Biological Effects Of Ionising Radiation

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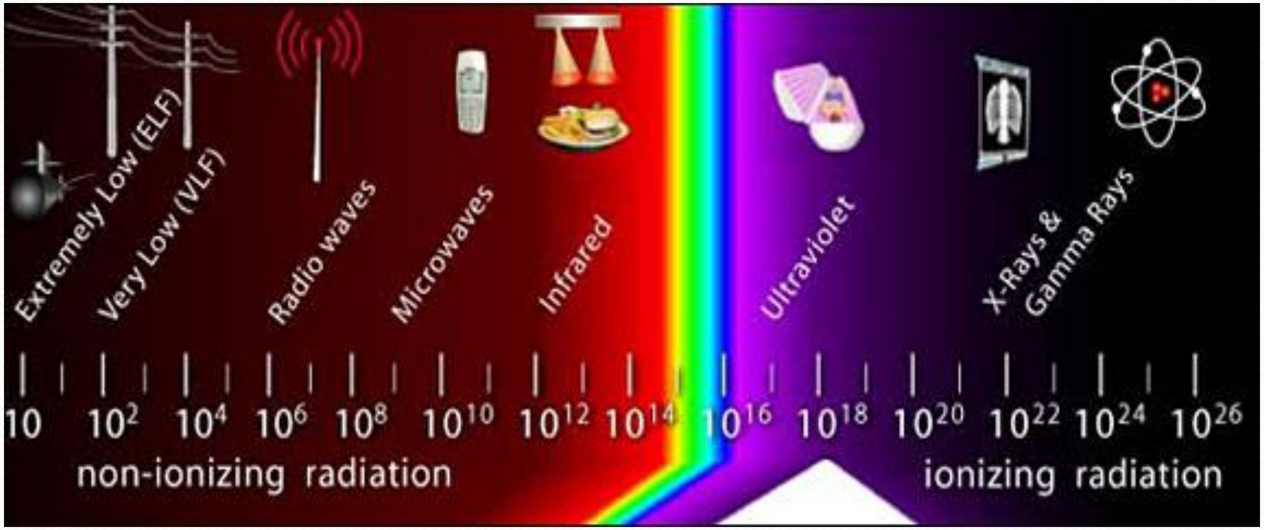
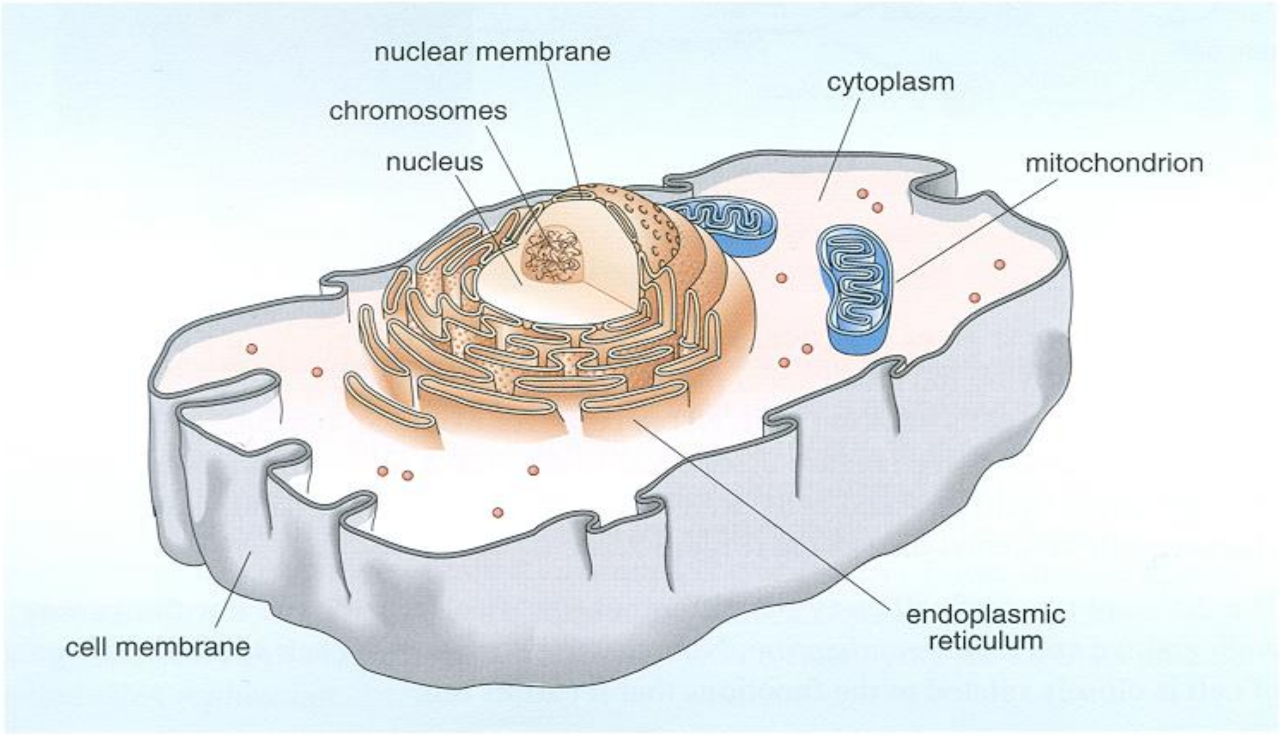
Two Types of Radiation
Electromagnetic Spectrum



Typical Representation of a Cell



Chemical Composition Of Typical Cell

Water	70%
Proteins	18%
Fatty Substances	5%
Carbohydrates, including sugars	2%
DNA and other nucleic acids	1%
Others	4%

Mechanisms of Radiation Damage

Radiation damage occurs via one of two ways –

Direct Damage occurs when radiation damages the DNA directly, causing ionization of the atoms in the DNA molecule. Ionisation of molecule invariably leads to its disruption.

Indirect Damage occurs when radiation interacts with non-critical target atoms or molecules, usually water. This results in the production of free radicals, which then attack other parts of the cell.

Direct Damage

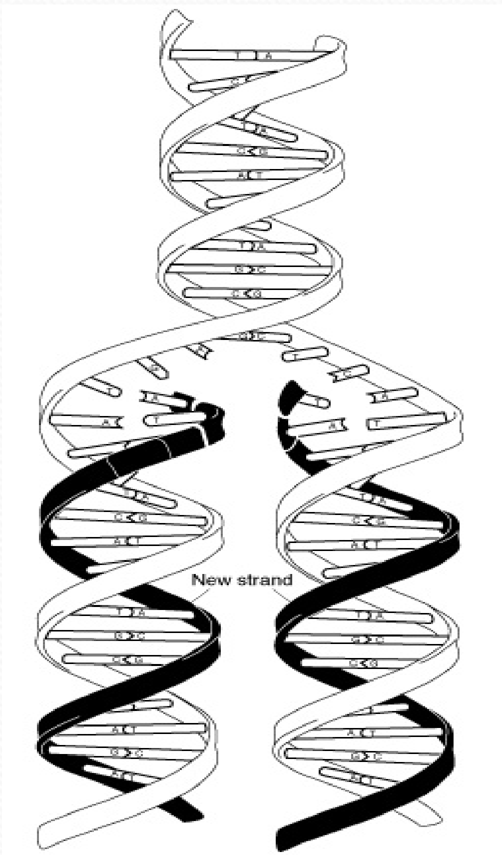
- Cell may be undamaged
- Cell may repair and work normally
- Cell repaired but abnormally
- Cell may die

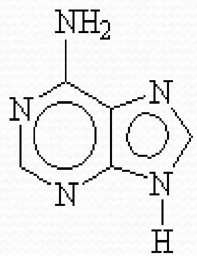
Indirect Damage

Indirect damage occurs when radiation interacts with non-critical target atoms or molecules, usually water.

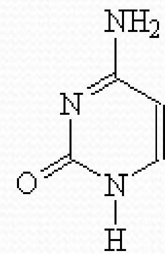
This results in the production of free radicals, which are atoms or molecules that have an unpaired electron and are highly reactive. These free radicals can then attack critical targets such as the DNA.

DNA (Deoxyribonucleic Acid)

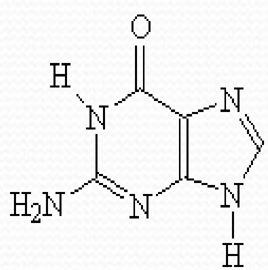




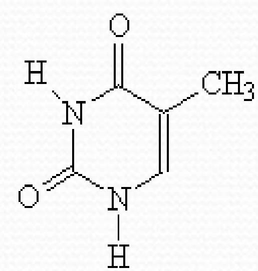
Adenine



Cytosine

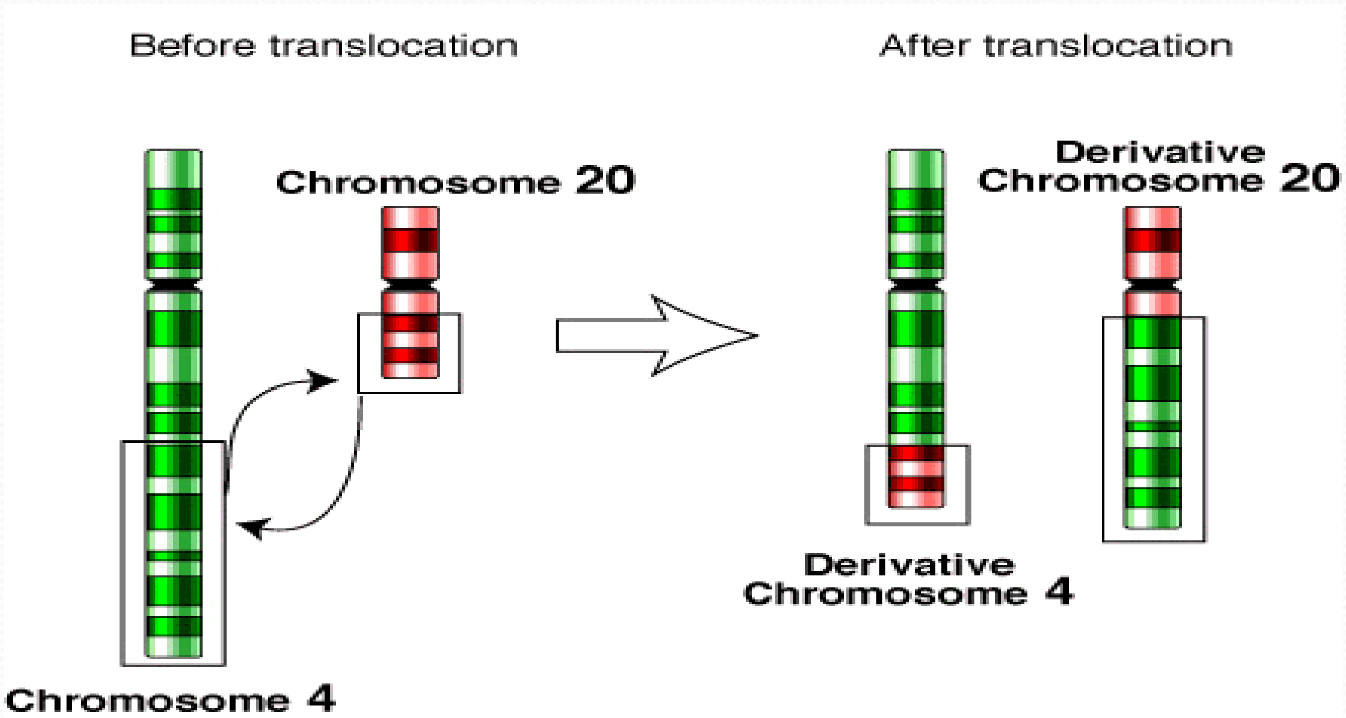


Guanine



Thymine

Potential Chromosome Damage



Quantifying Damage and Measuring the Dose
Two ways of expressing radiation dose

Equivalent Dose - is a measure of the biological damage. The unit of Equivalent Dose (HT) is Sievert

Equivalent dose = Radiation weighting factor x Absorbed dose

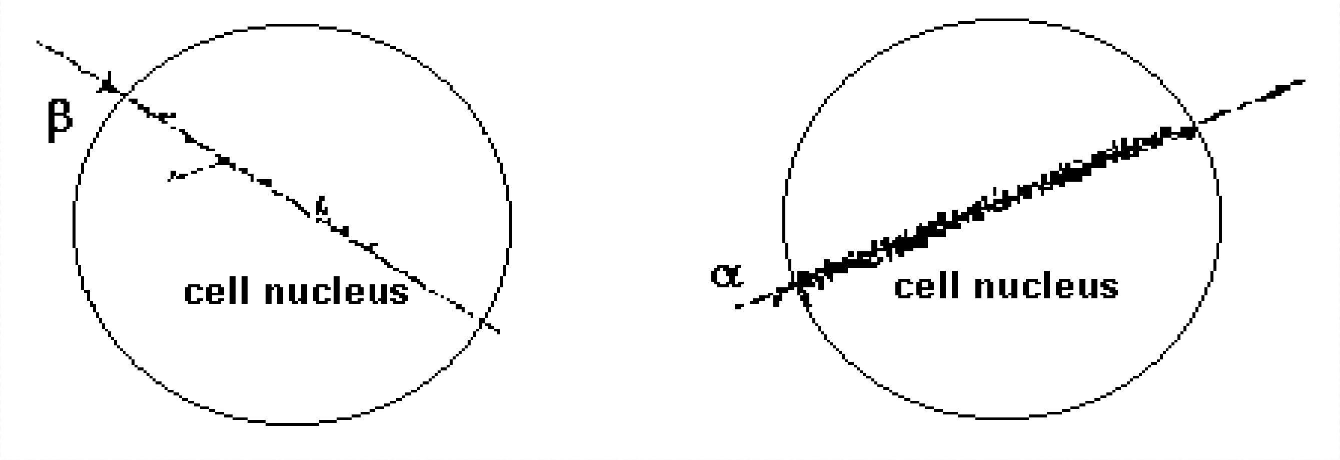
$$H_T = W_R D_T$$

Absorbed dose - total amount of ionizing radiation energy absorbed by an object. The unit of Absorbed Dose (DT) is Gray.

‘Radiation Weighting Factor’ (WR)

Alpha Particles	20
Beta Particles	1
Photons	1
Neutrons	5 - 20

Equivalent Dose (H_T) and Radiation Weighting Factor (W_R)



β-particle | **α-particle**

50 ionisations/nucleus | **12,500 ionisations/nucleus**

Effective Dose and Tissue Weighting Factor

$E = W_T H_T$

E - Effective Dose

WT - Tissue Weighting Factor

HT - Equivalent dose

If more than one organ is involved -

$$E = \sum_T W_T H_T$$

We use 'effective dose' when there is a non-uniform irradiation of the body

Tissue or Organ	W_T
Gonads	0.20
Bone Marrow	0.12
Colon	0.12
Lung	0.12
Stomach	0.12
Bladder	0.05
Breast	0.05
Liver	0.05
Oesophagus	0.05
Thyroid	0.05
Skin	0.01
Bone surface	0.01
Remainder	0.05

The harmful effects of ionizing radiation has on human tissue can be divided into two types: **Deterministic and Stochastic**.

Deterministic Effects

Deterministic effects only occur once a threshold of exposure has been exceeded. The severity of deterministic effects increases as the dose of exposure increases. Radiation doses involved here are usually substantial and delivered over a short space of time and there is a threshold dose below which no clinical effect is observed.

DOSE (Sv)	CLINICAL EFFECT
0.0 -> 0.25	No obvious injury
0.25 -> 0.50	Possible blood changes, no immediate clinical effect
0.50 -> 1.00	Blood cell changes, some injury, no disability
1.00 -> 2.00	Injury, possible disability, nausea/vomiting in 24 hr
2.00 -> 4.00	Injury and disability certain, death possible
4.00	50% probability of death

<u>Stochastic Effects</u>

There is only a probability of effect occurring, chance process. This means that although there is no threshold level for these effects, the risk of an effect occurring increases linearly as the dose increases. Since the probability for cancer at high doses increases with increasing dose, this relationship is assumed to hold true with low doses.

<u>Stochastic Effects</u> - No lower dose limit

Probability of effect

Biological Risks

Two prediction models used for working out biological risks -

Additive Model

A given dose produces a risk that is constant with time.

Multiplicative Model

A given dose produces a risk which is a constant multiple of the pre-existing spontaneous risk of cancer.

Important Radiation Effects

- **Molecular** Damage to enzymes, DNA etc. and interference to biological pathways
- **Subcellular** Damage to cell membranes, nucleus, chromosome
- **Cellular** Inhibition of cell division, cell death, cell transformation to a malignant state
- **Tissue, Organ** Disruption to central nervous system, bone marrow, intestinal tract. Induction of cancer
- **Whole Animal** Death; life shortening due to radiation exposure
- **Population** Changes in the genetic characteristics of individual members

Acute (short-term)
vs
Chronic (long-term) Effects

Summary :

Deterministic Effects The risk is more or less certain.

Stochastic Effects The risk is not certain, a ‘probability’ exists.

Additive model The risk is constant in time.

Multiplicative model The risk is a constant multiple of the spontaneous risk.

The model introduced in 1990 is the Multiplicative model.

Measuring Effects of Radiation

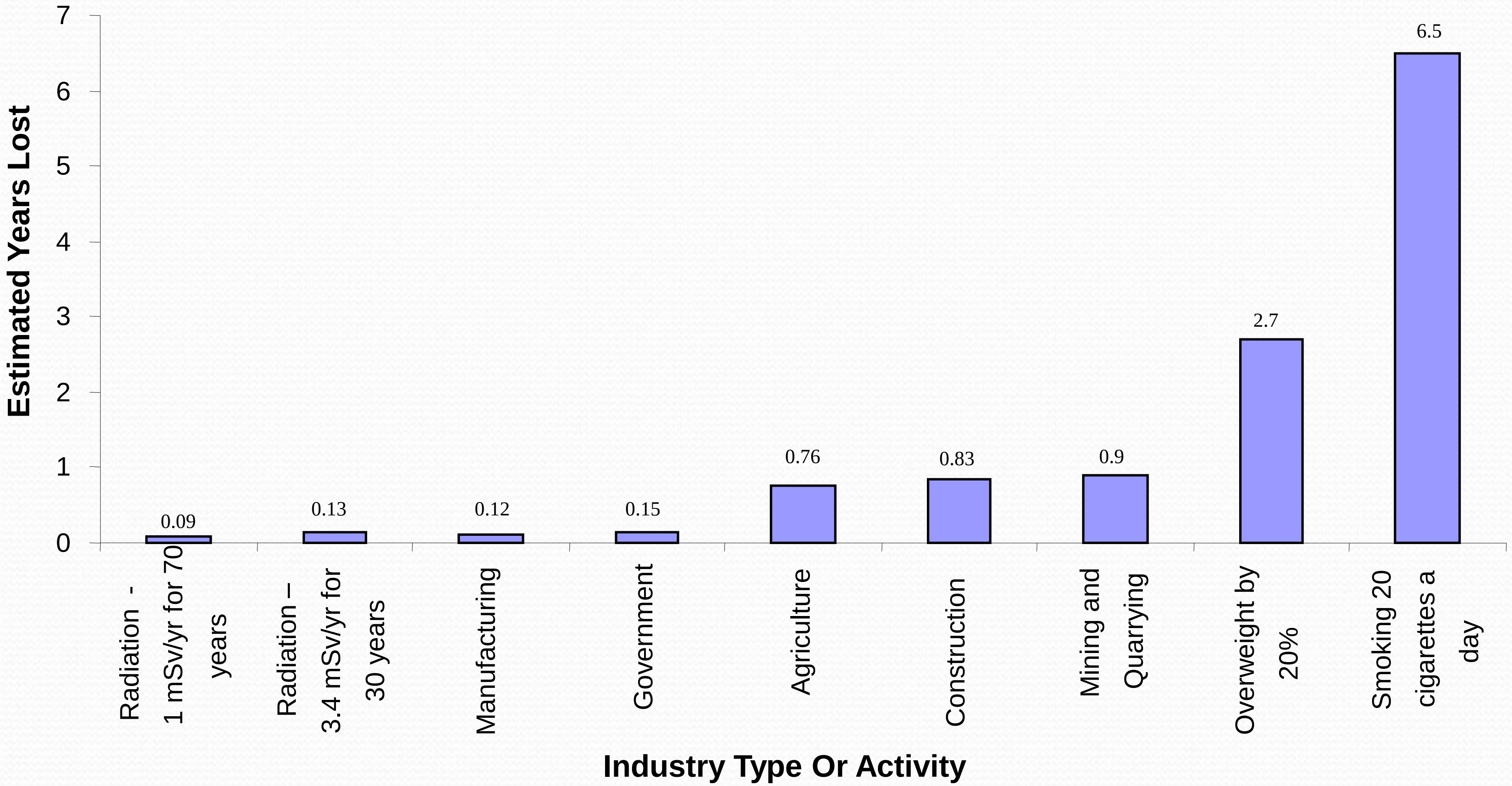
There are at least three ways to measure the effect of radiation :

- **Becquerels (Bq)** measure of activity as no. of disintegrations / second
- **Grays (Gy)** measure of the energy of radiation absorbed by the target material
- **Sieverts (Sv)** Measure of dose equivalents

Dose and Dose Rate Effectiveness Factor ICRP 1990

- Fatal cancers - 4%/Sv - β, X or γ only
- Non-fatal cancer - 1.2%/Sv
- Genetic factors - 0.6%/Sv
- Overall - 5.8%/Sv

Estimated Years of Life Expectancy Lost



Scenarios with one in million chance of death

5 hour flight by jet aircraft	Cancer (Cosmic Rays)
Living for 2 weeks in a granite building	Cancer (radioactivity)
Travelling 100 km by car	Road Accident
Travelling 1,000 km by air	Accident
Smoking 1 - 3 cigarettes	Cancer & Lung Disease
Drinking a half bottle of wine	Liver & Other Disease
Working as a Radiographer for 1 month	Cancer (X-Rays)
Working as a Radiologist for 2 weeks	Cancer (X-Rays)

Conclusions

Assume any exposure carries some risk

Risks are comparable

ALARP – As Low As Reasonably Practicable

Minimize Dose

Treatment

Whole Body v Partial Body Exposure

Exposure Levels and Symptoms

0.05 - 0.2Sv	No symptoms
0.2 - 0.5Sv	No noticeable symptoms
0.5 - 1Sv	Mild radiation Sickness
1 - 2Sv	Light radiation poisoning, 10% Fatality after 30 days
2 - 3Sv	Moderate radiation poisoning, 35% fatality after 30 days

Exposure Levels and Symptoms

3 - 4Sv Severe radiation poisoning, 50% Fatality after 30 days

4 - 6Sv Acute Radiation Poisoning, 60% Fatality after 30 days

6 - 10Sv Acute radiation poisoning, Near 100% Fatality after 14 days

10 - 50Sv Acute radiation poisoning, 100% Fatality after 7 days

In the UK the annual limit for a classified radiation worker is 20 mSv.

The mouth of a man who has suffered a 10 to 20 Gy dose 21 days after the exposure, note the damage to normal skin, the lips and the tongue.

Summary:

Ionising radiation causes damage at the cellular level

Absorbed dose gives a measure of the damage

Unit is the Gray 1 Gy = 1 J/Kg

Equivalent dose accounts for different types of radiation

Equivalent dose = Absorbed Dose x Radiation Weighting Factor

Unit is the Sievert e.g. for beta 1 Sv = 1 Gy

Summary Continued:

Effective dose is used for single organ doses

Effective dose = Equivalent dose x Tissue Weighting Factor

Unit is the Sievert (Sv)

Deterministic effects are known effects above a certain dose

Stochastic effects have a probability of occurrence