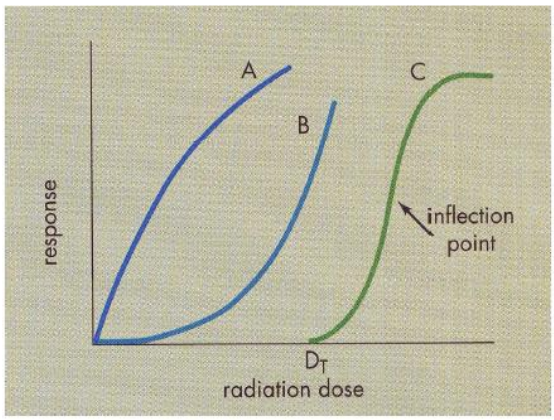
Dose Response and Dose Quantities – PHYS1250

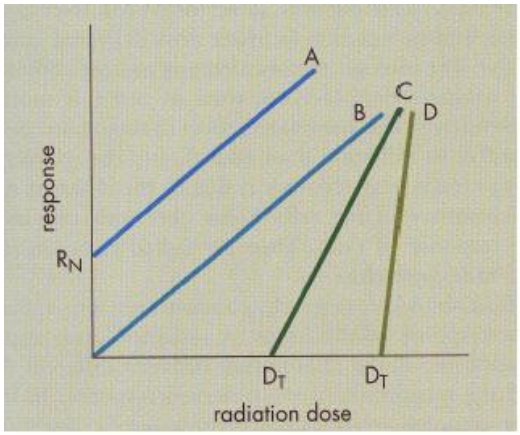
Dose Response Relationships

- Used to determine the cancer risk for a population for a given dose
- These relationships are used for setting acceptable limits to occupational exposure
- They are also used in radiation therapy to determine the amount of radiation that is needed to kill tumour cells and to limit dosage to healthy tissue
- The LNT – linear non-threshold model is used to determine radiation risk

Non-linear dose response relationships show a series of curved lines on a graph of response vs radiation dose.



The linear model shows straight lines instead of curves



Threshold Vs Non-Threshold

- Threshold is defined as the point at which a reaction will start to occur with increase stimulation
- No biological effects are observed below the threshold dose
- A non-threshold relationship assumes that there is no level at which there is a zero chance a having a biological effect

It has been suggested that radiation exposure up to a certain point can be healthy. This is called radiation hormesis, and it occurs at levels below a threshold point in non-linear relationships

Why the LNT model is used

- The model is simple to apply as you can simply add all the effective doses together to determine the risk without any consideration of the energy, type of radiation or the dose rate
- United Nations Scientific Committee on the Effects of Atomic Radiation states that an increase in radiation dose is proportional to the risk of tumour induction, however a linear dose response should not be expected in all cases

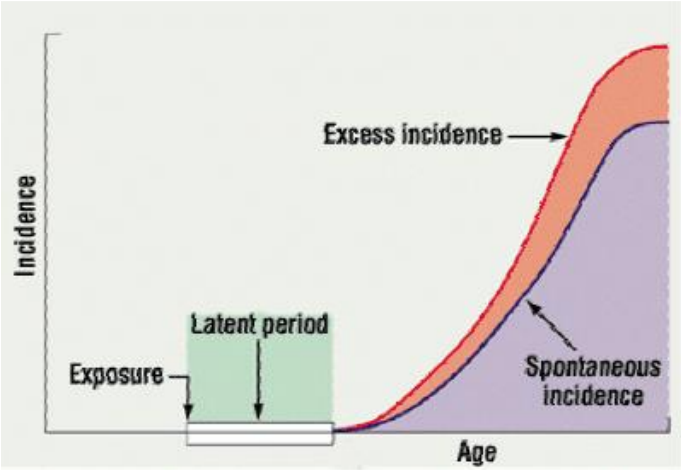
Estimating Radiation Risk

- There are 2 models used to estimate risk: relative risk model and absolute risk model
- There are 3 primary means to assess risk: excess risk, relative risk and absolute risk

Data from human populations that have been exposed to high doses of radiation are used to assess risk. These include: atomic bomb survivors, early pioneers working with radiation and patients irradiated during medical treatment

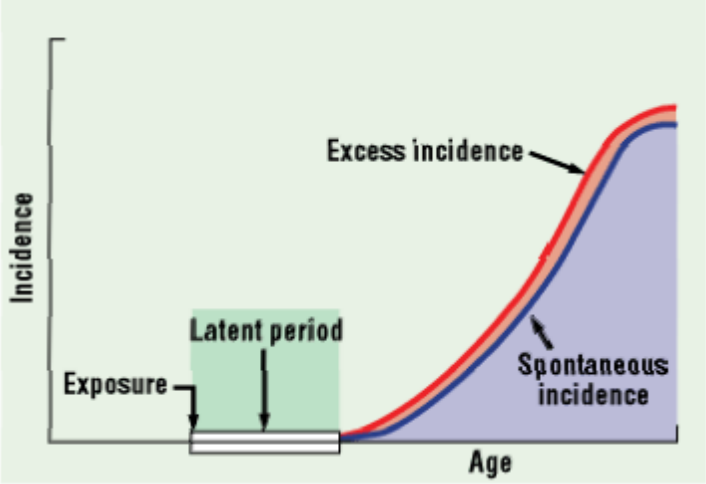
Relative Risk Model

- The relative risk model is thought to be the most accurate reflection of cancer risk
- This model states that excess risk is proportional to the spontaneous incidence of cancer, which increases with age
- In other words the excess incidence will increase at a greater rate than spontaneous incidence will after a latent period
- It follows that radiation induced cancers will increase with age



Absolute Risk Model

- This model depicts that excess risk is constant and does not increase with age
- This model uses a LNT relationship



Excess risk is the concept that if a population is irradiated then the additional cancers that would have formed in a similar population that wasn't irradiated is due to the radiation that was received

Excess risk = observed cases – expected cases

Relative Risk 2

- Relative risk is used when the doses that the population were exposed to are unknown
- Relative risk = observed effect / expect effect
- Relative risk model gives a percentage increase rather than a specific number. A relative risk of 1.5 indicates that there is a 50% increase in the exposed population

Absolute Risk 2

- Expressed as a percentage per Sievert

ALARA has now been replaced with ALARP – As Low As Reasonably Practicable

Exposure can be minimised by decreasing exposure time, increase radiation source and lead shielding of the body.

Some evidence suggests that the LNT model overestimates risk at low doses. However there is not much evidence for radiation hormesis and hence it is preferred. The contradictory evidence

against LNT is for the population in Ramsar, Iran which has background radiation 55-200 times greater than normal and yet there is no increase in cancer incidence. The radioactivity of Ramsar is due to the decay of radium 226 that is brought to the surface by hot springs. Over 2000 people are exposed to doses up to 260mSv a year. The LNT method predicts far more cases of cancer both in Chernobyl and in the rest of the world.

Background Radiation Levels

- Vary from place to place
- May vary up to a factor of 10 in a single country
- Cancer incidence is low in areas where background radiation is high and hence it is not considered a major factor in the induction of cancer

Protective Genes

Some evidence of animals and human observations suggest that high levels of background radiation have led to the activation of protective genes against cancer. It is unknown whether this gene is only expressed in people living in high background radiation areas or whether the gene would switch off if the radioactive area was left. It is also unknown how long someone would have to stay in an area of high BR for the gene to be activated

Dosimetric Quantities

- Dosimetric quantities include: exposure, absorbed dose, equivalent dose, effective dose, committed equivalent dose and committed effective dose.
- There are 2 main categories of radiation: non-ionising and ionising (directly ionising (charged particles) – electrons, protons, alpha particles; and indirectly ionising – photons and neutrons (neutral particles)

KERMA

- Kinetic Energy Release per unit Mass
- The average amount of energy transferred in a small volume from indirectly ionising radiation to directly ionising radiation – the energy transferred from a photon to an electron
- Once the energy is transferred from the photon to the electron, it is then lost by photoelectric and scatter events
- $K = dE_{tr} / dm$
- Unit of kerma is joules per kilogram
- The unit name is the gray, where 1 Gy = 1 J/Kg

CEMA

- Converted Energy Unit per Mass
- Measures the energy that is converted from directly ionising radiation, such as an electron, in a collision interactions with atomic electrons
- Also measure in grays

KERMA is the energy that is involved in indirect ionising radiation giving to direct ionising radiation. (energy given to electron by photon)

CEMA is the energy that is lost by electric collisions by incoming particles by directly ionising radiation (energy lost by electron through collisions)

Exposure

- Exposure = dQ / dm
- dQ is the total charge produces in air of mass dm
- measured in coulombs per kilogram (C/Kg)
- used to be measured in Roentgens, where 1 Roentgen = 2.58×10^{-4} C/kg

Absorbed Dose

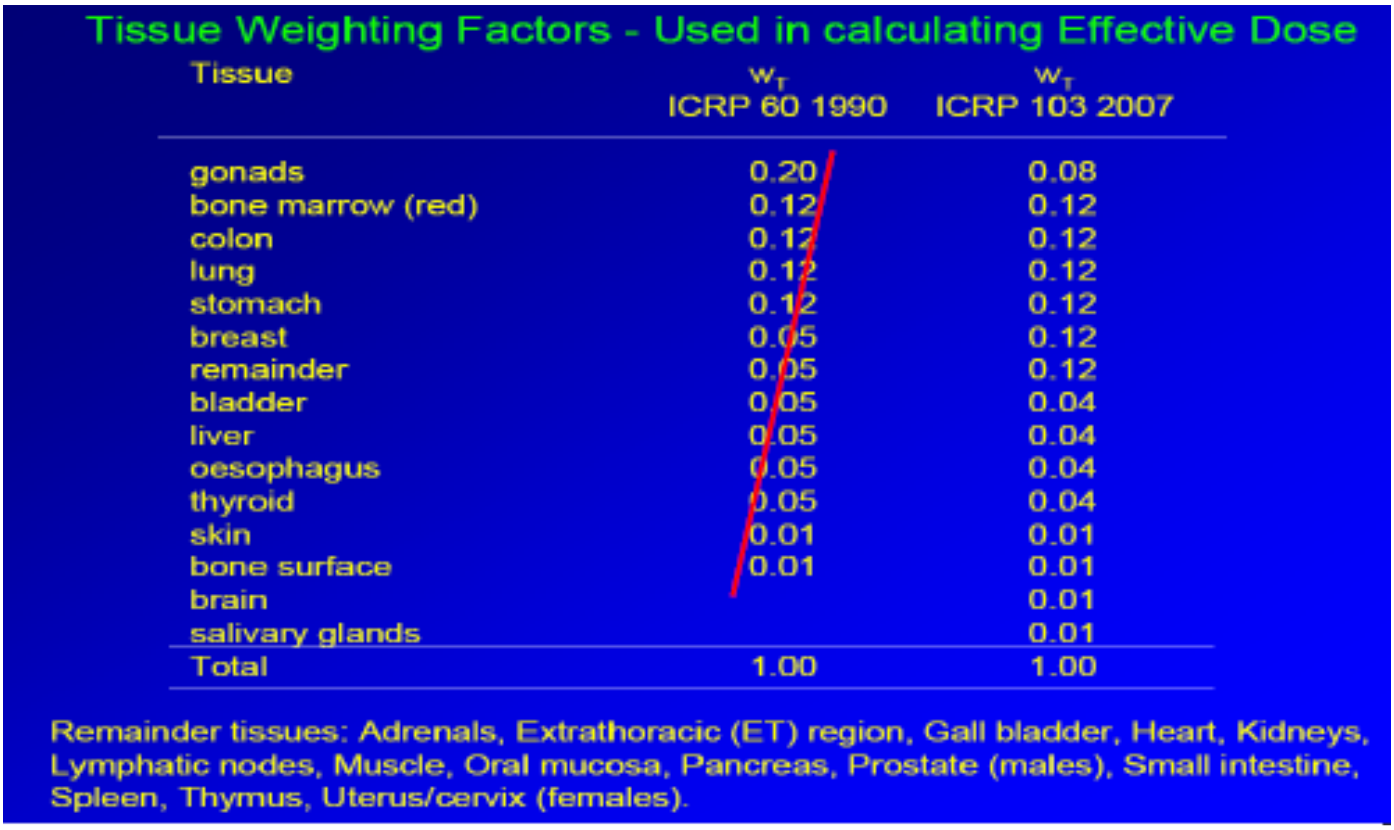
- The energy absorbed per unit mass of material
- D = de/dm
- Measured in Grays
- Skin/ entrance surface dose (ESD) is measured in mGy
- The patient risk is determined by organ doses which are different from ESD
- Calculating the ESD allows for estimation of organ doses
- Effected by both indirect and direct ionising radiation
- Ionising radiation transfers kinetic energy to secondary charged particles which then transfer their kinetic energy to the medium
- Directly ionising radiation deposits its K.E directly onto the medium

Equivalent Dose

- Equivalent dose ($H_T = \sum W_r \times D_{TR}$
- W_r is the radiation weighting factor which reflects the relative biological effectiveness of the radiation
- D_{TR} is the dosage averaged over the organ of interest, T, due to radiation R
- This is measured in Sieverts, which is also joules per kg

Effective Dose

- Takes into account the radio-sensitivity of the tissue being exposed
- Effective Dose (E) = $\sum W_T \times H_T$
- Measured is Sieverts



Committed Equivalent Dose is dose which will be delivered over a specified time, usually 50 years. To a given tissue or organ. Used when measuring radioactivity from radionuclides used in nuclear medicine. The effective committed equivalent dose can be determined by multiplying the tissue weighting factor of the organ being imaged.

Dose Limits

- ICRP recommends annual dose limits which should not be exceeded. There are no limits for medical exposures and the annual limit does not include background radiation
- Dose limits are put in place to reduce the risk of stochastic effects and to exclude deterministic effects
- Deterministic = shows pathology after a specific point (there is a threshold dose)
- Stochastic = risk of pathology increases with amount of radiation exposure
- Dose limits are set for whole body structures, or in some cases for specific organs
- A fetus has the same dose limit as a human – 1mSv over 9 months
- Occupational workers have a 20mSv per year averaged over defined periods of 5 years limit
- Occupational workers have a 150mSv limit on the lens of the eye, a 500 mSv limit to the skin, hands and feet. Members of the public have a dose limit 10 times lower at 15mSv and 50mSv respectively
- DR followed by RT then NM has the lowest annual exposure at 0.5mSv in 1990-1994

- Airline crews have a dose of 4, nuclear power operators have a dose of 6 and uranium miners have a dose of 12

ENTRANCE SURFACE DOSES (MGY)

		National Radiological Protection Board (Rounded Third Quartile Values)		
Examination	**Projection**	**Mid 1980's Survey**	**1995 Review**	**2000 Review**
Chest	PA	0.3	0.2	0.2
	LAT	1.5	0.7	1
Abdomen	AP	10	7	6
Lumbar Spine	AP	10	7	6
	LAT	30	20	14
	LAT L5/S1	40	35	26
Pelvis	AP	10	5	4

EFFECTIVE DOSES FOR EXAMS

Diagnostic Procedure	Typical Effective Dose (mSv)
Chest x ray (PA film)	0.02
Skull x ray	0.07
Lumbar spine	1.3
I.V. urogram	2.5
Upper G.I. exam	3.0
Barium enema	7.0
CT head	2.0
CT abdomen	10.0

Diagnostic Reference Levels

- Based on the fact that dose can vary significantly from hospital to hospital or even room to room
- The concept of diagnostic reference levels for each exam have been introduced to ensure that patient doses are not unduly high
- For DR the diagnostic reference levels are in entrance skin dose or dose-area product
- For NM it is the administered activity
- Diagnostic radiography DRLs are usually defined for a person of average size and are based on the 75th percentile of the distribution of means measured at number of sites
- The logic follows that if 75% of hospitals can reduce their mean dose below a certain value then the other 25% can do the same
- Hospitals in the UK are required to review their practice if the dosages exceed their DRLs
- Dose will usually have to be decreased unless the increased dosage can be justified

The ICRP states that:

- The fatal cancer radiation risk for whole body exposure of the general population remains unchanged at approximately 5% per Sievert
- The corresponding figure for a working population is approximately 4% per Sievert

RISKS FROM DR EXAMS

Examination	Projection	Typical Effective dose *(mSv)*	Estimated risk of fatal cancer
Skull	AP or PA	0.03	1 in 670,000
	LAT	0.01	1 in 2,000,000
Chest	PA	0.02	1 in 1,000,000
	LAT	0.04	1 in 500,000
Thoracic Spine	AP	0.4	1 in 50,000
	LAT	0.3	1 in 67,000
Abdomen	AP	0.7	1 in 29,000
Pelvis	AP	0.7	1 in 29,000

RISKS OF SPONTANEOUS CANCER

Natural Lifetime Risk of Fatal Cancer	
Lung Cancer	**1 in 16**
Colon Cancer	**1 in 44**
Breast Cancer	**1 in 21**

RISKS IN PERSPECTIVE

Activity	Probability of dying	Odds against
Mountaineering in the Himalayas	0.02 per expedition	50 to 1
Motorcycling	0.02 per year	50 to 1
Cigarette smoking (20 per day)	0.005 per year	200 to 1
Travel by air	0.003 per 100 hours	330 to 1
Housekeeping	0.0002 per year	5000 to 1
Road traffic accident - as a car driver	0.00017 per year	5900 to 1
Jogging	0.00015 per year	6670 to 1
Rock climbing	0.00014 per year	7150 to 1
Exposure to ionising radiation		
- at 0.2 mSv per year	0.00001 per year	100 000 to 1
- at 20 mSv per year	0.001 per year	1000 to 1

RISKS FROM CT

Examination	Estimated Risk of fatal cancer
Computed Tomography	
Chest	**1 in 2,500**
Pelvis	**1 in 2,000**

RISKS FROM NM EXAMS

Examination	Estimated Risk of fatal cancer
Nuclear Medicine	
Bone Scan	1 in 5,000
Lung Perfusion	1 in 20,000
Dynamic Cardiac	1 in 3,000