Dosimetric Quantities and Units

Contents

INTRODUCTION

International Commission on Radiation Units and Measurements (ICRU)

The group formally charged with defining the quantities and units employed in radiation protection.

Key Reports:

Fundamental Quantities and Units for Ionizing Radiation. ICRU Report 60 (1998).

Quantities and Units in Radiation Protection Dosimetry. ICRU Report 51 (1993).

International Commission on Radiological Protection (ICRP)

Make recommendations regarding radiation protection. Usually employ ICRU terminology, but sometimes get involved in defining radiological quantities and units.

Key Publications:

Recommendations of the International Commission on Radiological Protection. ICRP Publication 26 (1977)

Recommendations of the International Commission on Radiological Protection. ICRP Publication 60 (1990)

Recommendations of the International Commission on Radiological Protection. ICRP Publication 103 (2008)

U.S. Regulatory Agencies

Almost all U.S. regulatory agencies employ the quantities and units of ICRP 26.

The exception is the Department of Energy which employs the terminology of ICRP 60.

Four Dosimetric Quantities

- Exposure (X)
  - Units: roentgen (R), coulombs/kilogram (C/kg)
- Absorbed Dose (D)
  - Units: rad, gray(Gy), joules/kilogram (J/kg)
- Kerma (K)
  - Units: rad, gray(Gy), joules/kilogram (J/kg)
- Dose Equivalent , aka Equivalent Dose (H or DE)
  - Units: rem, sievert (Sv)

Exposure (X)
and
Exposure Rate ($\dot{X}$)

Exposure (X)

Quantity: Exposure (X)

Units: roentgen (R)

coulombs/kilogram

Unit conversions: 1 R = 2.58×10^{-4} C/kg

The quantity exposure reflects the intensity of gamma ray or x-rays and the duration of the exposure.

More specifically, it is a measure of the charge on the ions of one sign (negative or positive) resulting from the interaction of gamma ray and x-ray photons in a specified mass of air.

Exposure (X)

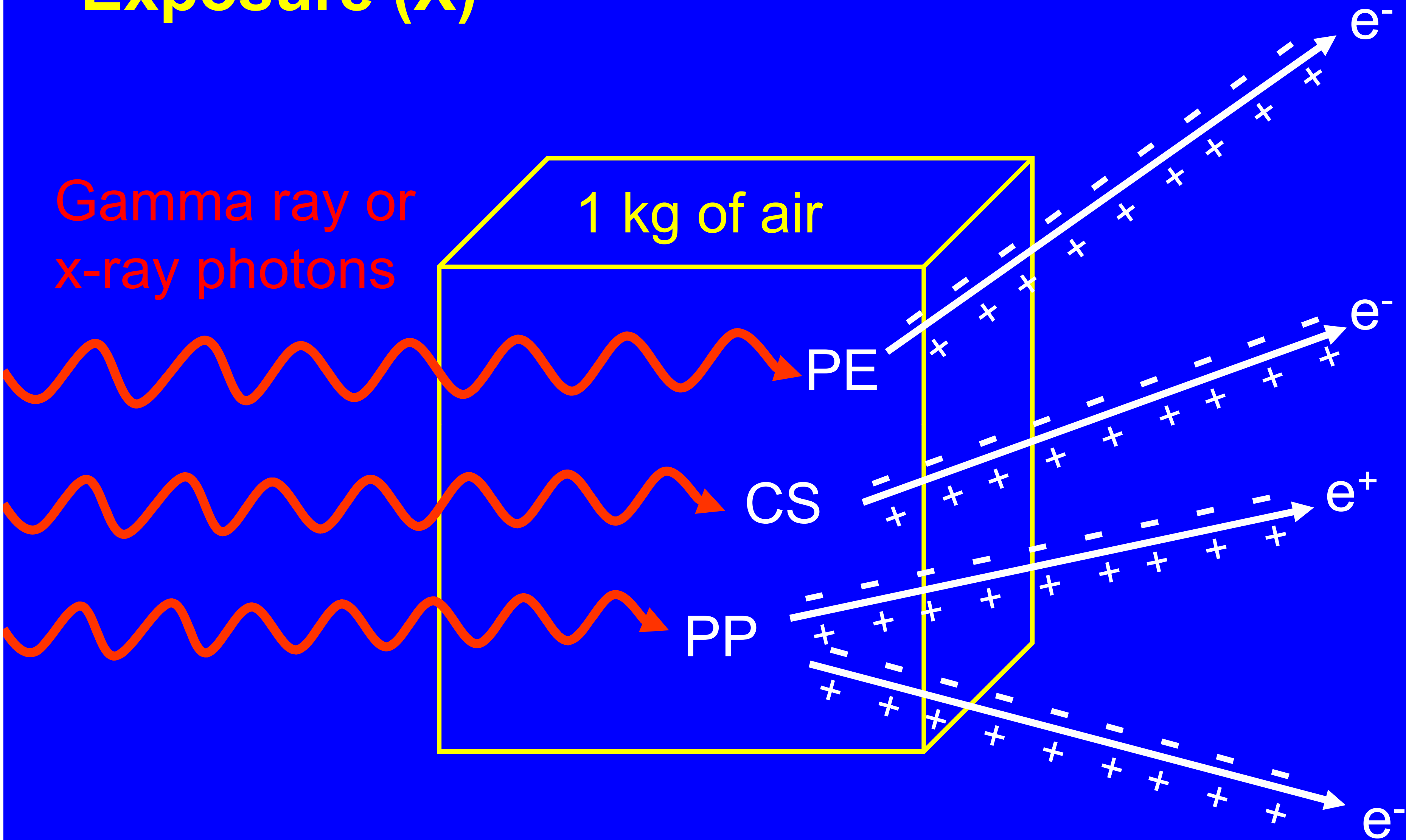
Current Definition of the Roentgen

$$1\ R = 2.58 \times 10^{-4}\ C/kg$$

Original Definition of the Roentgen

The quantity of x-ray or gamma ray photons that produces a charge of one sign, either positive or negative, of 1 esu (electrostatic unit) per 1 cc of air at STP (0.001293 g)

Exposure (X)



Exposure Rate ($\dot{X}$)

Quantity: Exposure Rate ($\dot{X}$)

Units: roentgen/hour ($R\ hr^{-1}$)

coulombs/kilogram/second ($C\ kg^{-1}\ s^{-1}$)

Unit conversions: 1 R/hr = $71.7 \times 10^{-8}\ C\ kg^{-1}\ s^{-1}$

The quantity exposure reflects the intensity of gamma ray or x-rays.

Exposure (X) and Exposure Rate ($\dot{X}$)

General Comments

The quantity is only defined for photons (e.g., gamma rays and x-rays). Instruments measuring exposure rate (e.g., in mR/hr) should not respond to charged particles (e.g., betas).

The quantity is only defined in air. The exposure of other materials (e.g., tissue) should not be expressed in units of exposure rate (e.g., mR/hr).

The quantity is considered unnecessary and is sometimes replaced by the absorbed dose rate or kerma rate to air.

Exposure Rate ($\dot{X}$)

Important Equation

$$\dot{X} = \frac{A\,\Gamma}{d^2}$$

$\dot{X}$ is the exposure rate (e.g., R/hr)
A is the source activity (e.g., Ci)
Γ is the specific gamma ray constant (e.g., R m^2 hr^{-1} Ci^{-1})
d is the distance from the source (e.g., m)

Exposure (X)

Important Equation

$$X = \left(\frac{A\,\Gamma}{d^2} \right) t$$

X is the exposure (e.g., R)
A is the source activity (e.g., Ci)
Γ is the specific gamma ray constant (e.g., R m^2 hr^{-1} Ci^{-1})
d is the distance from the source (e.g., m)
t is the duration of the exposure (e.g., hr)

Exposure Rate ($\dot{X}$)

Important Equation

$$d = \sqrt{\frac{A\ \Gamma}{\dot{X}}}$$

d is the distance from the source at which a given exposure rate will occur

Exposure Rate ($\dot{X}$)

General Comments about the Equation

$$\dot{X} = \frac{A\Gamma}{d^2}$$

It calculates the exposure rate for a point source.

It works reasonably well for other source geometries when the distance (d) is greater than five times the maximum dimension of the source.

It does not include the background exposure rate.

It does not consider the contribution to the exposure rate made by scattered photons.

Exposure (X) and Exposure Rate ($\dot{X}$)

Specific Gamma Ray Constant (Γ)

Each gamma emitting radionuclide has its own unique specific gamma ray constant.

The specific gamma ray constant is the exposure rate at a specified distance from a specified activity of the nuclide.

These constants are usually looked up in tables, but they can be calculated if necessary.

For look up tables, see PTP's Rad Health Handbook starting at page 69.

Exposure (X) and Exposure Rate ($\dot{X}$)

Specific Gamma Ray Constant (Γ)

The exposure rate constant for Co-60 is 1.32 R m^2 hr^{-1} Ci^{-1}

This means that the exposure rate at one meter from a one curie Co-60 source is 1.32 R/hr.

This is equivalent to 13.2 R/hr at one cm per mCi
(13.2 R cm^2 hr^{-1} mCi^{-1})

$$1.32\left(\frac{R\ m^2}{hr\ Ci}\right) = 1.32\left(\frac{mR\ m^2}{hr\ mCi}\right) = 13.2\left(\frac{R\ cm^2}{hr\ mCi}\right) = 13{,}200\left(\frac{mR\ cm^2}{hr\ mCi}\right)$$

Exposure (X) and Exposure Rate ($\dot{X}$)

Calculating the Specific Gamma Ray Constant (Γ)

To determine the specific gamma ray constant for a given radionuclide, individual constants are calculated for each of the radionuclide's gamma rays and x-rays and then the individual constants are summed. The formula for each constant is

$$\Gamma = 19.53\, E\, I \left(\frac{\mu_{en}}{\rho} \right)$$

Γ is the constant in R m^2 h^{-1} Ci^{-1}
E is the gamma energy in MeV
I is the gamma intensity (gammas/disintegration)
u_{en}/ρ is the mass energy absorption coefficient in cm^2 g^{-1}

Exposure Rate ($\dot{X}$) - example calculation

What is the exposure rate at one foot from a 30 curie iridium 192 source?

$$\dot{X} = \frac{A\ \Gamma}{d^2}$$

$$= \frac{30{,}000(mCi)\ x\ 4.6(R\ hr^{-1}\ cm^2\ mCi^{-1})}{(30cm)^2}$$

$$= 153\ R/hr$$

Exposure Rate ($\dot{X}$)

Rule of Thumb Regarding Radium-226

The exposure rate at one meter from a one curie Ra-226 source is approximately 1 R/hr.

As such, the exposure rate at one meter from one mCi of Ra-226 is approximately 1 mR/hr.

Similarly, the exposure rate at one meter from one uCi of Ra-226 is approximately 1 uR/hr above background.

Finally, the exposure rate at one foot from one uCi of Ra-226 is approximately 10 uR/hr above background.

Absorbed Dose (D)
and
Absorbed Dose Rate ($\dot{D}$)

Absorbed Dose (D) and Absorbed Dose Rate ($\dot{D}$)

Quantity: Absorbed Dose (D)

Units: rad

gray (Gy)

joules/kilogram

Unit conversions: 1 Gy = 1 J/kg = 100 rads

Absorbed Dose (D) and Absorbed Dose Rate ($\dot{D}$)

The quantity absorbed Dose (D) is a measure of the amount of radiation energy absorbed per unit mass (e.g., joules/kilogram or ergs/gram).

It applies to all types of radiation, e.g., x-rays, gamma rays, betas, alphas, neutrons

The absorbed dose can be calculated for any material, e.g., air, water, tissue, lead

Absorbed Dose (D) and Absorbed Dose Rate ($\dot{D}$)

General Comments

The absorbed dose reflects the energy deposited per unit mass, not the total energy:

A 100 kg person absorbing 100 joules of energy has an absorbed dose of 1 Gy (100 rads).

A 50 kg person absorbing the same energy has an absorbed dose of 2 Gy (200 rads).

The absorbed dose is material specific, e.g., the absorbed dose to human tissue from gamma rays or x-rays will be greater than the absorbed dose to air in the same situation.

Absorbed Dose (D) and Absorbed Dose Rate ($\dot{D}$)

Absorbed Dose or Dose Rate to Air (gammas, x-rays)

By definition 1 roentgen (R) = 2.58×10^{-4} C/kg

Since the charge on a single ion (e.g., electron) is 1.6×10^{-19} coulombs, an exposure of 1 roentgen results in the formation of 1.6125×10^{15} ion pairs/kg in air.

Since the average energy absorbed in air per ion pair produced is 34 eV (or so), an exposure of one roentgen equates to the absorption in air of 5.48×10^{16} eV/kg.

Absorbed Dose (D) and Absorbed Dose Rate ($\dot{D}$)

Absorbed Dose or Dose Rate to Air

Since 1 eV equals 1.6 x 10^{-19} joules, an exposure of one roentgen equates to an absorbed dose in air of 0.0088 J/kg or 0.0088 gray.

Since one gray equals 100 rads, an exposure of 1 roentgen equates to an absorbed dose 0.88 rads in air

Absorbed Dose (D) and Absorbed Dose Rate ($\dot{D}$)

Absorbed Dose or Dose Rate to Air

The absorbed dose or dose rate to air from photons (gamma rays and x-rays) is related to the exposure as follows:

$$D_{air} = 0.88 \ X$$

D_{air} is the dose or dose rate to air (e.g., rads or rads/hr)

X is the exposure or exposure rate (e.g., R or R/hr)

Absorbed Dose (D) and Absorbed Dose Rate ($\dot{D}$)

Important Equation

The absorbed dose or dose rate to any material can be calculated from the exposure or exposure rate as follows:

$$D_{material} = 0.88\,X\,\frac{\left(\dfrac{\mu_{en}}{\rho}\right)_{material}}{\left(\dfrac{\mu_{en}}{\rho}\right)_{air}}$$

$D_{material}$ is the dose or dose rate to the specified material (e.g., rads, rads/hr) due to photons.

X is the exposure or exposure rate (e.g., R or R/hr)

$(\mu_{en}/\rho)_{material}$ is the mass energy absorption coefficient for the specified material at the photon energy of interest

Absorbed Dose (D) and Absorbed Dose Rate ($\dot{D}$)

Absorbed Dose or Dose Rate to Tissue due to Photons

The absorbed dose or dose rate to human tissue due to photons can be calculated by using the following equation:

$$D_{tissue} = 0.88\, X \frac{\left(\frac{\mu_{en}}{\rho}\right)_{tissue}}{\left(\frac{\mu_{en}}{\rho}\right)_{air}}$$

Absorbed Dose (D) and Absorbed Dose Rate ($\dot{D}$)

Absorbed Dose or Dose Rate to Tissue due to Photons

The photon energy must be specified in order to determine the mass energy absorption coefficients (μ_{en}/ρ).

The energy selected is not very important because the ratio of the absorption coefficients for two materials tends to remain constant as a function of energy.   For the purpose of this example, we will use 1 MeV photons.

The mass energy absorption coefficient at 1 Mev for tissue is 3.074×10^{-2} cm^2/g

The mass energy absorption coefficient at 1 MeV for air is 2.789×10^{-2} cm^2/g

Absorbed Dose (D) and Absorbed Dose Rate ($\dot{D}$)

Absorbed Dose or Dose Rate to Tissue due to Photons

$$D_{tissue} = 0.88\ X\ \frac{(0.0307)_{tissue}}{(0.0279)_{air}}$$

$$= 0.97\ X$$

In other words, the absorbed dose to human tissue is approximately 1 rad if the exposure in air is 1 R.

If the exposure rate at a point is 1 R/hr, then the absorbed dose rate to tissue at that point is approximately 1 rad/hr.

KERMA (K)

Kerma

Quantity: Kerma (K)

Units: rad

gray (Gy)

joules/kilogram

Unit conversions: 1 Gy = 1 J/kg = 100 rads

Kerma is similar to absorbed dose except that it is a measure of the energy released (lost) by the radiation rather than the energy absorbed by a material.

Kerma

- Kerma is the energy transferred to charged particles per unit mass of material by indirectly ionizing radiation, e.g., gamma rays, neutrons. It is not defined for charged particle radiation (e.g., alphas, betas).
- Kerma is "***k***inetic ***e***nergy ***r***eleased in ***ma***tter"
- Kerma can be useful for explaining certain phenomena near the interface of two materials, e.g., the lack of damage to skin from high energy photons (e.g., Co-60 or multi MV x-rays).
- The concept of kerma is most widely employed in medical radiology

Kerma

- **Gamma rays or x-rays**

  In many, but not all, situations, the absorbed dose equals the kerma:

For Air:	Exposure	Absorbed Dose	Kerma
	1 roentgen	0.88 rad	0.88 rad

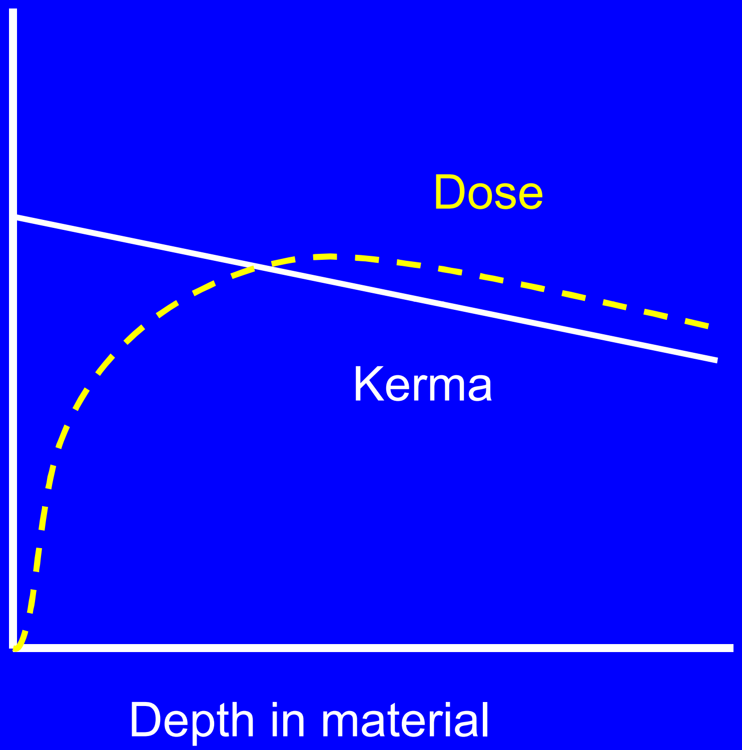
  Air kerma (rads) is sometimes used instead of exposure (R) to describe the intensity of photons.

- **Neutrons**

  In almost all situations, the absorbed dose equals the kerma because the range of the charged particles is short and there is no radiative loss (bremsstrahlung).

Kerma

Kerma and dose as a function of depth in a material



Attenuation

Dose Equivalent (H)

Dose Equivalent (Equivalent Dose)

Quantity: Dose Equivalent (H or DE).

Also referred to as Equivalent Dose.

Units: rem

sievert (Sv)

joules/kilogram

Unit conversions: 1 Sv = 1 J/kg = 100 rems

Dose Equivalent (Equivalent Dose)

General

- The quantity dose equivalent is an administrative concept employed for the purpose of radiation protection.
- It attempts to be a measure of the long term biological consequences for humans of a given exposure to radiation. This is why the regulatory limits are expressed as a dose equivalent rather than exposure or absorbed dose.
- It “is defined for routine radiation protection applications. It should not be used in the numerical assessment of high-level exposures” (ICRU 51).

Dose Equivalent (Equivalent Dose)

General

- The dose equivalent should only be applied to humans. Nevertheless, it is sometimes applied to other mammals.

- It can be calculated for any type of radiation.

Dose Equivalent (Equivalent Dose)

General

- The dose equivalent is calculated as follows:

$$H = D\ Q$$

H is the dose equivalent (e.g., rems, sieverts)

D is the absorbed dose to human tissue (e.g., rads, gray)

Q is the quality factor

Internationally, the quality factor (Q) has been replaced by the radiation weighting factor w_R:

$$H = D\ w_R$$

Dose Equivalent (Equivalent Dose)

Quality Factor (Q) and Stopping Power

- The value assigned the quality factor is based on the stopping power of the charged particles in water, i.e., the energy lost per unit distance travelled. The charged particles being referred to are those which transfer energy to the tissue.

- In the case of gamma ray or x-rays, the charged particles are electrons.

- In the case of neutrons, a mix of charged particles is involved: electrons, protons, carbon nuclei, etc.

Dose Equivalent (Equivalent Dose)

Standard Quality Factors (Q or w_R)

The quality factor depends on the energy of the radiation, but the dependence is minimal for beta particles, alpha particles and photons.

In almost all cases, the following quality factors (radiation weighting factors) are employed

Radiation	Q or w_R
Beta Particles (electrons)	1
Gamma rays and X-rays	1
Alpha particles	20

Dose Equivalent (Equivalent Dose)

Quality Factor for Neutrons

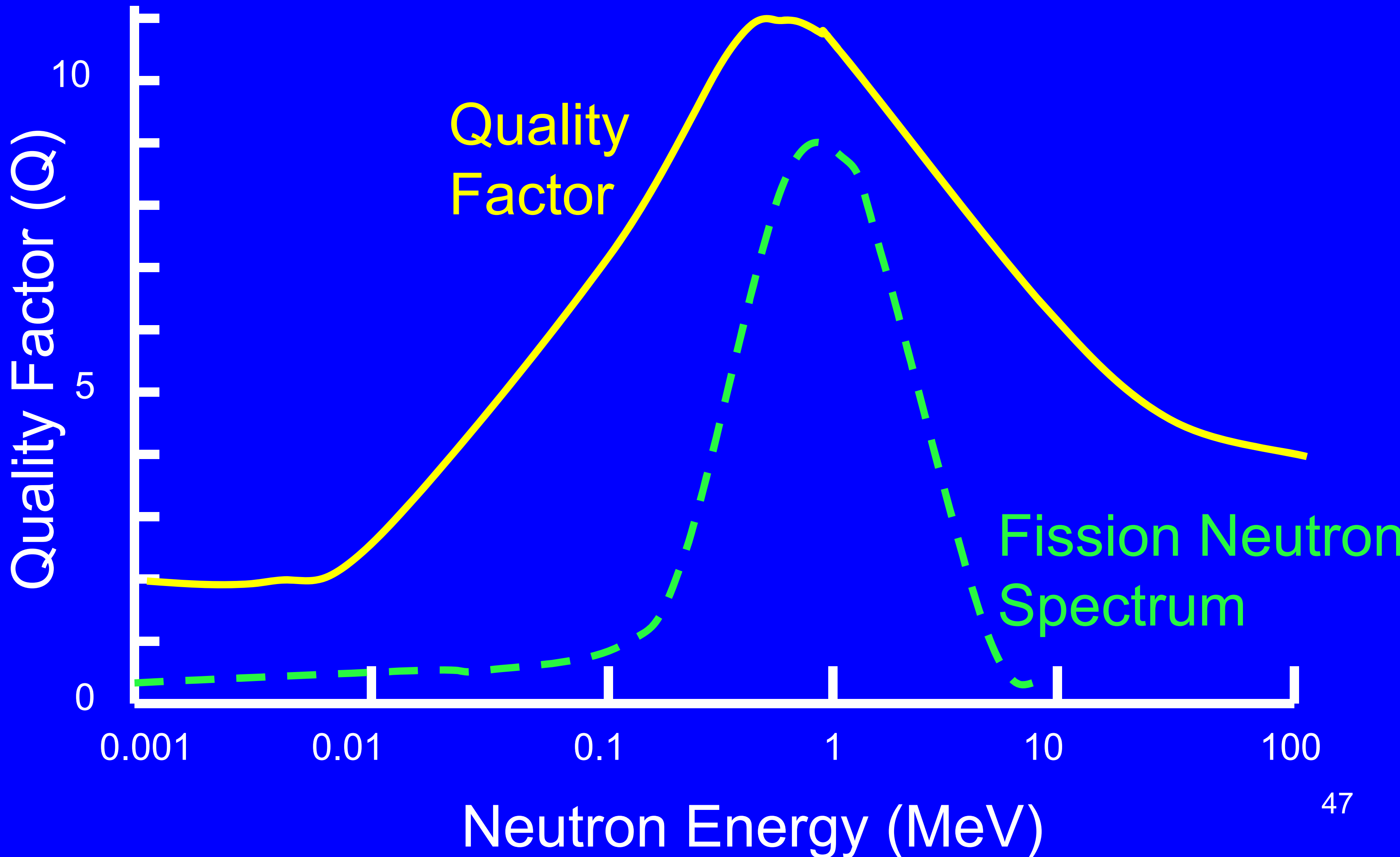
- Unlike the quality factors for beta particles, gamma rays, x-rays and alpha particles, the quality factor for neutrons is very dependent on neutron energy. Nevertheless, neutrons are often assigned a “default” quality factor of 10.

- Different regulatory agencies use different neutron quality factors . The NRC uses those of ICRP 26. DOE uses the higher quality factors recommended by ICRP 60.

- An accurate determination of the dose equivalent for neutrons requires that the neutron spectrum must be known - the neutron spectrum is rarely known

Dose Equivalent (Equivalent Dose)

Quality Factor for Neutrons (ca. those of ICRP 26)



Dose Equivalent (Equivalent Dose)

Quality Factor for Neutrons (10 CFR 20)

If the average neutron energy is known, it is tempting to apply the quality (radiation weighting) factor for that energy.

It's not the correct way to do the calculation, but it might be good enough.

TABLE 1004(B).2—MEAN QUALITY FACTORS, Q, AND FLUENCE PER UNIT DOSE EQUIVALENT FOR MONOENERGETIC NEUTRONS

	Neutron energy (MeV)	Quality factor[a] (Q)	Fluence per unit dose equivalent[b] (neutrons cm^{-2} rem^{-1})
(thermal)	2.5×10^{-8}	2	980×10^{6}
	1×10^{-7}	2	980×10^{6}
	1×10^{-6}	2	810×10^{6}
	1×10^{-5}	2	810×10^{6}
	1×10^{-4}	2	840×10^{6}
	1×10^{-3}	2	980×10^{6}
	1×10^{-2}	2.5	1010×10^{6}
	1×10^{-1}	7.5	170×10^{6}
	5×10^{-1}	11	39×10^{6}
	1	11	27×10^{6}
	2.5	9	29×10^{6}
	5	8	23×10^{6}
	7	7	24×10^{6}
	10	6.5	24×10^{6}
	14	7.5	17×10^{6}
	20	8	16×10^{6}
	40	7	14×10^{6}
	60	5.5	16×10^{6}
	1×10^{2}	4	20×10^{6}
	2×10^{2}	3.5	19×10^{6}
	3×10^{2}	3.5	16×10^{6}
	4×10^{2}	3.5	14×10^{6}

Dose Equivalent (Equivalent Dose)

Example Calculation

If the absorbed dose to a nuclear worker were 0.1 rads from neutrons of unknown energy and 0.3 rads from gamma rays, the worker's dose equivalent (equivalent dose) would be:

$$H = (D\,Q)_{neutron} + (D\,Q)_{gamma}$$

$$= (0.1 \times 10) + (0.3 \times 1)$$

$$= 1.3 \text{ rems} \quad \text{or} \quad 0.013 \text{ Sv}$$

Versions of the Dose Equivalent (Equivalent Dose)

It is an unfortunate fact of life that the ICRU, ICRP, etc. have defined a large number of dose equivalent quantities. Some of these include:

- Committed dose equivalent (committed equivalent dose)
- Effective dose equivalent (effective dose)
- Committed effective dose equivalent (committed effective dose)
- Collective dose equivalent (collective equivalent dose)
- Ambient dose equivalent
- Directional dose equivalent

Committed Dose Equivalent
(H_{50} or CDE)

Committed Dose Equivalent (Committed Equivalent Dose)

The Committed Dose Equivalent (H_{50} or CDE) is only calculated for internal exposures. In other words exposures resulting from inhalation, ingestion, absorption through the skin, or injection.

It is the total (integrated) dose equivalent over the 50 years following the intake of the radionuclide.

The committed dose is attributed to the year of the intake.

In a manner of speaking, it is the dose that you are committed to over the course of your life as a result of the intake in a given year.

Committed Dose Equivalent (Committed Equivalent Dose)

For short-lived nuclides (e.g., I-131), or radionuclides rapidly cleared from the body (e.g., H-3), the committed dose equivalent is the same as the dose equivalent delivered during the year of the intake.

For long-lived nuclides that remain in the body, the committed dose equivalent is much greater than the dose equivalent during the year of intake.

The concept simplifies bookkeeping. In a given year, (e.g., 2009) an employer only has to deal with the dose resulting from intakes during that year. They don't have to calculate the doses that result from intakes in previous years.

Effective Dose Equivalent
(H_E or EDE)

Effective Dose Equivalent (Effective Dose)

For the most part, the Effective Dose Equivalent (H_E or EDE) is only calculated for internal exposures. In other words, exposures resulting from radionuclides getting inside the body via inhalation, ingestion, absorption through the skin, or injection.

The concept is intended to deal with non-uniform radiation exposures. Although the doses to the different tissues/organs of the body are pretty much the same for external exposures, the different tissues/organs often receive very different doses for internal exposures.

Effective Dose Equivalent (Effective Dose)

The effective dose equivalent concept equates non-uniform internal exposures to external uniform exposures by considering the risk.

This allows external exposures to be added to internal exposures in order to calculate a total dose (e.g., the TEDE).

Total Dose = External Exposure + Internal Exposure

Effective Dose Equivalent (effective dose) for a Specific Tissue

The effective dose ($H_{E,T}$) for a given tissue is the product of the dose equivalent for that tissue (H_T) and the tissue weighting factor for that tissue (w_T) :

$$H_{E,T} = H_T \; w_T$$

The w_T reflects the risk of dying of cancer per unit dose equivalent to that tissue. The value assigned to the various tissues in the body has changed over time as the risk estimates have been refined.

Effective Dose Equivalent (effective dose) for a Specific Tissue

If the dose equivalent to the tissue is a committed dose equivalent (and it almost always is), we calculate a committed effective dose equivalent rather than an effective dose equivalent.

$$CEDE = CDE \times w_T$$

The NRC uses the weighting factors (w_T) of ICRP 26.

DOE uses those of ICRP 60.

As yet, no one uses the weighting factors recommended in ICRP 103.

Tissue Weighting Factors

Tissue/Organ	ICRP 26	ICRP 60	ICRP 103
Gonads	0.25	0.20	0.08
Breast	0.15	0.05	0.12
Red Bone Marrow	0.12	0.12	0.12
Lung	0.12	0.12	0.12
Thyroid	0.03	0.05	0.04
Bone Surfaces	0.03	0.01	0.01
Colon		0.12	0.12
Stomach		0.12	0.12
Bladder		0.05	0.04
Liver		0.05	0.04
Esophagus		0.05	0.04
Skin		0.01	0.01
Salivary Glands			0.01
Brain			0.01
Remainder	0.30	0.05	0.12
Total	1.00	1.00	1.00

Effective Dose Equivalent (effective dose) for a Specific Tissue - Meaning of the Tissue Weighting Factor

As an example, the ICRP 26 tissue weighting factor for the thyroid is 0.03. This can be interpreted in several ways:

- 3% of the deaths due to uniform whole body exposures are due to thyroid cancer.
- The risk due to a specific dose (e.g., 1 rad) just to the thyroid is 3% of the risk that would result if that dose were delivered to the entire body.
- 100 rems just to the thyroid carries the same risk as a 3 rems uniform exposure to the whole body.

Effective Dose Equivalent (effective dose) for a Specific Tissue - Meaning of the Tissue Weighting Factor

The sum of the weighting factors for all the tissues of the body is 1.

Effective Dose Equivalent (effective dose) for the Whole Body

The effective dose (H_E) for the whole body is the sum of the effective dose equivalents for the individual tissues:

$$H_E = \Sigma H_T w_T$$

Example:

The next slide shows the committed dose equivalent to the various tissues of the body when an individual ingests 0.1 mCi of I-131.

These committed doses are multiplied by the appropriate ICRP 26 weighting factors to get the effective dose equivalents for these tissues. Finally, these are summed to get the effective dose equivalent for the whole body.

Effective Dose Equivalent (effective dose) for the Whole Body

Tissue/Organ	W_T	H_T (rem)	$H_{E,T}$ (rem)
Gonads	0.25	0.02	0.005
Breast	0.15	-	-
Red Bone Marrow	0.12	0.03	0.004
Lung	0.12	-	-
Thyroid	0.03	130	3.900
Bone Surfaces	0.03	0.03	0.001
Small Intestine (remainder)	0.06	0.10	0.006
Stomach (remainder)	0.06	0.14	0.008
Bladder (remainder)	0.06	0.24	0.014
Liver (remainder)	0.06	0.04	0.002
$H_E = \Sigma H_T w_T$			3.940

Committed Effective Dose Equivalent ($H_{E,50}$ or CEDE)

Committed Effective Dose Equivalent (Committed Effective Dose)

There is not much to say about the committed effective dose equivalent ($H_{E,50}$ or CEDE).

Almost inevitably, when an effective dose equivalent is calculated, it is the committed effective dose equivalent. In other words, we almost always deal with the CEDE. The EDE is rarely calculated.

An exception: situations when the effective dose equivalent is calculated for a non-uniform external exposure. In this case, it would simply be an effective dose equivalent - the committed "concept" only applies to internal exposures.

Committed Effective Dose Equivalent (Committed Effective Dose)

To obtain the committed effective dose equivalent for a specific tissue, the committed dose equivalent to that tissue due to an internal exposure is multiplied by the tissue weighting factor:

$$\text{CEDE} = \text{CDE} \times w_T$$

$$H_{E,T,50} = H_{T,50} \times w_T$$

Total Effective Dose Equivalent (TEDE)

TEDE

The NRC currently limits a worker's total effective dose equivalent (TEDE) to 5 rems in a year.

This is intended to minimize the possibility of stochastic effects (e.g., cancer).

TEDE is pronounced "teddy"

It is the sum of the external exposure and the internal exposures:

TEDE = External dose equivalent + Internal dose equivalent

TEDE - external exposure

The external dose equivalent is measured with a dosimeter. Only dosimeters accepted by the regulatory agency as a "dosimeter of record" can be used (e.g., TLDs, OSL, film).

The analysis of the dosimeter typically results in three dose equivalents being reported :

Deep dose equivalent (DDE)

Shallow dose equivalent (SDE)

Dose to the lens of the eye (LDE)

Of these, the deep dose equivalent is used as the measure of the external exposure.

TEDE – internal exposure

The internal exposure is sometimes assumed to be zero.

However, if the internal dose equivalent is expected to be sufficiently large, it must be accounted for.

To calculate the internal exposure, the person's intake (e.g., pCi, Bq) via ingestion, inhalation, injection or absorption must be known.

The intake might be estimated on the basis of a whole body count, urine analysis, etc.

Once the intake is known, the committed effective dose equivalent (CEDE) can be determined from lookup tables (e.g., Federal Guidance Report 11.

TEDE – internal exposure

Such lookup tables are fine for the chemical form of radioactive material normally present in the workplace.

However, these tables should not be used to determine the CEDE due to the intake of the radiopharmaceuticals employed in nuclear medicine.

Determining the CEDE from the intake of radiopharmaceuticals involves the MIRD methodology.

The RADAR website is an excellent place to find out about this.

http://www.doseinfo-radar.com

TEDE – internal exposure

For the purpose of calculating the TEDE, the committed effective dose equivalent (CEDE) serves as the internal exposure.

TEDE = External dose equivalent + Internal dose equivalent

TEDE = DDE + CEDE

TEDE

The external exposure component of the TEDE is the actual exposure for a specified year, e.g., 2009.

The internal component of the TEDE (the CEDE) is the dose equivalent accumulated over the 50 years following the intake (e.g., 2009-2060) that year.

It might seem odd to do it this way, but that is how it is done.

Total Organ Dose Equivalent (TODE)

TODE

The NRC currently limits a worker's total organ dose equivalent (TODE) to 50 rems in a year.

The exception is the lens of the eye which is only allowed 15 rems in a year.

The limit on the TODE is intended to eliminate (not minimize) the possibility of deterministic (non-stochastic) effects such as cataracts.

The TODE is the sum of the external exposure and the internal exposures:

TODE = External dose equivalent + Internal dose equivalent

TODE

For most organs/tissues, the deep dose equivalent measured with a dosimeter serves as the external exposure.

For the lens of the eye, the eye dose equivalent is used as the external exposure.

As was true for the TEDE, the external exposure component of the TODE is the actual exposure for a specified year, e.g., 2009. On the other hand, the internal component of the exposure (the CDE) is the dose equivalent accumulated over the 50 years (e.g., 2009-2060) following the intake (e.g., in 2009).

TODE

Depending on its magnitude, the internal dose might or might not be calculated. If it must be calculated, the person's intake is estimated via a whole body count, urine analysis, etc.

For the purpose of calculating the TODE, the committed dose equivalent (CDE) serves as the internal exposure.

TODE = External dose equivalent + Internal dose equivalent

TODE = DDE + CDE

= LDE + CDE

TODE

In a previous example, an individual ingested 0.1 mCi of I-131. The following table indicated the committed dose equivalent (H_T) to each tissue, the committed effective dose equivalent for each tissue ($H_{E,T}$) and the summed whole body committed effective dose equivalent.

Tissue/Organ	**W_T**	**H_T (rem)**	**$H_{E,T}$ (rem)**
Gonads	0.25	0.02	0.005
Breast	0.15	-	-
Red Bone Marrow	0.12	0.03	0.004
Lung	0.12	-	-
Thyroid	0.03	130	3.900
Bone Surfaces	0.03	0.03	0.001
Small Intestine (remainder)	0.06	0.10	0.006
Stomach (remainder)	0.06	0.14	0.008
Bladder (remainder)	0.06	0.24	0.014
Liver (remainder)	0.06	0.04	0.002
$H_E = \Sigma H_T \; w_T$			3.940

TODE

If the individual's external deep dose equivalent (as measured by a dosimeter) was 1 rem, the TEDE is just below the 5 rems limit:

TEDE = DDE + CEDE

= 1 rem + 3.94 rems

= 4.94 rems

However, the TODE for the thyroid would exceed the 50 rems limit!

TODE = DDE + CDE

= 1 rem + 130 rems

= 131 rems

Inverse Square Law

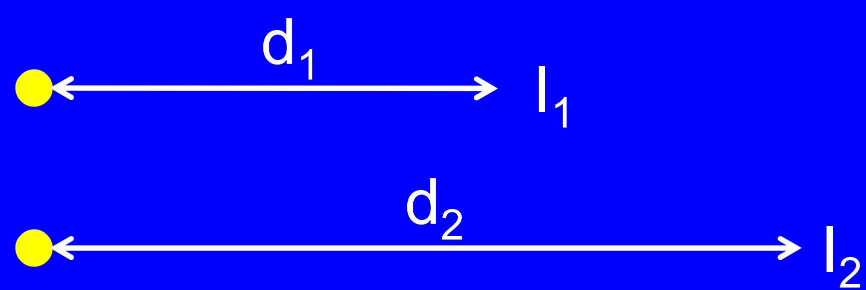
Inverse Square Law

As the distance from a source changes, the intensity of the radiation changes with the square of the distance:

$$I_2 = \frac{I_1 \, d_1^2}{d_2^2}$$

I_2 is the intensity of the radiation at distance 2 (d_2) in R/hr, rads/hr, rems/hr, n/cm^2/s, etc

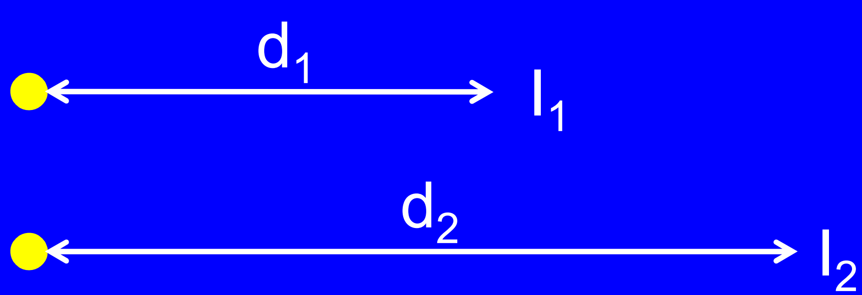
I_1 is the intensity of the radiation at distance 1 (d_1)



Inverse Square Law

$$d_2 = \sqrt{\frac{I_1\, d_1^2}{I_2}}$$

The above equation gives the distance (d_2) at which the intensity of the radiation will be, I_2 if the intensity of the radiation (I_1) is known at another distance (d_1)



Summary

Quantity	Symbol	Units	Radiation Type (from what?)	Absorbing Medium (in what?)
Exposure	X	roentgens C/kg	gamma and x-rays	air
	The quantity exposure is a measure of the intensity of gamma rays and x-rays in air. More specifically, it is a measure of the charge on the ions produced in air.			
Absorbed Dose	D	rad gray (Gy) J/kg	any type	any type
	The quantity absorbed dose is the radiation energy absorbed per unit mass of material			
Kerma	K	rad gray (Gy) J/kg	uncharged (photons, neutrons)	any type
	The quantity kerma is the energy released by uncharged particles (photons or neutrons) per unit mass of material through which the particles travel			
Dose Equivalent	H	rem sievert (Sv) J/kg	Any type	human tissue
	The dose equivalent is an administrative concept used for the purpose of radiation protection. It is related to the risk of dying of cancer due to an exposure. It is intended to apply in the low dose range of the regulatory limits			

Summary

As an approximation:

1 roentgen	≈	1 rad	≈	1 rad	≈	1 rem
(photons in air)		(absorbed dose to tissue)		(kerma in tissue)		(dose equivalent to tissue)

1 roentgen	≈	0.88 rad	≈	0.88 rad
(photons in air)		(absorbed dose to air)		(air kerma)

Summary

Key Equations:

$$\dot{X} = \frac{A\Gamma}{d^2}$$

$$D_{material} = 0.88\,X\,\frac{\left(\frac{\mu_{en}}{\rho}\right)_{material}}{\left(\frac{\mu_{en}}{\rho}\right)_{air}}$$

$$H = D\,Q = D\,w_R$$

$$H_E = H_T\,w_T$$

Summary

TEDE = External Exposure + Internal Exposure

(DDE) (CEDE)

TODE = External Exposure + Internal Exposure

(DDE or LDE) (CDE)

APPENDIX

Additional Dose Equivalent Quantities

Collective Dose Equivalent

The collective dose equivalent is simply the average dose equivalent to a population multiplied by the number of individuals in that population.

The units of the collective dose equivalent are therefore person-rems (or person-sieverts).

Ambient Dose Equivalent

The ambient dose equivalent, symbolized H*(10), is an operational quantity intended for environmental monitoring.

It is defined for penetrating radiation (photons and neutrons) at a depth of 10 mm.

Directional Dose Equivalent

The ambient dose equivalent, symbolized H*(0.07), is an operational quantity intended for environmental monitoring.

It is defined for weakly penetrating radiation (betas) at a depth of 0.07 mm.

Individual Dose Equivalent, Penetrating

The individual dose equivalent penetrating, symbolized H(10), is an operational quantity intended for personnel.

It is defined for penetrating radiation (photons and neutrons) at a depth of 10 mm.

Individual Dose Equivalent, Superficial

The individual dose equivalent superficial, symbolized H(0.07), is an operational quantity intended for personnel monitoring.

It is defined for weakly penetrating radiation (betas) at a depth of 0.07 mm.