A short introduction to radio-safety

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OUTLINE

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- Ionising radiation
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  - types of radioactivity
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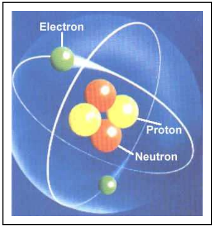
Short introduction - atom and nucleus

- **Matter** – consists of Atoms
- **Atom** = Nucleus + Electrons
- **Nucleus** = Protons + Neutrons
- **Elements** – ${}^{A}_{Z}X_{N}$
- **Z** – atomic number = number of protons (atoms with the same number of protons – have the same chemical properties)
- **N** – number of neutrons
- **A** = Z + N – mass number
- **ISOTOPE** - Z=const
- **ISOTONE** - N=const
- **ISOBAR** - A=const



Size of atom 10^{-10}**m**, size of nucleus 10^{-15}**m**

Ionising radiation - what is ionisation?

- **Radioactivity** - a natural and spontaneous process by which the unstable atoms of an element emit or radiate excess energy in the form of particles or waves.
- After emission the remaining **daughter** atom can either be a lower energy form of the same element or a completely different element.
- The emitted particles or waves are called **ionising radiation** because they have the ability to remove electrons from the atoms of any matter they interact with.

Ionising radiation - types of radioactivity

α	α decay is the emission from the nucleus of a tightly bound arrangement of 2p and 2n (- a helium nucleus) and is the result of spontaneous fission of an unstable heavy nucleus (Z>82). The alpha particles emitted are monoenergetic and generally have an energy of $\sim$5MeV
β	β particle (an electron or a positron) is emitted from the nucleus. There are two types of β decay: β^- : $\mathrm{n}^0 \rightarrow p^+ + e^- + \bar{\nu}_e$ β^+ : $\mathrm{p}^+ \rightarrow n^0 + e^+ + \nu_e$
neutrons	Electrically neutral particles, a result of nuclear fission or fusion. Free neutrons releasted from atom can react with nuclei of other atoms to form new isotopes, which, in turn, may produce additional radiation.

Generally – unstable heavy elements require a series of α and β decays until a lighter and more stable element is reached.

Ionising radiation - types of radioactivity

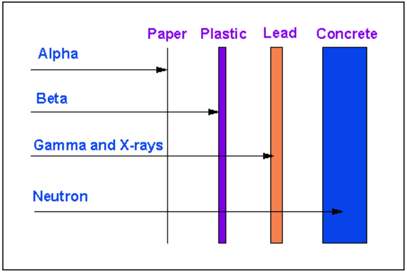
γ	It is common for the daughter nucleus to be left in an excited state with excess energy. This energy is rapidly released as electromagnetic γ radiation.
X-rays	X-rays have a wavelength in the range of 0.01 to 10nm, corresponding to energies in the range from 120eV to 120keV

X and γ-rays are types of electromagnetic radiation. They are not stopped by matter but are attenuated. Attenuation depends on:

- energy of radiation,
- thickness and density of absorber material.

Ionising radiation - penetrating distances

- α – $<$10cm air, will not penetrate skin, highly dangerous while absorbed by human body
- β – several meters in air, up to 0.8cm in tissue, use plastic shielding (low density materials)
- X-rays – penetrating, use lead shielding
- γ – more penetrating than X-rays, use lead or concrete shielding
- neutrons – very penetrating, use water, paraffin, polythene shielding (moderate neutrons), also concrete



Ionising radiation - natural and artificial sources of radiation

1. Natural sources of radiation
   - sources from the Earth's crust - sources in water and food, which are incorporated to the human body, to building materials (ie. radon gas, ^{40}K)
   - sources from outer space - cosmic rays
   - radiation produced by the atomic bombardment of the upper atmosphere by high-energy cosmic rays (ie. ^{14}C)
2. Artificial sources of radiation
   - medicine – emissions from nuclear medicine diagnostics and treatment, also from irradiated patients
   - global radioactive contamination – nuclear weapons testing
   - nuclear power station accidents
   - normal operation of nuclear facilities, like scientific research
   - products from everyday life (i.e. smoke detectors)

The exposure for an average person: $\mathbf{80\%}$ natural + $\mathbf{20\%}$ artificial radiation sources

Units

NAME	DEFINITION	UNIT
activity	the rate of disintegration of a source	1Bq
absorbed dose D_T	an energy dissipated per unit mass	$1\text{Gy} = 1\text{J/kg}$
equivalent dose H_T	an average measure of the radiation, that attempts to account for the different biological damage potential of different types of ionizing radiation	$1\text{Sv} = 1\text{J/kg}$

Units - Radiation Weighting Factors

Radiation Type and Energy	w_R
Photons, all energies	1
Electrons, (β particles), muons, all energies	1
Neutrons $<$10 keV	5
Neutrons 10 keV – 100 keV	10
Neutrons $>$100 keV – 2 MeV	20
Neutrons $>$2 MeV – 20 MeV	10
Neutrons $>$ 20 MeV	5
α particles, fission fragments	20

Equivalent Dose $H_T = w_R * D_T$
ie. 1Gy of β radiation $\rightarrow$ H_T**=1Sv**
but 1Gy of α radiation $\rightarrow$ H_T**=20Sv** !!

Units

NAME	**DEFINITION**	**UNIT**
activity	the rate of disintegration of a source	1Bq
absorbed dose D_T	an energy dissipated per unit mass	$1\text{Gy} = 1\text{J/kg}$
equivalent dose H_T	an average measure of the radiation, that attempts to account for the different biological damage potential of different types of ionizing radiation	$1\text{Sv} = 1\text{J/kg}$
effective dose E	sum of the doses from internal and external radiation sources, that attempts to account for the biological damage potential of different types of ionizing radiation and different organs	$1\text{Sv} = 1\text{J/kg}$

Units - Tissue Weighting Factors

Tissue or Organ	w_T
Gonads	0.20
Bone Marrow	0.12
Colon	0.12
Lung	0.12
Stomach	0.12
Bladder	0.05
Breast	0.05
Liver	0.05
Oesophagus	0.05
Thyroid	0.05
Skin	0.01
Bone surface	0.01
Remainder	0.05

Effective Dose E=$\sum H_T * w_T$

The interaction with matter

α, β, γ and X-rays interact with matter in two major ways:

ionisation	removal of an electron from an atom leaving an ion
excitation	addition of energy to the atom, giving an excited state

1. Charged particles (α, β) - after each ionisation will lose energy and will finally be stopped.
2. γ and X-rays - chargeless, more penetrating than α, β, interact via:

$\rightarrow$ photoelectric effect,

$\rightarrow$ the Compton effect,

$\rightarrow$ pair production.

The interaction with matter - biological effects

- **Deterministic Effects** – we are concerned with the clinical effects that result from exposure to ionising radiation – radiation doses involved here are usually substantial and delivered over a short space of time above a certain dose
- **Stochastic Effects** – there is only a probability of the effect occurring – here is no threshold dose below which the probability is zero and in the simplest approach we adopt the hypothesis that "probability" is proportional to dose received.

The interaction with matter - Clinical Effects of Radiation Exposure

Dose (Sv)	Clinical Effect
0→0.2	no symptoms
0.2→0.5	no noticeable symptoms
0.50→1	mild radiation sickness, blood cell changes, some injury, no disability
1→2	light radiation poisoning, 10% fatality after 30 days, injury, possible disability, nausea/vomiting within 24 hours
2→3	moderate radiation poisoning, 35% fatality after 30 days, injury and disability certain
3→4	severe radiation poisoning, 50% fatality after 30 days
4→6	acute radiation poisoning, 60% fatality after 30 days
6→10	acute radiation poisoning, near 100% fatality after 14 days
10→50	acute radiation poisoning, 100% fatality after 7 days

Basic safety standards and procedures - Minimising the External Hazard

- **LEAST ACTIVITY** – use the least amount of radioactive material required to get good results
- **LEAST TIME** – limit the time spent in the area – the dose received by a person working in the radiation area is directly proportional to the amount of time spent in the area.
- **DISTANCE** – if we double the distance from a point source of radiation, the dose/unit area in a given time is reduced by a factor of 4 (*double the distance, quarter the dose*)
- **SHIELDING** – use the correct shielding material for the given isotope

Basic safety standards and procedures - classification of radiation workers – Ionising Radiation Regulations

WORKER	Effective Dose E
Classified Worker (A)	6<E<20 mSv/year
Unclassified Worker (B)	1<E<6 mSv/year
Trainees and students >18 years	20 mSv/year
Trainees and students 16<18 years	6 mSv/year
Trainees and students <16	1 mSv/year
Members of the public	1 mSv/year
Women of reproductive capacity	1 mSv/year
Decontamination Worker	100 mSv
Life-saver	500 mSv

Note1: Annual Dose Limits are given per 5 years in average, so Classified Worker can get max. 100 mSv in one year, but 0 mSv in next 4 years.

Note2: Classified Workers (A) have Radiation Passbooks, personal dosimeters, dose assestmenst, medical care.

Basic safety standards and procedures - Radiation Areas

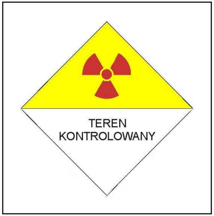
Supervised Radiation Area – if any person is likely to receive an effective dose greater than 1 mSv a year (or an equivalent dose greater than 1/10 of any relevant limit; or it is necessary to keep the conditions of the area under review to determine whether the area may require).

- In practice this requirement is extended to cover all areas used for handling radioactive materials which are not designated as Controlled Areas.
- There are no special restrictions on access to Supervised Areas, but radioactive materials, x-ray equipment, and equipment/workstations marked with the radiation hazard trefoil (because of potential contamination) should only be used by registered radiation workers.

Basic safety standards and procedures - Radiation Areas

Controlled Radiation Area – if any person is likely to receive an effective dose greater than 6 mSv a year (or an equivalent dose greater than 3/10 of any relevant limit; or it is necessary for special procedures to be followed to restrict significant exposure or limit the probability and magnitude of radiation accidents).

- Each Controlled Area must be physically demarcated.
- Access to Controlled Areas is restricted to Classified persons or persons (workers or visitors) following an approved written system of work.
- Entry into a Controlled Area must be solely for the purpose of carrying out approved duties or procedures and all involved must have received adequate training.



Basic safety standards and procedures - Minimising the External Hazard

- Wear radiation dosimeter (chest height).
- Eating, drinking, smoking or applying cosmetics are **prohibited**!!!
- Work **must not** be carried out by a person with an undressed cut or abrasion below the wrist.
- Hands must be washed before leaving the laboratory after handling radioactive materials.
- Radionuclides emitting penetrating radiations must be adequately **shielded**.
- Contamination must be cleared up without delay.

Thank you for your attention!