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Basics of radiobiology

Exercises & solutions

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1. Physical effect of ionising radiation

The new PhD student in your lab is accidently irradiated by a Co-60 source. The whole body absorbed dose is 15 Gy.

1. Compute the energy deposited in the body.

2. Derive the temperature increase in the body and judge which biological effects it may provoke?

1. Physical effect of ionising radiation

The new PhD student in your lab is accidently irradiated by a Co-60 source. The whole body absorbed dose is 15 Gy.

1. *Compute the energy deposited in the body.*

$$\Delta E = D \cdot \Delta m = 15 \text{ Gy} \cdot 70 \text{ kg} \approx 1\text{kJ}$$

2. *Derive the temperature increase in the body and judge which biological effects it may provoke?*

$$\Delta Q = c \cdot m \cdot \Delta T \rightarrow \Delta T = \frac{\Delta Q}{c \cdot m} \overset{\Delta Q = \Delta E}{=} \frac{D}{c} \approx 3 \text{ mK}$$

$$c = 4.816 \text{ kJ kg}^{-1} \text{ K}^{-1}$$

The temperature increase does not provoke any effects.
Yet it is a lethal dose for a human!

2. Energy deposition by cosmic radiation

Cosmic muons deposit around 2 MeV/(g/cm^2) in tissue.

How many charge-carrier pairs will be created in a human germ cell (diameter 0.05 mm) if it is hit by a cosmic-ray muon and if the energy for the production of a charge-pair is 30 eV?

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Solution:

- Water density: 1 g/cm^3
- Specific energy loss: 2 MeV/(g/cm^2) / 1 g/cm^3 = 2 MeV/cm = 0.2 keV/µm
- Cell diameter (50 µm): ΔE = 10 keV
- Charge-pairs: 10000eV / 33eV = 333 charge-carrier pairs

3. Mutation of a chromosome induced by cosmic radiation

What is the probability that cosmic muons cause chromosome (diameter 0.5 µm) aberrations in a human germ cell (diameter 50 µm)? The cosmic-ray-muon rate at sea level is roughly 1 muon / (cm^2 min).

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Solution:

- Probability to hit a certain chromosome in the cell:

$$\frac{S_{chromosome}}{S_{cell}} = \frac{(0.5\mu\mathrm{m})^2}{(50\mu\mathrm{m})^2} = 10^{-4}$$

- Probability to hit a particular chromosome:

$$\frac{(0.5\mu\mathrm{m})^2}{(10^8\mu\mathrm{m}^2\ \mathrm{min})} = 2.5\times10^{-9}\ \mathrm{min}^{-1} = 0.0013\ \mathrm{year}^{-1}$$

- 1 hit every 761 years

4. DDREF

We assume a hypothetic effect that has a cancer risk of 10% Sv^{-1} at high dose. Assuming a DDREF=5 for this specific effect, compute the number of induced effects for a population of 8 millions of habitants receiving a yearly mean dose of 1 mSv.

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Solution:

- Risk r = 10% Sv^{-1}
- Population $N=8x10^{6}$
- Dose D=1mSv
- Number of induced effects:

$$R \cdot (1/DDREF) \cdot D \cdot N$$
$$= 0.1\ \mathrm{Sv}^{-1} / 5 \times 10^{-3}\ \mathrm{Sv/year} \cdot 8 \times 10^{6}\ \mathrm{persons}$$
$$= 180\ \ \mathrm{persons/year}$$

5. Effective dose

Compute the effective dose for the following situation:

- dose to the gonades: 2 mSv
- dose to the bone marrow: 1 mSv
- dose to the thyroid: 5 mSv
- dose to the remaining tissue : 0 mSv

Tissue/Organ	Weighting factor (2007)
Bone marrow	0.12
Breast	0.12
Colon	0.12
Lung	0.12
Stomach	0.12
Bladder	0.04
Esophagus	0.04
Gonads	0.08
Liver	0.04
Thyroid	0.04
Bone surface	0.01
Brain	0.01
Kidney	Remainder
Salivary glands	0.01
Skin	0.01
Remainder tissues	0.12 †

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Solution

The effective dose is given by:

$$E = \sum_T w_T \ H_T = \left(2 \cdot 0.08 + 1 \cdot 0.12 + 5 \cdot 0.04\right) \ \text{mSv} = 0.48 \ \text{mSv}$$

6. Biological effects

Indicate the main stages of the biological effects of radiation.

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Solution:

1. Physical interaction with atoms and molecules
2. Radio-chemistry (radiolysis of water in case of low LET)
3. Cell survival (cellular reproduction and repair mechanisms)
4. Tissue and organ reactions (deterministic and stochastic)
5. Organism (radio-sensitivity of organs, detriment)
6. Population (genetic effects, detriment)

7. Deterministic effects

Indicate the deterministic effects in an individual receiving a whole-body dose of 0.1 Gy.

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Solution:

The threshold dose for deterministic effects is 0.5 Gy for an adult. Temporary sterility in males can be observed for doses above 0.15 Gy.

During the genesis of the human embryo (10 days to 9 weeks), tissue reactions can be observed for doses above 0.1 Gy.

Somatic effects, e.g. heart diseases, stroke, digestive issues, respiratory and hematopoietic disorders, chromosomal aberrations and cataract are subject to a threshold dose of 0.1 Gy.

8. High dose irradiation

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Solution:

1. Reduction of hematopoiesis (bone marrow, 0.5 Gy)
2. Permanent sterility in males (3.6 – 6 Gy) and females (2.5 – 6 Gy)
3. Visual impairment (cataract, 5 Gy)
4. Gastrointestinal disorders (nausea, diarrhea and vomiting)

The combination of gastrointestinal disorders with the destruction of the hematopoietic system leads to the death of the irradiated person.

Typical pathologies are a considerable loss of fluids and electrolytes by the body (dehydration), the deterioration of the nutritional system and infection.

9. Natural radiation induced cancer

Calculate for the Swiss population the annual number of induced cancers produced by natural radiation whose average effective dose is estimated at 5.5 mSv per year

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Solution:

$N = 7 \times 10^6$ persons, $D = 5.5\ mSv/yr$, $R = 5\%\ Sv^{-1}$

The risk associated to a dose of 5.5 mSv is:

$$\frac{5\ \%}{1\ Sv} = \frac{x}{5.5 \times 10^{-3}\ Sv} \rightarrow x = 0.0275\ \%$$

The number of radio-induced deaths is:

$$0.0275\ \% \ \times N = 1925\ persons/yr$$

10. Detriment

Which radiation effects are considered in evaluating the detriment?

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Solution:

Only stochastic effects of radiation on organs are considered in the calculation of the detriment.