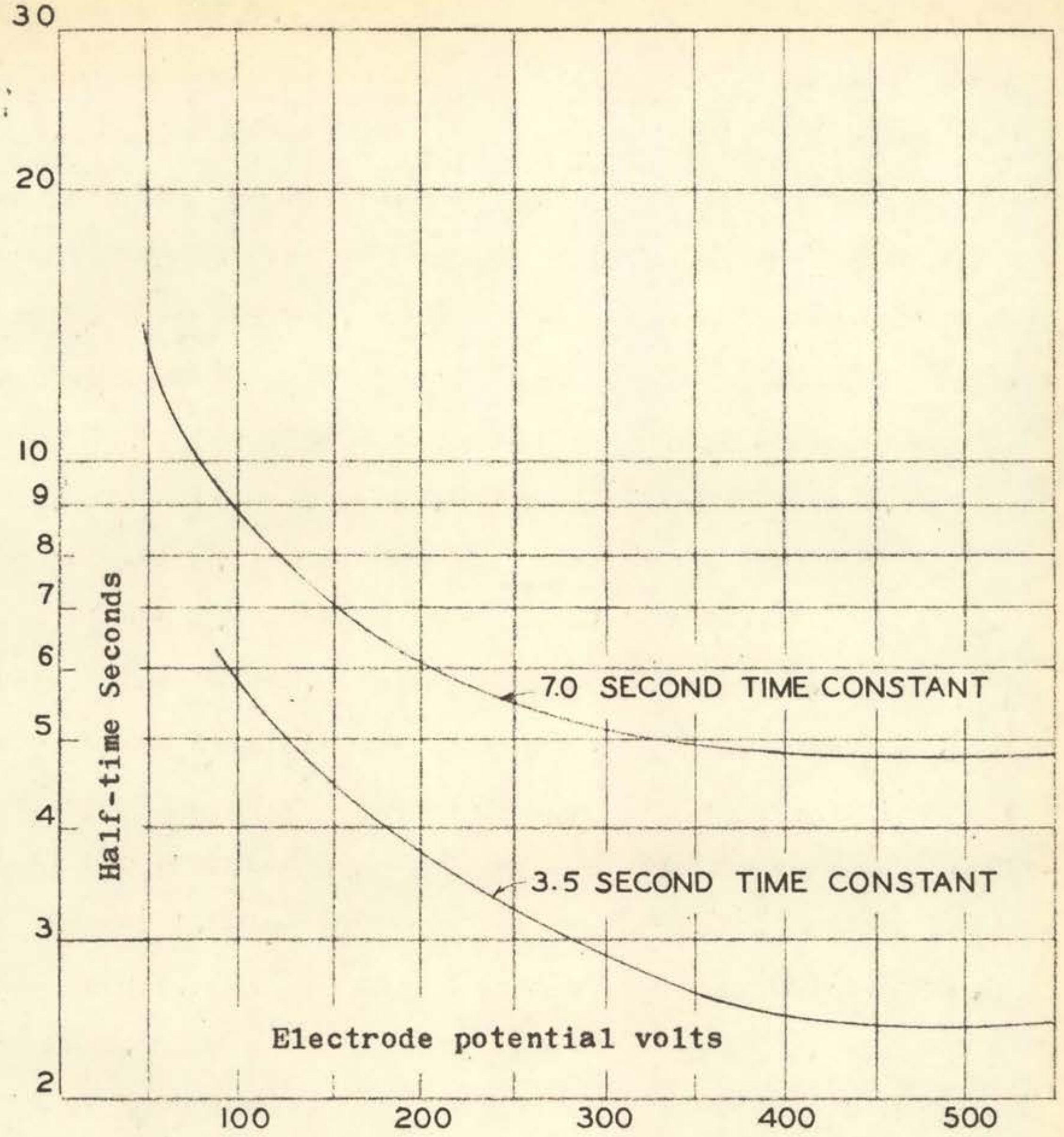


Figure 2.4 The instrument half-time as a function of electrode potential and the time constant of the ionization chamber.

than this minimum response time because of the properties of the gas.

It is necessary to take into account sensitivity, speed of response, efficiency, type of gas, the purity of the gas, the gas pressure, electrode potential and smoothness of operation in order to compare one ionization chamber with another.

CHAPTER III

IONIZATION CHAMBER CHARACTERISTICS

The size and shape of the ionization chamber is controlled chiefly by the size of the oil well borehole. The instrument must have a diameter that is not so large as to prevent it from being used with the standard casings employed in oil wells. The chamber shown in Figure 2.1 is 3-5/8 inches in outside diameter and approximately 30 inches in effective length.

Sensitivity is an important characteristic of radiation detectors used in oil well logging, and is defined as the ability of the logging instrument to detect the small variations in radioactivity encountered in the borehole. The current of the ionization chamber passes through the resistor R_2 and develops a voltage across the plates of C_1 which determines the signal applied to the recorder. The current of the ionization chamber and the value of R_2 are the most important factors in determining the sensitivity of a logging instrument. The factor R_2 also enters into the RC time constant of the instrument.

The speed of response of a logging instrument is usually expressed in terms of the half-time, which can be converted into the regular sixty-three percent time constant by multiplying the half-time by 1.45. Many factors affect the speed of response of the ionization chamber, such as the RC time constant, type of gas, the gas pressure and the electrode potential. The size of the center electrode will also have some effect on the chamber response. The RC time constant limits the minimum response time of the logging instrument, and is governed by the resistors R_1 and R_2 shown in Figure 1.3, the chamber inter-electrode capacity, the center electrode to ground capacity, and the electrometer input to ground capacity. The type of gas, the gas pressure and the electrode potential are very closely interrelated in controlling the response of the ionization chamber. The electrode potential converted to field intensity, X, in volts per centimeter and divided by the gas pressure, P, in atmospheres gives a term X/P that is useful in determining the instrument response. The drift velocity of ions in an electric field is a function of the ratio X/P and the type of gas used.

Efficiency is one of the important characteristics of an ionization chamber, and is defined as the percent of the incident radiation that is detected. Efficiency is very closely related to sensitivity and speed of response and is dependent on the type of gas and gas pressure.

The smoothness of operation of ionization chambers is dependent on the statistical fluctuations caused by the intermittent nature of the radiations associated with the disintegration of radioactive substances. These fluctuations vary in intensity with the intensity of the radiation according to the laws of probability, and are always present in the process of radioactive decay.

In determining the merit of an ionization chamber, the above described characteristics must be taken into account. The particular job at hand will dictate the characteristic carrying the most weight in determining the type of ionization chamber required. These characteristics of ionization chambers are so closely interrelated that if one feature is desired some other feature must be sacrificed. This will be brought out more clearly in the next chapter.

CHAPTER IV

TESTS ON THE PERFORMANCE OF IONIZATION CHAMBERS

A cleaning and filling process was formulated using a very pure grade of argon, commercially available in large cylinders at 2000 p.s.i. The gas pressure commonly used inside the chambers is approximately ninety atmospheres or 1300 p.s.i. The filling process must be performed with great care to avoid any contamination such as grease, oil, dust, air, metallic chips or moisture. The chamber was heated to 350° F. and alternately evacuated and flushed with argon several times over a period of three or four hours. During the filling process gas was passed through a cleaning train or purifier before going into the chamber. The cleaning train consisted of a number of tubes filled with calcium hydride (CaH_2) and one tube filled with silica gel through which the gas must pass before going into the ionization chamber. The cleaning train was heated to 350° F. and the gas flow adjusted to an extremely slow value to get efficient removal of any water vapor and other impurities. The flushing and filling process requires about six hours to complete.

The chamber with the purified gas gave a faster response half-time as shown by Figure 4.1 with the high voltage electrode at a negative polarity. (Negative ion collection). This phenomenon may mean that some electron collection is taking place, or that some polar impurity is present in the gas in just the right amount. The negative ion mobility is very sensitive to the presence of small amounts of impurity, particularly polyatomic gases of all kinds. The polyatomic gas causes inelastic collisions between electrons and gas molecules, this lowers the agitation energy and increases the mean free path of the electrons. The ion drift velocity is proportional to the mean free path and inversely proportional to the square root of the agitation energy. Hence the presence of the right amount of impurity in the gas may be the explanation for the faster response of the chamber with a negative polarity on the high voltage electrode. The flat portion of the curve is caused by the electrical RC time constant limiting the response half-time.

The minimum response half-time of a typical logging instrument using a 3-5/8 inch O.D. by 30 inch effective length ionization chamber and a 10^{11} ohm electrometer input resistor is 4.8 seconds as shown by Figure 2.4. This corresponds to an instrument time constant of 7.0 seconds. A short time constant for almost any instrument, and hence a fast logging speed, can be obtained by changing the value of the electrometer input resistor R_2 as shown in Figure 4.2. The desirable maximum logging speed is that value which corresponds with a progress of not over one sensitive length of the detector in the time corresponding

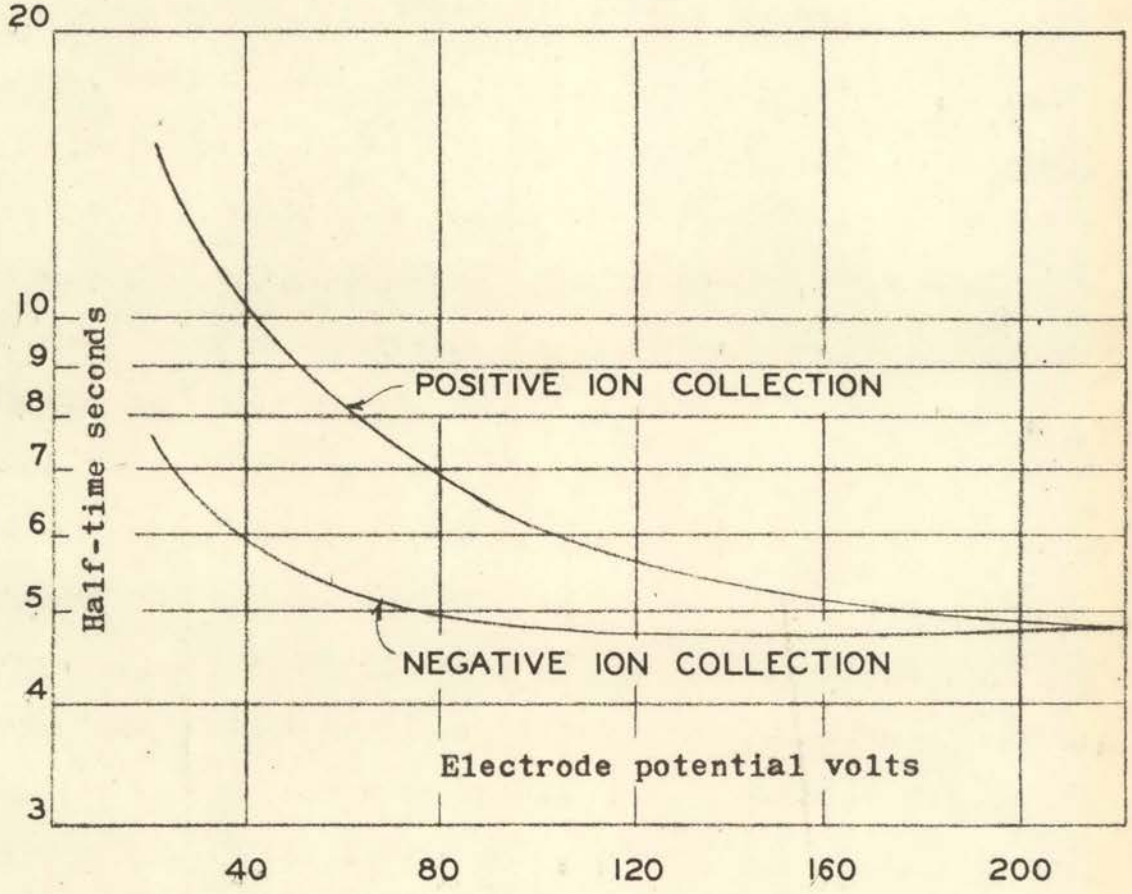


Figure 4.1 Ionization Chamber half-time as a function of the polarity of the electrode potential.

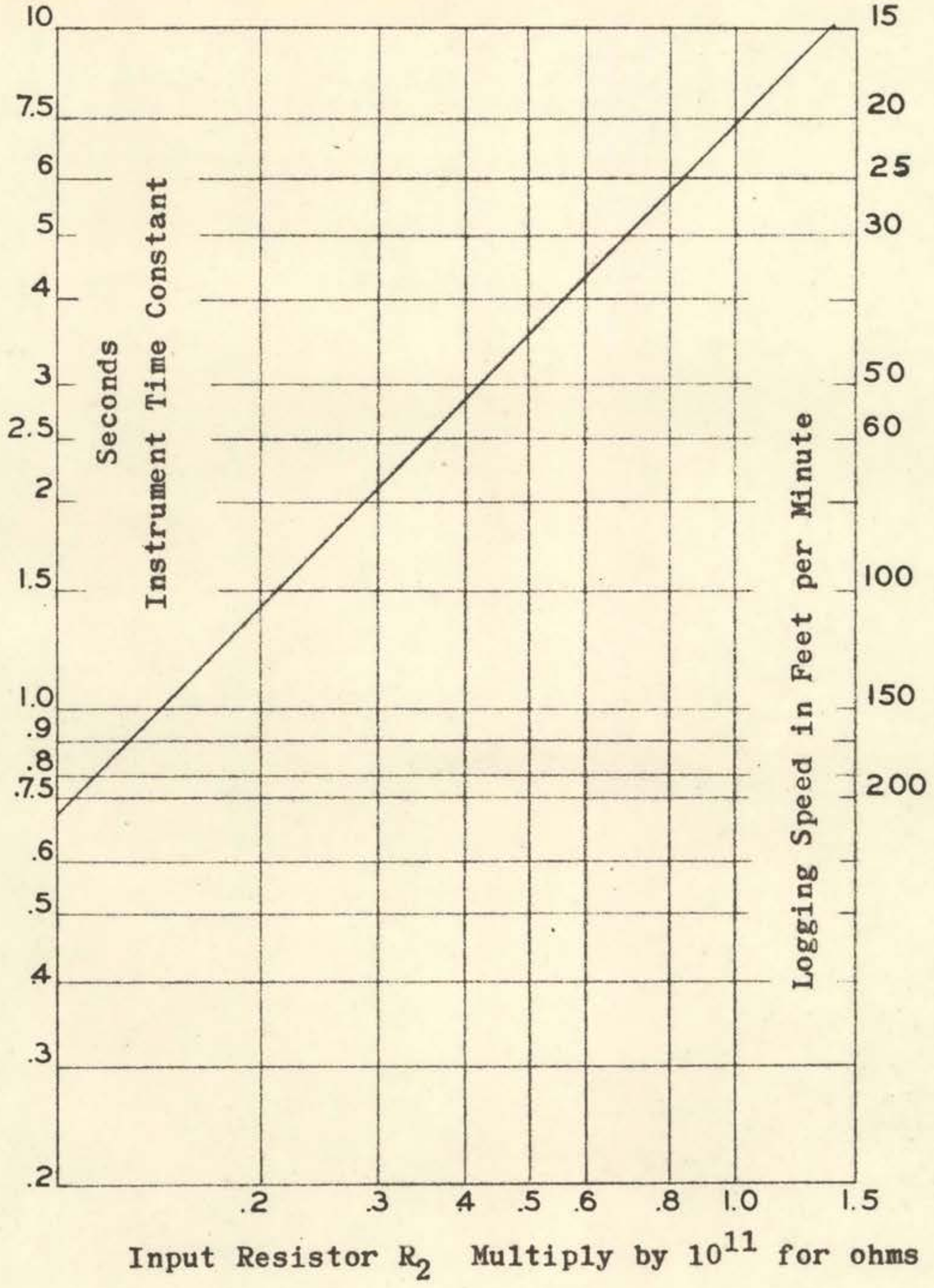


Figure 4.2 The instrument time constant and logging speed as a function of the input resistor.

to the instrument time constant. This ionization chamber has a sensitive length of approximately 2.5 feet. The desirable maximum logging speed is 2.5 feet in 7.0 seconds. This corresponds to a logging speed of approximately 22 feet per minute. This relationship between logging speed and instrument time constant should give a sixty-three percent response to a 2.5 foot thick strata. Figure 4.2 shows the value of the electrometer input resistor as the abscissa and the instrument time constant as the ordinate at the left hand margin and the corresponding desirable maximum logging speed at the right hand margin.

The permitted logging speed may vary from one section of the country to another and with the accuracy demanded for the particular survey. If double the probable error can be tolerated for certain strata the instrument time constant can be shortened and the logging speed can be increased four times. The instrument sensitivity is proportional to the electrometer input resistor so the minimum allowable instrument time constant obtained by reducing R_2 is controlled by the amount of reduced sensitivity that can be tolerated. The instrument with a 10^{11} ohm resistor R_2, a time constant of 7.0 seconds and a logging speed of 22 feet per minute will be referred to as a standard instrument when comparing different types of ionization chambers. Also, the standard chamber is one filled with argon gas to a pressure of approximately 90 atmospheres.

The RC time constant is chiefly controlled by R_2 as discussed above and shown by Figure 1.3. C is comprised of the electrometer input capacity, the center electrode capacity to ground and the chamber inter-electrode capacity. This capacity is fixed for any one type of ionization chamber and can be changed only by altering the size, shape or components of the ionization chamber. The standard ionization chamber with an RC time constant of 7.0 seconds has a R of 10^{11} ohms and a total C of 70 micro-microfarads, composed of the electrometer input capacity of 25 micro-microfarads, the center electrode capacity to ground of 16 micro-microfarads and the inter-electrode capacity of 29 micro-microfarads.

The inter-electrode capacity of a coaxial cylinder is given by equation (4.1)

$$C = \frac{k}{1.8 \times 10^{10} \ln b/a} = \text{farads per meter.} \quad (4.1)$$

k = Dielectric constant = 1 for a gas

b = Inner radius of the outer electrode

a = Outer radius of the inner electrode.

Center electrode of different sizes will change the inter-electrode capacity of the ionization chamber, but will have only a small effect on time constant of the overall instrument as shown by table 4.1.

TABLE 4.1

Center electrode Diameter	Inter-electrode Capacity	Total Capacity	RC time Constant $R = 10^{11}$ ohms
1.0 inch	42.2 mmf	83.2 mmf	8.3 Seconds
.625 inch	28.8 mmf	69.8 mmf	7.0 Seconds
.250 inch	17.6 mmf	58.6 mmf	5.9 Seconds
.125 inch	13.7 mmf	54.7 mmf	5.5 Seconds

Table 4.1 shows that an ionization chamber with a small size center electrode will have a slightly faster time constant, but the electrode potential required to give this faster time constant will be higher. The electric field in a coaxial cylinder ionization chamber is non uniform, and can be calculated for any point within the chamber by equation (4.2)

$$X = \frac{E}{x \ln b/a} = \text{Volts per centimeter} \quad (4.2)$$

X = field intensity at any point x

E = Electrode potential in volts

x = Distance in cm. from axis of center electrode

b = Inner radius in cm. of outer electrode

a = Outer radius in cm. of inner electrode

Table 4.2 shows the field intensity at various points within the ionization chamber for several values of electrode potential and for different sizes of center electrodes.

TABLE 4.2

C. E.	x - cm. from	X in Volts per Centimeter			
diameter	C.E. Axis	E - 90	E - 180	E - 270	E - 540
3.8 cm.	1.9 cm.	78.2	156	234	468
3.8 cm.	2.0 cm.	74.3	148	222	444
3.8 cm.	2.5 cm.	59.4	119	178	356
3.8 cm.	3.0 cm.	49.5	99	148.5	297
3.8 cm.	3.48 cm.	42.7	85.4	128	256
2.54 cm.	1.27 cm.	70.7	141.4	212	424
2.54 cm.	1.5 cm.	60.0	120	180	360
2.54 cm.	2.0 cm.	45.0	90	135	270
2.54 cm.	2.5 cm.	36.0	72	108	216
2.54 cm.	3.0 cm.	30.0	60	90	180
2.54 cm.	3.48 cm.	25.8	51.6	77.4	154.8
1.58 cm.	.8 cm.	76.4	152.8	229.2	458.4
1.58 cm.	1.0 cm.	61.2	112.4	183.6	367.2
1.58 cm.	1.5 cm.	40.8	81.6	122.4	244.8
1.58 cm.	2.0 cm.	30.6	61.2	91.8	183.6
1.58 cm.	2.5 cm.	24.5	49.0	73.5	147.0
1.58 cm.	3.0 cm.	20.4	40.8	61.2	122.4
1.58 cm.	3.48 cm.	17.6	35.2	52.8	105.6
.635 cm.	.317 cm.	118	236	354	708
.635 cm.	.5 cm.	75	150	225	450
.635 cm.	1.0 cm.	37.4	74.8	112	224
.635 cm.	1.5 cm.	25	50	75	150

TABLE 4.2 (Cont.)

C.E. diameter	x - cm. from C.E. Axis	X in Volts per Centimeter E - 90	E - 180	E - 270	E - 540
.635 cm.	2.0 cm.	18.7	37.4	56	112
.635 cm.	2.5 cm.	15	30	45	90
.635 cm.	3.0 cm.	12.5	25	37.5	75
.635 cm.	3.48 cm.	10.8	21.6	32.4	64.8
.317 cm.	.158 cm.	185	370	555	1110
.317 cm.	.5 cm.	58.5	117	175.5	351
.317 cm.	1.0 cm.	29.2	58.4	87.6	175.2
.317 cm.	1.5 cm.	19.5	39	58.5	117
.317 cm.	2.0 cm.	14.6	29.2	43.8	87.6
.317 cm.	2.5 cm.	11.7	23.4	35.1	70.2
.317 cm.	3. cm.	9.7	19.4	29.2	58.4
.317 cm.	3.45 cm.	8.4	16.8	25.3	50.6

The field intensity at the inner electrode is much higher than at the outer electrode. The difference in field intensity between the two electrodes increases as the size of the center electrode is decreased as shown by Figure 4.3 and table 4.2. The field intensity at the outer electrode is one of the important factors in determining the ionization chamber response. Figure 4.3 shows that ions formed near the outer electrode will travel in a low intensity field not much greater than at the outer electrode for the major portion of their travel to the collecting center electrode. The field intensity at the outer electrode is

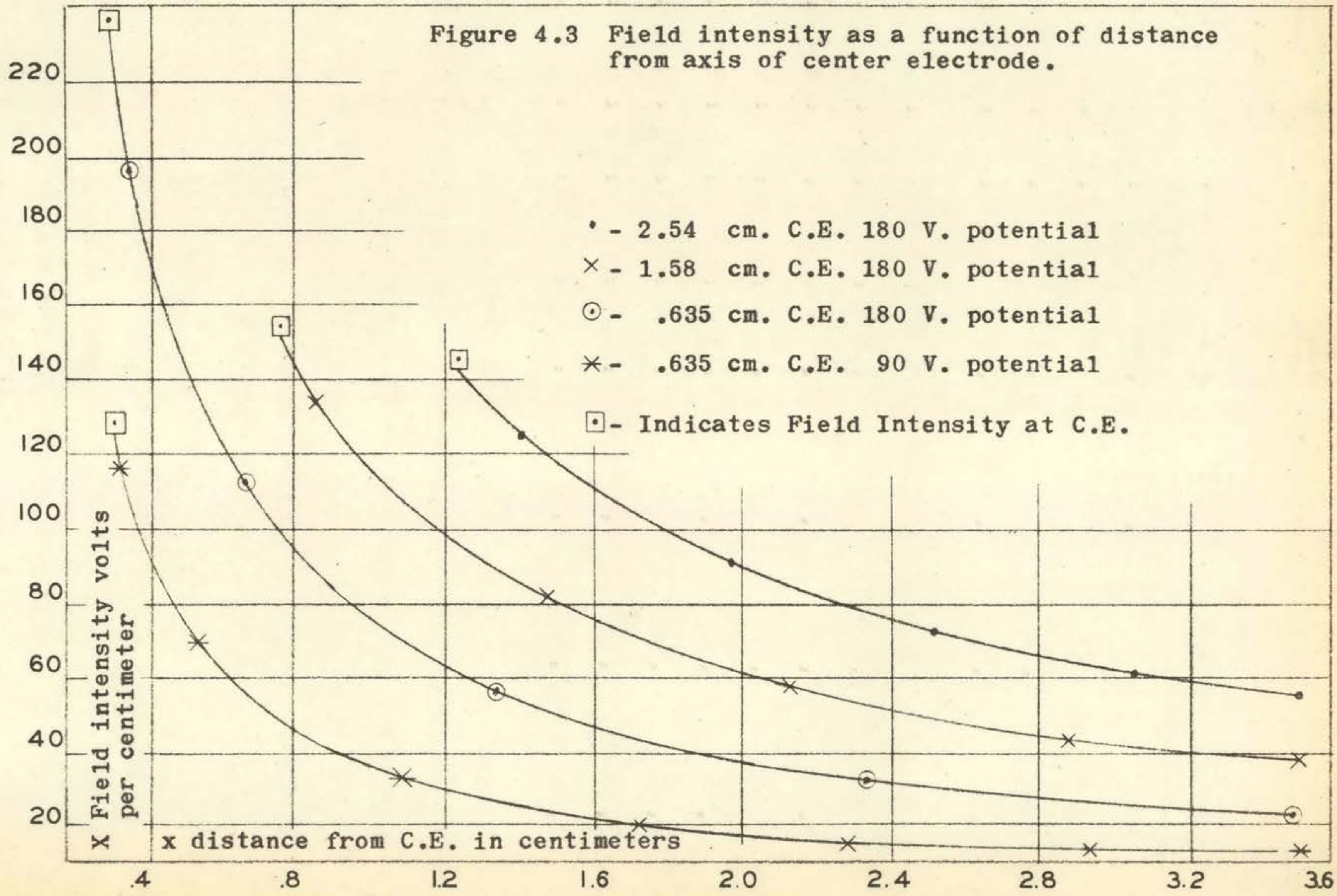


Figure 4.3 Field intensity as a function of distance from axis of center electrode.

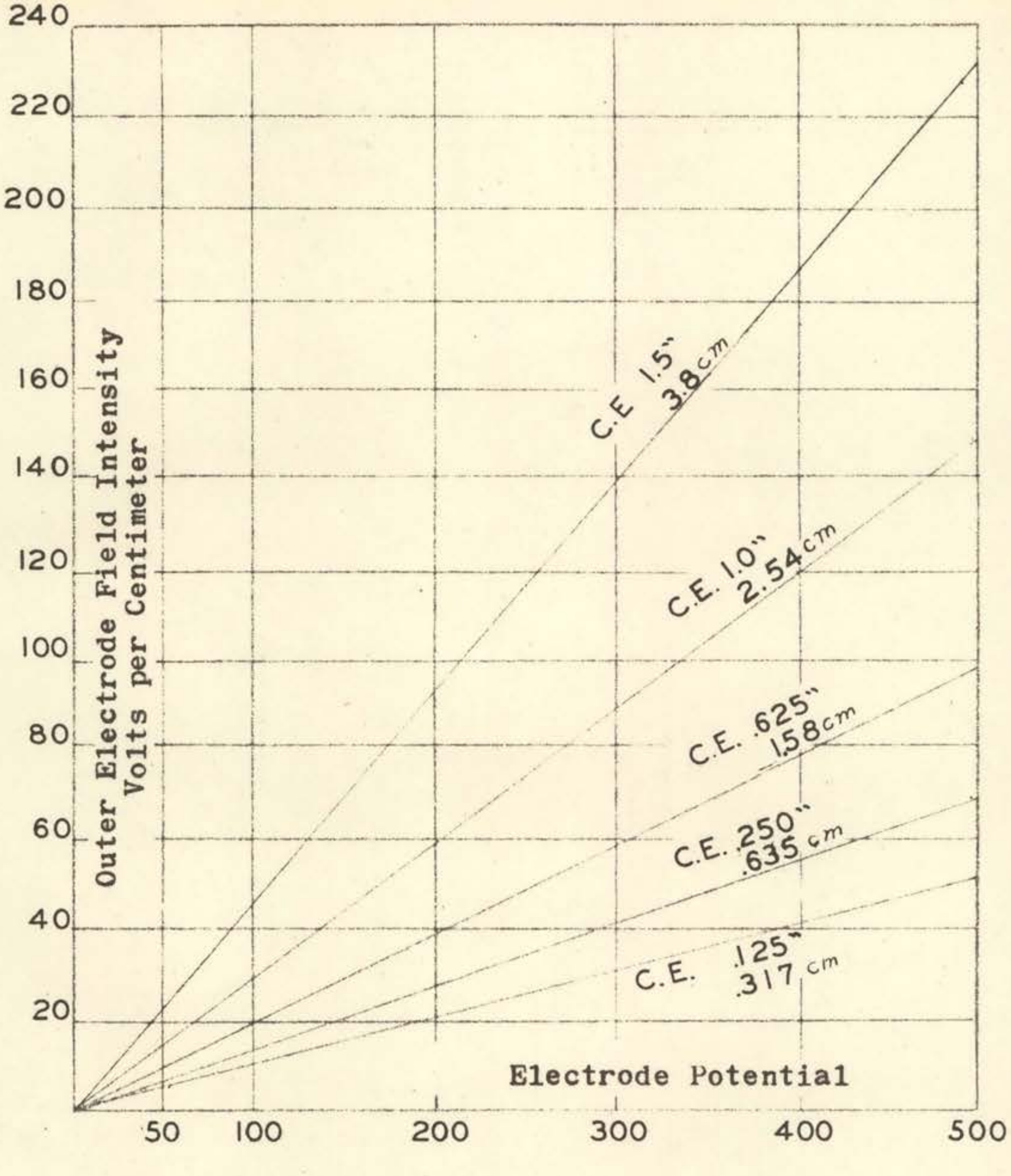


Figure 4.4 Field intensity as a function of electrode potential for various sizes of center electrodes.

a factor that can be used in predicting the response characteristics that various sizes of center electrodes will give to an ionization chamber. The curves of Figure 4.4 shows electrode voltage as the abscissa plotted against field intensity at the outer electrode as the ordinate for various sizes of center electrodes. The standard ionization chamber with a .625 inch center electrode and 180 volts electrode potential has a field intensity at the outer electrode of 35.2 volts per centimeter. From the curves of Figure 4.4 the electrode potential needed to give 35.2 volts per centimeter at the outer electrode can be found for any of the various sizes of center electrodes given. For the 1/8 inch center electrode 380 volts electrode potential is needed to give the same field intensity at the outer electrode as 180 volts for the standard chamber.

The type of gas in the chamber and its pressure is another important factor in determining the ionization chamber response. As stated in Chapter 3 the drift velocity of ions in an electric field is a function of the ratio X/P and the type of gas used. The gas under consideration at this time is argon. The RC time constant of the instrument is made short so that the drift velocity of the gaseous ions is the main factor in determining the response characteristic of the ionization chamber. In this case argon of the same purity was used in determining the effect of gas pressure on the instrument response. The response is a function of the field intensity X in volts per cm. at the outer electrode divided by the gas pressure P in atmospheres.

Table 4.3 gives the X/P ratio for various combinations of electrode potential, center electrode size and gas pressure.

TABLE 4.3

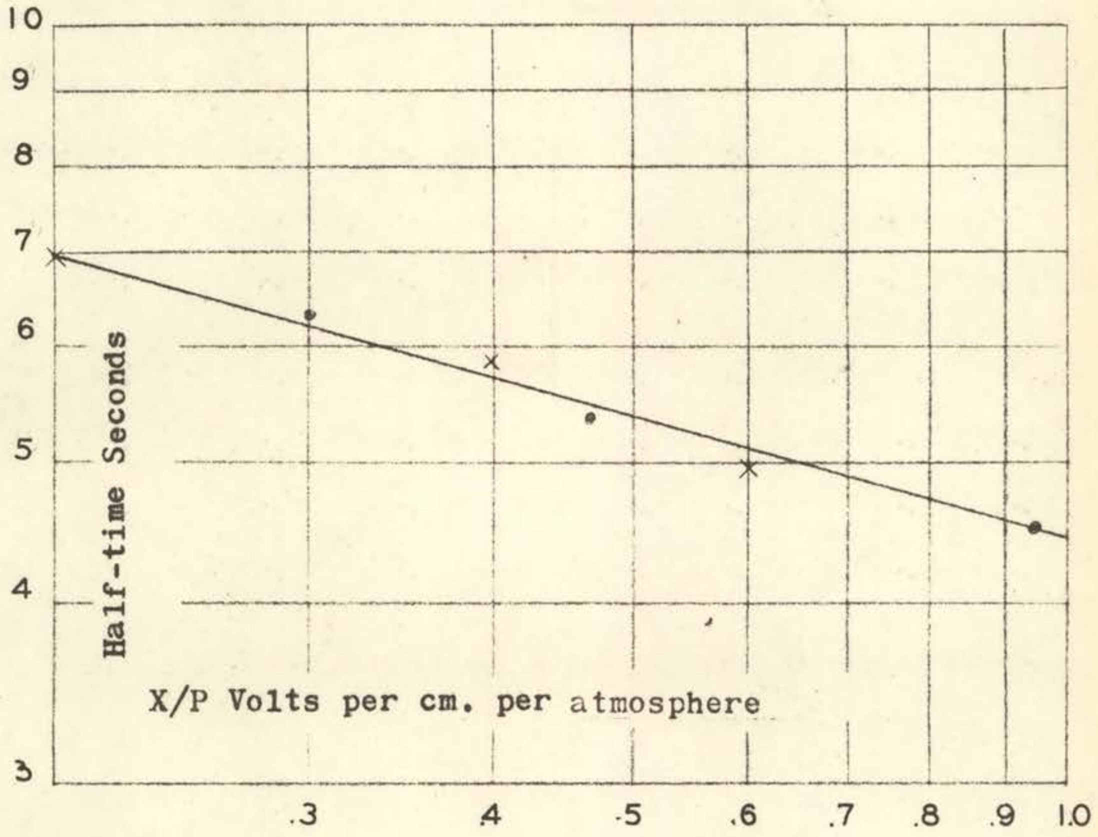
C.E. Diameter	X	P	X/P
3.8 cm.	42.7 v/cm.	90 atms.	.475 v/cm./atms.
3.8 cm.	85.4 v/cm.	90 atms.	.95 v/cm./atms.
3.8 cm.	128 v/cm.	90 atms.	1.42 v/cm./atms.
3.8 cm.	256 v/cm.	90 atms.	2.84 v/cm./atms.
2.54 cm.	22.8 v/cm.	90 atms.	.287 v/cm./atms.
2.54 cm.	51.6 v/cm.	90 atms.	.574 v/cm./atms.
2.54 cm.	77.4 v/cm.	90 atms.	.86 v/cm./atms.
2.54 cm.	154.8 v/cm.	90 atms.	1.72 v/cm./atms.
1.58 cm.	17.6 v/cm.	90 atms.	.196 v/cm./atms.
1.58 cm.	35.2 v/cm.	90 atms.	.392 v/cm./atms.
1.58 cm.	52.8 v/cm.	90 atms.	.588 v/cm./atms.
1.58 cm.	105.6 v/cm.	90 atms.	1.18 v/cm./atms.
1.58 cm.	17.6 v/cm.	145 atms.	.121 v/cm./atms.
1.58 cm.	35.2 v/cm.	145 atms.	.242 v/cm./atms.
1.58 cm.	52.8 v/cm.	145 atms.	.363 v/cm./atms.

TABLE 4.3 (Cont.)

C.E. Diameter	X	P	X/P
1.58 cm.	105.6 v/cm.	145 atms.	.726 v/cm./atms.
.635 cm.	10.8 v/cm.	90 atms.	.12 v/cm./atms.
.635 cm.	21.6 v/cm.	90 atms.	.24 v/cm./atms.
.635 cm.	32.4 v/cm.	90 atms.	.36 v/cm./atms.
.635 cm.	64.8 v/cm.	90 atms.	.72 v/cm./atms.
.317 cm.	8.4 v/cm.	90 atms.	.0935 v/cm./atms.
.317 cm.	16.8 v/cm.	90 atms.	.187 v/cm./atms.
.317 cm.	25.2 v/cm.	90 atms.	.280 v/cm./atms.
.317 cm.	50.5 v/cm.	90 atms.	.56 v/cm./atms.

The ratio of X/P can be used to predict the response of the ionization chambers under study, providing the RC time constant is short compared to the ion collection time. The range studied of the X/P ratio has been between .05 and 3.0. The ionization chamber response varies linearly with the X/P ratio. Two ionization chambers with different size center electrodes give the same response half-time when the X/P ratios are equal as shown by Figure 4.5.

The smoothness of operation of an ionization chamber is dependent on the statistical fluctuations caused by the intermittent nature of the radiations associated with the disintegration of radioactive substances. These fluctuations are dependent on the number of rays detected during



× - 3.8 cm. C.E. 90 atms. pressure

• - 1.58 cm. C.E. 90 atms. pressure

Figure 4.5 Half-time as a function of X/P in volts per centimeter per atmosphere an interval of time, usually determined by the instrument time constant. These variations obey the laws of probability, with the probable error equal to .6745 times the square root of N, where N is the number of rays detected during an interval of time. The observed time is usually express by the half-time response of the instrument or the half-time multiplied by 1.45 to give the instrument time constant.

The probable error can be determined from the statistical fluctuations as recorded on a logging chart. Figure 4.6 shows a typical statistical chart recorded by exposing the ionization chamber to a constant radium source. The probable error can be determined from this statistical chart, which should be run for a period of time equal to at least 100 instrument time constants. The probable error is approximately equal to one fourth the peak to peak error taken over a period of 25 instrument time constants. The probable error is equal to .6745 times the standard deviation. The nine-tenths error is also a useful term in determining the probable error from the statistical fluctuations, as it can be obtained graphically and is more accurate than the peak to peak error determination. The nine-tenths error can be defined as one-half the distance between two parallel lines drawn on the statistical chart between which the fluctuations remain ninety percent of the time. The probable error is .410 times the nine-tenths error.

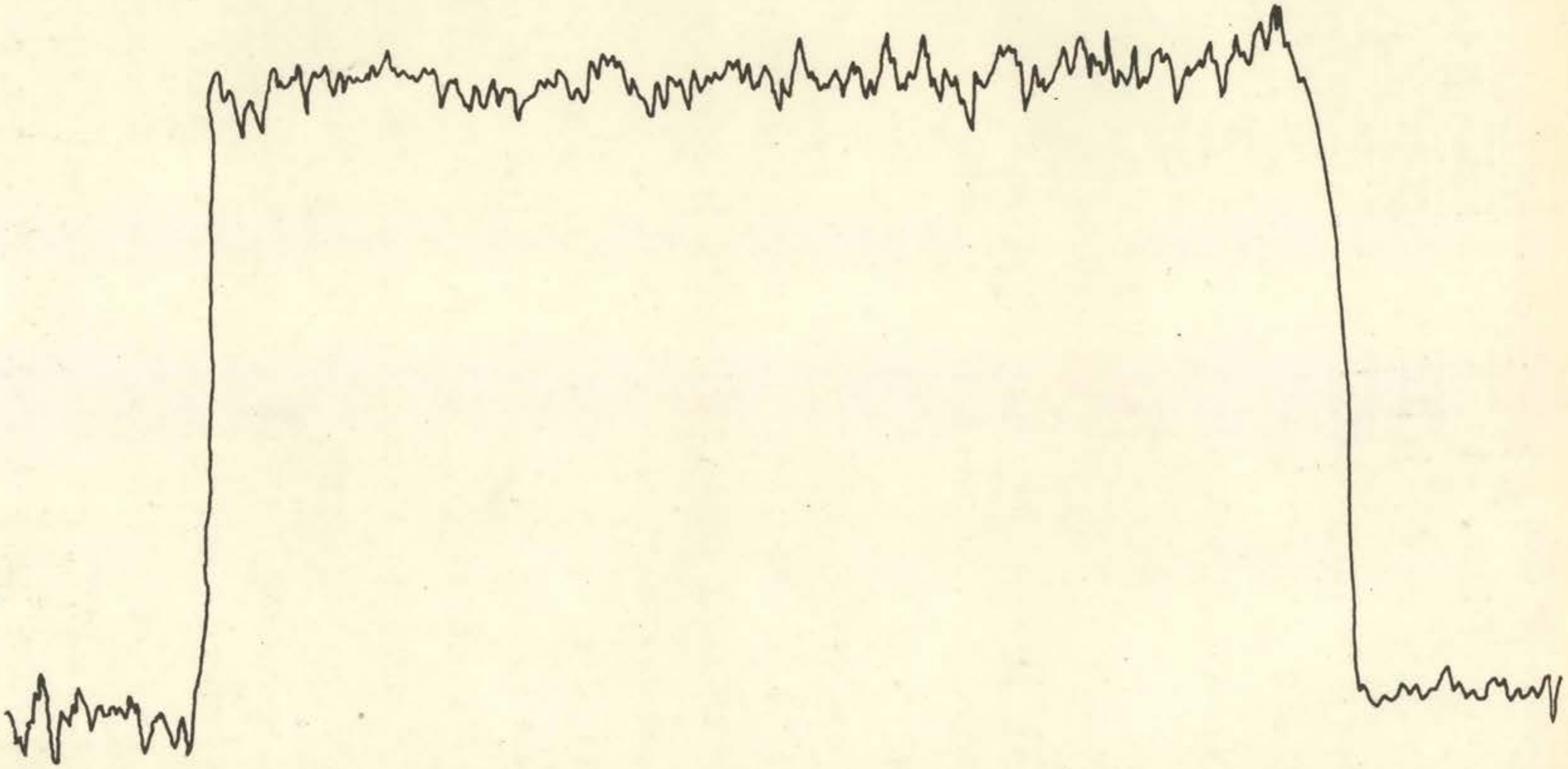


Figure 4.6 Typical Statistical Fluctuations

CHAPTER V

SPECIAL IONIZATION CHAMBERS

The accuracy demanded for the particular survey determines to a large extent the logging speed permitted and type of ionization chamber needed. The thirty inch chamber as previously described is good for detecting low intensity radiations but does not give as accurate a resolution of thin strata as a shorter chamber. The inter-electrode capacity will be less for a short chamber and hence a faster instrument time constant as shown by table 5.1.

TABLE 5.1

Chamber Length	C.E. Diameter	Inter-electrode Capacity	RC Time Constant $R - 10^{11}$ ohms
30"	1.0 inches	42.2 mmf.	8.3 seconds
30"	.625 inches	28.8 mmf.	7.0 seconds
30"	.250 inches	17.6 mmf.	5.9 seconds
15"	1.0 inches	21.1 mmf.	6.2 seconds
15"	.625 inches	14.4 mmf.	5.5 seconds
15"	.250 inches	8.8 mmf.	5.0 seconds
10"	10.0 inches	14.1 mmf.	5.5 seconds
10"	.625 inches	9.6 mmf.	5.0 seconds
10"	.250 inches	5.8 mmf.	4.7 seconds

However the maximum desirable logging speed of one instrument length per time constant will be slower. The maximum logging speed for the 15 inch chamber with a time constant of 5.5 seconds is 13.5 feet per minute and for the 10 inch chamber with a time constant of 5.0 seconds is 10 feet per minute as compared to 22 feet per minute for the standard ionization chamber. The 15 inch ionization chamber has a volume half that of the 30 inch chamber and therefore the sensitivity will be cut in half. However the sensitivity of the 15 inch chamber can be made equal to that of the 30 inch chamber by doubling the gas pressure.

The characteristics of a small size ionization chamber has been studied for comparison with the standard ionization chamber as described in Chapter 4. This chamber being approximately two inches inside diameter and nine inches long. The volume ratio of the two chambers is about seven to one, giving ionization chamber currents in the same ratio when the two chambers are under the same conditions of gas, gas pressure and radiation intensity. The characteristics of chambers of this type but of different lengths have been determined as shown in table 5.2.

TABLE 5.2

Chamber Length	C.E. Dia.	Inter-electrode Capacity	RC time Constant R-10^{11} ohms	Logging Speed
9"	1.0"	18.2 mmf.	5.9 sec.	7.6'/min
9"	.625"	11.0 mmf.	5.2 sec.	8.7'/min
9"	.250"	5.9 mmf.	4.7 sec.	9.5'/min
18"	1.0"	36.4 mmf.	7.7 sec.	11.7'/min
18"	.625"	22.0 mmf.	6.3 sec.	14.3'/min
18"	.250"	11.8 mmf.	5.3 sec.	17.0'/min
36"	1.0"	72.8 mmf.	11.4 sec.	15'/min
36"	.625"	44.0 mmf.	8.5 sec.	21'/min
36"	.250"	23.6 mmf.	6.5 sec.	28'/min

The RC time constant and hence the logging speed is directly proportional to the input resistor R_2. The logging speed can be increased by decreasing the value of resistor R_2, but the sensitivity is reduced in the same proportion. In this case the amount of sensitivity reduction that can be tolerated governs the logging speed.

The logging speed can be doubled and the sensitivity kept the same by filling the chamber to twice the pressure and decreasing the resistor R_2 by a factor of two. The use of krypton gas is another way of getting increased sensitivity, since its density is greater than that of argon at the same pressure.

A series of performance tests were made, comparing a krypton chamber at a pressure of 76 atmospheres, an argon chamber at 76 atmospheres and an argon chamber at 145 atmospheres pressure. The radiation for these tests was a 74 micro-curie source of radium at a distance of 24 inches. The results of these tests are shown in table 5.3.

TABLE 5.3

	Krypton 76 atms.	Argon 76 atms.	Argon 145 atms.
Ion Current (Micro micro amp.)	1.65	.066	1.26
Nine-tenths error %	2.6%	4.55%	3.1%
Half-time	4.8 sec.	4.0 sec.	4.7 sec.
Time Constant	6.95 sec.	5.8 sec.	6.8 sec.
Calculated weight of gas in chamber	165 gms.	64.7 gms.	126 gms.

TABLE 5.4

	$\frac{\text{Krypton 76 atms.}}{\text{Argon 76 atms.}}$	$\frac{\text{Krypton 76 atms.}}{\text{Argon 145 atms.}}$	$\frac{\text{Argon 145 atms.}}{\text{Argon 76 atms.}}$
Ratio weight of gas	2.55	1.31	1.94
Ratio currents	2.5	1.31	1.9
Ratio errors squared (adjusted for equal time constants)	2.53	1.27	1.96

CHAPTER VI

CONCLUSIONS

The data given in tables 5.3 and 5.4 show that for a given radiation intensity the current of the ionization chamber is in direct proportion to the amount of gas contained in the chamber, errors are proportional to the square root of current, and inversely proportional to the square root of the time constant. Gasses of higher desntiy have a somewhat slower ion collection time but with a higher electrode potential the response half-time can be made to approach the limit set by the RC time constant. Figure 6.1 shows that the X/P ratio will determine the ionization chamber response regardless of center electrode size, gas pressure and electrode potential. However this is valid only when the same type of gas is used in the chambers under comparison.

On a current basis and at the same pressure, krypton is 2.5 gimes more sensitive to the radiations of radium than is argon. This is a somewhat higher ratio than would be expected from the atomic weight of the two gasses. This difference is due to the fact that krypton is more compressible under pressure than is argon. The efficiency of krypton is also 2.5 times that of argon, since the

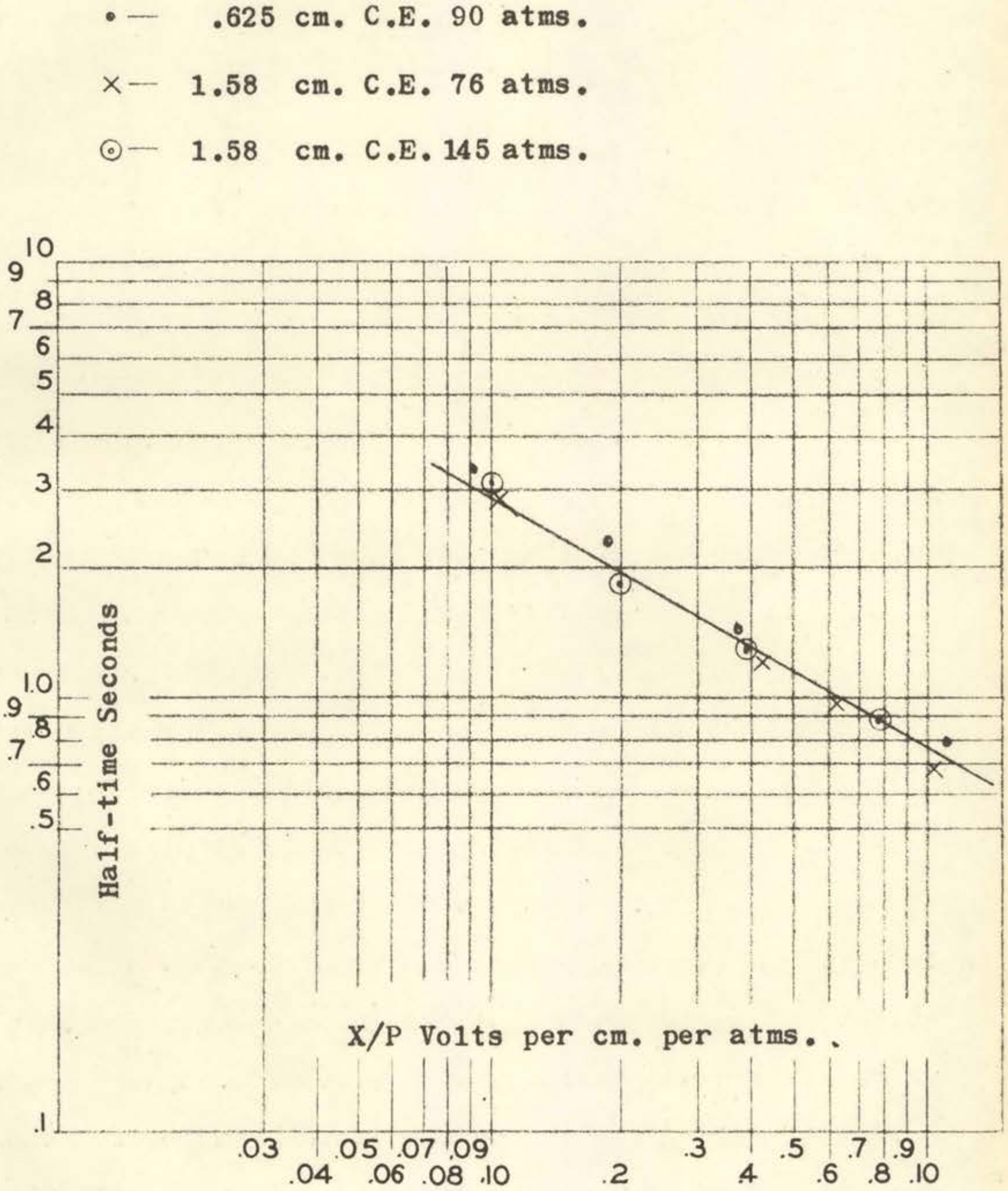


Figure 6.1 Half-time as a function of X/P for the sizes of center electrodes and gas pressures as indicated.

statistical errors have been found to be directly proportional to the square root of the current and inversely proportional to the square root of the time constant of the instrument. Current and efficiency have been found to increase in direct porportion to the weight of the gas. The RC time constant limits the minimum response half-time of an ionization chamber. The reduced sensitivity that can be tolerated governs the amount that the input resistor R_2 can be reduced and hence the maximum attainable logging speed. Increased gas pressure will help compensate for the reduced sensitivity caused by reducing R_2. Special chambers with the characteristics demanded for the particular service at hand are desirable.

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