Safe Working with Ionising Radiation

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Terms

- **Radioactivity:** For an atom to be stable the nucleus must contain a certain number of neutrons. If the number of neutrons is either greater or less than this value (which varies for different elements) the nucleus is unstable and decays by emitting energy in the form of radiation, and is said to be radioactive. Radioactivity can be defined as the process in which unstable atoms stabilise by emitting radiation. For example the tritium isotope of hydrogen is unstable and therefore radioactive. <u>For radiation to be considered as ionising</u> it must be capable of causing ionisation in the target material. This distinguishes this type of radiation from other <u>non-ionising types of radiation</u> such as light, radio and microwaves.

Terms

- **Ionisation:** When sufficient energy is given to an orbiting electron so that the electron is removed from the electric field of the nucleus, the atom is said to be ionised. This process can be caused by the interaction of photons or charged particles with an atom, resulting in an ion pair. The negative ion is the displaced electron, while the positive ion is the remaining atom that now has a net positive electrical charge. Photons and charged particles can indirectly cause multiple ionisation as they can cause release of single high-energy electrons, which may then have enough energy to ionise other atoms that they meet.

Terms

- The ionisation potential is the minimum energy needed to ionise an atom by the removal of an electron from an outer orbital shell – i.e. an electron that is not tightly bound to the nucleus. In the case of the hydrogen atom, the energy required is about 13 electron volts (eV). Electromagnetic radiation of energy less than 12 eV is called non-ionising radiation, i.e. light, infra-red, UV, microwave and longer wavelength radiation.

Types of Radiation

- **Alpha (α) particles:** These particles consist of 2 neutrons and 2 protons that are bound together without any accompanying electrons. Alpha particles are emitted from heavy nuclei containing a large number of neutrons and protons.
- **Beta$^-$ (β^-) particles:** These are high speed single electrons which are emitted from the nucleus. They arise from the change of a neutron into an electron and a proton inside the nucleus.
- **Beta$^+$ (β^+) particles:** These are high speed single positrons (positive electrons) which are emitted from the nucleus. They arise from the change of a proton into an positron and a neutron inside the nucleus. They annihila-te with electrons to produce two photons (gamma rays).

Types of Radiation

- **Gamma (γ) radiation:** Gamma radiation is a form of electromagnetic radiation and is emitted from the nucleus of the atom, often in association with alpha and beta particles. The gamma emission represents an adjustment in the energy and configuration of the nucleus following an alpha or beta transformation. Gamma rays are uncharged, have no mass and travel at the speed of light. They are correspondingly very penetrating, travelling up to several hundred metres in air and requiring significant thicknesses of relatively dense material to stop them (e.g. centimetres of lead or tens of centimetres of concrete).

Types of Radiation

- **X-radiation:** X-radiation is also a form of electromagnetic radiation and differs from γ rays only in its mechanism of production. While γ rays area a product of radioactive decay, X-rays are generally created artificially by an X-ray set. This has the advantage that should a problem arise then the generator can simply be switched off to make the situation safe.
- X-rays are produced when high-speed electrons, produ-ced for example in an X-ray tube, strike a solid target. The maximum energy of the X-rays in the spectrum produced is dependent upon the voltage applied across the electrodes of the X-ray tube - this applies the acceleration to the electrons thus increasing the energy with which they strike the target.

Types of Radiation

- **Neutron radiation:** Some radioactive decay processes result in the emission of a neutron from the nucleus of the atom. Californium-252 decays by the emission of an alpha particle but may also spontaneously decay by the process of fission - resulting in the release of neutrons.
- A common use for neutron sources is for moisture or density measurements of certain materials, for example soil, food or pavements.

The Half Life of a Radionuclide

- The decay of a radioactive material is statistical in nature, ie it is impossible to predict when any individual atom will disintegrate. However due to the very large number of atoms in even the smallest radioactive source, the rate of radioactive decay for each radionuclide can be predicted.
- A parameter often used when considering radioactive decay is the half-life. This is the time it takes for half of the radioactive material present to decay and is a constant for a specific radionuclide.
- Decay is exponential and the half-life, $t_{1/2}$ is related to the decay constant, λ, by, $\mathbf{t_{1/2} = 0.693/\lambda}$

The Half Life of a Radionuclide

- A useful form of this for calculating the fraction of material remaining after a given time is,

  $$\mathbf{N/N_0 = e^{(-0.693\ t/\ t1/2)}}$$

- There are also decay tables with remaining fractions of material after a given times.

Quantities and Units in Radiation Protection

Amount or concentration of radioactive substance

- **Activity:** The amount of radioactive substance present is referred to as the "activity", defined as the number of nuclear transformations taking place in unit time. The SI unit for activity is the becquerel (Bq). One becquerel is one nuclear transformation per second. The previous special unit was the curie (1 Ci = 3.7×10^{10} Bq) (disintegration/sec).
- The Bq is a very small unit hence for practical purposes we use kilo- or mega- becquerels (kBq/MBq).
- **Activity concentration:** The activity contained in unit volume of the substance. It is expressed in becquerels per millilitre (Bq ml^{-1}).

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Quantities and Units in Radiation Protection

Radiation Dose

- **Absorbed dose - external radiation:** There are a number of different quantities that can be used to express the general concept of “dose”. The basic quantity is “absorbed dose” which is the energy deposited by ionising radiation in a medium per unit mass of the irradiated material. The SI unit for absorbed dose is the gray (Gy). The previous special unit was the rad (1 Gy = 100 rad).

Quantities and Units in Radiation Protection

Radiation Dose

- **Dose equivalent:** To take account of the different biological effectiveness of different types of radiation, the quantity "dose equivalent" has been defined. This is obtained by multiplying the absorbed dose (Gy) by a quality factor (or *relative biological effectiveness*) for the type of radiation concerned.
- Beta, gamma and X-ray radiation have a factor of 1; alpha and neutrons have factors up to 20.
- The SI unit for dose equivalent is the sievert (Sv). The previous special unit was the rem (1 Sv = 100 rem).

Quantities and Units in Radiation Protection

Radiation Dose

- **Committed dose - internal radiation:** If a radioactive substance is taken into the body (injection, inhalation, inoculation), it begins to irradiate the tissues around it until it has been eliminated by metabolism or radioactive decay. The “committed dose equivalent” from a single intake of a radioactive substance is the total dose equivalent that an organ or tissue is “committed” to receive in this way in the following 50 years. This takes into account the radiological half-life of the material and its biological properties, i.e. its half-life within the body as it is metabolised and excreted, the way in which it is absorbed, how it is transported around the body and if it is concentrated in particular tissues.

Quantities and Units in Radiation Protection

Radiation Dose

- **Annual limits on intake (ALI):** Annual limits on committed dose equivalent, or committed effective dose equivalent, are used to define limits on the amount of radioactive substance which may be taken in during the year - i.e. the quantity of an isotope which if taken into the body would result in an exposure equivalent to the dose limit.
- The International Commission on Radiological Protection (IRCP) has calculated and published annual limits on intake (ALI) for all commonly encountered radioactive substances. Doses from internal radiation are often

Quantities and Units in Radiation Protection

Radiation Dose

referred to in terms of fractions of ALI rather than of committed dose equivalent.

- ALIs may be used to determine safe quantities for manipulating unsealed sources. For example an operation involving the injection of a radioisotope from a syringe has the risk that all the contents of the syringe could be injected into the worker. However, if the total activity is less than one tenth of the ALI for that isotope then if the worst happened the maximum internal dose would be 1/10th of the dose limit.

Biological Effects

Radiation Injuries

- The cellular damage performed by radiation is manifested in a range of detrimental effects. These effects are conventionally divided into deterministic and stochastic effects.

1. **Deterministic effects**

These are effects that are expected to occur above a certain threshold dose and are the result of extensive cell damage. Above this threshold, the severity of the effect is then directly dependent on the dose received by the part of the body exposed. Examples of deterministic effects are erythema (reddening of the skin), depilation (hair loss), nausea and blood count changes. These tend to be acute

Biological Effects

effects, which appear within days or weeks of an exposure. They are the result of relatively high exposures, certainly in excess of 0.2 Sv and more typically in excess of a few sieverts.

2. Stochastic effects

Stochastic effects are those effects where the probability of occurrence is proportional to the level of the radiation dose received. It is assumed that there is no threshold below which these effects cannot occur. An increase in dose will raise the probability that the effect will occur in the part of the body that has been irradiated. In contrast, the severity of the effect is independent of the dose received. Cancer and hereditary disorders are stochastic effects.

Principles of Protection from External Radiation

Protection Principles

The are four factors that affect dose to personnel: source activity, time, distance and shielding.

Source aktivity

- The large the source activity, or the higher the rating of an x-ray set, the greater the potential dose to a person. Personal (and overall) doses can thus be minimised, if the smallest activity actually necessary for the work is used.

Principles of Protection from External Radiation

Time

- The shorter the time spent near to the source, the smaller the dose to a person; this is an important factor to consider when planning work.

Distance

- For penetrating radiations (such as X and γ radiations), the dose rate from the source follows an inverse square law relationship – but only if the radiation comes from a point sources.

Principles of Protection from External Radiation

- If D = dose rate at 1 metre, then the dose rate at d metres = $D/(d^2)$, eg
- If the dose rate at 1 metre = 4 $\mu Sv h^{-1}$;
- Then the dose rate at 2 metres = $4/(2^2)$ $\mu Sv\ h^{-1}$ = 1 $\mu Sv h^{-1}$;
- And the dose rate at 0.5 metres = $4/(0.5^2)$ $\mu Sv\ h^{-1}$ = 16 $\mu Sv h^{-1}$;
- **At 1 mm, e.g. holding a vial = $4/(0.001^2)$ $\mu Sv\ h^{-1}$ = 4 000 000 $\mu Sv h^{-1}$!**
- A similar relationship holds for γ radiation in vacuum, but in air the relationship is modified by absorption of γ particles by the air. The effect of this relationship between dose rate and distance from the source, is to cause dose rates to increase very rapidly as the source is approached – and also to decrease dose rates rapidly when receding from the sources.

Principles of Protection from External Radiation

Shielding

- **Alpha (α) particles**
  Alpha particles are easily absorbed by matter: a thin sheet of paper is enough to completely stop even the most energetic alpha particle radiations (of energy typically 2.5-8.8 MeV). Alpha particles are of limited external hazard, but they can be very hazardous if the radioactive material is taken into the body.

Principles of Protection from External Radiation

Shielding

- **Beta (β) particles**
  Beta particles are more penetrating than alpha particles and have a range of roughly 4 metres per MeV in air, or 3.5 mm per MeV in perspex – ie a beta particle with an energy of 2 MeV might be expected to be completely stopped by roughly 8 m of air, or 7 mm of acrylic (perspex). Light materials – i.e. less dense materials like perspex or aluminium – are a better choice for beta particle absorption than heavy materials – such as steel or lead; this is because heavier materials produce Bremsstrahlung radiation (X-ray) when they absorb beta particles.

Principles of Protection from External Radiation

Shielding

- **Electromagnetic Radiations**
  Short wave (high energy) electromagnetic radiations – such as Bremsstrahlung, X-rays and γ rays, are even more penetrating than beta radiation. As the energy of the radiation increases, the radiation become more penetrating. Heavy (i.e. dense) shielding materials, eg concrete, steel or lead – can be used to reduce the intensity of these very penetrating radiations, although in theory the radiation cannot all be stopped.

For a single radiation energy, the attenuation of the radiation intensity follows an exponential law. This means that a fixed thickness of shielding material will only reduce the incoming radiation intensity by a fixed amount.

Principles of Protection from External Radiation

For example, if 1 cm of a shielding gives a factor 2 reduction – ie only one-half (50 %) of the radiation gets through the shielding, then using 2 cm of materials as a shield would give a factor 4 reduction (only one-quarter [25%] transmitted). Using 3 cm of the material as a shield would give a factor 8 reduction (only one-eighth [12.5%] transmitted).

The thickness of material that causes the radiation transmission to be reduced by half is called the “half value thickness” or “Half Value Layer (HVL)”.

Principles of Protection from External Radiation

Shielding

- **Neutrons**
  Neutrons are similar to protons but are uncharged. Charged particles (such as alpha and beta particles) interact quire heavily with matter, and are fairly heavily absorbed by most materials hence they are not usually very penetrating. Due to their zero charge, neutrons interact fairly weakly with most matter – this makes neutrons a rather penetrating form of radiation that is quite difficult to shield/stop. Neutrons are usually shielded with proton-rich materials, i.e. hydrogen-containing, such as water, hydrocarbons (plastics, waxes) due to their similar sizes which are therefore most effective at absorbing by a series of collisions.

General Principles of Protection Against Unsealed Radioactive Materials

The basic objective is to keep exposures as low as reasonably practicable, taking into account both external and internal exposure pathways. The principles of protection can be summarised as follows:

General Principles of Protection Against Unsealed Radioactive Materials

Appropriately designed facilities

1. Containment of unsealed radioactive materials
2. Minimisation of contamination
3. Design for ease of decontamination
4. Ventilation of the work area
5. Shielding against external radiations (if necessary)
6. Provision of washing and changing facilities where appropriate

General Principles of Protection Against Unsealed Radioactive Materials

Control of work

1. The use of the minimum quantity of radioactivity
2. Segregation of work with unsealed radioactivity where appropriate
3. Suitable systems of work (with local rules)
4. Monitoring of the workplace
5. Personal monitoring if appropriate

General Principles of Protection Against Unsealed Radioactive Materials

Personal protective equipment

1. Wearing of protective clothing
2. Use of respiratory protective equipment if appropriate

Controlled or supervised areas

- restriction of access, classification of workers and monitoring work areas for contamination and leakage

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