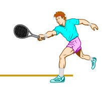
Health Physics

Dosimetric Quantities

(and terms)

Activity, A_p



Definition: $A = dN / dt = \lambda_p \times N$

where N is the number of radioactive atoms present at time t, dN the expectation value of the number of nuclear transitions in time interval dt, and λ_p the physical transformation constant (decay constant).

Units: **In SI 1 Becquerel = 1 s^{-1} (Bq) and its multiples kBq, MBq, GBq etc.**

1 Ci = 3.7×10^{10} Bq **1mCi = 37 MBq**

N.B.: **1 Ci is historical unit, equal to activity of 1 g of radium.**

Specific Activity, A_s or SA

Definition: Activity per unit mass.

$A_s = A / m = \lambda_p N / m = \lambda_p N_A / m_{mole}$

$N_A = 6.02 \times 10^{23}$

m_{mole} in g

Alternative Definition: A_s of an unknown isotope *i* can be derived using the fact that there are 3.7×10^{10} transformations per 1 gram of ^{226}Ra. So the A_s of ^{226}Ra is 3.7×10^{10} Bq per gram and the specific activity of the isotope *i* is:

$A_s(i) = 3.7 \times 10^{10}$ Bq/g $A_{Ra} T_{Ra} / A_i T_i$ [in Bq/g]

(where A is the atomic weigth and T is the half-life of Ra and isotope *i*)

Units: Bq / g or Ci / g

More info in chapter 4 of Cember, pg. 94;

Physical Half-Life, $T_{1/2\ p}$

$dN / dt = \lambda_p \times N$

$N(t) = N(o) \exp(-\lambda_p t)$

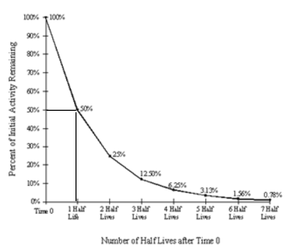
physical transformation constant called half-life, λ_p

$\lambda_p = \ln 2 / T_{1/2p}$

$N(t) = N(o) \exp(-\ln 2\ t / T_{1/2\ p})$

Physical Half-Life

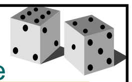
Physical Half-Life is the time it takes for 1/2 of the atoms of a particular radio-active element to undergo radioactive transformation.



Biological Half-Life, $T_{1/2\ b}$

Biological Half-Life is the time it takes for 1/2 of the constituents (atoms, molecules, etc.) of a compartment of a living organism (an organ or whole body) to leave this compartment.

Effective Half-Life, $T_{1/2e}$



$dN / dt = (\lambda_p + \lambda_b) \times N = \lambda_e \times N$

$N(t) = N(o) \exp(- \lambda_e t)$

Effective transformation constant, λ_e :
$\lambda_e = \lambda_p + \lambda_b$

$1/T_{1/2\,e} = 1/T_{1/2\,p} + 1/T_{1/2\,b}$

Linear Attenuation Coefficient, μ

Definition: fraction of photons that interact with medium per unit thickness of the attenuator:
$\mu = - (dN / N) / dx$

Units: cm^{-1}

Linear Attenuation Coefficient, μ

continued:

$N(x) = N_o \exp(- \mu x)$

Thus, $\exp(- \mu x)$ is probability that a photon traverses thickness x of an absorber without interacting with it.

Half Value Layer (HVL)

Definition: The thickness of a material that attenuates a photon beam by 50% is called the HVL.

N.B.: HVL = $\ln 2 / \mu$

Units: mm, cm, m etc.

Tenth Value Layer (TVL)

Definition: The thickness of a material that attenuates a photon beam by a factor of A=10 is called the TVL.

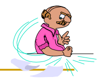
Number of TVLs 'needed' = $\log_{10} A$ (remember '**build-up**' factor – we will talk about it later)

Units: mm, cm, m etc.

Mass Attenuation Coefficient, Energy Absorption Coefficient Stopping Power

Definitions and Units: see Physics course such as PCS229 or PCS352.

Exposure, X

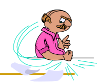


Definition:

$$X = dQ / dm$$

where dQ is the absolute value of total charge of ions of one sign produced in dry air, when all electrons liberated by photons in an air volume element of mass dm are stopped in the air.

Exposure, X



continued…

X only defined for photons with $E \leq 3$MeV

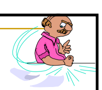
Units: SI unit is C / kg.

Historical unit is the Roentgen, R.

(1R = 1esu in 1 cm^3 of air at STP).

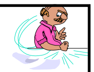
1R = 2.58×10^{-4} C / kg.

Exposure, X



- A traditional way to characterize photon radiation field strength
- Corresponds to the ability of the radiation field to produce ionization in air
- The traditional unit is the roentgen (R)
- 1 R = 1 sC/cm^3 charge of either sign at 0 ^oC, 760 mmHg (1 R = 2.58 C/kg of air)
- BY LUCK 1 R to air ~ 1 rem (10 mSv) to tissue!

Average Ion-Pair Energy, W



Definition: average energy (W) required to produce an ion-pair in a medium traversed by electrons.

In air: **W = 33.97** eV / ion pair

Units: eV / ion pair or Joule / C

Exposure Rate Constant, Γ (Specific Gamma Ray Constant)

Definition: Γ_δ is exposure rate, X/t, in R/h at distance d = 1 m from a source with the activity, A, of 1 Ci.

Or: $$\mathbf{X / t = \Gamma_\delta A / d^2}$$

Units: R m^2 h^{-1} Ci^{-1}

Absorbed Dose, D

- Definition:

$$D = dE_{abs} / dm$$

where dE_{abs} is the mean energy imparted by ionizing radiation to a mass element dm;

or the amount of energy absorbed per unit mass of absorber.

- Absorbed dose is the **fundamental dosimetric quantity in radiation protection**. All other quantities are based on the absorbed doses.
- It is strictly a physical quantity and can be applied to radiation interactions in any material
- Units: SI unit is the Gray, 1Gy = 1J/kg

Historical unit is the rad, 1 rad = 1 cGy

Relative Biological Effectiveness, RBE

Definition: $RBE = \frac{D_X}{D_i}$

[Dose from standard radiation (200 keV X_p rays) to produce a given biol. effect] **/** [dose from test radiation to produce same effect].

Units: RBE is dimensionless

Linear Energy Transfer, LET or `restricted` Stopping Power

LET characterizes the rate of energy loss of **charged particles** in an attenuating medium.

Units: keV / μm

Equivalent Dose, H_T

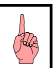
- Definition: $H_T = \Sigma_R \, w_R \, D_{T,R}$
- Use of radiation weighting factors, w_R normalizes risks for different types of radiation (α, β, γ, p, n …) to tissue T.
- Equal equivalent doses to a tissue or organ due to different radiations produce the same probability of stochastic effects. The radiation weighting factor “adjusts” for the varying ability of different radiations to produce these effects.
- Units: SI unit is the Sievert, 1Sv = 1J/kg
Historical unit is the rem, 1 rem = 1cSv

Radiation Weighting Factor, w_R (old quantity - Quality Factor, Q)

1 Gy of alpha particles and 1Gy of photons have different effects on tissue.

Q (ICRP 26/30), w_R (ICRP 60) , LET and RBE are closely related.

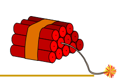
Radiation Weighting Factors, w_R



Radiation type	Energy E (MeV)	w_R
photons	all energies	1
electrons and muons	all energies	1
neutrons	$E < 0.01$	5
	$0.01 \le E < 0.1$	10
	$0.1 \le E < 2$	20
	$2 \le E < 20$	10
	$20 \le E$	5
protons (other than recoil protons)	$20 \le E$	5
alpha particles, heavy ions	all energies	20

Table A-2 in ICRP 60

Effective Dose, E



- Definition: $E = \sum_T w_T H_T$ with $\sum_T w_T = 1$

- Use of tissue weighting factors, w_T normalizes cancer risk for different tissues (→ partial exposure).

- Equal effective doses to different tissues or organs produce the same detriment. The tissue weighting factor "adjusts" for the varying sensitivity of tissues and organs and the varying detriment arising from exposure.

- Units: SI unit is the Sievert, 1Sv = 1J/kg
Historical unit is the rem, 1 rem = 1cSv

Tissue Weighting Factors, w_T

Tissue	w_T	Tissue	w_T
gonads	0.20	liver	0.05
bone marrow (red)	0.12	oesophagus	0.05
colon	0.12	thyroid	0.05
lung	0.12	bone surface	0.01
stomach	0.12	skin	0.01
bladder	0.05	remainder	0.05
breast	0.05		

Table A-3 in ICRP 60

Tissue Weighting Factors, w_T

continued…

Interpretation 1:

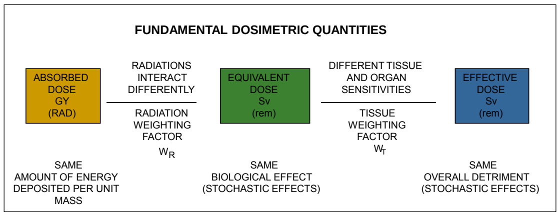
If a whole body dose, D, implies a 1% cancer risk of any kind, then the risk of cancer to the bladder is 0.05%.

Tissue Weighting Factors, w_T

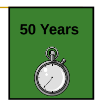
continued…

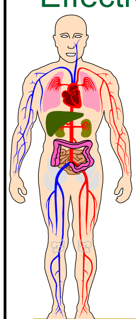
Interpretation 2:

An effective dose of 5rem to the bladder alone carries the same risk of cancer to the bladder as a 100rem uniform whole-body equivalent dose.



Committed Equivalent and Effective Dose





Dose quantities that reflect the eventual consequences of intake of radioactive material.

Committed Equivalent Dose (H_T50):

The equivalent dose to an organ or tissue that will occur over 50 years following an intake.

Committed Effective Dose (H_E(50)

The effective dose that will occur over 50 years following an intake.

Committed Equivalent Dose, H(τ)

Definition:

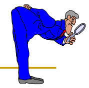
$$H_T(\tau) = \int_{t_o}^{t_o+\tau} (dH_T/dt)\, dt$$

for chronic dose to tissue T, over time τ, starting at time t_o.

If τ not specified, then τ =50 y for adults and 70 y for children.

Units: Sv, rem

Committed Effective Dose, $E(\tau)$



Definition:

$$E(\tau) = \sum_T w_T H_T(\tau)$$

Units: SI unit is the Sievert; 1Sv = 1J/kg

Collective Effective Dose, S

- Definition:

$$S = \sum_i \hat{E}_i N_i$$

- The sum of the effective doses to an exposed population
- Units: The SI unit is the man-Sievert

Annual Limit on Intake, ALI

Definition: ALI refers to that quantity of a radio-nuclide which, when taken into the body (Reference Man, ICRP 23) per one year, will deliver to that person an effective dose equal to the regulatory limit (20mSv/y for NEWs) over the 50 years (or for each year) of occupational exposure.

Units: Bq

Annual Limit on Intake, ALI

continued:
ALIs are for ingestion or inhalation and depend on chemical and physical form
Example:

ALIs for I-125

Ingestion	1 MBq (27 µCi)
Inhalation (Elemental)	1 MBq (27 µCi)
Inhalation (Methyl)	2 MBq (54 µCi)

ALI values for NEWs for most radionuclides and various routes of entering the body may be found in ICRP Publication 61.

Derived Air Concentration (DAC)

- *That concentration of a radionuclide in air (Bq/m^3) that if breathed in by unprotected Reference Man continuously for 2000 Hours, would result in an intake of 1 ALI.*

$$DAC = \frac{ALI}{2400 m^3}$$

- *Example:*
  - *The DAC for elemental I-125 vapour is 580 Bq/m^3*

Exemption Quantity, EQ

« Definition » : A regulatory quantity assigned to each radionuclide by the CNSC for licencing purposes.

As an example, no CNSC-licence is required for the handling of less than 1 EQ of a given radionuclide.

Units: Bq (kBq, MBq, GBq)

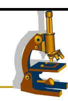
Exemption Quantity, EQ

continued:

A radiation warning label (RAYONNEMENT-DANGER- RADIATION) has to be posted in points of access to areas where more than 100 EQs of a given radionuclide are stored or handled.

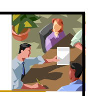
A special CNSC permission is required for projects involving more than 10’000 EQs of a given radionuclide.

Radiation Monitoring



a) Area monitoring (portable or fixed radiation monitors)
b) Technique monitoring (experimental procedures)
c) Personnel monitoring
d) Monitoring of internal radioactivity (whole body counter, bioassay)

Occupancy Factor, T



T is a modifying factor that enters into personal radiation dose estimations:

$$D = D_{T=1} \times T$$

Units: T is dimensionless, $T \leq 1$

Occupancy Factor, T

Exemples of Occupancy Factors

T=1 (full occ.) : offices, labs, wards
T= 1/4 (partial occ.) : corridors, elevators
T= 1/16 (occasional) : toilets, stairways

From: *NCRP-49, page 65.*

Psychological Hazard

Do not underestimate!

Effect from psychological factors (stress) might be more troublesome than real effect from radiation.