1 Introduction

Brachytherapy is a special procedure in radiotherapy that utilises the irradiation of a target volume (e.g. malignant cells) with radioactive sources placed at short distances from the target. 'Brachytherapy' is the Greek word for 'short distance treatment'. The opposite is 'teletherapy' where an external radiation source is used, e.g. an X-ray tube or a linear accelerator.

The radioactive sources are either implanted in the target tissue directly (interstitial brachytherapy) or are placed at distances of the order of a few millimetres from the target tissue, in body cavities such as the uterus, lung, mouth, etc. (intracavitary brachytherapy), or externally on structures such as the eye or the skin (ophthalmic applicators or surface moulds).

Shortly after the discovery of radium by Marie and Pierre Curie in 1898, the naturally occurring radionuclide $^{226}\text{Ra}$ and also the daughter nuclide radon ($^{222}\text{Rn}$) were used for cancer treatment (Mould et al. 1994). When artificially produced radionuclides became available from nuclear reactors and particle accelerators from the 1950s onwards, many new radionuclides entered the brachytherapy field (Thomadsen et al. 2005). Nowadays radionuclides used in brachytherapy include photon emitters (e.g. $^{103}\text{Pd}$, $^{125}\text{I}$, $^{170}\text{Tm}$, $^{169}\text{Yb}$, $^{192}\text{Ir}$, $^{198}\text{Au}$, $^{137}\text{Cs}$, $^{60}\text{Co}$) with mean photon energies ranging from 0.021 MeV to 1.25 MeV and beta emitters (e.g. $^{90}\text{Sr}$, $^{32}\text{P}$, $^{90}\text{Y}$, $^{106}\text{Ru}$) with maximum beta energies ranging from 0.54 MeV to 3.55 MeV.

Brachytherapy dose rates cover a very wide range leading to treatment times varying from minutes to months and have been divided into low, medium and high dose rates by the International Commission for Radiation Units and Measurements (ICRU 1985).

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In the following chapters we will only consider high dose rate (HDR) brachytherapy dosimetry for $^{192}\text{Ir}$, at present the most commonly used radionuclide worldwide for HDR brachytherapy.

$^{192}\text{Ir}$ is produced in a nuclear reactor via neutron capture by stable $^{191}\text{Ir}$ and has a half-life of 73.827 days ± 0.013 days (DDEP 2004). $^{192}\text{Ir}$ decays by beta emission and electron capture to excited states of $^{192}\text{Pt}$ and $^{192}\text{Os}$ (Baltas et al. 2007). The daughters decay to the ground states by gamma emission. The beta particles emitted from the $^{192}\text{Ir}$ source are either absorbed within the source encapsulation or in the tissue very close to the source, so it is effectively a gamma source.

$^{192}\text{Ir}$ has a very complicated gamma ray spectrum. The average energy of the gamma rays emitted by an HDR $^{192}\text{Ir}$ Isodose Control Flexisource, comprising a radioactive $^{192}\text{Ir}$ cylinder placed inside a sealed stainless steel capsule, is...
around 400 keV. The Flexisource is similar in design compared to the Nucletron microSelectron-v1 ‘classic’ HDR $^{192}$Ir-source (obsolete since 1 January 2014). The microSelectron-v1 source had an average photon energy of 397 keV (Goetsch et al. 1991). At NPL the HDR $^{192}$Ir Nucletron microSelectron-v1 ‘classic’ source has been used for the HDR brachytherapy calibration service from 2004 to 2013. Since 2014 an HDR $^{192}$Ir Flexisource has been used for the calibrations of secondary standard chambers. There are other brachytherapy afterloaders and sources available, marketed for instance by Varian or Bebig.

HDR treatments are delivered by remote controlled afterloaders, which are stepper motor driven systems that transport the radioactive source from a shielded safe into an applicator placed inside the patient. At the end of the pre-programmed dwell time, the source is moved back to the safe.

2 Source characterisation in terms of reference air kerma rate

In 1985 and 1997, the ICRU (reports 38 and 58) defined a quantity for the characterisation of photon-emitting brachytherapy sources, the reference air kerma rate (RAKR), which is the kerma rate to air, in air, at a reference distance of 1 m, corrected for air attenuation and scattering (SI units: Gy s$^{-1}$). For typical HDR sources, it is more appropriate to express RAKR in mGy h$^{-1}$ at 1 m or for LDR sources, in µGy h$^{-1}$ at 1 m.

The air kerma rate is given by

$$K_{\text{air}} = \frac{d}{dt} \left( d\frac{E_{\text{tr}}}{dm} \right)$$

where $dE_{\text{tr}}$ is the sum of the initial kinetic energies of all charged particles liberated by uncharged particles in a small volume of dry air with mass $dm$.

In 2004, the ICRU report 72 provided a slightly revised definition of the RAKR for low-energy photon sources used for brachytherapy. Low-energy or contaminant photons, for example, characteristic X-rays produced in the outer layers of the steel or titanium encapsulation of brachytherapy sources, contribute insignificantly to the absorbed dose rate in water or tissue at distances >1 mm. The ICRU recommends that only photons of energy greater than $\delta$ should be considered for the definition of the RAKR. The value of the energy cut-off, $\delta$, is typically of the order of 5 keV for low-energy sources with average photon energies $\leq$50 keV (e.g. $^{103}$Pd, $^{125}$I) and 10 keV for high-energy sources with average photon energies $>50$ keV (e.g. $^{192}$Ir and $^{60}$Co). The selection of this value depends on the energy spectrum of the emitted photons and on the type of source encapsulation.

The air kerma rate can be measured at any suitable distance from the radiation source. The reference air kerma rate is given by

$$K_{R} = K_{\delta}(d) \cdot \left( \frac{d}{d_{\text{ref}}} \right)^{2}$$

where $\dot{K}_R$ is the RAKR, $\dot{K}_\delta(d)$ is the air kerma rate measured at a distance $d$ owing to photons of energy greater than $\delta$ and $d_{\text{ref}}$ is the reference distance of 1 m. The measurement distance needs to be large enough so that the source can be considered a point source. The direction from the source centre to the reference point shall be at right angles to the long axis of the source (ICRU 1985, IAEA 2002).

3 Measurement of RAKR at the hospital

Hospital physicists need to characterise their own brachytherapy sources in terms of RAKR. The numerical value of this quantity is usually required as input parameter for the treatment planning system. A calibrated dosimeter comprising an ionisation chamber and an electrometer is needed to determine RAKR. The ionisation current produced in the ionisation chamber being irradiated is measured and then converted to reference air kerma rate.

If the ionisation chamber and the electrometer are already calibrated, RAKR can be calculated using the following equation (Bidmead et al. 2010):

$$\dot{K}_R = M \cdot k_{\text{ion}} \cdot k_{\text{sg}} \cdot N_{\dot{K}_R}$$  \hspace{1cm} (3)

where $\dot{K}_R$ is the reference air kerma rate of the hospital source (Gy s$^{-1}$),

$M$ is the corrected ionisation current (A) measured by the hospital physicist (= ionisation current corrected to standard atmospheric conditions x electrometer calibration coefficient),

$k_{\text{ion}}$ is the ion recombination correction factor,

$k_{\text{sg}}$ is the source geometry factor which accounts for any change of the well chamber response because of geometric differences between the source type used during calibration at NPL and the source type being measured by the user (Shipley et al. 2015) and

$N_{\dot{K}_R}$ is the calibration coefficient of the ionisation chamber (Gy C$^{-1}$).

In the next chapter you will learn how ionisation chambers for HDR $^{192}$Ir are calibrated against the NPL primary standard and how the calibration coefficient of the secondary standard, $N_{\dot{K}_R}$, in terms of Gy C$^{-1}$ is determined.

4 NPL's air kerma standard for HDR $^{192}$Ir brachytherapy sources

4.1 Measurement equation and correction factors

The NPL has established a spherical graphite-walled ionisation chamber as a primary standard for $^{192}$Ir which realises the physical quantity of interest (here: RAKR in terms of Gy s$^{-1}$ at 1 m) from first principles.

The cavity chamber was originally used as a high-energy transfer standard for protection level calibrations. The graphite wall of the chamber is 4 mm thick, i.e. there is sufficient build-up material in the chamber wall to provide charged particle equilibrium for secondary electrons produced by $^{192}$Ir $\gamma$-rays (Goetsch et al. 1991).
The following measurement equation, based on Bragg-Gray and large cavity theory, applies to the NPL primary standard and shows how the RAKR of an HDR $^{192}$Ir Isodose Control Flexi source is determined from the measured ionisation current. For more information on cavity theory see the lecture notes on ‘Quantities, Units, and Ionising Radiation Fundamentals’. The measurement equation for the $^{192}$Ir primary standard is given by:

$$K_R = \frac{I}{\rho_{air}} \cdot \frac{\bar{W}_{air}}{e} \cdot \frac{1}{(1-g)} \cdot \left(\frac{\mu_{en}}{\rho}\right)_{graph} \cdot \left(\frac{S}{\rho}\right)_{air} \cdot \bar{g} \cdot k_h \cdot k_{att+sc} \cdot \left(\frac{d}{d_{rel}}\right)^2 \cdot k_{dec} \cdot k_{Tp} \quad (4)$$

where $K_R$ is the reference air kerma rate (Gy s$^{-1}$) at a reference time, $I$ is the ionisation current (A = C s$^{-1}$) measured at distance $d$, $\rho_{air}$ is the density of dry air (kg m$^{-3}$), $V_{air}$ is the internal volume of the chamber cavity (m$^3$) which was measured in the Centre for Basic, Thermal and Length Metrology at NPL using a co-ordinate measuring machine. $V_{air}$ was found to be $1.0252E-04$ m$^3$ with an uncertainty of 0.12% ($k = 2$).

$\bar{W}_{air}$ is the average energy (J) required to produce an ion pair in dry air per unit charge (C), where $\bar{W}_{air}/e = (33.97 \pm 0.05)$ J C$^{-1}$ ($k = 1$).

$g = 0.0007$ is the fraction of secondary electron energy lost to bremsstrahlung in air.

The next three terms follow from cavity theory and need to be applied because the ionisation chamber is made of graphite and not air. The values were evaluated by calculation using Monte Carlo techniques.

$$\left(\frac{\mu_{en}}{\rho}\right)_{graph} = 1.0016$$ is the ratio of the mean photon-energy-fluence-weighted photon mass energy-absorption coefficient of air to that of graphite and

$$\left(\frac{S}{\rho}\right)_{air} = 1.0082$$ is the product of the ratio of the mean electron-fluence-weighted electron mass stopping power of graphite to that of air and the fluence perturbation correction factor.

$\Pi_i k_i$ is the product of further correction factors to be applied to the primary standard. Some of these were determined by Monte Carlo simulations, i.e. the wall correction factor = 1.0453 which needs to be applied because the collecting volume is surrounded by a graphite wall which attenuates and scatters the primary photon beam (NB the central electrode correction factor = 0.9984 is already included in the wall correction factor) and the product of the radial and axial non-uniformity correction factors = 0.9981.

The following three correction factors were determined by measurement: the stem scatter correction factor = 0.9974, the polarity correction factor = 0.9995 and the ion recombination correction factor = 1.0028. The latter is dose rate dependent and given for a typical ionisation current of 20 pA.

$k_h = 0.9970$ is the humidity correction factor.

$k_{att+sc}$ (uncertainty: 0.06%, $k = 1$) is the combined air attenuation and scatter correction factor which corrects the measured ionisation current at $d = 1.433$ m for air attenuation and scatter between the source and the point
of measurement (see definition of RAKR in section 2). \( k_{\text{att+sc}} \) depends on air temperature and pressure and the air attenuation and scatter correction factor is usually found to be in the range 1.0165 \( \pm \) 0.0006.

The next factor, \((d/d_{\text{ref}})^2\), follows from the inverse square law and corrects the measured current at distance \( d = 1.433 \text{ m} \) (see figure 1) to the current that would have been measured at the reference distance \( d_{\text{ref}} = 1 \text{ m} \).

\( k_{\text{dec}} \) is the decay correction factor. \(^{192}\text{Ir} \) has a relatively short half-life, \( \tau_{1/2} = 73.827 \) days, and the measured ionisation current at the actual measurement time, \( t_{\text{now}} \), needs to be corrected to a reference time, \( t_{\text{ref}} \). When the secondary standard ionisation chamber is calibrated with the calibrated source, the measured ionisation current is corrected to the same reference time, \( t_{\text{ref}} \), before the primary standard to secondary standard ratio is calculated.

\( k_{\text{Tp}} \) is the air temperature and pressure correction factor which converts the ionisation current measured at temperature \( T \) and pressure \( p \) to the standard temperature \( T_{\text{STD}} = 293.15 \) K (= 20 °C) and the standard pressure \( p_{\text{STD}} = 1013.25 \) mbar.

By applying all correction factors of equation 4 to the measured primary standard ionisation current, \( I \), it is possible to derive the RAKR of the \(^{192}\text{Ir} \) source from first principles.

A detailed description of the primary standard cavity chamber can be found in NPL report DQL-RD 004 (Sander and Nutbrown 2006). The numerical values of the correction factors mentioned in the NPL report refer to the old source type (HDR \(^{192}\text{Ir} \) Nucletron microSelectron-v1 ‘classic’). The air kerma primary standard has been re-commissioned for the new source type (HDR \(^{192}\text{Ir} \) Isodose Control Flexisource) at the beginning of 2014.

The total uncertainty of the source calibration is estimated to be 0.7% \( (k = 2) \).

### 4.2 Source calibration set-up at NPL

Figure 1 shows the set-up used at NPL for the RAKR measurement.

![Figure 1. Set-up for \(^{192}\text{Ir} \) HDR source calibration at NPL (not to scale)]
The cavity chamber is set up at a source to chamber distance of 1.433 m and the measured ionisation current is normalised to the reference distance of 1 m by applying the inverse square law. The lead collimator was developed to reduce the amount of scattered radiation from the floor and the walls of the exposure room reaching the collecting volume of the cavity chamber and to avoid irradiating the chamber stem and connectors. Both the source-to-chamber distance and aperture size were chosen to give a uniform field over the whole of the ionisation chamber, which is circular in cross-section.

4.3 Traceability to the NPL primary standard

The HDR brachytherapy calibration service at NPL is for dosemeters (ionisation chambers and electrometers) intended to be used as secondary standards or instruments required for measurement of the greatest accuracy. The ionisation chambers used in the hospital are calibrated directly against the NPL primary standard for HDR $^{192}$Ir.

The calibration is a two-step process:

First, the RAKR of the HDR $^{192}$Ir Isodose Control Flexisource at NPL is determined using the NPL primary standard cavity chamber. The source is characterised in terms of Gy s$^{-1}$ at 1 m. Once the RAKR is known, the $^{192}$Ir source can be used to calibrate an ionisation chamber. The customer’s ionisation chamber is connected to a calibrated electrometer and the calibrated source is moved to the dwell position corresponding to the maximum chamber response (‘sweet-spot’).

The calibration coefficient of the ionisation chamber, $N_{RKR}$, is the ratio of the primary standard measurement (RAKR of $^{192}$Ir source) to the secondary standard measurement (ionisation current measured with the source placed at the ‘sweet-spot’). The ionisation current is also corrected for ion recombination effects and $N_{RKR}$ is given by:

$$N_{RKR} = \frac{\text{RAKR (Gy s}^{-1}\text{)}}{\text{ionisation current (A)} \cdot k_{\text{ion}}} = \text{calibration coefficient (Gy C}^{-1}\text{).} \quad (5)$$

The calibration coefficient, $N_{RKR}$, is reported on the calibration certificate for the ionisation chamber and enables the hospital physicist to determine the RAKR of the hospital source (see equation 3).

5 Secondary standard ionisation chambers for $^{192}$Ir brachytherapy sources

Well-type ionisation chambers are suitable secondary standards for HDR $^{192}$Ir brachytherapy sources. Thimble chamber/jig combinations can also be used. However, there is no standardised calibration procedure for thimble chamber/jig combinations at NPL as the end users have a variety of jigs. Thimble chambers need to be clamped in a suitable calibration jig with a source to chamber distance of typically 10 cm. There is significant potential for non-reproducible source positioning as catheters supported in the calibration jig may not always be parallel and there are many possible adjustments. In comparison, the well chamber method is less sensitive to
source positioning errors owing to the $4\pi$ measurement geometry inherent in the design.

Figure 2 shows a few well-type ionisation chambers suitable for measuring HDR sources. The source can be moved through a suitable transfer tube or a plastic catheter connected to the treatment head of the afterloader and the insert of the well chamber.

Figure 3 shows a thimble chamber clamped on a source calibration jig. In the bottom right hand corner two transfer tubes can be seen which link the two catheters left and right of the thimble chamber to the brachytherapy afterloader.

![Figure 2. Well chambers for HDR brachytherapy sources](image1)

![Figure 3. Thimble chamber / Nucletron jig combination](image2)

In well-type ionisation chambers, a 370 GBq $^{192}$Ir source will produce ionisation currents in the order of, say, 40 nA – 80 nA because the collecting volume is quite large (for the chambers shown in figure 2 ranging from approximately 150 cm$^3$ to more than 250 cm$^3$) and the brachytherapy source is close to the collecting volume. In thimble chambers (collecting volume $\leq 0.7$ cm$^3$) mounted on a calibration jig, the same source will generate ionisation currents of only a few pA.

The calibration procedure for both instruments is similar.

### 5.1 Calibration of a well-type ionisation chamber for $^{192}$Ir at NPL

The well chamber is positioned at least 1 m from any wall and 1 m above floor level on a low scatter surface. Before commencing measurements, sufficient time is allowed for the chamber to reach thermal equilibrium with the surrounding air. Well chambers are usually left to settle overnight. The well chamber is then connected to a calibrated electrometer. Measurements are taken after a warm-up period of at least 30 minutes during which the electrometer, ionisation chamber and cables are allowed to settle.

The point of maximum response (‘sweet-spot’) of the well chamber is found by stepping the $^{192}$Ir source through the chamber and by plotting the corrected ionisation current versus the dwell position of the source (see figure 4).

The ‘sweet-spot’ is the reference point and the hospital physicist needs to place the hospital source at the same position when using the chamber for measuring the RAKR of $^{192}$Ir sources.
The $^{192}\text{Ir}$ source is then sent to the dwell position corresponding to the maximum chamber response and at least five measurements of the ionisation current are taken. The electrometer calibration coefficient is applied and all ionisation currents are corrected to the same reference time, $t_{\text{ref}}$, as mentioned in section 4.1 by applying a decay correction.

An ion recombination correction factor, $k_{\text{ion}}$, is also applied. $k_{\text{ion}}$, which is the reciprocal of the ion collection efficiency, $A_{\text{ion}}$, is determined by using the two-voltage technique (Attix 1984). $k_{\text{ion}}$ is given by:

$$k_{\text{ion}} = \left(\frac{4}{3} - \frac{I_{300}}{3I_{150}}\right)^{-1}$$  \hspace{1cm} (6)

where $I_{300}$ is the instrument response in amps with the polarising potential set to 300 V and $I_{150}$ is the instrument response in amps with the polarising potential set to 150 V. During calibration at NPL, the collecting electrode and guard electrode are positive with respect to the outer electrode (chamber housing). This potential gradient will ensure that the negative current is collected by the electrometer.

The ionisation current is normalised to standard atmospheric conditions: $T_{\text{STD}} = 20 \degree C$, $p_{\text{STD}} = 1013.25$ mbar.

The well chamber calibration coefficient, $N_{kR}$, can now be obtained by applying equation 5.

The total uncertainty of the well chamber calibration coefficient is 0.8% ($k = 2$).
5.2 Calibration of a thimble chamber/jig combination for $^{192}$Ir at NPL

For thimble chamber/jig combinations, the calibration procedure is similar to the well chamber calibration procedure. When using the Nucletron Source Calibration Jig (obsolete since 2015), the thimble chamber is set up between two catheters, such that the distance from the centre of the $^{192}$Ir source to the centre of the thimble is 10 cm for both catheters. During calibration at NPL, for Farmer-type thimble chambers the polarising potential is usually set to 250 V. The collecting electrode and guard electrode are positive with respect to the graphite thimble. This potential gradient will ensure that the negative charge is collected by the electrometer.

The point of maximum response (‘sweet-spot’) of the thimble chamber is found by stepping the $^{192}$Ir source through both catheters parallel to the long axis of the chamber (see figure 3) and by plotting the corrected ionisation current versus the dwell position of the source. The response curves look similar to a well chamber response curve (see figure 4). The corrected ionisation current is calculated for both channels and the mean current is used for the calculation of the calibration coefficient, $N_{\text{th}}$, again in terms of (Gy C$^{-1}$ at 1 m). The recombination correction for thimble chambers set up in the Nucletron calibration jig and used for measuring HDR $^{192}$Ir sources is negligible and therefore $k_{\text{ion}}$ is taken as unity. The source geometry factor, $k_{\text{sg}}$, is also taken as unity for thimble chamber/jig combinations because the thimble chamber measures at only one point relative to the brachytherapy source, as opposed to well chambers which perform a $4\pi$ measurement.

The total uncertainty of the thimble chamber calibration coefficient determined at NPL is 1.3\% ($k = 2$) for the HDR $^{192}$Ir Isodose Control Flexisource. This is greater than the uncertainty quoted for well chamber calibration coefficients, which is mainly due to the positional uncertainty in the set up of the thimble chamber in the calibration jig. The IPEM code of practice for HDR brachytherapy (Bidmead et al. 2010) therefore recommends the use of well-type ionisation chambers as secondary standards for HDR $^{192}$Ir.

6 From RAKR to dose rate to water

The calibrated ionisation chambers and electrometers are returned to the brachytherapy centres and the hospital physicists can now use the calibrated instruments to determine the RAKR of their own HDR $^{192}$Ir sources. This will be discussed in more detail in the presentation: ‘HDR Brachytherapy Dosimetry in the Clinic’.

The ionisation current is measured with the HDR $^{192}$Ir source located at the point of maximum response of the secondary standard. The RAKR of the hospital source can be determined from equation 3 in terms of Gy s$^{-1}$ at 1 m, traceable to the NPL primary standard for HDR $^{192}$Ir.

There are a number of different afterloaders and source types currently in use in hospitals. If the $^{192}$Ir source type in the hospital is different from that used for the calibration of the well chamber at NPL, a source geometry correction factor, $k_{\text{sg}}$, is required to correct the calibration coefficient for any change of
the well chamber response due to the geometric differences between the sources (Shipley et al. 2015). These correction factors will be issued as part of the calibration certificate.

Although brachytherapy gamma ray sources are currently calibrated for RAKR, patient dosimetry is based on dose rate to water. The American Association of Physicists in Medicine (AAPM) published the Task Group 43 protocol (Nath et al. 1995) and an update (TG-43U1) by Rivard et al. in 2004. This protocol allows the calculation of dose rate to water at a point \((r, \theta)\) near the source from air kerma strength\(^1\) or RAKR. Many treatment planning systems are based on the TG-43 formalism.

The reference point \((r_0 = 1 \text{ cm}, \theta_0 = \pi/2)\) for dose rate calculations is chosen to lie on the transverse axis of the source at a distance of 1 cm from its centre. The dose rate to water at a distance of 1 cm is

\[
\dot{D}(r_0, \theta_0) = S_K \Lambda \tag{7}
\]

where \(\dot{D}(r_0, \theta_0)\) is the dose rate to water at the reference point in terms of Gy h\(^{-1}\), \(S_K\) is the air kerma strength in terms of Gy cm\(^2\) h\(^{-1}\) and \(\Lambda\) is the dose rate constant which is defined as the dose rate to water at a distance of 1 cm on the transverse axis of a source with one unit air kerma strength (1 U = 1 Gy cm\(^2\) h\(^{-1}\)) in a water phantom. The dose rate constant includes the effects of source geometry, the spatial distribution of radioactivity within the source, encapsulation and self-filtration within the source and scattering in water surrounding the source. The numerical value of \(\Lambda\) depends on the source type.

Equation 7 is only a special case and the general equation for the dose rate \(\dot{D}(r, \theta)\) at point \((r, \theta)\) can be written as

\[
\dot{D}(r, \theta) = S_K \Lambda \left( \frac{G(r, \theta)}{G(r_0, \theta_0)} \right) g(r) F(r, \theta) \tag{8}
\]

where \(S_K\) is the air kerma strength, \(\Lambda\) is the dose rate constant, \(G(r, \theta)\) is the geometry function, \(g(r)\) is the radial dose function and \(F(r, \theta)\) is the anisotropy function as defined in TG-43 (Nath et al. 1995).

Tabulated values of \(G(r, \theta)\), \(g(r)\) and \(F(r, \theta)\) for various brachytherapy sources can be found on the Carleton University, Canada website at: http://www.physics.carleton.ca/clrp/seed_database/ (Taylor and Rogers 2008) or the BRAPHYSYS website at http://www.uv.es/braphysys/.


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\(^1\) Air kerma strength is the quantity used in North America for the specification of brachytherapy gamma ray sources. Air kerma strength has units of cGy cm\(^2\) h\(^{-1}\).
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