Nuclear Physics and Astrophysics

PHY-302

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Lecture 24
Medical Imaging

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Effects of Radiation

We now know what “radiation” is

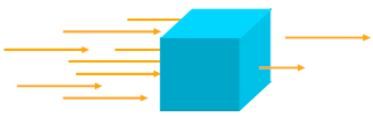
But what does it mean for our bodies?

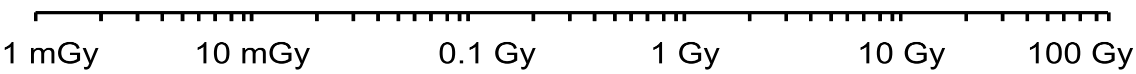
Radioactivity is quantified in these units:

Curie (Ci)
1 Ci is the amount of radioactive material in which number of decays in 1 s is same as in 1g of pure radium (3.7×10^{10} s^{-1})

Becquerel (Bq)
1 Bq is the amount of radioactive material with an average of 1 decay per s.
This is the modern SI unit

Gray (Gy)
Quantifies energy absorbed from radioactive source:
radiation energy transfer
1 Gy = 1 J / Kg
not a good indicator of potential biological harm





Sievert (Sv)
Each type of radiation has different ionising ability
Each part of human body interacts differently to radiation
Define new unit - quantify biologically equivalent dose
Sievert has units of J/Kg

$$\text{equivalent dose (Sv)} = \text{absorbed dose (Gy)} \,.\, W_T \,.\, W_R$$

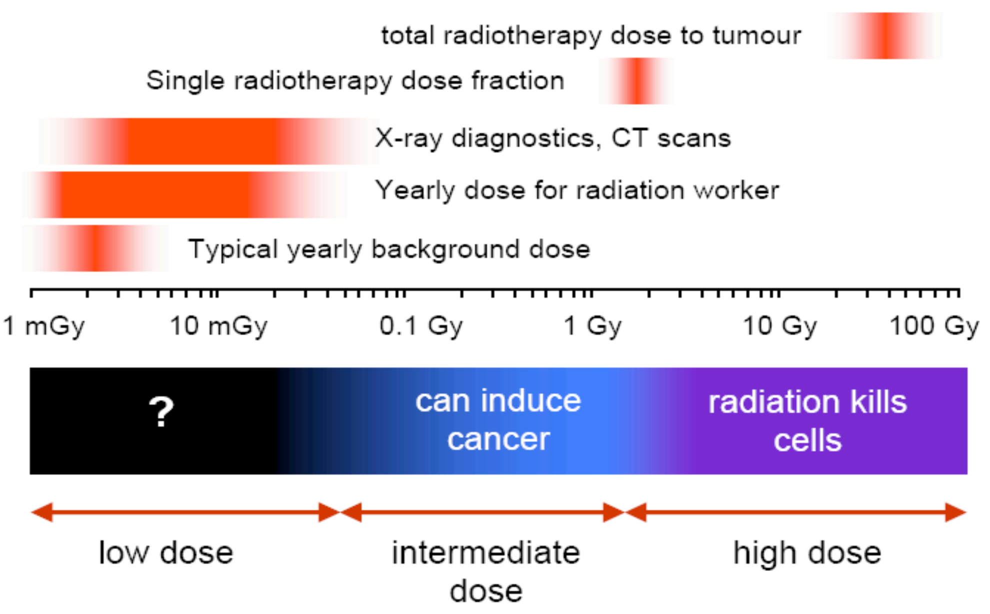
W_R = weighting factor for radiation type

photons		1
$e^{\pm}$		1
neutrons	<10 keV	5
neutrons	10-100 keV	10
neutrons	0.1-2 MeV	20
neutrons	2 - 20 MeV	10
neutrons	>20 MeV	5
protons		5
alpha		20

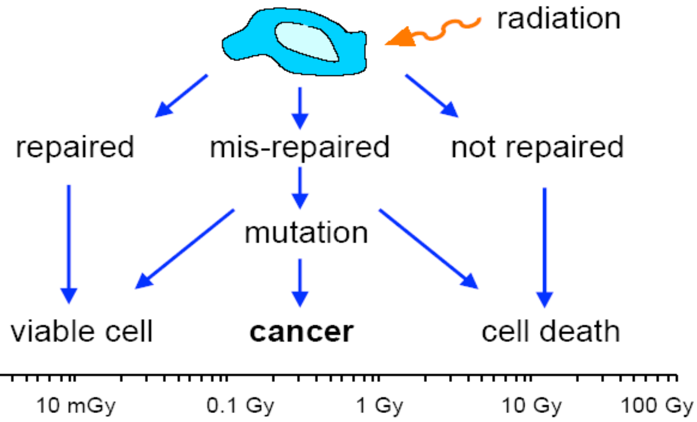
W_T = weighting factor for tissue type

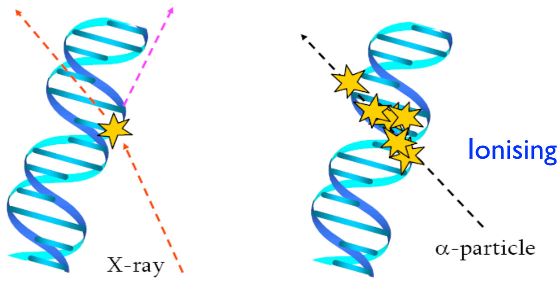
gonads	0.20
bone marrow, colon lung, stomach	0.12
bladder, brain, breast, kidney, liver, muscle intestine, uterus	0.05
bone, skin	0.01

Why are some tissues more susceptible than others?



What Does Radiation Do To Cells?



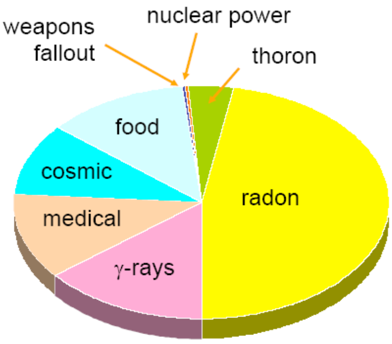


easily repaired

harder to repair

Ionising radiation can directly damage DNA within cells

How Much Are We Exposed To?



Average UK dose ~ 2.5 milli-sieverts per year

- Radon - heavy noble gas
- Naturally occurs in soil
- Cause of 20,000 deaths per year in EU
- Second largest cause of lung cancer
- ^{222}Rn is alpha emitter - lifetime ~ 4 days
- As a gas it can seep out of soil
- Can be breathed in - hence dangerous

cosmic rays	10%
gamma rays from ground	14%
food & drink	12%
radon & thoron	50%
medical	14%
nuclear power/weapons	0.5%

Rn has a 4 day lifetime, why is it dangerous?

equivalent dose:

0.05 - 0.2 Sv — no change; possible genetic mutation; potential cancer
disputed! (search term: hormesis, linear no threshold model)

0.2 - 0.5 Sv — no noticeable symptoms

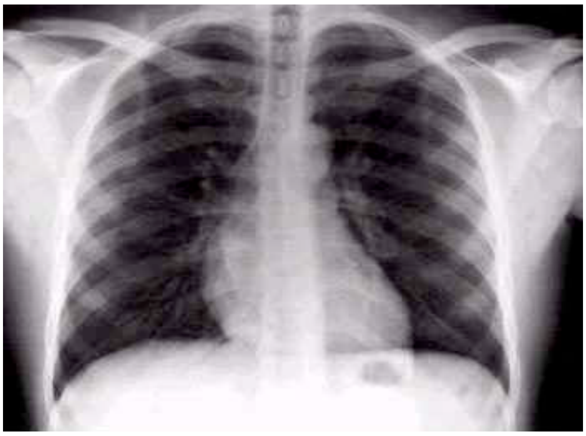
0.5 - 1.0 Sv — Mild radiation sickness with headache and increased risk of infection. Temporary male sterility is possible.

1 - 2 Sv — Light radiation sickness; nausea, vomitting; 10% fatalities after 30 days

2 - 4 Sv — Severe radiation sickness; 50% fatalities after 30 days

Effects of radiation can be dangerous
But natural radiation is one of the driving forces of Darwinian evolution
We would not be here without it!

neutrons are electrically neutral - why are they dangerous to humans?



- Biggest application of nuclear physics is medicine
- X-rays discovered in 1895
- Note: X-rays produced from atomic electron transitions (not strictly nuclear physics!)
- Lead to many new medical technologies
  - detection & imaging
  - therapeutic uses (e.g. cancer treatment)

Techniques developed in nuclear / particle physics transferred into medical useage
nuclear physicists are in high demand!

Nuclear Medicine - Diagnostic Imaging

Diagnostic imaging single largest area of nuclear medicine

Basic requirements of a good imaging system are:

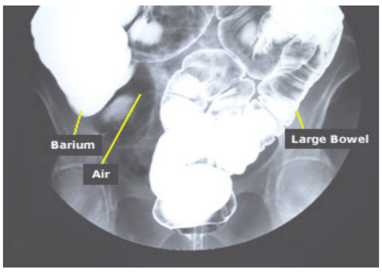
- A detection device able to record energy & positions of radiation from body
- Use of suitable radionuclide with high activity to deliver acceptable number of counts but delivery of low dose to patient
- Use of a radiopharmaceutical - drug capable of being absorbed by certain organ or region of body

Most frequent isotope used for scans is ^{99}Tc (technetium)

- unique x-ray emitter: 140 keV (technically: produced from gamma decays)
- no associated beta / alpha decays
- half life = 6 hours
- cheap - £30 per gram
- binds easily to bio-molecules

Another application:
ingestion of high Z nuclei - improve x-ray imaging by contrast increase

e.g. 'barium meal' : high Z barium nucleus absorbs / scatters more x-rays



radioactive isotope ingestion:

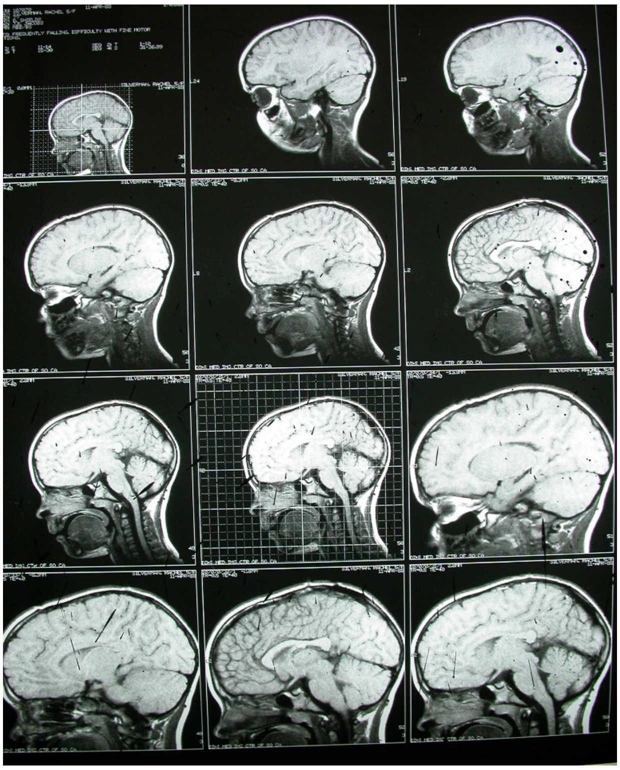
Can probe working body parts

e.g. thyroid gland absorbs iodine

patient administered radioactive (gamma active) ^{131}I and ^{132}I

gamma-ray imaging camera can view passage of iodine through thyroid gland

Tomography



Tomography is the ability to image complete slice through internal structure of body

Achieved by passing many x-ray beams through region of interest from many angles

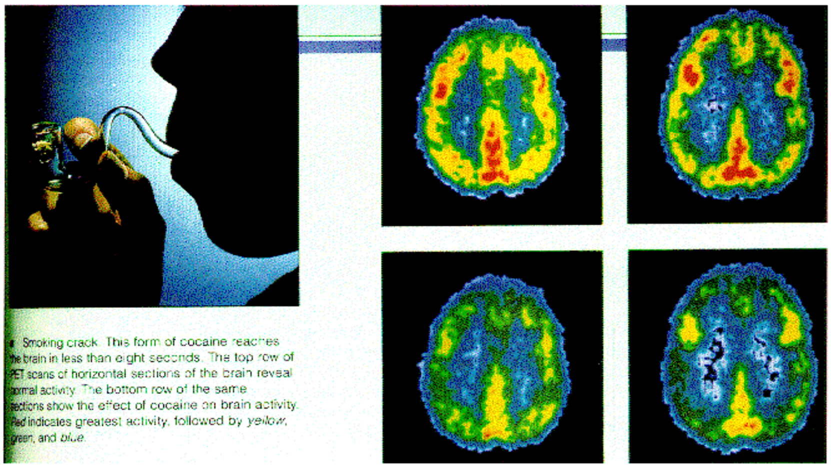
For each beam intensity loss is measured

Computer combines intensity loss over all angles to create 3d image

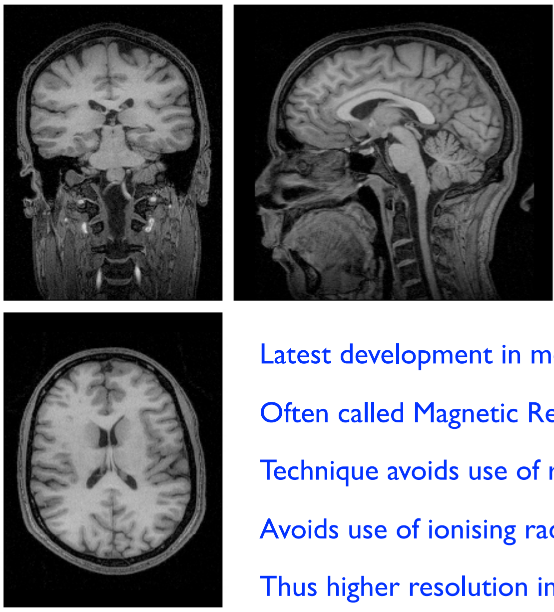
Known as Computerised Axial Tomography (CAT)

Positron Emission Tomography

- A β^+ emitter radionuclide is introduced to area under study
- Positron annihilates with electrons to two back-to-back 511 keV photons in coincidence
- Detecting both photons identifies a line along which annihilation occurred
- Observation of many photon pairs maps out distribution of radionuclide in body
- Can be done in real time - i.e. monitor live processes (CAT scans cannot do this)
- Scanners use ^{15}O (lifetime=2 mins) and ^{13}N (lifetime=10 mins)



Nuclear Magnetic Resonance Imaging



Latest development in medical imaging

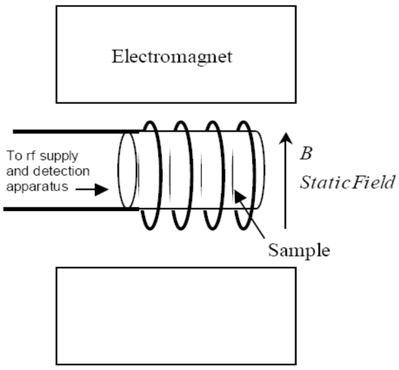
Often called Magnetic Resonance Imaging (avoid use of the word “nuclear”)

Technique avoids use of radionuclides

Avoids use of ionising radiation - no known side effects

Thus higher resolution images can be taken - take image over longer time

Pioneered by Sir Peter Mansfield (Nobel prize 2003) – ex QM student!



- Makes use of nuclear Zeeman effect
- In NMR spectroscopy a large B field is applied to sample
- This causes energy levels to split into m_I sub-states
- An RF field is applied at exactly frequency to excite spin state
- The excited state then decays via photon emission again
- Emitted photon is detected and density of photons measured
- motion of atomic electrons modifies B field seen by nucleus
- makes exact splitting dependent on chemical environment !
- Thus NMR can infer environment by resonance scan
- position information is obtained by applying additional weak magnetic field gradient in orthogonal directions