Radiation Safety Training Module: Diagnostic Radiology
Biological Effects of Radiation

Radiological Safety Division
Atomic Energy Regulatory Board

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- Radiation quantities and units
- Structure of Cell
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- Biological effects of radiation
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Introduction

- Radiation interacts with cell (basic unit of life) and produces various biological effects.
- In this presentation, we address the mechanism of radiation interaction and its results
- The knowledge about biological effects, will help us to minimize the exposure and its effects while working in the field of radiation.
- In the field of Diagnostic Radiology, order of radiation doses dealt with are very low.
- In most of the imaging techniques these effects are not normally observed, however some radiological procedures involving Interventional Radiology, C-Arm may induce biological effects in patients as well as operator.

Radiation Quantities and Units

- Before knowing about the biological effects, it is necessary to know the quantification of radiation and its various units.
- The biological effects of radiation are dependent on many parameters such as Type of Radiation, Type of Tissue, Acute or Chronic exposure, hence the effect is also measured in different quantities with weighting factors.

Radiation Quantities and Units

(International Commission on Radiation Units & Measurements-ICRU)

Types of Ionizing Radiation:

INDIRECTLY IONIZING RADIATIONS

- X- and Gamma rays –electromagnetic radiations
- Neutrons - uncharged particles

DIRECTLY IONIZING RADIATIONS

- Electrons, protons – charged particles
- Both types of radiation transfer part or all of their energy when they interact with matter.

KERMA K

(**K**inetic **E**nergy **R**eleased per unit **Ma**ss)

- It is defined as the sum of the initial kinetic energies of all the charged particles (in joules) released by radiation in a material of mass 1Kg.
- SI unit of Kerma is Gray
- 1 Gy = 1 J/Kg
- When reference material is air, it is called Air Kerma
- Relevant for X-rays, gamma rays and neutrons

Exposure, X

- Defined as the absolute value of the total charge of ions of either sign produced in the air by photons when all the secondary electrons (positrons & electrons) liberated by photons in air of mass Δm are completely stopped in air.
- Unit of Exposure is Coulomb/Kg
- The unit of Exposure in use is Roentgen, R.
- Roentgen is defined as the amount of X or Gamma radiation which would liberate 1 electrostatic unit of charge of either sign in 1 c.c. of air at STP
- 1R = 1esu of charge liberated per cc of air at STP

  $= 2.58 \times 10^{-4}$ C/Kg (air)

Absorbed **Dose, D**

- **The effects of radiation depend not only on the energy transferred to the medium, but also on the energy absorbed by it**
- **Absorbed dose is defined as the amount of energy absorbed per unit mass of the medium at the point of interest.**
- **SI unit of dose is gray (Gy)**
- **1 Gy = 1 J/Kg**
- **Old unit = rad**
- **1 Gy = 100 rad**

Equivalent Dose, H_T

- Effects of radiation depend not only on the absorbed dose, but also on the type of radiation
- Biological effects caused by the same dose of different type of radiation may be different if they have different rates of energy loss per unit path length.
- Hence, absorbed dose is multiplied by Radiation Weighting Factor for each type of radiation.

Equivalent Dose, H_T (continued)

Recommended radiation weighting factors

Radiation type	Radiation weighting factor, W_R
Photons	1
Electrons and muons	1
Protons and charged pions	2
Alpha particles, fission fragments, heavy ions	20
Neutrons	A continuous function of neutron energy

Equivalent dose $H_T = \sum_R W_R D_{T,R}$

Special name for the equivalent dose is sievert (Sv) | 1 Sv = 1 J/Kg.

Effective dose, E

- Exposure to radiation may occur to whole body (uniform exposure) or to individual organs (non-uniform exposure)
- Non-uniform exposure will have to be restricted in order to avoid deterministic as well as stochastic effects (explained in further slides) as per the dose limits prescribed by International Commission of Radiation Protection.
- Different organs have different susceptibility for the induction of stochastic effects, viz., cancer & hereditary effects. Hence, different Tissue Weighting Factors are assigned to each tissue/organ

Effective dose, E (continued)

Recommended Tissue Weighting Factors, W_T

TISSUE	W_T	$\sum W_T$
• Bone-marrow (red), colon, lung, stomach Breast, remainder tissues*	0.12	0.72
• Gonads	0.08	0.08
• Bladder, Oesophagus, Liver, Thyroid	0.04	0.16
• Bone surface, brain, salivary glands, skin	0.01	0.04
	Total	1.00

*Remainder tissues: Adrenals, Extrathoracic(ET) region, Gall bladder, Heart, Kidneys, Lymphatic nodes, Muscle, Oral mucosa, Pancreas, Prostate, Small intestine, Spleen, Thymus, Uterus/cervix

$E = \sum_T W_T H_{T,}$ (W_T represents the contribution of Tissue T to the total risk due to stochastic effects resulting from uniform exposure of whole body)

- Special name for Effective dose is sievert (Sv), 1 Sv = 1 J/Kg

BIOLOGICAL EFFECTS OF RADIATION

SOURCES OF INFORMATION FOR HUMAN DATA

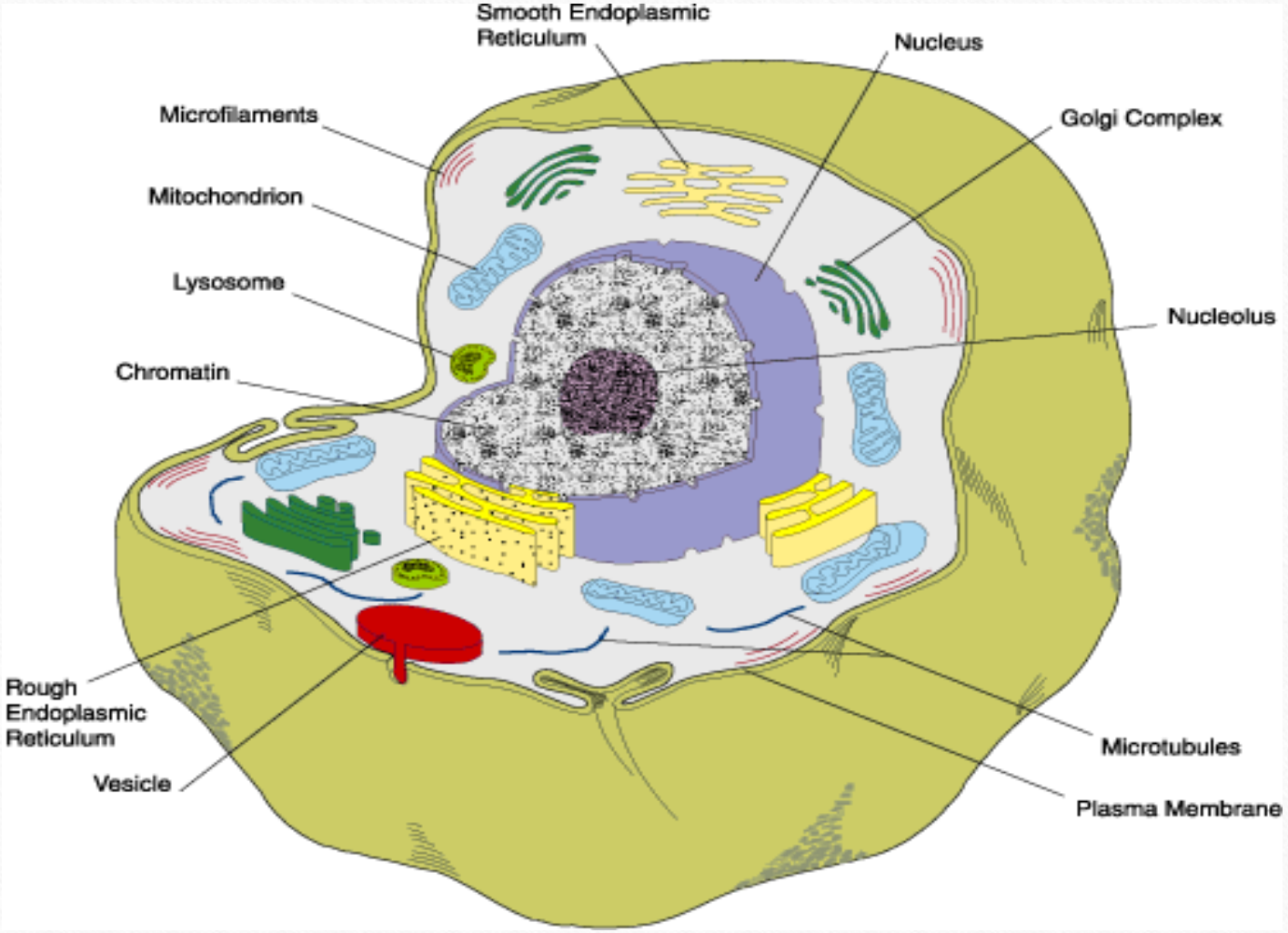
Studies on Biological Effects of Radiation have included population from the following categories

- Pioneer X-ray technicians & Radiologists
- Radium dial painters
- Uranium miners
- Radiation accident victims
- Diagnostic/Therapeutic applications
- Survivors of Atomic Bomb explosions in Hiroshima & Nagasaki

Human Body

- The smallest unit of body is called a cell.
- An adult person's body has about 10^{14} cells.
- Cells of different organs have different shapes & sizes.

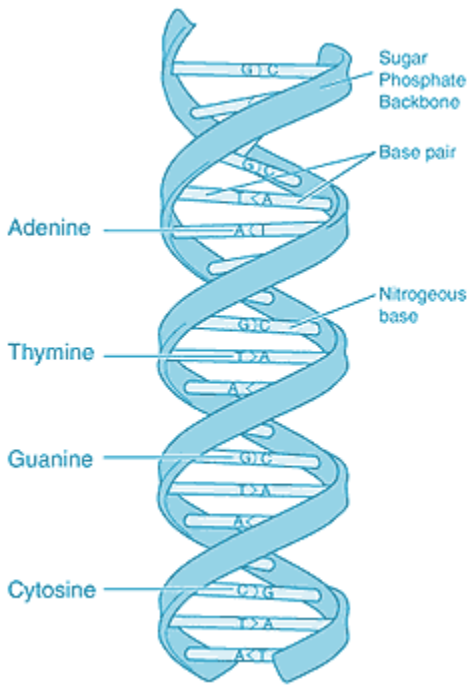
Structure of Cell



Cell

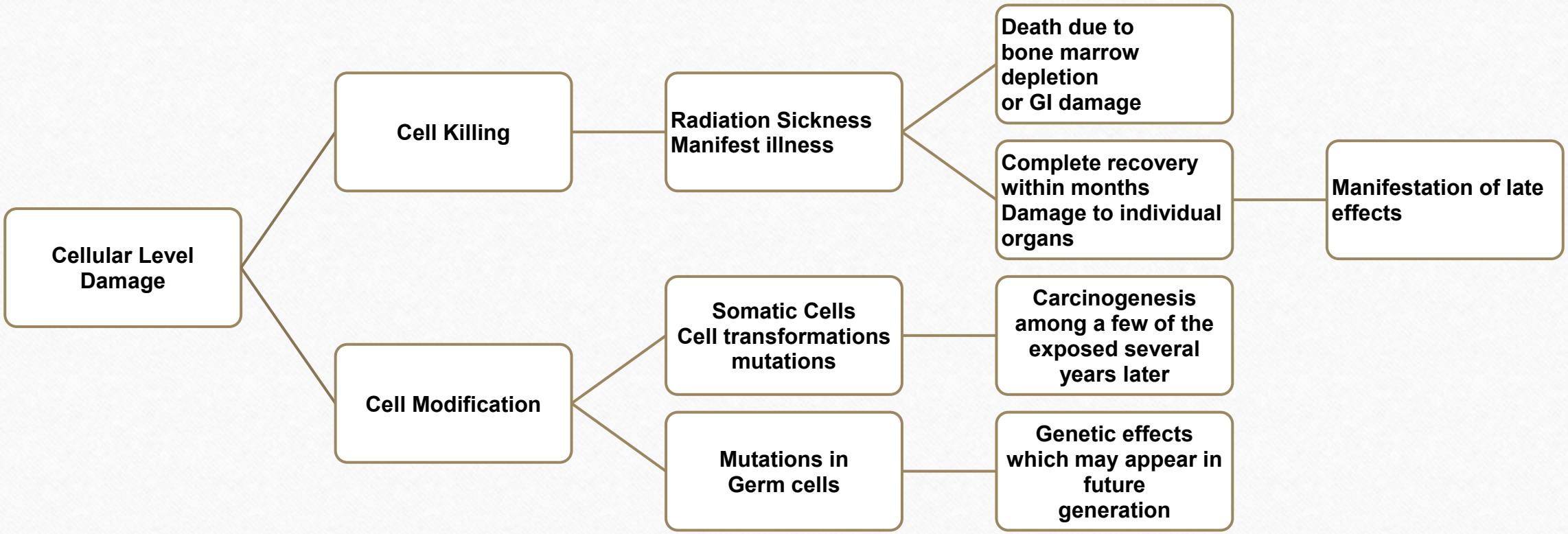
- The most sensitive organelle of the cell is the NUCLEUS.
- Nucleus contains 46 thread like structures which are called CHROMOSOMES
- Each chromosome contains one very complex sensitive molecule called DEOXYRIBONUCLEIC ACID (DNA)
- DNA contains very specialised coded language made up of 4 molecules, A,T, G & C which are arranged in very specific order.

The target in the cell: DNADeoxyribonucleic Acid (DNA)



- DNA is the **ultimate sensitive target molecule**
- When DNA is damaged by radiation, its coded language is also damaged resulting in death of cell or abnormal modification of cell.

Relationship between cellular level damage and biological effects



Cells

The cells can be classified into two types:

1. Somatic cells – all cells of body
2. Germ cells- Sperms in Males & Eggs /Ova in Females

Somatic Cells & Germ Cells

- A somatic cell is any cell forming the body of animal/human being,
- eg., skin cell, lung cell, nerve cell, muscle cell
- Somatic cells have 23 pairs of chromosomes (=46)

- Germ cells are the cells involved in the formation of a baby
- Only two types.

  (1)Sperms (present in males) &

  (2)eggs (ova)present in females)
- Germ cells have only 23 chromosomes

Mechananisms of induction of radiation damage

MECHANISM OF INDUCTION OF DAMAGE

DIRECT EFFECT- Due to direct deposition of energy in THE TARGET MOLECULE (Deoxyribonucleic Acid-DNA)

Proportion of Direct Effect≈ 30%

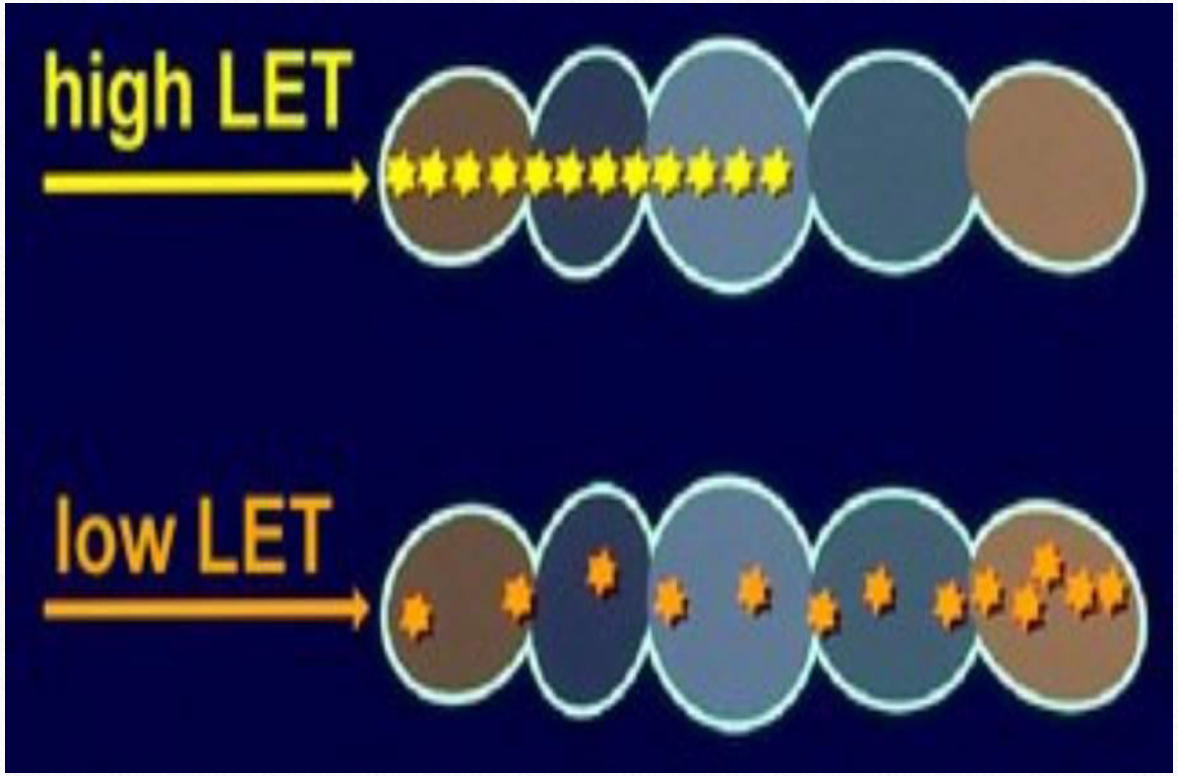
INDIRECT EFFECT- Due to deposition of energy in the surrounding water & reaction of free radical formed in the water with the Target Molecule-DNA

Proportion of Indirect Effect ≈70%

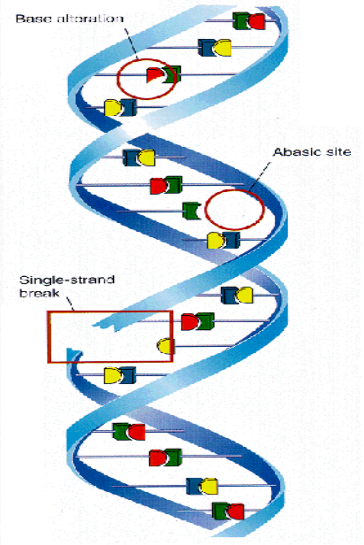
Effects also Depend on Radiation quality

Charged particles like α & protons are more harmful

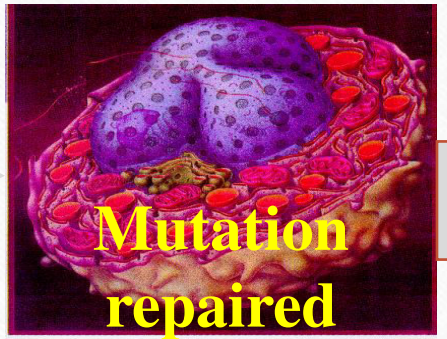
Uncharged particles like X and γ are relatively less harmful



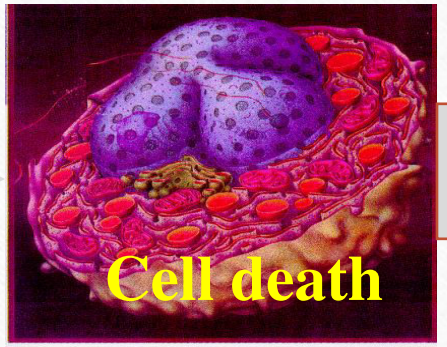
Outcomes after cell exposure



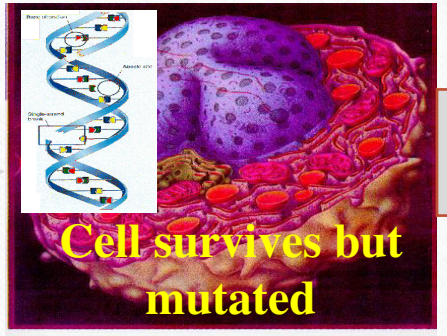
DNA Mutation



Viable Cell



Unviable Cell



Cancer?

Damage due to exposure may lead to…

- Inhibition of cell division
  - Delay or inhibit the process of cell division, which may impair the functions of tissues or organs
- Chromosome aberrations
  - Lead to rearrangement of genetic information. Serve as biological dosimeter (detectable above 100 mSv)
- Gene mutation
  - Alteration in the information content of genes
- Cell death
  - Can lead to cell death

Repair Mechanism

Human body has a very good self repair mechanism for damaged cells

- 999 of 1000 lesions are repaired
- 999 of 1000 damaged cells die (not a major problem as millions of cells die every day in every person)
- many cells may live with damage (could be mutated)

Some Tissues are more sensitive than others – (Radio Sensitivity)

High RS	Medium RS	Low RS
Bone Marrow Spleen Thymus Lymphatic nodes Gonads Lymphocytes (exception to the RS laws)	Skin Mesoderm organs (liver, heart, lungs…)	Muscle Bones Nervous system

Biological Effects depend on

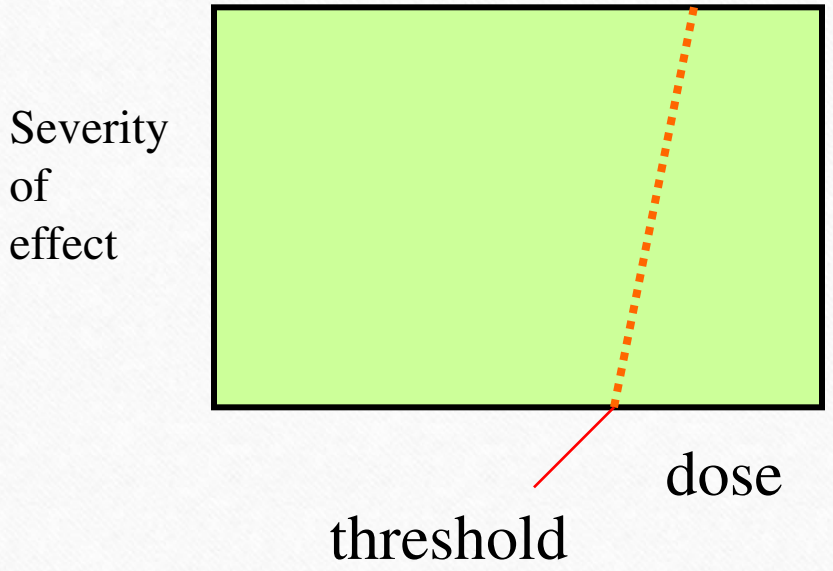
- Radiation Type (LET)
- Acute or Chronic Exposure
- Somatic Cells or Germ Cells
- Type of tissue involved
- Whole body or localised
- Sensitivity of Individual

Biological effects of ionizing radiation

- **Deterministic (Threshold/non-stochastic)**
  - Existence of a dose threshold value (below this dose, the effect is not observable)
  - Severity of the effect increases with dose
  - A large number of cells are involved
    - e.g. Lens opacities, skin injuries, infertility, epilation, etc
- **Stochastic (Non-Threshold)**
  - No threshold dose for occurrence
  - Probability of the effect increases with dose
  - Generally occurs with a single cell
    - e.g. Cancer, genetic effects

Deterministic effects

- Due to cell killing
- Have a dose threshold - typically several Gy
- Specific to particular tissues
- Severity of harm is dose dependent

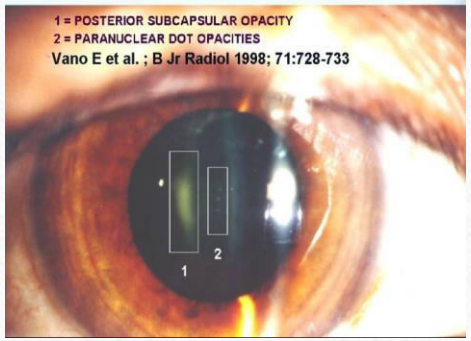


Examples for deterministic effects

- Skin reddening (erythema)
- Skin breakdown (desquamation)
- Cataract of the lens of the eye
- Sterility (Temporary/Permanent)
- Death due to acute radiation syndrome (whole body)

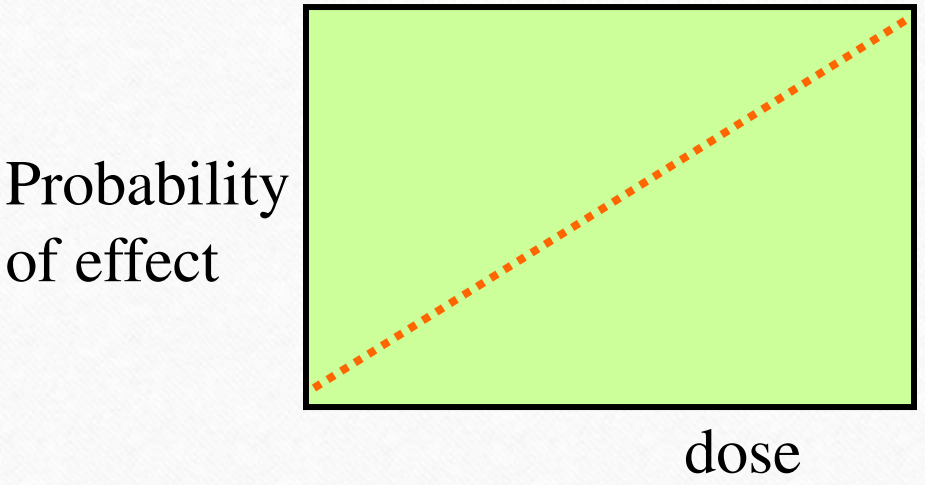
Threshold Doses for Deterministic Effects

- Cataracts of the lens of the eye 2-10 Gy
- Permanent sterility
  - males 3.5-6 Gy
  - females 2.5-6 Gy
- Temporary sterility
  - males 0.15 Gy
  - females 0.6 Gy



Stochastic effects

- Due to cell changes (DNA) and proliferation towards a malignant disease
- Severity (example cancer) independent of the dose
- No dose threshold - applicable also to very small doses
- Probability of effect increases with dose



Stochastic effects

Categorized as per the cell affected

- Somatic Effect
  - Early Effect
  - Late Effect
- Hereditary (Genetic) Effect
  - Late Effect

Delayed effects of radiation

Classification:

- SOMATIC: they affect the health of the irradiated person. They are mainly different kinds of cancer (leukemia is the most common, with a delay period of 2-5 years, but also colon, lung, stomach cancer…)

- GENETIC: they affect the health of the offspring of the irradiated person. They are mutations that cause malformation of any kind (such as mongolism)

Whole body Exposure (Acute)

Dose Range	Immediate Effect
Less than 0.1 Gy	No detectable effect
Above 0.1 Gy	Chromosome aberrations detectable
Above 0.5 Gy	Transient reduction in WBC count
Above 1 Gy	Nausea, vomiting, diarrhea (NVD)
3 – 5 Gy	Lethal Dose (LD50/60)
5 – 10 Gy	Severity of above effects Almost 100% death (at higher dose)

Local Irradiation (Acute)

Dose Range	Region	Effect
0.15 Gy	Testes	Temporary Sterility
3.5 - 6.0 Gy	Testes	Permanent Sterility
1.5 - 2 Gy	Ovaries	Temporary Sterility
2.5 - 6 Gy	Ovaries	Permanent Sterility
3 Gy	Hair follicles	Temporary Epilation
5 Gy	Eye	Cataract (after 5-10 yrs)
6 Gy	Skin	Skin Erythema
10 -20 Gy	Skin	Burns, Blisters, Wounds, Necrosis, Permanent hair loss

Early erythema 11 days after exposure.

DETERMINISTIC vs STOCHASTIC EFFECTS

DETERMINISTIC (NON-STOCHASTIC) EFFECTS	STOCHASTIC EFFECTS
eg. All whole body syndromes & partial body effects (such as Diarrhea, vomiting, Skin erythema, cataract)	eg. Cancer & hereditary(genetic effects)
Occurs due to cell killing	Occurs due to cell modification (mutation/chromosomal aberration)
Threshold dose exist	Probabilistic in nature
Severity of symptoms increases with dose	Probability/risk or chance increases with dose
Definite to occur in all individuals beyond threshold doses	occurs by chance in some individuals

DOSE LIMITS

DOSE LIMITS

Guidelines are set up by International Commission of Radiological Protection (ICRP)

AIMS OF RADIOLOGICAL PROTECTION

- To prevent deterministic effects
- To limit the occurrence of stochastic effects to acceptable limits

SYSTEM OF DOSE LIMITATION

1) No practice shall be adopted unless its introduction produced a net positive benefit

2) All exposures shall be kept As Low As Reasonably Achievable (ALARA), economic & social factors being taken into account

3) Dose to individuals shall not exceed recommended limits.

Exposure due to natural background radiation & medical exposure excluded in arriving at the dose limits.

DOSE LIMITS

Application	Occupational	Public
Effective Dose	20mSv per year. averaged over defined period of 5 years, with no more than 50 mSv in a single year	1 mSv per year. Averaged over 5 years.
Annual Equivalent dose to individual organs		
Eye lens	150 mSv	15 mSv
Skin	500 mSv*	50mSv
Hands & feet	500 mSv**	-

DOSE LIMIT FOR PREGNANT WOMAN

- Equivalent dose of 1 mSv to the surface of the abdomen after declaration of pregnancy for the reminder period of pregnancy

Summary

- Effects of ionizing radiation may be deterministic and stochastic, immediate or delayed, somatic or genetic
- Some tissues are highly radiosensitive
- Each tissue has its own risk factor
- Risk from exposure may be assessed through such factors
- Taking into account the various beneficial applicationss of radiation in industries, medicine, agriculture etc., radiation source should be handled with care rather than fear.

Expected questions to know after studying this lecture

- What is the difference between Deterministic Effects and Stochastic Effects?
- Which is the most sensitive component in the cell for radiation damage?
- What is the minimum dose required to see the occurrence of deterministic effect?
- What are the delayed effects of radiation?

DEFINITIONS

- **Acute Exposure**-Few Gy received in few hours

  (mainly occurs following radiation accidents)

  More harmful.
- **Chronic Exposure-** Small exposures received during long durations

  (eg. Occupational type of exposures)

  Less harmful
- **Early Effects**- occurs within hours weeks/months
- **Late Effects**- occurs after years to decades

DEFINITIONS

- **Whole Body Exposures – More harmful**
- **Partial Body Exposures – Less harmful**

Symptoms differ in each case

- **Somatic Effects – Exposed person suffers from harmful effects**
- **Genetic Effects / Hereditary effects – Future generations suffers from genetic diseases**

e.g. children , grand children & so on.

ANNUAL DOSE PER PERSON FROM NATURAL SOURDES OF RADIATION

Source	Annual Effective Dose (Mean) mSv
External	
Cosmic	0.36
Terrestrial Sources	0.41
Internal	
potassium-40	0.18
Radon-220,222 & daughters	1.26
Uranium,thorium etc,	0.16
Total	**2.37**

RADIATION RISK COMPARED TO RISK IN OTHER ACTIVITIES

Activity	Chance of Death per Year
Smoking 20 cigarettes/day	1 in 200
Deep-sea fishing-Accidents	1 in 400
Death-Natural causes-40 year old	1 in 500
Radiation work (2 mSv/year)	1 in 12,500

RADIATION RISK COMPARED TO RISK IN OTHER ACTIVITIES

Activity	Chance of Death per Year
1 mSv of radiation dose	1 in 20,000
Accident at home	1 in 11,000
Working in manufacturing	1 in 11,000
Accident on the road Working in transportation Working in construction	1 in 5000 1 in 4000 1 in 3000

TYPICAL RADIATION EXPOSURES & THEIR MAGNITUDE

- 0.1 mSv – 25h jet journey at cruising altitude
- 0.2 mSv – Chest X-ray-single exposure
- 1-2 mSv Avg. annual dose for radiation worker
- 2 mSv mammographic examination/Lumbar spine X-ray
- 10 mSv Barium enema (including fluoroscopy)

References and sources for additional information

- The Essential Physics of Medical Imaging (J. T. Bushberg, J.A. Seibert, E.M. Leidholdt, J M Boone)
- The Physics of Radiology (H.E. Johns, J.R. Cunnighnam)
- Introduction to Health Physics (H. Cember)
- Radiation Detection and Measurement (G. Knoll)
- IAEA Presentations on Diagnostic Radiology

List of presentations in the training Module

Basics of Diagnostic X-ray Equipment
Biological effects of Radiations
Medical X-ray imaging techniques
Planning of Diagnostic X-ray facilities
Quality Assurance of X-ray equipment
Quality Assurance of Computed Tomography equipment
Radiation Protection in Diagnostic Radiology Practice
Causes, prevention and investigation of excessive exposures in diagnostic radiology
Regulatory Requirements for Diagnostic Radiology Practice

THANK YOU