CALIBRATION OF PERSONAL DOSIMETERS: QUANTITIES AND TERMINOLOGY

V.E. ALEINIKOV
Joint Institute for Nuclear Research,
Dubna, Russian Federation

Abstract

The numerical results obtained in the interpretation of individual monitoring of external radiation depend not only on the accurate calibration of the radiation measurement instruments involved, but also on the definition of the quantities in term of which these instruments are calibrated. The absence of uniformity in terminology not only makes it difficult to understand properly the scientific and technical literature but can also lead to incorrect interpretation of particular concepts and recommendations. In this paper, brief consideration is given to definition of radiation quantities and terminology used in calibration procedures.

1. INTRODUCTION

By the end of the 1980s, a vast amount of new information had accumulated, prompting a new look at the basis of protection against exposure to ionizing radiation. Following these developments, the ICRP, in 1990, revised its standing recommendations [1]. The new recommendations included, amongst other things a new definition of body dose quantities to which the limits are related. Body dose quantities are not measurable as they are defined as average doses in organs and tissues of the human body. Moreover, their values depend on the individual person and on the orientation of the person in the radiation field. For radiation protection practice, special "operational" quantities are therefore important whose values can be determined from measurements and in the units of which measuring instruments can be calibrated. As early as in 1985 the International Commission on Radiation Units and Measurements (ICRU) presented a concept of radiation protection quantities for measurements in area and individual monitoring of external radiation [2]. In this concept, the "operational" quantities are defined so as to be applicable to all types of ionizing radiation, and provide a reasonable and conservative approximation to the effective dose for most photon energies. The concept was further developed by the ICRU in the following years [3 – 5]. The new ICRU quantities are increasingly accepted world-wide. Recent draft standards of the International Organization for Standardization (ISO) in the field of dosimetry make use of the new ICRU quantities. Many countries are preparing for the introduction of these quantities.

The numerical results obtained in the interpretation of individual monitoring of external radiations depend not only on the accurate calibration of the radiation measurement instruments involved, but also on the definition of the quantities in term of which these instruments are calibrated. The absence of uniformity in terminology not only makes it difficult to understand properly the scientific and technical literature but can also lead to incorrect interpretation of particular concepts and recommendations. It is this which has led to the need for the compilation of a unified glossary on calibration of personal dosimeters to be used by participants of the IAEA CRP on Intercomparison for Individual Monitoring of External Exposure to Photon Radiation.

2. OPERATIONAL QUANTITIES AND PHANTOMS

2.1. Personal Dose Equivalent, $H_p(d)$

To obtain an estimate of the effective dose, the operational quantity for the personal dose, **personal dose equivalent, $H_p(d)$,** is used. The **personal dose equivalent, $H_p(d)$,** is the dose equivalent in ICRU 4-element tissue, at an appropriate depth, *d*, below a specified point on the body.

Unit: J kg^{-1}

The special name for the unit of personal dose equivalent is sievert (Sv).

Any statement of personal dose equivalent should include a specification of the reference depth, *d*. In order to simplify notation, *d* should be expressed in mm.

For weakly penetrating radiation, a depth of 0.07 mm for the skin and 3mm for the eye are employed. The personal dose equivalent for these depths is then denoted by $H_p(0.07)$ and $H_p(3)$, respectively.

For strongly penetrating radiation, a depth of 10 mm is frequently employed, with analogous notation.

2.2. Phantoms

For the calibration of personal dosimeters the definition of $H_p(d)$ is considered to include the following phantoms [6] consisting of ICRU 4-element tissue:

- **slab phantom** of 300 mm x 300 mm x 150 mm depth to represent the human torso (for the calibration of whole body dosimeters);
- **pillar phantom,** a circular cylinder with the diameter of 73 mm and the length of 300 mm, to represent a lower arm or leg (for the calibration of wrist or ankle dosimeters);
- **rod phantom,** a circular cylinder with the diameter of 19 mm and the length of 300 mm, to represent a finger (for the calibration of finger dosimeters).

Personal dosimeters should, in principle, be calibrated using standardized phantoms. Three phantoms have been selected for calibrations and type tests with photon, beta and neutron radiations:

a) ISO water slab phantom

The phantom to represent the human torso with regard to backscattering of the incident radiation is the ISO water slab phantom of 30 cm x 30 cm x 15 cm depth. The front face of the water phantom consists of a 2.5 mm thick PMMA (PMMA is polymethyl methacrylate with a density of 1.19 g cm^{-3} and a mass composition of 8.05% H, 59.99% C and 31,96% O) plate. The other phantom sides are 10 mm thick PMMA.

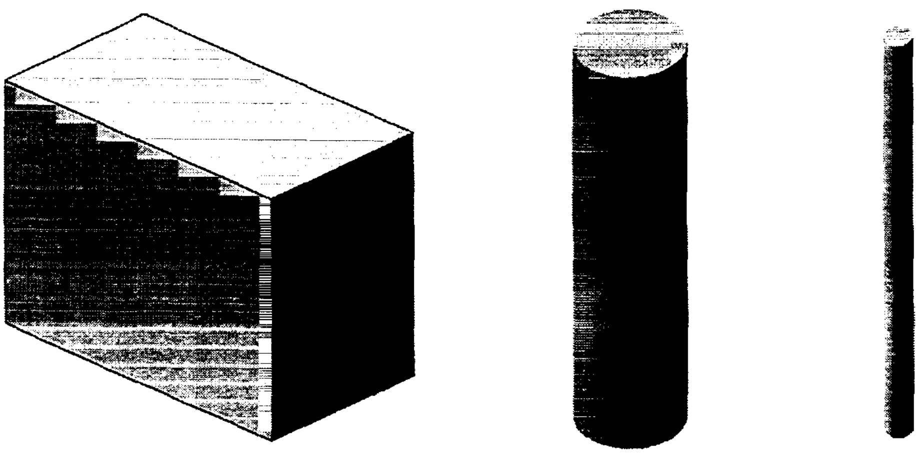
b) ISO water pillar phantom

The phantom to represent a lower arm or leg with regard to backscattering of the incident radiation to test wrist or ankle dosimeters, is the water pillar phantom, a right circular cylinder with a diameter of 73 mm and length of 300 mm. The walls of the phantom consist of PMMA; the circular walls are 2.5 mm thick, the end walls have a thickness of 10 mm.

c) ISO PMMA rod phantom

The phantom to represent a finger with regard to backscattering of the incident radiation to test finger dosimeters, is the PMMA rod phantom, a right circular cylinder with a diameter of 19 mm and a length of 300 mm. The phantom consist of PMMA.

A schematic drawing of the phantoms is given in Figure 1.



(a) **(b)** **(c)**

FIG. 1. Phantoms for the calibration of personal dosimeters: ISO water slab phantom (a) (300 mm x 300 mm x 150 mm), ISO water pillar phantom (b) (73 mm in diameter, 300 mm in height) and ISO PMMA rod phantom (c) (19 mm in diameter, 300 mm in height).

It is obvious that these three types of phantoms are only approximate representations of the respective parts of the body. They do, however, serve the purpose because

- according to the definition of $H_p(d)$, a personal dosimeter should be constructed in such a way that it is sensitive to radiation backscattered from the body; the difference in backscatter between the standardized phantom and the actual part of the body where the dosimeter is worn is thereby, in principle, automatically measured;
- the three different shapes of phantoms cover the needs of calibrations and type-testing
  1) of whole body dosimeters worn, for example, on the trunk to estimate the effective dose, and
  2) of wrist or ankle dosimeters and of finger dosimeters to estimate the partial body doses;
- reference phantoms in which the quantity $H_p(d)$ is defined for calibration of personal dosimeters are consistently composed of ICRU 4-element tissue and are the same shapes as the phantoms actually used; the conversion coefficients given in the standards only relate to the reference phantoms;

- the use of reference phantoms enable consistent calibration conditions to be established at different laboratories.

When these phantoms are used, no correction factors shall be applied to correct for any differences in backscatter relative to ICRU tissue.

3. TERMINOLOGY

Primary Standard

A standard which has the highest metrological quantities in a specified field. Primary standards are maintained at national laboratories that a) perform research for the purposes of metrology and b) participate in recognized international intercomparisons of primary standards laboratories.

Secondary Standard

A standard whose value is fixed by direct comparison with a primary standard, and is accompanied by a certificate which documents that traceability.

Tertiary Standard

A standard whose value is fixed by comparisons with a secondary standard.

National Standard

A standard recognized by an official national decision as the basis for fixing the value, in a country, of all other standards of the given quantity.

Reference Source

A reference source shall be a secondary standard source calibrated with primary standards by a national primary laboratory or at an acknowledged reference laboratory which holds appropriate standards.

Influence quantity

An influence quantity (parameter) is a quantity which may have a bearing on the result of a measurement without being the objective of measurement.

Conventional True Value (of a Quantity)

The conventional true value of a quantity is the best estimate of the value of the quantity to be measured, determined by a primary or secondary standard or by a reference instrument that has been calibrated against a primary or secondary standard.

Response

The response, R, of a measuring instrument is the quotient of the indication, M, of the instrument and the conventional true value of the measured quantity. The type of response should be specified. For example "fluence response" R_{Φ} (response with respect to fluence, Φ)

$$R_{\Phi} = M/\Phi$$

or "dose equivalent response" R_H (response with respect to dose equivalent H)

$$R_H = M/H$$

Calibration

A calibration is the set of operations that establish, under specified conditions, the relationship between the quantity indicated by a dosimeter and the corresponding value realised by standards.

Arrangement for the calibration of personal dosimeters at angle α is given in Figure 2.

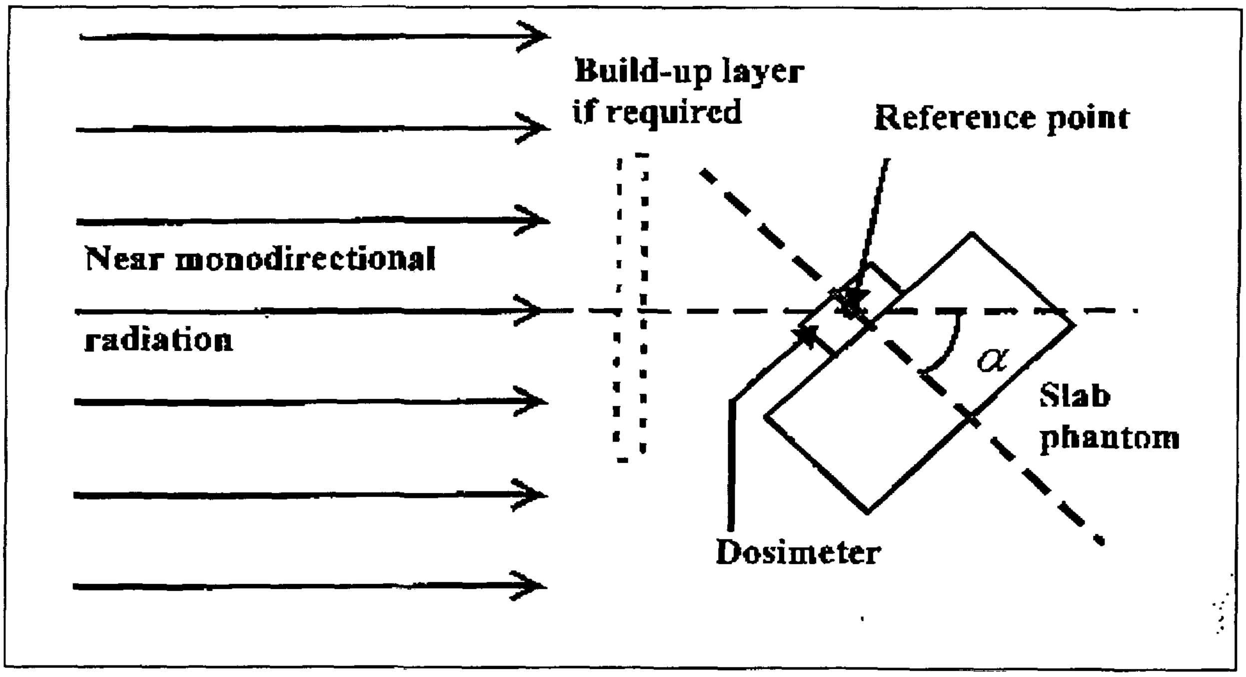


FIG. 2. Arrangement for the calibration of personal dosimeters at angle α.

Calibration Factor

The calibration factor, N, is the conventional true value of the quantity the instrument is intended to measure (measurand), H, divided by the indication, M, (corrected if necessary) given by the instrument under reference conditions i.e.

$$N = \frac{H}{M}$$

Reference conditions

The reference conditions represent the set of influence quantities for which the calibration factor is valid without any correction.

Note: The value for the quantity to be measured may be chosen freely in agreement with the properties of the instrument to be calibrated. The quantity to be measured is not an influence quantity.

Standard test conditions

The standard test conditions represent the range of values of a set of influence quantities under which a calibration or a determination of response is carried out.

Calibration conditions

The calibration conditions are those within the range of standard test conditions actually prevailing during the calibration.

Before any calibration is made the dosimeter shall be examined to confirm that it is in a good serviceable condition and free of radioactive contamination. The set-up procedure and the mode of operation of the dosimeter shall be in accordance with its instruction manual. The calibration conditions represent the range of a set of influence quantities under which a calibration actually is carried out. These conditions should lie within the range of standard test conditions recommended in international standards. Ideally, calibrations should be carried out under reference conditions. As this is not always achievable (e.g. for ambient air pressure) or convenient (e.g. for ambient temperature) a (small) interval around the reference values can be used. The deviations of the calibration factor from its value under reference conditions caused by these deviations should in principle be corrected for. In practice the uncertainty aimed at serves as a criterion as to which influence quantity has to be taken into account by an explicit correction or whether its effect may be incorporated into the uncertainty. The standard test conditions together with the reference conditions recommended by ISO are given in Tables I and II.

Reference direction

The reference direction is the direction, in the co-ordinate system of a dosimeter, with respect to which the angle to the direction of radiation incidence is measured in unidirectional fields.

Reference orientation

The reference orientation of the dosimeter is that for which the direction incident radiation coincides with the reference direction of the dosimeter.

Reference point of a measuring instrument (dosimeter)

The reference point of a measuring instrument is the point to be used in order to position the instrument at the point of test. The reference point should be marked on the instrument by the manufacturer. If this proves impossible, the reference point should be indicated in the accompanying documentation supplied with the instrument.

Note: When calibrating or type-testing a personal dosimeter, the dosimeter and the recommended standard test phantom should be regarded as a unit. The reference point of this unit by convention is the reference point of the dosimeter and this should be positioned at the point of test.

Point of test

The point of test is the point in the radiation field at which the reference point of the instrument is placed for purposes of calibration or type test and at which the conventional true value of the quantity to be measured is known.

TABLE I. RADIOLOGICAL PARAMETERS

Influence quantities	Reference conditions	Standard test conditions (unless otherwise indicated)
Photon energy	^{137}Cs (1)	^{137}Cs (1)
Angle of radiation incidence	Reference orientation	Reference orientation ± 5^0
Contamination by radioactive elements	Negligible	Negligible
Radiation background	Ambient dose equivalent rate $H^*(10)$ 0.1 μSv h^{-1} or less if practical	Ambient dose equivalent rate $H^*(10)$ less than 0.25 μSv h^{-1}

(1) Another radiation quantity may be used if the rated range for the photon energy does not comprise the energy emitted by ^{137}Cs.

TABLE II. OTHER PARAMETERS

Influence quantities	Reference conditions	Standard test conditions (unless otherwise indicated)
Ambient temperature	20^0	18^0C to 22^0C 1)2)
Relative humidity	65%	50% to 75% 1)2)
Atmospheric pressure	101.3 kPa	86 to 106 kPa 1)2)
Stabilisation time	15 min	>15 min
Power supply voltage	Nominal power supply voltage	Nominal power supply voltage ± 3%
Frequency 3)	Nominal frequency	Nominal frequency ± 1%
A.C. power supply	Sinusoidal	Sinusoidal with total wave form harmonic distortion less than 5% 3)
Electromagnetic field of external origin	Negligible	Less than the lowest value that causes interference
Magnetic induction of external origin	Negligible	Less than twice the value of the induction due to the earth's magnetic field
Assembly controls	Set up for normal operation	Set up for normal operation

(1) The actual values of these quantities at the time of test shall be stated.

(2) The values in the table are intended for calibrations performed in temperate climates. In other climates, the actual values of the quantities at the time of calibration shall be stated. Similarly, a lower limit of pressure of 70 kPa may be permitted where instruments are to be used at higher altitudes.

(3) Only for assemblies which are operated from the main voltage supply.

Kerma to Dose Equivalent Conversion Coefficient

The kerma - to - dose equivalent conversion coefficient, h_k, is the quotient of the dose equivalent, H, and the air kerma, K_a, at a point in the radiation field:

$$h_k = H/K_a$$

Any statement of these conversion coefficients requires the statement of the type of dose equivalent, e.g. ambient, directional or personal dose equivalent.

Relative intrinsic error, I(%)

The relative intrinsic error is defined as the quotient, expressed as a percentage, of the error of the indication, H-M, of a quantity and the conventional true value of the measurand, H, when the measuring instrument is subjected to a specified reference radiation under specified reference conditions

$$I(\%) = 100 \cdot (H-M)/H$$

Half value layer (air kerma), HVL

The half value layer (air kerma), HVL, is the thickness of specified material which attenuates the photon beam to an extent such that the air kerma rate is reduced to one half of its original value. In this definition, the contribution of all scattered photon radiation other than any which might be present initially in the beam concerned, is deemed to be excluded.

Effective energy, E_{eff}

The effective energy, E_{eff}, of radiation comprised of X rays with a range of energies, is the energy of those monoenergetic X rays which have the same HVL.

Backscatter factor

The backscatter factor is the ratio of air kerma in front of a phantom to the air kerma at the same position free in air. The field is considered to be unidirectional with a direction of incident perpendicular to the phantom surface.

Traceability

Calibrations should be traceable to an appropriate national standard. This means:

- That each reference instrument used for calibration purposes has itself been calibrated against a reference instrument of higher quality up to the level at which the higher quality instrument is the accepted national standard.
- That the frequency of such calibration, which is dependent on the type, quality, stability, use and environment of the lower quality standard, is such as to establish reasonable confidence that its value will not move outside the limits of its specification between successive calibrations.
- That the calibrations of any instrument against a reference instrument is valid in exact terms only at the time of calibration, and its performance thereafter must be inferred from a knowledge of the factors mentioned above.

The mode of operation of the reference instrument shall be in accordance with its calibration certificate and the instrument instruction manual, e.g. set zero control, warm up time, battery check, application of range or scale correction factors. The time interval between periodic calibrations of the reference instrument shall be within the acceptable period defined by national regulations. Where no such regulations exist, the time interval should not exceed 3 years. Measurement shall be made regularly, using either a radioactive check source or a calibrated radiation field, to determine that the reproducibility of the reference instrument is within 2% of the certificated value. Corrections shall be applied for the radioactive decay of the source and for changes in air density from the conditions when applicable.

4. CONCLUDING REMARKS

Most of the quantities and terms discussed have been defined by the ICRU and the ISO. The relevant definitions have been extracted from ISO standards [6] and IAEA draft Handbook on Calibration [7] to which reference should be made for further details and explanatory information.

REFERENCES

[1] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION. Recommendations of the International Commission on Radiological Protection. ICRP Publication 60, Annals of ICRP **21**, 1–3, Pergamon Press, New York (1991).

[2] INTERNATIONAL COMMISSION ON RADIATION UNITS AND MEASUREMENTS. Determination of Dose Equivalents Resulting from External Radiation Sources, ICRU Report 39, ICRU, Bethesda, MD (1985).

[3] INTERNATIONAL COMMISSION ON RADIATION UNITS AND MEASUREMENTS. Determination of Dose Equivalents from External Radiation Sources -Part 2, ICRU Report 43, ICRU, Bethesda, MD (1988).

[4] INTERNATIONAL COMMISSION ON RADIATION UNITS AND MEASUREMENTS. Measurement of Dose Equivalents from External Photon and Electron Radiations, ICRU Report 47, ICRU, Bethesda, MD (1992).

[5] INTERNATIONAL COMMISSION ON RADIATION UNITS AND MEASUREMENTS. Quantities and Units in Radiation Protection Dosimetry, ICRU Report 39, ICRU, Bethesda, MD (1993).

[6] INTERNATIONAL STANDARDS ORGANIZATION. Reference Photon Radiation: Calibration of Area and Personal Dosemeters and the Determination of their Response as a Function of Photon Energy and Angle of Incidence, ISO/DIS 4037-3.

[7] INTERNATIONAL ATOMIC ENERGY AGENCY, IAEA Calibration Handbook.