Chapter 31

Nuclear Energy; Effects and Uses of Radiation

Lecture 2

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Absorbed Dose (AD)

The energy deposited per kg in any medium by any radiation type.

$AD = \frac{10J}{100kg} = 0.1 \frac{J}{kg} = 0.1 Gy$
$= 10 \text{ rad}$

Units: Grey (Gy) or Rad

$\frac{2J}{50kg} = \frac{1}{25} Gy = 0.04 Gy$
$= 0.04 J/kg$

$1 Gy = 1 J/kg$

$1 Rad = 0.01 J/kg \Rightarrow 1 Gy = 100 \text{ rad}.$

Note that AD applies to any radiation and any matter.

$AD = 0.5\ Gy$, $m = 60\ kg \Rightarrow AD = 0.5 \frac{J}{kg}$

Question:

energy absorbed $= 0.5 \frac{J}{kg} \times 60\ kg = 30J$.

Which is more dangerous to living tissues, an absorbed dose of 1 Gy of alpha radiation OR 1 Gy of gamma radiation? (Note the same absorbed dose but the radiation is different)

$\frac{10J}{10kg} = 1\ Gy$

In fact absorbed dose does not quantify the danger of a given radiation to living tissues. Therefore, we need a better assessment!

Effective Dose (ED)

AD ← dose, ↑ absorbed

${}^{4}_{2}He^{++}$

$ED = AD \times RBE$

RBE: relative biological effectiveness of a given type of radiation defined as the number of rads of X-rays or γ-radiation that produces the same biological damage as 1 rad of the given radiation.

1 rad of α-particles

Radiation Type	RBE
X- and γ rays	1
β (electrons)	1
Protons	2
Slow neutrons	5
Fast neutrons	≈ 10
α particles and heavy ions	≈ 20

$1\ rad = 0.01 \frac{J}{kg}$

For α-particles RBE = 20.

This means that 1 rad of α-radiation produces the same biological damage as 20 rads of X-rays or γ-rays.

Units

AD	ED
Gray (Gy)	Sievert (Sv)
Rad	rem

has No units ↓

$ED = AD \times RBE$

Sv ← Gy

rem ← Rad

Since 1 Gy = 100 rad

⇒ 1 Sv = 100 rem

Note that RBE has NO dimensions (No units).

Human expsure to radiation

We are constantly exposed to radiation comming from different sources; like:

- cosmic rays
- natural radioactivity in rocks and soil.

Upper limit Effective Dose per person per year in the US:

From natural radioactive background: 300 mrem

From X-rays and scans: ≈ 60 mrem

Additional allowed in US 100 mrem

Maximum Total allowed in US ≈ 460 mrem = 4.6 mSv

Upper limit Effective Dose per person per year for radiation workers (hospitals, power plants, research): ≈ 20 mSv

Such workers wear badges called TLD (thermoluminescent dosimeter) to monitor the radiation levels workers are exposed to.

Large doses of radiation cause symptoms like: nausea, fatigue and loss of body hair. In general called radiation sickness. Very large doses can be fatal. A dose of 10 Sv over a short period is usually fatal.

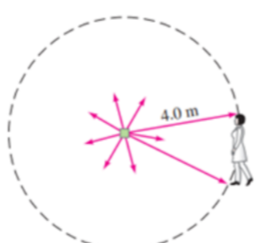


FIGURE 31–16 Radiation spreads out in all directions. A person 4.0 m away intercepts only a fraction: her cross-sectional area divided by the area of a sphere of radius 4.0 m. Example 31–12.

As we move further away from the radiation source, our bodies will be exposed to lesser amounts of radiation.

Intensity of radiation (Energy/unit area) is proportional to $\frac{1}{r^2}$.

$$\frac{\text{Energy intercepted by her body}}{\text{total radiate energy}} = \frac{\text{Surface area of her body}}{4\pi r^2}$$

$4\pi r^2$: surface area of the sphere.

Example 31-11]

Limiting the dose.
A worker in an environment with a radioactive source is warned that she is accumulating a dose too quickly and will have to lower her exposure by a factor of ten to continue working for the rest of the year. If the worker is able to work farther away from the source, how much farther away is necessary?

Intensity $\propto \frac{1}{r^2}$, need a reduction by a factor of 10.

$I \to \frac{I}{10}$ $\Rightarrow$ If she is 4m away from the source

$\Rightarrow$ $I \to \frac{I}{(4)^2} = \frac{I}{16}$. This is a reduction of more than a factor of 10.

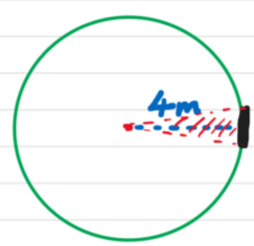
$\frac{1}{r^2} \geq \frac{1}{10}$

Example 31-12]

Whole-body dose.
What whole-body dose is received by a 70-kg laboratory worker exposed to a 40-mCi $^{60}_{27}Co$ source, assuming the person's body has cross-sectional area $1.5\,m^2$ and is normally about 4.0 m from the source for 4.0 h per day? $^{60}_{27}Co$ emits rays of energy 1.33 MeV and 1.17 MeV in quick succession. Approximately 50% of the rays interact in the body and deposit all their energy. (The rest pass through.)

Note The radiation that passes through the body body of the worker (E_{worker}) is only a fraction of the total energy (E_{tot}) emitted by the source.

$$\frac{E_{worker}}{E_{tot}} = \frac{A_{worker}}{A_{tot}} = \frac{1.5\ m^2}{4\pi(4)^2\ m^2}$$



$\therefore E_{worker} = 7.5 \times 10^{-3} E_{tot}$

Energy radiated per decay $E_\gamma = (1.33 + 1.17) = 2.5$ MeV ($M \to 10^6$, $eV \to 1.6\times10^{-19}$ J)

Total radiated energy per second:

$$E_{tot} = A E_\gamma = (40\times10^{-3} s^{-1} \times 3.7\times10^{10})(2.5\times10^{6}\times1.6\times10^{-19} J)$$

A: activity; $(40\times10^{-3} s^{-1} \times 3.7\times10^{10})$: how many decays/s

$\therefore E_{tot} = 5.92\times10^{-4}$ J/s. (total radiated energy by the source each second)

Energy deposited in the workers body per second is

$$E = \left(\tfrac{1}{2}\right) E_{worker} = \left(\tfrac{1}{2}\right)(7.5\times10^{-3} E_{tot})$$

$$= \left(\tfrac{1}{2}\right)\left(7.5\times10^{-3} \times 5.92\times10^{-4} \tfrac{J}{s}\right)$$

$$E = 2.22\times10^{-6} \text{ J/s}$$

$$AD = \frac{E}{m} = \frac{2.22\times10^{-6} \text{ J/s}}{70 \text{ kg}} = 3.17\times10^{-8} \frac{J}{kg} \times \frac{1}{s}$$

($\frac{J}{kg}$ = Gy)

$$AD = 3.17\times10^{-8} \frac{Gy}{s}$$

Absorbe Dose in 4 hours is AD_{4h}

$AD_{4h} = AD \times (4 \times 60 \times 60s) = 3.17 \times 10^{-8} \frac{Gy}{s} \times 14400s$

$AD_{4h} = 4.56 \times 10^{-4}\ Gy$

↗ for γ RBE = 1

$ED = AD \times RBE = 4.56 \times 10^{-4} \times 1 = 4.56 \times 10^{-4}\ Sv$

$= 0.456 \times 10^{-3}\ Sv$

$= 0.456\ mSv$

$= 45.6\ mrem$