



Biological Effects of Radiation

Aoife Gallagher

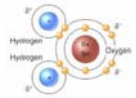
Department of Medical Physics & Bioengineering,
St. James's Hospital

Content

- **MECHANISMS:** How does radiation inflict biological damage?
- **DOSIMETRY:** How do we quantify a 'dose' of radiation?
- **EFFECTS:** What are the potential biological effects of radiation?
- **RISKS & LIMITS:** What level of risk is associated with working with diagnostic radiation?
What limits are considered acceptable?
Risk & "doses" in context.

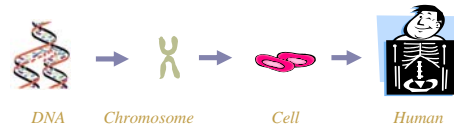
Interaction of Radiation & Matter

- The adult body is composed of 70% water.
- When ionising radiation interacts with the body, electrons are ripped from the water molecules.
- Ionising radiation has the ability to affect the chemical state of a material and so cause changes which are biologically important.



Radiobiology

Radiation biology is the branch of biology concerned with the effects of ionising radiation on living systems.



The biological effects of ionising radiation originate primarily from damage to the DNA of a cell or cells.

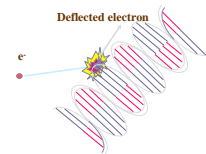
Interaction of Radiation with Matter

The action of radiation on the cell is classified as either :
Direct or Indirect.



Direct Attack

- Incident radiation directly attacks the DNA of the water molecule and ionises water molecules; electrons are released.



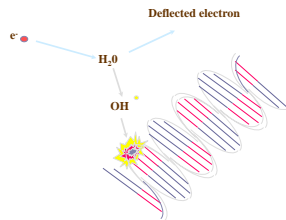
- The ionised water molecules can react further - forming highly reactive molecules such as hydrogen peroxide, or radicals such as hydroperoxyl.



- Biologic chain reaction occurring.

Indirect Attack

When free radicals produced by the interaction of radiation with water molecules act on a vital molecule such as DNA, the damaging action of the ionisation radiation is indirect.



Dosimetry



Absorbed dose (Measured in **grays; Gy**) :

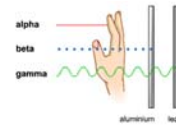
The 'gray' is a measure of the energy deposited in a material by incident ionising radiation.



(1 Gray = 1 Joule of energy deposited in 1kg of tissue).

Equivalent Dose (Sv)

- In order to get a measure of the biological damage to a human for a particular type of radiation, one must take into consideration the type of radiation involved.
- The biological effect of a given absorbed dose (Gy) depends on the type of radiation involved.



For example: 1cGy of alpha particles is approx. 20 times as harmful as 1cGy of diagnostic X-rays.

- Equivalent dose is a measure of dose which takes account of the type of radiation involved – measured in **sieverts (Sv)**.

Effective Dose



- The Effective Dose takes into account the fact that all organs are not equally sensitive to radiation (Measured in **sieverts; Sv**).
- Tissue weighting factors required - The more sensitive the tissue is to radiation, the higher the tissue weighting factor.

Tissue weighting factors	
Tissue	Tissue Weighting Factor, W_T
Gonads	0.20
Red bone marrow	0.12
Colon	0.12
Lung	0.12
Stomach	0.12
Bladder	0.05
Breast	0.05
Liver	0.05
Esophagus	0.05
Thyroid	0.05
Skin	0.01
Bone surfaces	0.01
Remainder	0.05

(ICRU 60, 1991; NCRP 116, 1993)

Effects of Radiation on DNA

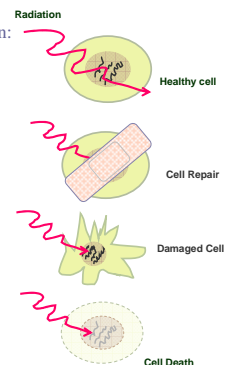
The type of effect the radiation can have on the DNA is determined by whether it is a

A **low dose** which mainly damages cells,
or
a **high dose** which mainly kills cells.

Effects of Ionising Radiation on DNA

Basically, there are four things that can happen:

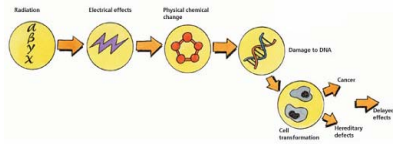
1. The radiation may pass through the cell without doing any damage.
2. The radiation may damage the cell, but cell repairs damage.
3. The radiation may damage the cell so that the cell not only fails to repair itself but reproduces itself in the damaged form – **Biological Response**.
4. The radiation may cause so much damage, cell dies.



Low-Dose Radiation

The low dose or “stochastic” effects (statistical), which could be seen are:

Carcinogenesis (i.e. induction of cancer)
and
Genetic effects (i.e. damage seen in offspring)



Stochastic Effects



- There is no threshold dose - There is no strict safe threshold level of dose - even a very tiny dose could cause these effects.

BUT

- As the dose goes down, it is much less likely that effects will be seen i.e. the probability of a biological effect increases with the dose.
- Doses experienced by patients during **most** diagnostic examinations and by staff involved in these procedures would be considered “Low Level”.

Deterministic Effects

In case of very high doses, the type of biological effects seen are called “Deterministic” Effects (Definite).

Effects include :

- Cataracts,
- Reddening of the skin,
- Burns,
- Hair loss,
- Blood changes,
- Temporary or permanent sterility,
- Nausea,
- CNS damage,
- Death.



Deterministic Effects

Result from high radiation doses.

- They are dose related
- The injury increases in severity as dose increases.
- They are generally not an issue in diagnostic imaging - the doses are too low.
- Have a threshold dose before any effect appears – limits
- They are predictable
- Mechanisms are relatively well understood e.g. in radiotherapy
- Repair and recovery can occur.

Deterministic Effects



(FDA Website)



Vano et al.



Vano et al.

Limits & Risk

Aim of limits:

- To prevent occurrence of deterministic effects
- To protect against unacceptable risk of stochastic effects.

ICRP (1990) Limits	Radiation Workers	Gen Public
EFFECTIVE DOSE	20mSv/yr	1mSv/yr
EQUIVALENT DOSE	Lens 150mSv/yr Skin 500mSv/yr Hands/feet 500mSv/y	Lens 15mSv/yr Skin 50mSv/yr
DOSE TO THE FOETUS (after declaration of pregnancy)	1mSv	1mSv

Limits & Risk in Context

When do Deterministic Effect become visible?

- **20 Sv:** Death within hours due to CNS failure.
- **5-10 Sv:** Death within days due to destruction of cells in gut lining.
- **2-5 Sv:** Death within weeks due to bone marrow failure.

BUT

Limit for occupational exposure is 20 mSv

Risk in Context

Occupational Limit: 20mSv/yr

- Intraoral : ~ 0.005 mSv *
- Chest X-ray (P/A) : ~ 0.02 mSv *
- CT Chest : ~ 8 mSv *
- PTCA : ~ 15.1 mSv *
- DEXA Scan : ~ 0.001- 0.01 mSv ⁺ (depending on make, model of equipment and scan mode)

Background (natural radiation): 3mSv/yr

Return Dublin to New York flight : 0.05 mSv.

*Radiation Exposure of the UK Population from Medical and Dental X-ray Examinations, NRPB-W4, March 2002.
+Radiation Dose, Radiation Protection and the ionising radiations regulations, NOS (CD Edition 2004 & 2006)

RPII Results 2001

TYPE	No. of workers (N) receiving annual dose/collective annual dose (in the range (mSv))										
	0-0.1	0.1-0.2	0.2-0.5	0.5-1.0	1.0-2.0	2.0-5.0	5-10	10-15	15-20	20-50	>50
Diagnostic	2546	101	46	14	2	2					
Radiotherapy	233	1				1					
Nuclear Medicine	132	6	4	2							
Dentistry	2125	10	6								
Veterinary	407	3							1		
Other Medical	297	5	6								

Summary



- Biological damage due to radiation stems mainly from damage to DNA.
- The 'Sievert' is the unit of dose of most interest in radiation protection.
- Damage may be deterministic or stochastic.
- In DEXA radiography, stochastic effects are the most relevant, and can result in carcinogenesis or genetic defects.