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A SPECIAL REPORT

RADIOACTIVE TRACER TECHNIQUES AS APPLIED TO EVALUATION OF MUSTARD GROUND CONTAMINATION

By

P. A. Leighton, Colonel, C.W.S.
S. B. Bogese, Captain, C.W.S.
Paul T. Masley, Tec Sgt., C.W.S. (senior author)

Dugway Proving Ground

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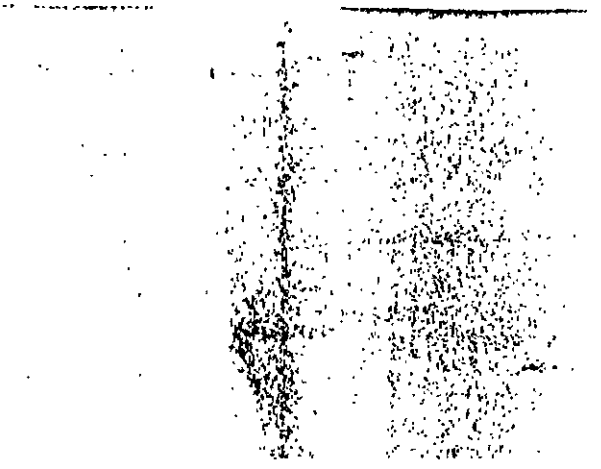

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ABSTRACT

OBJECT

The object of this report is to describe techniques used in the application of radioactive tracer methods to the estimation of liquid agent ground contamination in certain field experiments involving mustard (H) filled munitions.

RESULTS

1. The radiotracer method of H ground contamination assessment has been developed into a standard procedure in which quantitative radioactivity measurements are performed by means of Geiger-Mueller tubes.

2. The radiotracer method of H ground contamination assessment has been compared with other methods of H ground contamination assessment and has been found to be the most precise of any method used previously.

3. Techniques have been developped allowing a whole radiotracer field test evaluation to be made more rapidly than that of any previously known method except the Grinnell photoelectric photometer procedure.

4. Steps have been undertaken, but not completed, to develop modified radioactivity measurement apparatus which will speed up the radiotracer assessment of large scale field experiments.

5. A large amount of experience and information regarding the operation of electronic apparatus of special application to this problem has been gained.

CONCLUSIONS

The following conclusions are made on the basis of evidence presented or referred to in this report:

1. The radiotracer method of evaluating ground contamination has antiquated all methods used previously in the solution of the contamination evaluation problem except the photoelectric photometer method.

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2. The radiotracer method is more rapid than all previously used methods except the photoelectric photometer method.

3. The radiotracer method is the most precise of all known methods of ground contamination assessment.

4. The radiotracer method is capable of greater detection sensitivity than any other known method.

5. The radiotracer method is somewhat more complex in operation and apparatus than any of the other methods.

6. The radiotracer method is, at the present time, more costly for large scale testing than any of the others, but there is some indication based on knowledge concerning the development of manufacturing processes for plutonium that this cost can be greatly reduced.

7. The radiotracer apparatus is, in part, in an excellent state of development at the present time, and furnishes a firm foundation for future development.

RECOMMENDATIONS

1. Consideration should be given to the possibility of the use of the radiotracer method in the problems other than areal radioactivity measurements.

2. Negotiations should be undertaken with the Government agency responsible for the operation of plutonium manufacturing plants for the purpose of obtaining various desirable radiotracer materials.

3. Because specialized electronic apparatus is used in all radiotracer measurements, a department or section of research should be organized which will have the responsibility of investigating the extension of radiotracer techniques and developing new apparatus for the study and measurement of radioactive phenomena.

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I. INTRODUCTION

A. Object

The object of this report is to describe techniques used in the application of radioactive tracer methods to the estimation of liquid H ground contamination in certain field experiments involving various H-filled munitions.

B. Authority

Project B 6a, letter SPCVB 471.6, dated 9 December 1943.

II. HISTORICAL

The study of liquid H ground contamination has been difficult because of limitations imposed by available techniques of quantitation. Practically all standard practice now includes the addition of a tracer of one sort or another to the liquid agent in order to assist in defining at least the shape of the liquid-contaminated area. Organic dyes, such as Rhodamine B Base and Victoria Blue B Base were early incorporated into H samples in munitions to be used for field tests, and later, colorimetric analyses of the dye content of H picked up on pie plates, absorbent panels, and even the soil of the contaminated area, were made in order to attempt an estimation of the degree of contamination imposed on the area. Organic dyes have been shown to be unreliable as tracers for liquid H because of fading due to chemical reaction with soil or due to the action of the sunlight. Accordingly, the use of metal compounds soluble in H was advocated as a tracer technique by the British. Thus, copper, zinc, and nickel oleates, stearates, and naphthenates have been investigated as tracer compounds. It has been shown, however, that the length and complexity of the analyses for metal content of field soil samples of H contaminated areas made this method of little value for large scale field tests. The search for faster and more reliable techniques suggested that radioactive tracer techniques might be applied successfully to the evaluation of ground contamination experiments. Preliminary tests of the radioactive tracer method were conducted at this station in January 1944, and indicated great promise for the idea. Since then, the method and techniques have been extended and expanded.

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Certain commercial and educational organizations have used radioactive tracer techniques in a fashion similar on a miniature scale to those applied in this work (see (1) and (2) in Bibliography) but it is believed that this is the first instance in which radiotracer techniques have been applied to large scale investigations of areal radioactivity contamination. Accordingly, this historical background is limited.

III. THEORETICAL

Uranium, thorium, and protoactinium are parent elements, each, of three series of elements whose atomic nuclear structure is such that the nucleus is said to be in a state of instability. During the course of time, each such unstable nucleus undergoes a rearrangement in an attempt to gain a stable state. In the process of rearrangement, matter is emitted from the atomic nucleus. This emitted matter has been proved to be sub-atomic particles (alpha particles; electrons; neutrons; protons) travelling in space with velocities somewhat less than that of light. Accompanying, or closely following the ejection of matter from the nucleus undergoing rearrangement is a loss of atomic energy in the form of an electromagnetic radiation (gamma rays). Gamma rays, travelling with virtually the velocity of light, are capable of penetrating matter to a degree far greater than that shown by other electromagnetic radiations (light; radio waves). This property has allowed gamma rays to be utilized for the purpose of "seeing" through the human body in search of functional derangement in illness, and through thick metal castings and weldings in search of faults. It is possible to use gamma rays in this manner because the relatively tremendous energy of gamma rays is absorbed preferentially by matter of high density or greater thickness. The gamma ray detector used in this application of gamma rays is usually the photographic plate or sometimes the fluorescent screen. Gamma rays are an essential part of the radiotracer technique described in this report, primarily because their great penetrating power allows ready detection if suitable detecting apparatus is used.

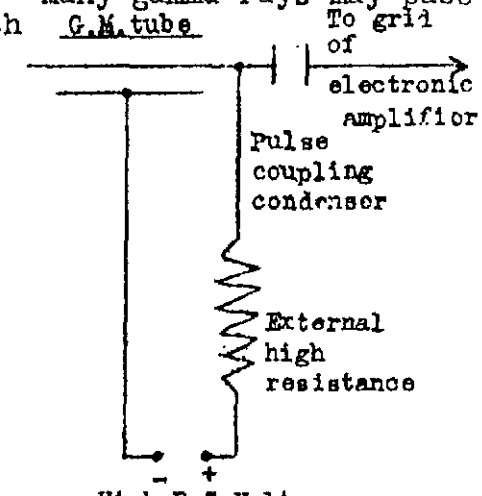
In other, but similar, radiotracer techniques the material products of nuclear disintegration have been used in manners similar to be described here for the gamma rays. The human eye is incapable of responding to gamma rays in the manner that it responds to "visible" light, and at best is a very poor detector. The photographic plate has already been mentioned as a detector. It shows fair ability in certain applications. Even better is the ionization chamber, which will be discussed in detail later. Probably the best detector of gamma rays (and when properly designed, of alpha particles, and high velocity electrons or beta rays) is the Geiger-Mueller counter.

Much discussion will revolve about the Geiger-Mueller counter, and so, it may sometimes be referred to as G-M counter, or simply as a counter. Many other types of detectors are known, and practically all have been used in the study of nuclear constitution, but for the present purpose the G-M counter and the ionization chamber are of particular interest.

A. The Geiger-Mueller Counter

The Geiger-Mueller counter is an electronic tube belonging to the diode family. It consists of two metallic electrodes of greatly unequal area enclosed within a space capable of being evacuated to, and maintained at, a pressure of several centimeters of mercury. The enclosing material, or envelope, is usually a glass cylinder sealed at both ends. Figures 1 and 8 (Appendix A) show samples of G-M counters enclosed in glass envelopes, and Diagram I (Appendix B) is a drawing of a typical G-M counter.

In the simplest application of the G-M counter, a high potential electrical field (DC) is impressed between the electrodes in a circuit which includes a very high external resistance in addition to the potential source and counter electrodes (note accompanying diagram). The passage of a single penetrating radiation (gamma ray, or simply ray or photon) through the counter tube, under conditions of high electrode potential stress, may, by virtue of derangement of the inter-electrode electric field (as a result of ionization of gas or other molecules or atoms) cause an electrical "discharge" to occur. This can happen only if part or all of the energy of the ray is absorbed somewhere inside the counter. Many gamma rays may pass through the counter for every one which is absorbed. These are not detected. If a ray should be detected, however, the discharge of the electric field causes a current to flow in the external circuit high resistance. As a result, the voltage drop across the resistance increases from zero to some value which is an appreciable fraction of the total applied potential. When the drop becomes great enough, the current which was flowing between the counter electrodes ceases to flow because the potential is insufficient to maintain it. When this happens, the voltage drop across the external resistance again drops to zero, and the original interelectrode potential is attained. The counter is then ready to respond to the presence of another penetrating radiation. The process of discharge and recharge can occur very rapidly -- up to once every one-one hundred thousandth of a second in a good G-M counter. With the assistance of suitable external electronic apparatus, this



rapidly occurring process, repeated over and over, many times a minute, but only once for each gamma ray, can be made to produce a record of the total number of rays absorbed in the counter over a measured time. Thus, a measure of the intensity of gamma radiation or radiation flux may be had. The "counts" shown by a Geiger-Mueller counter in the presence of radioactive material become, when measured under certain conditions, a measure of the concentration of ground contamination of liquid H when the radioactive material was present in the H as a tracer. For example, assume that a milligram of radioactive material having 10,000 nuclei decomposing per unit time is distributed evenly throughout 100 pounds of H. This H, contained in a munition, is then scattered over a ground area, A. A small fraction, a, of this area picked up and held close to a G-M counter shows a count per unit time of 10. Then, it can be said that the amount of H on area a was exactly 10/10,000 of 100 pounds, or 0.1 pound.

B. The Ionization Chamber

The penetrating characteristics of gamma rays were mentioned above. Also mentioned was a characteristic which may be called "ionizing ability". Ionizing ability of penetrating radiations is shown in any matter in which penetrating radiation energy may be absorbed. It is the basis upon which chemical reactions initiated or influenced by penetrating radiations are explained. It is the basis upon which the functioning of an ionization chamber is explained, though, in strict sense, chemical reaction may not occur here. Ionizations of gas molecules or atoms occur, none the less, and a measure of the degree of ionization can be used to represent the intensity or radiation flux density of the penetrating radiation causing the ionization.

The ionization chamber is a device consisting of two metallic plane parallel or concentric cylindrical electrodes so arranged as to allow formation and maintenance of an electrical field between them under the influence of a relatively low voltage DC potential. The space between the electrodes is filled with a gas at atmospheric or higher pressure. Passage of ionizing radiations (gamma rays) through the gas causes an ionization which results in a decrease of the specific resistance of the gas. This decrease may be measured, with appropriate electrical apparatus, and related to the concentration of radioactive material producing the rays. The relationship is governed by (1) the physical dimensions of the chamber electrodes, (2) the type of gas, (3) the pressure of the gas, and (4) the potential difference between the electrodes (for a given type of radiation). The ionization chamber differs from the Geiger-Mueller counter by virtue of its inability to distinguish between individual radiation quanta or photons, but treats all passing through at about the same time as a unit. It is, in effect, a self-contained integrator rather than a differentiator.

The electrical current across the electrodes which results from passage of ionizing radiation may be measured by a sensitive galvanometer if high flux density radiation is under study. For maximum sensitivity, however, the currents which result from minimal amounts of radiation are usually utilized in the production of a voltage drop across a high resistance (which in the case of the Dugway ionization chambers is of the order of 100,000 megohms). This voltage drop is then measured by a suitable vacuum tube voltmeter. Photographs of a simple concentric cylinder chamber operating at atmospheric pressure are shown in Figures 16 and 17 (Appendix A), and the circuit diagram of its associated vacuum tube voltmeter is shown in Diagram 2 (Appendix B). This unit was designed at the University of California for the purpose of measuring penetrating radiation capable of inflicting damage upon the human body. It is known as a radiation protection meter, and because of its low sensitivity, it is not used in the usual field tracer studies.

For field testing purposes, a much more sensitive instrument is required and has been built. This instrument is the heart of a machine which is called the radioactivity ground scanner. The radioactivity ground scanner (or simply, the scanner) was designed to scan and record continuously the changes in tracer concentration of an H-tracer contaminated ground area. A more complete description of this unit, and a sample of the data obtained with it are given later.

C. The Radioactive Tracer Method

In actual practice, the radiotracer method is somewhat more complex than described in earlier paragraphs. The use of naturally radioactive elements such as uranium, thorium, protoactinium, and their radioactive decomposition products as tracers is not widespread. This is true because natural "radioelements" are rare and costly, and do not always lend themselves to the preparation of chemical compounds which have suitable properties. At present, the production of "artificial" radioelements has advanced to the stage where a great variety of nuclearly unstable atoms, ranging from hydrogen to uranium, can be produced almost at will, and sometimes at relatively low cost. Preparation of such radioactive elements is called "nuclear bombardment". There are various machines capable of nuclear bombardment, and most of the large educational institutions in this country have one or another of such machines for the purpose of pure research in the field of nuclear constitution. The most useful machine for the mass production of artificially radioactive elements is known as the "cyclotron".

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The Massachusetts Institute of Technology, the University of California (Berkeley, Calif.), Washington University (St. Louis, Mo.), and Columbia University (New York City) have applied this complicated electronic device for this purpose.

The process of nuclear decomposition of the nuclei of a mass of atoms of a given radioactive element proceeds according to a certain exponential law. This law is known as the Law of Radioactive Disintegration and is expressed by the equation N = $N_o e^{-\lambda t}$. The law states in effect that the number of radioactive nuclei undergoing disintegration at any time is a function of the total number of undisintegrated nuclei present. If N_o unstable nuclei are present in a mass of radioactive nuclei at time t_o, then after time t, there will be just N such nuclei undisintegrated. The constant λ is a numerical value called the radioactive constant. It is characteristic for each radioelement, natural or artificial and is a measure of the number of nuclear disintegrations occurring in unit time. An important derived disintegration law is the "half-life law". It may be stated by the equation $1/2 = e^{-\lambda t}$. Insertion of the radioactive constant of the radioelement under consideration in this equation and solution for t gives a number which expresses the time necessary for a collection of disintegrating atoms to become just half that number of disintegrating atoms. Let it be assumed that a weight of one gram of absolutely pure radium is available for examination. This gram of radium contains $\frac{6.02 \times 10^{23}}{226.05}$ or 2.66×10^{21} atoms of radium capable of disintegration. Let it be assumed further that in this mass of atoms. the process of nuclear disintegration starts at normal rate at time t_o. Let a G-M counter stand ready to count each nuclear decomposition which occurs, beginning at t_o. Let the counter continue to count, once for each nuclear decomposition which occurs until a time t_1 when 50% of the 2.66×10^{21} or 1.33×10^{21} counts have been registered. It will be found, if one keeps track of the time, that the time interval between t_o and t_1 is about 1590 years. This time period is, then, the half-life for radium radioactivity, and as far as in now known, it will always take 1590 years for half of any number of a collection of radium atom nuclei to disintegrate. Decomposition for a gram weight of radium occurs, then, at the rate of $\frac{1.33 \times 10^{21}}{1590 \times 365 \times 24 \times 60}$ or 1.59×10^{12} counts per minute, as an average rate over a period of 1590 years.

If all known naturally radioactive elements and their half-lives are considered it will be noted that some radioelements have a half-life as long as 1.34×10^{10} years (thorium), and some have a half-life as short as 1×10^{-11} seconds (thorium C^1).

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This brings up the question of what kind of radioelement, based on half-life considerations, can be used in a desired tracer application. It is apparent that a radioelement having a half-life of 10^{-11} seconds disappears completely even before there is time to think of what to do with it. On the other hand, a radioelement having a half-life of 10^{10} years disintegrates so slowly that a prohibitively large amount of the material would be needed to give enough counts per unit time to act as a decent tracer. It is true that in the case of radium, one gram will give about 2×10^{12} counts per minute; but, one gram is worth about 20,000 dollars. On this basis, the use of almost any naturally radioactive element for field testing of liquid H contaminations would require fabulous sums of money. The next consideration, then, is cheaper and more plentiful artificially radioactive elements. It has been judged that such an element should have a half-life somewhere between 5 and 30 days (for application to this radiotracer problem). An examination of the list of artificial radioelements most readily available suggested radiophosphorous (mass isotope 31; half-life 14 days; beta radiation) and radiomanganese (mass isotope 52; half-life 6.5 days; gamma radiation) as the most promising materials. Further considerations concerning penetrating power of the respective radiations brought the choice down to radiomanganese of the 6.5 day half-life. The decay curve for this radioelement is shown on Graph II, appendix C.

Hitherto, in this report, all disintegrations have been specified in terms of counts (per unit time), but a unit of disintegration rate (radioactivity concentration; activity) often useful in this work is the millicurie (one thousandth of a curie). The millicurie (mc.) represents a disintegration rate of 2.22×10^9 counts per minute (atoms per minute). The real significance of this unit is that any radioactive material showing 2.22×10^9 counts at any time t can be said to have an activity of 1 mc. regardless of any chemical or physical property it may also have. At any time later than time t, its activity will be some fraction of 1 mc., and, if t is known, the new, lesser activity can be calculated with accuracy and without trouble. This calculation is done most easily by means of a "decay curve" of which Graph II (appendixC) is a sample applying to radiomanganese 52. As stated previously, the rate of decrease of activity with time is a function of the half-life of the radioelement in question, and this rate cannot be altered in any way by any chemical or physical means available. Radioactive disintegration has zero temperature coefficient, zero pressure coefficient, and as far as chemical reaction is concerned, zero reactivity constant. Once an activity has been determined, any decrease in activity as a result of time can be calculated with an exactness depending on the accuracy of measurement of lapsed time, and on the exactness of the value for the half-life of that radioelement.

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Any deviation from calculated values can mean only that some of the material containing the activity measured originally became separated from the main body, and strictly of an amount indicated by the calculated deviation. One degree of specificity of the radiotracer technique is hereby indicated.

D. Special Considerations

The penetrating ability shown by gamma rays is of interest at times when it is desirable to screen off the radiations of a radioactive material. The law describing the degree of absorption of the radiation in matter is similar in form to the radioactive disintegration law. It may be expressed by the equation $I = I_0 e^{-\mu d}$, where I is the amount of radiation left when an incident radiation I_0 passes through a material of thickness d. The constant μ is characteristic of the material in question, for any given type of radiation. It may be determined easily with the assistance of a G-M counter and thick sheets of the material in question. With known I, I_0, and d values, μ may be calculated for the material and radiation type. In an actual laboratory measurement, it was found that 3.8 cm. of cast lead transmitted only 9.1% of the transmitted radiation from radiomanganese 52. On this basis, the value of μ for lead of considerable thicknesses may be calculated to be of the order of 0.63 cm^{-1}. The absorption of these rays in any other metal will be approximately directly proportional to the ratio of densities of this metal and lead.

A word or two concerning the ability of penetrating radiations to inflict damage upon the tissues of the human body should not be omitted. The ionizing ability of penetrating radiations of high flux density can produce undesirable chemical reactions in tissue. Probably the most fearsome effect is that of producing mutations in progeny as a result of changes enforced upon the gene structure of chromosomes. Even beyond this lies the possibility that heavy dosages of penetrating radiations to the proper region of the body will cause sterility. The male is considerably more susceptible than the female in this respect. It is for these reasons that all work involving large amounts of gamma ray producing radioactive material must be done in such a way as to minimize the time and intensity of exposure. The constant use of heavy lead shields in the storage and handling of concentrations of radioactive material is an important part of the answer to the problem of protection. Distance is also a very important factor since gamma rays from a point source of radiation follow the law of rectilinear propagation. Two government publications ((3) and (4) in Bibliography) may be used as guides in the assessment of protective conditions for handling radioactivity concentrations.

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A typical lead carrier for radioactivity is shown in Figure 15 (Appendix A) and in Diagram III (Appendix B). A number of these carriers and other forms of lead shielding should be used in any installation where gamma ray emitting material is used. Later in this report, mention will be made of shields for G-M counters and for ionization chambers. The reason for this is that in addition to the radiations produced by large concentrations of prepared radioactive material in the vicinity of measuring instruments, there is always present what is known as "background radiation". This everpresent background may be the result of traces of radioactive materials in the soil and in the air, and is always partly the result of very penetrating radiations from outer space (cosmic rays). Since, over any small time interval, and for a small area such as that of a radiation detecting instrument, the total flux density of this radiation is never constant, the ability of the detecting instrument to measure small amounts of added radioactivity is considerably lessened. This can be overcome to some extent through the extensive use of thick absorbent shieldings. Of the materials available, the metal lead seems to be the best.

IV. EXPERIMENTAL

A. Detection and Measurement Apparatus in Detail

The electroscope, the spinthariscope, the photographic plate, the Wilson cloud chamber, the photoelectric cell, the ionization chamber, and the Geiger-Mueller counter are devices used for the detection and sometimes the measurement of penetrating radiations. Of these, the Geiger-Mueller counter and the ionization chamber, as used here, will be discussed.

1. The Geiger-Mueller Counter and Counting Rate Meter (None-Portable)

As mentioned earlier, the G-M counter consists generally of two metallic electtrodes within an evacuated envelope. One of these electrodes is usually a very fine wire of tungsten (3 to 5 mils). The other electrode is usually a cylinder of sheet copper or thin-walled tubing fixed in position concentric with the wire. The wire is stretched taut and insulated from the cylinder by means of appropriate metal-in-glass seals. The evacuated envelope is usually made of glass, but sometimes, a part metal-part glass envelope is used. The dimensions of the cylindrical electrode are not critical except that the length should exceed the diameter by a factor of 2 1/2 to three or more.

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Generally, the envelope has dimensions of the order of 1 to 1 1/2 inches as the diameter, and four to eight or ten inches as the length. The envelope containing the electrodes, which must be clean, smooth, and free of radioactive material, is evacuated to a very low pressure, degassed, and filled with argon, air, nitrogen, helium, or mixtures of these gases. Argon containing 10 to 20 percent air is commonly used for counters having copper cylinders. The gas pressure in the envelope is generally of the order of 4 to 12 centimeters of mercury. The required pressure depends on the exact mixture of gases, the exact character of the inner surface of the copper cylinder, the voltage applied between the electrodes, the electrode spacing, and on other factors of less known influence.

A type of cylindrical electrode developed recently at the Massachusetts Institute of Technology and used almost exclusively at this station is known as the bismuth cathode counter. This counter is shown in Figure 1 (Appendix A) and in Diagram I (Appendix B). This counter has an outer cylinder of coarse mesh copper screen heavily coated electrolytically with the metal bismuth. This type of cylindrical electrode was designed primarily for use in detecting gamma rays and is especially suitable for work with radio-manganese. The reason for this seems to be the greater ability of this type of cathode to convert more incoming gamma ray energy into useful work than lower density copper metal exhibits. In the case of the bismuth cathode counter, the tendency is to use argon as the interelectrode gas. It is recommended that so-called "self-quenching" agents such as alcohol vapor, toluene vapor, etc., be avoided in this type of counter.

A possible theory of counter action as a penetrating radiation detector was mentioned in the Theoretical section, but it many be enlarged upon to some extent. The mention of "self-quenching" action was made above. It is unfortunately true that some counters do not act in the best manner when, under seemingly proper conditions, a discharge occurs between the electrodes. In these counters, the discharge seems to persist well beyond the time that the voltage drop in the external circuit reaches the point where ionization of the gas within the counter should cease. As a result, a single absorbed quantum of radiation will produce a continuous inter-electrode discharge, or a discharge which continues well beyond the time allowable for "fast" counter action. Since it has been found that addition of organic vapors to the gas in the counter often serves to make a poorly operating counter into a fast counter, it has been concluded that faulty counters exhibit a low rate of de-ionization after discharge. The organic molecules present seem to serve to gather up the stray ions resulting from ionization and to stop the ionization process after the desired discharge has resulted.

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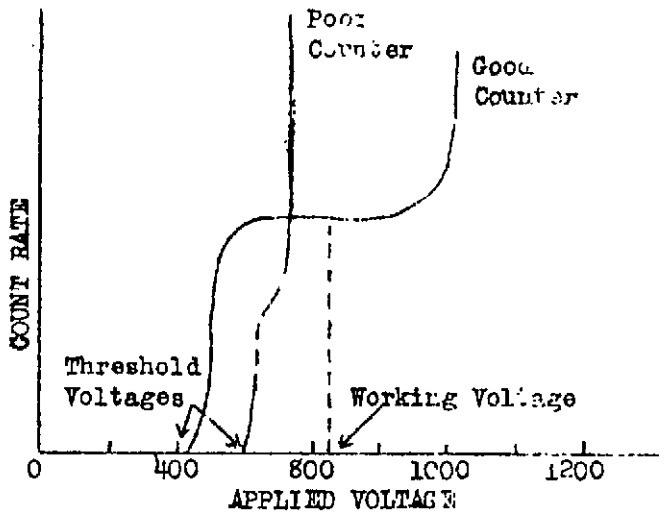
One of two tests designed to determine the characteristics of a Geiger-Mueller is a determination of the "plateau" of the counter. This is accomplished by determining, for a constant source of radioactivity, the count rate output of the counter as a function of voltage applied to the electrodes. A good counter shows a plateau curve (example is given at right) with the flat portion being an appreciable fraction of the total applied voltage. The significance of a long, flat plateau is that the same count rate will be given for a constant source of activity for relatively large changes in voltage applied. By way of contrast, the plateau curve of a poorly operating counter is shown also in the figure above. In this case the count output at any voltage applied varies as the voltage over the whole range of voltage. In fact, the count rate jumps quickly from zero to infinity with but a slight increase of applied voltage. A counter showing this type of plateau requires a very well-regulated high voltage power supply to be usable at all. This is not true of the counter having a broad, flat plateau. For purposes of nomenclature, the voltage at which the counter just begins to count is known as the "threshold voltage" and the voltage at which the counter is operated, on the plateau, is the "working voltage". Counter action may now be described as a drop of interelectrode potential from the operating voltage to a point somewhere below the threshold potential for each count. The reflection of this voltage change per discharge when applied to a small coupling condenser in the counter circuit allows transmittal of the resulting "voltage pulse" suitable electron tube amplifiers for conversion into mechanical, aural, or visible light energy.



Another common counter test, a determination of counter operation "speed", is the measurement of two strong sources of activity, first together, and then separately. If the net count rate for both sources together is less than the sum of the two measured separately, the counter is missing counts at the higher counting rate measured (that of the two together).

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By a series of comparisons at different counting rates, which may be made different by changing the distance of activity from the counter, the counting rate at which the counter is not capable of "keeping up" with the frequency of count arrival may be determined. A decision may then be made, regarding the maximum counting rate at which accurate counting may be expected.

Usually, the central wire of the counter is the positive side of the applied potential. Sometimes, 400 volts is sufficient to operate a counter. Generally, 1000 to 1800 volts is necessary. The resistance in series with the counter and high voltage supply may be a fixed resistance ranging from 10,000 ohms to over 10,000,000 ohms, or may be the input circuit of an electronic tube with its variable resistance characteristic. Most usually, an electron tube is used as the high resistance. A tube connected in such an application is shown as the "pre-amplifier" of the Massachusetts Institute of Technology counting rate meter (Figures 1, 2, 3, 4, Appendix A, and Diagram IV, Appendix B). As shown in the pre-amplifier circuit, the central electrode of the counter tube is connected to the input grid of the electronic tube, a type 6J7, with a high resistance, R_1, connected from grid to 6J7 cathode. The outer cylinder of the counter (the counter cathode) is at ground potential. Between 6J7 cathode and ground, there is another high resistance, R_3. The positive high potential of about 1500 volts is applied to the plate of the 6J7. Since internal plate-grid resistance is small, and since the grid is effectively at cathode potential with no current flowing in R_1 (no discharge in the counter tube), the central electrode of the counter is at practically 1500 volts potential. When a discharge occurs in the counter, the voltage drop across R_1 becomes relatively large. This results in the imposition of a high negative bias on the 6J7 grid and the grid-plate impedance rises to a very high value. As a result, the voltage of the central electrode drops from its original voltage to a value below threshold and the counter discharge is extinguished. The change in plate potential resulting from a change in grid voltage resulting from discharge is reflected as a change in voltage drop across cathode resistor, R_3, and this voltage pulse is transmitted across coupling condenser C_2, (a very special high voltage, high potential, low capacitance condenser) to the grid of the first amplifier tube, V-2, a 6SJ7 type. Here, this pulse, and others like it, is treated further, as will be explained shortly.

It is seen, then, that an electron tube serving as a high resistance in series with the high voltage supply to the counter serves as a very sensitive voltage gate, or control tube, assisting the counter in its function as radiation detector.

There are other electronic circuits in which an electron tube or tubes serves as an "external extinguisher", but the net action of each is essentially the same.

The voltage pulse applied to the grid of amplifier V-2 is simply amplified and passed to the grid of V-3. Tubes V-3 and V-4 together make up what is called a "multivibrator". In this multivibrator, the pulses are broadened to a certain "wavelength" and equalized in height ("clipped", or further amplified). A small part of the resulting equalized pulse energy is passed from the multivibrator to the grid circuit of audio amplifier V-15 which makes each pulse audible in a small loudspeaker. The main fraction of the pulse energy, however, is passed to amplifier V-5. The tube V-5 again amplifies each pulse by an amount regulated by its screen voltage, and at the same time, this tube serves by virtue of circuit design, to isolate the "hot" side of the RC tank circuit in its plate circuit at constant input impedance while pulse energy is being applied. Control of the screen voltage allows control of the calibration of the whole counting rate meter. This is so because the pulse output of V-5 feeds the RC tank circuit, C_{12} and R_{19}, R_{20}, and R_{21}, which also, as the grid circuit of vacuum tube voltmeter V-6 and the true energy integrator of the arriving pulses, causes recording milliammeter M-1 to respond in accordance with the rate of pulse arrival at the RC tank circuit.

To conclude the analysis of the other electron tubes in the counting rate meter, there are rectifiers for low voltage (supplying 300 volts for plates and screens) and high voltage power supplies (supplying 2200 volts for the counter tubes V-7 and V-8 respectively), and voltage regulator gas tubes V-13 and V-14. In addition, there are tubes V-9 and V-10. These two tubes are part of an electronic high voltage stabilizer circuit. Changes in output voltage as a result of alteration of lead resistance or line voltage are noted in the grid circuit of V-10. This change reflected in the plate circuit of V-10 results in a change of the effective bias voltage of the electronic gate V-9 which becomes more or less conducting as may be required in order to resist the change.

It is necessary, in counting rate meters, to calibrate the vacuum tube voltmeters in terms of recorder deflection as a function of the rate of arrival of pulses at the RC tank circuit in the vacuum tube voltmeter grid circuit. This is accomplished by an auxiliary electronic instrument known as a multivibrator pulse generator. Such a device designed and built at the Massachusetts Institute of Technology is shown in Figures 7 (the small black box atop the cathode ray oscilloscope), 5, and 6, Appendix A, and Diagram V, Appendix B, shows the schematic circuit diagram. This design of multivibrator is very ingenious in that low frequency oscillations are

produced which are controlled by virtue of locking of the multivibrator oscillator with a number of oscillation frequencies which are integral multiples or submultiples of 60 cycle AC voltage. This voltage is seen, in Diagram V Appendix B, to be obtained from the filament voltage of the 6SC7 oscillator via condensers C_{12} and C_{13}. Also a part of the scheme is the design of the counting rate ranges of the counting rate meter. These are, respectively, 20,000, 10,000, 5,000, 2,000, 1,000, 500 and 200 counts per minute full scale deflection of the recorder chart paper when the calibration is proper. Since the vacuum tube voltmeter plate current varies linearly with the count rate (when properly adjusted), only a single calibration point for each range is necessary for accurate calibration. The pulse generator supplies, respectively, the 60 cycle multiples or sub-multiples of 14,400, 7,200, 3,600, 1,800, 900, 450, and 200 pulses per minute. The signal from the generator is introduced at "calibrate input" in Diagram IV, Appendix B. This point, it may be observed, is at the grid of the first amplifier tube. Thus, the whole counting rate meter from this point on to the recorder is calibrated at one time. Adjustments necessary to produce the required fractional deflection of properly calibrated full scale deflection are made by means of the variable resistances in the screen circuit of the amplifier tube preceding the vacuum tube voltmeter. The shafts of these seven range setting resistances are seen at the top of Figure 3, and the resistances themselves may be seen at the top of Figure 4 (Appendix A).

It is necessary, from time to time, to check the frequency output of the seven ranges of the pulse generator. On the 200 count per minute range, a stopwatch timing of audible clicks in the audio amplifier circuit (V-15 Diagram IV, Appendix B) loudspeaker is utilized. On the higher ranges, this is not feasible. However, a simultaneous application of pulse generator voltage and low voltage 60 cycle AC to the vertical deflecting plates of an oscilloscope allows, by observation of the resultant oscilloscope patterns, a check on the pulse generator as its signal feeds the counting rate meter for calibration. This arrangement may be seen in Figure 7, Appendix A. Unfortunately, the oscilloscope pattern is not visible in the photographs. If slight adjustments in the frequency of the pulse generator are required on any range, range setting variable resistances in the oscillator multivibrator circuit are used. These may be seen in Figures 5, and 6 (Appendix A) and in Diagram V (Appendix B).

The Massachusetts Institute of Technology counting rate meters, model 200 series, represent one type of instrument which will translate the happenings within a G-M counter into

a record of penetrating radiation detection and measurement. Other designs of instruments serve to drive mechanical tally counters whereby each pulse occurring over a known period of time is recorded individually. From this data, the rate of counter discharges per unit time can be calculated. The net result is the same, but the M. I. T. type counting rate meter functions to great advantage where large numbers of samples of radioactivity-containing materials must be measured quickly, and wherein the range of activity concentration in the various samples varies greatly. A typical M. I. T. counting rate meter tracing may be seen in Graph I, Appendix C. The wavy lines represent normal statistical variations in the rate of arrival of radiations at the counter tube. The curve is evaluated on the basis of the average value of each sample tracing. According to the laws of statistical variation, greatest accuracy is obtained if the sample is measured over a period of time approximately inversely proportional to its activity content.

2. The Portable Geiger-Mueller Counter and Counting Rate Meter

The apparatus discussed in the previous pages is a laboratory-type precision instrument. The need for a portable (field) type of radioactivity detector has brought about development of such a device. One version of a semi-quantitative portable G-M counter and counting rate meter may be seen in Figure 8, Appendix A, and a circuit diagram is shown in Diagram VI (Appendix B). This instrument uses low filament drain electronic tubes and is similar in many respects of design to the M. I. T. model 200 series counting rate meters. Several differences may be pointed out, however. First, the instrument is entirely battery powered. The high voltage for the counter tube is obtained through utilization of energy from an audio frequency generator oscillating at high amplitude. The oscillator output is rectified in the same electronic tube (multi-purpose tube type 3A8GT) which is used to generate the audio frequency oscillations. Another difference is that the counter tube cathode, rather than being at ground potential, is at high negative potential while the central electrode is essentially at ground potential. A further point is that there are only two counting rate ranges, 0-1000 and 0-10,000 counts per minute for full scale deflection of the 0-1 ma. milliammeter on the front panel. Standardization is obtained by means of a small source of radiocobalt at a standard distance. The voltage control (a 200 mmf. variable condenser in the oscillator tank circuit) is varied until the desired full scale deflection is obtained. (The counter used has no plateau). Figure 8, Appendix A, shows a cylindrical lead shield for the portable G-M counter with a rectangular window cut out so that the instrument can be used as a scanner for a relatively

large radiotracer contaminated area. It is especially useful in the evaluation of H-tracer crater loss. The portable G-M counting rate meter has some inherent drawbacks from the point of calibration stability. Its use as a quantitative meter is limited. A better field device is the radioactivity ground scanner.

3. The Radioactivity Ground Scanner

The principle of the ionization chamber as used in the detection and measurement of penetrating radiations was explained earlier in this report. Briefly, the energy of a gamma ray may be absorbed in matter and converted into energy of ionization. For example, if the matter is a gas, the process of gaseous ionization resulting from gamma ray energy conversion decreases the specific resistance of the gas. The change in specific resistance of the gas can be measured by means of appropriate electronic apparatus, and recorded. The ionization chamber, consisting of two electrodes with a relatively low value of DC potential between them is the primary indicator of the resistance change. Measurement of the decrease of the change of electrical resistance due to the presence of ionizing radiations is complicated by the fact that this change in resistance must be measured in a system which is inherently one of extremely high impedance. Furthermore, the amount of matter capable of absorbing the radiation energy in a gas is very small. This drawback can be overcome to some extent by increasing the amount of matter present. In the case of gases this means increased pressures. The increase of efficiency of radiation absorption is almost directly proportional to the increase in the gas pressure. If full advantge is to be taken of increased gas pressures in ionization chamber work, very special and ingenious answers to problems of matching of high impedances coupled with problems of high pressure insulating fittings must be solved. Once this is done, a machine which will measure radiotracer directly and continuously on the ground in the field can be built and used. Such a machine, a radioactivity ground scinner, has been built and is under preliminary study at this station.

The radioactivity ground scanner, shown in Figures 9 and 10, Appendix A, and in Diagrams VII and VIII, Appendix B, is a self-powered vehicle designed to carry two sets of pressure ionization chambers, their lead shields, associated electronic and recording apparatus, and a crew of two people across a radiotracer-mustard contaminated ground area to allow direct field measurement of contamination densities.

The scanner vehicle is essentially a large sheet metal box measuring externally 12 1/2 x 6 1/2 x 3 3/4 feet built on a standard automobile chassis. The metal box has appropriate window space. At its front end are two derrick-like steel-pipe beams to carry two sets of pressure ionization chambers and their lead shields in "scanning" position. It also carries in the front end, a 220 volt 60 cycle 3-phase 1 HP AC motor which provides driving power for the vehicle when geared by two standard automobile transmission gearing systems in tandem. Also in the front end are the steering mechanism and a Selsyn transmitting unit driven from the left front wheel axle. The Selsyn system has its receiving unit on the recorder box so that the recorder charts may be driven by it at a chart speed proportional to the speed of the vehicle. At the rear end of the box is an aircooled four cylinder gasoline motor, a 220 volt 60 cycle 3 phase AC generator power unit, a cooling fan for the motor, a 6 volt DC generator (for the gasoline motor storage battery), and, above the motor-generator power unit compartment, an air-cooling gas-filtering system for the inside of the box. The air cooling unit is shown in Figure 12 (Appendix A). The gasoline motor, not visible in any of the figures, is directly behind the left half of the vehicle control panel. The right side of this compartment is occupied by the AC generator which is driven by four V-belts from the gasoline motor. The vehicle also carries a gasoline tank (at the rear), a cooling system water tank (underneath the cooling fan motor), and is provided with both 6 volt DC and 110 volt AC interior and exterior lighting.

The vehicle is able to travel, under its own power, at speeds of 3.1, 7.5, 12.5, 13.8, 23.0 and 41.0 feet per minute. With the assistance of towing truck, it can be made to travel up to 35 miles per hour on a smooth road. Its weight, exclusive of two 550 pound lead shields is slightly over 6000 pounds.

The electronic system, which is the heart of the unit, is located at the left of the middle of the box. The electronic system and recorder unit is a dual chamber affair, one channel for each set of ionization chamber units. One of these units operates at the left of the vehicle, and the other operates at the right. The complexity of the overall chamber-electrometer-recorder units in dual push-pull arrangement requires a block diagram for clarification. This diagram is number IX, Appendix B.

Each chamber unit consists of two pressure ionization chambers, (shown also in Figures 11 and 14, Appendix A, and in Diagram IX, Appendix B) inside a lead shield. Each chamber consists of a 0.25 cubic foot RCAF oxygen cylinder provided

with a special pressure head fitting. This pressure fitting is designed to carry, inside the cylinder, and well insulated from it, a 7/16 inch internal diameter aluminum tube having an external taper along its length (Diagram X, Appendix B). This tube, is the internal electrode of the ionization chamber; the chamber cylinder is the external electrode. Each cylinder has mounted above it on the pressure fitting, a cylindrical housing for the electronic electrometer-amplifier (Figures 11 and 14, Appendix A; Diagram X, Appendix B). The ingenious method of electrometer-on-chamber mounting allows a very short connection from the central electrode to the control grid of the electrometer tube of each half channel. The grid circuit fixed resistance of each electrometer tube, a 6J7GT operating at low filament voltage, is an IRC 100,000 megohm resistance. Since this resistance value represents the order of magnitude of the normal chamber interelectrode resistance, some idea may be gained of the insulation required for the central electrode carried by the pressure fitting. Diagram X, Appendix B, shows details of this pressure fitting design, and Figures 18, 19, 20 and 21 (Appendix A) are photographs of the pressure fittings and electrometer housing construction. The design had to be such that the head, with its insulators, could withstand a gas pressure of 1500 to 2000 pounds per square inch over long periods of time.

The schematic circuit of each electrometer-pre-amplifier unit in each electrometer housing is indicated in drawing XI, Appendix B. It will be seen that each 6J7GT electrometer tube is direct coupled to a 6J5 pre-amplifier, also contained in the electrometer housing. Besides these tubes and associated sockets, resistances, and condensers, there is a small 6 volt relay which serves to short, momentarily, the input grid circuit of the electrometer tube when necessary. A multi-conductor cable supplying battery voltage to the electrometer electronic circuits, and coupling the pre-amplifier to the recorder amplifier to the recorder amplifier inside the vehicle completes the electrical part of the chamber unit. It will be noted also by reference to the circuit diagram that each chamber is part of a push-pull input circuit. The push-pull arrangement is carried on through to the recorder units. The push-pull circuit was used because of its greater inherent stability against changes in supply voltage, microphonics, and normal drift peculiar to direct-coupled amplifiers. A generous amount of negative current feedback is applied to the electrometer to further heighten the stability and the input impedance. The electrode voltages chosen for the electrometer tube are such as also to maintain the input impedance at the highest possible level.

The electronic unit has four sensitivity ranges. These are marked 1, 10, 100 and 1000 in Diagram XI, Appendix B.

Range 1 is the highest sensitivity range. The others are multiples of ten, as indicated. The range setting, it will be seen is really dependent on the input grid resistance of the recorder amplifier tube, and on alteration of the amount of feedback to the electrometer. The recorders are Esterline-Angus 0-1 milliampere units whose charts are driven by a Selsyn unit operating from the left front wheel axle.

All filament, plate, screen, and bias voltages are obtained from batteries. There is actually 360 volts of "B" battery voltage used. One-half of this voltage is applied between the electrodes of each chamber of each dual unit. One set of 180 volt batteries is heavy duty type so that plates and screens may be supplied also from them. The other set of 180 volt batteries is of a miniature type since they supply only the current across two of the chambers.

The overall amplification of the electronic unit is such that a 30 microvolt change of the input grid voltage of the electrometer will produce full scale recorder deflection on the highest sensitivity range.

The gas used in the chambers is argon of the greatest possible purity. Argon with a purity of 99.95% is obtainable from the Air Reduction Company. The impurity is nitrogen. The gas pressure in the chambers may be as high as 1500 pounds per square inch, depending on the sensistivity desired. In normal cases of scanner operation, a pressure from 500 to 1000 pounds per square inch has been found sufficient. Pure argon is required in this application for reasons relating to ionization and ion recombination characteristics. The presence, as an impurity, of even slight traces of polyatomic gases, such as water vapor and organic vapors, results in a great increase in the so-called RC constant of the ionization chamber. On the basis of theoretical considerations, the velocity at which ionization results, and can be maintained properly within the chamber, is not dependent on the pressure of a perfect gas. Argon is the nearest practical approach to this state. The velocity with which ions can travel through the chamber gas does depend, however, on the gas pressure. If some polyatomic gas impurity is present, it is possible to visualize ions becoming associated with these more readily polarizable molecules and thus be impeded to a greater extent in their attempt to pass from their original position to an electrode. Similar impedance to rapid passage is offered in a perfect gas if the number of gas molecules in the path of travel is relatively great. Ionization chamber action is such that some ionized particles arrive at their respective electrodes sooner than others. Accordingly, the growth curve of current

across the electrodes with time is essentially exponential for reasonable interelectrode potentials. The concept of the RC constant of a chamber is thus explained. There is more to this RC factor, however. The input grid resistance of the electrometer tube is 100,000 megohms. The chamber in itself is a condenser in parallel with the grid resistance. Such a circuit does have a characteristic RC constant. Therefore, the total RC of an ionization chamber electrometer is the sum of two individual RC values. If the gas in the chamber is relatively impure, the total RC value will be high as compared with the RC value for a chamber containing no gas. It will also be higher for higher pressures of absolutely pure gas. The only reasonable means of shortening the RC value is to use the purest possible gas at the lowest pressure consistent with required sensitivity. The chambers, as operating at the present time with a gas pressure slightly in excess of 500 pounds per square inch, have an RC constant of 15 to 16 seconds. It is hoped that in time, as the chambers become "cleaned up", it will be possible to decrease this value to about 8 seconds. It is possible to obtain a further decrease by increasing the ionization chamber potential. The importance of this RC value in chamber operation will be indicated in later paragraphs.

B. Procedure for Conversion of the Activity Prior to Incorporation into the Agent

The radioactive tracer, radiomanganese mass isotope 52, is obtained from the Massachusetts Institute of Technology as the dioxide. Rapid shipment from the source to the consumer is important because the half-life of the material is only 6 1/2 days. Samples of high activity should be shipped by plane if possible. Upon arrival at this station, the sample activity is checked roughly by measuring the response of the G-M counter when the sample is placed a standard distance away under standard conditions of shielding of the counter tube. The radiation protection meter may also be used for checking the activity. The radiomanganese dioxide, together with the filter paper containing it, is then placed in a small glass flask shaped somewhat like a squatting duck (Figure 15, Appendix A). This flask has a sintered glass plate sealed into the tail. The tracer on the filter paper is treated with a minimal quantity of 3% perchloric acid containing 6% hydrogen peroxide. It is important to add just enough to completely dissolve the dioxide with heating. The hot solution is then filtered through the sintered glass plate directly into a small Claissen flask. Two washings of the filter paper with hot water are added to the filtrate. Manganous carbonate is then carefully added until the excess perchloric acid in the warmed solution is just neutralized. This reation is complete

when no more CO_2 bubbles appear. An excess of manganous carbonate is to be avoided. The volume of the resulting neutral solution of radiomanganese perchlorate should not exceed 50 ml. in order to facilitate the rapid removal of water. The solution in the Claissen flask is then evaporated to dryness in vacuo (30 mm. mercury pressure) with the assistance of a boiling water bath. The waxy manganese perchlorate residue is dried by continuing the distillation for about 10 minutes after all the water has been removed. The weight of dioxide, as received, is of the order of 20 to 40 mg., and this weight may represent an activity ranging from 50 to 400 mc.. Consequently, the amount of solid manganese perchlorate finally obtained will be about 30 mg., with an activity of at 95% that of the original sample. It is recommended that all the chemical work involved in the conversion of the dioxide to the perchlorate be accomplished in the shortest possible time, as automatically as possible, and behind as much shielding bulk lead as possible in order to minimize the effects of exposure of the operator's body to the penetrating radiations.

After the radiomanganese perchlorate has been isolated in a dry state, it is dissolved in a known volume (100-200 ml.) of hot butyl cellosolve. Its activity is evaluated by comparing, by means of the G-M counter or the radiation protection meter, the strength of 1 ml. of the "stock solution" with that of known radioactivity standard. The radioactivity standard used here is a sample of radiocobalt chloride dissolved in water. This sample had an activity originally of 0.50 mc. Radiocobalt can be used as a standard for short times because its half-life is rather long, (about 5 years). Its standard activity must, however, be reckoned in terms of equivalent radiomanganese activity because the response of the G-M counter to the gamma rays of radiocobalt is not quite the same as to the gamma rays of radiomanganese. For the particular setup used here (bismuth cathode counter; 1.25 inches lead shielding), the 0.50 mc. radiocobalt has an equivalent radiomanganese activity of 0.55 mc., and it is this value which is used in evaluating the activities of unknown strong sources of radiomanganese activity.

C. Incorporation of the Activity into the Agent

The amounts of activity incorporated into the H of the munition to be tested range from 2 to 30 mc. per 100 pounds of H. The degree of precision desired in evaluating the H ground contamination determines the value of the activity to be added. For evaluation of H spray patterns where the H is spread over a large area, it is desirable to use 20

to 30 mc. of activity per 100 pounds of H. Where the area covered by the H is small, as in the case of static ground burst munitions, the lower concentrations of activity will suffice.

It is ascertained first whether the munition containing the H will possess a sufficient void if 2% by weight of butyl cellosolve should be added to the H. If so, the required amount of activity stock solution is diluted with an amount of butyl cellosolve representing about 1.5% by weight of the H in the munition. The diluted activity in the butyl cellosolve is then poured into the H in the munition and thoroughly mixed by shaking, rolling, or, if possible, stirring. A sample of the thoroughly mixed H is then removed. Usually 150-200 ml. is sufficient. This H containing the activity in the same concentration as that in the munition is used later for checking back if anything goes wrong, and for making up standard soil or absorbent panel samples for evaluation of the field unknowns. The munition is then ready for the field test.

A great deal of trouble was encountered in keeping the minute amount of radiomanganese in solution in the H. Much investigative work led finally to the conclusion that radiomanganese as the perchlorate will remain dissolved in H containing 1% butyl cellosolve as solutyzer for several hours. This period of time is generally long enough to enable incorporation of the activity in the H and to perform the field test. A great factor of safety may be gained by increasing the butyl cellosolve concentration to 1.5 or 2.0 per cent. Levinstein H containing 2% butyl cellosolve causes only a 4 or 5 per cent deposition of the activity within 8 hours after incorporation, and from 10 to 20 per cent deposition after 24 hours, depending on the character of the H. It is best to check the deposition rate of the activity from the H by periodic removal of a small amount of H from the standard sample after quiet standing for as long a period as must elapse between the time the activity is incorporated and the time the munition is used in the field test. In this way, the 5 or 10% deposition can be corrected for in the final evaluation if it is observed.

D. Procedures for Field Sampling.

1. Geiger-Mueller Counter Samples

a. Direct Soil Sampling

Evaluation of the degree of contamination means a determination of the liquid H concentration per unit area of the contaminated area. If the target area is gridded in some manner, it is necessary only to pick up a known area of soil,

at known grid points, to measure the activity content of each sample of the soil, and to extrapolate the measurement data into a picture of contamination density for the contaminated area. If the area has not been gridded beforehand, the problem is more complex. The soil samplers used here are 5 cm. diameter short iron cylinders beveled at one end and welded at the other to an appropriate metal handle. In practice, the cylinder is plunged into the soil to a depth of 1/2 inch or so, and withdrawn therefrom in such a way as to pick up a disc of soil measuring 19.7 sq. cm. in area. The sample of soil is transferred to a marked widemouthed container. Several other samples of soil may be picked up near the same spot in order to make the sampling more representative, and also to increase the precision of the activity determination to follow. The number of samples taken per contaminated area depends on the degree of precision desired. Usually, one sample per square meter will give an excellent final picture, and generally, one sample per 9 square meters will give an adequate picture. For very large areas, one sample may be allowed to represent 100 square meters (as in the case of airplane spray patterns).

The activity measurement for each sample of soil involves thorough mixing (grinding if necessary), and portioning, if necessary down to a weight of soil, which will be contained in the soil holder which supports the soil sample about the counter during measurement. The soil holders used here consist of double-walled sheet brass cylinders arranged concentrically and fastened together at one end. The inner cylinder is of such diameter as to fit snugly around the counter tube. The sheet brass used to make the inner cylinder should be very thin. The outer cylinder is of such size as to allow the formation of a hollow cylinder of soil having a thickness of from one to two centimeters, and a length equivalent to that of the cylindrical electrode of the counter (5 inches). Each soil sample can then be measured for activity content under conditions of placement with respect to the active volume of the counter tube equivalent to those for all other samples. Figure 1 (Appendix A) shows a typical soil sample holder and Diagram XII, Appendix B, shows details of construction.

Standards are prepared by adding known amounts of 10, 100 and 1000 times diluted samples of the H standard to samples of soil (blank) weighing approximately the same as the field samples actually measured. It is very important to note with exactness the time of day for each measurement of activity content, for subsequent corrections in counting rate data due to activity decay must be made.

b. Absorbent Panel Sampling

A method of sampling of the contaminated area considerably more elegant than direct soil sampling is sampling by means of absorbent panels. These panels measuring 18 x 18 x 3/16 inches were originally developed by the British for observation of drop sizes in H contamination studies. These panels may be laid out before a test on the area to be contaminated. After the test, they may be picked up quickly, scanned for number and size of drops of liquid agent, and prepared for activity study. This preparation consists simply of "stripping" off a layer of absorbent material sufficiently thick to contain all the liquid agent which has penetrated through the first fractional millimeter or so of thickness, and yet thin enough to enable rolling the strip into a cylinder whose inner diameter is slightly greater than the diameter of the counter tube. The width of the strip (length of the cylinder) should be the same for all strips, and should approximate the length of the cylindrical electrode of the counter.

The preparation of standard is accomplished by dropping, as evenly as possible, a known amount of dilute standard H sample over a whole panel and stripping and measuring as in the case of the field panels.

2. Radioactivity Ground Scanner

The techniques of field sampling for H-tracer content evaluation by means of the radioactivity ground scanner are much less firmly established than the techniques for G-M counter sampling. At the present time, only a few field tests have been run with the scanner, and more field tests will be required to ascertain the best mode of application of the scanner. However, an outline of the methods used thus far is indicated.

The problem of scanner sampling differs from that of G-M counter sampling in that the scanner measures the activity directly on the ground while the vehicle travels over it at a steady rate. As in the case of the counter sampling, a permanent record of the data is given by the scanner measuring instrument, but, unlike the counter, the interpretation of these data is considerably more difficult. In the first place, in every measurement involving motion, the instrument is measuring an infinite series of small areas in rapid succession. Secondly, the ever present background varies at a rate similar to the rate of travel of the vehicle thus making the evaluation of low activity concentrations difficult because the law of averages cannot be applied.

In actual practice, a scanner field record depends on two controllable factors. One of these is the vehicular speed, and the other is the height of the scanner chambers above the ground area being measured. The vehicular speed determines, by virtue of the RC factor regulating the speed of response of the ionization chamber-electrometer input circuit to changes in radioactivity, the magnitude of the recording milliammeter swing for equal tracer concentrations. For example, let an RC constant of 20 seconds be assumed for a chamber passing over a tracer concentration in 20 seconds in one trial and in 5 seconds in another. In the first case, the recorder deflection will be $1 - \frac{1}{e}$ or 63% of the value which would have been observed if the chamber passed over the same tracer concentration in infinite time. In the second case, the recorder deflection will be $1 - \frac{1}{e^4}$ or 20% of the value which would have been observed if the chamber passed over the same tracer concentration in infinite time. It is evident, on the basis of this concept, that the vehicle must pass over the unknown tracer contaminated area at the same speed at which it passes over a standard tracer contaminated calibration area. The factor of the height of the scanner chamber determines the degree of definition of the differences of tracer concentration with distance along the line of travel. This is obvious if one considers the chamber passing over the area at a height of, for example, 20 feet, and then at a height of 1/2 foot.

At the present state of knowledge of scanner operation it is necessary to use relatively more tracer for a scanner operation than for a comparable operation where soil samples for G-M counter measurement are to be taken. The reason is based on limitations of response of the chamber to concentrations of tracer so small as to cause a recorder deflection only slightly greater than the normal background response. The normal background response of the chamber represents a fairly appreciable fraction (from 5 to 10%) of full scale deflection on the highest sensitivity range. It is also rapidly variable over short periods of time, and it cannot be assigned an average value in the same manner that it can in G-M counter work. As in the case of the G-M counter work, however, the background variation has much less effect on the accurate recording of areas of heavy tracer contamination.

At the present time, activity concentrations of from 20 to 30 mc. per hundred pounds of agent (in bombs) are used in scanner operations. With these concentrations, it is possible to detect an H ground concentration of one gram per square meter with a precision of 20%. This apparent disadvantage of the scanner method as compared with the counter method is less important than it may appear. This is so because the technique of the counter soil sampling procedure for maximum

sensitivity prevents measurement of sufficient ground area to to thoroughly representative of the unit area of one square meter. The scanner, on the other hand, scans a hundred times as much area as is considered in a single soil sample and therefore measures a much more representative sample of the unit area. It is not unusual to find soil samples representing 1/200 of a square meter of area showing H concentration values considerably different from H concentration values obtained at the same spot by the scanner. This is especially true in the case of bomb munition studies where H concentrations may change abruptly within a distance of several inches along the ground. In spray operations, the H areal concentrations change much less abruptly with distance.

As in the case of the standard H sample taken from the munition after addition of the radiotracer for counter-evaluated operations, a sample of H-tracer is taken for the preparation of radioactivity area standards for use with the scanner. However, considerably more of the standard H-tracer must be taken in the latter case. The sample should be of the order of 500 to 1000 grams. In bomb munitions, where the agent is expected to be relatively concentrated on the ground, concentrations of the order of 500 grams per square meter, or even greater, may be present. If the standard scanner area sample is one square meter in area, then one calibration point alone will require 500 grams of H. The simplest method for preparation of scanner standard areas is to sprinkle, on several different absorbent paper panels measuring 36 x 36 x 3/16 inches, different known weights of the standard H-tracer diluted in a volatile solvent such as acetone. If the H concentrations on the panel are made to range from 1 to 500 grams in about 5 steps, a good calibration curve of recorder deflection as a function of H-tracer areal concentration can be obtained. This calibration is performed by placing the panels on the ground in the path of travel of the ionization chamber units as the vehicle travels at a speed the same as that to be used for scanning the unknown area. It is necessary that the long diameter of the scanning area be less than 36 inches so that the whole scanning area may be less than 0.84 square meters (0.84 square meters per square yard).

Another solution to the standard area calibration problem is to sprinkle the H-tracer over a known ground area and then pass over the area with the scanner chambers. In this procedure, the area cannot be picked up and moved at will—a disadvantage.

After the tracer has been added to the agent in the munition, the field test may proceed. It is necessary, however, that the target area used for a scanner operation be very flat and relatively free of weeds and brush, in constrast

to target requirements for a G-M counter test. Whereas in soil sampling allowances may be made in taking samples on grid points on or near weeds, no such compromise is possible in a scanner operation. Weeds entraining scattered P along a grid line traversed by the scanner chambers must be removed prior to scanning. Furthermore, mounds of ground which are the bases of bushes and weed clumps must not be too high above normal ground level, or errors in tracer measurements resulting from decreases in scanner-to-activity distance at these points will be observed. A further consideration is that the weight of the shields at the ends of the 8 foot beams is about 600 pounds The vehicle must have flat ground for travel in order to prevent excessive jerking and swinging of the chamber-shield units.

After the munition has been exploded, and during the time the scanner chamber-electrometer system has been allowed to warm and become calibrated, the target area may be gridded. This is done easily by laying out, with the aid of steel tapes, a base line having marks at 1, 3 or 6 meter points. Another base line is then set up at 90 degrees to the first and also marked off at 1, 3 or 6 meter points. The scanner chamber-to-chamber distance, with the chambers in scanning position, is 6 meters. If, then, both sides of the scanner are used at one time (simultaneous recording), two grid lines six meters apart may be measured with one traverse. If one meter grid scanning is desired, five traverses will cover ten one yard grid lines. The sixth traverse will begin with the eleventh grid line, etc. It is best for easy evaluation of records obtained, to start at the same base line for each traverse rather than at opposite base lines on alternate traverses. The reason for this lies, again, in the chamber-electrometer RC constant. Actual measurement of a given scanning area is not recorded until approximately RC seconds after the area has been passed over. If vehicular speed is known, the exact point on the recording trace may be measured off with reference to the time the base line was crossed on each traverse. Since the recording chart is driven at a rate proportional to the vehicular speed, it is actually unnecessary to mark the chart except at the time the chambers pass over the primary base line. For more accurate traverse-distance versus chart-distance relationship, however, it is desirable to mark the chart again at a secondary base line near the end of the traverse.

When the area has been gridded, and the electrometers are warmed up (the warming up takes about an hour), the chamber scanning height is set. This height seems to be optimal at 20-25 cm. with the present arrangement. At this height, the actual scanned area is of the order of 0.5 square meter. Definition with this scanning area is considerably better than for scanning area of one square meter. With the scanning height set, the vehicular speed is chosen. This is based on the

overall activity concentration, the desired definition, and the chamber RC constant, as stated earlier. A chamber RC constant of 15 seconds dictates that the vehicular speed not exceed 7.5 feet per minute for very low concentrations of activity. At this rate, about 85% of full scale deflection at zero speed will be recorded for a scanned area of 0.5 square meter. The exact figure is relatively unimportant because the scanner chamber response to activity concentration at the speed to be used is determined when the chambers are passed over the standard panels. The important factor is to get maximum response for a given concentration consistent with optimal vehicular velocity.

Just before the first traverse is made across the contaminated area, calibration is undertaken. On every other or every third traverse, the machine is again passed over a calibration panel representing a medium H concentration in order to note any pronounced changes in the original calibration. Experience has shown that the only factor producing changes in calibration is that of temperature change in the chamber and electrometer units which are most exposed to direct sunlight.

With calibration carried out carefully, and the area scanned successfully, the problem of evaluating the recording strip tracings remains. This is mentioned in the next section.

E. Evaluation of Measuring Data

1. Geiger-Mueller Counter Samples

The data obtainable from the MIT G-M counting rate meter are the counter tube background counts, the unknown sample counts, the known field sample counts, and the known standard sample counts. Few field samples exceed 10,000 counts per minute and the usual field sample indicates a count rate of somewhere between 100 and 3000 counts per minute. In addition to the data obtainable from the counter, there must be available a notation of times when certain things happened. The most important of these is the time when the activity of the stock solution was measured, and the time when the activity was added to the munition. Of importance also is the notation of the time each field sample was measured. Each measurement requires an average of from 5 to 8 minutes. This means that a period of several days may elapse between the time the first field sample and the time the last sample are measured. In the meantime the process of radioactive decay proceeds according to law. If the indicated times are not known, activity corrections due to this decay cannot be made. A typical example of the various data which must be collected and used in

evaluation of a radiotracer operation by means of the G-M counter is presented as follows:

A sample of radiomanganese dioxide was received at 0900 hours on 10/17. The sample had an activity of 210 mc. when sent out from MIT four days earlier. On 10/18, at 0000 hours, it was converted to the perchlorate which was dissolved in 175 ml. butyl cellosolve. A one ml. sample of the "bucel" solution was checked for activity by means of the G-M counter by comparison with the standard cobalt activity, and was found to have an activity of 0.703 mc. The total activity of the bucel solution at the time of measurement was 123 mc. The amount of activity upon arrival was 136.5 mc (four days decay). The difference between 123 mc. and 136.5 mc. represents decay between time of arrival and time of conversion and measurement, and loss in conversion. The decay for 15 hours can be calculated from the decay curve, and the conversion loss can be found by difference.

At 0730 hours on 10/18, 9.4 ml. of the bucel solution, which then had an activity of 0.682 mc. per ml., was diluted to 50 ml. with butyl cellosolve, and the mixture was added to the H contained in a rocket head (20 pounds of H). The H-cellosolve mixture was thoroughly shaken, and 40 ml. sample of the mixture was withdrawn by means of a squeeze-bulb operated siphon. This sample was returned to the laboratory, and immediately, a 1 ml. sample was withdrawn therefrom and diluted with 9 ml. of acetone. This 10 times diluted sample of H was diluted again by a factor of 10. The diluted solutions were set aside to be used later for the preparation of standard soil samples.

In the meantime, the rocket head had been launched against a hard ground area (1000 hours). The pattern produced was nearly all contained within a square area measuring 25 yards on a side. Three hundred and thirty soil samples were taken from within this area. Each sample was actually an area of 19.7 sq. cm. Table I, below, gives, for several of these samples, the pertinent counter data found when the activity content of the samples was determined. The term "counts" means counts per minute.

TABLE I

Sample Tabular Data for a Typical Geiger-Mueller Evaluation

Sample	Date Measured	Time Measured	Sample Total Counts	Sample Net Counts *	Elapsed Time **	Sample Corrected Counts ***
BKG'	10/19	1025	62	---	---	---
T-10	10/19	1040	136	74	25	83
Q-11	10/19	1340	450	388	28	435
BKG'	10/19	2000	58	---	---	---
O-2?	10/19	2125	84	16	35	1?
N-4	10/19	2145	580	52?	36	60?
BKG	10/20	0800	58	---	---	---
O-1?	10/20	0805	178	120	46	14?
L-?	10/20	1500	890	826	53	1050

BKG' represents background count value at time given.

* This value is total counts minus nearest BKG' count.

** This time in hours is the time between that when sample was measured and the time the rocket was launched.

*** By reference to the radiomanganese decay curve (Graph II, Appendix C), it is determined that the fraction of activity undecayed after 25 hours is about 89 percent. Division of Sample Net Counts (74) by 0.89 gives the decay corrected value of 83 which is the Sample Corrected Counts value, and which represents the counts which would have been observed if the sample had been counted at 1000 hours on 10/18. This, of course, was impossible, but the decay law allows its determination just as surely as though this had actually been done. Similarly, the fraction of undecayed activity after 53 hours (sample L-9) may be found to be 79 percent whereupon the Corrected Count value for L-9 is 826/0.79 or 1045 counts. This whole process of determining the corrected count values for the multitude of samples under study for each operation may be greatly simplified through the use of the Working Curve for Decay Correction (Graph III, Appendix C). On this graph, it is necessary only to refer to the date and time (hours) of the measurement (abscissae) to obtain the undecayed fraction value (ordinates) by which the Net Counts figures are divided to correct to the time of launching, otherwise known as "zero time". This curve must be made anew for each operation, but this is done simply by erasing the dates and times for the previous curve and substituting the new values.

After the field samples had been counted, the standard soil samples were measured on the counter. These samples were prepared by adding known volumes of 10 and 100 times diluted standard H sample to 75 gram weights of uncontaminated soil. The soil was wetted by the solvent, but this was allowed to evaporate leaving the H and activity on the soil. After

thorough mixing, the sample was measured in the same manner as the unknown samples. The counter results were then corrected for decay to zero time, whereupon a calibration curve showing the relationship between sample corrected count and H content could be drawn. This curve was used in the H content evaluation of the field samples. It is convenient to convert the absolute H contents for each individual sample of the standards directly into equivalent H content per square meter of soil. If only one circle of 19.7 sq. cm. of soil was taken for each field sample, the conversion figure for each standard sample is simply

$$\frac{\text{absolute weight of H in standard sample}}{19.7} \times 10^4.$$

It is necessary to remember that the "purity" of the H is decreased by the amount of butyl cellosolve co-solvent added. A knowledge of the densities of the original H and of butyl cellosolve allows the use of volumetric procedures in the dilution measurements, and in the final calculations of H content of the standard soil samples. A sample of the H content evaluation curve may be seen in Graph IV, Appendix C.

Generally, it is desirable to check the activity content of the standard H sample in order to assure knowledge of the thoroughness of mixing, and to check the degree of activity deposition in the H, if suspected. Since the amount of activity added to the H in the munition is known at the time of addition of the activity, it is possible to calculate the theoretical count value of a unit weight or volume of the H used as the standard sample. It was known for example, that 0.703 mc. (as of 0000 hours) of activity per ml. of undiluted butyl cellosolve solution was added to the H at 0730 hours. Since 9.4 ml. of this solution was added to the 20 pounds of H in the rocket head, the activity content of 1 ml. of standard H solution should have been approximately

$$\frac{(0.703 \times 9.4) - (0.703 \times 9.4 \times 0.0315^*)}{\frac{20 \times 453}{1.32^{**}} \times 0.98^{***}} \text{ or } 0.95 \times 10^{-3} \text{ mc.}$$

* The decay between 0000 hours and 0730 hours was 3.15%.

** The density of the original H (Levenstein) was 1.32 g. per ml.

*** The addition of butyl cellosolve solutyzer decreased the effective H content by 2%.

One mc. of activity represents 2.22×10^9 counts per minute. Therefore, each ml. of standard H should have shown 2.22×10^9 times 0.95 times 10^{-3} or 2.11×10^6 counts per minute, or, each ml. of 100 times diluted standard H should have shown 2.11×10^4 counts per minute. Actually, the counter tube

[redacted]

and counting setup used here had an overall counting efficiency of about 1%, whence the actual observed count rate for 1 ml. of 100 times diluted standard H sample should have been 2.11×10^2 counts per minute. The observed counts per minute of 1 ml. of 100 times diluted standard H was 2.03×10^2, a reasonably good check. It is true, of course, that the efficiency figure for this counter tube under the particular conditions of use must be known with some degree of accuracy. Counter tubes of the same construction may have slightly different efficiencies. Further, a marked change in efficiency will be observed if the type of soil holder is changed so as to alter the effective thickness of soil about the counter tube, or length of the counter tube cathode covered with the activated material. Finally, the efficiency will be altered if a different type of energy radiation is used. Once it has been determined for a particular set of conditions, however, the efficiency of the counting figure is extremely valuable.

V. DISCUSSION

A. Geiger-Mueller Counter Evaluations

A large number of field tests concerned with the assessment of liquid agent contamination of large areas of ground, both by means of airplane sprays and ground burst munitions, were conducted at this station prior to the introduction of the radiotracer method in this work. The methods of assessment which were used involved principally the collection of scattered H drops on absorbent panels, pie plates, large filter papers, and even large funnels, with subsequent colorimetric quantitation of the collected dyed H. The colorimetric quantitation procedures ranged from visual estimation of stains collected on absorbent panels and photoelectric photometry of absorbent panels to actual dilution colorimetry of the dyed liquid agent collected in funnels or on pie plates. In all methods excepting the one involving photoelectric photometry, the number of people required for the actual assessment procedures was undesirably large, or the time required for a complete assessment was undesirably great. Furthermore, these methods never seemed to be reliable because of lack of comparison with methods of assessment other than colorimetry. There were no other procedures and the data presented as results of these tests represented the best of the "state of the art" at the time.

The introduction of the radiotracer method (evaluation by means of the Geiger-Mueller counter) represented the introduction of a method whose basis differed from those in use. For the first time, comparisons of results obtained by two different methods could be made. As a result of these comparisons, it became evident that the new procedure had to be

given serious consideration as a basic method of assessment. It is true that some of the earlier results obtained by this method were considerably less certain than more recent results, but this was due for the most part to the difficult problem which was concerned with the precipitation of the radiotracer from the H samples used in the tests. The development of the radiomanganese perchlorate-butyl cellosolve system of incorporating activity in H samples practically eliminated radiotracer precipitation. When this was accomplished, doubts concerning the trustworthiness of the radiotracer method disappeared, and it was then accepted as a standard method. It was not used more often in these tests because of the relatively high cost of the radiotracer to be used in the very largest munitions in the test programs. The cost of radiomanganese dioxide at the present time, as obtained from the Massachusetts Institute of Technology, ranges from $0.70 to $1.00 per millicurie, thus the cost of tracer for a 500 pound bomb test would range from $50 to $100, depending on the degree of precision desired in the test.

While it is not the function of this report to discuss in detail the results obtained in the radiotracer method as compared with results obtained in other methods, agencies familiar with the problem of liquid agent ground contamination may verify conclusions drawn in the above paragraphs by consulting the Dugway Proving Ground Weekly Reports, given in the following list. Special attention should be given to the data presented in D.P.G. Weekly Report No. 83, 22 November 1944. The radiotracer method reached its highest peak of perfection in the evaluation of the results of the H-filled rocket tests described in this Weekly Report.

1 Report No. 47, 15 March 1944
2 Report No. 51, 12 April 1944
3 Report No. 53, 26 April 1944
4 Report No. 54, 3 May 1944
5 Report No. 56, 17 May 1944 (Field Exp. 17-3)
6 Report No. 61, 21 June 1944 (Field Exps. P-17-16; 17-17)
7 Report No. 83, 22 November 1944 (Field Exps. P-22-1;-2)
8 Report No. 83, 22 November 1944 (Field Exps. P-22 all)

With respect to radiotracer techniques, those involving evaluation of radiotracer samples by means of the Geiger-Mueller counter have now been well standardized. The two M.I.T. Model 200 Series counting rate meters in use at this station have been utilized in such a manner that a whole radiotracer operation including the incorporation of the activity into the liquid agent of the munition being tested, the field test itself, the activity measurements and the H content calculations on up to 1000 soil samples or absorbent panel samples, has been completed in eight (8) days. The number of

people used in all phases of the work except the field test itself could not conveniently be more than two. Only one person was required to prepare and change samples as the samples were measured. These two people each worked one eight hour shift per day, in succession, for seven days, and on the last day of the proceedings, worked together on the conversion of counting data to degree of contamination data. There should be little doubt that the radiotracer method is far superior in saving manpower to all other evaluation methods used previously, except the photoelectric photometer procedure.

The accuracy of the standardized radiotracer method is limited only by the degree of precision obtainable in the taking of field samples. Direct soil sampling methods, have not been developed to the highest degree but there is no doubt about the precision of absorbent panel sampling, and subsequent radioactivity quantitation by means of the Geiger-Mueller counter. Assuming perfect field sampling to bepossible in both direct soil sampling and absorbent panel sampling, the precision of the radiotracer method in itself is limited only by the cost of preparation of the radioactive tracer. This is true because the use of tracer in quantities larger than described herein would, in even the lightest of liquid agent ground concentrations give count rates far in excess of those affected by variations in background count, which at present is often a troublesome factor in the counting of weak soil samples. As far as the precision of liquid agent areal contamination is concerned, this is governed solely by the number of samples taken from the contaminated area. Here, too, the use of large amounts of activity is desirable because speed of counting samples may be increased somewhat when the activity count rate for weak samples is high.

With this method, H contamination densities of the order of one gram per square meter have been determined with an estimated degree of precision of 10 per cent, and H contamination densities at and above 5 g. per sq. meter have been determined with an estimated degree of precision of from 3 to 5% when an activity concentration of 25 mc. per 100 pounds of H, and soil samples representing 19.7 sq. cm. area are used. An equivalent degree of measurement precision can be obtained with an activity concentration of from 3 to 5 mc. per 100 pounds of H by absorbent panel samples representing 560 sq. cm. area.

While the M.I.T. integrating-type counting rate meters have been used exclusively in this work, other installations interested in radiotracer methods use the so-called scaling circuit counting rate meters. It is difficult, at this time, to see the advantages of the scaling circuit counting rate meter over the integrating circuit counting rate meter.

The former, like the latter, must be calibrated by means of a pulse generator of one form or an other. It is possible for scaling-circuit counting rate meters to give incorrect results with less evidence of malfunction than properly designed integrating meters, and this may happen more frequently than may be suspected. Aside from the lack of a permanent record of counting by the scaling circuit, as compared with an integrating meter operating a recording meter, the scaling meter has the added disadvantage in the necessity for more constant checking of the preliminary determination of count rate for each sample in order to ascertain the time that is required to give a final count showing the minimum statistical variation errors.

The ability of a Geiger-Mueller counter tube to convert gamma ray energy into useful work within the counter itself is of great importance. This ability is spoken of here as the efficiency of counting. In terms of numerical values, this efficiency of counting shows what fraction of all gamma rays passing through the counter at any time actually show up as recorded counts in the counting rate meter. The efficiency of counting is a function of the counter tube characteristics for a given geometrical relationship between the source of activity and the counter tube. Of these characteristics, the type of cathode material seems to play the most important part. Probably, the type of surface of the cathode material and the amount of cathode material are of great importance. The type and pressure of the gas used in the counter tube are still other factors in determining the efficiency of counting.

For even the best of counter tube characteristics the efficiency of counting is ridiculously low when gamma ray investigations are made. For example, with the most favorable conditions of geometric placement of the radioactivity sample about the M.I.T. bismuth cathode counter, the efficiency of counting of the gamma rays of radiomanganese mass isotope 52 is of the order of only one per cent. This is to say that for every one hundred gamma rays passing through the counter, only one has its energy converted into ionization resulting in a pulse in the counter. It is obvious that the radiotracer method, now fairly costly for large scale field experiments, could be cut to about one per cent of the present cost of radiomanganese if the efficiency of counting could be made to be one hundred per cent. If the efficiency of counting figure could be merely doubled, the resulting gain would be well worth the time and effort spent. The M.I.T. bismuth cathode gamma ray counter presumably represents the most recent development in counter tubes with respect to increasing the efficiency of counting for gamma rays. It might be mentioned

here that alpha particle counters closely approach a 100% efficiency of counting. Beta ray counters show a counting efficiency figure of 50 to 80 percent unless they are especially designed for maximum efficiency.

In resumé, it may be stated that the radioactive tracer method using the Geiger-Mueller counter as an evaluating instrument is one of precision and rapidity, as compared with methods used previously in liquid agent contamination problems. The photoelectric photometer evaluation of absorbent panels is extremely rapid as compared with the radiotracer method, but is somewhat less precise and reliable. Although this radiotracer method may be designated as rapid, it is now admitted to be relatively slow as compared with the projected method of areal radioactivity evaluation. This projected method utilizes the ionization chamber mounted on a suitable vehicle which traverses the liquid agent-tracer contaminated area and records directly the changes in radiotracer concentration during traverse. This is the radioactivity ground scanner method.

B. The Radioactivity Ground Scanner Method

Although, at the present time, the radioactivity ground scanner is availbale for study at this station, the instrument, and its method of application to radiotracer areal contamination studies has not as yet been developed to the point where definite statements regarding its characteristics may be made. In preliminary studies, it showed great promise as a step forward in radiotracer techniques. Further studies have forced the conclusion that the instrument needs more development. An indication of results obtained is given in Graph V, Appendix C. These calibration curves were obtained by running the machine over absorbent panels containing known amounts of H-radioactivity with several different vehicular speeds, chamber heights, and chamber gas pressures. No attempt is made in this report to interpret these curves in detail. They are more or less self-explanatory upon close examination. Before the following table of net deflections is H-activity concentrations on the panels is presented, it should be pointed out that in this test one pair of chambers (the ones on the right hand side of the vehicle) did not have the required high quality electrometer grid input resistors. The calibration data for these chambers are not expected to be permanently accurate, for these chambersdo not maintain their assigned characteristics for any length of time. The poor quality resistors used are extremely temperature sensitive, and probably suffer with changes in relative humidity of the atmosphere. Their position at the imput of the electrometer circuit makes stability difficult throughout.

TABLE II

Final Calibration Data for Both Right and Left Ionization Chambers as Obtained from Graph V.

H Concentration on Calibration Panel, Grams per sq. meter	Number of Adjacent Panels	Units Deflection, Net * Right Chambers	Left Chambers
1.5	2	2.0	2.0
3.0	1	4.5	4.0
6.0	1	8.5	9.0
12.5	1	14.5	13.0
12.5	2	16.5	14.0
62.5	1	66	66.5
62.5	4	72.5; 86.5	67.0;76.0
125	1	140	130

* From background deflections averaging 5.5 and 3 chart units, respectively.

VI. CONCLUSIONS

The following conclusions are made on the basis of evidence presented or referred to in this report:

A. The radiotracer method of evaluating ground contamination has antiquated all methods used previously in the solution of the contamination evaluation problem except the photoelectric photometer method.

B. The radiotracer method is more rapid than all previously used methods except the photoelectric photometer method.

C. The radiotracer method is the most precise of all known methods of ground contamination assessment.

D. The radiotracer method is capable of greater detection sensitivity than any other known method.

E. The radiotracer method is somewhat more complex in operation and apparatus than any of the other methods.

F. The radiotracer method is, at the present time, more costly for large scale testing than any of the others, but there is some indication based on knowledge concerning the development of manufacturing processes for plutonium that this cost can be greatly reduced.

G. The radiotracer apparatus is, in part, in an excellent state of development at the present time, and furnishes a firm foundation for future development.

VII. RECOMMENDATIONS

A. Consideration should be given to the possibility of the use of the radiotracer method in the problems other than areal radioactivity measurements.

B. Negotiations should be undertaken with the Government agency responsible for the operation of plutonium manufacturing plants for the purpose of obtaining various desirable radiotracer materials.

C. Because specialized electronic apparatus is used in all radiotracer measurements, a department or section of research should be organized which will have the responsibility of investigating the extension of radiotracer techniques and developing new apparatus for the study and measurement of radioactive phenomena.

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APPENDIX A - PHOTOGRAPHS

Figure

1. Geiger-Mueller Counter and Pre-Amplifier Assembly
2. M. I. T. Counting Rate Meter (front view)
3. M. I. T. Counting Rate Meter (top view of sub-panel)
4. M. I. T. Counting Rate Meter (bottom view of sub-panel)
5. M. I. T. Multivibrator Pulse Generator (top view of sub-panel)
6. Multivibrator Pulse Generator (bottom view of sub-panel)
7. Complete Assembly of Counter Electrical Apparatus
8. Portable Geiger-Mueller Counter Assembly
9. Radioactivity Ground Scanner (front view)
10. Radioactivity Ground Scanner (side view)
11. Ionization Chambers and Electrometers (removed from shield)
12. Scanner Vehicle Control Panel and Cooling System
13. Scanner Electronic Amplifier and Recorder Units
14. Ionization Chambers and Electrometers (removed from shield)
15. Special Apparatus for Radiomanganese Conversion
16. University of California Radiation Protection Meter (side view)
17. University of California Radiation Protection Meter (front view)
18. Scanner Ionization Chamber Pressure Head and Electrometer Housing Unit Couplings
19. Scanner Ionization Chamber Pressure Head Coupling (exploded view)
20. Electrometer-Pre-Amplifier Unit(top view, cover removed)
21. Electrometer-Pre-Amplifier Unit (side view)

APPENDIX A

FIGURE 1. GEIGER-MUELLER COUNTER AND PRE-AMPLIFIER ASSEMBLY

Showing method of electrical attachment to pre-amplifier and method of mounting in pre-amplifier housing above the latter. The cylinder at the lower right is a brass soil holder which will fit over the counter when the latter is mounted. The glass jar is a typical soil sample jar containing a prepared soil standard. The six contact Jones plug (upper left) connects pre-amplifier to the counting rate meter.

FIGURE 2. M. I. T. COUNTING RATE METER (front view)

FIGURE 3. M. I. T. COUNTING RATE METER (top view of sub-panel)

Electron tubes and auxiliary controls are (left to right):
Front Row: 6C6 High Voltage Regulator; High Voltage Regulator Control Resistance Shaft; 6SJ7 First Amplifier; Vacuum Tube Voltmeter Zero Control Shaft; Vacuum Tube Voltmeter Sensitivity Control Shaft.
Second Row: 6C5 High Voltage Regulator Gate; 1/4 watt Neon Bulb Regulator; 1/4 watt Neon Bulb Regulator; 6SJ7 Second Multivibrator; 6AC7/1852 Vacuum Tube Voltmeter.
Third Row: 2X2/879 High Voltage Rectifier; VR 105 Low Voltage Regulator; VR 105 Low Voltage Regulator; 6SJ7 First Multivibrator; 6SJ7 Integrator.
Fourth Row: Low Voltage Power Supply Filter Condenser; 6X5 Low Voltage Rectifier; Multivibrator Bias Control Shaft; 6K6 Audio Amplifier.
Fifth Row: Controls marked 1-7 are Counting Rate Range Setting Control Resistances.

FIGURE 4. M. I. T. COUNTING RATE METER (bottom view of sub-panel)

Pre-amplifier plug connector is in the lower right hand corner. The filter condenser above this plug supports the special polystyrene dielectric high voltage coupling condenser (C_2 in Diagram IV, Appendix B).

FIGURE 5. M. I. T. MULTIVIBRATOR PULSE GENERATOR (top view of sub-panel)

The black metal tube is the 6SC7 multivibrator tube. The glass tube atop the power transformer is a 5W4 rectifier. The eight variable resistance shafts are bias and seven range setting controls.

FIGURE 6. MULTIVIBRATOR PULSE GENERATOR (bottom view of sub-panel)

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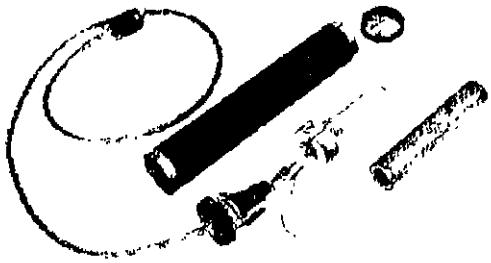


FIGURE 1
[illegible] COUNTER AND PRE-AMPLIFIER ASSEMBLY

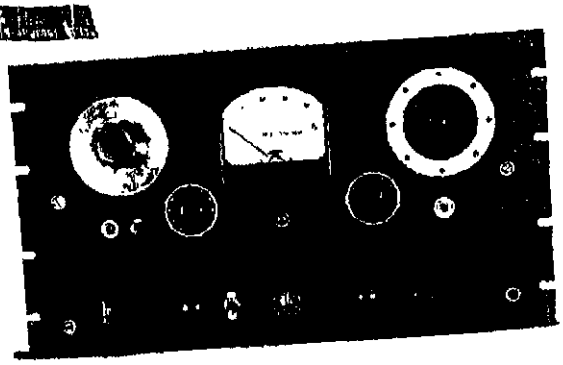


FIGURE 2
M.I.T. COUNTING RATE METER (Front view)

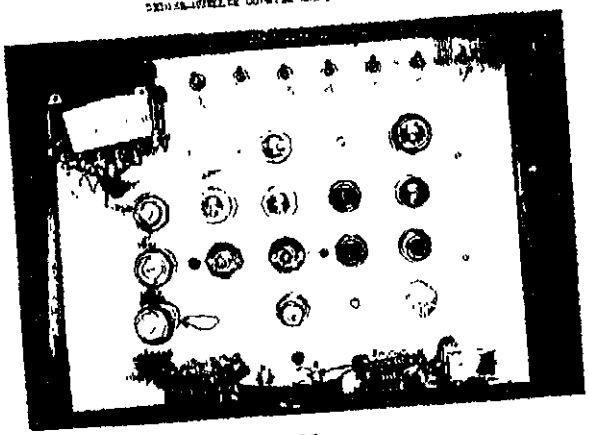


FIGURE 3
M.I.T. COUNTING RATE METER (Top view of sub-panel)

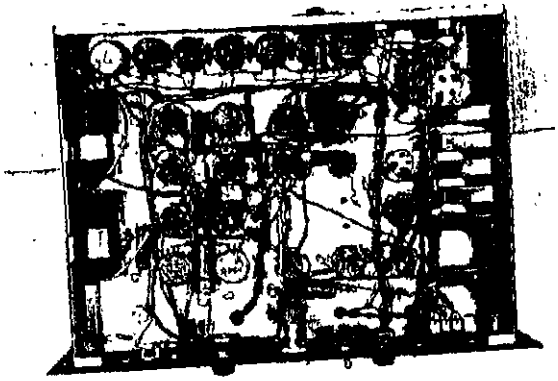


FIGURE 4
M.I.T. COUNTING RATE METER (Bottom view of sub-panel)

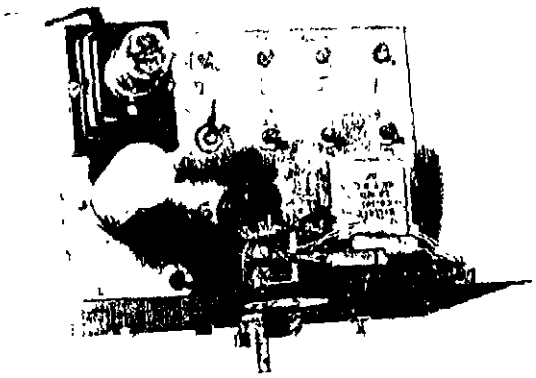


FIGURE 5
MULTIVIBRATOR PULSE OSCILLATOR (Top view of sub-panel)

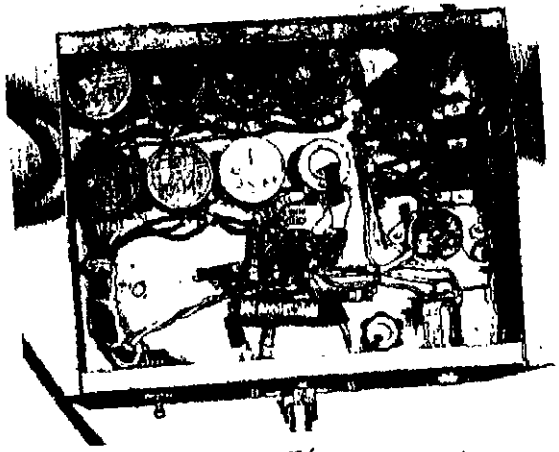


FIGURE 6
MULTIVIBRATOR PULSE OSCILLATOR (Bottom view of sub-panel)

BUREAU OF SHIPS DRAWING
Photo No. 1547

[redacted]

FIGURE 7. COMPLETE ASSEMBLY OF COUNTER ELECTRICAL APPARATUS

Showing two counting rate meters, two Esterline-Angus AC chart driven recording milliammeters, multivibrator pulse generator, and cathode ray oscilloscope. The pulse generator is arranged to feed pulses to counting rate meter for calibration. Leads pass also to the oscilloscope for simultaneous calibration of the pulse generator. In the foreground is shown two types of lead shields for the Geiger-Mueller tubes. One tube is shown in its pre-amplifier housing atop the right shield. The cylindrical shields at the left (one atop the other) are 2 5/8 inches internal diameter and have 1 1/4 inch walls. The single shield at the right is designed to contain both mounted counter tubes. The shape of the horizontal cross-section of this shield is that of a torus along a diameter. The holes are 2 3/4 inches in diameter and the minimum wall thickness is two inches. The black L-block in the lower right is a steel shell filled solidly with lead dioxide. It is 1 1/2 inches thick.

FIGURE 8. PORTABLE GEIGER-MUELLER COUNTER ASSEMBLY

The Geiger-Mueller tube housing cover has been removed, showing the G-M tube mounted above the pre-amplifier. The cylindrical lead shield (with cutout window for defining directional response of the counter) is of 3/4 inch wall thickness. The counting rate meter and batteries are in the aluminum tray behind which is the rubberized cloth carrying case. Also shown is a spring driven Esterline-Angus recorder (optional) and necessary crystal headphones.

FIGURE 9. RADIOACTIVITY GROUND SCANNER (front view)

The beams supporting the lead shields containing the ionization chambers and electrometers are extended into scanning position.

FIGURE 10. RADIOACTIVITY GROUND SCANNER (side view)

Showing beam and shield-chamber unit, steering wheel and part of AC motor drive (to right of steering post), Selsyn transmitter unit operating from left front wheel (to left of steering post), part of recorder unit (lower left corner of window), shield and battery compartments, and gasoline motor cooling fan (rear).

[redacted]

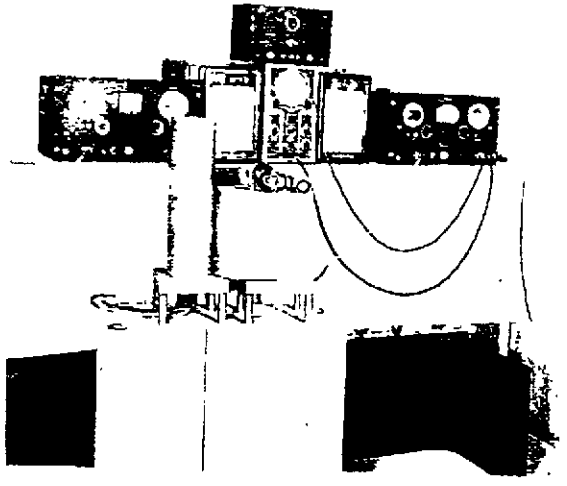


FIGURE 7
COMPLETE ASSEMBLY OF COUNTER ELECTRICAL APPARATUS

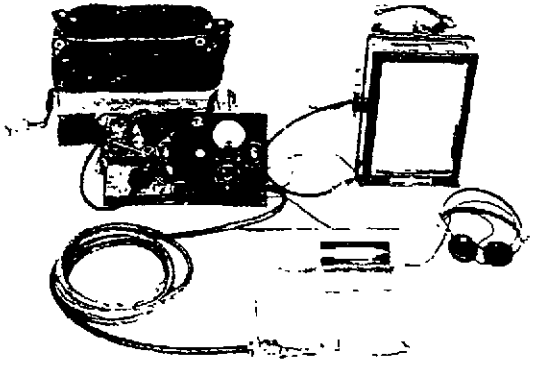


FIGURE 8
PORTABLE GEIGER-MUELLER COUNTER ASSEMBLY

FIGURE 9
RADIOACTIVITY GROUND SCANNER (front view)

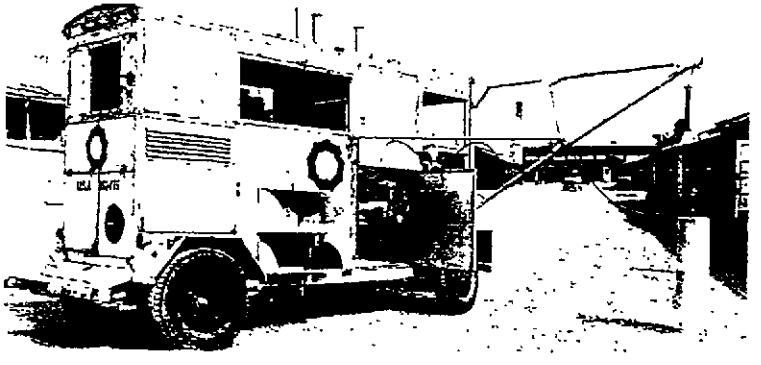


FIGURE 10
RADIOACTIVITY GROUND SCANNER (side view)

DUGWAY PROVING GROUND
Photo No. 1587 A

FIGURE 11. IONIZATION CHAMBERS AND ELECTROMETERS (removed from shield)

The lead shield (behind the chambers) is 22 inches tall, has a wall thickness of 1 1/2 inches at the top and 2 1/2 inches at the bottom. The weight is 550 pounds. Below the shield is the sheet metal weather cover for the electrometers. When components are assembled, the chambers fall into place inside the shield, but separated therefrom by a thin fiber bakelite insulation. The oblong metal plate consisting of two halves (lengthwise split), and the strap metal yoke are bolted into position on the shield to produce a single unit. The chambers are supported at the neck and insulated from the metal plate by peripherally slotted insulating fiber discs. Visible is one pressure gauge attached to coupling head of the front chamber. Electrometer housings are connected together and grounded to the shield.

FIGURE 12. SCANNER VEHICLE CONTROL PANEL AND COOLING SYSTEM

Centrifugal pump behind fan motor pumps water from tank underneath motor to top of left side of cooling compartment. Water trickles through loose packing while fan blows air through and out screen at left. Air was previously filtered through a bed of coarse absorbent charcoal to the right of the fan. The electronic amplifier and recorder units shown in Figure 13 are at the extreme right of the picture.

FIGURE 13. SCANNER ELECTRONIC AMPLIFIER AND RECORDER UNITS

From bottom center to top to right to bottom are shown, respectively, the battery compartment, the amplifier control panels (2), the Esterline-Angus milliammeter recorders (2), the Selsyn receiving unit, the amplifier filament ammeter, the multiconductor A-N connector from electrometers operating on the left side of the scanner. The Selsyn unit drives the recorder charts at a rate proportional to the speed of the vehicle.

FIGURE 14. IONIZATION CHAMBERS AND ELECTROMETERS (removed from shield)

A view showing bakelite lining of shield and steel cable and pulley.

FIGURE 16. SPECIAL APPARATUS FOR RADIOMANGANESE CONVERSION

The radiomanganese dioxide sample arrives in screw cap bottle (lower right). Tweezers are used to transfer filter paper containing activity to glass "duck" (atop small Claissen flask). Radiomanganese is treated with 3% perchloric acid containing 6% hydrogen peroxide with heating. Filter paper disintegrates and radiomanganese dioxide dissolves. Filtration of solution through sintered glass plate in tail of "duck" into flask allows separation from filter paper. Flask is then prepared for vacuum removal of excess water with special receiver ready to catch any liquid "bumping" over. Dry residue of radiomanganese perchlorate is dissolved in butyl cellosolve (hot) and transferred to cylindrical bottle (right center) which fits snugly into lead radioactivity carrier (left center).

[redacted]L

FIGURE 11
IONIZATION CHAMBERS AND ELECTROMETERS (removed from shield)

FIGURE 12
SCANNER VEHICLE CONTROL PANEL AND COOLING SYSTEM

FIGURE 13
SCANNER ELECTRONIC AMPLIFIER AND RECORDER UNITS

FIGURE 14
IONIZATION CHAMBERS
AND ELECTROMETERS
(removed from shield)

FIGURE 15
SPECIAL APPARATUS FOR RADIOMANGANESE CONVERSION

DUGWAY PROVING GROUND
Photo No. 1567 B

FIGURE 16. UNIVERSITY OF CALIFORNIA RADIATION PROTECTION METER (side view)

The ionization chamber is shown at the left, with the vacuum tube voltmeter assembly shown at the right.

FIGURE 17. UNIVERSITY OF CALIFORNIA RADIATION PROTECTION METER (front view)

Showing the inside of the ionization chamber and the front of the vacuum tube voltmeter assembly, with the controls and the microammeter.

FIGURE 18. SCANNER IONIZATION CHAMBER PRESSURE HEAD AND ELECTROMETER HOUSING UNIT COUPLINGS

Showing ionization chamber with the pressure head and gauge at the left and the housing of the electrometer at the right set on a peripherally slotted bakelite fiber disc.

FIGURE 19. SCANNER IONIZATION PRESSURE HEAD COUPLING (exploded view)

Showing the cylindrical aluminum electrode (upper left) and an extra polystyrene insulator with an enclosed center terminal wire (lower left). The polystyrene insulator fits into a steel cone that is machined to fit into a bakelite cone (center) which in turn is fitted into the pressure head coupling. All these fittings are put together using gasket cement. This is necessary to hold the pressure that is sometimes necessary for most efficient operation of the scanner.

FIGURE 20. ELECTROMETER-PRE-AMPLIFIER UNIT (top view - cover removed)

FIGURE 21. ELECTROMETER-PRE-AMPLIFIER UNIT (side view)

The cover is shown at the left and the pre-amplifier unit is shown at the right.

[redacted]

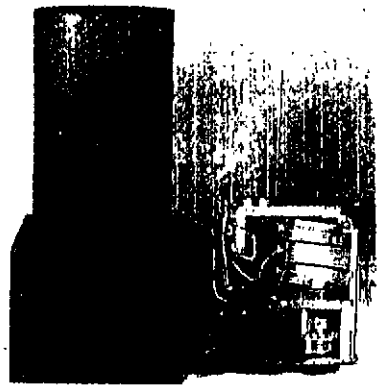


FIGURE 16
UNIVERSITY OF CALIFORNIA
RADIATION PROTECTION METER (SIDE VIEW)

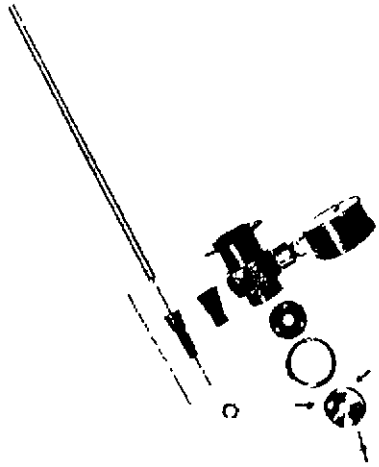


FIGURE 19
SCANNER IONIZATION CHAMBER PRESSURE HEAD ASSY
(EXPLODED VIEW)

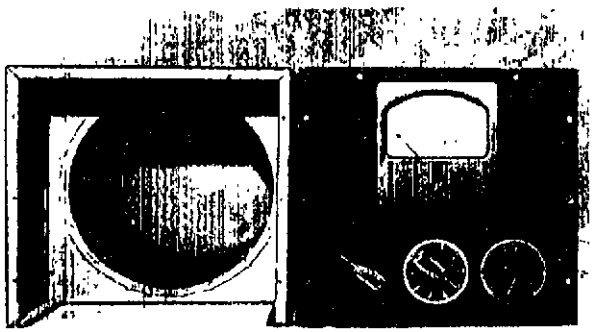


FIGURE 17
UNIVERSITY OF CALIFORNIA RADIATION PROTECTION METER (FRONT VIEW)

FIGURE 20
ELECTROMETER-PRE-AMPLIFIER UNIT (TOP VIEW, COVER REMOVED)

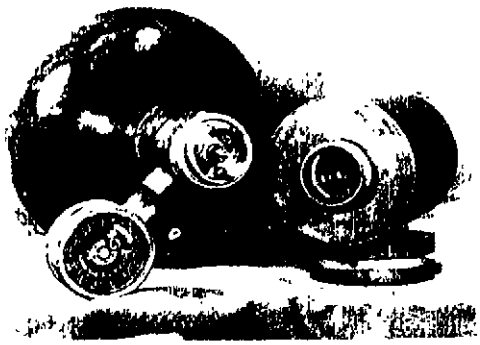


FIGURE 18
SCANNER IONIZATION CHAMBER PRESSURE HEAD AND
ELECTROMETER HOUSING UNIT COUPLINGS.

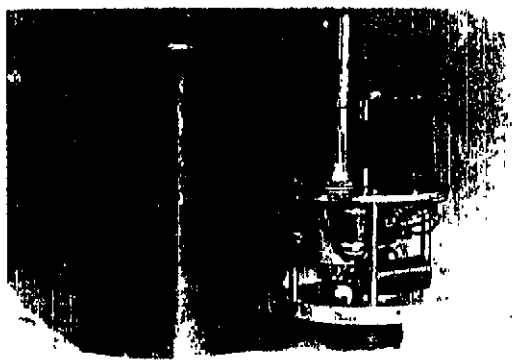


FIGURE 21
ELECTROMETER-Pre-AMPLIFIER UNIT
(SIDE VIEW)

UNIVAC PHOTO GROUND
Photo No. 1567 C

[redacted]

APPENDIX B - DIAGRAMS

GEIGER-MÜLLER COUNTER
M.I.T. BISMUTH COATED CATHODE TYPE

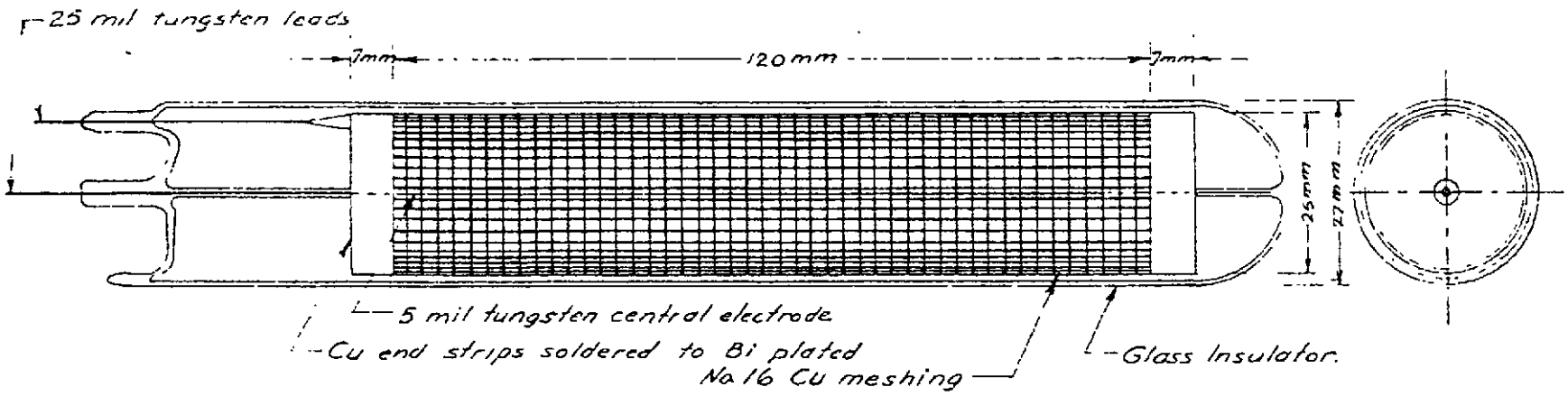
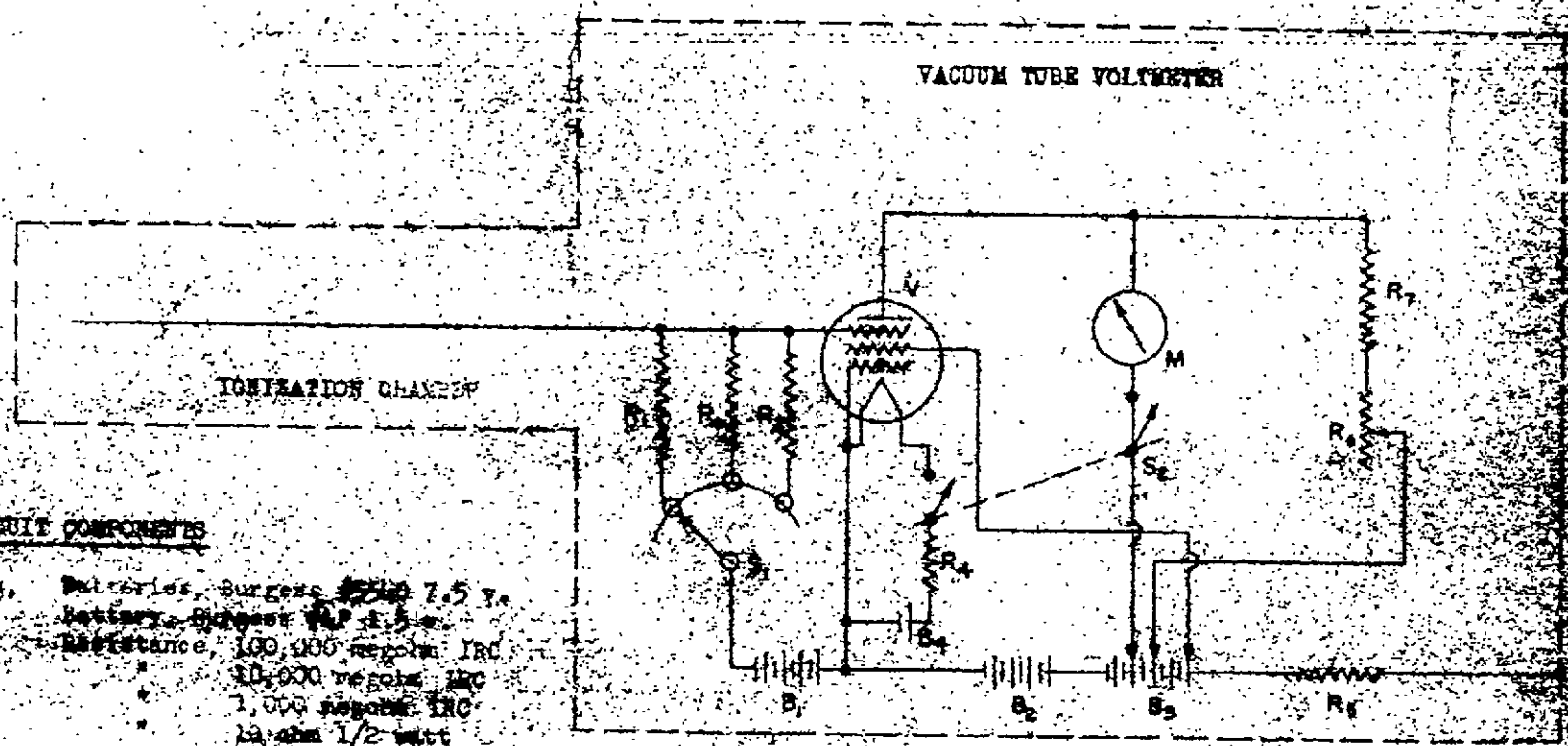


DIAGRAM I

PHOTO NO. 1587-D.

CIRCUIT DIAGRAM FOR UNIVERSITY OF CALIFORNIA
RADIATION PROTECTION METER IONIZATION CHAMBER

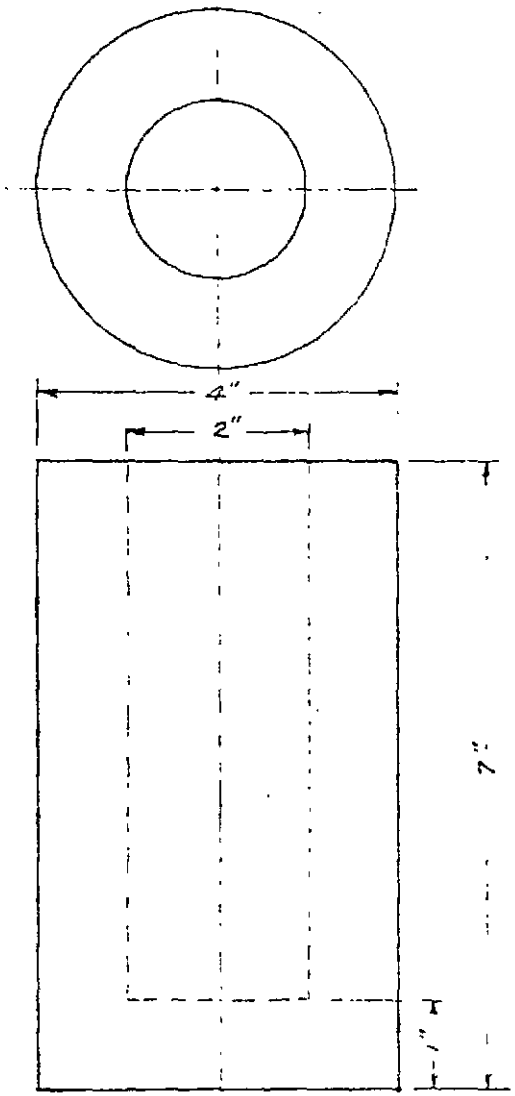


CIRCUIT COMPONENTS

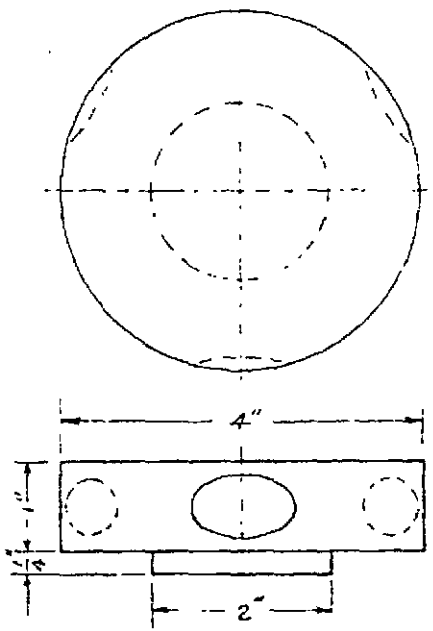
B_1, B_2, B_3, Batteries, Burgess [illegible] 7.5 v.
B_4, Battery, Burgess [illegible] 1.5 v.
R_1, Resistance, 100,000 megohm IRC
R_2, " 10,000 megohm IRC
R_3, " 1,000 megohm IRC
R_4, " 44 ohm 1/2 watt
R_5, " 10,000 ohm 1/2 watt
R_6, " 10,000 ohm variable wirewound
R_7, " 10,000 ohm 1 watt
S_1, Switch, rotary 6 contact, rebuilt with 3-1 1/2 inch long polystyrene insulators for contacts and suitable polystyrene shaft extension
S_2, Switch, DPST
V, Tube, type RCA 959 acorn mounted on polystyrene reproduction of regular ceramic type socket
M, Milliammeter, 50 microampere full scale, Weston model 731

DIAGRAM E
[illegible]

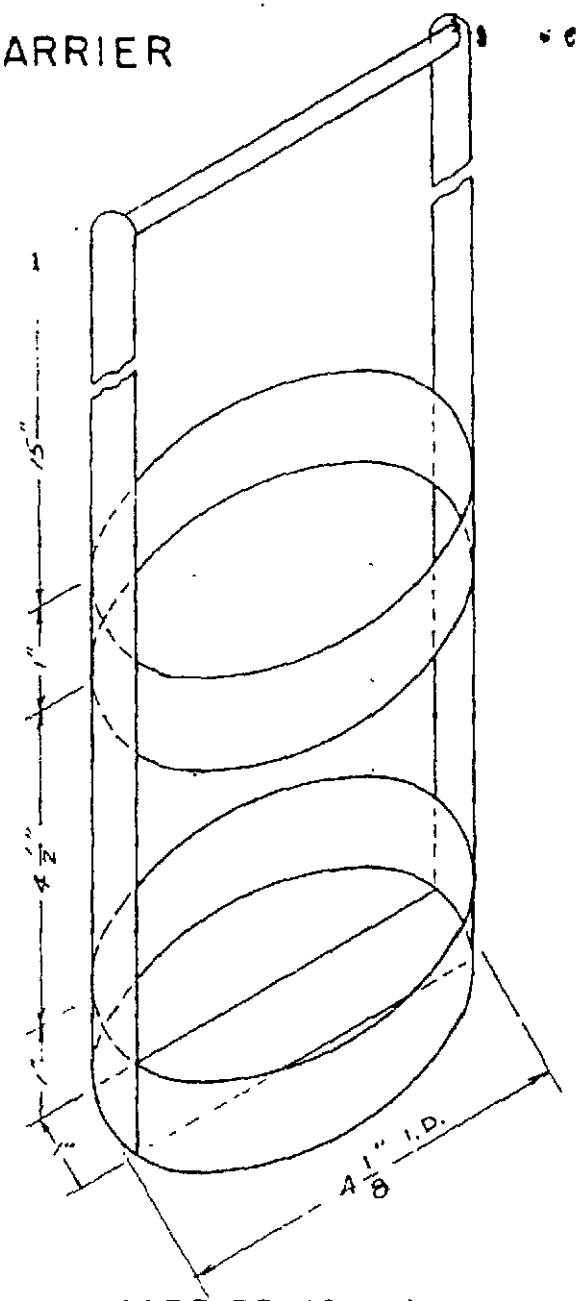
SHIELD AND LID AND SHIELD CARRIER FOR R-A SAMPLES



SHIELD (Lead)



LID (Lead)



CARRIER (Steel)

DIAGRAM III
PHOTO NO. 1587-F

[redacted]

DPGSR No. 55

Appendix B-Diagram IV
Legend

CIRCUIT COMPONENTS FOR
M. I. T. G-M COUNTING RATE METER

C-1	Condenser, 0.5 mfd., 1000 volts, paper
C-2	" 50 mmf., special mica
C-3	" .01 mfd., 600 volts paper
C-4	" .002 mfd., mica
C-5	" .25 mfd., paper
C-6	" 5 mmf., mica
C-7	" .5 mfd., 400 volts, paper
C-8,9	" .0001 mfd., mica
C-10	" .25 mfd., paper
C-11	" .0002 mfd., mica
C-12	" 2 mfd., polystyrene
C-13,14,16	" 8 mfd., electrolytic
C-17	" .2 mfd., paper
C-18	" .25 mfd., 2000 volts, paper
C-19,20	" 50 mmf., mica
C-21	" .1 mfd., paper
C-22	" 1.0 mfd., paper, 400 volts
F-1	Fuse, 1/16 ampere Littlefuse
J-1	Jack, Jones, 6 contact
J-2	Jack, closed circuit, for connection to Esterline-Angus model AW 0-5 ma. recording milliammeter
PL-1	Plug, Jones, 6 contact
R-1	Resistor, 10 megohm, 1 watt
R-2	" 5 megohm, 1 watt
R-3	" 6 megohm (2000 volt insulation)
R-4	" 1 megohm, 1 watt
R-5	" 0.5 megohm, 1/4 watt
R-6	" 0.2 megohm, 1 watt
R-7	" 0.3 megohm, 1 watt
R-8	" 1 megohm, 1 watt
R-9	" 0.1 megohm 1/2 watt
R-10	" 0.25 megohm, 1 watt
R-11	" 50,000 ohm, 1/2 watt
R-12	" 0.25 megohm, 1 watt
R-13	" 0.1 megohm, 1/4 watt
R-14	" 2000ohm, 1 watt, variable
R-15	" 0.5 megohm, 1/4 watt
R-16	" 3300 ohm, 10 watt
R-17	" 30,000 ohm, 1 watt
R-18	" 0.1 megohm, 1/4 watt
R-19,20,21	" 10 megohm, 1/4 watt
R-22	" 50,000 ohm, 1 watt, variable (Range 7)
R-24	" 25,000 ohm, 1 watt, variable (Range 6)

[redacted]

R-25	Resistor	10,000 ohm, 1 watt, variable (Range 5)
R-26	"	15.000 ohm, 1 watt, variable (Range 1)
R-27	"	8,500 ohm, 1 watt
R-28	"	15,000 ohm, 1 watt, variable (Range 4)
R-29	"	15,000 ohm, 1 watt, variable (Range 2)
R-30	"	7,500 ohm, 1 watt, variable (Range 3)
R-31	"	300 ohm, 1 watt, variable
R-32	"	12,000 ohm, 12 watt
R-33	"	1000 ohm, 1/2 watt
R-34	"	1000 ohm, 1 watt
R-35	"	2000 ohm, 1 watt, variable
R-36	"	150 ohm, 1/2 watt, variable
R-37	"	1000 ohm, 10 watt
R-38	"	3500 ohm, 10 watt
R-39	"	10,000 ohm, 10 watt
R-40	"	0.3 megohm, 2 watt
R-41	"	0.1 megohm, 1/4 watt
R-42	"	0.2 megohm, 1/4 watt
R-43	"	0.3 megohm, 1/4 watt
R-44	"	0.3 megohm, 1/4 watt
R-45,46,47	"	0.25 megohm, 1/4 watt
R-48	"	2.25 megohm, 1/4 watt
R-49	"	100 megohm, IRC metallized
R-50	"	10 megohm, 1 watt
R-51	"	1 megohm, 1/4 watt
R-52	"	0.5 megohm, 1/4 watt
R-54	"	1 megohm, 1 watt variable
R-55	"	1 megohm, 1/4 watt
R-56,to 62	"	0.75 megohm, 1/4 watt
R-63	"	1 megohm, 1 watt, variable, linear
R-64	"	2000 ohm, 10 watt
R-65	"	0.5 megohm, 1 watt, variable
S-1	Switch, push-button, polystyrene insulation	
S-2, 5	"	rotary, 2 gang, 8 contact
S-3	"	toggle, SPST
S-4	"	toggle, DPST
T-1	Transformer, General Radio No. 365-428 or RCA No. 33390	
V-1	Vacuum tube, type 6J7	
V-2,3,4	"	type 6SJ7
V-5	"	type 6SJ7GT
V-6	"	type 6AC7/1852
V-7	"	type 6X5
V-8	"	type 2X2/879
V-9	"	type 6C5
V-10	"	type 6C6
V-11, 12	Neon bulbs, 1/4 watt, bayonet base, internal resistance out	
V-13, 14	Regulator tubes, gas, type VR 105-30	
V-15	Vacuum tube, type 6K6G	

CIRCUIT DIAGRAM FOR MASSACHUSETTS INSTITUTE OF TECHNOLOGY
GEIGER-MÜLLER COUNTER COUNTING RATE METER

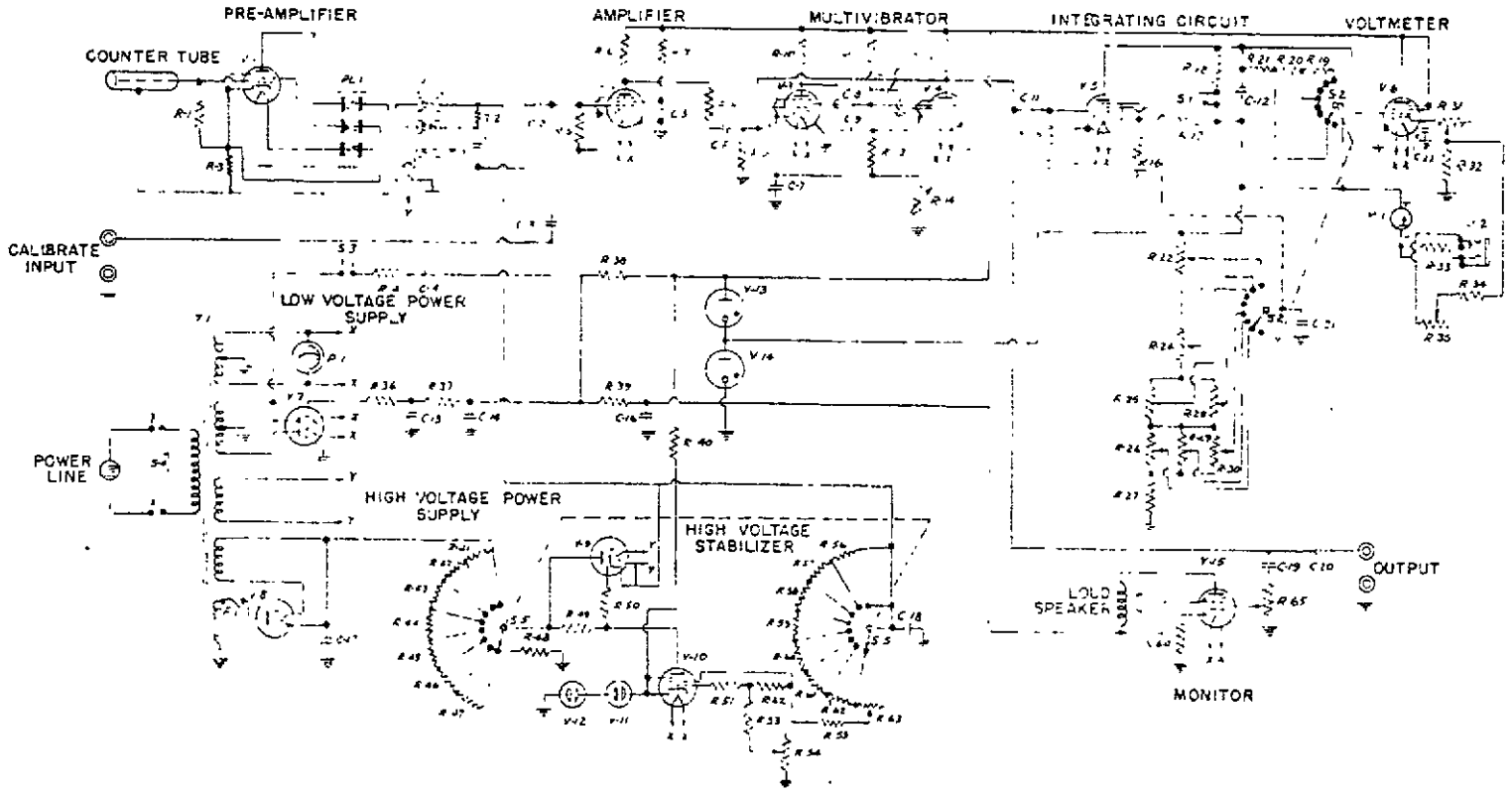


DIAGRAM IV
PHOTO NO. 1537-G

[redacted]L

DPGSR No. 55, Appendix B - Diagram V Legend

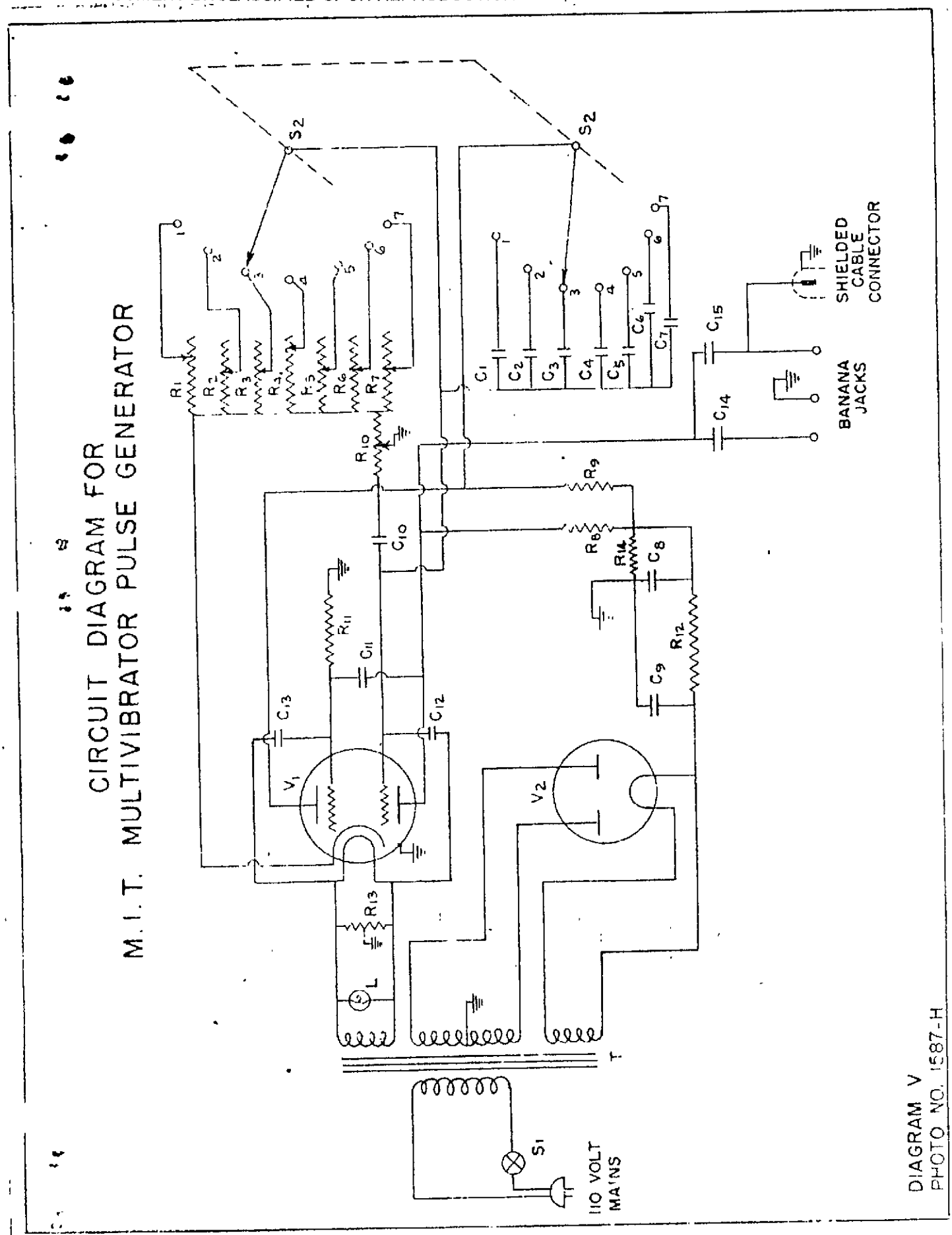
CIRCUIT COMPONENTS FOR M.I.T. MULTIVIBRATOR PULSE GENERATOR

C_1	Condenser, .005 mfd., paper, 400 volt
C_2	" .015 mfd., " "
C_3	" .02 mfd., " "
C_4	" .04 mfd., " "
C_5	" .12 mfd., " "
C_6	" .35 mfd., " "
C_7	" 1.0 mfd., " "
C_8, C_9	" 8 mfd., 600 volt electrolytic
C_{10}	" .008 mfd., mica, 600 volt
C_{11}	" .05 mfd., paper, 400 volt
C_{12}, C_{13}	" .003 mfd., paper, 400 volt
C_{14}	" .000005 mfd., mica, 600 volt
C_{15}	" .00005 mfd., mica, 600 volt
L	Lamp panel, 6 volt, jewel light
R_1	Resistor, 25,000 ohm, variable, wirewound
R_2	" 50,000 ohm, " "
R_3, R_4	" 100,000 ohm, " "
R_5, R_6, R_7	" 500,000 ohm, " "
R_8, R_9, R_{14}	" 200,000 ohm,
R_{10}	" 10,000 ohm, variable, wirewound
R_{11}, R_{12}	" 125,000 ohm, 1 watt
R_{13}	" 100 ohm, 2 watt, wirewound, with CT
S_1	Switch, toggle, SPST
S_2	Switch, rotary, 2 gang, 7 contact
T	Transformer, Thordarson type 13R19 or equivalent
V_1	Vacuum tube, type 6SC7, multivibrator oscillator
V_2	Vacuum tube, type 5W4, rectifier

Calibration Pulse Ranges

Range	Pulse Frequency, per minute
1	14,400
2	7,200
3	3,600
4	1,800
5	900
6	450
7	200

[redacted]L



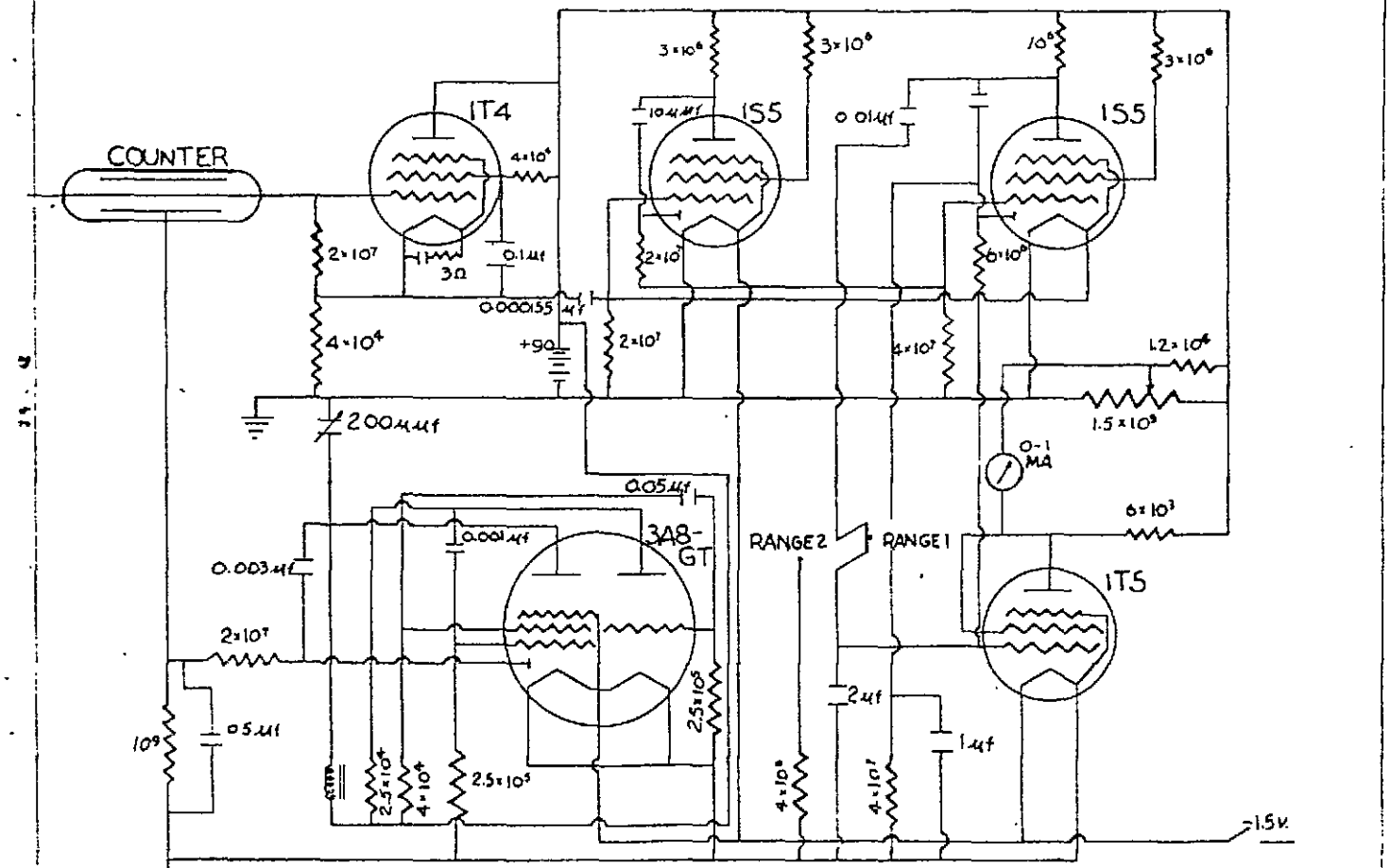


DIAGRAM VI

CIRCUIT DIAGRAM FOR M.I.T. PORTABLE G-M COUNTER

LEFT SIDE
RIGHT SIDE
REAR
FRONT
TOP
GLASS
BOOM TRAVEL POSITION
BOOM IMAGE
GENERATOR COMPARTMENT
ENGINE
GENERATOR
RADIOACTIVE GROUND SCANNER
BODY ASSEMBLY

RADIOACTIVITY GROUND SCANNER (FLOOR PLAN)

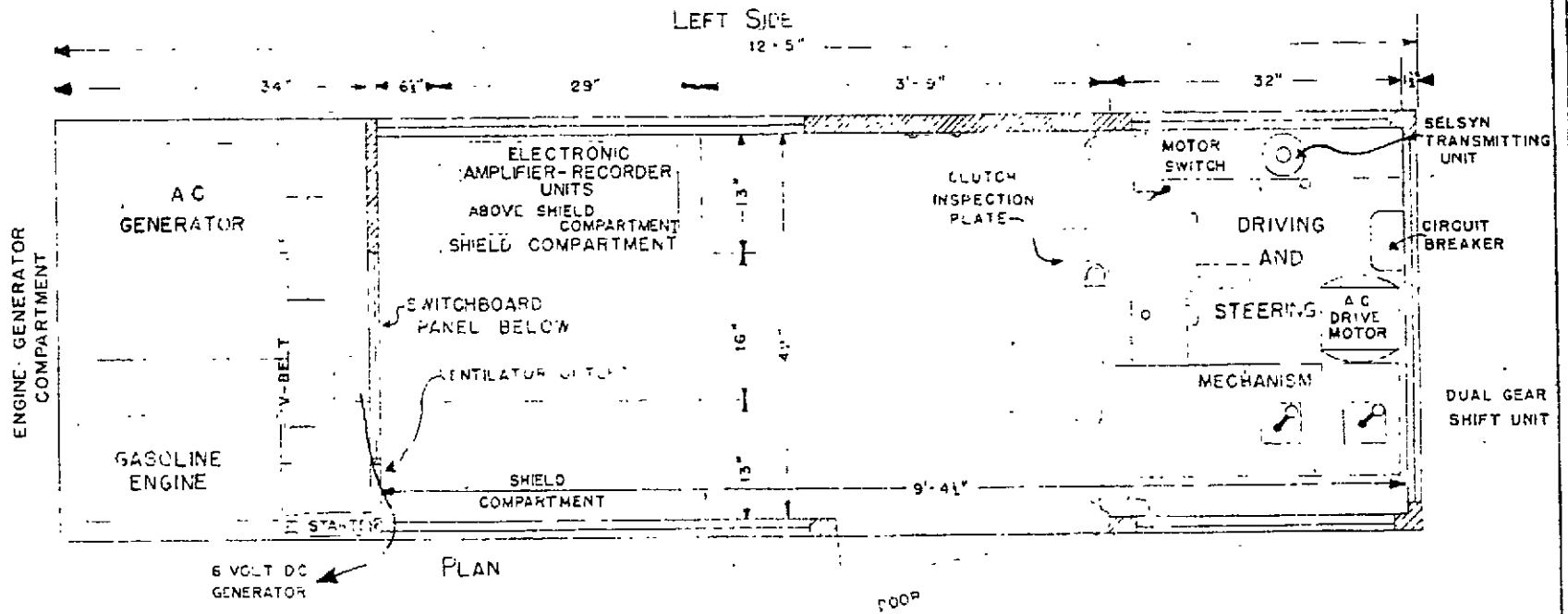


DIAGRAM VIII

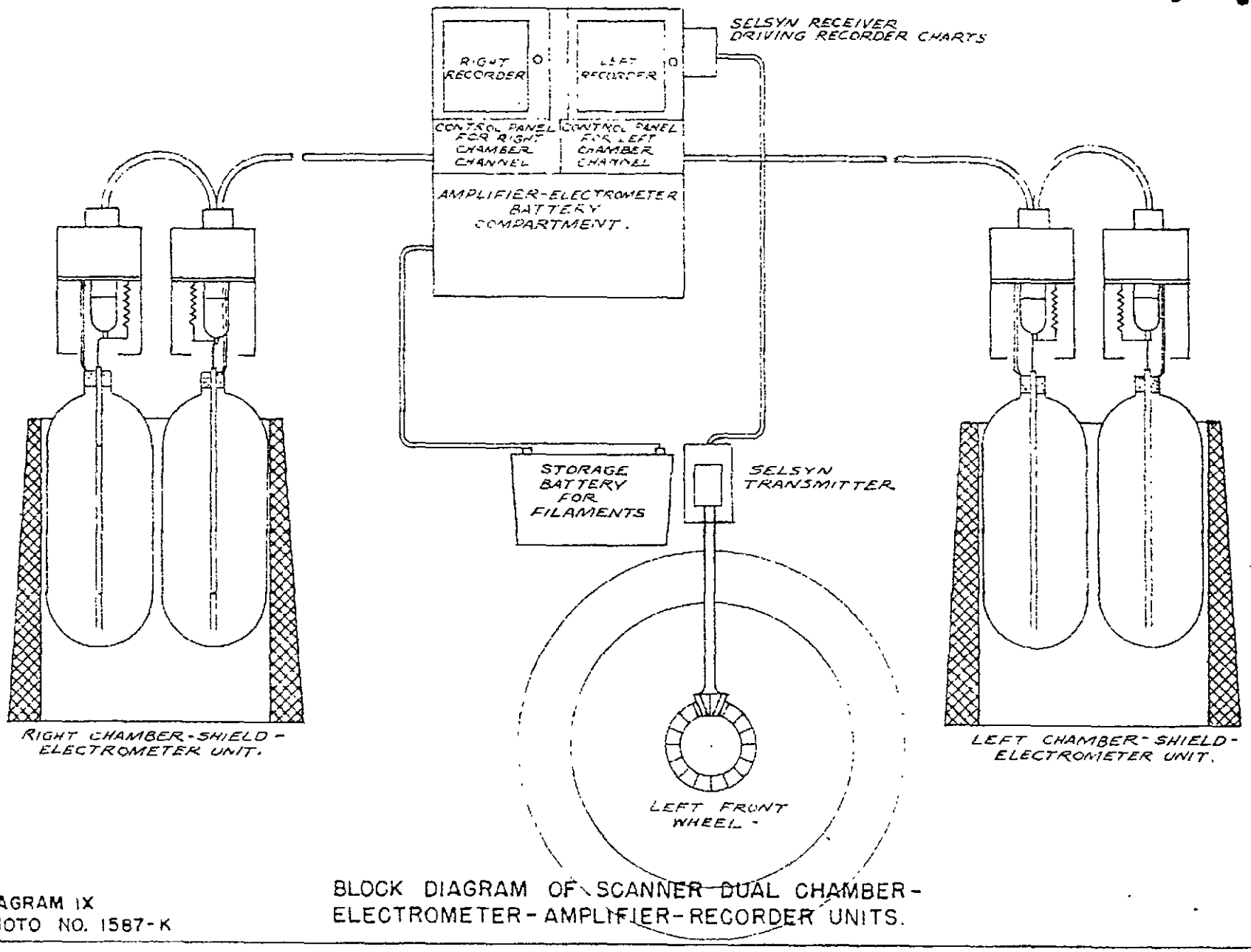
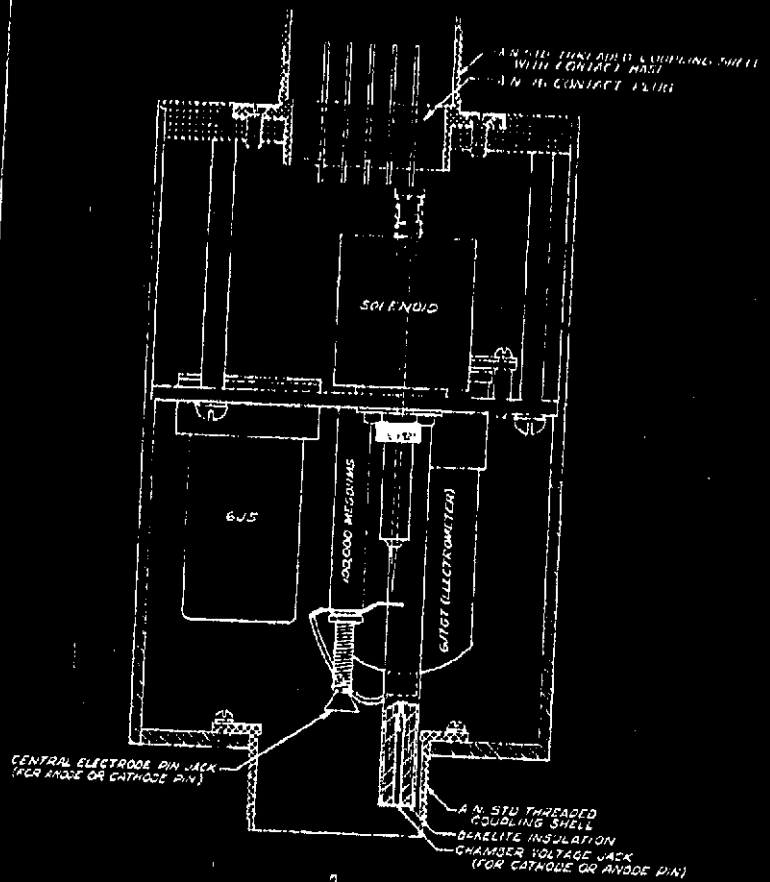


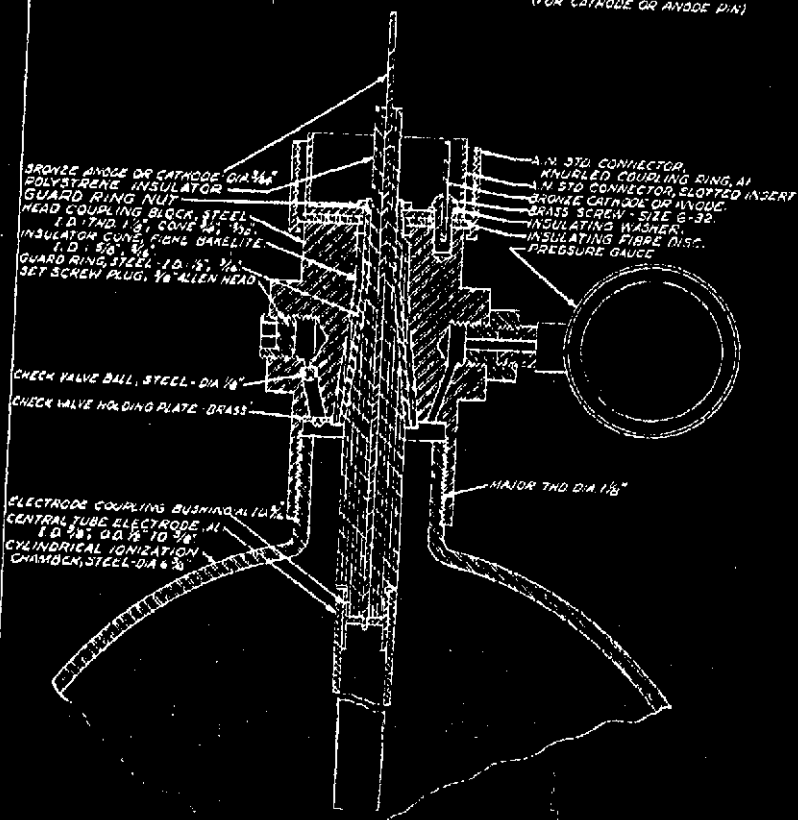
DIAGRAM IX
PHOTO NO. 1587-K

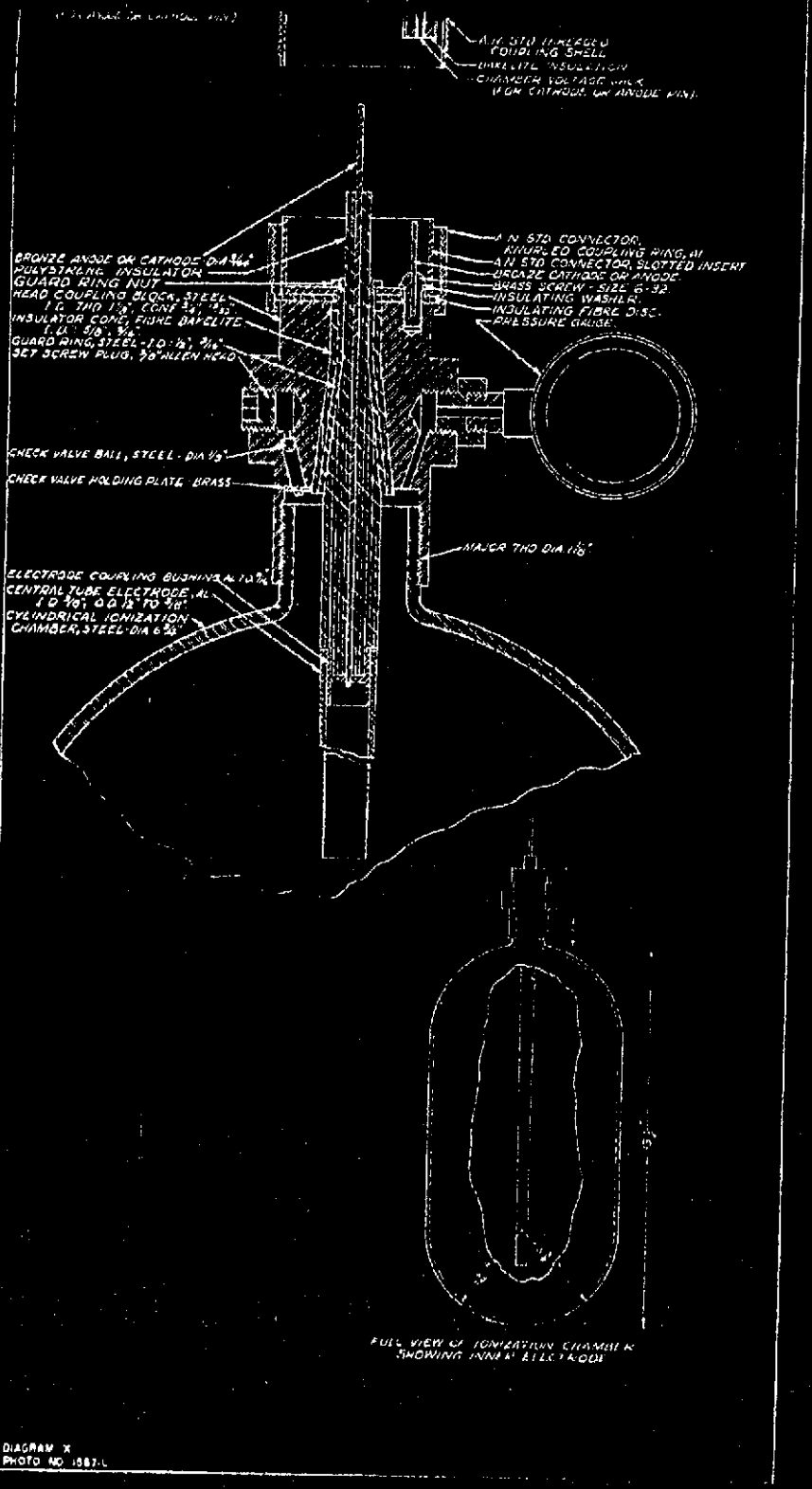
BLOCK DIAGRAM OF SCANNER DUAL CHAMBER-ELECTROMETER-AMPLIFIER-RECORDER UNITS.

ELECTROMETER-AMPLIFIER AND IONIZATION CHAMBER HEAD COUPLING UNIT

INTERIOR VIEW OF ELECTROMETER AND AMPLIFIER UNIT (ARROW) AND CROSS-SECTIONAL VIEW OF UNIVERSAL ION CHAMBER HEAD, SHOWING METHOD OF JOINING THE TWO UNITS SO THAT CONDITIONS SUITABLE FOR MEASUREMENT OF ELECTROMETER TIME MAY BE OBTAINED FROM THIS COMBINATION HEAD







[redacted]

DPGSR No. 55

Appendix B - Diagram XI
Legend

CIRCUIT COMPONENTS FOR RADIOACTIVITY GROUND SCANNER CIRCUIT DIAGRAM

A	Ammeter, 0-1 ampere, Weston Model 506
B_1	Batteries, bank of 4 Burgess type 30ZN tapped at — 22½ volts
B_2	Batteries, bank of 4 Burgess type 21308 tapped at + 45 volts
B_3	Battery, automobile storage, 51 plate or larger
C_1, C_2	Condenser, 4 mfd., 150 volt, C-D type BR 415
C_3, C_4	" 0.25 mfd., 400 volt, paper
E-A M	Milliammeter, recording, Esterline-Angus type AW, 0-1ma.
F_1, F_2	Fuse, 1/16 ampere, Littlefuse (control panel)
R_1, R_2	Resistor, 100,000 megohm, IRC
R_3, R_4	" 0.15 megohm, 1 watt, IRC type WW4
R_5, R_6	" 20 megohm, 1 watt
R_7	" 15,000 ohm, variable, wirewound
R_8, R_9	" 0.5 megohm, IRC type WW4
R_{10}, R_{11}	" 65,000 ohm, 1 watt
R_{12}, R_{13}	" 10,000 ohm, variable, wirewound (ZERO ADJ.)
R_{15}, R_{16}	" 50,000 ohm, IRC type WW4
R_{17}, R_{18}	" 0.5 megohm, IRC type WW4
R_{19}, R_{20}	" 10,000 ohm, 1 watt
R_{21}	" 0.1 megohm, 1 watt
R_{22}	" 100 ohm, 2 watt, variable
R_{23}	" 15,000 ohm, IRC type WW4
R_{24}, R_{25}	" 4000 ohm, 1 watt
R_{26}	" 10,000 ohm, variable, wirewound ("METER CALIB.")
R_{27}, R_{28}	" 7 1/2 ohm, 5 watt, wirewound
R_{29}	" 30 ohm, 10 watt, wirewound
S_1	Switch, toggle, DPDT ("ION. VOLTS")
S_2, S_2	" toggle, DPST ("+ B")
S_3	" toggle, DPST ("BIAS")
S_4	" rotary, 5 contact, 2 gang ("SENS. RANGE")
S_5, S_6	" push short ("INPUT SHORT")
S_7	" toggle, SPST ("FILAMENT")
SR_1, SR_2	Solenoid, relay, grid input shorting, 6 volt DC
V_1, V_2	Vacuum tube, electrometer, type 6J7GT, RCA or Sylvania
V_3, V_4	" pre-amplifier, type 6J5 metal
V_6, V_6	" recorder output, type 6SN7GT

Designations within the parentheses refer to controls on control panel of scanner electronic unit.

[redacted]

CIRCUIT DIAGRAM FOR RADIOACTIVITY GROUND SCANNER ELECTROMETER-AMPLIFIER

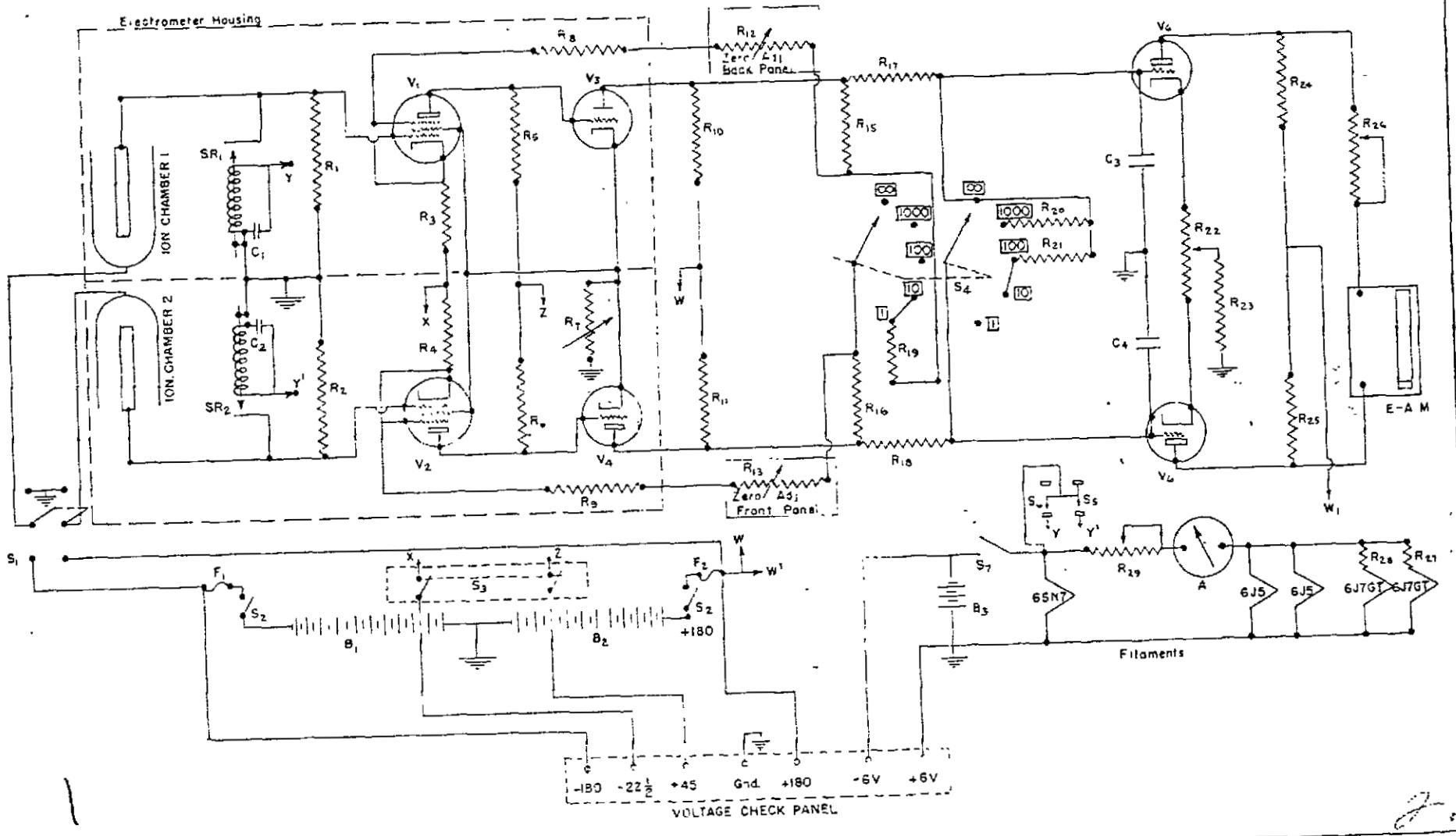


DIAGRAM XI

PHOTO NO 1587-M

SOIL SAMPLE HOLDER
FOR GEIGER-MÜLLER TUBES

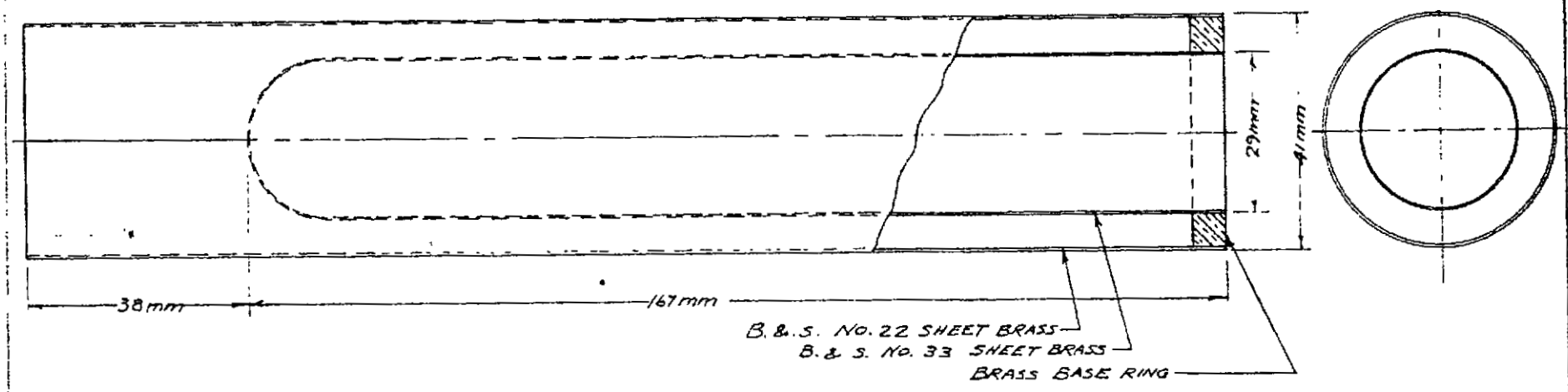


DIAGRAM XII
PHOTO NO. 1587-N

APPENDIX C - GRAPHS

Graphs

I. Typical Recorder Tracings Obtained from an M.I.T. Counting Rate Meter

II. Decay Curves for Radiomanganese (Mn 52), Half-Life 6.5 Days

III. Working Curve for Decay Correction of Measured Samples

IV. H Content Evaluation Curve for Counter No. 213, Operation of 10/18

V. Preliminary and Final Scanner Calibration Curves

[redacted]

Appendix C - Graph I

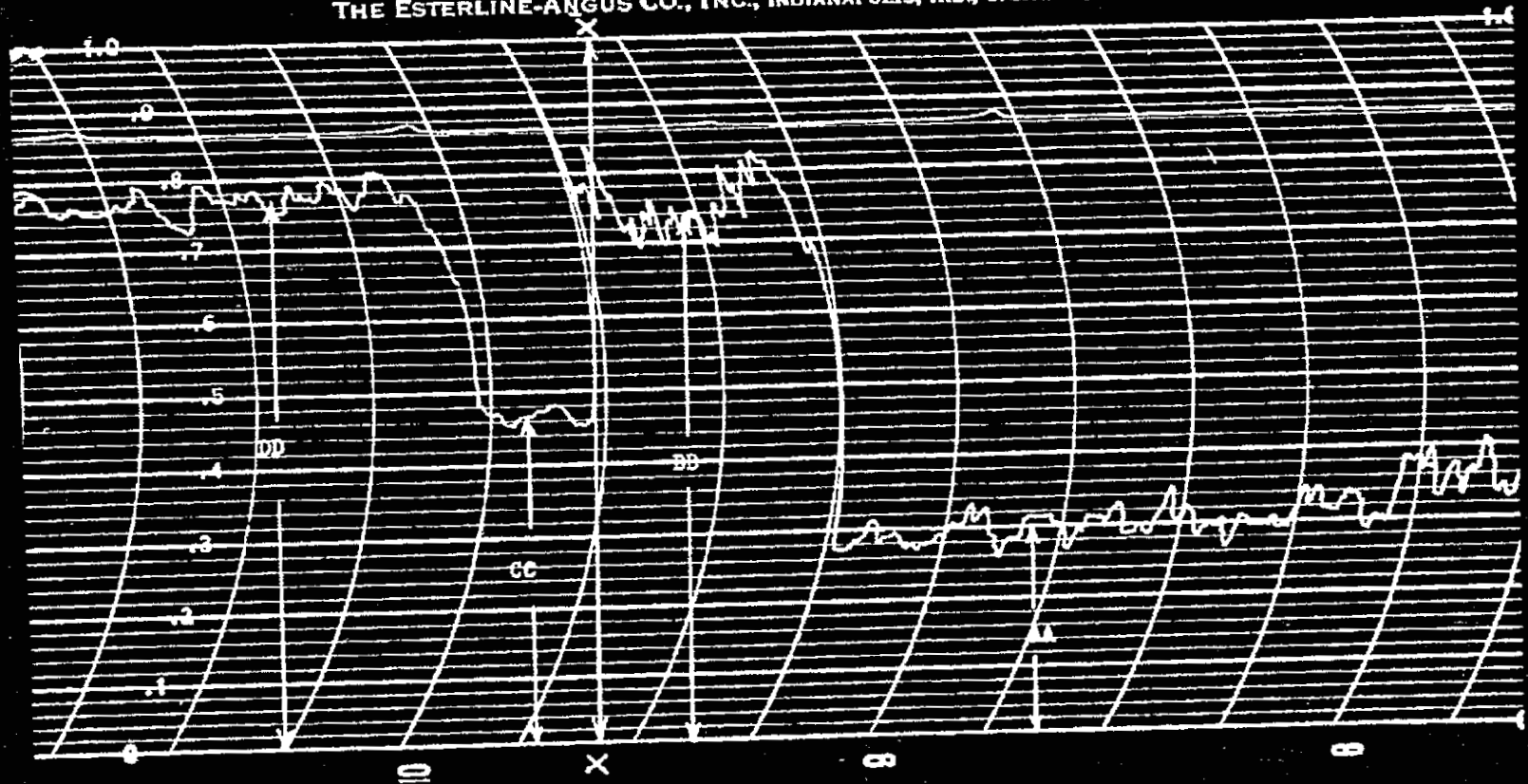
GRAPH I. Typical Recorder Tracings Obtained from an M.I.T. Counting Rate Meter

The line XX' represents swing of the Esterline-Angus meter neddle for full scale deflection on any range. The tracing indicated by the line AA is a typical background tracing recorded by the counter when it was shielded by 1¼ inches of lead. The line AA is 30 scale divisions on the 200 count per minute full scale range. The background count figure is, then, 60 counts per minute.

The tracing indicated by line BB is also a background recording, but with no shielding for the counter tube. The recorded value is 75 scale divisions on the 200 count per minute range, or 150 counts per minute.

The tracing CC is that of an approximate 0.5 mc. radiocobalt source at 3 feet (counter shielded) and tracing DD is that of the same source at 5½ feet. Tracing CC was on the 5000 count per minute range whereas tracing DD was on the 1000 count per minute range.

[redacted]

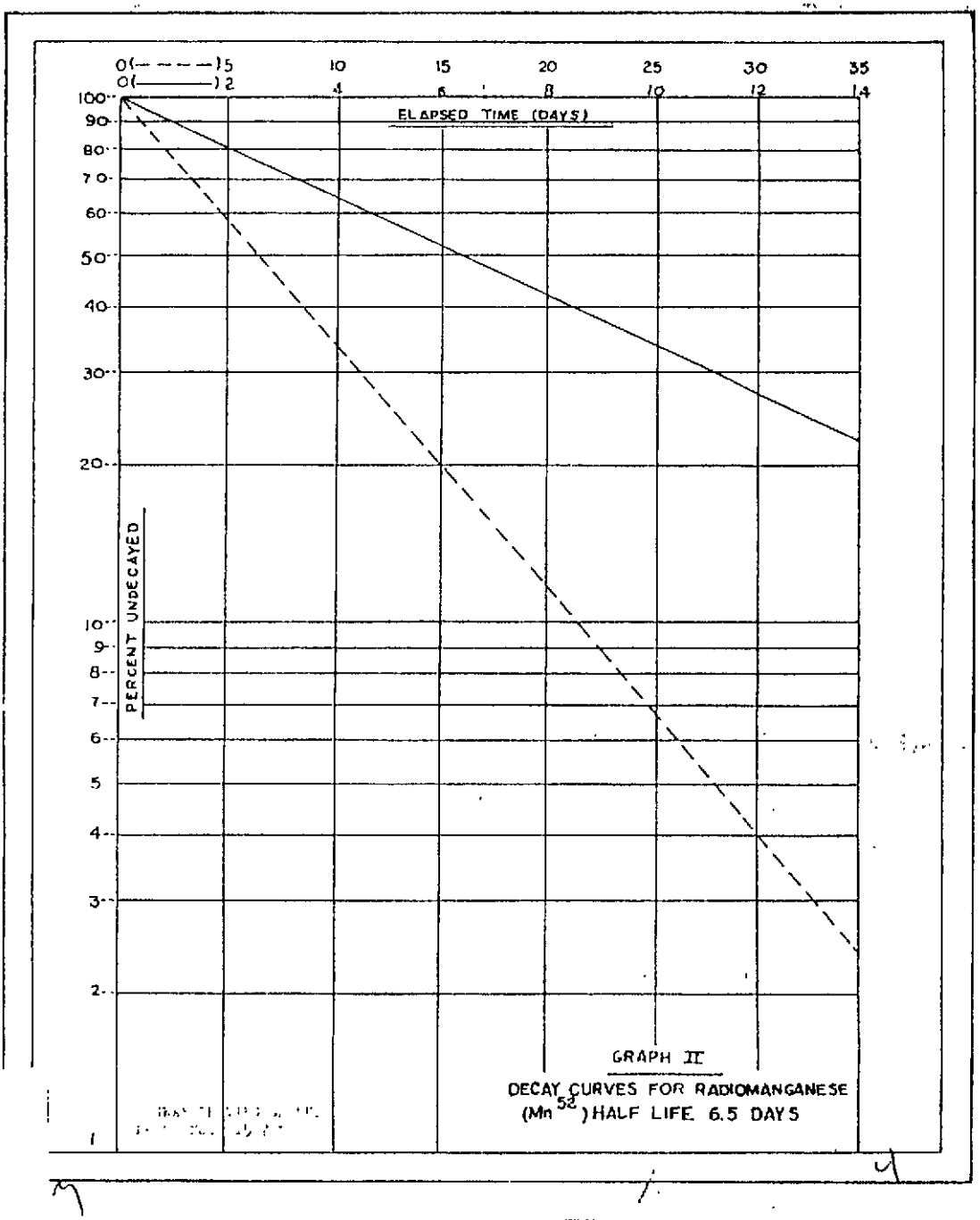


GRAPH I

TYPICAL RECORDER TRACINGS OBTAINED FROM

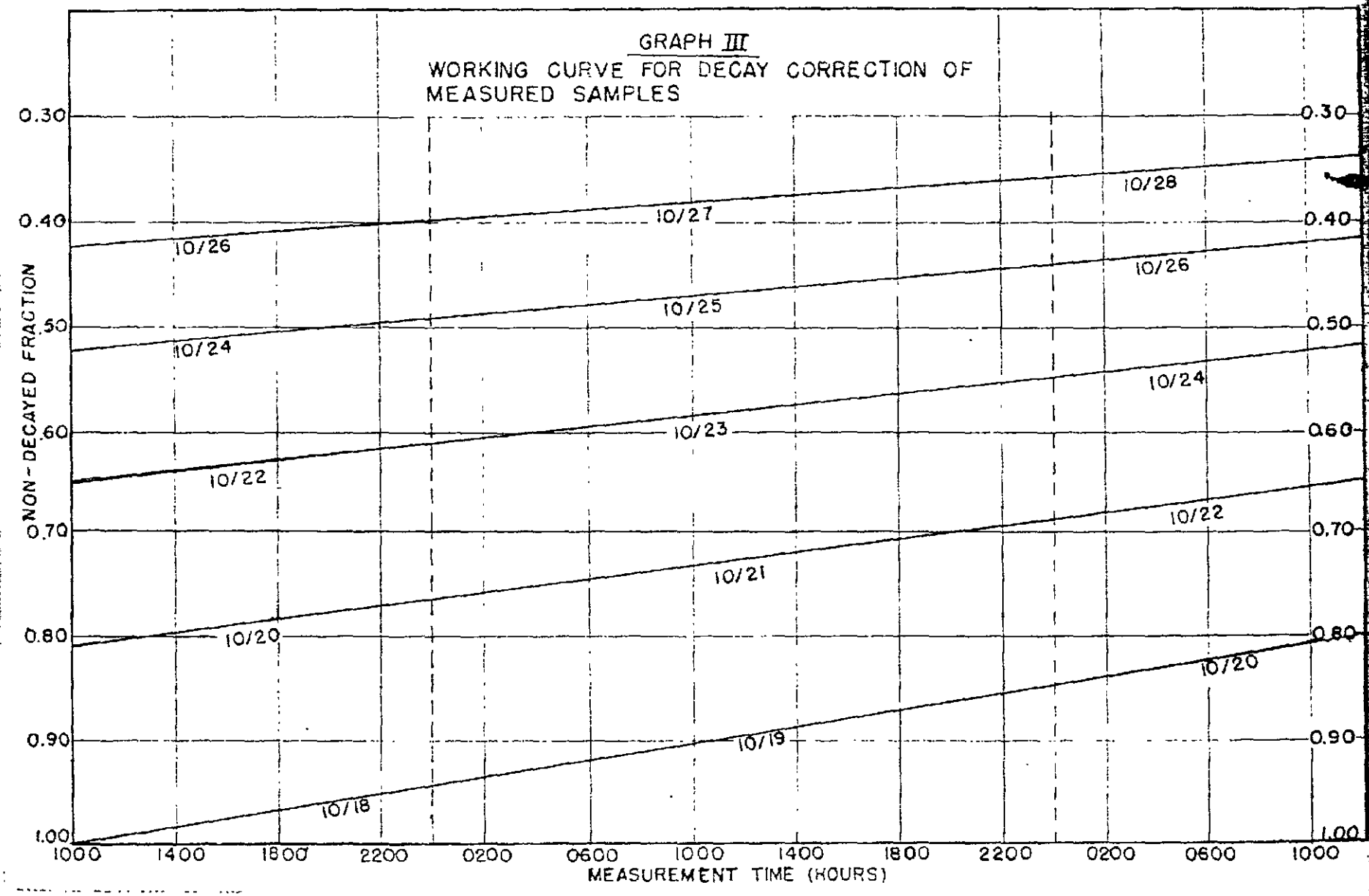
AN M. I. T. COUNTING RATE METER

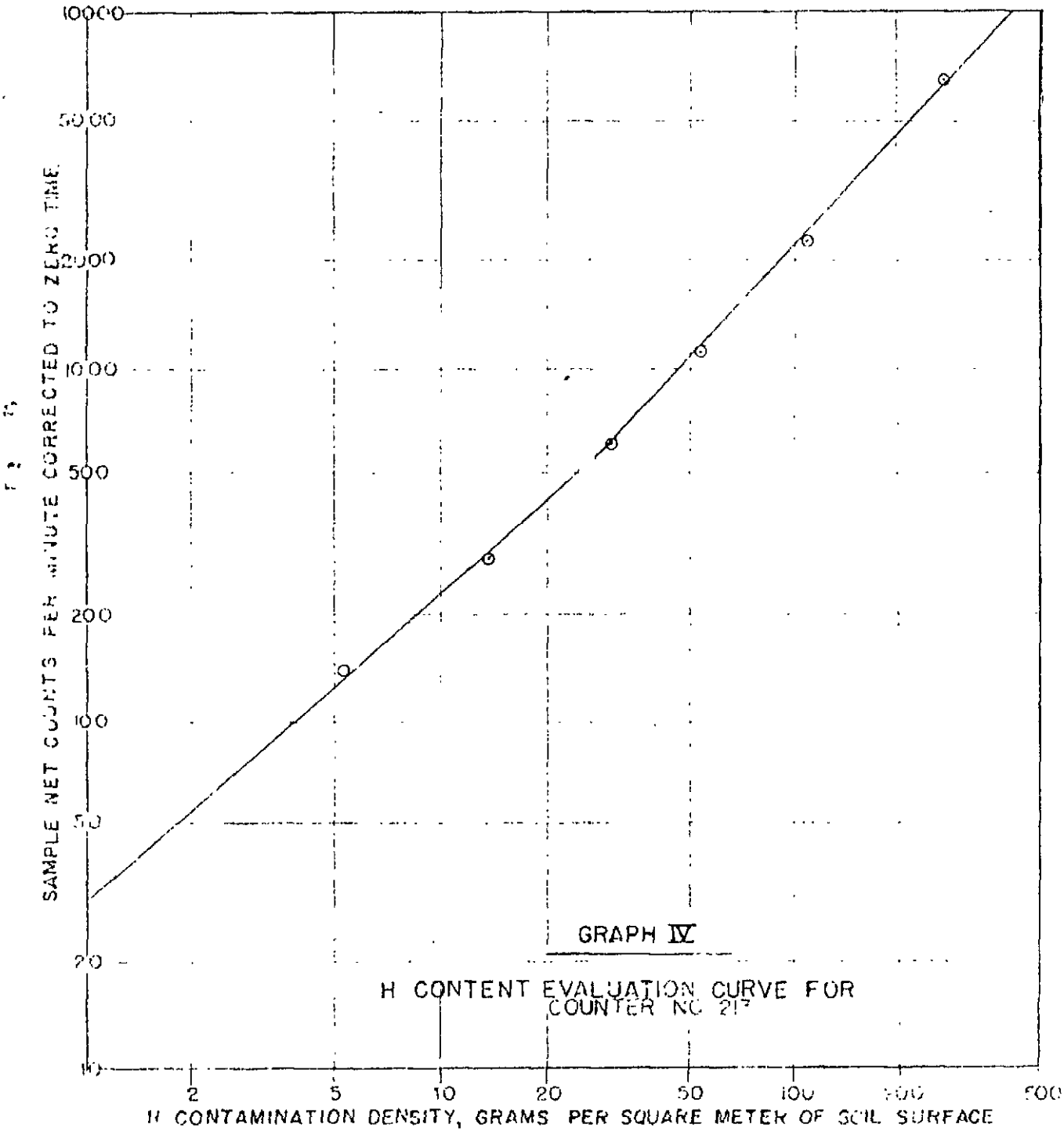
Dugway Proving Ground
Photo No. 1587 0



GRAPH II

DECAY CURVES FOR RADIOMANGANESE (Mn^{52}) HALF LIFE 6.5 DAYS



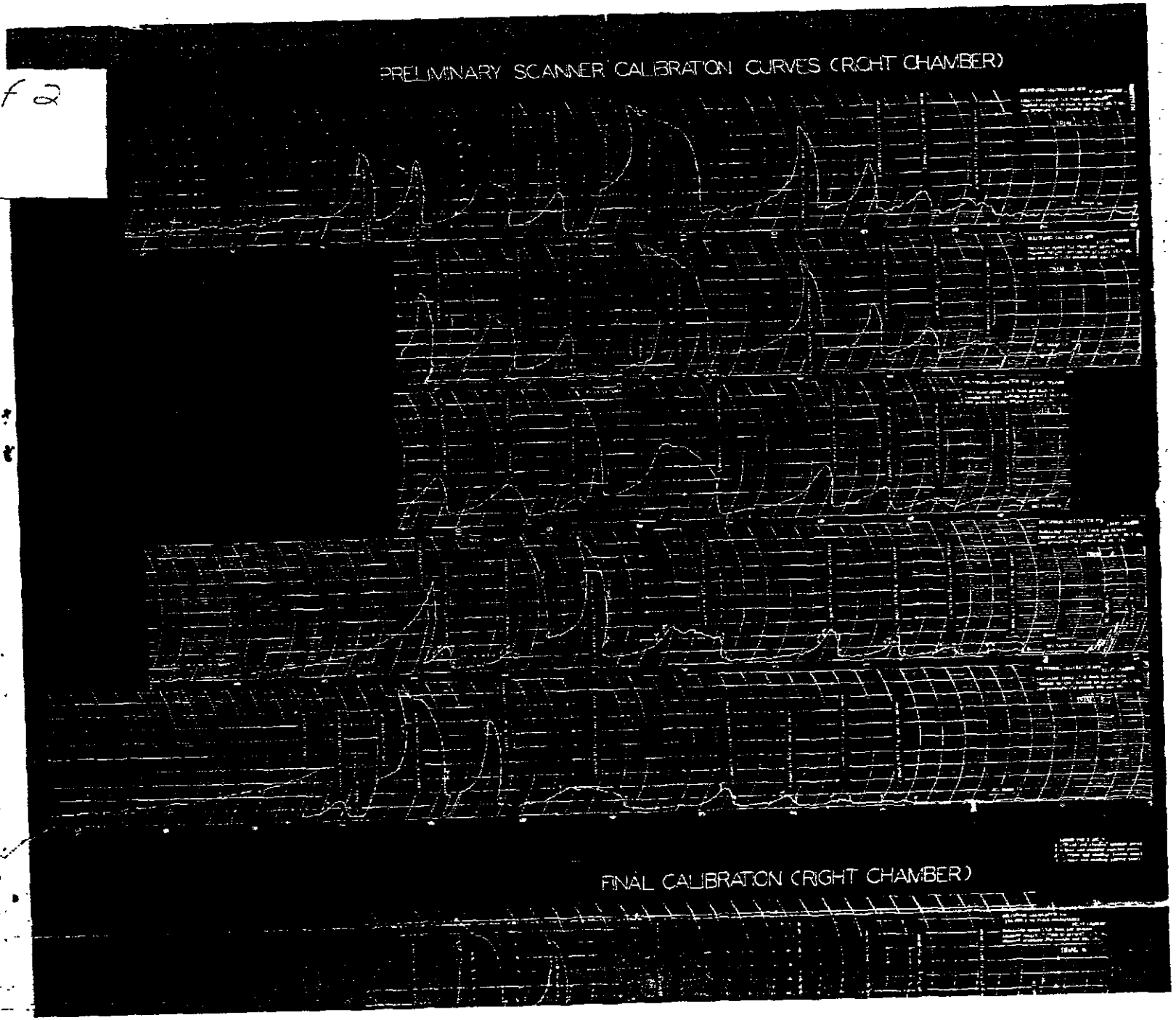


GRAPH IV

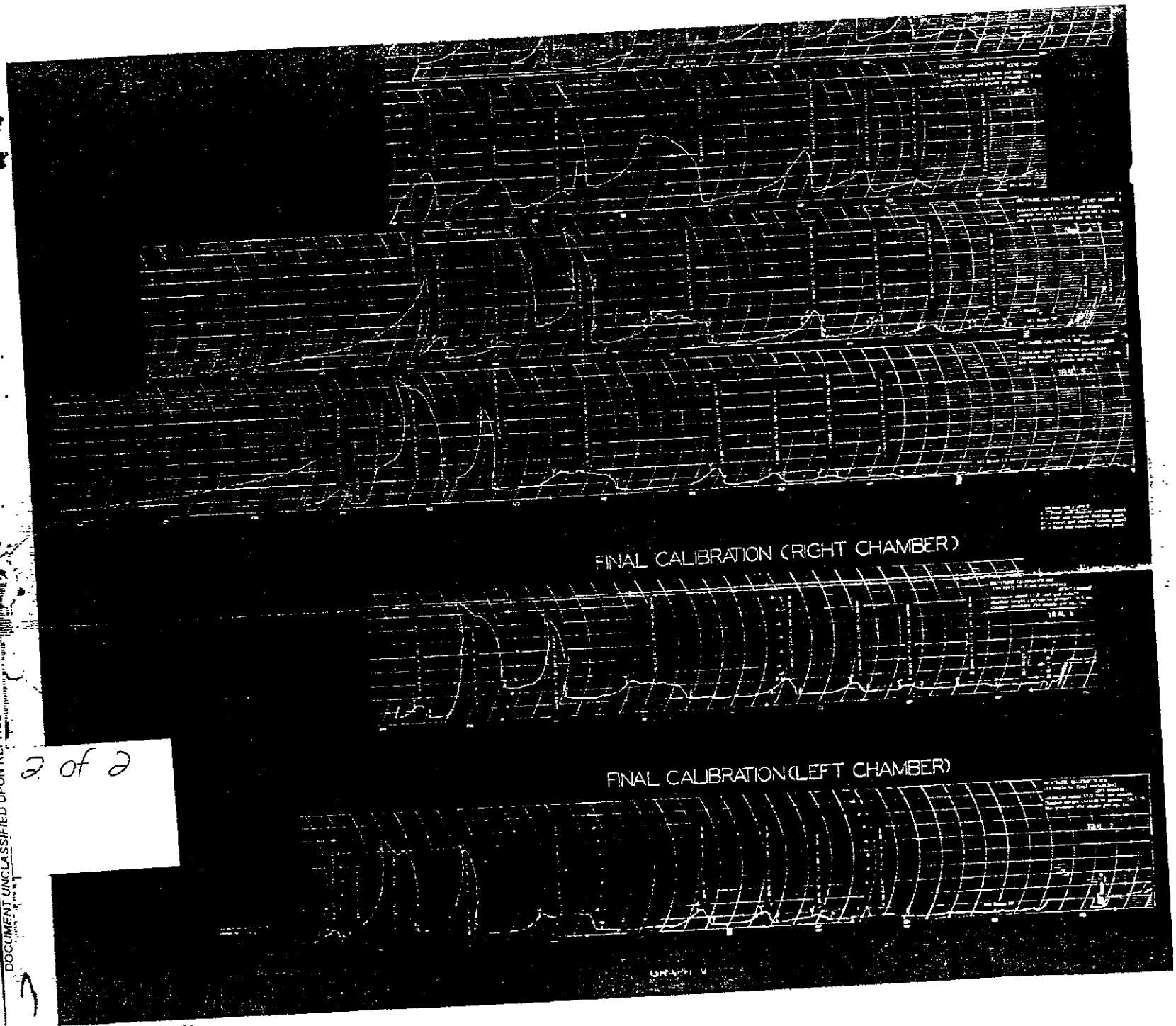
H CONTENT EVALUATION CURVE FOR
COUNTER NO 217

1 of 2

PRELIMINARY SCANNER CALIBRATION CURVES (RGHT CHAMBER)



FINAL CALIBRATION (RIGHT CHAMBER)



FINAL CALIBRATION (RIGHT CHAMBER)

FINAL CALIBRATION (LEFT CHAMBER)

2 of 2

APPENDIX D

RESUME OF METHOD FOR PREPARATION OF RADIOMANGANESE BY NUCLEAR BOMBARDMENT AT M. I. T.

From a letter from Prof. J. W. Irvine, Jr., Assistant Professor of Chemistry, MIT Radioactivity Center, dated August 12, 1944:

For this preparation chromium metal electroplated on a MIT shaking target head is very nearly an ideal target. Mn^{52} is made by (d, 2n) reaction on Cr^{52}. At 14 million volts bombarding energy the (d, 2n) reaction is a highly probable one. The Cr^{52} isotope is approximately 50 per cent abundant. With such heads we are able to bombard with beam currents of from 400 to 500 microamps without burning the target These factors all combine to make possible the high yield and relatively low cost of Mn^{52}.

After bombardment the chromium is dissolved from the target head with concentrated HCl. Twenty milligrams of Mn are added to the solution as a carrier and hydrogen sulfide metals precipitated with H_2S. After boiling to remove the H_2S the Mn is separated from the Cr by repeated treatment with 30 per cent H_2O_2 in a NaOH solution. In this reaction Mn is oxidized to hydrated MnO_2 and the Cr remains in solution as chromate ion. Because of the large amount of Cr and the small amount of Mn it has been impossible to remove all the Cr by single precipitation of MnO_2. To remove the Cr quantitatively requires from 3 to 6 precipitations. Since the activities due to radioactive Cr isotopes are negligible compared with the activity of Mn^{52} no attempt is made to separate the Cr quantitatively but it is simply reduced to a relatively small concentration.

After two precipitations of the Mn from an alkaline solution with H_2O_2 the precipitate is dissolved and an aliquot removed for activity measurements by means of gamma rays. The Mn is then precipitated a third time, filtered, washed thoroughly and shipped to Dugway.

When the Mn was sent in the form of manganese tetrapyridine thiocyanate it was necessary to remove the Cr completely to prevent interference with the precipitation of the above complex compound. This was accomplished by a series of 4 precipitations with sodium hydroxide and hydrogen peroxide.

APPENDIX D

The nuclear properties of Mn^{52} are as follows:

This isotope decays by positron emission (0.582 MEV) in 33 per cent of the disintegrations and by K capture in 67 per cent of the disintegrations. Both modes of disintegration leave the resulting Cr^{52} nucleus in the same excited state. This product nucleus then decays by the cascade emission of 3 gamma rays whose energies are 0.736, 0.94, and 1.46 MEV. The half life for this isotope is 6.5 days. These properties make this isotope a fairly satisfactory one for the type of use to which it is being put.

DPGSR No. 55

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RADIOACTIVE TRACER TECHNIQUES AS APPLIED TO EVALUATION OF MUSTARD GROUND CONTAMINATION

Submitted by:

P. A. Seighton
P. A. LEIGHTON
Colonel, C.W.S.

(Absent)
STEPHEN B. BOGESE
Captain, C.W.S.

(Absent)
PAUL T. MaSLEY
Tec.Sgt., C.W.S.

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Recommending approval:

Luman F. Ney
LUMAN F. NEY
Major, C.W.S.
Director of Technical Operations

Approved:

Grayd. C. Essman
GRAYDON C. ESSMAN
Colonel, C.W.S.
Commanding

CONTROL NUMBER
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RADIOACTIVE TRACER TECHNIQUES AS APPLIED TO EVALUATION OF MUSTARD GROUND CONTAMINATION

Submitted by:

P. A. Leighton
P. A. LEIGHTON
Colonel, C.W.S.

(Absent)
STEPHEN B. BOCESE
Captain, C.W.S.

(Absent)
PAUL T. MASLEY
Tec.Sgt., C.W.S.

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Recommending approval:

Luman F. Ney
LUMAN F. NEY
Major, C.W.S.
Director of Technical Operations

Approved:

Graydon C. Essman
GRAYDON C. ESSMAN
Colonel, C.W.S.
Commanding

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