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ELECTRICAL AND MECHANICAL
ENGINEERING REGULATIONS
(By Command of the Army Council)

TELECOMMUNICATIONS
V 001

GENERAL PRINCIPLES OF RADIAC INSTRUMENTS

Errata

Note: These Pages 0 and 01 will be filed immediately in front of Page 1, Issue 1 dated 5 Oct 54.

1. The following amendments will be made to this Regulation.

2. Page 13, para 55, line 3

Delete: 'Fig 9'
Insert: 'Fig 10'

Delete: 'Fig 10'
Insert: 'Fig 9'

Distribution - Class 800. Code No. 2

Page 13, para 57, line 1

Delete: 'Fig 9'
Insert: 'Fig 10'

Page 14, Fig 9

Delete: Existing caption
Insert: 'Waveforms for cold-cathode count-rate meter circuit'

Page 15, Fig 10

Delete: Existing caption
Insert: 'Cold-cathode count-rate meter circuit'

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GENERAL PRINCIPLES OF RADIAC INSTRUMENTS

INTRODUCTION

1. Because atomic or thermo-nuclear weapons may be used in a future war, a range of instruments is being introduced into the Service for the evaluation of hazards due to radioactivity. These instruments are referred to as RADIAC instruments. RADIAC is a contraction of 'Radiation, detection, identification and computation'.

2. This Regulation deals primarily with those instruments which are to come into general use for evaluating the radiation hazard from an atomic explosion but the principles of more specialised instruments that may be introduced on a limited scale are briefly described.

ATOMIC STRUCTURE

3. A neutral atom of any pure element consists of a nucleus surrounded by electrons. The nucleus is very dense and is made up of protons and neutrons. The number of protons in the nucleus equals the number of electrons which revolve in orbits around the nucleus. This number is the 'atomic number' of the element. The 'atomic weight' of an element is its mass compared with oxygen, assumed to be 16. The integer nearest in value to the atomic weight is called the 'mass number' and for nearly all atoms is equal to the sum of the number of protons and neutrons. It is possible for an element of fixed atomic number to exist in a number of forms known as isotopes, of differing atomic weights but the chemical nature of all isotopes having the same atomic number is identical.

4. A proton is a positively charged particle, of mass slightly less than that of an hydrogen atom which consists of one proton and one electron.

An electron is a negatively charged particle, mass about 1/1840 of that of the proton and charge equal and opposite to that of the proton.

A neutron is a particle with zero charge and mass slightly greater than that of the proton.

NUCLEAR RADIATIONS

5. In general, a particular element may have a number of isotopes, some of which are stable and some of which are unstable, or radioactive. The nucleus of an unstable atom will, at some time, emit radiation and change into an isotope of another element. This process will continue until a stable isotope is formed.

6. Radioactive processes are random in occurrence and the emission of radiation from a particular unstable nucleus is not influenced by other atoms of the same, or different substances, undergoing disintegration nearby. The rate of nuclear disintegration is unaffected by external factors such as pressure or temperature.

7. The number of radioactive atoms of a particular element present in a given isolated sample decreases exponentially with time, ie, the percentage decrease in activity, over a certain fixed interval, is the same wherever the interval is taken. The time taken for this number to decrease to one half of the number originally present is characteristic of a particular isotope and is known as the half-life.

8. There are four types of radiation emitted from the nucleus of an unstable atom which may require to be detected. These are:-

(a) alpha particles

(b) beta particles

(c) gamma radiation

(d) neutrons

Their properties are described below.

Alpha particles

9. Alpha particles are helium nuclei; two protons and two neutrons. The penetrating power of an alpha particle emitted from an unstable nucleus is very limited. Its range will only be 3cm to 9cm in air. The particle has great ionising power; an alpha particle of average energy will produce about 180,000 ion-pairs in air. If an alpha particle strikes a fluorescent screen a minute flash of light (scintillation) can be observed.

Beta particles

10. Beta particles are electrons emitted from an unstable nucleus as the result of the transformation of a neutron to a proton. Beta particles have a range up to several metres in air. Their ionizing power is from 1/10 to 1/100 that of an alpha particle.

Gamma radiation

11. Gamma radiation is electromagnetic radiation of the same nature as light but of much shorter wavelength. However, certain properties of gamma radiation are best explained by assuming that the energy of the radiation is contained in discrete bundles or quanta which are conveniently referred to as photons. The penetrating power of gamma radiation is extremely great, but the ionizing power is relatively small, being of the order of 1/100 that of a beta particle for each photon.

Neutrons

12. A neutron is an uncharged particle with approximately the same mass as a proton. It can be considered as a proton and an electron combined. It does not ionize gases.

DEFINITIONS OF UNITS

13. The Curie. The strength of a radioactive source is measured in Curies (C), millicuries (mC) or microcuries (μC). One Curie is that amount of activity which corresponds to 3.7×10^{10} disintegrations per second.

14. The Rontgen. The total absorption, or dose, of gamma radiation is measured in Rontgens. One Rontgen is that amount of X- or gamma radiation which produces ion-pairs (positive and negative ions) having a total charge of one electrostatic unit in 0.00129 grams of air (ie in 1c/c of air at normal temperature and pressure. One electrostatic unit of charge is equal to $\frac{1}{3 \times 10^9}$ coulomb).

15. The Rontgen-equivalent-physical, (r.e.p.) or the Rontgen-equivalent-man (r.e.m.) is, in effect, the quantity of radiation of any kind which has the same physiological effect as one Rontgen of gamma radiation.

16. The electron volt. The energy of radiation is measured in electron volts (eV) or millions of electron volts (meV). The electron volt is that amount of energy which is possessed by an electron as a result of acceleration by a potential difference of 1 volt.

TYPES OF INSTRUMENTS REQUIRED

17. Service requirements exist for the following classes of instrument or device:-

(a) Devices for measuring the total gamma radiation dose received by personnel from the gamma flash which occurs at the time of burst of an atomic weapon. (Flash dosimeters).

(b) Instruments for measuring the total gamma radiation dose received by personnel who have to work in a contaminated area. (Dosimeters).

(c) Instruments for measuring the beta and gamma radiation intensity in a contaminated area. (Dose-rate meters or Survey meters).

(d) Instruments for detecting and measuring radioactive contamination of personnel, clothing and equipment, food and water. (Contamination meters).

(e) Instruments, suitable for training, when the use of the operational instrument would necessitate exposing the user to an unacceptable level of radiation.

It is possible that the instruments being developed for requirement (b) will also meet requirement (a).

18. Specialised requirements also exist for instruments to detect neutrons and alpha particles. A range of ancillary test and calibration equipment for the various radiac instruments is also being introduced.

MEASUREMENT OF NUCLEAR RADIATION

19. Nuclear radiation is detected and measured by its ionizing effect on matter and usually by its ionizing effect on a gas. Devices for detecting radiation by this means are called ionization chambers or counters. These devices are described in paras 20-25 and their application to the detection of particular particles in paras 26-34.

Ionization chamber

20. A schematic diagram of the fundamental circuit for measurement of ionization in gases is shown in Fig 1. X is a chamber containing a gas which is ionized by the passage of radiation. C1 includes the distributed capacity of the system. A potential difference is applied between the plates of the chamber through R1. If this potential difference is large enough, all the positive ions liberated will move to the negative electrode and the negative ions move to the positive electrode. Hence the reduction in charge on the electrodes produces a voltage pulse across the resistance, R2, which may be detected electronically.

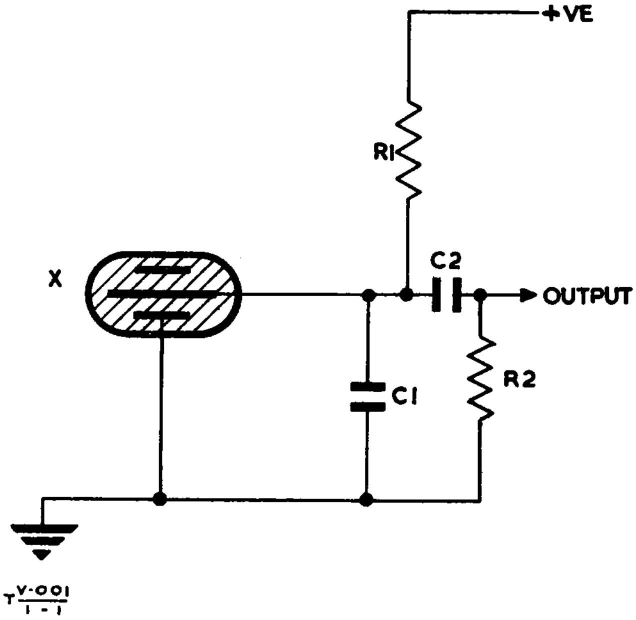

Fig 1 - Basic counter circuit

21. Assuming that the chamber is filled with air and that the potential applied to the chamber is sufficient to collect all the ions formed but does not accelerate any of them to a sufficient extent to cause secondary ionization, the current that will flow in R2, due to a particular continuous gamma ray dose rate, can be calculated.

By definition, 1 Rontgen produces 1 e.s.u. in 1cc of air

Therefore R Rontgens per hour would produce

VR e.s.u. per hour in Vcc of air

ie $\frac{VR}{3.6 \times 10^3}$ e.s.u. per sec in Vcc of air

ie $\frac{VR}{3.6 \times 10^3 \times 3 \times 10^9}$ coulomb per sec in Vcc of air

ie $\frac{VR}{10.8}$ µµA

For a chamber volume of 200cc this represents a current of 18.5µµA for a dose rate of one R/hr. A current of this order can only be measured in a portable instrument by the use of very large resistors and an electrometer valve and even then is approaching the lower limit for practicable measurements. It is evident that a more sensitive counter is required for the lower dose rates which have to be measured.

Proportional counter

22. A more sensitive device can be obtained by replacing the positive electrode of the ionization chamber by a wire (to increase the potential gradient in the vicinity of the wire) and increasing the applied potential. The electrons formed in each

initial ionizing event are now accelerated sufficiently to cause further ionization by collision. (Fig 2) The total ionization is proportional to the number of ions formed initially and the voltage drop produced is equal to that which would be produced by operation as a simple ion chamber multiplied by a factor known as the gas amplification factor. The gas amplification factor may vary from 1 to 10,000 but is constant for a range of applied potentials. A counter operating in this region is called a proportional counter.

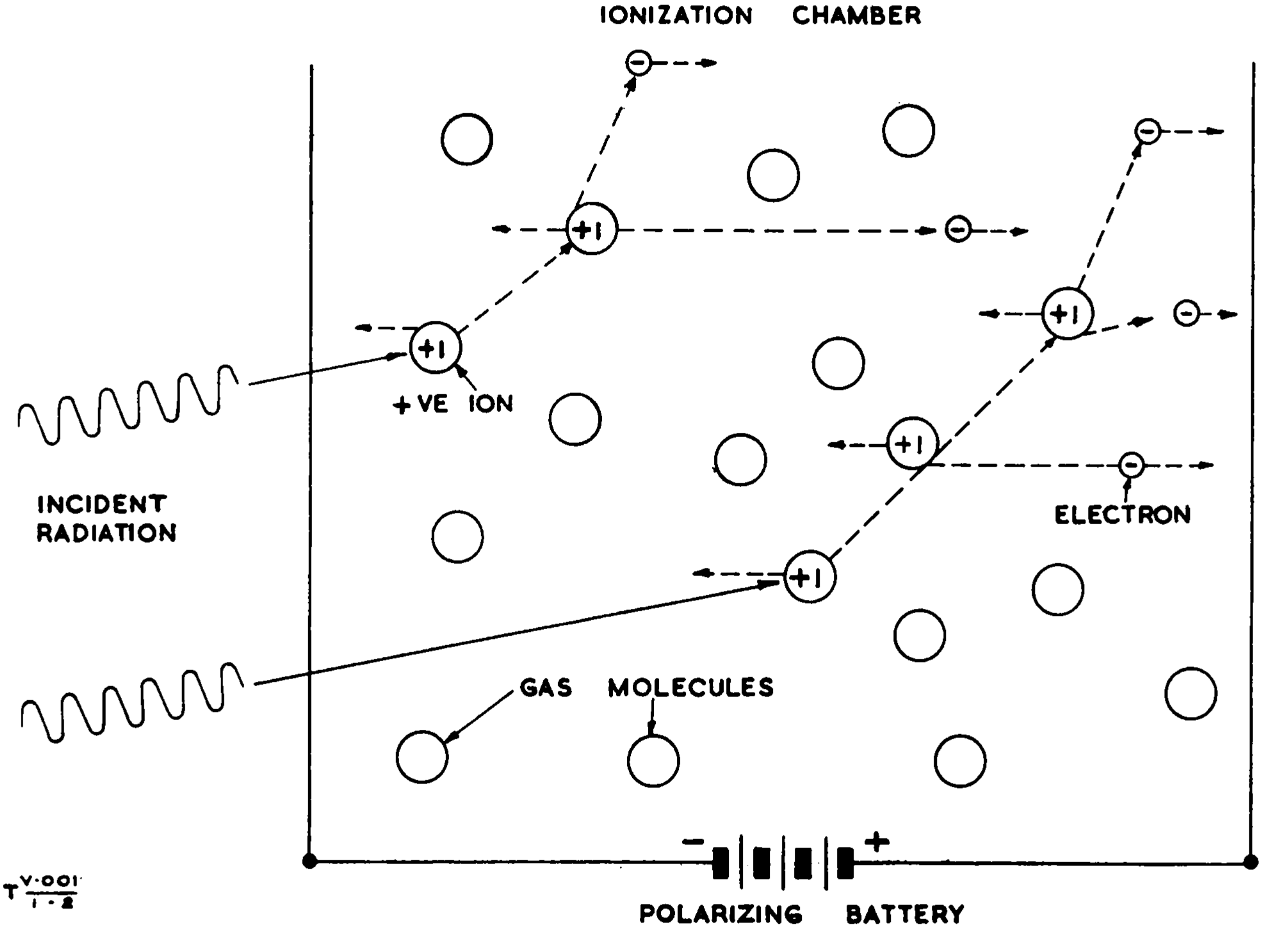

Fig 2 - Multiple ionization

23. As the applied potential is increased still further, a region of limited proportionality is entered in which the size of the larger current pulses, due to each particle or proton, becomes constant although smaller pulses still receive proportional gas amplification. With further increases of applied potential the Geiger threshold is approached at which the amplitude of all the amplified pulses is constant. The effects of increasing the applied potential are shown in Fig 3, in which curve, A, corresponds to the arrival of a beta particle and curve, B, to an alpha particle.

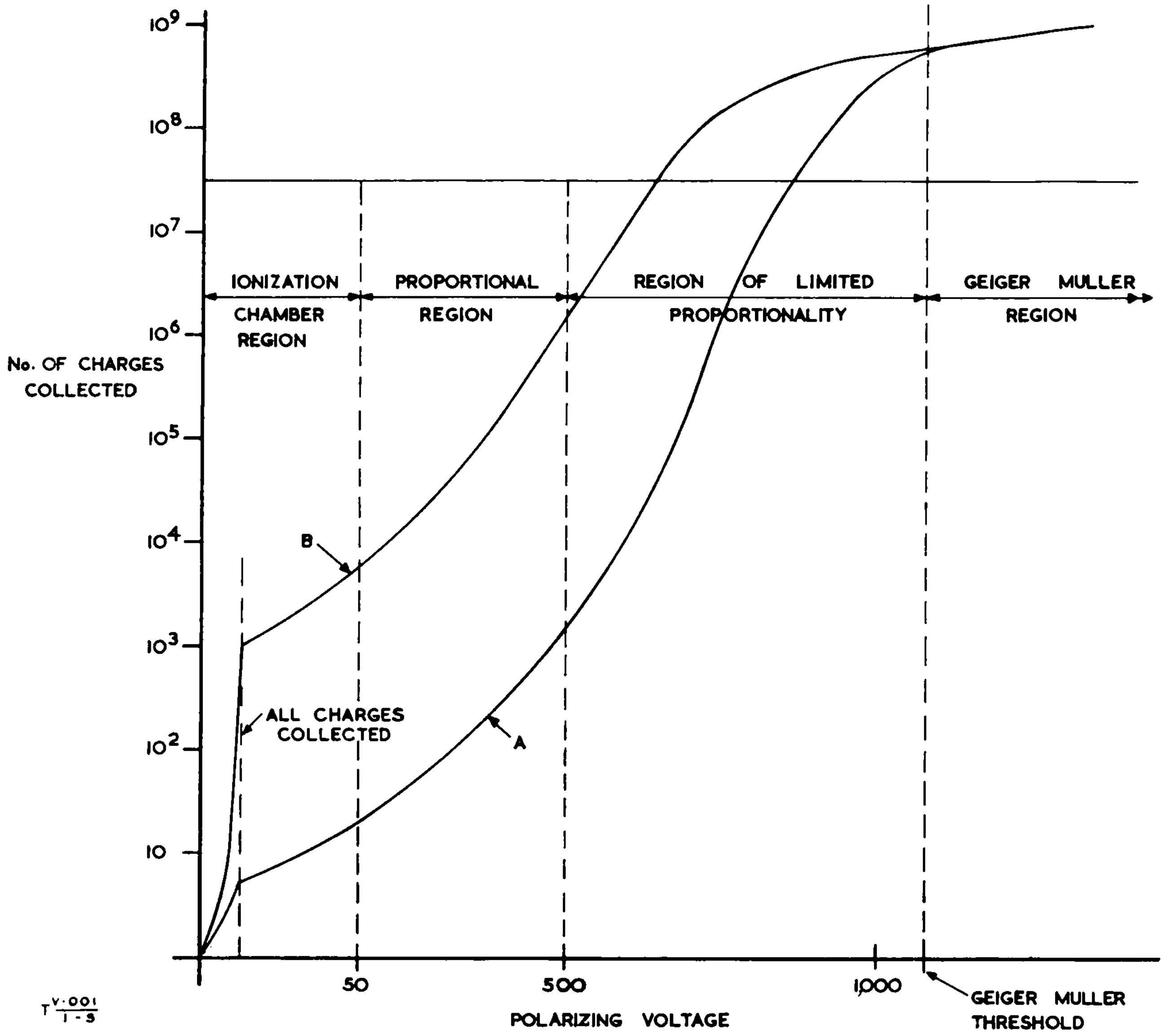

Fig 3 - Effect of increasing polarising voltage

Geiger counter

24. In the Geiger region the avalanche of electrons increases as it approaches the anode until it is limited by the positive ion space-charge. The result is that the pulse output produced from an initial single ion-pair is the same as that from a large number of ions formed simultaneously. The output pulse amplitude does however, depend on the applied potential, becoming larger as the potential is increased, until the counter breaks into continuous discharge due to the occurrence of multiple pulses. The characteristic curve of a Geiger counter is shown in Fig 4. The operating potential is usually in the middle of the flat plateau about 100V above the threshold voltage

25. The output pulse from a Geiger counter has a sharp initial rise, due to the collection of the fast moving electrons, followed by a longer period of recovery whilst the positive ions are collected, which may be about 100μseconds. The time taken for the discharge to cease is very important and is usually made as short as possible. Further details and methods of terminating or quenching the discharge are given in para 46-49.

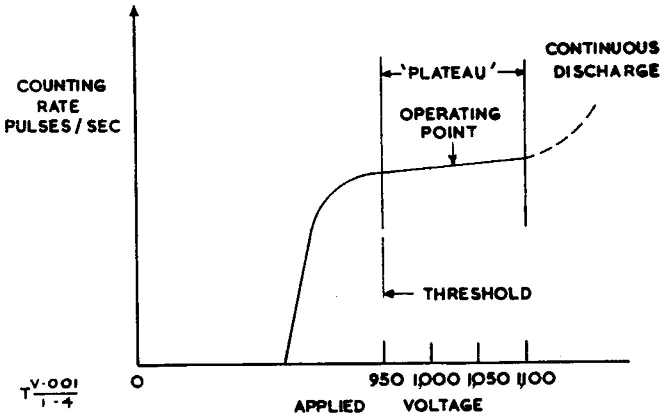

Fig 4 - Geiger counter characteristic

Detection of alpha particles

26. The detection of alpha particles is rendered difficult in practice by their very short range in air. This necessitates the counter being placed very close to the source of activity and makes it almost impossible to use a window of some thin material, as can be used in a beta particle counter.

27. Proportional counters, operating in air have been used in non-portable equipment for alpha particle detection but it is likely that scintillation counters will be used for many applications, in the future.

28. In a scintillation counter, the particles are allowed to strike a fluorescent screen and the resultant light-scintillations are concentrated on to the cathode of a photo-multiplier tube by a suitable optical system. The output from the photo-multiplier is fed to a suitable counting or recording circuit.

Detection of neutrons

29. As neutrons carry no charge, they cannot be detected except by observing their effect on matter. A method of measuring neutron fluxes which has been used in a portable instrument is to allow the meutrons to strike a boron compound, when alpha particles are liberated. The number of alpha particles liberated is proportional to the neutron flux.

30. A boron counter is usually a cylindrical counter of the proportional kind filled with boron trifluoride gas and argon. The two electrodes of the proportional counter are sealed in the cylinder. Boron trifluoride is a highly corrosive compound and suitable materials must be used, especially for the cathode. Another type of counter is being developed in which solid boron is deposited on the inside of the cylinder.

Detection of beta and gamma radiation

31. The remainder of this Regulation is concerned with techniques for the detection and measurement of beta and gamma radiation. An assessment of radiation hazards resulting from the use of atomic weapons can normally be made by measurements of beta and gamma radiation intensities and in some cases by a measurement of the gamma intensity only. The instruments which are to be introduced into the Service have facilities for one or both of these measurements. Instruments for the detection and measurements of alpha particles and neutrons are required for specialised purposes only and will not be dealt with further.

32. Instruments for the measurement of beta and gamma radiation normally use either ionization chambers or Geiger counters. The more sensitive instruments usually employ Geiger counters.

33. Instruments for the measurement of beta radiation must, obviously, offer as little obstruction as possible to the entry of beta particles. A Geiger counter tube for beta particle detection must have a very thin glass wall and ionization chambers must have a thin window. Thicknesses corresponding to a weight of about $10mg/cm^2$ are required to avoid serious losses in practice. Some instruments are provided with windows which can be covered by a thicker panel; gamma radiation only, is measured with the window closed and the total beta and gamma radiation with the window open.

34. When a Geiger counter is used for the detection of gamma radiation, the discharge is started by beta particles liberated from the walls of the counter.

INSTRUMENTS USING IONIZATION CHAMBERS

Typical survey meter

35. The ionization chamber used in a typical survey meter consists of a box with a volume of about 200cc, filled with air at atmospheric pressure. In order to avoid end effects, the walls of the chamber must be made of a material having a mean atomic number similar to that of air. A plastic loaded with graphite to make it conducting is usually used.

36. The collector electrode, which consists of a metal rod or hoop, is located in the centre of the chamber by a high grade insulator. The leakage resistance of this insulator must be high compared with the grid resistor of the electrometer valve used to measure the current from the chamber; this resistor may be 10^{11} ohms. The insulator is often fitted with a guard ring to divert any leakage current out of the measuring circuit.

37. A special high resistance test set is being introduced into the Service to measure the leakage resistance of the insulators used in this type of instrument. This test set will be able to measure resistance up to 10^{13} ohms directly. Care will have to be taken in servicing these instruments that the insulators do not deteriorate on account of dirt or damp. Grease deposited on any of the grid circuit components by handling them must be removed by a suitable solvent.

38. The small currents produced by ionization chambers are normally measured in portable instruments by connecting a high resistance across the chamber and including this resistance in the grid circuit of an electrometer valve. A simplified circuit of a typical survey meter is shown in Fig 5. This instrument has a single range, 0 - 3 Rontgens per hour.

39. Referring to Fig 5, a microammeter, M1, calibrated directly in dose-rate is connected in the anode circuit of the electrometer valve, V1. The standing current through V1 is backed off by a current from the filament cell, BY3, adjusted by RV1, while the input resistor, R1, is short-circuited by SWA.

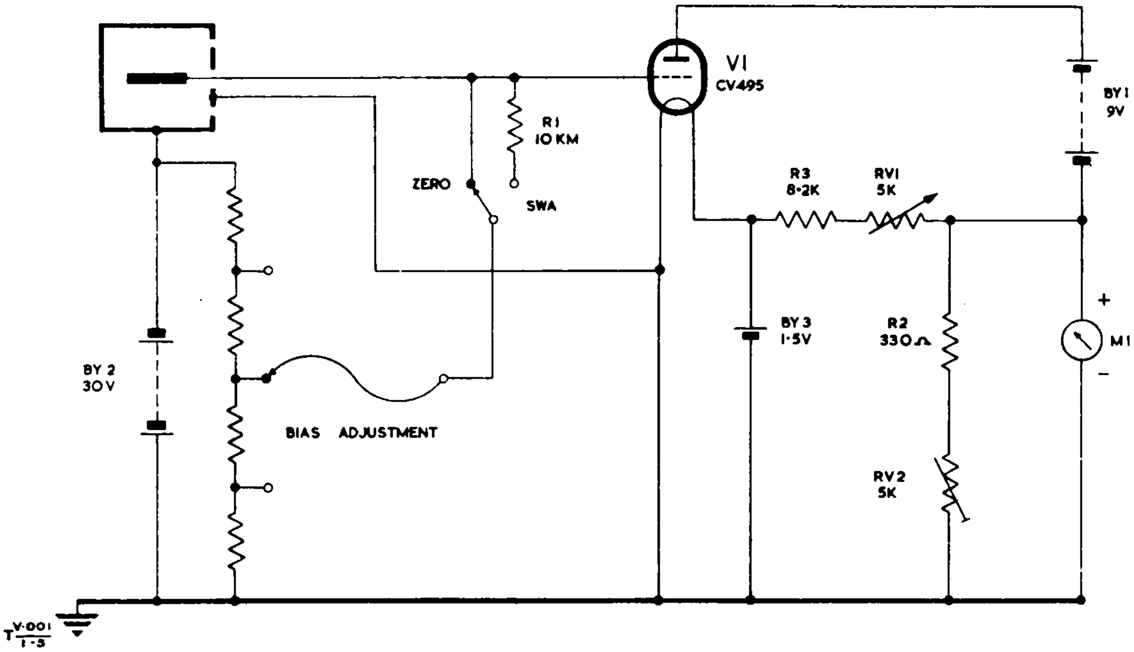

Fig 5 - Simplified circuit of typical survey meter

40. When ionization is produced in the chamber by external radiation, the negative ions are driven to the collecting electrode by the polarising voltage from BY2 and the resultant current flowing through R1 causes the grid potential to fall. The anode current therefore falls and the backing-off current remaining constant, a reading proportional to the dose rate appears on M1.

41. An on-off switch, (not shown) SWA and RV1 are operated by knobs on the outside of the instrument. A calibration adjustment, RV2, is provided and can be adjusted after removal of a protective cover. In view of the importance of maintaining a high degree of insulation in the grid circuit, the instrument is contained in a sealed case, which is fitted with a desiccator. The batteries are housed in a separate compartment, so that the instrument does not have to be unsealed for battery replacement.

Quartz fibre dosimeters

42. A special type of instrument which employs an ionisation chamber is the quartz fibre dosimeter. These instruments are being provided to measure the gamma radiation dose received by personnel. They are about the size of a fountain pen and are intended to be carried in the pocket. A schematic diagram of the instrument is given in Fig 6.

43. The whole instrument is contained in a light alloy tube. An insulator mounted in the tube supports a looped nickel-copper wire to which is attached a quartz fibre. This fibre is fixed at either end, but is otherwise free to move. The upper part of the tube contains an optical system, by means of which the position of the fibre can be viewed against a scale calibrated in Rontgens. The lower part of the tube contains a plunger mechanism which, on being pushed in, enables connection to be made to the nickel wire for charging the fibre.

44. The instrument is charged by applying a potential difference of 150-200V between the fibre and the tube. The quartz fibre is repelled from the tube, acting as the movable leaf of an electroscope. It will gradually collapse towards the loop as the potential falls. This fall will occur when the air in the chamber becomes conducting due to the ionisation caused by the passage of radiation. Instruments of various sensitivities can be produced by altering the capacities of the system. Instruments with full-scale deflections from 0.5 Rontgen to 500 Rontgen have been made or are under development.

45. These instruments are completely sealed and repairs in service workshops will not be practicable but the serviceability of the instrument can be simply checked.

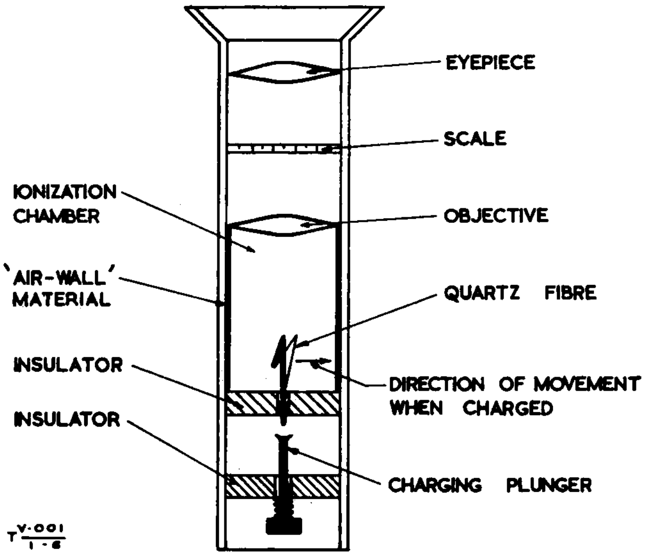

Fig 6 - Schematic diagram of quartz fibre dosimeter

INSTRUMENTS USING GEIGER COUNTERS

General

46. A Geiger counter in its usual form consists of a cylindrical sealed tube of a conducting material, or with a conducting coating, which is earthed, along the axis of which is suspended an insulated, positively charged, fine-wire electrode. The tube is usually filled with an inert gas at a low pressure.

47. During the period of recovery which occurs after the sudden initial change of potential (see para 25) in a discharge, several things may be happening. The positive ions liberated in the discharge move relatively slowly towards the cathode. When these have moved far enough for the field in the counter to be restored to its original form, a further Geiger discharge can occur. However, when the positive ions are neutralised by electrons from the cathode, ultra-violet radiation will be produced which may in its turn liberate an electron from the counter wall and thus initiate a secondary discharge. This process could continue indefinitely. Such a continuous discharge can be stopped either by preventing the production of secondary

electrons or by lowering the potential on the central wire long enough for all the positive ions to be neutralised and the emission of secondary electrons to cease.

48. If a resistor is placed in series with the supply to the counter, (R1, in Fig 1), the potential across the counter will fall during the period of discharge. If the resistor is large enough, the fall in potential will be sufficient to stop the discharge. This method of quenching has two limitations:-

(a) If the resistance is too large, the recovery time will be increased, due to the value of the time-constant of the resistor together with the distributed capacity of the system.

(b) If the resistor is too small, the length of the plateau of the characteristic curve, which can be used (see para 24) will be reduced. (If the potential drop across the resistor is small, the maximum working potential at which quenching is still effective and the counter is operating under Geiger conditions will be restricted).

Because of the difficulty of choosing a suitable value of resistor, the potential of the cathode is sometimes reduced automatically, by a suitable circuit, after each discharge.

49. A simpler method of quenching the discharge is to add a small quantity of a polyatomic organic vapour to the filling. The photons liberated when the positive ions are neutralised at the cathode are absorbed by the polyatomic vapour, which dissociates. Such a counter is called self-quenched. Its life will be limited by excessive decomposition of the added vapour, and may be of the order of 10^8 counts.

Power supplies for Geiger counters

50. A Geiger counter tube requires a power supply of a few microamps at several hundred volts. In a portable instrument this is often obtained from a valve oscillator feeding a voltage-multiplying rectifier system.

Counting circuits

51. A large number of counting and indicating circuits have been developed for use in instruments employing Geiger counters. Three such circuits are explained below. The indicating meter in these circuits can be calibrated in counts per second, but if a calibration in dose-rate is required an assumption must be made as to the energy of the radiation being monitored. This can be done for the radioactive products of an atomic explosion and instruments using Geiger counters are normally calibrated directly in dose-rates.

52. A simple count-rate meter circuit is shown in Fig 7. Pulses from the Geiger counter are fed to the grid of the amplifier valve, V1. The pulse appearing at the anode of V1 may overshoot slightly. Any overshoot is removed by the rectifier, MR1, before the pulse is fed to an integrating circuit consisting of C5 and either R6 and RV1 or R7 and RV2, depending on the range in use. The voltage across C5, which will be proportional to the rate of arrival of pulses, is then fed to a valve-voltmeter. RV1 and RV2 are pre-set calibration adjustments for the two ranges provided.

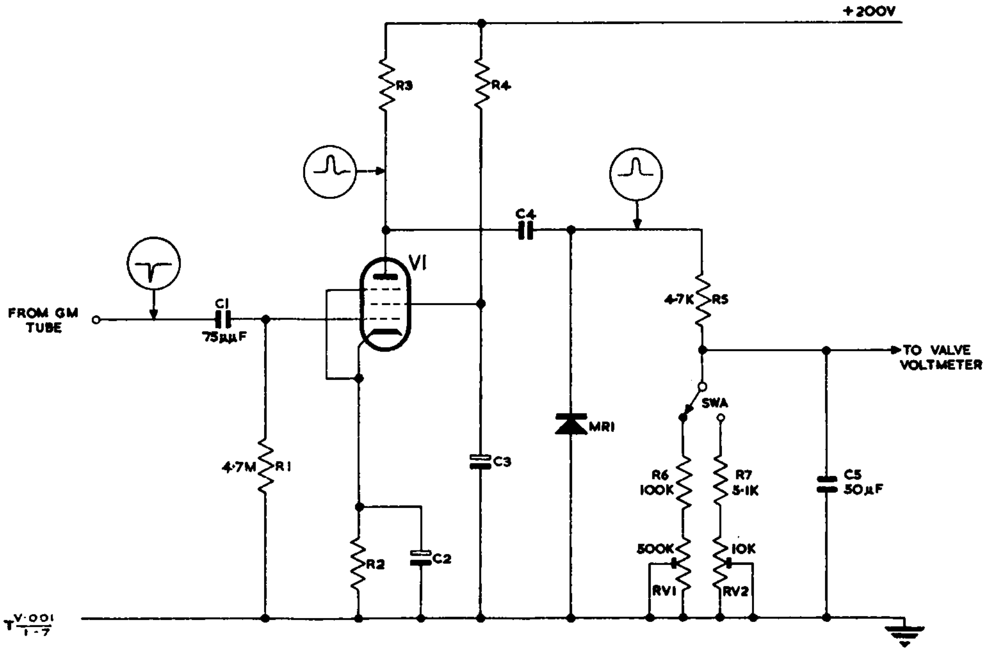

Fig 7 - Simple count-rate meter circuit

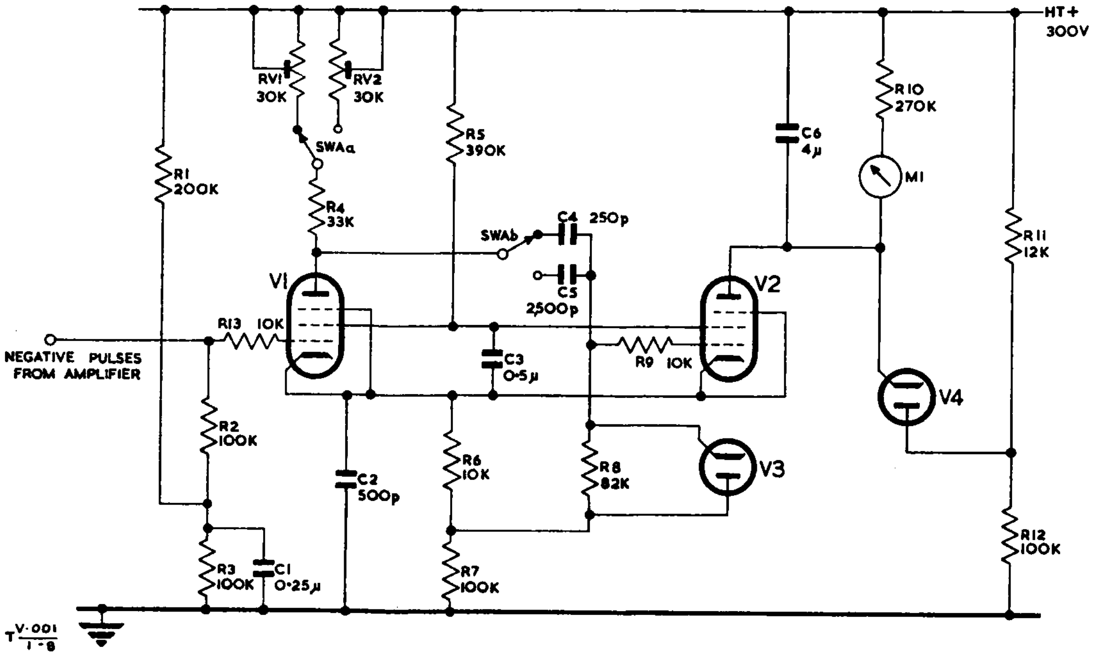

Fig 8 - Trigger count-rate meter circuit

53. A more accurate circuit is shown in Fig 8. This is a cathode-coupled flip-flop circuit and has the advantage over the more usual valve-voltmeter circuit in that it has a very small intrinsic drift and does not require re-setting between ranges. If accurate work is being done, allowance must be made for the paralysis time of the circuit by suitable statistical methods.

54. When a negative pulse arrives from the Geiger counter via an amplifying stage, V1 is cut-off, V2 starts to conduct and passes a current pulse before the circuit returns, after a time determined by the time-constant of the coupling circuit, to its stable state. The pulses are integrated by R10 and C6 and the resultant voltage is read on M1, which can be calibrated in counts per second. Range selection is carried out by switching the coupling condensers and a separate pre-set calibration control is provided for each range. The meter is protected from overloads by diode, V4.

55. In a battery-operated portable instrument the use of cold-cathode valves gives a large saving in battery consumption. A count-rate measuring circuit using such valves is shown in Fig ~~9~~ 10 and explanatory waveforms are shown in Fig ~~10~~ 9.

56. The cold-cathode valve, V1, possesses the characteristic of presenting a high impedance between its anode and cathode until an input pulse causes a discharge. When a discharge takes place the valve becomes a constant-voltage element with a definite voltage drop of about 90 volts between anode and cathode. This state continues until the valve can no longer draw sufficient current from the circuit to maintain the discharge, when it quenches and the valve again presents a high impedance between anode and cathode.

57. In the circuit in Fig ~~9~~ 10, the initial conditions are as follows:-

(a) The anode voltage (waveform at C) is equal to the H.T.voltage minus the voltage Vm across the metering circuit.

(b) The trigger electrode of V1 passes a small corona current to the auxiliary cathode and then, via R5, to earth. The size of this current is determined by R2. This current primes the valve, ready for any incoming pulse and maintains the voltage between the grid and auxiliary cathode just below that at which striking occurs.

When a discharge occurs in the counter, X1, due to the arrival of a particle, a negative pulse is fed via C4 to the auxiliary cathode (waveform at B) and the valve strikes, the trigger electrode potential being held steady by C2. The anode voltage falls and C3 is charged up. C1 is larger than C3, so that the voltage fluctuation at E is relatively small. When C3 is fully charged, the only current available to maintain the discharge is that through R4 and this being insufficient, the valve becomes non-conducting and C3 discharges through R4.

58. Each time a pulse arrives from X1, C3 is charged to a defined voltage and therefore, a definite charge flows through the meter circuit. These pulses are integrated by the long time-constant, C1, R1 and a reasonably steady meter reading is produced. C2 is connected between the trigger electrode and anode rather than between the trigger electrode and earth so that the anode voltage, as it recovers after each discharge, forces the grid voltage back to its initial value, so preventing the circuit from being paralysed for a period as a result of the long time-constant in the grid circuit.

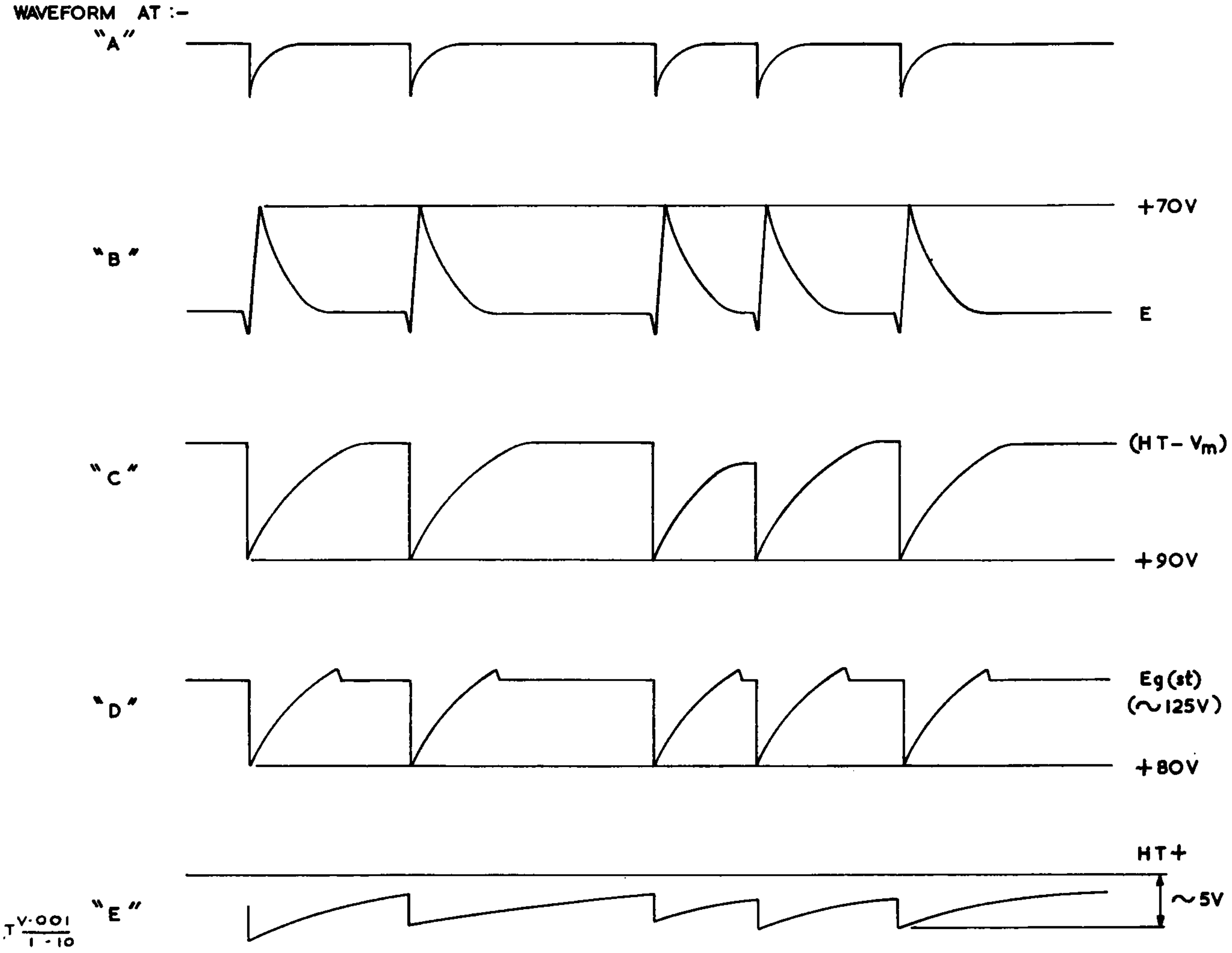

Fig 9 - Waveforms for Cold-cathode count-rate meter circuit

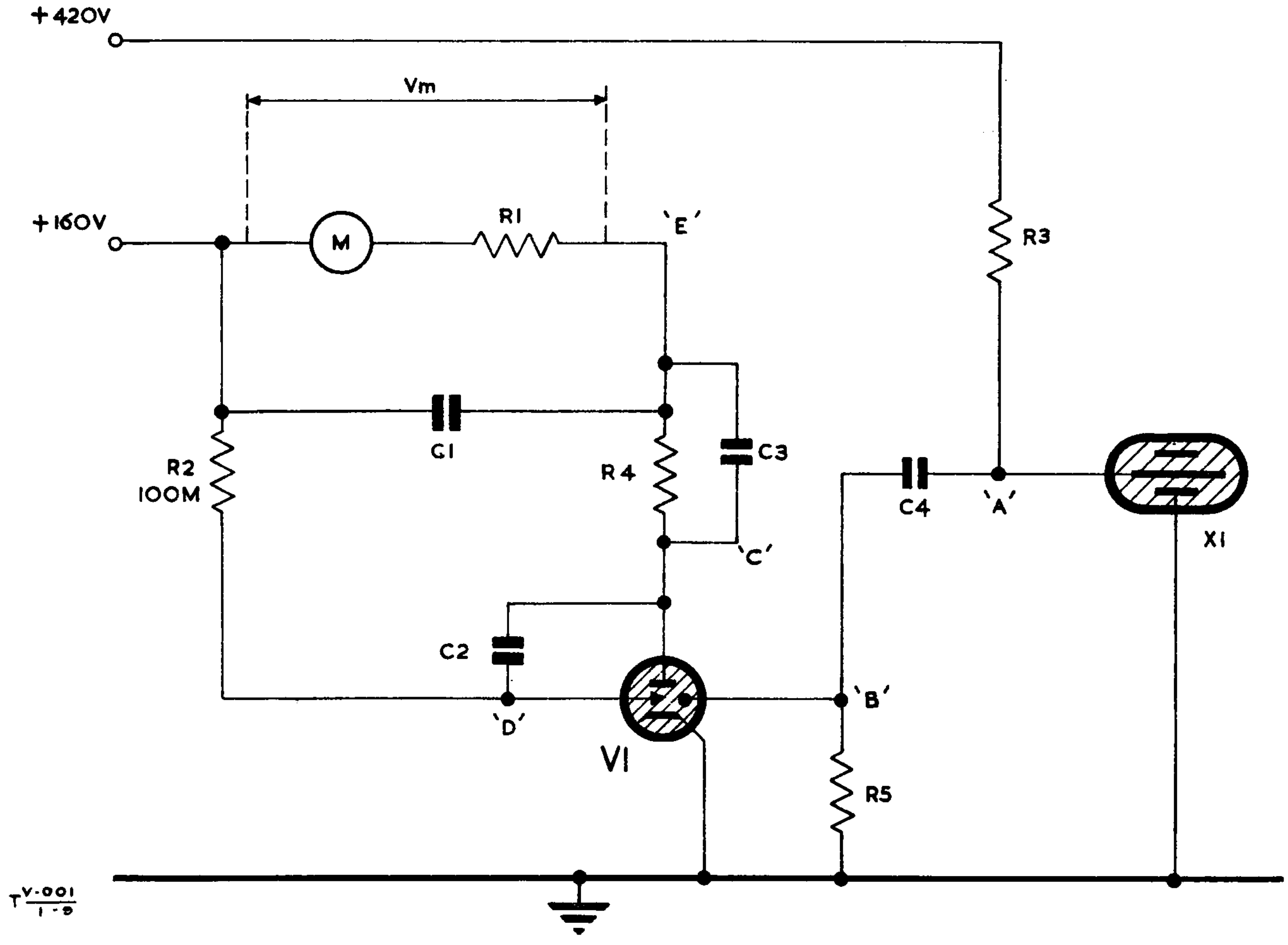

Fig .10 - ~~Waveforms for cold-cathode count-rate meter circuit~~
Cold-cathode count-rate meter circuit

RADIOACTIVE SOURCES

59. A range of radioactive sources is being introduced into the Service for use in training personnel in the operation of radiac instruments and for the calibration of these instruments. When these sources are held in units or depots precautions have to be taken to eliminate possible radiation hazards to personnel. The precautions are at present laid down in ACI 109/54, for training sources held by units and in Gen K 010 for bulk storage of sources.

60. Dose-rate and contamination meters are normally calibrated by setting up the counter of the instrument at a known distance from a source of known strength and adjusting the instrument until the reading shown corresponds with the calculated dose-rate. Some instruments have a built-in source of beta particles and arrangements are made to move the source in front of the window of the ionization chamber when calibration is to be checked. However, the usual arrangement is to provide a separate jig to locate the source and the instrument. When a millicurie source is required the jig is so constructed that it can be used to screen the source when it is not in use.

61. Sources used for calibration of instruments are usually of cobalt 60 (a radioactive isotope of cobalt which emits both beta and gamma radiation, the beta radiation not penetrating the source holder). The sources which are built-in to some instruments for calibration are of a material which emits beta particles only and strontium 90 is usually used for this purpose. Very small radium sources are also used for special purposes.

62. The dose-rate, R, in Rontgens per hour, at a distance dcm from a source is given by the formula:-

$$R = \frac{kW}{d^2}$$

where W is the strength of the source in millicuries and k is a constant, having the value 8.4 for radium and 13.0 for cobalt 60.

63. The half-life of cobalt 60 is 5.3 years. The strength, WT, of such a source after time T years is given by:-

$$W_T = \frac{Wo}{1.14^T}$$

where Wo is the original strength of the source. Cobalt 60 sources are supplied with a plate showing the date of calibration. The half-life of strontium 90 is 19.9 years; the decay of radium sources can be neglected because the half-life of radium is thousands of years.

REFERENCES

64. Further information on aspects of the techniques used for the detection and measurement of radioactivity may be found in the following publications:-

Electrical Counting by W.B. Lewis (Cambridge University Press)
The Measurement of Radioactivity by D.Taylor (Methuen)

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END