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Secondary standard dosimetry laboratories for the calibration of dosimeters used in radiotherapy

Laboratoires secondaires d'étalonnage en dosimétrie pour l'étalonnage des dosimètres utilisés en radiothérapie

OIML D 21 Edition 1990 (E)

ORGANISATION INTERNATIONALE
DE MÉTROLOGIE LÉGALE

INTERNATIONAL ORGANIZATION
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Foreword

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International Recommendations and International Documents are published in French (F) and English (E) and are subject to periodic revision.

This publication – reference OIML D 21 (E), edition 1990 – which is under the responsibility of TC 15/SC 1 *Measuring instruments for ionizing radiations used in medical applications*, was approved by the International Committee of Legal Metrology in 1988.

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SECONDARY STANDARD DOSIMETRY LABORATORIES for the CALIBRATION of DOSIMETERS USED in RADIOTHERAPY

1. Introduction

1.1. High accuracy in the dosimetry of ionizing radiations is essential in order to assure the quality of radiotherapy throughout the world and in order to compare successfully clinical results on an international basis. Similar requirements exist in other related areas of work where radiation is internationally applied, for example in radiobiological studies. This accuracy can only be achieved if calibrated radiation dosimeters are available and checked regularly to maintain acceptable measurement performance.

1.2. In many countries the lack of convenient access to a primary standardising laboratory has inhibited the provision of calibrated dosimeters and their regular re-calibration. One practical solution to this problem is the establishment of a wider network of calibration laboratories equipped with a reference instrument calibrated by one of the primary laboratories. Such secondary standardising laboratories, operating to prescribed procedures with careful maintenance of standards and consistency checks, are capable of providing calibrations of field instruments with an accuracy only slightly inferior to that obtained by direct comparison with a primary standard.

Note: By 1986, Secondary Standard Dosimetry Laboratories (SSDLs) were established in over 40 countries. Most of them are members of the International Atomic Energy Agency/World Health Organisation (IAEA/WHO) Network of SSDLs which was established in 1976. This Network assists in developing working methods, in establishing access to primary standards and, through the IAEA Dosimetry Laboratory, in performing dose intercomparisons.

1.3. The main role of SSDLs is to bridge the gap between the Primary Standard Dosimetry Laboratories (PSDLs) and the user of ionizing radiation by enabling the transfer of dosimeter calibrations from the primary standard to the field instrument. SSDLs should also advise the user in the proper use of field instruments. Their tasks therefore include the maintenance of secondary standard dosimeters, the calibration of field instruments against them, and the issuing of calibration certificates that specify all relevant calibration conditions. In order to assure their continued competence, SSDLs must participate, whenever possible, in measurement comparisons with other laboratories in cooperation with other SSDLs and PSDLs.

2. Scope

2.1. In this Document, the SSDL is understood to be a part of the national service of metrology and whose responsibility is to verify field dosimeters by calibrating them against secondary standard instruments which are traceable to primary national and/or international standards [1].

2.2. This Document is intended as a guide for the establishment and the operation of an SSDL. It provides guidance on procedures for testing, verification and calibration of instruments which include secondary standards, field instruments and associated calibration equipment for radiation therapy.

2.3. This Document does not cover instrumentation used for radiation protection measurements.

The general criteria, developed by IAEA/WHO for the establishment of an SSDL including suitable staff and laboratory layout have been published by IAEA/WHO [2].

2.4. This Document does not cover considerations of the radiation safety requirements for laboratory staff and other persons. Such requirements should conform either to national regulations or available international recommendations shall be followed.

3. Quantities and dissemination schemes

3.1. Quantities and Units

The radiation quantities, units and their symbols are defined and listed by the International Commission on Radiation Units and Measurements, ICRU, Report 33 [3].

The International System of Units, SI, was adopted by the 11th General Conference of Weights and Measures in 1960 and now has been officially introduced in almost all countries. The general implementation of the SI causes difficulty for the continued use of the special radiation units of rontgen, rad, rem and curie, because of the inconvenient factors introduced by the SI equivalents. In accordance with a proposal by ICRU the 1975 meeting of the 15th General Conference of Weights and Measures adopted special names for SI radiation units namely the becquerel (Bq) for the unit of activity of radionuclides and the gray (Gy) for the unit of absorbed dose. In 1977 the special name sievert (Sv) was proposed jointly by ICRU and ICRP (International Commission on Radiological Protection) for the unit of dose equivalent and was approved by the 16th General Conference of Weights and Measures in 1979. No special name has been proposed for the SI unit of exposure.

The ICRU recommended that the special radiation units (rontgen, rad, rem and curie) be phased out by 1985, and be replaced by the appropriate SI units [3]. During the transition period the SI units were to be used jointly with the old special radiation units, the latter being written in brackets [4]. Radiation quantities, units and symbols used in this Document are listed in Table 1.

3.2. Dissemination Schemes

Two modes are envisaged for the operation of a dissemination chain comprising a primary standard at a PSDL, a calibrated secondary standard and calibration of a users' instrument at an SSDL.

3.2.1. Firstly the simple transfer of calibration, expressed in terms of a calibration factor, can be carried out by the measurement of the same quantity at each stage of the chain. This mode is preferred because there is no need for conversion factors and consequently less chance of introducing errors.

3.2.2 Secondly the case where the quantity the end user requires to measure differs from the quantity in terms of which the initial calibration of the secondary standard is provided. In this case conversion factors can be applied to derive a calibration for the secondary standard in terms of the quantity required by the user.

TABLEAU 1 : GRANDEURS, UNITES ET SYMBOLES DE RAYONNEMENTS UTILISES DANS LE PRESENT DOCUMENT

Grandeur	Unité SI	Symbole	Nom spécial de l'unité SI	Symbole du nom spécial	Relation entre l'unité SI et l'ancienne unité spéciale
Dose absorbée	joule par kilogramme	$J \cdot kg^{-1}$	gray	Gy	1 Gy = 100 rad
Débit de dose absorbée	joule par kilogramme seconde	$J \cdot kg^{-1} \cdot s^{-1}$	gray par seconde	$Gy \cdot s^{-1}$	$1\ Gy \cdot s^{-1} = 100\ rad \cdot s^{-1}$
Kerma	joule par kilogramme	$J \cdot kg^{-1}$	gray	Gy	1 Gy = 100 rad
Débit de kerma	joule par kilogramme seconde	$J \cdot kg^{-1} \cdot s^{-1}$	gray par seconde	$Gy \cdot s^{-1}$	$1\ Gy \cdot s^{-1} = 100\ rad \cdot s^{-1}$
Exposition	coulomb par kilogramme	$C \cdot kg^{-1}$	—	—	$1\ C \cdot kg^{-1} = \frac{10^4}{2{,}58} R$
Débit d'exposition	coulomb par kilogramme seconde	$C \cdot kg^{-1} \cdot s^{-1}$	—	—	$1\ C \cdot kg^{-1} \cdot s^{-1} = \frac{10^4}{2{,}58} R \cdot s^{-1}$
Activité	un par seconde	s^{-1}	becquerel	Bq	$1\ Bq = \frac{10^{-10}}{3{,}7} Ci$

Note: Le SI autorise l'expression de ces unités en d'autres unités de temps, c'est-à-dire minutes et heures.

Possible dissemination chains illustrating routes between the various primary and user quantities are shown in Figure 1. The calibration factors initially determined for the secondary standard are denoted by N and the factor given by the SSDL for the users' instrument by N. Examples of the first mode of operation are illustrated by the chains shown by the horizontal solid lines. For example, an absorbed dose standard, D is used to provide an absorbed dose calibration factor ND for the secondary standard which is in turn used to calibrate a users' instrument to yield a factor ND [5]. In the second mode of operation the transition between quantities is illustrated by the vertical dotted lines, indicating the application of conversion factors to the secondary standard. For example, four such transitions are illustrated in Figure 1 and are grouped into two types. The first (a) includes only ionisation chamber-independent factors and the second (b) includes both chamber-independent and chamber-dependent factors. The second transition (b) therefore necessitates the use of appropriate dosimetry protocols [6, 7, 8, 9]. Other dissemination routes are possible but are of limited practical value.

4. Calibration equipment and facilities [*]

4.1. Calibration set-up for X-rays

A schematic diagram of a suitable layout of the apparatus for calibrating dosimeters with X-rays is shown in Figure 2. This calibration set-up usually consists of an X-ray generator with a protective housing around the X-ray tube; initial (D_1), beam limiting (D_2) and shielding (D_3 and D_4) diaphragms; shutter (S); filters (F); monitor chamber (M); absorbers for HVL measurements (A); reference ionisation chamber (R); and ionisation chamber of the instrument to be calibrated (I).

The different components of the calibration set-up should be mounted on a bench — similar to an optical bench — with suitable holders and trolleys for precise adjustment. These components, including holders and trolleys, should be rigidly mounted, produce the minimum scattered radiation and be totally outside the useful beam.

4.1.1. X-ray generators

Two X-ray generators are likely to be required: for example one for low energy X-ray qualities with a tube voltage range from about 10 to 60 kV and another for medium energy X-ray qualities with a voltage range from about 50 to 300 kV. At least 30 mA tube current is desirable for the low energy and 10 mA for the medium energy range. Each X-ray generator shall have its own calibration bench.

The effective focal spot size of the X-ray tube should be between 2 mm and 5 mm. A low inherent filtration is required for the X-ray tube to be used effectively down to the lower tube potentials. The inherent filtration of the lower energy tube should be no more than about 2 mm beryllium and for the higher energy tube no more than about 4 mm aluminium equivalent [**].

The X-ray generator should be of the constant potential type with any superimposed alternating potential not greater than 10 % (peak to peak) of the mean potential at the tube currents employed for calibration work. The tube voltage should be continuously variable over its useable range and be re-settable at any voltage with a precision of ± 1 %.

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[*] Many of the recommendations given in this section are based upon information contained in IAEA Technical Report Series No. 185.

[**] The measurement of the inherent filtration in terms of aluminium equivalent is described in point 3.1.3.3 of ISO Standard 4037 [10].

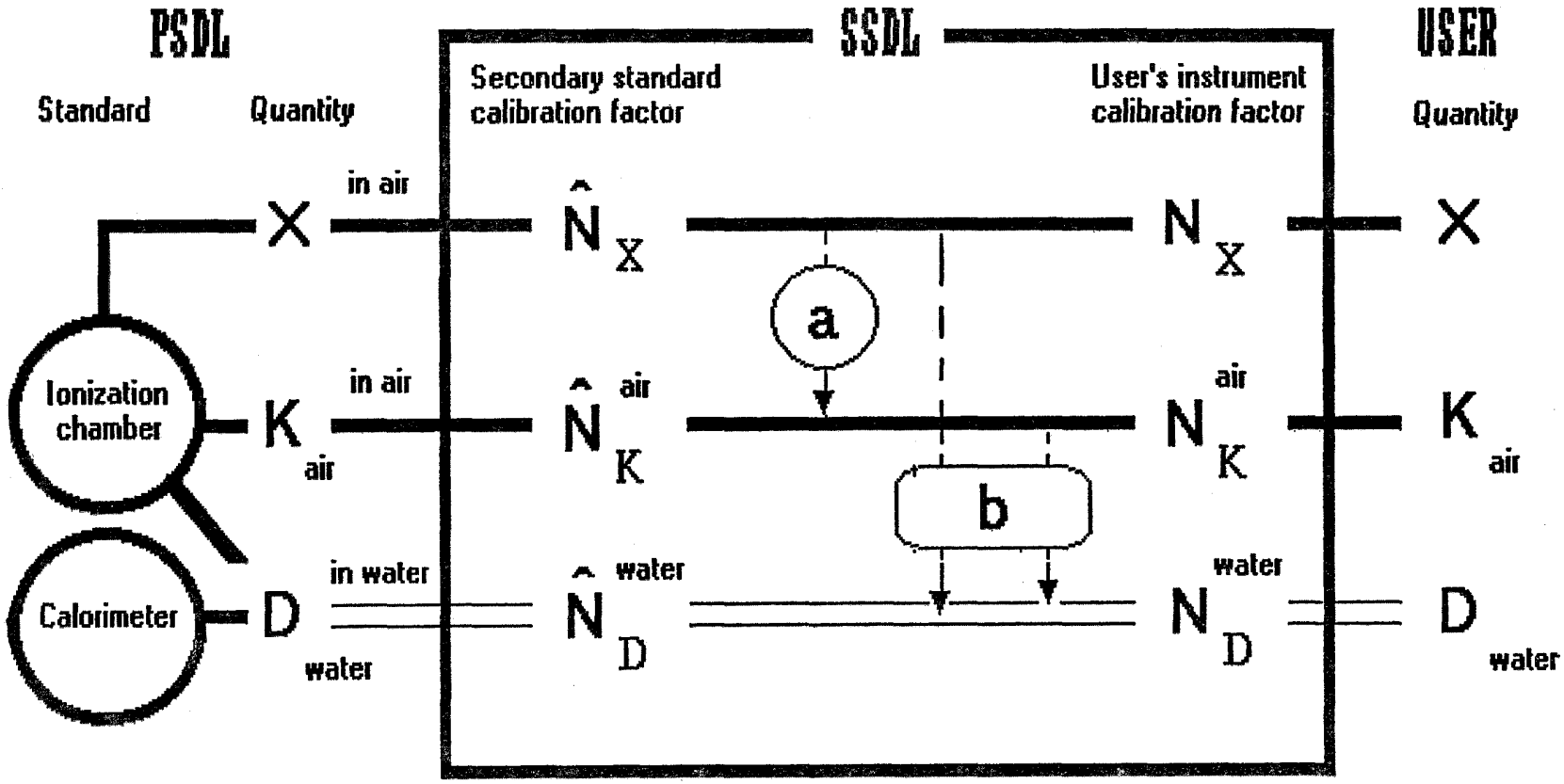

FIG. 1 DISSEMINATION SCHEMES FOR DOSIMETRY QUANTITIES

X = exposure, K = kerma, D = absorbed dose.

The medium is indicated by a suscript for quantities and a superscript for calibration factors.

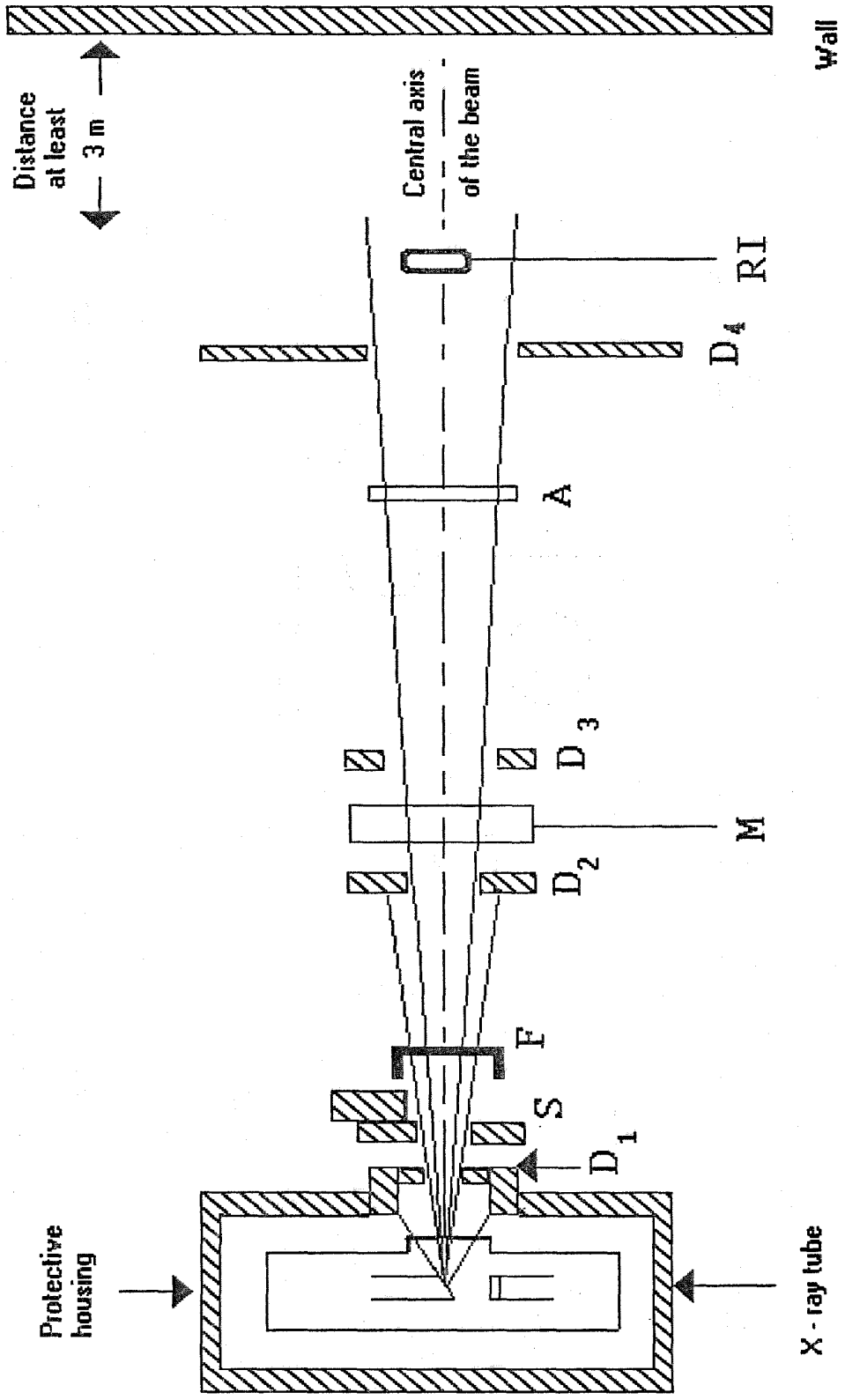

FIG. 2 SCHEMATIC DIAGRAM OF A CALIBRATION SET-UP FOR X-RAY
(for symbols, see text of point 4)

A stabilizer should be used to reduce variation in voltage to less than 0.3 % for expected changes in mains voltage or frequency.

The X-ray tube should be mounted in a protective (shielding) housing which would permit no appreciable radiation to emerge in any direction other than that of the useful beam. Calibrations should normally be in the range of air kerma rates from about 10 mGy/min to 1 Gy/min. (Corresponding to exposure rates of about 1 R/min to 100 R/min). The size of the laboratory and the shielding should be such that the contribution of scattered radiation at the measurement position does not exceed 5 % of the exposure rate.

The X-ray tube must be adjustable so that the X-ray beam can be accurately aligned with the axis of the calibration bench. After alignment the tube must be fixed rigidly in position.

4.1.2. Initial diaphragm (D_1)

This is often supplied as part of the X-ray tube housing; it should be just large enough to allow the transmission of the largest field expected to be used and should be as close as possible to the X-ray tube target.

4.1.3. Shutter (S)

This can be either two shutters or one dual-purpose shutter and serves two purposes as follows:

a) a safety shutter, which may be part of the X-ray tube housing, to attenuate the radiation to a safe level for personnel, and thus to allow improved X-ray beam stability by making it unnecessary to switch the high potential to the X-ray tube on and off for each irradiation;

b) a fast-acting shutter, having a transmission of less than 0.1 %, to begin and to terminate each irradiation and which permits an operating time between full irradiation and zero irradiation of the chamber to be less than 0.1 % of the usual irradiation time. (The irradiation time should be corrected if necessary).

Unless acting as an initial diaphragm (D_1), the aperture of the shutter must be larger than the diameter of the X-ray beam at its position. A shutter thickness of about 1 mm lead for the low energy X-ray qualities (≤ 60 kV tube voltage) and a thickness of about 15 mm lead for the medium energy X-ray qualities (50 to 300 kV tube voltage) is necessary to achieve the required attenuation of the beam. The shutter's position in the radiation beam, in relation to the filters (F) and the beam limiting diaphragm (D_2), is arbitrary.

4.1.4. Filters (F)

For calibration purposes the X-ray beam normally requires additional filtration. This should be chosen so that the radiation qualities used in calibration are similar to those in use for radiotherapy. Filters made from metal of adequate purity should be mounted as close as possible to the shutter, with the highest atomic number filters nearest to the X-ray tube window. A suitable set of filters may be mounted on a wheel to facilitate changing.

Aluminium filtration alone may be used to achieve X-ray beams with half-value layers up to about 4 mm Al (about 0.15 mm Cu). For higher half-value layers copper filtration should be used (with 1 mm Al after the Cu filter). For half-value layers above 2 mm Cu tin filtration should be used, followed by 0.5 mm Cu and 1 mm Al.

Note: The filter material should be as homogeneous as possible ie, without pin-holes, flaws, and cracks etc. Suitable filter sets can usually be constructed from aluminium and copper sheets with thickness varying by 0.1 to 5 mm. Materials of suitably high purity are available commercially. Particular attention should be paid to avoiding impurities of higher atomic number.

4.1.5. Beam limiting diaphragm (D_2)

This defines the size of the useful beam at the point of measurement and should be either adjustable or interchangeable. Its thickness should be sufficient to transmit less than 0.1 % of the radiation outside the useful beam.

This diaphragm may be made of steel or brass with a thickness of about 6 mm for the low energy range or must be made of lead (or other suitable high density material) with a thickness of about 15 mm for the medium energy range.

At the plane of the chamber to be calibrated or tested, the field size should be as small as possible in order to reduce scattered radiation, stem leakage, etc., and yet must be sufficiently large to uniformly irradiate the ionisation detector. The non-uniformity of the beam over the area of the detector should be less than 1 %.

4.1.6. Monitor chamber (M)

For X-ray calibrations, unless the simultaneous irradiation method (tip to tip calibration - see point 4.1.9) is used, a transmission ionisation chamber should be positioned to accept the entire collimated beam after it has passed through the filters and the beam limiting diaphragm. All readings of the reference ionisation chamber and of the instrument to be calibrated should be normalised via the monitor chamber readings.

4.1.7. Shielding diaphragm (D_3)

The effect on the monitor chamber of back-scattered radiation from the reference chamber and from the chamber to be calibrated is normally small; however, if it is found to be significant corrective action should be taken. It may be reduced by introducing a shielding diaphragm (D_3) to shield the monitor chamber. This diaphragm may be adjusted to reduce penumbra but should not limit the useful beam.

Note: It is good practice to place all the components listed in points 4.1.2 through 4.1.7 as close to the target as possible consistent with the production of a narrow penumbra, in order to minimise scatter at the position of the ionisation chambers.

The beam limiting (D_2) and the shielding (D_3) diaphragms may be mounted close to the two sides of the monitor chamber.

4.1.8. Additional diaphragm (D_4)

An additional adjustable or interchangeable diaphragm, somewhat further from the target may sometimes be used to reduce the penumbra still further, and it provides additional shielding to that given by the shielding diaphragm (D_3) described in point 4.1.7.

4.1.9. Ionisation chamber support system (R, I)

When the substitution method of calibration is being used, the point of measurement of the reference ionisation chamber and that of the ionisation chamber of the intrument to be calibrated must be positioned alternately at the same point on the axis of the useful beam.

If the simultaneous irradiation method is being used for comparing thimble chambers of similar size and scattering properties, they must be fixed side by side or tip-to-tip symmetrically about the axis of the useful beam at the same distance from the source.

The support system must be capable of adjustment, and of holding the chambers rigidly. The support should be wholly outside the X-ray beam in order to produce a minimum of scattered radiation at the measurement position. An interchange of the reference ionisation chamber and the ionisation chamber of the instrument to be calibrated should be possible using mechanical devices capable of easy and speedy operation. The support system should also be capable of holding a phantom (for the simultaneous irradiation method) or two phantoms (for the alternative irradiation method) when quantities in media other than air are to be determined.

The central axis of the radiation beam should be determined radiographically and defined optically, e.g. a laser or light beam can provide an easy alignment of the calibration system.

The support system should be sufficiently long to enable the source-chamber distance to be about equal to the source-skin distance (SSD) used in radiation therapy; however, in practice, a longer distance is often necessary to accommodate beam shutter, filter wheel, monitor chamber, etc. For low-energy radiation (10 to 60 kV) a distance of between 30 and 50 cm is recommended, while for medium-energy and high-energy radiation a distance of between 50 and 100 cm is recommended. However, for low-energy radiation additional data may have to be obtained at values of source-chamber distance less than 30 cm.

In order to reduce errors due to uncertainty in chamber positions, an easily removable and accurately replaceable device should be available to check the position of the chambers; for example a telescope mounted perpendicular to the beam of radiation can be used for this purpose. At 50 cm distance from the target, for instance, the chamber centres must be within 0.5 mm of the same target distance if errors due to variable positioning are not to exceed 0.2 %.

4.1.10. Absorbers for half value layer (HVL) measurements (A)

The absorbers used in the HVL measurements should be fixed approximately half way between the measurement chamber and the source, however, attention should be paid to the possibility of backscatter from the absorber to the monitor. Aluminium sheets with thicknesses between 0.02 and 5 mm are needed and should have a purity of 99.99 % for half-value layer measurements. Copper sheets from 0.1 to 5 mm thickness are also needed; however, they need not have high purity. An HVL absorber should have adequate uniform thickness and should be as homogeneous as possible, i.e. without air-holes, flaws, cracks, etc.

Where possible the accuracy of the thickness measurement should be ± 5 μm or ± 1 % whichever is the greater. To achieve this weighing may be required for foils thinner than about 0.5 mm: such foils must be sufficiently uniform in thickness.

4.2. Calibration set-up for gamma-rays

Gamma-ray calibration may be carried out with either a ^{60}Co or ^{137}Cs teletherapy unit. The activity of the source should be high enough to produce an air kerma rate of at least about 0.1 Gy/min (corresponding to an exposure rate of about 10 R/min) at 1 metre distance. The source should have adequate shielding and a variable size beam collimator. Any associated timing errors due, for example, to source or shutter transit times should be determined and appropriate correction applied if necessary.

A gamma-ray source requires no additional filtration or monitor chamber. It should have its own built-in shutter and/or source storage arrangement. The exposure timer should be used to normalise measurements for different irradiation periods. The requirements of the calibration bench and of the ionisation chamber support system are otherwise similar to those of a calibration set-up for X-rays.

The availability of a gamma-ray beam is strongly recommended since it provides a continuously available reference source for constancy checks (see point 6.2).

5. Instruments

5.1. Reference instruments

An SSDL must have a secondary standard dosimeter, calibrated and recalibrated as necessary at a PSDL. This will normally be stored carefully under conditions which minimize the possibility of change in its calibration factor. It may be used for the routine calibration of other instruments, or it may be used solely to check from time to time the calibration of one or more tertiary (reference) standard instruments which are then used for routine calibrations. It is essential that a laboratory's secondary standard dosimeter and any reference standard dosimeters are maintained with the utmost care and should conform to IEC Publication 731 (1983) specifications [11] for reference class instruments. A radioactive source should be available to provide an overall check on the dosimetry system. The overall uncertainty attributed to the calibration of a field instrument is likely to be less when it is compared directly with a secondary standard rather than a tertiary level reference instrument. The difference is expected to be small, and in any case such differences must be balanced against the greater possibility of a change in the calibration factor of the secondary standard, if routinely used; it is emphasized that the whole work of the SSDL depends on the stability of the secondary standard instrument.

A reference dosimeter usually consists of three basic units — the ionisation chamber, the measuring assembly, and may also include a portable stability check source.

5.1.1. Ionisation chamber

The ionisation chamber of a secondary standard dosimeter must have a high degree of long term stability and low energy dependence. Any variation in the response should not be greater than 0.5 % in a year.

Thimble ionisation chambers for medium- and high-energy radiation measurements usually have sensitive volumes between about 0.1 cm^3 and about 1.0 cm^3. The change in response with energy of such chambers should be less than ± 2 % in the range of half-value layers from 2 mm Al to 3 mm Cu, i.e. from approximately 70 kV to 250 kV X-ray tube potentials. For a chamber stated as being suitable for use with high-energy radiation, the total wall thickness (including a separate build-up cap if provided) must be adequate to give electron equilibrium at least for ^{60}Co gamma radiation. The response of such a chamber for ^{60}Co gamma radiation, using the appropriate build-up cap, must not differ from the response for X-rays of 1.8 mm Cu half value layer, about 200 kV, by more than 5 %.

Ionisation chambers for measuring low-energy radiation usually possess an entrance window consisting of a thin membrane or mesh through which the radiation enters the measuring volume (thin-window chambers). The limit of variation of response of such chambers will normally be within ± 2 % in a range of half-value layers from 0.05 mm to 2 mm Al, i.e. from approximately 12 kV to 70 kV X-ray tube potentials.

The ionisation chamber of a secondary standard dosimeter should be unsealed, designed to equilibrate rapidly with exterior ambient atmospheric conditions.

The ionisation chamber may be calibrated together with the measuring assembly or separately. In the latter case its calibration factor should be given in units of the appropriate radiation quantity per unit charge.

Special cables are necessary to connect the ionisation chamber to the measuring assembly. In general, a high insulation co-axial cable will generate electrical noise whenever it is flexed or otherwise deformed. Although this will usually be shortlived, it may give rise to errors if the cable is moved during a measurement. The cable may generate also a d.c. potential difference when it is strained, and this may take some time to decay; measurements may be impossible during this time. The co-axial cable connecting the ionisation chamber to the measuring assembly should therefore be of a "non-microphonic" or "low-noise" type, designed to minimise these effects.

5.1.2. Measuring assembly

The main purpose of this device is to measure the charge or current from the ionization chamber and convert it into a form suitable for display, control or storage. It may also provide a power supply for the ionisation chamber polarising potential.

The long-term stability of the measuring assembly must be better than ± 0.5 % in a year.

A display device must be provided for the visual presentation of data from which the value of the relevant radiation quantity can be derived.

The measuring assembly may be calibrated with the ionisation chamber or the measuring assembly may be calibrated separately. In the latter case, the measuring assembly shall be calibrated in units of electrical charge or current. The measuring ranges of such a charge/current measuring instrument shall be appropriate for the ionisation chamber(s) with which it is to be used.

5.1.3. Portable stability check source

The purpose of a portable stability check source is to enable a constancy check to be made of the overall performance of the complete dosimeter and to ensure that no significant change occurs between calibration of the secondary standard at the PSDL and use for calibration at the SSDL. It must be noted that such a source should not under any circumstances be used for chamber calibration. Such a device should irradiate the ionisation chamber uniformly. The geometrical relationship between the radioactive source and the chamber must be accurately repeatable so as to minimize the effect of small changes in chamber position. It must be possible to determine the temperature at the position of the ionisation chamber. The relative standard deviation of a single check source measurement, determined from 10 repeated measurements, should not exceed 0.3 %: higher values should lead to an investigation.

To protect laboratory personnel from unwanted radiation the source should be adequately shielded and provided with a shutter which prevents escape of radiation when not in use.

A typical check source, for a thimble chamber, is a cylindrical source of $^{90}Sr + ^{90}Y$, encapsulated in silver foil. $^{90}Sr + ^{90}Y$ is a pure beta-particle emitter, with ^{90}Sr half-life of about 28 years, so it needs a decay correction of only a few tenths percent per month. The maximum energy of the ^{90}Y beta particles (2.2 MeV) is adequate to penetrate the silver encapsulation and the chamber wall.

In cases where a portable stability check source is not available, or is not sent with the secondary standard to the PSDL, the constancy of the secondary standard must be checked by the methods described in point 6.2.

5.2. Monitor instrument

5.2.1. Monitor chamber

This is a parallel-plate transmission chamber whose sensitive volume should extend beyond the diameter of the largest beam required. As far as possible the radiation field should not be disturbed by the monitor chamber, and in particular it must not create shadows in the effective radiation beam. The walls should be sufficiently thin so as not to add significantly to the filtration of the beam. This may not be possible at lower radiation energies, and then the filtration added by this component should be included in the total filtration. If the chamber window thicknesses do not ensure electron equilibrium, care should be taken that the response of the chamber is not influenced by any variation in scattering conditions around the chamber during the measurement. The variation of response with energy of a monitor chamber should be less than ± 15 % in the range used, and should not exceed 0.5 % over the range of energies that may occur during a single calibration due to unwanted variation in tube voltage.

5.2.2. Requirements for repeatability

The current/charge measuring instrument to be used with the monitor chamber must have good repeatability. The standard deviation of a single measurement must not exceed 0.2 % with constant input current.

5.3. Other dosimeters

Other suitable dosimeters may be needed as working standards, transfer and field instruments. They should take the place of a secondary standard instrument for general use in the SSDL, such as measurement of half-value layer or field uniformity, or for research or training programs, or for measurements at other institutions.

5.4. Stable voltage sources

The measuring assembly and the monitor instrument may include power supplies for the ionisation chamber polarising potential. If not, stable voltage sources with an appropriate range (for example 0-500 volts) are necessary for the reference and for the monitor ionisation chambers.

5.5. Time measurement

A timer may be used with a shutter to measure the irradiation time, or it may be used to control the measurement time without the use of a shutter. One timer may serve both functions, or separate timers may be used. An electronic timer is recommended and an uncertainty of time of exposure measurement of 0.1 % should be achieved. When the shutter is used to control the irradiation the influence of opening and closing time should be assessed.

5.6. Ambient atmospheric monitoring and measuring instruments

Appropriate instruments must be available to determine temperature and pressure, and monitor the relative humidity of the ambient air.

The thermometer, suitable for determining the air temperature in the vicinity of the ionisation chambers, should be capable of temperature measurement within an uncertainty of ± 0.2 °C, and the barometer capable of determining atmospheric pressure with an uncertainty of less than ± 0.1 %.

A portable precision aneroid barometer should be available if calibrations of dosimeters are to be carried out in the field.

In addition ambient monitoring equipment may be provided for continuously recording temperature, pressure, and humidity within the laboratory.

The instruments used must have calibrations traceable to the national standards for pressure and temperature.

5.7. Distance measuring device

It must be possible to determine and maintain the chamber position relative to the source. The chamber position must be reproducible with an uncertainty of less than ± 0.5 mm for distances above 50 cm and should have less uncertainty at shorter distances.

5.8. Phantoms

When required a suitable phantom must be available for calibrations. For accuracy and consistency, there are advantages in using a water phantom but this sometimes presents practical problems and a phantom of suitable solid material is equally acceptable. Both types have been described [6, 12] and both are available commercially. It should be noted that when the simultaneous irradiation method is to be used for in-phantom calibration, the phantom will require two holes, each accurately fitted to the type of ionisation chamber to be used in it and located at the same depth in the phantom material (see point 4.1.9).

5.9. Ancillary equipment

Some ancillary equipment in addition to that described above may be useful as regular SSDL equipment:

— films or possibly a small fluorescent screen for checking adjustment of the beams;
— an apparatus for testing the atmospheric venting of ionisation chambers;
— personnel dosimeters for radiation safety monitoring;
— desk or pocket calculator;
— precision voltmeter and/or multimeter.

Some additional equipment may be useful if it is available for use as needed:

— a suitable micrometer for thickness measurement of filters and absorbers;
— suitable balance for determining thickness of thin filters and absorbers by weighing;
— portable radiation protection survey meters to check on radiation leakage from the X-ray tube, and on radiation levels in occupied areas;
— access to a small machine shop, for construction and modification of laboratory equipment.

6. Accuracy and reliability

6.1. Accuracy goals

It should be the goal of the SSDL to achieve the following accuracy for the calibration of users' instruments for radiation therapy:

	^{60}Co gamma-rays	X-rays
Reference-class instruments	± 1 %	± 2 %
Field-class instruments	± 2 %	± 3 %

These accuracy goals are given in terms of agreement in percent with the PSDL that calibrates the secondary standard instrument. Systematic uncertainties in the primary standard at the PSDL are not included in these figures. A reference-class instrument is an instrument whose performance and stability are sufficient for it to be used for calibrating other instruments; and a field-class instrument is an instrument whose performance and stability are sufficient for it to be used for ordinary routine measurements [11]. These terms refer to the quality of the instruments, not to their use. A reference-class instrument used for routine therapy-beam calibration is considered to be a field instrument.

The calibration accuracy achieved by an SSDL can be checked by comparing the calibration given to a working standard with that given by a PSDL, or by an inter-comparison of calibrations determined by several SSDL's. The difference between the calibration factors should not be significantly greater than the accuracy goals given above.

6.2. Overall constancy check

In order to ensure the reliability of the secondary standard instrument, all measurements that are periodically repeated under specified conditions should be considered part of a redundant constancy check. Careful records should be maintained of all measurements, and any deviation from an expected value should be investigated at once. Such a constancy check should include the use of the portable check source, measurements in a ^{60}Co or ^{137}Cs gamma-ray beam at a fixed position and comparison of the secondary standard instrument with another reference-class instrument. If the secondary standard instrument is also compared with another instrument in an X-ray beam, it will test constancy of energy response. It is preferable that the secondary standard chamber is compared with an ionisation chamber of different size and construction, since it is very unlikely that the two will be in error in the same way.

At least three-fold redundancy should be established for this constancy check. Then as long as no discrepancies in the measurements are found, there can be a very high degree of confidence that the secondary standard has maintained a constant calibration factor. A careful, redundant constancy check combined with periodic tests of calibration accuracy, can reduce the need for periodic recalibration of the secondary standard to the point where many years can elapse between recalibrations. Recalibration of the secondary standard instrument should of course take place whenever the constancy check or the calibration accuracy tests show discrepancies significantly greater than the accuracy goals of the SSDL.

When a new secondary standard instrument is acquired, the redundant constancy check should be established, and if it can be arranged the instrument stability tested for at least a few weeks, before the instrument is sent to the PSDL for calibration. The procedure should be repeated immediately after the instrument returns from the PSDL, and at appropriate intervals thereafter.

7. The calibration report

This section describes the information that should be given in a calibration report for a field instrument. The report should include, but not necessarily be limited to, the information described here. It should provide additional information if it is useful to, or requested by, the user of the instrument.

7.1. Give the name of the SSDL, the date of the report and a unique number that identifies the report.

Note: the report number should appear on each page of the report.

7.2. Give the name and address of the owner of the field instrument, the date the instrument was received and the identification of the instrument including manufacturer, model and serial number.

7.3. Describe the calibration conditions, method and standards used.

7.3.1. For the radiation source include its type, a suitable descriptor of its beam quality or energy, the distance from the source to the calibration position, the size of the radiation field at the calibration position and the exposure (or kerma or absorbed-dose) rate during calibration.

7.3.2. For the field instrument give the reference conditions. That is describe the method of use during calibration and include the switch positions, scale point at which the calibration was carried out, the magnitude of the leakage current (and whether a correction was applied) and the angle of the chamber axis relative to the beam axis. Give the results of scale linearity and range tests and the results of any special tests that were found necessary such as atmospheric venting.

7.3.3. Describe the calibration procedure. The method should be detailed; whether by "tip-to-tip", substitution, in air or in specified phantom, or whatever method is used. For an absorbed-dose calibration give the composition of the phantom and the depth of the dosimeter during the calibration.

7.3.4. Identify the secondary standard and give the date of its most recent calibration at a PSDL. If a measurement assurance check with a PSDL has been performed, give the date of the most recent check.

7.4. Give a correction factor or a calibration factor.

Note: How the reported factors should be applied to the responses of the calibrated measuring system should be made absolutely clear.

7.4.1. A correction factor is the numerical factor by which the uncorrected result of a measurement is multiplied to compensate for an assumed systematic error. Correction factors will normally be reported for instruments that have a scale marked in units of a relevant quantity such as exposure, kerma or absorbed dose.

7.4.2. A calibration factor is frequently the more convenient way to state the result of the calibration and it establishes, under the specified conditions of the calibration, the relationship between values indicated by the measuring system subjected to the calibration and the corresponding known values of the measurand obtained from the secondary standard.

The calibration factors may have units such as coulombs per kilogram per scale division ($C \cdot kg^{-1}$/scale division) or grays per scale division (Gy/scale division) or grays per coulomb (Gy/C) for example.

Note: The physical quantity in the numerator of the calibration factor must be stated fully and normally will be exposure, air kerma, water kerma or water absorbed dose. For example: the calibration factor may be given as the factor by which the reading of the instrument under the reference conditions is multiplied in order to give exposure in millicoulombs per kilogram (mC/kg).

7.4.3. Give the temperature and pressure to which the correction factor or calibration factor has been normalised. The humidity at which the factor applies should also be stated.

7.4.4. Give the uncertainty, or accuracy, associated with the correction factor or calibration factor, with a brief explanation of how it was obtained.

7.5. If there is an applicable regulation governing recalibration specify the date on which recalibration is required. Otherwise specify a recommended recalibration date.

7.6. Provide the signature and title of the responsible person at the SSDL as well as the signature(s) or initials of the person(s) carrying out the calibration.

Note: The signature(s) or initials of the person(s) carrying out the calibration should appear on every page of the report that has any calibration data.

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