Introduction to Radiochemistry

Lecture 12

Luca Doria
SFU & TRIUMF

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Radioprotection

Introduction

- Types of Radiation
- Radiation Sources
- Units
  - Physical
  - Protection
  - Operational
- Legislation

- Summary

Types of Radiation

- alpha: ^{4}He nuclei (2p+2n)
- beta: electrons or positrons
- gamma rays (also X-rays)
- heavy charged particles (alpha,p, ions)
- neutrons

Sources

- Radioactive Isotopes (natural or artificial)

- Particle Accelerators

- Nuclear Reactors

- X-ray generators

- Cosmic Rays

Screening

Radiation	Screen	Distance in Air
Alpha	Paper/Water	several cm
Beta	Low density materials	several m
Gamma	High density materials	several tens of m
Neutrons	High-Hydrogen materials	several hundreds m

Activation

Activation is the process where a non-radioactive material can become radioactive after irradiation.
An example is a nuclear/particle physics laboratory where an accelerator is at work. The interaction of the beam with surrounding materials can lead to activation. Typical examples are (mean lifetime in parentheses):

In Air: ^{24}Na(15h) , ^{22}Na(2.6y) , ^{152}Eu(13y)

In Aluminum: ^{24}Na(15h) , ^{22}Na(2.6y)

In Copper or Steel: ^{54}Mn(312d) , ^{60}Co(5.3y)

If an area is highly activated, a time of the order of magnitude of the mean lifetime must be waited before safe access would be possible.

Some materials become activated with such long-lived isotopes that they become effectively radioactive waste (example: $^{26}Al(7 \times 10^5 y)$, $^{53}Mn(3.7 \times 10^6 y)$)

Body Contamination and Damages

How can radiation reach the body?

1) Direct Exposure
2) Inhalation (activated air, radioactive dust particles)
3) Ingestion

Which damages can radiation induce?

1) Ionization: electrons can be knocked off molecules creating dangerous free radicals which are very reactive

2) DNA damage: beta and gamma radiation can break a DNA helix but repair is possible. Alpha and neutrons can break both helixes leading to not-reparable damage.

Units of Measure (Physical)

Activity A: unit: Becquerel , 1Bq = 1 disintegration/s = 27pCi (Ci= Course)

Absorbed Dose D: unit: Gray, 1Gy = 1J/Kg = 100rad (rad is not standard)

Fluence F: unit: $1/m^2$. F=dN/da where dN is the number of particles incident on a small sphere of cross section da. This unit is used in dosimetric calculations and it can be shown to be equivalent to F=dl/dV where dl is the sum of all the distances of the particles in a volume dV.

Kerma K: unit: Gray. The Kerma is the total kinetic energy of all the particles liberated by indirectly ionizing radiation in a volume divided by the mass of the volume.

Linear Energy Transfer (LET): unit: J/m. Mean energy dE lost by a charged particle by electron collisions while travelling a distance dl in a material. LET = dE/dl.

Units of Measure (Protection)

Organ Absorbed Dose D_T: unit: Gray. It is the mean absorbed dose by an organ of mass m_T:

$$D_T = \frac{1}{m_T}\int_{m_T} D\,dm$$

Equivalent Dose H_T: unit: Sievert (1Sv=100rem). It is the total absorbed dose D_T absorbed by an organ due to all the kinds of radiations it was exposed to. The sum is weighted by a factor expressing the damaging power of the radiation:

$$H_T = \sum_R w_R \cdot D_{T,R}$$

Radiation type	w_R
Photons, electrons and muons	1
Neutrons, $E_n < 1$ MeV	$2.5 + 18.2 \times \exp[-(\ln E_n)^2/6]$
$1 \text{ MeV} \leq E_n \leq 50$ MeV	$5.0 + 17.0 \times \exp[-(\ln(2E_n))^2/6]$
$E_n > 50$ MeV	$2.5 + 3.25 \times \exp[-(\ln(0.04E_n))^2/6]$
Protons and charged pions	2
Alpha particles, fission fragments, heavy ions	20

Units of Measure (Operational)

- **Ambient dose equivalent,** $H^*(10)$ (unit: sievert): The dose equivalent at a point in a radiation field that would be produced by the corresponding expanded and aligned field in a 30 cm diameter sphere of unit density tissue (ICRU sphere) at a depth of 10 mm on the radius vector opposing the direction of the aligned field. Ambient dose equivalent is the operational quantity for *area monitoring*.
- **Personal dose equivalent,** $H_p(d)$ (unit: sievert): The dose equivalent in ICRU tissue at an appropriate depth, d, below a specified point on the human body. The specified point is normally taken to be where the individual dosimeter is worn. For the assessment of effective dose, $H_p(10)$ with a depth $d = 10$ mm is chosen, and for the assessment of the dose to the skin and to the hands and feet the personal dose equivalent, $H_p(0.07)$, with a depth $d = 0.07$ mm, is used. Personal dose equivalent is the operational quantity for *individual monitoring*.

from: Particle Data Book (2013)

Health Effects and Legislation

- **Lethal dose**: The whole-body dose from penetrating ionizing radiation resulting in 50% mortality in 30 days (assuming no medical treatment) is 2.5–4.5 Gy (250–450 rad)†, as measured internally on the body longitudinal center line. The surface dose varies due to variable body attenuation and may be a strong function of energy.

- **Cancer induction**: The cancer induction probability is about 5% per Sv on average for the entire population [2].

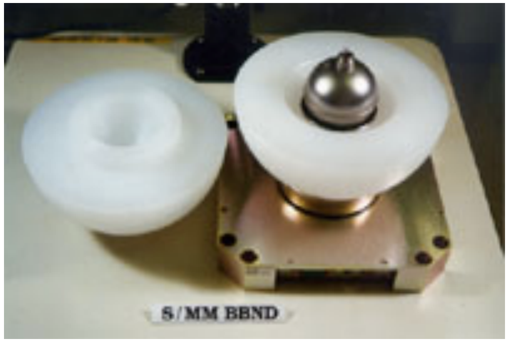
- **Recommended effective dose limits**: The International Commission on Radiological Protection (ICRP) recommends a limit for radiation workers of 20 mSv effective dose per year averaged over 5 years, with the provision that the dose should not exceed 50 mSv in any single year [2]. The limit in the EU-countries and Switzerland is 20 mSv per year, in the U.S. it is 50 mSv per year (5 rem per year). Many physics laboratories in the U.S. and elsewhere set lower limits. The effective dose limit for general public is typically 1 mSv per year.

from: Particle Data Book (2013)

Neutron Detectors

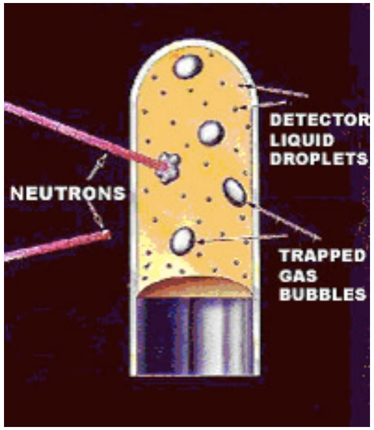
Rem Counters: Portable Counters for thermal neutrons. They may contain high-Z converter materials (Cd, Pb). Common models respond to neutrons up to 10-15MeV. The counter (gas-filled) is embedded in a polyethilene moderator. Rem counters usually measure H*(10).

Bonner Sphere Spectrometer (BSS)



This detector is comprised by a counter surrounded by a sphere of polyethylene as moderator. Spheres with various diameters with different response functions exist. Various scintillator materials are used, like ^3H or BF_3. Tritium gives good gamma/neutron separation

Bubble Detector



A super-heated liquid acts as active material where neutrons induce the formation of bubbles.

Track Etched Detector

Made by insulator materials where the track energy deposit is visible as small damages in the material's structure.

Photon Detectors

Geiger-Mueller Counter: Very common, cheap and easy to operate. Can count photons but does not give any spectral information. It is based on a gas chamber operated in the Geiger-Mueller region.

Ionization Chamber

Similar to Geiger-Mueller counters they operate at lower voltages. They can also be portable.

Scintillators

Crystal scintillators coupled to PMTs are very common photon detectors.
For the operating principle, see the Radiation Detector's lecture.
Instead of a crystal, silicon-based detectors can be used.

Dosimeters

Personal dosimeters are passive, portable detectors used by persons accessing ionizing radiation fields usually for professional reasons.

Typically, they are based on a film which is blackened by radiation or track etched detectors.

Semi-passive dosimeters are less common and are based on a miniaturized ionization chamber.

Active dosimeters are portable small devices which detect continuously the radiation dose and are also able to send an alarm if certain thresholds are surpassed.

They are usually measuring $H_p(10)$.

Area Classification (EU)

TYPE	LIMITS	MEASURES
Supervised Area	1-6 mSv/year	-
Controlled Area	6mSv/year - 2mSv/hour	limited stay
High-Radiation Area	2-100 mSv/hour	limited stay
Forbidden Area	>100mS/hour	limited stay

Protect Yourself

How to protect yourself from radiation:

- Stay behind shielding.
- Do not eat and/or drink in radiation areas.
- Do not smoke.
- Do not enter with open wounds.
- Wear protective clothing if needed.
- Wash your hands after work.
- Wear a dosimeter all the time.

With radioactive sources:

- Do not damage they surface.
- Do not use tools on them
- Do not expose them to a beam
- After use, put them back in a safe

Summary

- Most dangerous: gammas and neutrons

- Unit of measure: physics and radio protection

- Measurement

- Legislation

- How to avoid contamination