PHY138Y
Nuclear and Radiation

Professor Tony Key
MP401
key@physics.utoronto.ca

Announcement

Test 4 (Nuclear and Radiation)

Tuesday, April 8th, at 18h.

- **If** you wrote a previous test at an alternate sitting, you will receive an email asking if you wish to do the same for Test 4. You must confirm or decline by **replying** no later than **17h on Monday 31 March.**
- **OR**, if you have **not** written at a previous alternate sitting, **but** you do have a **valid reason** for wanting to write at the alternate sitting of Test 4, you must **register in person** for this alternate sitting in MP129 before **17h on Monday 31 March**
- **N.B.** Only those who have registered will be allowed to write at the alternate time. Deadline for registration is, again, **17h on Monday 31 March**

Announcements

Written problem set #5
– due Friday at 5 PM NBNB

MP Problem Set #6 available Wednesday
Due Sunday 6th April

Pre-class Quiz #6 (available Wednesday)
(SNV and SNVI)
Due next Wednesday (2nd April)

Van Kranendonk Prize
for
an Outstanding TA
(tutor or lab demo)

Nominations to
ugchair@physics.utoronto.ca
or MP129, or me, or Dr Savaria
with a brief statement

Today

Review and complete
SNIV – Biological Effects

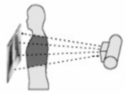
SNV – Radioisotopes in Medicine

Wednesday & Monday

SNV – Radioisotopes in Medicine
- complete

BIOLOGICAL EFFECTS OF RADIATION

An X-ray machine, rated at 120 kVp and 10mA, delivers exposures of 800 $mR.s^{-1}$. Estimate the dose received in a chest X-ray from an exposure of 10 ms, clearly stating any assumptions you need to make.



Plan (Model)

1. Calculate exposure (X) from exposure rate and time
2. Knowing X, calculate dose in air (D_{air})
3. From D_{air}, calculate energy fluence reaching skin, Ψ
4. This energy fluence enters the body, $\Psi = \Psi_{in}$
5. Calculate energy fluence leaving body – Ψ_{out}
6. Calculate difference $\Delta \Psi = \Psi_{out} - \Psi_{in}$
7. Multiply by chest area - get energy deposited in body
8. Divide energy by mass of body exposed to get dose

Formulae needed

$$D_{air} = 8.69 \cdot 10^{-3} \; X$$

$$\Psi_m(0) = D_m(x)/(\mu_{en}/\rho)_m$$

$$\Psi(x) = \Psi(0) \exp(-\mu_{en} x)$$

$$D_m(x) = S(\Psi_{in} - \Psi_{out})/M$$

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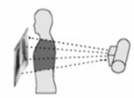
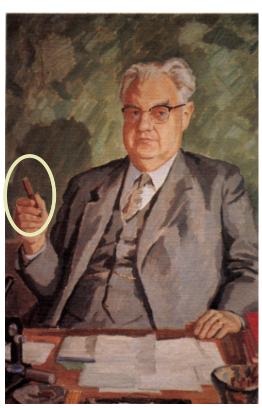


Who is this guy?

1. J.J. Thomson
2. Charlie Chaplin
3. Rolf Sievert
4. Niels Bohr
5. Albert Einstein



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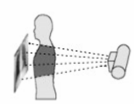


AVERAGE ABSORBED DOSE ~ 50 µGy
Is this a serious health risk?

Radiation Type	W_R (RBE)	Radiation Type	W_R (RBE)
Photons*, electrons	1	α -particles	20
Protons	2	neutrons – function of energy	

*W_R = 1 can be used for the full range of X-ray energies used in this course.

Organ or Tissue	W_T	ΣW_T
Colon, Lung, Breast, Stomach, Bone Marrow	0.12	0.60
Gonads	0.08	0.08
Bladder, Oesophagus, Thyroid, Liver	0.04	0.16
Bone, Skin, Salivary Glands, Brain	0.01	0.04
Other Organs (grouped)	0.12	0.12

The **Equivalent Dose** is the absorbed dose (in Gy or rad) multiplied by W_R.

Measured in Sieverts $H = W_R \times D$

The **Effective Dose** is the Equivalent Dose multiplied by W_T, summed over all exposed organs

Measured in Sieverts $H_{eff} = \Sigma W_T H_T$.

Suppose a chest X-ray delivers an absorbed dose (D) of 100μGy to a patient's lungs.

Radiation Type	W_R (RBE)
Photons*, electrons	1
Protons	2
α -particles	20
neutrons – function of energy	

The equivalent dose (H) is --

A. 100 μSv
B. 24 μSv
C. 12 μSv
D. 6 μSv
E. don't know

Suppose a chest X-ray delivers an equivalent dose (H) of 100μSv to a patient's lungs.

Organ or Tissue	W_T	ΣW_T
Colon, Lung, Breast, Stomach, Bone Marrow	0.12	0.60
Gonads	0.08	0.08
Bladder, Oesophagus, Thyroid, Liver	0.04	0.16
Bone, Skin, Salivary Glands, Brain	0.01	0.04
Other Organs (grouped)	0.12	0.12

The effective dose (H_{eff}) is --

A. 100 μSv
B. 24 μSv (good try!)
C. 12 μSv
D. 6 μSv
E. don't know

...ie. if that patient had been exposed to a whole body dose of 12μSv, the effect on his or her health would be the same as the 100μSv dose to his or her lungs.

That is the meaning of

Effective Dose

Suppose a chest X-ray delivers an equivalent dose (H) of 100μSv to a patient's lungs.

Organ or Tissue	WT	ΣWT
Colon, Lung, Breast, Stomach, Bone Marrow	0.12	0.60
Gonads	0.08	0.08
Bladder, Oesophagus, Thyroid, Liver	0.04	0.16
Bone, Skin, Salivary Glands, Brain	0.01	0.04
Other Organs (grouped)	0.12	0.12

If one lung is now totally shielded during the exposure, the effective dose (H_{eff}) is --

A. 50 μSv
B. 24 μSv
C. 12 μSv
D. 6 μSv
E. don't know

With Shielding

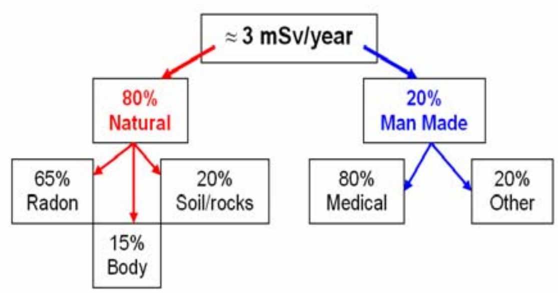
If that patient had been exposed to a whole body dose of 6μSv, the effect on his or her health would be the same as the 100μSv dose to his or her lungs, when one lung was shielded.

The Effective Dose (H_{eff}) to the tissue is that dose which, if it were given to the whole body, would have the same risk to health.

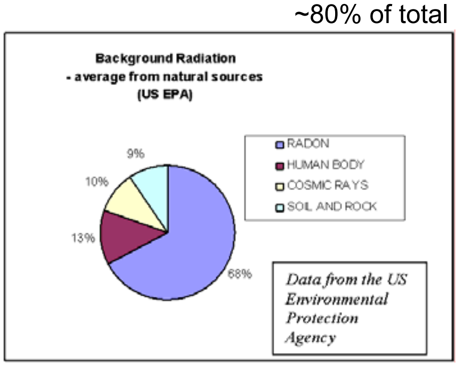
(e.g. probability of death from cancer).

We now investigate what is a “safe” level of exposure.

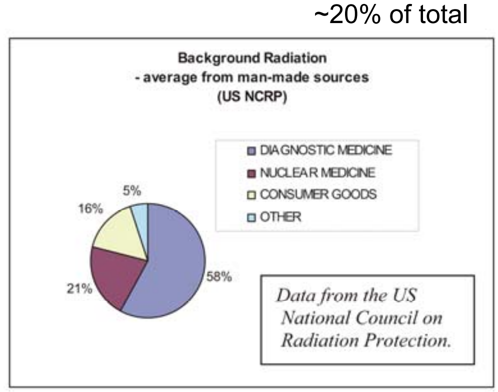
We use the environmental background (whole body!) as a guide and as a baseline.

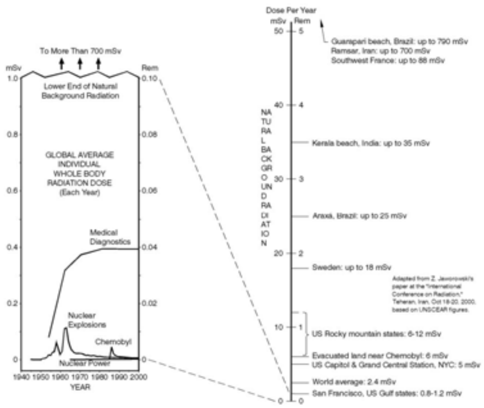


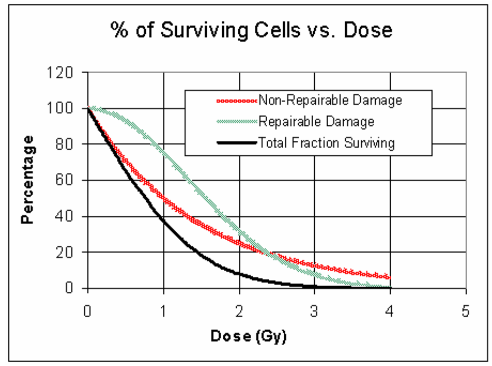
~80% of total



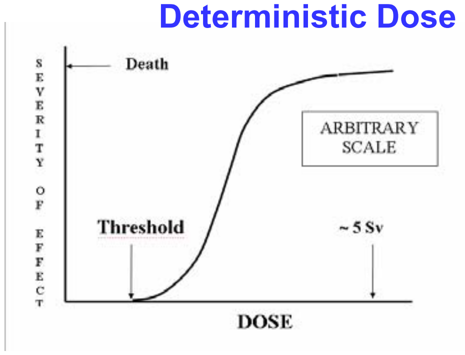
~20% of total



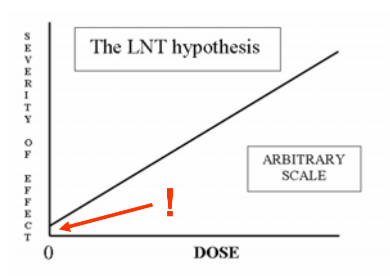




Deterministic Dose



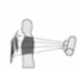
Stochastic Dose



Probability of fatal cancer ~ 5×10^{-5} x (No. of mSv received).

"AVERAGE" ABSORBED DOSE ~ 50 μGy
Is this a serious health risk?
Calculate H_{eff}?

An X-ray machine, rated at 120 kVp and 10mA, delivers exposures of 800 mR.s^{-1}. Estimate the dose received in a chest X-ray from an exposure of 10 ms, clearly stating any assumptions you need to make.



A. Yes, absolutely!
B. No!
C. I've no %$# idea!
D. I don't care, I'm OK!
E. I am a real dummy!

H_{eff} ~ 50 x 1 x (0.12+0.12+0.06) ~ 15 μSv

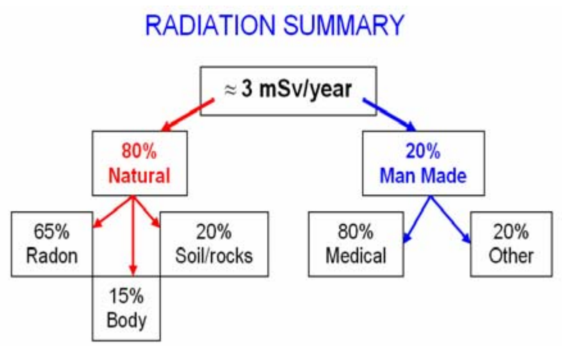
D **W_R** **lung** **breast** **~ bone**

Radiation Summary

Medical, dental procedures
~ tens or hundreds of μSv

Natural background, radiation limits
~ tens of mSv

Sickness and Death **~ 1 – 5 Sv**



Stochastic Dose

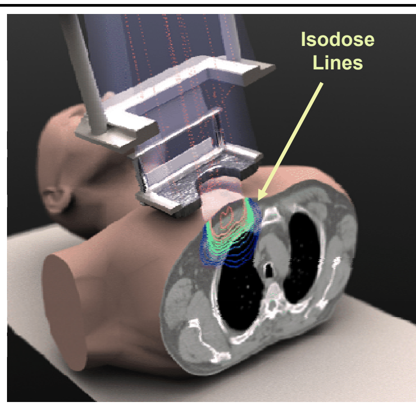
Probability of fatal cancer
~ 5 x 10^{-5} x (No. of mSv received)
~ 5% per Sv

The Canadian Nuclear Safety Commission sets limits of allowable radiation to less than 50 mSv per year

The Health Physics Society recommends against quantitative estimation of health risks below 100mSv in a lifetime

Model for Electron Beam Therapy Calculations

Thanks to Professor D.W.O. Rogers



SNV: Radioisotopes in Diagnosis and Therapy

- **DIAGNOSIS**: Tracers
  Isotopic Dilution
  SPECT
  PET
- **THERAPY** : Teletherapy
  Brachytherapy

TRACERS

TRACERS

Radio isotope	Half-life	Decay Mode	Organ to be scanned
^{123}I	13 hours	EC , γ	Thyroid
^{131}I	8 days	β^- , γ	Thyroid
^{198}Au	2.7 days	β^- , γ	Liver
^{201}Tl	3.0 days	EC , γ	Heart
^{111m}In	2.8 days	IT, γ	Blood
^{85}Sr	65 days	EC , γ	Bone

EC: Electron Capture. IT: Isomeric Transition

Most popular ^{99m}Tc

TRACERS

^{99m}Tc

(Technetium)

Half-life
~ 6 hours

ISOTOPIC DILUTION (Tracers)

DYE DILUTION

Suppose a 5 litre bucket of dye were thrown into a swimming pool. After complete mixing, 1litre of the water taken from the pool was found to have 1 ml of dye mixed in it.

What is the volume of the swimming pool?

A. 100 litres
B. 1,000 litres
C. 2,000 litres
D. 5,000 litres
E. 10,000 litres

ISOTOPIC DILUTION

100 µCi of tritium, ^{3}H, was given to a person in the form of tritiated water that was totally absorbed through the gut. After time for equilibriation, a blood sample was taken that showed an activity of 92 Bq per ml of fluid. Calculate the total volume of water in the body.

SINGLE PHOTON EMISSION COMPUTED TOMOGRAPHY (SPECT)

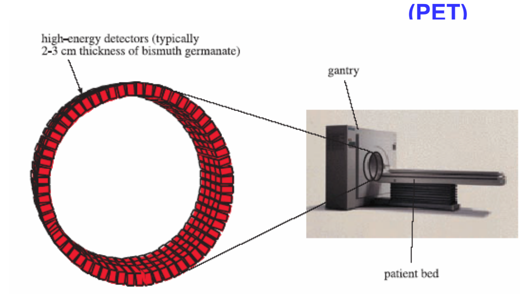
POSITRON EMISSION TOMOGRAPHY (PET)

POSITRON EMISSION TOMOGRAPHY(PET)

Radioisotope	Half-life (min)	Max. β+ Energy (MeV)
^{11}C	20	0.96
^{13}N	10	1.19
^{15}O	2	1.70
^{18}F	110	1.7
^{82}Rb	1	3.15

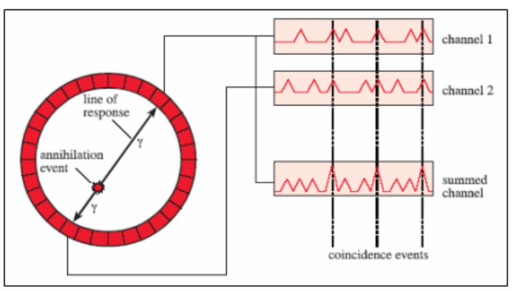
β^{+} emitters

POSITRON EMISSION TOMOGRAPHY (PET)



Positron Emission Tomography

$e^{+} + e^{-} \longrightarrow 2\gamma$



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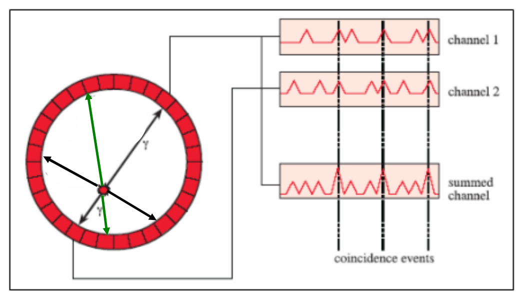
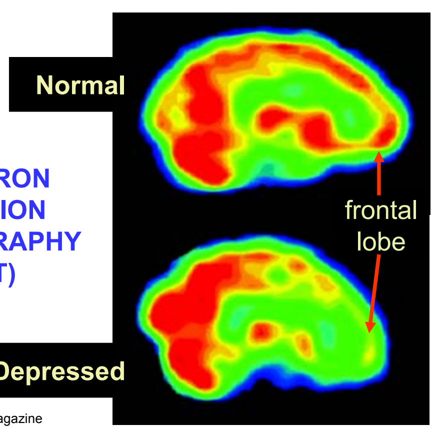


POSITRON EMISSION TOMOGRAPHY (PET)



Courtesy the Walrus magazine

COMMITTED DOSE

When a radioisotope is ingested or implanted in a patient, it is important to know the total dose given to the patient over the lifetime of the radioactivity in the patient's body

This quantity is called the Committed Dose

Consider first the case when the Radioisotope remains in the body or organ for ever, and that there is no Biological Excretion

Let R(0) be the initial activity ingested or implanted

Let e_n be the energy released in each decay

Let λ_n be the nuclear decay constant

Let m be the mass of the organ

Consider first the case when the Radioisotope remains in the body or organ for ever, and that there is no Biological Excretion

Initial Dose Rate = $\dot{D}_m(0) = (dD/dt)_{t=0} = e_n R(0)/m$

Committed Dose = $e_n R(0)/(m\lambda_n)$

$$D_m(0 \rightarrow \infty) = \dot{D}_m(0) / \lambda_n$$