

**SPECIFICATION OF  
BRACHYTHERAPY  
SOURCE STRENGTH**



**AAPM REPORT NO. 21**

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BRACHYTHERAPY  
SOURCE STRENGTH**

REPORT OF AAPM  
Task Group No. 32\*

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## I. Introduction

It is common practice to express source strength of brachytherapy sources in terms of activity or equivalent mass of radium. The output of a brachytherapy source, in terms of exposure rate in free space, can then be obtained by multiplying the source strength by the appropriate exposure-rate constant. In 1974, the National Council of Radiation Protection and Measurements (NCRP) pointed out several shortcomings of these methods, the most important being that they do not specify strength in terms of directly measured quantities.<sup>1</sup> The NCRP recommended that brachytherapy sources should be specified in terms of exposure rate at 1 m in free air with corrections for air attenuation. A similar suggestion was made by Dutreix and Wambersie<sup>2</sup> in 1975. Despite the sound rationale of this proposal there has been little progress towards the use of this specification method in the clinical community. Recent adoption of SI units, and replacement of exposure by air kerma, has reopened this discussion. Gibb and Massey<sup>3</sup>, Aird and Day<sup>4</sup>, Jayaraman, Lanzl and Agarwal<sup>5</sup>, comite Francais Measure des Rayonnements Ionisants (CFMRI)<sup>6</sup>, Loevinger<sup>7</sup>, Williamson and Morin<sup>14</sup>, and British Committee on Radiation Units and Measurements (BCRU)<sup>8</sup> have contributed to the discussion in recent publications. The BCRU and CFMRI have recommended specifying brachytherapy source strength in terms of air-kerma rate, with a unit of  $\mu\text{Gy m}^2\text{h}^{-1}$ .

In the present paper, recommendations are set forth that, in many respects, are similar to those cited above. These recommendations have been approved by the Radiation Therapy Committee and the Science Council of the American Association of Physicists in Medicine (AAPM) and thus represent the official policy of the AAPM regarding this matter. This report considers the needs of the clinical community and includes a discussion of the ramifications of these recommendations.

## II. U.S. Standards for Brachytherapy Sources

In the United States, the National Bureau of Standards (NBS) provides standards for radiation dosimetry including the calibration of brachytherapy sources. The NBS standards have been compared to other national standards and to the international standards maintained by the International Bureau of Weights and Measures (Bureau International des Poids et Mesures, BIPM) Located in Paris. The BIPM has the responsibility of comparing BIPM primary standards with those of the national standards laboratories. In the United States, the convention has been adopted that instruments used for calibration of radiation therapy beams shall have calibrations directly traceable to NBS.<sup>9,10</sup> For that purpose, "directly traceable" is defined to mean that the instrument has been calibrated either at NBS or at one of the AAPM-accredited dosimetry calibration laboratories (ADCLs).

For brachytherapy sources, establishing suitable traceability to NBS standards is more complicated than for instruments used for calibration of therapy beams, due to the wide range of half-lives encountered, and due also to the large number of sources used in some clinical procedures. As a result, two levels of traceability to NBS are defined and traceability by statistical inference is recognized as an existing practice.

Direct traceability is established when the source is calibrated at NBS or at a suitably accredited brachytherapy calibration laboratory.

Secondary traceability is established when the source is calibrated by comparison with a source of the same kind, the calibration of which is directly traceable to NBS. For long-half-life sources (such as  $^{137}\text{Cs}$ ), the comparison should be made by the method of substitution, using either an external ionization chamber or a well-type ionization chamber. For short-half-life sources (such as  $^{192}\text{Ir}$  or  $^{125}\text{I}$ ) the comparison should be made using a well-type ionization chamber (or equivalent detector) that has been calibrated using a directly traceable source; and the constancy of the well-type chamber should be assured by use of a suitable long-half-life source.

Secondary traceability by statistical inference is established when a source is part of a group of sources, of which a suitable random sample has been calibrated by comparison with a directly traceable source. The comparison should be carried out in the same manner as for secondary traceability. In this case the following minimum information must be supplied: number of sources in the batch, number of sources in the sample, mean and standard deviation of the sample and range of values in the sample.

Brachytherapy sources other than radium are calibrated at NBS in terms of exposure rate; the NBS standards of exposure are spherical graphite ionization chambers and free-air chambers.  $^{137}\text{Cs}$  sources are calibrated in terms of exposure rate at about one meter in air using a working standard source (of the same kind) that has previously been calibrated by using the spherical graphite ionization chambers. The source to be calibrated is compared to the working standard using a large-volume spherical aluminum chamber (2.8 liter)<sup>11</sup>.

Brachytherapy sources of  $^{192}\text{Ir}$  are calibrated in a different manner because of their lower exposure rate and shorter half-life<sup>12</sup>. A composite source containing about 50 seeds was prepared, and exposure rate from this composite source was measured in open-air scatter-free geometry at 1 m, in the same manner as for  $^{137}\text{Cs}$  sources, using the spherical graphite ionization chambers. Each  $^{192}\text{Ir}$  source was then measured individually in a well-type ionization chamber to establish the calibration of this chamber in terms of exposure rate at 1 m. This well-type ionization chamber now serves as the working standard for calibration of  $^{192}\text{Ir}$  sources. Calibration of other well-type ionization chambers can be obtained by comparison with the NBS well-type ionization chamber using an  $^{192}\text{Ir}$  source.

Brachytherapy sources of  $^{125}\text{I}$  were calibrated in terms of exposure rate in free space at 1 m using a free-air ionization chamber<sup>13</sup>. The routine calibration procedure is essentially the same as for  $^{192}\text{Ir}$  seeds except for the use of a free-air chamber as the primary standard,

At the time of writing, NBS does not offer calibration standards for  $^{252}\text{Cf}$  and  $^{198}\text{Au}$ , or for other potential brachytherapy sources.



### III. Source Specification Methods Currently in Use

Determination of the dose distribution from a brachytherapy source in tissue requires a knowledge of source strength and a number of conversion factors. In this section, currently used methods of source specification and the calculation of exposure rate in free space are described. Not treated is the calculation of dose rate in tissue, which may proceed from that of exposure rate in free space but is preferably based on dose measurements in phantom around a source of known strength.

#### A. Activity of the Radionuclide

The source strength can be specified in terms of the activity of the radionuclide in the source. For an activity A, the exposure rate at a point of interest in free space may be given by the expression

$$\dot{X}(r, \theta) = A (\Gamma_s)_x G(r, \theta) \alpha(r, \theta) \quad (1)$$

where

$$G(r, \theta) = \begin{cases} \frac{1}{r^2} & \text{for point source approximation,} \\ \frac{\theta_2 - \theta_1}{Lh} & \text{for line source approximation,} \end{cases}$$

and

$$\alpha(r, \theta) = \begin{cases} e^{-\mu t} & \text{for point source approximation,} \\ \frac{1}{\theta_2 - \theta_1} \int_{\theta_1}^{\theta_2} e^{-\mu t \sec \theta} d\theta & \text{for line source approximation.} \end{cases}$$

The lengths and angles are shown in Fig. 1. L is the active length of the line source, t is the thickness of encapsulation material,  $\mu$  is the effective absorption coefficient of the encapsulation material and  $(\Gamma_s)_x$  is the exposure-rate constant for a bare point source of the radionuclide.  $G(r, \theta)$  is a geometry factor and  $\alpha(r, \theta)$  is a dimensionless quantity that accounts for absorption and scatter in the source material and encapsulation.

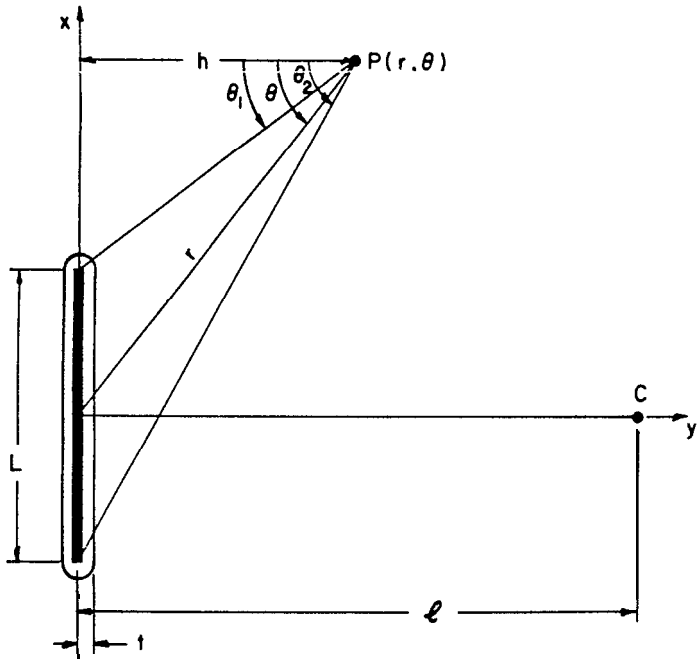


Fig. 1. Schematic drawing of the geometry of a line source calculation.

The concept of effective attenuation coefficient for these calculations has been a subject of many investigations, including recent studies by Williamson and Morin<sup>14</sup> and Cassell<sup>15</sup>. It should be noted that, for polyenergetic radionuclides e.g. <sup>226</sup>Ra, the effective attenuation coefficient depends on absorber thickness, due to selective absorption of the lower energy gamma rays. In the case of <sup>226</sup>Ra, measured values of  $\mu$  are available and may be used<sup>16,17</sup>. However, when such values are not available, calculated values using mass energy-absorption coefficients have to be used<sup>14</sup>.

For a point source with spherical encapsulation,  $\alpha$  is a constant that depends upon photon energy and encapsulation thickness. For heavily filtered sources with non-spherical encapsulation, the effect of anisotropy may be large. Anisotropy correction factors have been calculated by using the angular exposure distribution, normalized to the calibration exposure rate. For <sup>125</sup>I and <sup>192</sup>I, seeds, these factors can be significant.<sup>18,19</sup>

For a linear source,  $\alpha$  is a function of  $r$  and  $\theta$ , and is proportional to the Sievert integral indicated. Young and Batho<sup>20</sup> have shown that the exposure rate from any linear radium source can be expressed in the form:

$$\dot{X}(x,y) = \frac{A}{L^2} F(j,k,\mu t) \quad (2)$$

where  $j$  and  $k$  are Cartesian coordinates of the point in terms of active length  $L$  (i.e.  $j = x/L$  and  $k=y/L$ ). The function  $F$  has been tabulated and these tables are used in some computerized dose calculation systems currently in clinical use. One of the key advantages of the Young and Batho scheme is that the same function  $F$  can be used for radium sources of any length. The same tables are also used for radium substitutes such as <sup>137</sup>Cs sources by some of the computer systems. For better accuracy, similar tables should be recalculated for each radionuclide.

### B. Exposure Rate at a Reference Point in Free Space

Source strength can be specified in terms of exposure rate  $\dot{X}_\ell$  at a specified distance  $\ell$  (usually 1 m) along the perpendicular bisector of the line source. If the source calibration is performed at (or if the result is corrected to) a point that is at a distance of 1 m from the source center, the line-source geometry factor is negligibly (less than 0.01%) different from the point-source geometry factor  $1/r^2$  and  $\alpha$  reduces to  $e^{-\mu r}$ . Under these conditions,  $\dot{X}_\ell$  is given by

$$\dot{X}_\ell = \frac{A}{\ell^2} (\Gamma_\delta)_X e^{-\mu \ell} \quad (3)$$

Exposure rate at any point in free space is given by

$$\dot{X}(r, \theta) = \frac{\dot{X}_\ell \ell^2}{e^{-\mu r}} G(r, \theta) \alpha(r, \theta) \quad (4)$$

The exposure rate at any point  $(r, \theta)$  is calculated from the measured exposure rate at the calibration distance  $\ell$ . The source activity is not implicitly required in equation 4.

### C. Equivalent Mass and Apparent Activity

Brachytherapy sources for which exposure is well defined, can be specified in terms of equivalent mass of radium, which is defined as that mass of radium, encapsulated in 0.5 mm Pt, that produces the same exposure rate at the calibration distance as the source to be specified.

For a source with an equivalent mass of radium  $m_{eq}$  the exposure rate at the calibration distance  $\ell$  is given by the expression,

$$\dot{X}_\ell = \frac{m_{eq}}{\ell^2} (\Gamma_\delta)_{X, Ra} \quad (5)$$

provided the specification point is far enough away that the source may be treated as a point source.  $(\Gamma_\delta)_{X, Ra}$  is the exposure-rate constant for radium encapsulated in 0.5 mm Pt, in terms of exposure rate at a unit distance per unit mass of radium. This method of specification is thus equivalent to the specification in terms of exposure rate, as described above. The gamma-ray energy of radium is so high that the air attenuation at one meter can be neglected.

A similar method is that of specifying source strength as the activity of a bare point source (of the same radionuclide) that produces the same exposure rate at the calibration distance as the source to be specified. In analogy with the equivalent mass of radium method, the "apparent" source activity  $A_{app}$  is defined by its calibration-distance exposure rate, i.e.,

$$\dot{X}_\ell = \frac{A_{app}}{\ell^2} (\Gamma_\delta)_X \quad (6)$$

This method has been extensively applied for  $^{125}\text{I}$  seeds<sup>21</sup>.

#### **D. Air-Kerma Rate at a Reference Point in Free Space**

Source strength can be specified in terms of air-kerma rate at a specified distance in free space (usually 1 m) along the perpendicular bisector of the line source. BCRU<sup>8</sup> and CFMRI<sup>6</sup> have recommended this method of specification. ICRU has employed this method of specification of source strength in its report on intracavitary therapy<sup>24</sup> and has recommended the name "reference air-kerma rate" for source strength. This method of specification of source strength is currently being used in most of Europe.

#### IV. Discussion

Using the activity of the radionuclide in the source as the method of specification (Section III A) suffers from a number of problems. It is difficult to determine the actual activity in a brachytherapy source, and different methods of determination may yield different values. Likewise, it is difficult, for some radionuclides, to determine the exposure-rate constant, especially for encapsulated sources. In practice neither activity nor exposure-rate constant need be known: a purely arbitrary value would do for one or the other, provided the product of the two gives an accurate value of the exposure rate at the calibration point. When activity and exposure-rate constant are treated as separate parameters in the dose calculation, it is inevitable that attempts will be made to determine them with ever-increasing accuracy. Not only is this wasted effort, from the viewpoint of brachytherapy, but it is inevitable that independent choice of these parameters will in some cases be inappropriate, and lead to incorrect values of the desired quantity, exposure rate at the calibration point. For these reasons, the AAPM is in agreement with NCRP<sup>1</sup>, CFMRF<sup>2</sup>, and BCRU<sup>3</sup> in concluding that activity is an unsuitable method of specifying brachytherapy source strength.

Source strength specification in terms of the exposure (or air-kerma) rate at a specified distance (Section III B and D) is recommended. Exposure (or air-kerma) rate is a measured quantity that can be directly traceable to a national standard. Dose rate in tissue, the quantity of interest in clinical dosimetry, is much more closely related to exposure (or air-kerma) rate than to the activity encapsulated in a source, and a knowledge of the exposure (or air-kerma) rate constant is unnecessary.

The equivalent mass of radium (Section III C) is essentially the same as exposure-rate specification since equality of exposure rate is used to define the equivalent mass of radium. Specification in terms of equivalent mass of radium also facilitates the use of radium dosage tables (e.g. Manchester System tables)<sup>22</sup> for clinical dosimetry. However, the equivalent mass of radium is now fast becoming a matter of historical interest only. Although radium

tables may still be of some utility in planning brachytherapy procedures, it is probable that they will be replaced by more convenient computer-generated planning aids (such as planning nomographs)<sup>23</sup> and, in any case, they may be readily converted to reflect source strength defined on the basis of exposure (or air-kerma) rate. Radium tables should generally not be used for final dosimetric evaluation. Computerized systems should be used to obtain dose distributions on which clinical decisions may be based for individual patients.

It should be noted that both the radium-equivalence method and the apparent-activity method involve dividing exposure rate by the exposure-rate constant to get the source strength and then multiplying by the exposure-rate constant to calculate the exposure rate. Aside from the obvious redundancy, this manipulation of a "dummy" constant leads to the real possibility of error, especially since the division may be performed by the manufacturer using one value, and the multiplication by the user using another value.

Thus, it may be concluded that exposure (or air-kerma) rate at a specified distance is the method of choice, among the four methods currently in use. However, it must be noted that the quantity exposure is in the process of being phased out. The BIPM and most European standards laboratories have already replaced exposure by the quantity air kerma, and the U.S. is expected to follow suit in the near future.

Another quantity that might be used to specify source strength is dose rate at a specified distance in the medium. The reason for not recommending this quantity is that it is very difficult to measure dose rate accurately around sources at distances of clinical interest. In consequence, this quantity, although more directly related to clinically desired dose, currently lacks national standards and would result in much greater variability among institutions than would air-kerma rate.

## V. Recommendations

(i) Specification of brachytherapy sources should be in terms of the quantity air-kerma strength, defined as the product of air-kerma rate in free space and the square of the distance of the calibration point from the source center along the perpendicular bisector, i.e.,

$$S_K = \dot{K}_\ell \ell^2 \quad (7)$$

The calibration measurement must be performed with the distance between detector and source large enough that the source can be treated as a point source and the detector can be treated as a point detector. Recommended units for air-kerma strength are  $\mu\text{Gy m}^2\text{h}^{-1}$ .

(ii) Brachytherapy sources used in radiation therapy should have calibrations that establish direct or secondary traceability to NBS, as defined in Section II above. The level of traceability should be stated in appropriate documentation accompanying each source.

(iii) Traceability by statistical inference is used by at least one manufacturer of short-lived sources and is frequently used in the clinical setting to verify a shipment of sources. The existence of this practice is recognized but no recommendation is made for or against it.

(iv) Calibration laboratories should specify the strength of brachytherapy sources in terms of air-kerma strength.

(v) The source supplier should furnish a certificate that gives the air-kerma strength of each source. The supplier should also state, for regulatory and radiation protection purposes, an estimate of the activity contained. The calibration certificate should provide the information shown in the Appendix. The supplier should make available, on request by the purchaser, documentation that supports such claims as: the uncertainty of the measurements is within  $\pm 5\%$  and the precision of the measurements is within  $\pm 2\%$  with 95% confidence limits.

(vi) The physicist or radiotherapist performing brachytherapy calculations should use the air-kerma strength for dose calculations, and should not use activity, exposure-rate constant, air-kerma rate constant, or equivalent mass of radium.

(vii) Computerized systems of dose calculation for brachytherapy should be modified to accept air-kerma strength as the specification of sources, and appropriate changes should be made in dose calculation algorithms as well as other treatment-planning aids,



## VI. Recommended Quantities and Their Relationships

Air kerma is related to exposure as

$$K \approx X \quad (W/e) \quad (8)$$

where  $W/e$  is the mean energy expended per unit charge released in air. This relationship assumes that the radiative fraction,  $g$ , of air kerma is negligibly small, a reasonable approximation for brachytherapy photon energies. Thus, for brachytherapy purposes, air kerma and exposure differ from each other only by a constant multiplicative factor.

For a source with activity,  $A$ , the air-kerma strength is given by

$$S_K = A \quad (\Gamma_\delta)_X \quad e^{-\mu t} \quad (W/e) \quad (9)$$

This expression can be reformulated as

$$S_K = A \quad (\Gamma_\delta)_K \quad e^{-\mu t} \quad (10)$$

where  $(\Gamma_\delta)_K$  is the air-kerma rate constant for the bare source.

Exposure rate at any point in free space is given by the expressions,

$$\dot{X}(r, \theta) = A \quad (\Gamma_\delta)_X \quad G(r, \theta) \quad (11)$$

$$= \frac{S_K}{e^{-\mu t} \quad (W/e)} \quad G(r, \theta) \quad \alpha(r, \theta)$$

Exposure rate at the calibration point  $l \gg L$  is given by

$$\dot{X}_l \approx \frac{S_K}{l^2 \quad (W/e)} \quad (12)$$

Equivalent mass of radium is given by

$$m_{eq} = \frac{S_K}{(\Gamma_\delta)_{X, Ra} \quad (W/e)} = \frac{S_K}{(\Gamma_\delta)_{K, Ra}} \quad (13)$$

where  $(\Gamma_s)_{X^*Ra}$  and  $(\Gamma_s)_{K^*Ra}$  are exposure-rate and air-kerma-rate constants for encapsulated radium (0.5 mm Pt) expressed in terms of mass of radium (instead of activity).

Air-kerma rate at any point in free space is given by

$$\dot{K}(r,\theta) = \frac{S_K}{e^{-\mu r}} G(r,\theta) \alpha(r,\theta) \quad (14)$$

The equations used in this report represent relationships between physical quantities. As such, the equations can be used with any consistent set of units, without introduction of numerical factors. Table I lists the symbols for the dimensional quantities used in this paper, and gives the units for three systems suitable for use with these equations. Any one of these three systems of units can be used, provided it is used consistently throughout a calculation. "Traditional" brachytherapy units involve roentgen, rads, centimeters, etc. SI units are now in international use for scientific purposes. The recommended unit for air-kerma strength is  $\mu\text{Gy m}^2\text{h}^{-1}$  which is numerically equal to  $\text{cGy cm}^2\text{h}^{-1}$ ; i.e.,  $1 \mu\text{Gy m}^2\text{h}^{-1} = 1 \text{cGy cm}^2\text{h}^{-1}$ . The numerical calculations can, if desired, be simplified by using convenient multiples or submultiples of the units of air kerma and absorbed dose.

Our recommendations agree with those of the BCRU<sup>8</sup>, CPMRI<sup>6</sup>, and ICRU<sup>24</sup> in that the source strength is specified directly in terms of air-kerma rate in free space at one meter. The name "reference air-kerma rate" as used by the BCRU and CPMRI is, however, not used here since the source strength defined in that manner does not have the dimensions of a kerma rate, which may lead to confusion in teaching and clinical use. The name "air-kerma strength" as defined here is appropriate for a quantity with the dimensions kerma rate times distance squared.

Table I. Quantities and Units Used in Brachytherapy

Quantity	Symbol	Units		
		Traditional	SI	Recommended
Length	r, l, t, h	cm	m	cm, m
Time	--	h	s	h
Activity	A	mCi	Bq	MBq
Exposure	X	R	C kg <sup>-1</sup>	--
Exposure Rate	$\dot{X}$	R h <sup>-1</sup>	C s <sup>-1</sup> kg <sup>-1</sup>	--
Air Kerma	K	rad	Gy	Gy
Air-Kerma Rate	$\dot{K}$	rad h <sup>-1</sup>	Gy s <sup>-1</sup>	Gy h <sup>-1</sup>
Air-Kerma Strength	S	rad cm <sup>2</sup> h <sup>-1</sup>	Gy m <sup>2</sup> s <sup>-1</sup>	μGy m <sup>2</sup> h <sup>-1</sup>
Absorbed Dose	D	rad	Gy	Gy
Absorbed Dose Rate	$\dot{D}$	rad h <sup>-1</sup>	Gy s <sup>-1</sup>	Gy h <sup>-1</sup>
Exposure-Rate Constant	$(\Gamma_{\delta})_X$	R cm <sup>2</sup> mCi <sup>-1</sup> h <sup>-1</sup>	C s <sup>-1</sup> m <sup>2</sup> Bq <sup>-1</sup>	--
Air-Kerma Rate Constant	$(\Gamma_{\delta})_K$	rad cm <sup>2</sup> mCi <sup>-1</sup> h <sup>-1</sup>	Gy m <sup>2</sup> Bq <sup>-1</sup> s <sup>-1</sup>	μGy m <sup>2</sup> MBq <sup>-1</sup> h <sup>-1</sup>
Equivalent Mass of Radium	m <sub>eq</sub>	mg	kg	--
Geometry Factor	G(r, θ)	cm <sup>-2</sup>	m <sup>-2</sup>	cm <sup>-2</sup> , m <sup>-2</sup>
Effective Attenuation Coefficient	μ	cm <sup>-1</sup>	m <sup>-1</sup>	cm <sup>-1</sup> , m <sup>-1</sup>

Some of the conversion factors are:

$$1 \text{ Gy} = 1 \text{ J kg}^{-1}$$

$$1 \text{ Gy} = 100 \text{ rad}$$

$$1 \text{ mCi} = 37 \text{ MBq}$$

$$W/e = 0.876 \text{ cGy R}^{-1} = 8.76 \text{ mGy R}^{-1} = 33.97 \text{ Gy kg C}^{-1} = 33.97 \text{ J C}^{-1}$$

The value of W/e, quoted above, is for dry air<sup>25</sup>. It is the value used at NBS, at the time of writing.

## VII. Practical Considerations

If brachytherapy sources are specified in terms of air-kerma rate, a number of changes are required in clinical practice. Some of the ramifications are mentioned in this section as guidelines to physicists, dosimetrists, source suppliers, calibration laboratories, software vendors, and regulatory agencies.

With the proposed specification in terms of air-kerma strength, exposure-rate and air-kerma-rate constants are not required for dose calculations. The recommended method of specification will result in better consistency among suppliers and users, as well as more uniform clinical dosimetry for individual patients. It will reduce the probability of gross dosimetry errors, which can result from mishandling of unnecessary factors in dose calculations.

An estimate of the activity of a radioactive source is still required for regulatory and radiation protection purposes. We suggest that activity (in mCi or MBq) of the radionuclide in the source be estimated from the air-kerma strength using equation 9 or 10 and the best-known value of the exposure-rate or air-kerma-rate constant. For example, an  $^{125}\text{I}$  seed with an air-kerma strength of  $1.0 \mu\text{Gy m}^2\text{h}^{-1} = 1.0 \text{ cGy cm}^2\text{h}^{-1}$  has an estimated activity given by

$$\begin{aligned}
 A &= \frac{S_K}{(\Gamma_{\delta})_X (W/e) e^{-\lambda t}} \\
 &= \frac{(1.0 \text{ cGy cm}^2 \text{ h}^{-1})}{(1.45 \text{ R cm}^2 \text{ h}^{-1} \text{ mCi}^{-1}) (0.876 \text{ cGy R}^{-1}) (0.92)} \quad (15) \\
 &= 0.86 \text{ mCi} \approx 32 \text{ MBq}
 \end{aligned}$$

Some changes will be necessary in patient dosimetry. If it is desired to employ radium dosage tables for pre-planning and estimating dosages, the equivalent mass of radium can be calculated from the air-kerma strength by using equation 13. For example, a  $^{226}\text{Ra}$  source with an air-kerma strength of  $100 \mu\text{Gy m}^2\text{h}^{-1} = 100 \text{ Gy m}^2\text{h}^{-1}$  has an equivalent mass of radium given by

$$\begin{aligned}
 m_{eq} &= \frac{S_K}{(\Gamma_\delta)_{X, Ra} (W/e)} \\
 &= \frac{(100 \text{ cGy cm}^2 \text{ h}^{-1})}{(8.25 \text{ R cm}^2 \text{ mg}^{-1} \text{ h}^{-1})(0.876 \text{ cGy R}^{-1})} \\
 &= 13.8 \text{ mg}
 \end{aligned}
 \tag{16}$$

Currently, treatment planning systems specify the source strength as the activity of the radionuclide or the equivalent mass of radium and then employ approximate forms of equation 1 to compute exposure rate. It is recommended that air-kerma strength be specified as input in these algorithms, and that equation 11 or its equivalent be employed for exposure computations. It should be noted that this requires a minor change in the currently employed algorithms for exposure-rate calculations: specifically the product  $A (\Gamma_\delta)_X$  must be replaced by  $S_K/(W/e)$ . Since  $(W/e)$  is a constant, this recommendation is replacing two variables  $A$  and  $(\Gamma_\delta)_X$  by a single variable  $S_K$ . All other aspects of the dose calculation programs such as tissue attenuation factors, obliquity effect, Sievert integrals, etc. are unaffected by this change.

**Appendix:** Information Recommended for Manufacturer's Certificate of Calibration.

Manufacturer's name and address.

Certificate number.

Serial or lot number, model number.

Radionuclide, nominal activity, half-life.

Surface contamination: method of test, date of test, result of test.

Leakage : method of test, date of test, result of test.

Active contents: chemical and physical form, mass, volume.

Encapsulation: materials of construction, dimensions, diagrams illustrating all dimensions.

Air-kerma strength, in  $\mu\text{Gy m}^2\text{h}^{-1}$ . Date of calibration, and level of traceability to NBS standards.

The certificate should also contain statements such as the following:

Air-kerma strength is the product of air-kerma rate in free space and the square of the distance of the calibration point from the source center along the perpendicular bisector.

The air-kerma rate is not isotropic around the source. The mean source strength, averaged over all directions, can be obtained by applying the factor \_\_\_\_ to the air-kerma strength.

Documentation of the calibration procedures employed is available on application to (name to be supplied by manufacturer).

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