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Dosimetric Quantities and Units Introduction

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Dosimetric quantities and units
Introduction

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INTRODUCTION

- The connection to the medical profession is obvious.

The term **dose of radiation** was initially used in a pharmacological sense: and is analogous to its meaning when used in prescribing a **dose of medicine**.

- Very soon it turned out that **physical methods** to describe a "dose of radiation" proved superior to any biological methods.

INTRODUCTION

- Radiation dosimetry is a now a pure **physical science.**
- Central are the methods for a quantitative determination of **energy deposited** in a given medium by directly or indirectly ionizing radiations.
- A number of physical quantities and units have been defined for describing a beam of radiation and the dose of radiation.
- This talk deals with the most commonly used **dosimetric quantities** and their **units in diagnostic radiology**.

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DOSIMETRIC QUANTITIES AND UNITS

- Basic dosimetric quantities
- Application specific dosimetric quantities
- Quantities related to stochastic and deterministic effects
- Conversion coefficients for the assessment of organ and tissue doses

Basic dosimetric quantities

- Fluence
- Energy fluence
- Kerma and kerma rate
- Energy imparted
- Absorbed dose

- Based on ICRU Report 60

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RADIATION FIELD OR RADIOMETRIC QUANTITIES

Radiation Field

- The term radiation field is a very general term that is used to characterize in a quantitative way the radiation in space consisting of particles.

- There are two very general quantities associated with a radiation field:

    - the **number**, N of particles
    - the **energy**, R transported by the particles (which is also denoted as the radiant energy)

RADIATION FIELD OR RADIOMETRIC QUANTITIES

Radiation Field

- **ICRU-Definition of particle number:**
  The **particle number, *N*,** is the number of particles that are emitted, transferred, or received. Unit: 1

- **ICRU-Definition of radiant energy:**
  The **radiant energy, *R*,** is the energy (excluding rest energy) of particles that are emitted, transferred, or received. Unit: J

- For particles of energy E (excluding rest energy):

$$R = E \cdot N$$

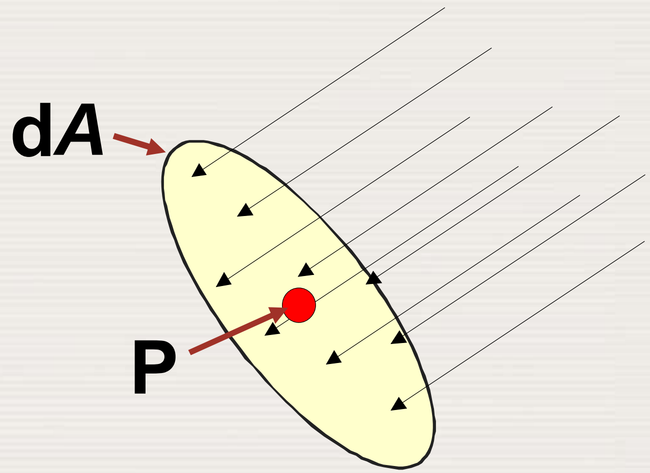
Particle Fluence

How can the number of particles be determined at a certain point in space?

Consider a point P($\vec{r}$) in space within a field of radiation.

Then use the following simple method:

In case of a parallel radiation beam, construct a small area d*A* around the point P in such a way, that its plane is **perpendicular** to the direction of the beam.



Determine the number of particles that intercept this area d*A*.

RADIATION FIELD OR RADIOMETRIC QUANTITIES

Particle Fluence

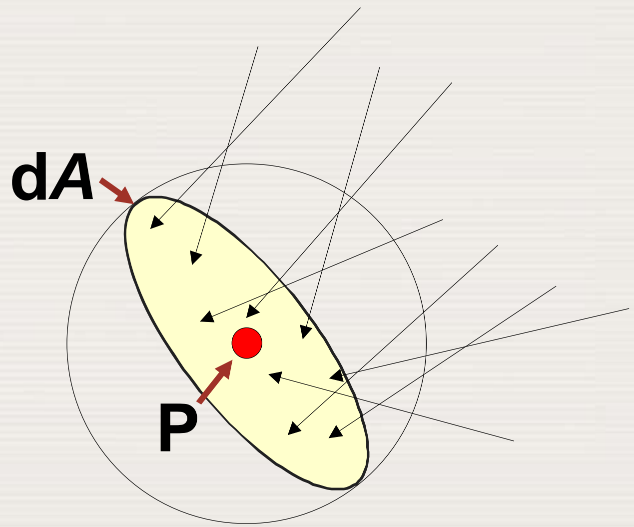
In the general case of **nonparallel** particle directions it is evident that a fixed plane cannot be traversed by all particles perpendicularly.

A somewhat modified concept is needed!

The plane d*A* is allowed to move freely around P, so as to intercept each incident ray perpendicularly.

Practically this means:

- Generate a **sphere** by rotating d*A* around P
- Count the number of particles **entering** the sphere



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Fluence & Energy fluence

The fluence, Φ, is the quotient dN by da, where dN is the number of particles incident on a sphere of cross-sectional area da, thus

$$\Phi = \frac{\mathrm{d}N}{\mathrm{d}a}$$

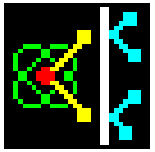
Unit: m^{-2}.

The energy fluence, Ψ, is the quotient dR by da, where dR is the radiant energy incident on a sphere of cross-sectional area da, thus

$$\Psi = \frac{\mathrm{d}R}{\mathrm{d}a}$$

Unit: J m^{-2}.

Example: Bremsstrahlung fluence



Xertex_p5.exe

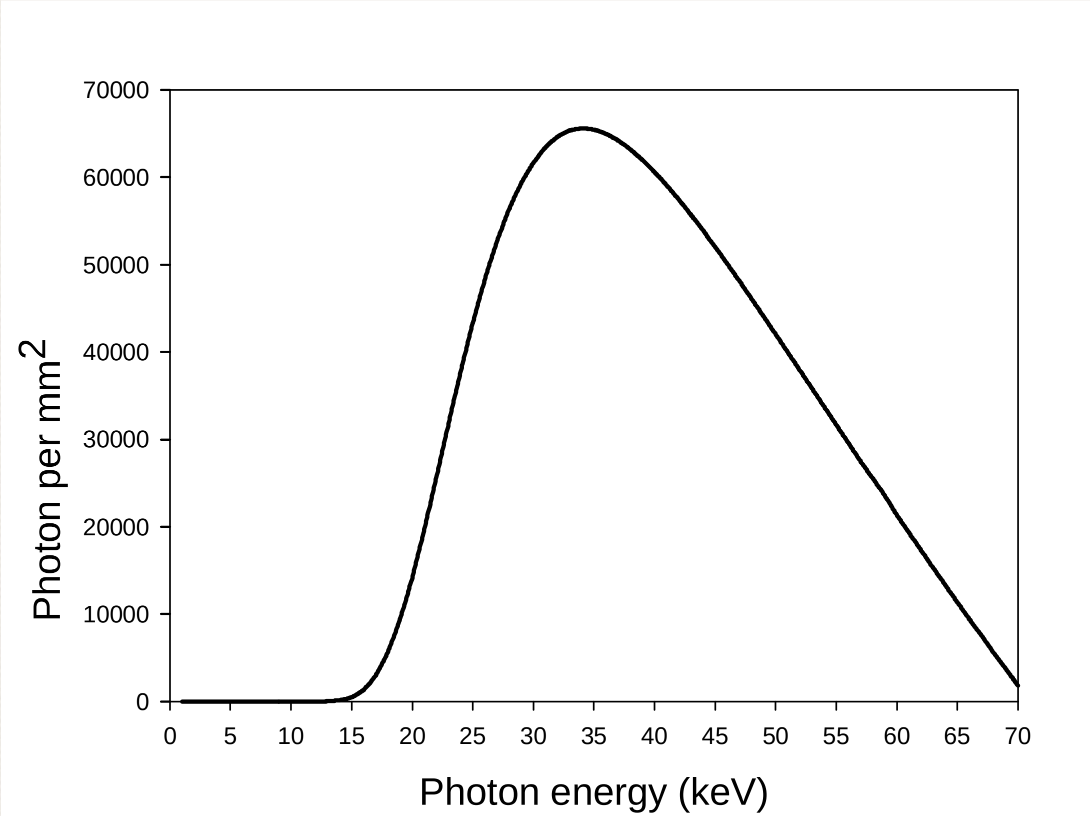
RQR 5: 70 kV; HVL = 2.58 mm Al

Target; W, 12^0, Total filtration; 2.6 mm Al

At 75 cm for 1 mAs

Total fluence = 2030295 photons/sq.mm.

= 2.03×10^{12} photons m^{-2}



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Example: Bremsstrahlung energy fluence

Xertex_p5.exe

RQR 5: 70 kV; HVL = 2.58 mm Al

Target; W, 12^0, Total filtration; 2.6 mm Al

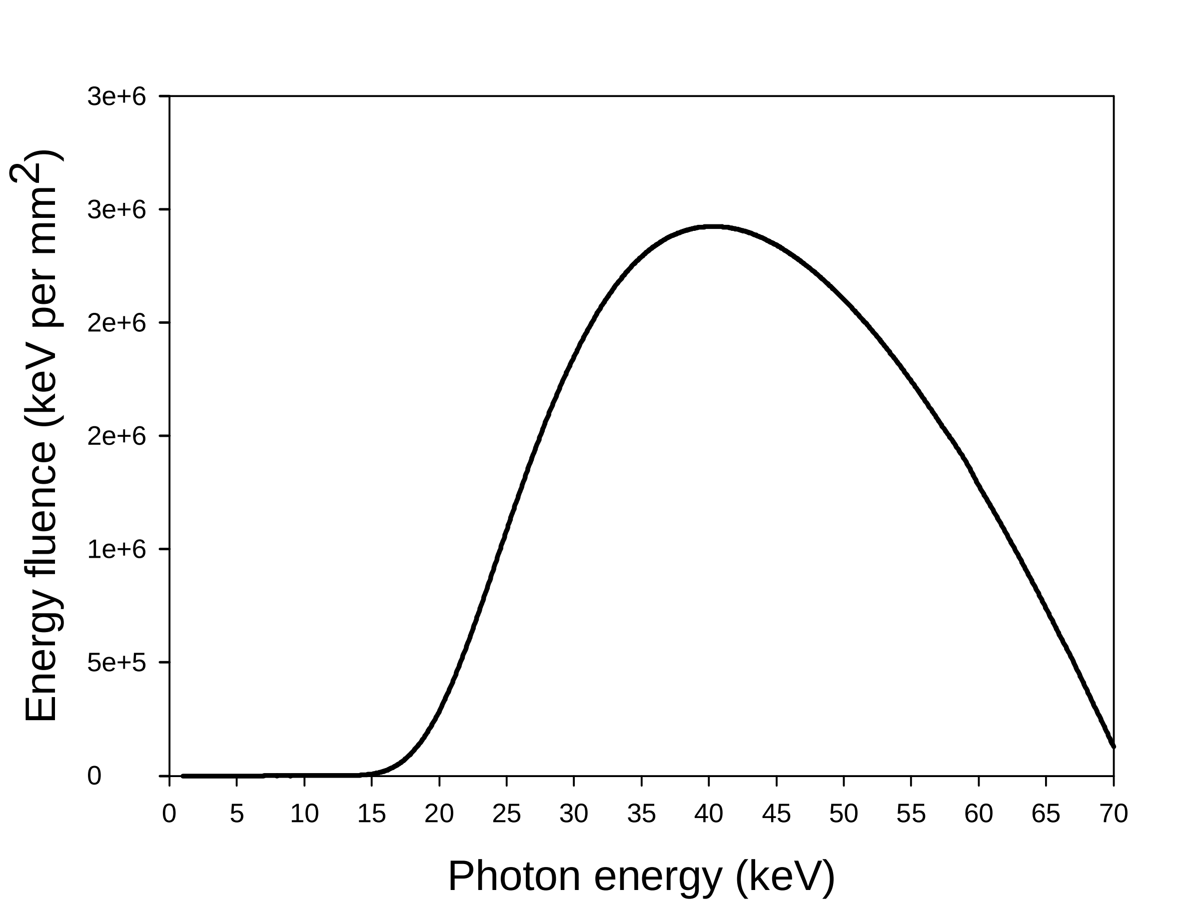
At 75 cm for 1 mAs

Total energy fluence = 81378447 keV/sq.mm.

= 1.30 x 10^{-2} J.m^{-2}

h=6.62 x 10^{-34} J/s

h=4.13 x 10^{-18} keV/s



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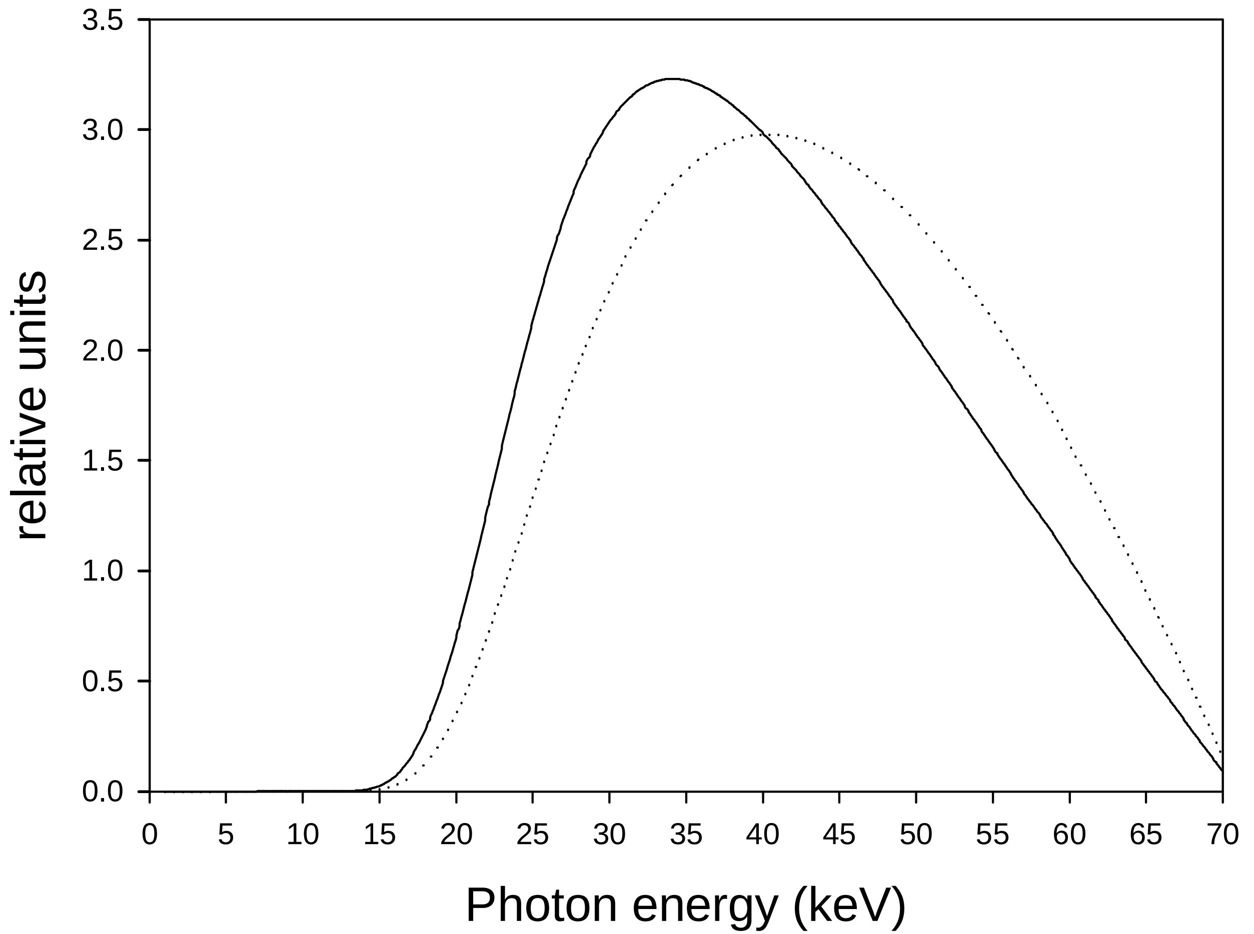
Comparison of fluence and energy fluence



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Common characteristics of Kerma and Absorbed Dose:

- They are generally defined as:

$$\frac{\text{radiation energy (transferred or absorbed)}}{\text{mass}} \left[\frac{\text{J}}{\text{kg}}\right]$$

- They can also be defined as:

$$\text{radiation field quantity} \times \text{mass interaction coefficient} \left[\frac{\text{J}}{\text{kg}}\right]$$

Kerma and kerma rate

The kerma, K, is the quotient $\mathrm{d}E_{tr}$ by dm, where $\mathrm{d}E_{tr}$ is the sum of the initial kinetic energies of all the charged particles liberated by uncharged particles in a mass dm of material, thus

$$K = \frac{\mathrm{d}E_{tr}}{\mathrm{d}m}$$

Unit: J kg^{-1}. The special name for the unit of kerma is gray (Gy).

The kerma rate,

$$\dot{K} = \frac{\mathrm{d}K}{\mathrm{d}t}$$

Unit: J kg^{-1}s^{-1}or (Gy s^{-1}).

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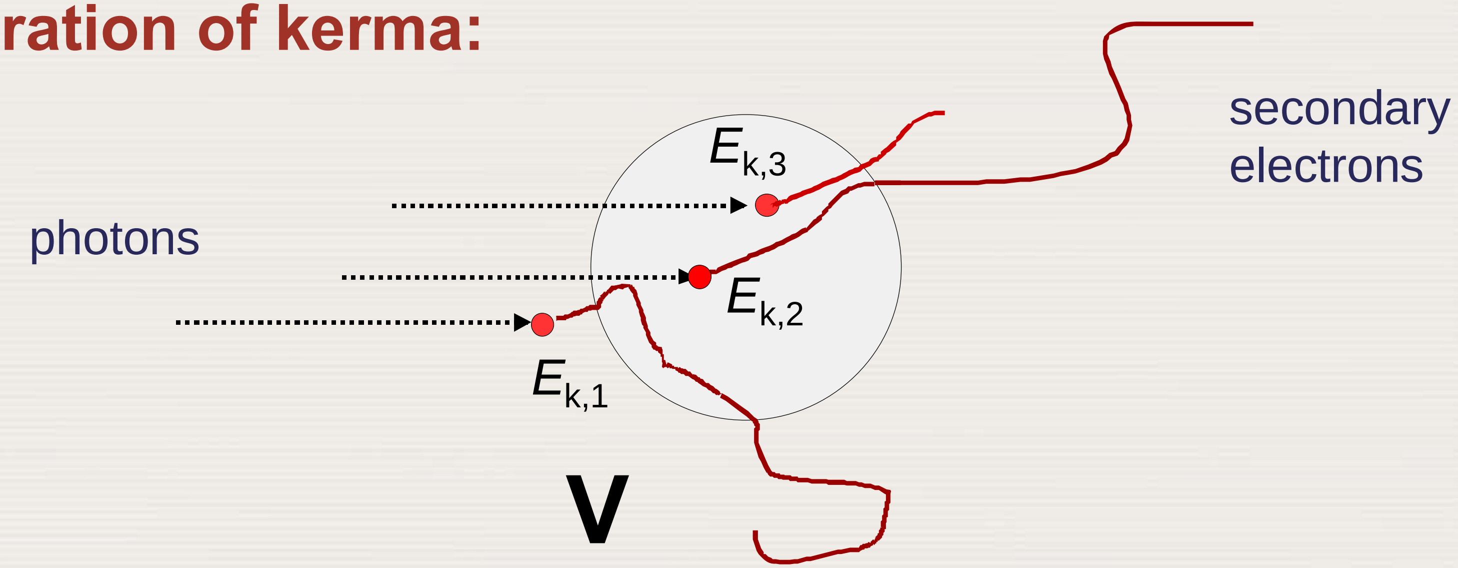
DOSIMETRIC QUANTITIES
Kerma

Illustration of kerma:



Collision energy transferred in the volume: $E_{tr} = E_{k,2} + E_{k,3}$

where E_k is the initial kinetic energy of the secondary electrons.

Note: $E_{k,1}$ is transferred **outside the volume** and is therefore not taken into account in the definition of kerma!

Energy imparted

The mean energy imparted, $\bar{\varepsilon}$ to the matter in a given volume equals the radiant energy, R_{in}, of all those charged and uncharged ionizing particles which enter the volume minus the radiant energy, R_{out}, of all those charged and uncharged ionizing particles which leave the volume, plus the sum, ΣQ, of all changes of the rest energy of nuclei and elementary particles which occur in the volume, thus

$$\bar{\varepsilon} = R_{in} - R_{out} + \Sigma Q$$ Unit: J.

For the photon energies used in diagnostic radiology, ΣQ **is zero.**

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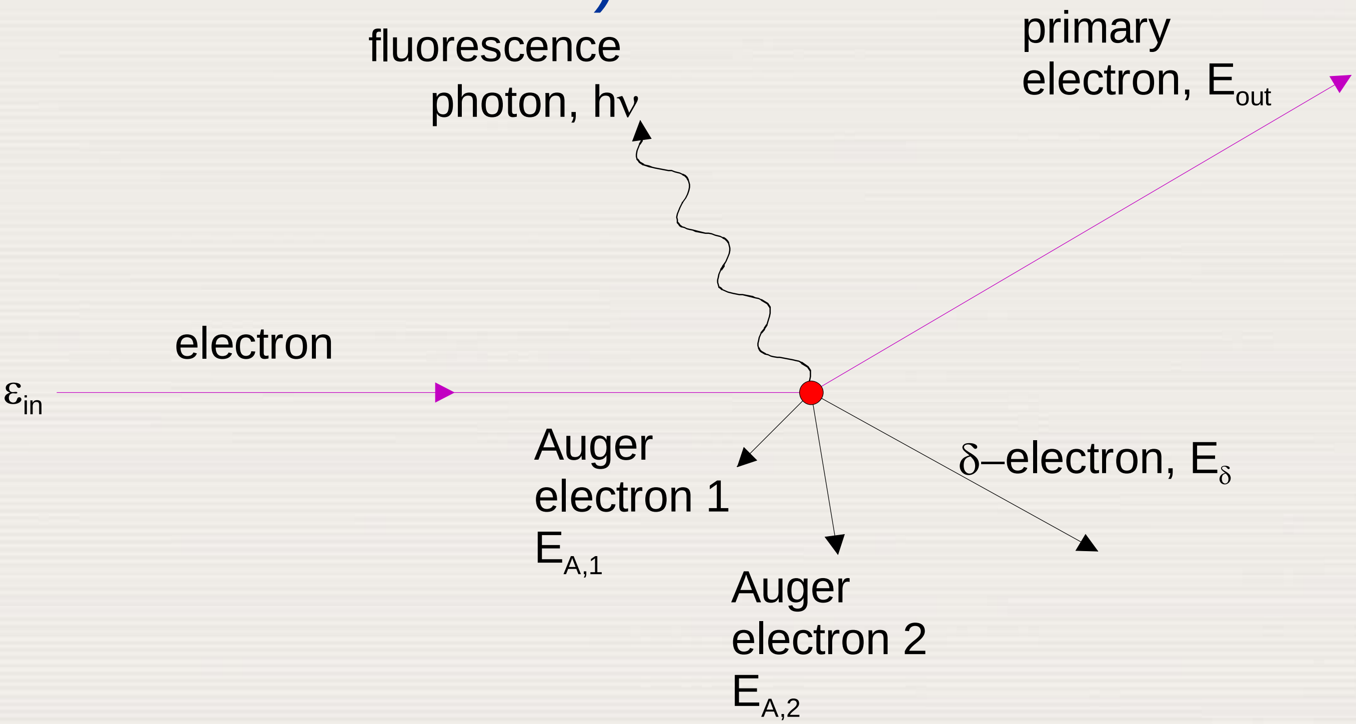
Fundamentals of the Absorption of Radiation Energy

Example for energy deposit ε_i with **Q = 0** (electron knock-on interaction):



$$\varepsilon_i = \varepsilon_{in} - (E_{out} + E_{A,1} + E_{A,2} + E_\delta + h\nu)$$

Absorbed dose

The absorbed dose, *D*, is the quotient d $\bar{\varepsilon}$ by d*m*,

where d $\bar{\varepsilon}$ is the mean energy imparted to matter of mass d*m*, thus

$$D = \frac{\mathrm{d}\bar{\varepsilon}}{\mathrm{d}m}$$

Unit: J kg^{-1}. gray (Gy).

Where the production of Bremsstrahlung negligible, absorbed dose and kerma are numerically equal when secondary electron equilibrium is established.

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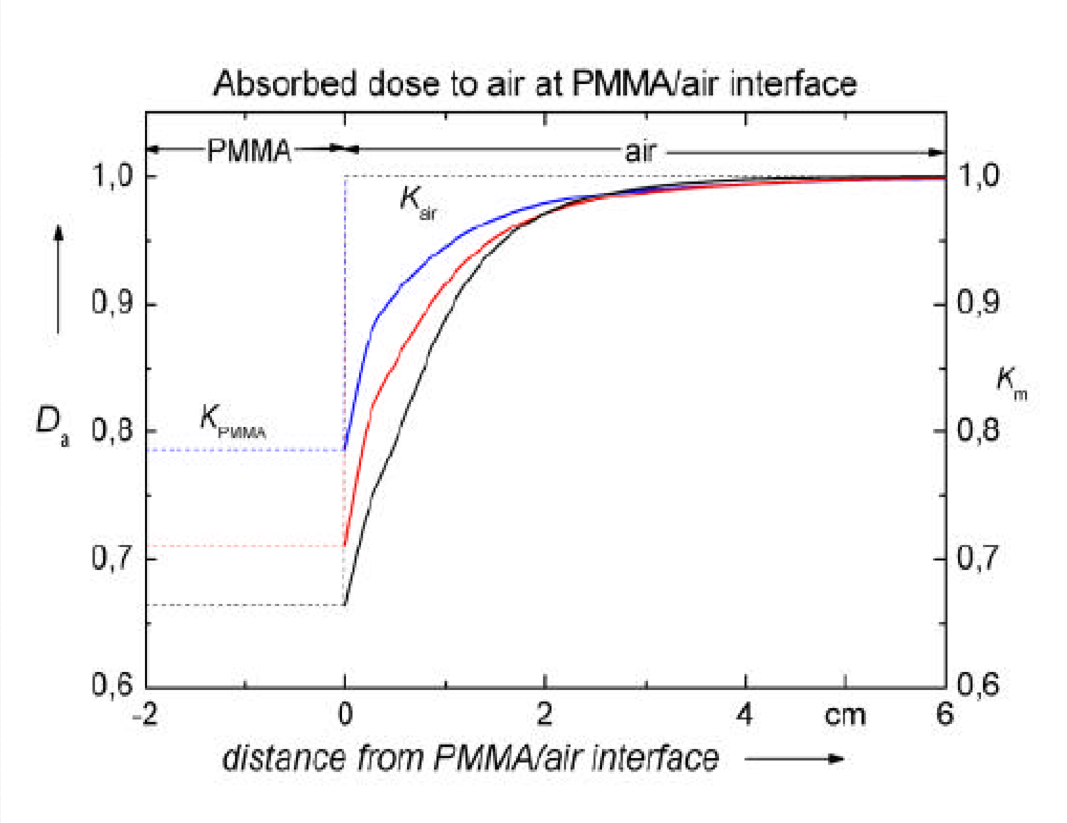
Dose to air at PMMA/air interface



– 70 kV, 2.5 mm Al, – 100 kV, 3.97 mm Al, –150 kV, 6.57 mm Al

ICRU *versus* IAEA
basic dosimetry quantities

Quantity	ICRU	IAEA
Fluence	no	Φ
Energy fluence	Ψ	Ψ
Kerma	K (K_a for air)	K (also for air)
Energy imparted	no	$\bar{\varepsilon}$
Absorbed dose	D	D
Exposure	X	no

Application specific dosimetric quantities

- Rationale for choice of quantities
- Incident air kerma
- Entrance surface air kerma
- X ray tube output
- Air kerma-area product
- Air kerma-length product
- Quantities for CT dosimetry

Based on ICRU Report 74

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Rationale for choice of quantities

Several application specific quantities have been found useful in the past for measurements in diagnostic radiology. However, there has been ambiguity in the names of the quantities and their (sometimes incorrect) use. ICRU 74 provides a consistent set of quantities, which is adopted in this Code of Practice

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Incident air kerma & Entrance surface air kerma

The incident air kerma, $\boldsymbol{K_i}$, is the kerma to air from an incident X ray beam measured on the central beam axis at the position of the patient or phantom surface. *Only the radiation incident on the patient or phantom and not the backscattered radiation is included*.

The entrance surface air kerma, $\boldsymbol{K_e}$, is the kerma to air measured on the central beam axis at the position of the patient or phantom surface. The radiation incident on the patient or phantom *and the backscattered radiation (**B**)* are included.

$$K_e = K_i\, B$$

X ray tube output

The X ray tube output, $Y(d)$, is defined as the quotient of the air kerma at a specified distance, d, from the X ray tube focus by the tube current-exposure time product P_{It}., thus

$$Y(d) = K(d)/P_{It}$$

Unit: Gy (A·s)$^{-1}$ or Gy (mA·s)$^{-1}$

The tube current–exposure time product, P_{It} is also referred to in this Code of Practice as the tube loading.

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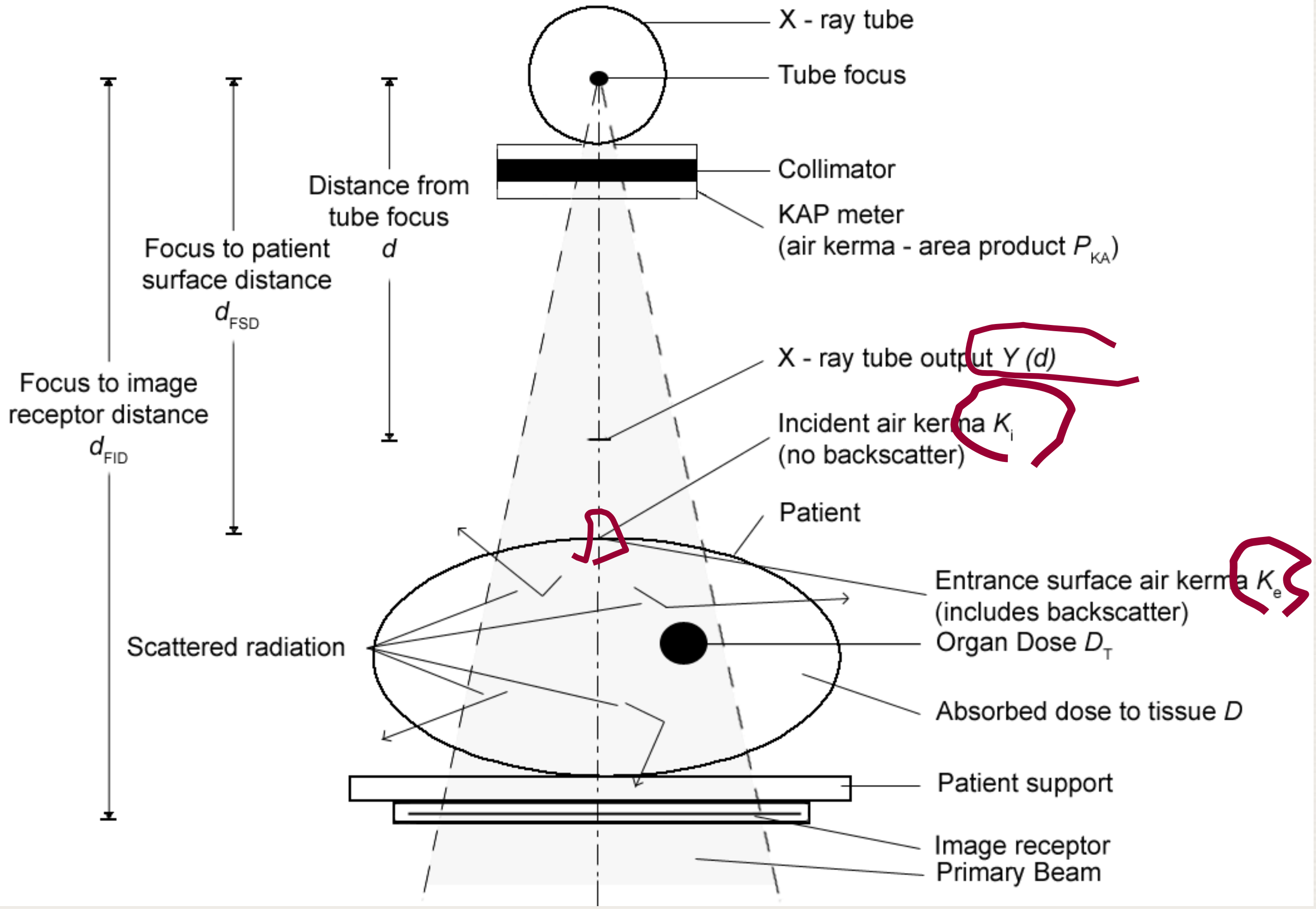
Zero Dimensional quantities



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Air kerma-area product

The air kerma-area product, P_{KA}, is the integral of the air kerma over the area of the X ray beam in a plane perpendicular to the beam axis, thus

$$P_{\mathrm{KA}} = \int_A K(x,y)\,\mathrm{d}x\mathrm{d}y$$

Unit: Gy m^2

P_{KA} has the useful property that it is approximately invariant with distance from the X ray tube focus (when interactions in air and extra-focal radiation can be neglected), as long as the planes of measurement do not include a significant contribution from backscattered radiation from the patient or phantom.

Air kerma-length product

The air kerma-length product, P_{KL}, is the integral of the air kerma over a line, L, thus

$$P_{\mathrm{KL}} = \int_L K(z)\,dz$$

Unit: Gy m

air kerma-length product is applied to the dosimetry of CT and to the dosimetry of dental panoramic examinations. In the literature for dental panoramic dosimetry, this quantity has been termed the "dose-width product"

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Quantities for CT dosimetry (1)

The computed tomography air kerma index, $C_{a,100}$, measured free-in-air for a single rotation of a CT scanner is the quotient of the integral of the air kerma along a line parallel to the axis of rotation of the scanner over a length of 100 mm and the nominal slice thickness, T . The integration range is positioned symmetrically about the volume scanned, thus

$$C_{a,100} = \frac{1}{T}\int_{-50}^{+50} K(z)\,\mathrm{d}z$$

Unit: Gy

$$C_{a,100} = \frac{1}{N\,T}\int_{-50}^{50} K(z)\,dz$$

Multi detector CT:
N simultaneously acquired slices

Quantities for CT dosimetry (2)

The computed tomography air kerma index is also measured inside PMMA head and body phantoms

$$C_{\mathrm{W}} = \frac{1}{3}\left(C_{\mathrm{PMMA,\,100,\,c}} + 2\ C_{\mathrm{PMMA,\,100,\,p}}\right)$$

The quantity $C_{\mathrm{PMMA,100,c}}$ is measured at the centre of the standard CT dosimetry phantom and $C_{\mathrm{PMMA,100,p}}$ is the average of values measured at four positions around the periphery of the same phantom. A weighted “computed tomography dose index” (CTDI) was first introduced by Leitz *et al.* and is used in IEC and the European CT Dosimetry protocol.

Quantities for CT dosimetry (3)

The subscript *n* is used to denote when the value of $C_{a,100}$ or C_W has been normalised to unit tube current-exposure time product, P_{It}, thus

$$ {}_nC_W = \frac{C_W}{P_{It}}; \qquad {}_nC_{a,100} = \frac{C_{a,100}}{P_{It}} $$

A further quantity, C_{VOL}, takes into account the helical pitch or axial scan spacing thus

$$ C_{VOL} = C_W \frac{NT}{l} = \frac{C_W}{p}; \qquad {}_nC_{VOL} = \frac{C_{VOL}}{P_{It}} $$

where *N* is the number of simultaneously acquired tomographic slices, *T* the nominal slice thickness, *l* is the distance moved by the patient couch per helical rotation or between consecutive scans for a series of axial scans and P_{It} is the tube loading for a single axial scan

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Quantities for CT dosimetry (4)

The quantity

$$p = \frac{l}{NT}$$

is known as the CT pitch factor (or pitch) for helical scanning.

The CT air kerma-length product determined for the standard CT dosimetry phantom and a complete CT examination, $P_{\text{KL,CT}}$, is calculated using

$$P_{\text{KL,CT}} = \sum_j {}_n C_{\text{VOL}_j} l_j P_{\text{It}_j}$$

where the index j represents each serial or helical scan sequence forming part of the examination, l_j is the distance moved by the patient couch between or during consecutive scanner rotations and is the total tube loading for scan sequence j. This quantity is analogous to the 'dose length product' introduced in EC guidelines

ICRU *versus* IAEA application specific quantities

Quantity	ICRU	IAEA
Weighted CT air kerma index	$C_{K,PMMA,w}$	C_W
Normalized weighted CT air kerma index	${}_nC_{K,PMMA,w}$	${}_nC_W$
CT air kerma-length product	$P_{KL,CT}$	$P_{KL,CT}$ (defined using ${}_nC_{VOL}$)

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Quantities related to stochastic and deterministic effects

- Organ and tissue dose
- Equivalent dose
- Effective dose

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Organ and tissue dose

The mean absorbed dose in a specified tissue or organ is given the symbol, D_T, in ICRU Report 51. It is equal to the ratio of the energy imparted, $\bar{\varepsilon}_T$, to the tissue or organ to the mass, m_T, of the tissue or organ, thus

$$D_T = \frac{\bar{\varepsilon}_T}{m_T}$$

The mean dose to the glandular tissues within the breast has been referred to in the literature as both “mean glandular dose” and “average glandular dose”. The term “mean glandular dose” and the notation D_G are used in this Code of Practice.

Equivalent dose

The equivalent dose, H_T, to an organ or tissue, T, is defined in ICRP Report 60. For a single type of radiation, R, it is the product of a radiation weighting factor , w_R, for radiation R and the organ dose, D_T, thus

$$H_T = w_R \, D_T \qquad \text{Unit: sievert (Sv)}$$

The radiation weighting factor, w_R, allows for differences in the relative biological effectiveness of the incident radiation in producing stochastic effects at low doses in tissue or organ, T. For X ray energies used in diagnostic radiology, w_R is taken to be unity

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Effective dose

The effective dose, E, is defined in ICRP Report 60. It is the sum over all the organs and tissues of the body of the product of the equivalent dose, H_T, to the organ or tissue and a tissue weighting factor, w_T, for that organ or tissue, thus

$$E = \sum_{T} w_T H_T$$

Unit: sievert (Sv)

The tissue weighting factor, w_T, for organ T represents the relative contribution of that organ to the total detriment arising from stochastic effects for uniform irradiation of the whole body

Conversion coefficients for the assessment of organ and tissue doses

A conversion coefficient, *c*, relates the dose to an organ or tissue to a readily measured or calculated dosimetric quantity, thus

$$c = \frac{\text{organ or tissue dose}}{\text{measured or calculated quantity}}$$

Suffices are added to *c* to indicate the two quantities that are related, for example the coefficient

$$c_{D_\mathrm{T},K_\mathrm{i}} = D_\mathrm{T} / K_\mathrm{i}$$

relates the organ dose, D_T, to the incident air kerma, K_i

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Thank you for your attention