ROUTINE FALLOUT SURVEILLANCE

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The Creation and Atmospheric Transport of Fallout Materials

Before embarking on a description of Australia's network of fallout monitoring stations and the types of fallout measured, I shall give a brief account of how radioactive debris from a nuclear explosion is injected into the atmosphere and how it finds its way into the Australian environment. The direction that radioactive fallout takes following an explosion and the pattern of its deposit depends upon many factors including the location of the explosion site, the season of the year and the local weather pattern at the time of detonation. Because of our familiarity with the results we shall consider an atmospheric explosion at Mururoa in Polynesia during the late winter or early spring months.

Table 1 shows the typical dimensions of a debris cloud formed immediately after nuclear explosions of various yields - the so-called "mushroom cloud". As far as the fate of the fallout is concerned, the vertical dimension of the cloud is the important parameter. Figure 1(a) shows a typical debris cloud from a 50 kiloton nuclear explosion at Mururoa superimposed on a model of the atmosphere. The upper and lower tropopauses are invisible barriers above which the air is usually very stable and below which there is considerable vertical turbulance; there is only a slow migration of air and airborne material between these two regions across a tropopause barrier. Thus any debris forcibly injected above the tropopause by the power of the explosion will tend to remain there for months or years; debris remaining below the tropopause would be deposited on the ground in a matter of a few weeks by turbulence and precipitation mechanisms i.e. rainfall and snowfall. Hence fallout from explosions of less than 100 kiloton would be deposited quickly. Bearing in mind that more than half of the radioactive material is contained in the upper third of a debris cloud, most of the radioactive material from explosions of more than 1 megaton would be placed in the stable area above the upper tropopause and only filter slowly back into the lower atmosphere from where it would be deposited relatively quickly.

Most of the debris cloud from a 50 kiloton explosion would be carried eastwards by the prevailing winds at speeds which vary with altitude as indicated in Fig. 1(b), and, by the time it had circumnavigated the earth, the debris would have spread laterally to cover most of the latitudes of Australia. The time taken for the first fallout to reach Australia by this route would be 10-14 days and is illustrated by trajectory (a) in Fig. 1(c). Debris in the stem of the mushroom cloud could be carried in any direction by the lighter winds blowing at that altitude at the time of the explosion. Surface winds which would carry the fallout westwards to Australia are rare but even if such a trajectory was followed, it is comforting for us to note that the time taken would be similar to that for the higher altitude debris to reach Australia by the round-the-world route and that there would be considerable radioactive decay of the material in the meantime.

Radioactive debris in the lower atmosphere is subject to all of the vertical and horizontal movements characteristic of atmospheric air masses; some debris is deposited as 'dry' fallout by this mechanism. However, a far greater amount of fallout occurs when the radioactive particles form nuclei for raindrops (and snowflakes in colder climates) and arrive on the ground as rainfall or 'wet' fallout. Having reached the ground, fallout can follow a large number of environmental pathways, some of which result in ingestion by man. Radioactive material can contaminate leafy vegetables externally or be taken up from the soil by the plant roots; the vegetation can then be eaten by either man or animals. If eaten by animals it can be transferred to man via meat or dairy products. Man may also ingest fallout through drinking contaminated water or eating fish. Identification of the various pathways of fallout materials to man and the characteristics governing the rates of transfer through man's environment has been a major research study for many years throughout the world and has included contributions from Australia.

Australia's Monitoring Program

Australia's fallout monitoring program is made up of three parts. Firstly, there is a continuous surveillance of ground level air for the detection of any fresh fission products. This would give us our first indication of the arrival of any fresh fallout over Australia. Secondly, there is a program to measure fresh fission products in other environmental samples. This program is only 'switched on' when the arrival of fresh fallout is anticipated from a known nuclear explosion or if fresh fission products are detected by the ground level air surveillance program, and continues only as long as the fallout is being detected in sufficient quantities to be of interest from the scientific or health point-of-view. The third part of Australia's fallout monitoring program is a continuing one designed to measure selected long-lived fission products in environmental samples. The types of sample collected vary from time to time depending upon the activities being deposited and upon information required to build up a model of transfer mechanisms from one environmental type to another.

This monitoring program was introduced in 1957 by the Atomic Weapons Tests Safety Committee. The environmental samples have been radiochemically analysed and the data processed by the Australian Radiation Laboratory. The Committee operated in a management role until 1973 when all functions were taken over and continued by the Laboratory. The Australian Ionising Radiation Advisory Council has, in recent years, maintained an overview of the program and the results produced by it.

Air Sampling Program

For the air sampling program, samplers are operated by Bureau of Meteorology officials on behalf of the Australian Radiation Laboratory at six locations around the Australian coast-line viz. Perth, Adelaide, Melbourne, Sydney, Brisbane and Townsville. Each sampler consists basically of a one horse-power electric motor, a rotary blower and a sampling head mounted on a metal frame. Air is sucked through a special polystyrene fibre filter 14 cm in diameter which collects over 99 per cent of particulate matter in the airstream. The sampler operates continuously and in the week between filter changes, approximately 8000 cubic metres of air are sampled. The filters are sent to the Australian Radiation Laboratory where filters from all six stations are monitored together for the presence of gamma-emitting radionuclides using a large lithium-drifted germanium detector inside a low-level shield.

This measurement is very sensitive and activities of the order of a few microbecquerels per cubic metre (or 10^{-16} curies per cubic metre) are detectable. If fresh fission products are detected, the filters are then measured individually to determine at which sampling stations the fallout is present and consideration given to initiating the second part of the sampling program if this has not already been done on advance information received from other sources. In the absence of fresh fission products these measurements provide information of purely scientific interest from the activities of long-lived artificial and natural radionuclides present on the filters.

Short-lived Radionuclide Monitoring Program

This program is initiated when information gained from a variety of possible sources indicates the likelihood that short-lived fission products will be detectable in the environment other than by the ultra-sensitive air sampling program. The program then continues for as long as useful information is obtainable. The information obtained serves two purposes - it allows a determination to be made of any health hazards arising from the fallout and it provides scientific information about fallout material and its pathways through the environment. The program entails:

a. collecting fallout deposited in precipitation or as 'dry fallout' at the twenty-five locations throughout Australia shown in Fig. 2;

b. analysing for iodine-131, liquid milk collected daily at the nine major milk-processing plants throughout Australia also shown in Figure 2;

c. changing and analysing air filters twice per week instead of the usual once per week.

The aims of the program to monitor fallout deposit are:

a. to give, for the country-wide network of monitoring stations, a day-to-day indication of changes in the level of fresh fission products in fallout, and

b. to provide a basis for estimating external radiation doses from the fallout to populations living in the centres being monitored.

Fallout deposit has, in the past, been collected on 30 cm diameter adhesive discs exposed at a height of 1.2 metres above the ground at twenty-five locations. Other than for one collector which is looked after by the local postmaster, the Bureau of Meteorology carries out the field-work for the Laboratory. Each disc is replaced daily and the exposed disc forwarded promptly to the Australian Radiation Laboratory for analysis. The discs are ashed to produce small standard-sized samples and after a short delay to allow for the decay of natural radionuclides, the samples are measured on sensitive, low-background beta counters.

The adhesive disc method of collecting fallout deposit is simple and cheap. The results are sufficiently accurate to meet the requirements outlined above but inaccuracies do occur due to incomplete collection in heavy storms. There are also uncertainties in translating the total beta-activity measured on a disc to the gamma dose-rate due to fallout received by a person living in the environment in which the disc was exposed. These inaccuracies can be reduced by using a more elaborate and expensive collector employing ion exchange resin and the gamma radiation counters which are now more readily available. Such a system is likely to be used in future.

In Australia, milk is the major dietary source for the intake of iodine-131 from fallout. This radionuclide is absorbed readily by the body and part of it is concentrated in the thyroid gland. The potential hazard of a localised radiation dose to the thyroid is greater for infants, who have a low thyroid mass and consume relatively large quantities of fresh milk.

With the co-operation of the various State milk marketing authorities, a litre of milk is forwarded to the Australian Radiation Laboratory daily from each of nine major plants processing milk for distribution to the public the following day. At the Laboratory, the milk is chemically processed to extract the fraction containing any iodine-131. This fraction is then monitored to determine the concentration of iodine-131 in the original milk, and the radiation dose to the thyroid of a typical young child is computed. The detection limit for iodine-131 using the routine procedure is less than 100 millibecquerels per litre.

When fresh fission products are detected in air filters, the frequency of changing over the air filters is increased to twice per week. The information gained from this part of the program is purely scientific as any health hazard arising from breathing the air would be insignificant compared with that which would arise from the presence of that fallout on the ground and in certain foodstuffs, such as milk. From the gamma ray spectra emitted by the fresh fission products, it is possible to get information about the characteristics of the bomb which produced them and to estimate the contribution from various explosions which might produce a mixed fallout cloud.

Long-lived Radionuclide Monitoring Program

Of the many radionuclides produced in a nuclear explosion, strontium-90 and caesium-137 are the two long-lived ones which are a potential health hazard. The monitoring program is intended to evaluate their concentrations in the environment, the trends of change in these concentrations and their effects in terms of population dose. By initially measuring the concentrations of the radionuclides in a range of environmental samples and continuing these measurements on a regular basis over a period of years, it is possible to establish the factors governing these concentrations. Once this has been done, monitoring can be restricted to one or two key items and from these data, other concentrations and resultant radiation doses can be deduced.

Strontium-90 is of importance because, after ingestion, it is deposited almost exclusively in bone where, as a beta radiation emitter, it irradiates the bone and bone marrow, thus increasing the risk of either bone cancer or leukaemia; it cannot be responsible for other tumours or mutations. Caesium-137 becomes distributed throughout the soft tissues. Being a gamma radiation emitter, it irradiates the whole body and can be responsible for an increased incidence of all cancers and induce genetic changes.

Over various periods of time, analyses for strontium-90 and for caesium-137 have been carried out on deposit milk, soil, vegetables, flour, drinking water and human bones. Sufficient is now known about the transfer mechanisms of the two radionuclides in the environment for the measurement of strontium-90 in deposit and milk to give us all the information required. The collection sites for fallout deposit are at the six State capitals, six provincial centres in the dairying areas serving the capitals and at Townsville and Darwin. The fallout deposit collects in a 30 cm diameter funnel and is washed through an attached column containing ion exchange resin by rainwater or added distilled water. The resins are replaced every three months and the exposed ones sent to the Australian Radiation Laboratory for radiochemical analysis for strontium-90. The collection units are supervised by Bureau of Meteorology, CSIRO and State Government staff.

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Twenty litres of milk are collected monthly at milk processing plants in the six State capitals and forwarded to the Australian Radiation Laboratory. The samples are physically processed and then combined into three-monthly samples for radiochemical analysis for strontium-90. Analyses for caesium-137 in milk were carried out on a regular basis until 1978; occasional analyses on selected samples for the concentrations of caesium-137 in milk will continue to be made to check that the concentrations are declining as predicted.

Table 1: Typical debris cloud dimensions

Explosion yield	Altitude of cloud top	Mean cloud diameter
kilotons	kilometres	kilometres
5	7	2
20	10	4
50	14	6
100	16	10
500	20	20
megatons		
1	23	30
10	30	60

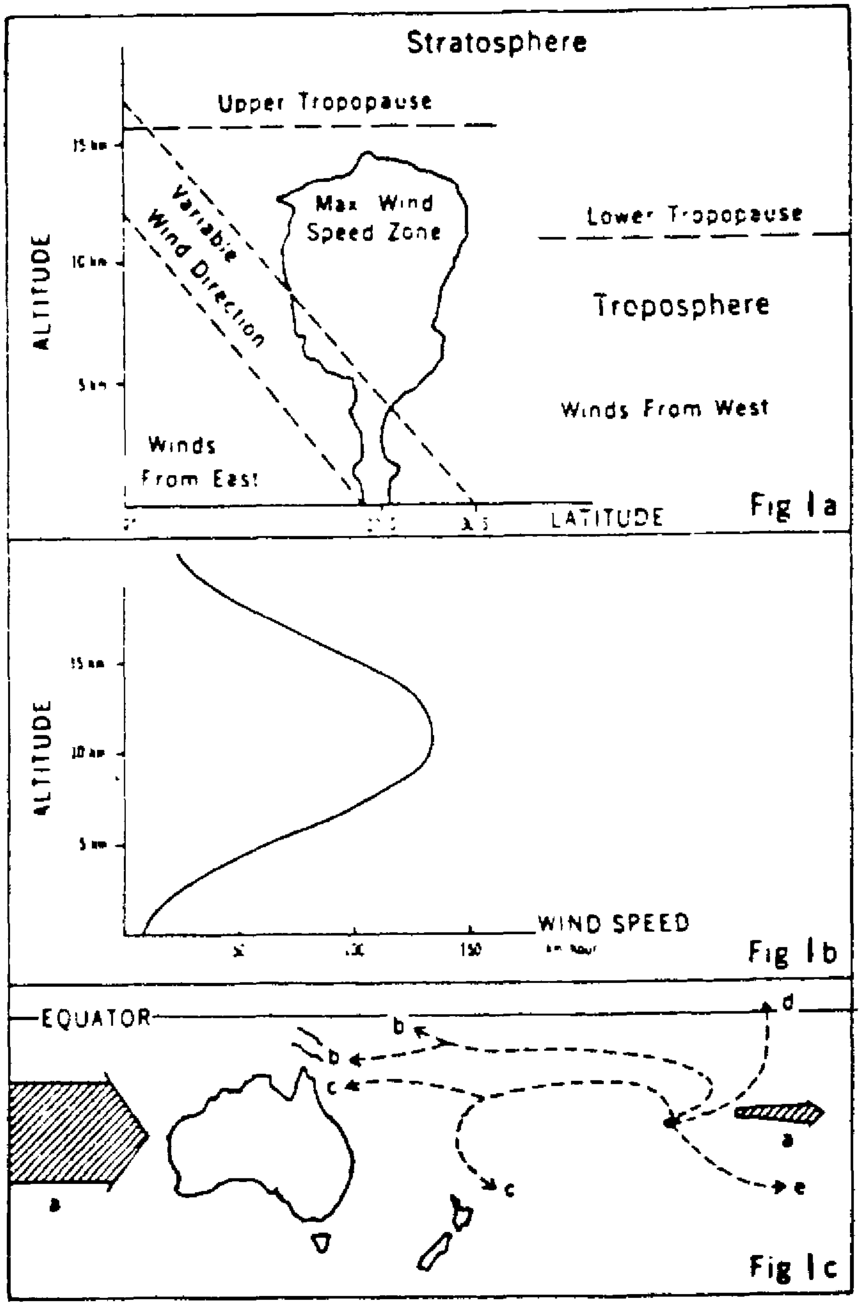
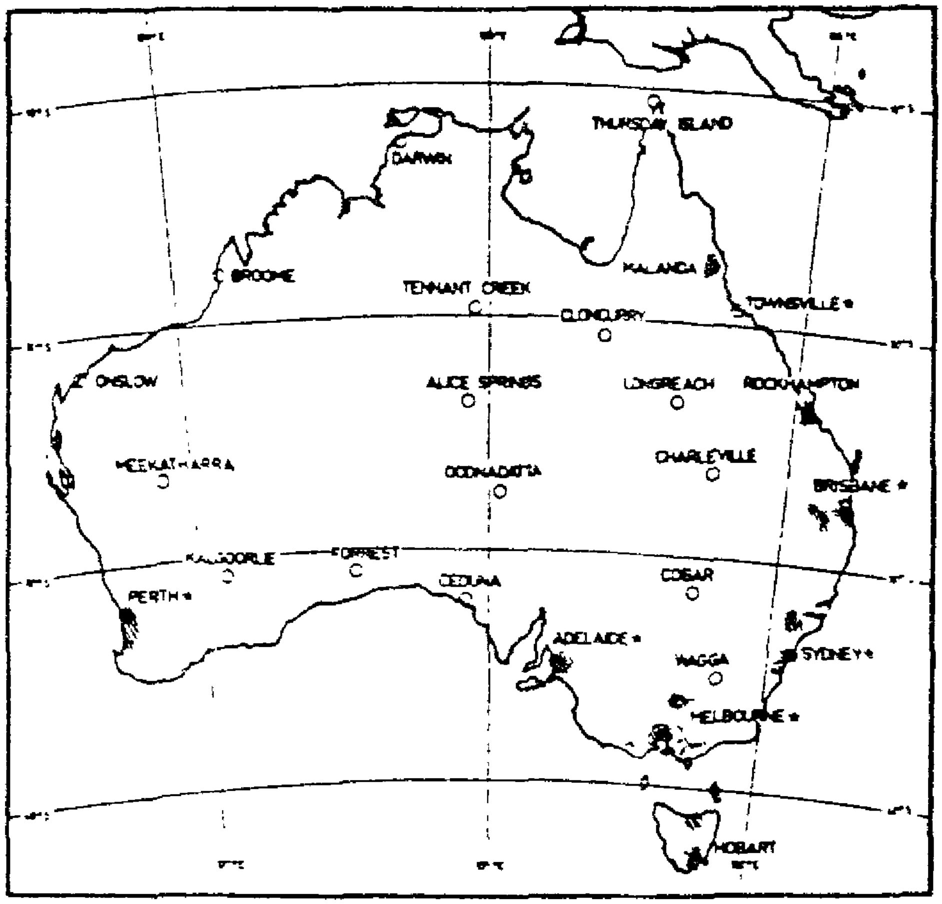


Fig 1(a) Zonal wind directions during the southern hemisphere winter.

Fig 1(b) Typical wind speed distribution with altitude in winter westerly winds.

Fig 1(c) Debris trajectories from the Mururoa test site. Trajectory (a) is associated with upper level westerly winds, and trajectories (b) to (e) with variable wind directions in the lower layers.



○ —— SPIERS stations sampling fallout deposit for total activity measurement.

—— Major milk supplies providing daily samples for iodine-131 assay. The shaded areas indicate the location and extent of the dairying districts.

* —— These stations also conduct air sampling for detection and identification of fresh fission products by -spectrometry.

FIGURE 2. Short-term program: Daily monitoring for fresh fission products.

RADIAC EQUIPMENT

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Introduction

In this paper RADIAC equipment will be described, including particular types referred to in the companion paper presented earlier in the Seminar. As defined in that paper RADIAC equipment is RADiation, Indicating, And Computing equipment required for Civil Defence or military purposes in the event of nuclear weapons being employed.

The range of equipment is wide and varied, and includes more than just radiation detecting and measuring instruments. It covers dosimeters (direct and indirect-reading types), survey meters (hand-held, vehicle-mounted and airborne types), contamination meters, warning systems, ground-zero indicators, bomb-power indicators, nuclear-burst indicators, weapons radiation calculators, radiation calibration equipment, training equipment and various other specialised items.

In general, instruments for civil defence and military applications tend to be developed by different authorities so that two sets of equipment are generated in each country. This applies even in the case of instruments having a common function in both applications, and therefore requiring to have identical radiation measuring characteristics (that is, radiation energy dependence, sensitivity, accuracy, etc.): for example, portable hand-held high-range survey meters for monitoring radioactive fallout fields of radiation.

RADIAC radiation detecting and measuring instruments listed above differ from conventional instruments employed in hospitals, industry and nuclear research and development establishments. Differences are as follows:

a. RADIAC instruments are designed to have radiation detection and measurement characteristics which are matched to weapons radiation and civil defence or military requirements.

b. RADIAC instruments are required to be more rugged than laboratory-type instruments, and to withstand a wide range of environmental conditions.

c. RADIAC instruments are required to measure high levels of radiation as necessary for emergency operations in the event of a nuclear attack. These levels are much higher than those covered by the normal laboratory instruments used for radiation protection.

Radiation Quantities and their Units of Measurement

It might be expected that the subject of radiation quantities and their units of measurement would be a relatively simple and straightforward one. However, in practice, a particular issue concerning RADIAC instruments is a lack of standardisation on the quantity to be measured, and its unit of measurement. Since this issue is clouded with confusion in the civil defence (and military) world, it will be considered in some detail here, before going on to the equipment itself. The four relevant radiation quantities will be described, together with their traditional pre-SI and new SI units, and their use will be discussed.

The first radiation quantity "activity" is used to specify an amount of radioactive material in terms of its ability to emit radiation. It is measured by the number of atoms disintegrating per unit time. The pre-SI unit is the curie (symbol Ci), which is defined as a disintegration rate of exactly 3.7×10^{10} atoms/s. The SI unit is the becquerel (Bq), which is defined as a disintegration rate of exactly 1 atom/s.

Pre-SI Unit: curie (Ci)
SI Unit: becquerel (Bq)
Conversion : 1 Ci = 3.7×10^{10} Bq, exactly.

Often one is concerned with the distribution of radioactive material over some surface, for example, the ground: appropriate units are then Bq/cm^2 or Bq/m^2.

The second radiation quantity "exposure" is applicable only to X- or gamma radiation, and refers to the ability of these radiations to produce ionisation in air. The pre-SI unit is the roentgen (R), which is defined so as to correspond to the production of one electrostatic unit of charge (1 esu) in 0.001293 gram of air, that is, 1 cm^3 at normal temperature and pressure. The SI unit, for which no special name has been assigned, is the coulomb/kilogram (C/kg).

Pre-SI Unit: roentgen (R)
SI Unit: coulomb/kilogram (C/kg)
Conversion : 1R = 2.58×10^{-4}C/kg, exactly.

The third radiation quantity "absorbed dose" refers to the amount of energy which is absorbed in an irradiated material. The pre-SI unit is the rad (no symbol), which is defined as energy absorption of 100 erg/gram of material. The SI unit is the gray (Gy), which is defined as an energy absorption of 1 joule/kilogram (J/kg).

Pre-SI Unit: rad (no symbol)
SI Unit: gray (Gy)
Conversion : 1 rad = 0.01 Gy = 10mGy = 1 cGy

To see the fundamental difference between the two quantities "exposure" and "absorbed dose" consider the following experiment:

a. A suitable ionisation chamber is placed in a gamma radiation field for a period of time such that the ionisation in it corresponde to a radiation exposure of 1R.

b. The ionisation chamber is removed and a block of aluminium is placed in the same position. The absorbed dose received by the material in an equal period of time is determined.

The results are given in Table 1, for gamma radiation fields of three different photon energies, these results being obtained by calculation. Also in the table are corresponding results for three other materials, including human tissue. These results show clearly that there is no simple relationship or ratio, between the absorbed dose in rads and the exposure in roentgens. Nevertheless, these two quantities, and their respective units, have not been distinguished in the civil defence (or military) world. This loose approach is undesirable, and is hardly justified by the fact that the ratio of the two quantities is approximately unity when the material is human tissue. This particular material is, of course, the one of interest when one is concerned with biological effects of radiation. Incorrect expressions such as "a dose of 3R", or "an exposure dose of 3R" are not helpful to understanding of the subject.

The fourth radiation quantity "dose-equivalent" refers to the product of the absorbed dose and a "relative biological effectiveness (RBE)" factor. The RBE factor (or quality factor) is introduced to take into account the fact that biological effects do not depend only on the energy absorbed in tissue. Different RBE factors may be required for different biological effects, and the factors may vary with the type of radiation. In civil defence (and military) work one is concerned primarily with acute radiation effects. For such effects the RBE factor for the gamma radiation in the initial and residual radiations of a weapon is established as unity. However, the RBE factor for the neutron component of the initial radiations, has not been firmly established to date, but is tentatively taken to be unity for the time being. It is possible that this value may change, either upwards or downwards, as a result of further radiation research. The pre-SI unit of dose-equivalent is the rem (no symbol). The SI unit is the sievert (Sv).

Pre-SI Unit: rem (no symbol)
SI Unit: seivert (Sv)
Conversion: 1 rem = 0.01 Sv = 10 mSV = 1 cSv

To stress the difference between absorbed dose and dose-equivalent the use of these quantities in the Oak Ridge National Laboratory Y12 plant nuclear accident in 1958 will now be cited. In this accident several persons were exposed to mixed gamma and neutron radiation from a drum containing a highly enriched uranium solution which became critical. The gamma and neutron absorbed doses received by these persons were determined in extensive retrospective studies, and it was decided that the RBE factor for the neutron component should be about 2. Table 2 shows the results determined for three of the victims (designated as A, E and H). The total absorbed dose in column 4 is obtained by simply adding the component gamma and neutron absorbed doses. The total dose-equivalent in column 5 is obtained by including the RBE factor of 2 quoted above. This example clearly shows the distinction between absorbed dose and dose-equivalent, and also that the RBE factor need not necessarily be unity. The advantage of dose-equivalent is that it enables different types of radiations to be measured on a common scale relating to a specified biological effect. In the example quoted it would be expected that the observed radiation sickness symptoms in the victims would correlate with the dose-equivalent values, not with the absorbed dose ones.

As stated earlier a particular issue at the present time is the lack of standardisation on the radiation quantity that RADIAC instruments should be designed and calibrated to measure, and the unit of measurement to be employed. In this matter the first consideration is, of course, selection of the radiation quantity, the appropriate unit (pre-SI or SI) then following automatically. It is the writer's personal belief that the appropriate quantity on which to standardise is dose-equivalent (or dose-equivalent rate in the case of radiation-rate measuring instruments). There appears to be much justification for this as follows:

a. In civil defence (or military) work one is interested primarily in biological effects in persons.

b. Radiation levels recommended by health authorities are given in terms of dose-equivalent.

c. RADIAC instrument design and calibration can make allowance for inclusion of RBE factors and, in fact, already does so. For example, on the supposition that the RBE factors are unity, the US direct-reading military dosimeter Model IM-185 has been deliberately designed so as to equally weight its responses to the gamma and neutron components of weapons initial radiation. The total response recorded by this instrument may therefore be interpreted as a "dose-equivalent", although the US documentation describes it as a "dose" in rads. As another example, the UK indirect-reading individual dosimeter/reader system Model DT-236 has provision in the reader for adjusting the gamma and neutron responses so as to match the RBE factors of these radiations. Thus the system provides for any change that may be made in these factors in the future as a result of further research. It may therefore

c. (continued)

be interpreted as measuring "dose-equivalent", although the UK documentation describes it as measuring "dose" in rads.

Having provided the background to the subject the current position in the US, UK and Australia may now be stated It is as follows:

a. The practice in the US and UK of describing military dosimeters as measuring "dose" is being retained, and the pre-SI unit rad is being converted to the corresponding SI unit centigray (cGy) so as to obtain a simple one-to-one conversion. Similarly, military survey meters will be described as measuring "dose-rate" in cGy/h.

b. On the other hand, in the US and UK the practice of describing civil defence dosimeters as measuring "exposure" is being retained, together with the pre-SI unit the roentgen (R). Similarly, civil defence survey meters will be described as measuring "exposure-rate" (or perhaps "dose-rate") in R/h.

c. In Australia there appear to be firm proposals that civil defence instruments should measure "dose-equivalent", and the units proposed are the millisievert (mSv) for dosimeters, and the millisievert/hour (mSv/h) for survey meters. On the other hand, military RADIAC instruments are likely to be procured from US, Canada and/or UK, and the practice given in a. above will apply.

It is evident from this discussion that an unsatisfactory situation exists, and that this is likely to remain so. A particular matter of concern is that Australian civil defence and military RADIAC instruments are likely to employ different sets of radiation quantities and units.

Civil Defence RADIAC Equipment in the United Kingdom

Civil Defence RADIAC equipment in the UK was developed many years ago, and the designs are now considered to be obsolescent. Four main types (ref. Fig. 1) which would be used in emergency operations are as follows:

a. RADIAC Survey Motor No. 2. This is a portable instrument with three linear ranges 0-3, 0-30, and 0-300 R/h.

b. Contamination Meter No. 1, Mark 2, Model 1092. This is a portable instrument with an approximately logarithmic range 0.1 to 10 mR/h.

c. Quartz-Fiber Dosimeters. These have a range 0-5 R, 0-50 R, or 0-150 R.

d. Dosimeter Charger.

Fairly recently the Home Office produced a specification for a new survey meter. An instrument made by Plessey (ref. Fig. 2) is claimed to meet this specification. It has a range up to 3000 mGy/h (300 rad/h), and a digital display. The electronics employ nuclear hardened C-MOS technology. The detector is an energy-compensated halogen-quenched Geiger-Muller tube. Provision is made for automatic self-testing and fault indication. There is also provision for an optional remote sensing head.

RADIAC equipment employed in the various UK Monitoring Stations and Control Posts (see companion paper) include the following items:

a. Ground-Zero Indicator. This is a robust drum-shaped instrument consisting of four pin-hole cameras arranged so that a mark indicating the bearing and elevation of a nuclear burst is recorded on sensitised paper.

b. Bomb-Power Indicator. This instrument records the blast peak overpressure caused by the explosion.

c. Atomic Weapon Detection Recognition and Estimation Yield (AWDREY). This instrument utilises the thermal and electro-magnetic pulses from the weapon to detect the explosion and determine its yield. AWDREYs are sited at 13 selected Group Control Posts to provide coverage over the whole UK.

d. Fixed Survey Meter. This is a remote-reading radiation meter with the detector mounted in the open outside the Post. It is capable of measuring from 0.1 to 500 R/h.

In the event of a nuclear attack the Ground-Zero Indicators would be used to determine the position and height of burst of the weapon. Knowing the distance to the weapon enables the overpressure readings on the Bomb-Power Indicators to be used to obtain an estimate of the weapon yield. The weapon yield may also be estimated roughly from the size of the spot on the Ground-Zero Indicators. Data from all Posts within the Group is taken into account and cross-checked with AWDREY information, so as to obtain the best determination possible of the weapon location, height of burst, and yield. As described in the companion paper this data is then used, together with meteorological data, to produce a fallout prediction of the hazard-zone type. The Fixed Survey Meters are used to record the time-of-arrival of radioactive fallout, and the radiation dose-rates at intervals thereafter. As described in the companion paper these dose-rate readings are used to establish, on a firm basis, the direction and speed of the fallout front, and the width and intensity of the fallout pattern.

Civil Defence RADIAC Equipment in the United States and Canada

The main civil defence RADIAC instruments (ref. Fig. 3) used in the US are as follows:

a. Item No. CD V-715. This is a portable high-range survey meter with four linear ranges 0-0.5, 0-5, 0-50 and 0-500 R/h.

b. Item No. CD V-717. This is similar to item a. except that the detector is mounted in a probe attached to the instrument by a 25 foot cable. This probe can be positioned outside a shelter, and readings taken inside.

c. Item No. CD V-700. This is a portable low-range survey meter or contamination meter with three linear ranges 0-0.5, 0-5 and 0-50 mR/h.

d. Item No. CD V-742. This is a high-range quartz-fiber dosimeter, 0-200 R.

e. Item No. CD V-750. This is the ancilliary dosimeter charger.

Some of these RADIAC instruments are allotted to Monitoring Stations. Some are organised into kits suitable for equipping public fallout shelters, or state and local emergency services. A typical Shelter Kit would include a CD V-715 Survey Meter, a CD V-700 Contamination Meter, two CD V-742 Dosimeters and a CD V-750 Dosimeter Charger. A typical Operational Monitoring Kit would include all the items in a Shelter Kit plus another Survey Meter (either a CD V-715 or a CD V-717). As may be expected in a country as large as the US, very large numbers of instruments are required: recent figures are something like 1.5 million Shelter Kits plus 5.5 million Operational Monitoring Kits.

The actual numbers of these instruments available at the present time are about 650,000 survey meters, 450,000 contamination meters, 3,000,000 dosimeters and 500,000 dosimeter chargers. They date from the early 1960s. Found to be unreliable when procured from the manufacturers, they have been put through a substantial retrofit program by the Federal Emergency Management Agency (FEMA), and are now considered to be suitable for operational use.

FEMA is developing a new dosimeter consisting almost entirely of plastic materials (ref. Fig. 4), which is claimed to have excellent performance, and will cost about $US 10 when in production. The range of this instrument is 200 R full scale. Oak Ridge National Laboratory is developing an ancilliary piezoelectric dosimeter charger which will eliminate the need for a battery.

FEMA is also developing another dosimeter of similar construction to the one described above, but with a sensitivity of only 2 R full scale. It will be provided with a double scale, one marked 0 to 120 R/h, and one marked 0 to 12 R/h. The concept is that this instrument will be useful as a dose-rate meter, by observation of the reading on the appropriate scale, after a timed exposure (1 or 10 minutes, respectively, for the two scales quoted).

RADIAC instruments employed in Canada include the usual portable high and low-range survey meters, high and low-range dosimeters and dosimeter chargers. Some particular instruments are as follows:

a. Radiation Detector, Model RD108D. This is a portable high-range survey meter made by Canadian Admiral Corporation. It has a quasi-logarithmic range from 1 to 500 R/h.

b. Low-Range Survey Meter, Model CCD100-10B. This is a portable instrument made by Canadian Admiral Corporation. It serves as a survey meter in low dose-rate areas, and is also used for decontamination control.

c. Quality Fibre Dosimeter, Model CCD-200. This is a high range (0 to 200 R) dosimeter made by the Landsverk Electrometer Company.

d. Charger RADIAC Detector, Model 5120A and Radiological Dosimeter Charger, Model 643. These are dosimeter chargers made by Canadian Admiral Corporation and Bendix, respectively.

Under peace-time conditions the equipment is stored by the municipal and provincial authorities. There is a pre-arranged plan for its rapid distribution to Monitoring Stations and Emergency Services in the event of an emergency.

Practically all states in the US have RADIAC maintenance and calibration facilities for civil defence instruments, the centres being under the control of FEMA through the central Radiological Instrument Test Facility located in Washington. Experience has been that this national approach has the advantage of ensuring standardisation of equipment and calibration procedures. In Canada procurement of civil defence RADIAC equipment is financed by federal and provincial funds on a 3 to 1 cost-sharing basis. Maintenance and repair of instruments is financed completely by federal funds. Additional funds are spent on instrument modification and upgrading. All instruments are checked for performance at regular intervals to ensure that stocks are operational.

Civil Defence RADIAC Equipment in Australia

No RADIAC instruments have been manufactured in Australia, and stocks available have been procured from overseas. These include considerable numbers of the CD-V-715 survey meters, CD V-700 contamination meters and CD V-750 dosimeter chargers, which were discussed earlier. Because of the troubles with these particular instruments the FEMA retrofit program is expected to be of particular interest.

Figs. 5 to 10 show Australian RADIAC calibrators which were developed by this writer at Materials Research Laboratories some years ago. These provide for the routine calibration of gamma-measuring RADIAC instruments, including all relevant civil defence (and military) survey meters, contamination meters and dosimeters, made by different manufacturers. The three equipments employ radioactive Caesium-137 sources.

The original set of these three equipments is located at Materials Research Laboratories, and is employed from time to time for investigational studies into the performance of RADIAC instruments. In conjunction with a constant potential 300 kV laboratory X-ray facility, also at Materials Research Laboratories, it is possible to test the behaviour of RADIAC instruments over a wide range of photon energies.

Another set of the three equipments, which includes some engineering refinements developed by Engineering Development Establishment, is installed in the Army RADIAC Calibration and Maintenance Centre at Bandiana. All Australian RADIAC instruments are checked at this Centre on a regular, routine basis.

Measurement of the Initial Radiation of a Weapon

In the companion paper it was pointed out that there may be a requirement to measure the initial radiations of a weapon. These are the radiations emitted within the first minute after the explosion. They contain high-intensity, very short duration pulses of gamma and neutron radiation. None of the RADIAC dosimeters discussed under the last three side-headings are capable of measuring these radiations. For this purpose special RADIAC dosimeters are needed which are capable of measuring both gamma and neutron radiation, at dose-rates up to the order of 10^6 Gy/s (10^8 rad/s). Two military RADIAC instruments which have been developed for this purpose will now be described.

The US direct-reading military dosimeter Model IM-185 has a similar appearance to a conventional quartz-fiber type dosimeter, and is designed to be worn or carried in the conventional chest position. The ionisation chamber element is a special one operating on the Secondary Emission Mixed Radiation (SEMIRAD) principle so as to measure both the gamma and neutron components in the initial radiations of a weapon. The dosimeter also measures the gamma radiation in the residual radiations. A direct-reading capability is achieved by a conventional quartz fiber/optical system. The ionisation chamber must be evacuated, and regular pumping down is required when the instrument is in use.* For this purpose the ancilliary charger is equipped with a suitable ion pump. Conceived in the late 1950s the IM-185 has had many troubles, and development is not yet completed.

The UK military dosimeter/reader system Model DT-236 employs a dosimeter worn on the wrist like a wrist-watch. This dosimeter contains a radio-photoluminescent glass element for measurement of the gamma component, and a silicon diode element for measurement of the neutron component. The responses of the two detectors are measured, and combined together to give the total dose, in an ancilliary reader. It is expected that this equipment will be in full production in the UK by the end of this year. There is a competitive German version of the equipment already on the market. Indications are that measurement of the gamma component is proving to be a source of trouble, and there may be a requirement to find a more suitable type of detector.

TABLE 1. ABSORBED DOSE (RADS) IN DIFFERENT MATERIALS CORRESPONDING TO A RADIATION EXPOSURE OF 1 ROENTGEN (1R)

Material	Gamma Photon Energy (MeV)		
	0.1	0.5	3.0
Air	0.87	0.87	0.87
Human Tissue	0.95	0.96	0.95
Aluminium	1.28	0.84	0.84
Lead	85	2.79	0.99

TABLE 2. RADIATION DOSES RECEIVED BY OAK RIDGE NUCLEAR ACCIDENT VICTIMS

Victim	Gamma Absorbed Dose (rad)	Neutron Absorbed Dose (rad)	Total Absorbed Dose (rad)	Total Dose-Equivalent (rem)
A	269	96	365	461
E	174	62	236	298
H	17	6	23	29

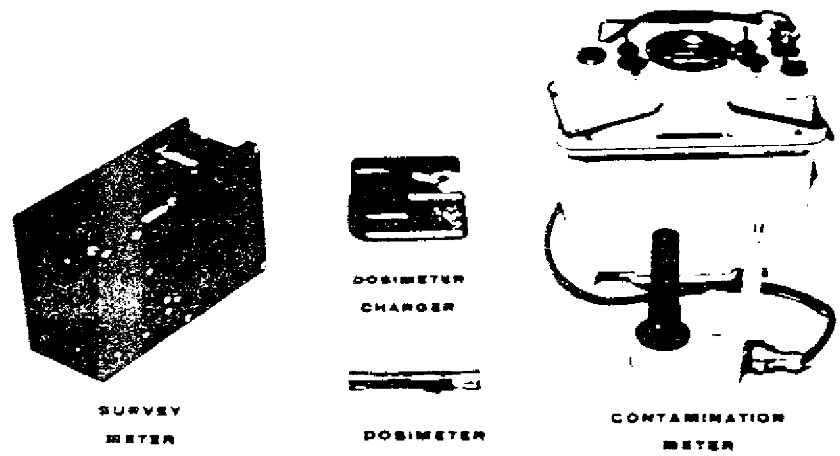


FIG. 1. TYPICAL U.K. CIVIL DEFENCE RADIAC EQUIPMENT

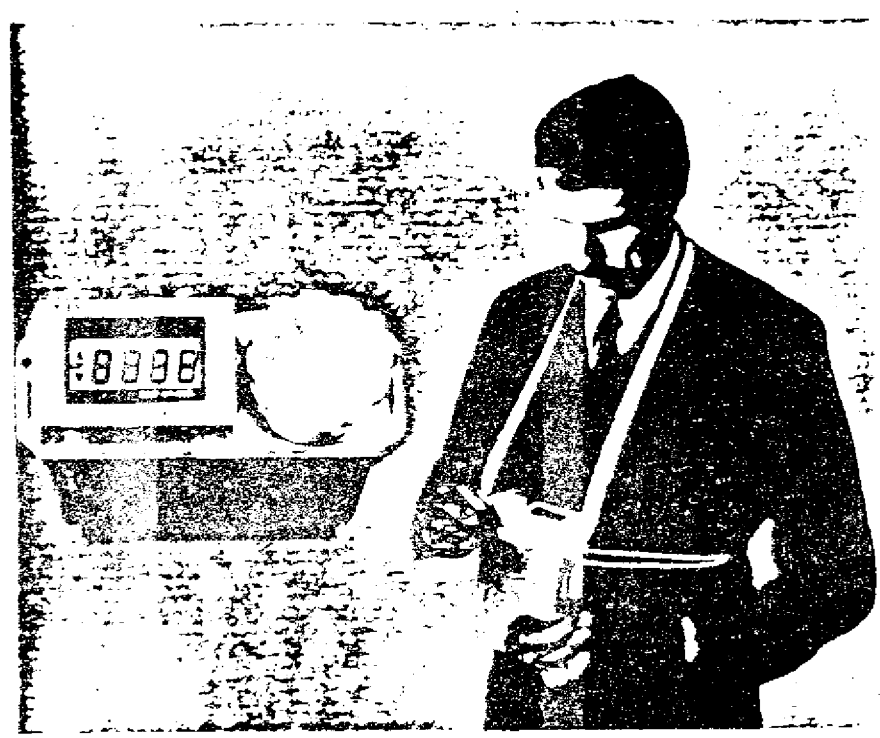


FIG. 2. NEW U.K. CIVIL DEFENCE RADIAC SURVEY METER

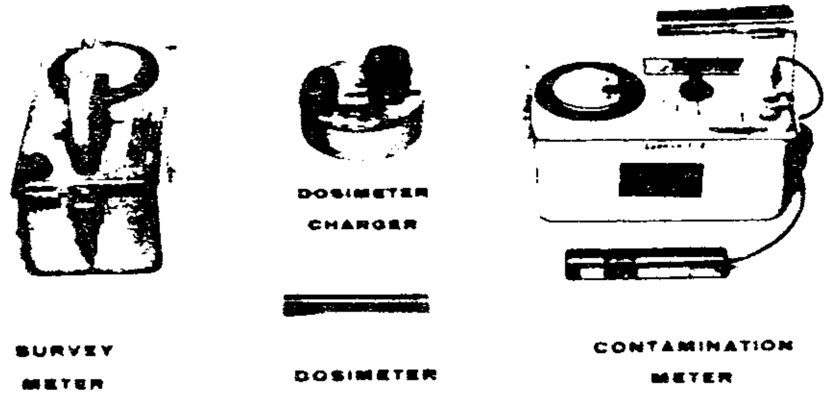


FIG. 3. TYPICAL U.S. CIVIL DEFENCE RADIAC EQUIPMENT

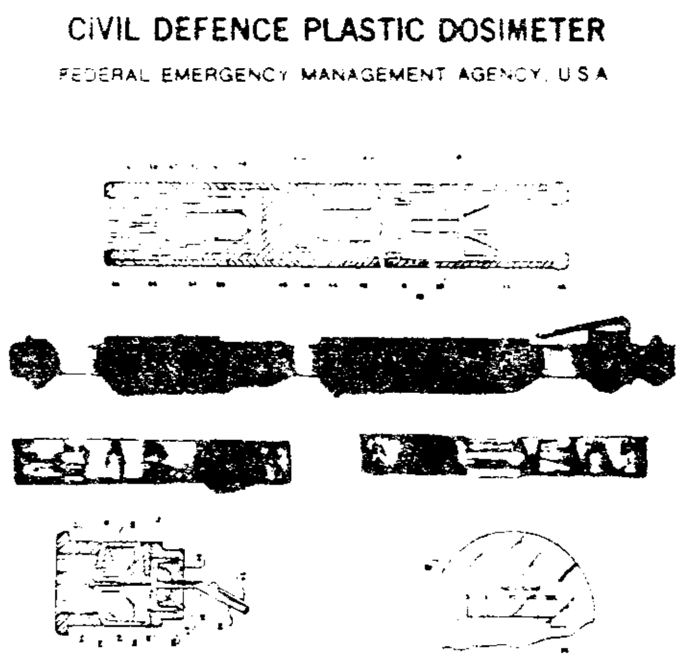
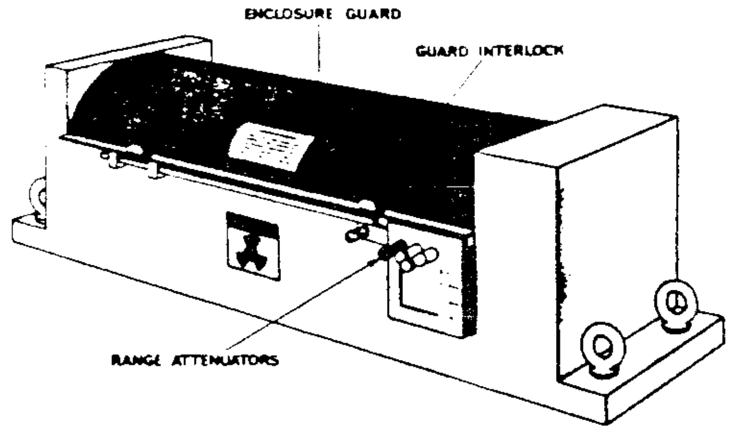
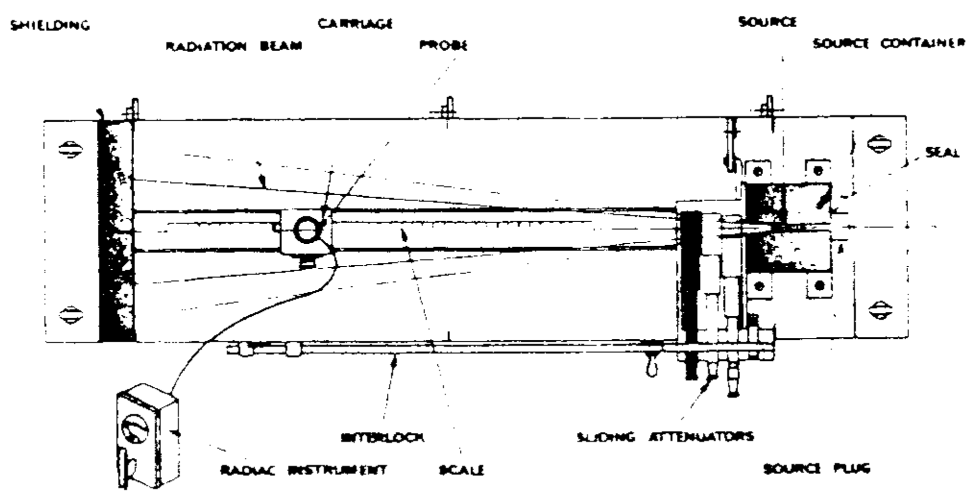


FIG. 4. NEW U.S. CIVIL DEFENCE RADIAC DOSIMETER



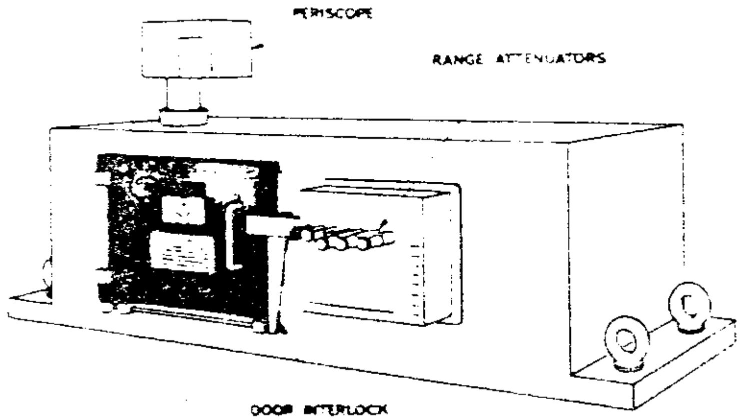
LOW INTENSITY GAMMA CALIBRATOR

FIG. 5. RADIAC LOW INTENSITY GAMMA CALIBRATOR
Developed at Materials Research Laboratories, Melbourne



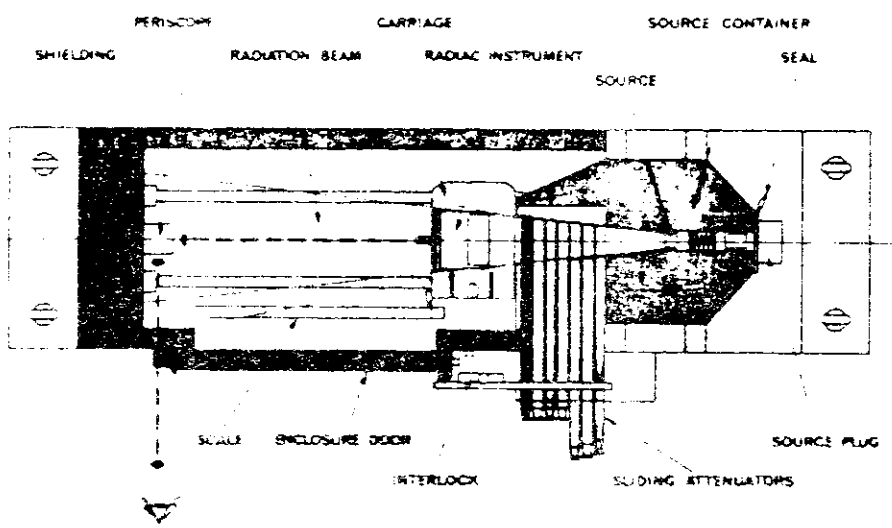
LOW INTENSITY GAMMA CALIBRATOR

FIG. 6. RADIAC LOW INTENSITY GAMMA CALIBRATOR
OPERATIONAL FEATURES



HIGH INTENSITY GAMMA CALIBRATOR

FIG. 7. RADIAC HIGH INTENSITY GAMMA CALIBRATOR
Developed at Materials Research Laboratories, Melbourne



HIGH INTENSITY GAMMA CALIBRATOR

FIG. 8. RADIAC HIGH INTENSITY GAMMA CALIBRATOR
OPERATIONAL FEATURES

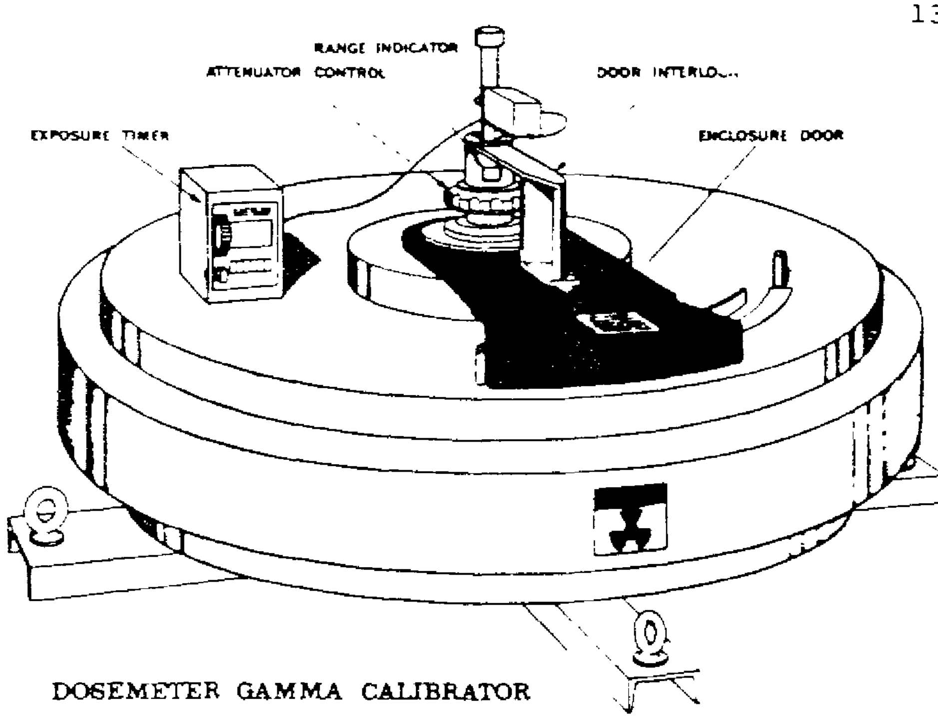


FIG. 9. RADIAC DOSEMETER GAMMA CALIBRATOR
Developed at Materials Research Laboratories, Melbourne

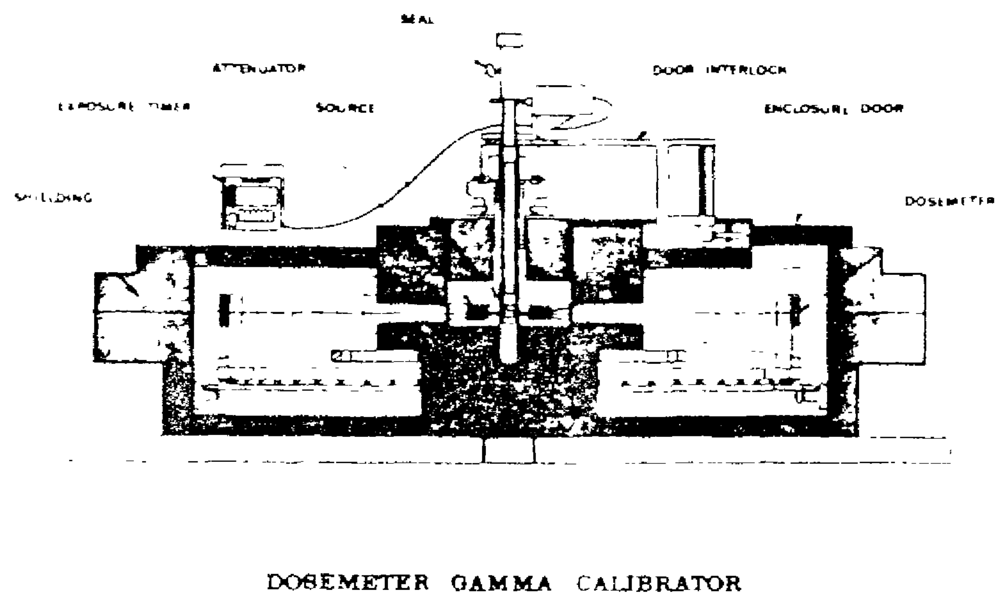


FIG. 10. RADIAC DOSEMETER GAMMA CALIBRATOR
OPERATIONAL FEATURES