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College on Medical Physics
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Fundamental Dosimetry, Secondary Standardization, Application in Radiation Therapy and Radiation Protection

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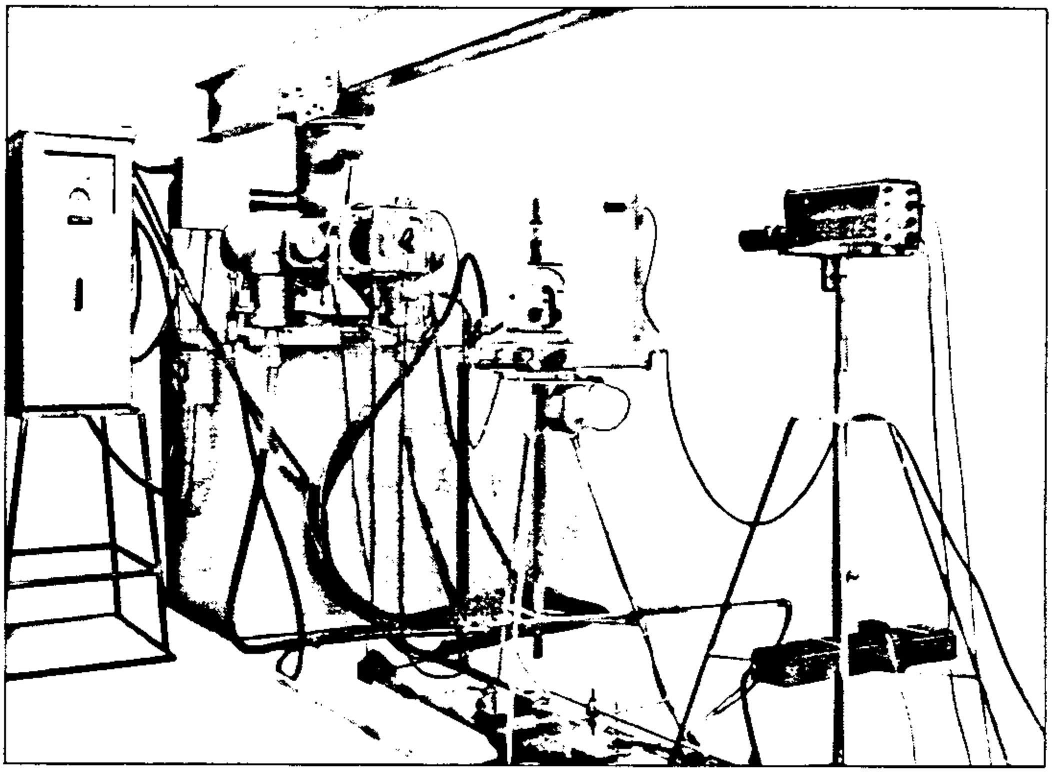


TECHNICAL REPORTS SERIES No. 133

Handbook on Calibration of Radiation Protection Monitoring Instruments

INTERNATIONAL ATOMIC ENERGY AGENCY, VIENNA, 1971

The energy imparted, ε, by ionizing radiation to the matter in a volume is:

$$\varepsilon = R_{in} - R_{out} + \sum Q$$

where

R_{in} = the radiant energy incident on the volume, i.e. the sum of the energies (excluding rest energies) of all those charged and uncharged particles which enter the volume,

R_{out} = the radiant energy emerging from the volume, i.e. the sum of the energies (excluding rest energies) of all those charged and uncharged ionizing particles which leave the volume,

$\sum Q$ = the sum of all changes of the rest mass energy of nuclei and elementary particles in any nuclear transformations which occur in the volume.

(a) ε is a stochastic quantity.

(b) The expectation value of ε, termed the mean energy imparted, $\bar{\varepsilon}$, is a non-stochastic quantity.

ad (a) A stochastic quantity varies discontinuously in space and time, and its value cannot be predicted except by reference to a probability distribution.

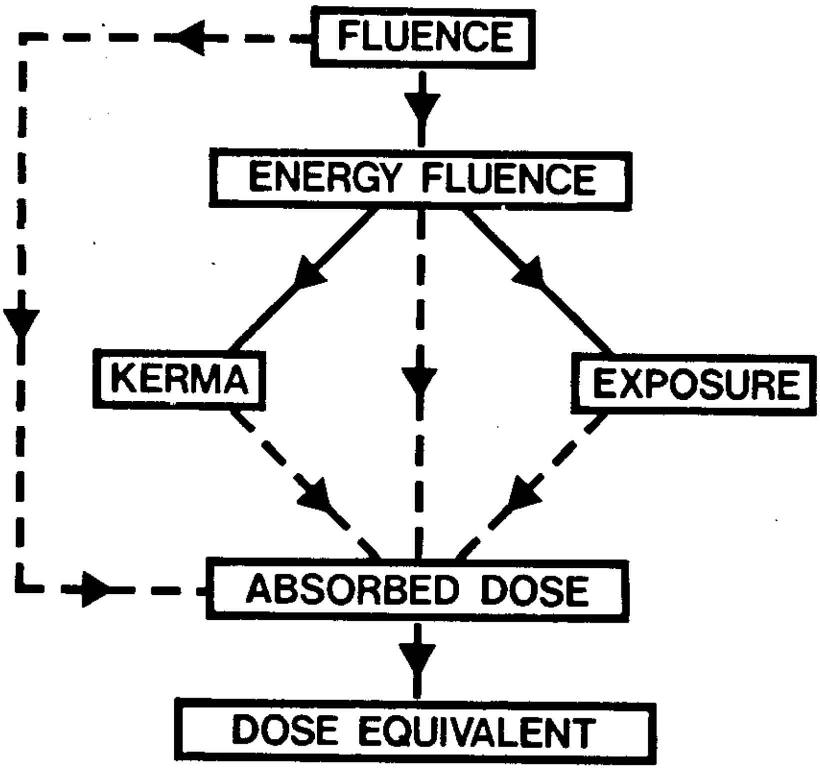
ad (b) A non-stochastic quantity is continuous in space and time, and one can refer to its gradient and its rate. For given conditions, its value can be estimated as the average of the observed values of an associated stochastic quantity.

Medical Physics Handbooks 15

FUNDAMENTALS OF RADIATION DOSIMETRY

J R GREENING

Second Edition



An equipment for measuring absorbed dose via temperature changes caused by irradiation of a suitable material is called a calorimeter. It is clear that such a dosemeter is of no practical use in routine radiotherapy and even less in radiation protection measurements. Therefore, other ways had to be found and historically have been taken to measure absorbed dose to water. This way is based on the property of radiation to ionize air and leads to the quantity Exposure (X) and its unit Roentgen (R).

Exposure and Air Kerma

The definition of exposure is: "The exposure, X, is the quotient dQ/dm where dQ is the absolute value of the total charge of the ions of one sign produced in air when all the electrons liberated by photons in a volume element of air having mass dm are completely stopped in air".

$$\text{Exposure} = X = \frac{dQ}{dm}$$

The special unit of exposure is the roentgen (R)

$$1\ R = 2.58 \times 10^{-4}\ C\ kg^{-1}\ \text{(exactly)}$$

This definition of the exposure contains already a prescription how to determine its unit. The piece of equipment constructed in accordance with the definition of the quantity exposure is the free air chamber. In the free air chamber, the defined mass of air (dm) is controlled by the diameter of the collimating diaphragm of the radiation beam and the length of the collecting electrodes. Great care must be taken to ensure an electrical field such that straight lines of force between the electrodes define a precisely known volume element. In order to meet the requirement that all electrons liberated by photons in the volume element having mass dm are completely stopped in air, the distance of the electrodes and the collimating diaphragm from the precisely known volume element has at least to be equal to the range of the electrons (secondary electrons) liberated by the photons in that volume

Introduction

In both radiotherapy and radiation protection one would like to determine the effect ionizing radiation is having on living human tissue. Therefore, it is the task of dosimetry to provide measurement techniques which relate as closely as possible with this effect.

In radiotherapy, the effect is usually represented by the absorbed dose to a particular tissue or organ. As the human body is mainly composed of water, for normalization purposes dose prescriptions are usually quoted in the quantity of absorbed dose to water, leaving it to the radiotherapist to take account of the difference between water and muscle, fat and bone and to the radiobiologist to take account of the relative biological effectiveness of different types of radiation.

In radiation protection, the quantities dose equivalent to particular organs and effective dose equivalent (a weighted average of the dose equivalent to a number of organs) are used for the dose limitation system of regulations. They are closely related to absorbed dose in water. Therefore, a central issue of dosimetry is the determination of absorbed dose to water.

Definition of absorbed dose

In ICRU Report 33, the quantity absorbed dose is defined as follows:

The absorbed dose, D, is the quotient of $d\bar{\varepsilon}$ by dm, where $d\bar{\varepsilon}$ is the mean energy imported by ionization radiation to matter of mass dm

$$D = \frac{d\bar{\varepsilon}}{dm}$$

$$W_{air} = 33.97 \text{ eV per ion pair} = 33.97 \text{ J C}^{-1}$$

With that information we are able to determine the absorbed dose to air by measuring the exposure.

The definition of the roentgen is that it corresponds to 2.58×10^{-4} C kg^{-1}. The average total energy deposited per unit of ionization charge produced is given by $W = 33.97$ J C^{-1}.

Therefore, the absorbed dose to air resulting from the exposure of X roentgen is given by:

$$D_{air} = 2.58 \times 10^{-4} \text{ C kg}^{-1} \times 33.97 \text{ J C}^{-1} \times X$$

$$D_{air} = 0.8764 \times 10^{-2} \times X \text{ Gy}$$

Thimble Chamber

Clearly, the free air chamber is a device not suitable for routine measurements in the field. For practical purposes the so-called thimble ionization chamber is used. The wall of the thimble is made of an air equivalent (with respect to photon interaction) material which establishes electron equilibrium. A central electrode collects the charge produced in the air volume of the thimble. As air equivalence of the thimble wall can only be approximated and as the introduction of a central electrode causes some disturbances, the response of the thimble chamber to radiation will have to be corrected. The correction can be found by intercomparing its response to the exposure measured with the free air chamber. The resulting correction factor is called the calibration factor (N_x).

The Cavity Chamber

In order to understand the cavity theory we have to make some theoretical considerations, for our purpose very simplified:

The original special unit of absorbed dose, the rad, was in c.g.s units of energy, the erg, as 100 ergs per gram. With the introduction of the SI units this is now expressed as 0.01 joules per kilogram and the special unit, the gray (Gy) is used equal to 1 joule per kilogram. As we always will still find the old units of exposure in the literature, we should know the conversion to the new units

$$1 \text{ Gy} = 100 \text{ rad} = 1 \text{ J/kg}$$

$$1 \text{ rad} = 0.01 \text{ Gy} = 100 \text{ erg/g}$$

Note: The SI unit, J/kg, is also the unit of other quantities, therefore it is important to specify the quantity "absorbed dose" when this is what is measured. In addition, any of the quantities to which the unit gray refers (kerma, specific energy or absorbed dose) can apply to any material. It is therefore also important to state the material to which absorbed dose applies (for example: "absorbed dose to air", or "absorbed dose to water").

Calorimetry

In principle, the absorbed dose delivered to a medium can be obtained by measuring the heat produced in the material by radiation. In practice, there are, however, many problems, one of which is the very small amount of heat produced by the radiation. For example, if the medium is graphite with a specific heat of 700 J $kg^{-1}K^{-1}$ and an absorbed dose of 2 Gy is delivered, the resulting temperature rise will be about 3 mK. If this temperature rise is to be measured to a precision of about 1%, temperature differences of a few microkelvin have to be measured. The situation is even more difficult if water is the reference material, as its specific heat is approximately 5 times higher than that of carbon.

If we consider only the interaction of the secondary electrons, produced by the radiation beam, with the material m, we can describe the energy absorbed by the material by

$$D_m = s_m \Psi_m$$

$$s_m = \text{collision stopping power of m}$$

It is clear that all the interaction coefficients are energy dependent.

As we have seen, the use of the free air chamber is restricted to photon energies up to about 300 keV as is the thimble chamber. For determination of exposure of photons with energies higher than 300 keV, an ionization chamber is constructed underlying the so-called Bragg-Gray cavity theory. For our purposes, we can describe the theory in the following way:

Consider a small air filled cavity situated inside an otherwise homogeneous block of graphite and let us assume that:

- firstly 1) the linear dimensions of the cavity (i.e. its size) are small compared with the range of the secondary electrons liberated in the surrounding graphite as a result of the absorption of the incident photons.

  This means that the electrons will not loose a significant fraction of their energy in traversing the cavity although, of course, some energy will be lost and it is the associated ionisation produced that we are going to detect and use for our measurement. The consequence of this is that the secondary electron flux throughout the whole material will not be disturbed in any way by the presence of the cavity.

- secondly 2) The thickness of the surrounding graphite is larger than that of the maximum range of the secondary electrons. This means that all the electrons traversing the cavity will have been liberated in the graphite.

element. The secondary electrons produced by the photons via compton and photoelectric effect in turn create many ionizations each and the collection of all the tertiary electrons produced in such a way gives the charge dQ stated in the definition of the exposure. This charge dQ is measured by an electrometer.

It should be noted that some part of the range of some of the secondary electrons liberated in the defined volume will be outside the volume from which the ionization charge is collected. For this reason, the charge will be underestimated. Fortunately, there is a compensation in that other secondary electrons generated outside the defined volume will create ionizations which are collected and measured. When these two effects will balance we speak of having electronic equilibrium.

It is the range of the secondary electrons and the requirement for electronic equilibrium which limits the use of a free air chamber to photons up to about 300 keV.

Absorbed Dose to Air

The definition of the exposure requires that all the energy imparted to the secondary electrons (produced by photo-electric, compton and pair production processes) is transferred to the air. Part of this energy transferred results in the production of ionization (tertiary electrons) - which is detected and used as the measurement signal - whilst the whole of the energy transferred to the air provides the absorbed dose.

The ratio between the total energy imparted by the electrons to air and to the charge which is produced simultaneously (by the fraction of the total absorbed energy which produces ionization) is expressed by the quantity W. Fortunately, for the range of secondary electron energies with which we are concerned, W in air can be considered as energy independent and has the constant value:

Combining (a) and (b) we receive

$$D_{gr} = s_{gr,a} \, J \, \frac{W}{e} \qquad \text{(c)}$$

The absorbed dose to graphite also is related to the absorbed dose in air by

$$D_{gr} = D_{air} \frac{(\mu_{en}/\rho)_{gr}}{(\mu_{en}/\rho)_{air}} = 0.8764 \times 10^{-2} \times X \times \frac{(\mu_{en}/\rho)_{gr}}{(\mu_{en}/\rho)_{air}} \qquad \text{(d)}$$

Combining (c) and (d) results in

$$X = A \frac{(\mu_{en}/\rho)_{air}}{(\mu_{en}/\rho)_{gr}} \, s_{gr,a} \, J \, \frac{W}{e}$$

With that the cavity theory provided us with an equation for the determination of exposure for higher photon energies than that limiting the use of the free air chamber. The resulting primary standard is the cavity chamber. However, again we have an upper limit of energies of about 3 MeV for the use of the cavity chamber as a primary standard of exposure. With increasing energy the difference between stopping power in air of the secondary electrons and the mass energy transfer coefficient of the corresponding photons decreases, thus invalidating the assumption for the cavity theory that the photon interaction in the cavity is negligible in comparison with the secondary electron interaction.

A radiation source will give rise to a radiation field. The radiation field is characterized by a fluence of particles defined by ICRU as $\Phi = dN/da$ where dN are the particles incident on a sphere of cross sectional area da. Reference to a sphere with a certain cross sectional area rather than to the cross section itself removes the need to specify the orientation of the cross sectional area and the definition applies equally well to mono-directional or multi-directional particles. The SI unit of fluence is m^{-2}. Consideration may be given to the energy carried by the particles rather than to the particles themselves. The energy fluence, Ψ, is defined as dR/da where dR is the radiant energy entering a sphere of cross sectional area da. The SI unit of energy fluence is Jm^{-2}. The radiant energy, R, is the energy, excluding rest energy, of the particles concerned. If a photon beam interacts with a material m, the kinetic energy of the produced secondary electrons can be calculated from the energy fluence of the beam by

$$K_m = \left(\frac{\mu_{en}}{\rho}\right)_m \Psi m$$

K_m = kerma in m (Kinetic Energy Released in Material)

$\left(\frac{\mu_{en}}{\rho}\right)_m$ = mass energy transfer coefficient

The energy absorbed by the material m caused by the radiation beam can be described as

$$D_m = \left(\frac{\mu_{en}}{\rho}\right)_m \Psi m$$

D_m = absorbed dose in m

$\left(\frac{\mu_{en}}{\rho}\right)_m$ = mass energy transfer coefficient of m

Absorbed Dose to Water from Exposure or Air Kerma

We have discussed the definition of exposure and air kerma and we have to relate these quantities to the absorbed dose in water.

$$X = \frac{K_{air}\,(1-g)}{W/e}$$

Taking $W/e = 33.97$ J/C (for Co-60)

$g = 0.0032$ (for Co-60)

we get

$$X = 0.0293 \times K_{air} \times \text{C/kg} \qquad \text{if } K_{air} \text{ in grays}$$

or $$X = 1.136 \times K_{air} \times \text{R} \qquad \text{if } K_{air} \text{ in rads}$$

For conditions of electronic equilibrium, e.g. at a depth of at least 0.5 cm in a water phantom

$$D_w = X \times \frac{W}{e} \times \frac{(\mu_{en}/\rho)_w}{(\mu_{en}/\rho)_{air}}$$

Taking a value of 1.11 for the ratio of the mass energy absorption coefficients for Co-60 gamma radiation, we get

$$D_w = 37.59 \times X \times \text{Gy} \qquad \text{if } X \text{ in C/kg}$$

or $$D_w = 0.972 \times X \times \text{rads} \qquad \text{if } X \text{ in R}$$

- thirdly 3) The thickness of the surrounding graphite is sufficiently small that the attenuation of photons in it does not result in a significantly non-uniform photon exposure (or intensity) over the irradiated graphite.

Clearly there is a conflict between our two latter conditions and the compromise thicknes of the graphite will depend on the radiation quality being used since this controls both the range of the secondary electrons and the absorption of the photons. For the Co-60 radiation of particular interest to us a thickness of the graphite wall of about 500 mg cm^{-1} is an acceptable compromise.

The energy absorbed by the air (D_a) of the cavity is due to the secondary electrons produced in the surrounding graphite and can be written by

$$D_a = s_a \Psi_a$$

If we would replace the air cavity by graphite we would have

$$D_{gr} = s_{gr} \Psi_{gr}$$

As the air cavity was designed in such a way that $\Psi_a = \Psi_{gr}$, we have

$$D_{gr} = D_a \frac{s_{gr}}{s_a} = D_a \quad s_{gr,a} \qquad \text{(a)}$$

Only secondary electrons produced in the graphite, traversing the cavity, give rise to tertiary electrons in the cavity. If we collect those tertiary electrons we get a charge density J (C/kg_{air}) and therefore the absorbed dose to the air cavity is

$$D_a = \frac{W}{e} J \qquad \text{(b)}$$

As some of the factors used in the calculations depend on the irradiation conditions, it is necessary to specify these conditions if accurate results are to be obtained. Such sets of recommendations are known as codes of practice, or protocols. Most of these codes of practice are national ones, taking into account the national particularities. Great Britain, for example, has a code which takes into consideration that all radiotherapy departments in the country use only one type of reference dosemeter and therefore their code is not directly applicable to other types of dosemeters.

In order to overcome this problem, the IAEA has recently published (Technical Reports Series No. 277 - 1987) a protocol entitled "Absorbed Dose Determination in Photon and Electron Beams - An International Code of Practice".

As the IAEA Protocol is more recent than the other protocols and has been written by authors from different countries who are each familiar with their own national protocols, it is of more general application than any of the individual protocols. As one of its aims was the support of therapy dosimetry in developing countries, it gives numerical corrections linked to individual types of ionization chambers.

The cavity chamber, even very handy, should not be used in routine measurements for reasons of cost-effectiveness. Our thimble chamber, which we described as a practical substitute for the free air chamber, however, already has many of the features of a cavity chamber. Increasing the thickness of its thimble wall (putting on an appropriate build-up cap) makes it suitable to measure exposure (and air kerma) also at high energies. Clearly, also at higher energies it has to be calibrated by comparing its radiation response with the exposure determined by a cavity chamber.

Primary Standard Dosimetry Laboratories (PSDLs) are the custodians of primary standards. They usually operate free air chambers for low and medium energy X-rays and cavity graphite chambers for Co-60 radiation energy. There are about 18 of those PSDLs, all of them located in industrialized countries. It is clear that those few PSDLs could not possibly calibrate all dosemeters in the world used for legal dosimetric measurements, where calibration of the dosemeters is required by law.

Therefore, Secondary Standard Dosimetry Laboratories (SSDLs) were set up. With their secondary standard dosemeters they calibrate the field instruments of the consumer.

Def.: A secondary standard dosemeter is composed of an ionization chamber, power supply, measuring assembly (electrometer) and an overall radioactive check source, all of highest metrological properties in accordance with the state of the art. The dosemeter must have a valid calibration certificate issued by a PSDL.

Explanation: An overall radioactive check source is a container which provides in its interior a suitable radiation field produced by Sr-90 into which the sensitive volume of the ionization chamber can be inserted in a geometrically reproduceable manner. It is used to determine short term and long term stability for quality control of the dosemeter.

New Values of some Physical Interaction Coefficients for Dose Measurements

We have seen that the primary standardization of exposure is based on two equations corresponding to two different measuring concepts:

(a) free air chamber ($h\nu < 300$ keV)

$$X = \frac{Q}{V_\rho} \Pi K_i$$

(b) graphite cavity chamber ($Cs137 < h\nu < 3$ MeV)

$$X = \frac{Q}{V} s_{C,a} \frac{(\mu_{en}/\rho)_a}{(\mu_{en}/\rho)_C} \Pi K_i$$

And we have seen that the primary standardization of air kerma (K_{air}) is realized with the same equipment as the exposure standardization, using the equation

$$K_{air} = X \frac{W_{air}/e}{1 - g}$$

and the calibration of a secondary standard dosemeter in a primary laboratory is based on

$$N_x = \frac{X}{M_u} \quad \text{or} \quad N_k = \frac{K_{air}}{M_u} \qquad M_u = \text{reading of the secondary standard}$$

The relationship between the air kerma calibration factor (N_k) and the exposure calibration factor (N_x) of the secondary standard dosemeter is given by

Finally, the relation between absorbed dose to water and air kerma is given by

$$D_w = K_{air} (1-g) \frac{(\mu_{en}/\rho)_w}{(\mu_{en}/\rho)_{air}}$$

Therefore, $D_w = 1.104 K_{air}$ of D_w and K_{air} are both expressed in either grays or rads.

Problems in Using Simple Conversion Formulae

In principle it would be possible to take a chamber calibrated in exposure or air kerma, use it to measure one of these quantities in a phantom, and then to convert the result to absorbed dose to water using above cited equation. One difficulty in using this simple procedure is that a chamber calibrated in air needs further correction when it is used in a phantom. Another problem is that the photon energy at present used by primary standardising laboratories is cobalt-60 gamma radiation whereas radiotherapy departments in hospitals often use much higher energy X and electron radiation.

Codes of Practice for Radiotherapy Dosimetry

To solve these problems, calculations have been carried out in order to provide factors to convert the calibration factors for a chamber calibrated in air at a certain energy to calibration factors when the chamber is used in a phantom for other energies. In addition to taking account of the differing origins of the secondary electrons in the two media, the calculations also have to make allowance for wall attenuation and the effect of the displacement of the medium by the chamber which is different for different chambers.

APPROXIMATE CHANGES OF CALIBRATION FACTORS OF EXPOSURE AND AIR KERMA SECONDARY STANDARDS

Table I

Physical quantity:	Exposure		Air kerma	
Primary standard (used for calibration)	Free-air chamber	Graphite cavity chamber	Free-air chamber	Graphite cavity chamber
Radiation	X-rays (medium and low energy)	^{60}Co	X-rays (medium and low energy)	^{60}Co
Influence of the new values of the relevant physical constants on the calibration factor (in percent):				
$s_{C,a}$	-	-0.7%	-	-0.7%
W_{air}/e	-	-	+0.35%	+0.35%
g	-	-	-	-0.1%
$(\mu_{en}/\rho)_{a,C}$	-	-0.1%	-	-0.1%
Total change of calibration factor:	-	-0.8%	+0.35%	-0.55%

More accurate data depend on the density of the graphite chamber wall, the size of the cavity and the scattered component in the incident beam.

Primary Standardization

A) Exposure

1) free air chamber ($h\nu < 300$ keV)

$$X = \frac{Q}{V\rho} \Pi Ki$$

2) graphite cavity chamber (Cs 137 < $h\nu$ < 3 MeV)

$$X = \frac{Q}{V} s_{C,a} \frac{(\mu_{en}/\rho_a}{(\mu_{en}/\rho_c} \Pi Ki$$

B) Air Kerma ($K_{air} = X \frac{W_{air/e}}{1 - g}$)

1) free air chamber ($h\nu < 300$ keV)

$$K_{air} = \frac{Q}{V\rho} \frac{W_{air/e}}{1 - g} \Pi Ki$$

2) graphite cavity chamber (Cs 137 < ν 300 keV)

$$K_{air} = \frac{Q}{V} s_{C,a} \frac{(\mu_{en}/\rho)_a}{(\mu_{en}/\rho)_c} \frac{W_{air}/e}{1 - g} \Pi Ki$$

Recommendations of CCEMRI (Comité Consultatif pour les Etalons de Mesure des Rayonnements Ionisants) for implementation Jan. 1, 1986:

$s_{C,a}$ (Co-60) = 1.0003 (correction: -0.7%)

$\frac{(\mu_{en}/\rho)_a}{(\mu_{en}/\rho)_c}$ (Co-60) = 0.9990 (correction: -0.1%)

W_{air}/e = 33.97 (correction: +0.35%)

g (Co-60) = 3.2×10^{-3} (correction: -0.1%)

In its function as the central laboratory of the SSDL network the Agency's Dosimetry Laboratory provides support by:

- organizing and performing annual dose intercomparisons among member laboratories of the SSDL network;

- performing dose intercomparisons for some one hundred radiation therapy centres each year;

- accepting SSDL staff for on-site training;

- undertaking technical co-operation missions to SSDLs;

- designing and developing special devices for use in SSDLs.

Results from many years of TLD postal dose intercomparison measurements with TLDs in hospitals and SSDLs of developing countries confirmed that traceability of radiation measurements has been established.

High accuracy with respect to air kerma and exposure in the SSDLs of our Member States starts to be demonstrated by the first results of the IAEA CARE programme. Part of this programme for Improving Coherence and Accuracy of SSDL REference Instrumentation within the IAEA/WHO Network of SSDLs consists (for purpose of redundancy) of calibration of two independent reference class dosemeters (each consisting of ionization chamber, battery operated power supply and electrometer) in the SSDLs of the Network.

Maintaining and improving performance of SSDLs is supported, in addition, through training courses, workshops, seminars and fellowships for SSDL staff involving more and more the SSDLs by them providing manpower, organizational support and their laboratory facilities.

$$N_k = N_x \frac{W_{air}}{e} \frac{1}{1-g}$$

In its 8th meeting in 1985, Section I of the "Comité Consultatif pour les Etalons de Mesure des Rayonnements Ionisants" (CCEMRI) to the "Comité International des Poids et Mesures" (CIPM) has put forward a recommendation on new values of physical interaction coefficients used in primary standardization. Those changes are:

$s_{C,a}$ (Co-60) = 1.0003 (correction: -0.7%)

$$\frac{(\mu_{en}/\rho)_a}{(\mu_{en}/\rho)_C} \text{ (Co-60)} = 0.9990$$ (correction: -0.1%)

W_{air}/e = 33.97 J/C (correction: +0.35%)

g (Co-60) = 3.2×10^{-3} (correction: -0.1%)

The use of these new values (recommended for 1 January 1986) led to some changes in the determination of exposure and air kerma with primary standards as can be seen from the above mentioned equations. Secondary standards calibrated before the introduction of the new values of interaction coefficients can be adjusted to the changes outlined above by correcting the old calibration factor.

Approximate changes of calibration factors of exposure and air kerma secondary standards are given in table (I). More accurate data depend on the density of the graphite chamber wall, the size of the cavity and the scattered component in the incident beam of the primary laboratory which calibrated the secondary standard dosemeter. Accurate values were partly already published in the open literature by the primary laboratories or can be requested from them.

(a) area monitoring, in which hand-held or fixed dosemeters (monitors) are used to measure the ambient radiation, probably in the quantity exposure or air kerma.

(b) individual monitoring, in which small film or TLD monitors are worn on the surface of bodies of those people particularly at risk, in the quantity exposure or air kerma.

I used by purpose the word monitoring and not dosimetry for the measurement of radiation, as in radiation protection situations one has only a rough idea about the energy and type of radiation and its directional incidence, both in space and in relation to human beings in their working environment. Therefore, on one hand, the radiation protection officer has to relate the reading (signal) of the monitor to metrological quantities in order to establish traceability and normalization. On the other hand, the required derived quantity has to be estimated, which is only possible if the reading of the monitor beforehand was related to a metrological quantity.

At present, the metrological quantities used in radiation protection are still air kerma and exposure. To facilitate the work of the radiation protection officer, manufacturers tried to design radiation protection monitors in such a way that the metrological quantity can be determined from the signal with known accuracy (for example: better than 30%)* and that theoretically determined conversion factors relate those metrological quantities to the effective dose equivalent.

In order to narrow the huge gap existing between exposure (air kerma) and effective dose equivalent, the ICRU 39 proposed new metrological radiation protection quantities which simulate more closely real radiation protection situations. The implementation of these recommended quantities is under investigation.

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*) if the instrument has a calibration

The IAEA/WHO Network of SSDLs

Traceability of measurements in dosimetry is defined as the property of a result of such a measurement whereby it can be related to appropriate standards, generally international or national standards, through an unbroken chain of comparisons.

Developed countries generally have established methods to guarantee the traceability of dosimetric measurements (for example the output measurement of a Co-60 machine by a hospital physicist or the individual monitoring provided by a commercial service).

The complete lack of such traceability links in most developing countries, especially in the field of radiotherapy with the highest possible accuracy requirements of dosimetric measurements, has been preoccupying IAEA and WHO for a long time. Therefore, in 1968, the IAEA with the participation of WHO convened a panel of experts to discuss the dosimetric requirements of radiotherapy centers. The panel recommended the setting up of dosemeter calibration centers (later called Secondary Standard Dosimetry Laboratories - SSDLs) in developing countries. In 1974, experts mainly from the large national standard laboratories discussed the concept of SSDLs and their role in metrology. An SSDL was defined as a laboratory designated by the competent national authority to undertake dosimetry calibrations. For the proper function of the SSDLs the need for dose intercomparison and coordination of the work of individual laboratories was recognized. This led to the establishment of the international IAEA/WHO Network of SSDLs. The network's secretariat is shared by IAEA and WHO, with the Agency's Dosimetry Laboratory (DOL) functioning as the network's central laboratory. Support to the Network is given by most of the big national laboratories, by international bodies e.g. BIPM, ICRU, ICRP, IEC, OIML, and by an SSDL Scientific Committee. Today the Network comprises 50 laboratories, 36 of them located in developing countries. Most of them are equipped with modern instrumentation including radiation machines and secondary standard dosemeters suitable for therapy and radiation protection dose rate levels.

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Radiation Protection Dosimetry

It can be claimed that radiation protection dosimetry is a far more important subject than radiotherapy dosimetry. In most countries there are considerably more health physicists and technicians than medical radiotherapy physicists and their technicians. Only a small proportion of the radiation received by a population arises from radiotherapy compared with other medical and non-medical uses of radiation.

The relatively small amount of time given in this lecture to the practical aspects of radiation protection dosimetry (metrology of radiation protection) is that primary and secondary standardization is in that connection less important than the estimation of the derived quantities based on dose equivalent.

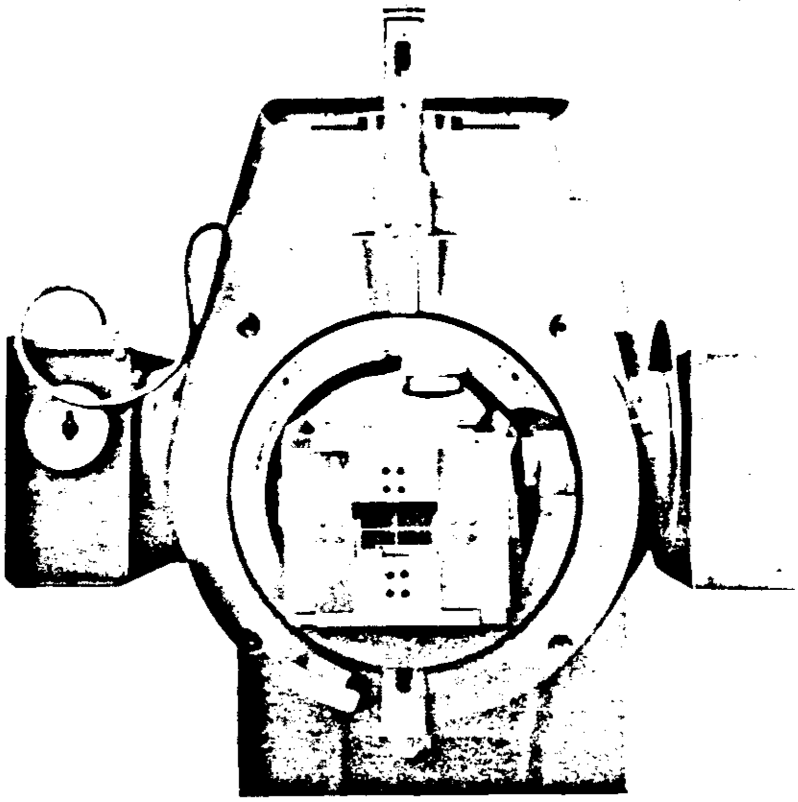
Radiation protection practice as laid down by regulation is governed by three principles

- justification
- dose limitation
- optimization

The evaluation of all these items needs the evaluation of the detrimental effects of radiation. Those detrimental effects of radiation are estimated by derived radiation quantities based on dose equivalent. The most important quantity considered to be an index of risk and detriment is the effective dose equivalent to the whole body weighted according to the different sensitivities of various organs.

The effective dose equivalent is not measurable.

In practical radiation protection two main types of measurements are carried out:



TECHNICAL REPORTS SERIES No. 110

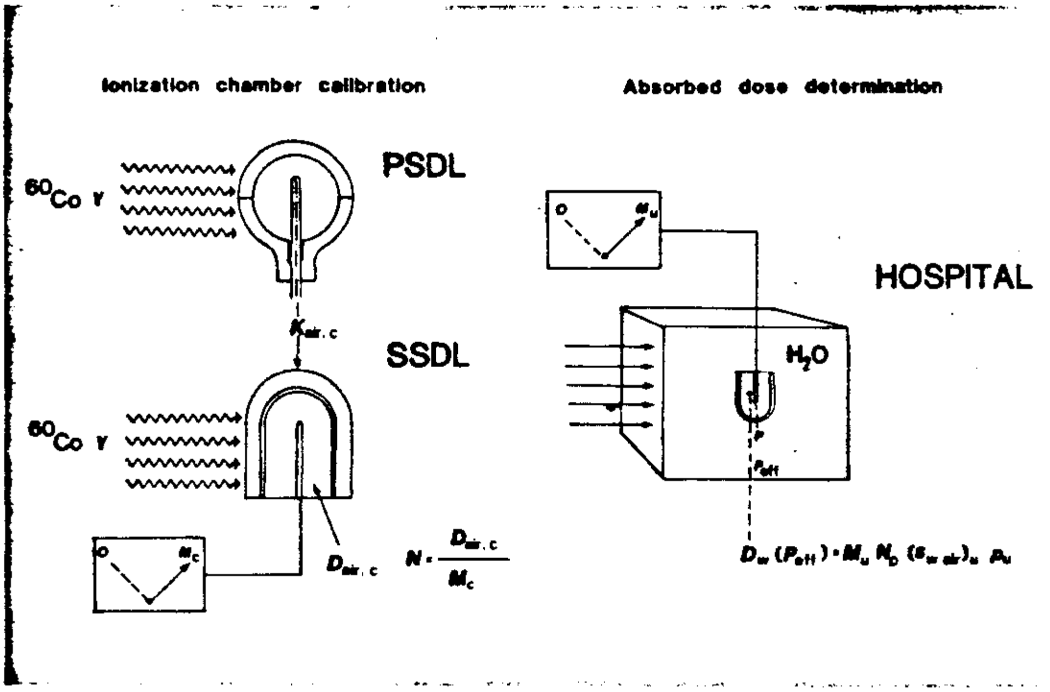
Manual of Dosimetry in Radiotherapy

John B. Massey

PUBLISHED ON BEHALF OF IAEA, WHO and PAHO

INTERNATIONAL ATOMIC ENERGY AGENCY, VIENNA, 1970

A good review indicating peculiarities of radiation protection measurements is given in ICRU 20 (1971) with emphasis on radiation protection instrumentation and in IAEA Technical Reports Series 183 (1971) with regard to calibration methods. TRS 183 was just updated and the updated edition will be published still this year.



TECHNICAL REPORTS SERIES No. 277

Absorbed Dose Determination in Photon and Electron Beams

An International Code of Practice

INTERNATIONAL ATOMIC ENERGY AGENCY, VIENNA, 1987

ICRU REPORT 20

Radiation Protection Instrumentation and Its Application