



Biological Effects of Ionizing Radiation on Man

UNDERSTANDING RADIATION

Q If I stand next to a container of radioactive material will I become radioactive?

A No



Introduction

- Biological effect begin with the **ionization of atoms** of the cell molecules
- Biological effects depend on the **type, energy and dosage** of the **radiation**, cellular **type** and **stage** etc.
- Ionizing radiation absorbed by cells or tissues has enough energy to **remove electrons** from the atoms that make up **molecules of the tissue**
- When the electron that was shared by the two atoms to form the **molecular bond is dislodged** by ionizing radiation, the bond is broken and thus, the molecule falls apart.

Content

- Ionizing radiation
- Sources of radiation
- Definitions and unit of radiation exposure
- Mechanism of radiation damage/injury
- Somatic and Genetic effect
- Others



Ionizing radiation

- Two types:
 - Electromagnetic radiation (x-ray and gamma ray)
 - Particulate radiations (alpha, beta, proton, neutrons etc)



Rule of Thumb:

Object is a possible radiation hazard
if its emission is greater than or
equal to twice that of "background"

OR

$$\text{Radiation Hazard} \geq 2x \text{ Background}$$



Biological Effects of Radiation

- The principle hazard from radiation exposure is an increase in the risk of cancer induction.



Radiation sources

- Natural background radiation
- Man-made radiation

Natural background radiation

- We are all exposed to ionizing radiation from natural sources at all times.
- Levels of natural or background radiation can vary greatly from one location to the other
- Main sources are:
 - Cosmic rays
 - Radioactivity in the Earth (U-238, Th-232 etc)
 - High natural background areas
 - Natural radioactivity in the body (K- 40, C-14)
 - Radon progeny (largest exposure to public)

RADIATION RISKS IN EVERYDAY LIFE

(a) Cosmic-rays

- radiation from interstellar space
- Sea-level at equator 0.2mSv/y; 10,000 ft 1 mSv/y
- Filtering effect of atmosphere reduces radiation at sea level

(b) Radiation from Terrestrial Sources

- Rocks and soil
- Sandstone/limestone lower than granite
- Geographical location

(c) Radioactivity in the Body

- Due to ingestion and inhalation of naturally occurring radionuclides
- Depending on location, diets and habits and accident (e.g. Chernobyl accidents)
- E.g. K-40; C-14; Cs-137 etc

Radon progeny (e.g.)

- Radon-222 originates from Uranium-238 or (Rn-220 from Th-232)
- Rn-222 is a gas which **diffuse out** of the ground to mix with air - breathing
- As the Rn-222 decays, its radioactive progeny, which are not gases, can be trapped in the lungs of people breathing the air
- Resulting in the lungs exposure to alpha and beta radiation
- Lung dose ranged from 2 to 8 mSv in some Canadian cities (1979)

Man-made radiation

- Medical exposure
 - X-ray, nuclear medicine, CT and radiotherapy
 - E.g Chest x-ray = 0.1 mSv
- Miscellaneous sources
 - Ceramics, smoke detectors, flying in aircraft etc add about 3 μ Sv per year
 - Fallout from atmospheric nuclear weapons test add about 10 μ Sv per year
 - Occupational doses add another 3 μ Sv per year

How radiation affects man??

Radiation Effects

- Depends on:
 - The **total dosage** and **exposure rate**
 - More dosage, more severe
 - Acute/Chronic exposure rate
 - The **extent** and **part** of body exposed
 - Different organ response differently
 - Cell sensitivity
 - Most active in reproducing themselves
 - Have high metabolic rates
 - The **age** of the individual exposed
 - Children suffer more severe effect compare to adult if given same dose of radiation

Order of radiosensitivity of somatic tissue/organ

- 1. Blood and Bone Marrow
- 2. Lymphatic System
- 3. Digestive Tract
- 4. Reproductive Organs
- 5. Nervous System
- 6. Thyroid Gland
- 7. Eyes
- 8. Lungs
- 9. Liver and Gall bladder
- 10. Kidneys
- 11. Circulatory System
- 12. Skin
- 13. Hair
- 14. Bones

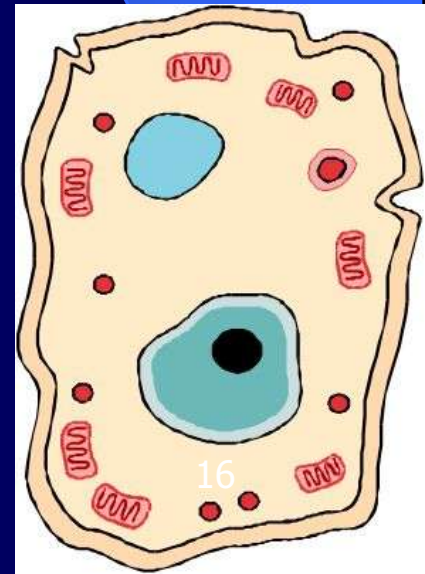
Total Dos

Total dose

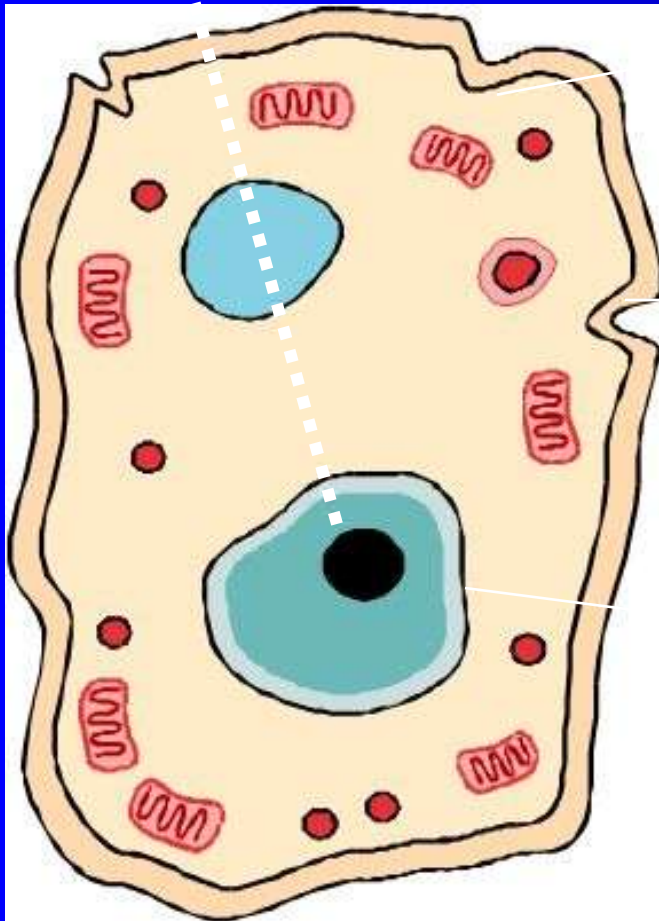
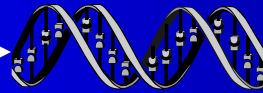
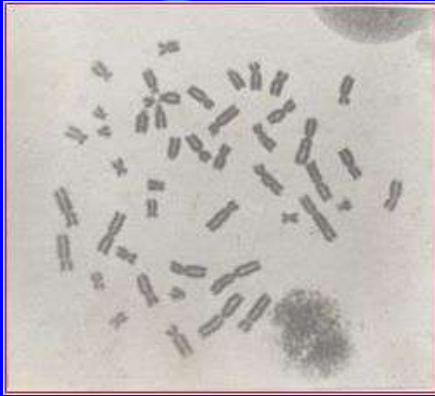
- Types of radiation – expressed in dose equivalent (α , β , γ , neutron dll.)
- Energy of Radiation (unit eV, keV and MeV)
- Radiation intensity (Ci, Bq)
- Time of exposure

Basic structure of living things

- Atoms
- Atoms combined to form molecules (protein, fats, carbohydrates, vitamins etc)
- Human cells made of molecules
- Cells are building blocks for tissues & organs



Human cell



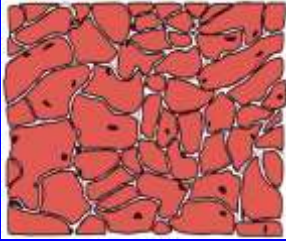
Cytoplasm - fluid-like substance where metabolism takes place, 75% water (most resistant)

Cell membrane - control uptake/output of soluble substance

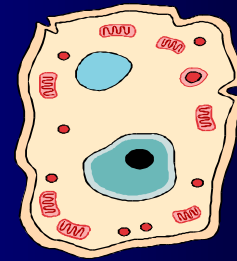
Nucleus - containing DNA, Chromosomes and genes critical & strategic role in cell functions (most sensitive)

Human Body

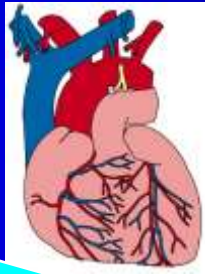
Tissues



Cells



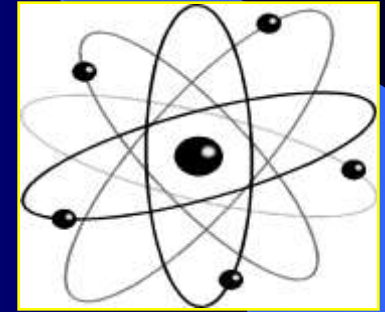
Organ



Human being



Atom/
Molecules



Possible Effects of Radiation on Cells

- ❑ Cells are undamaged by the dose (no impact)
- ❑ Cells are damaged, repair the damage and operate normally (ok)
- ❑ Cells are damaged, repair the damage and operate abnormally \Rightarrow **cancer/genetic effect**
- ❑ Cells die as a result of damage – depend on how sensitive the cells to radiation \Rightarrow **die**

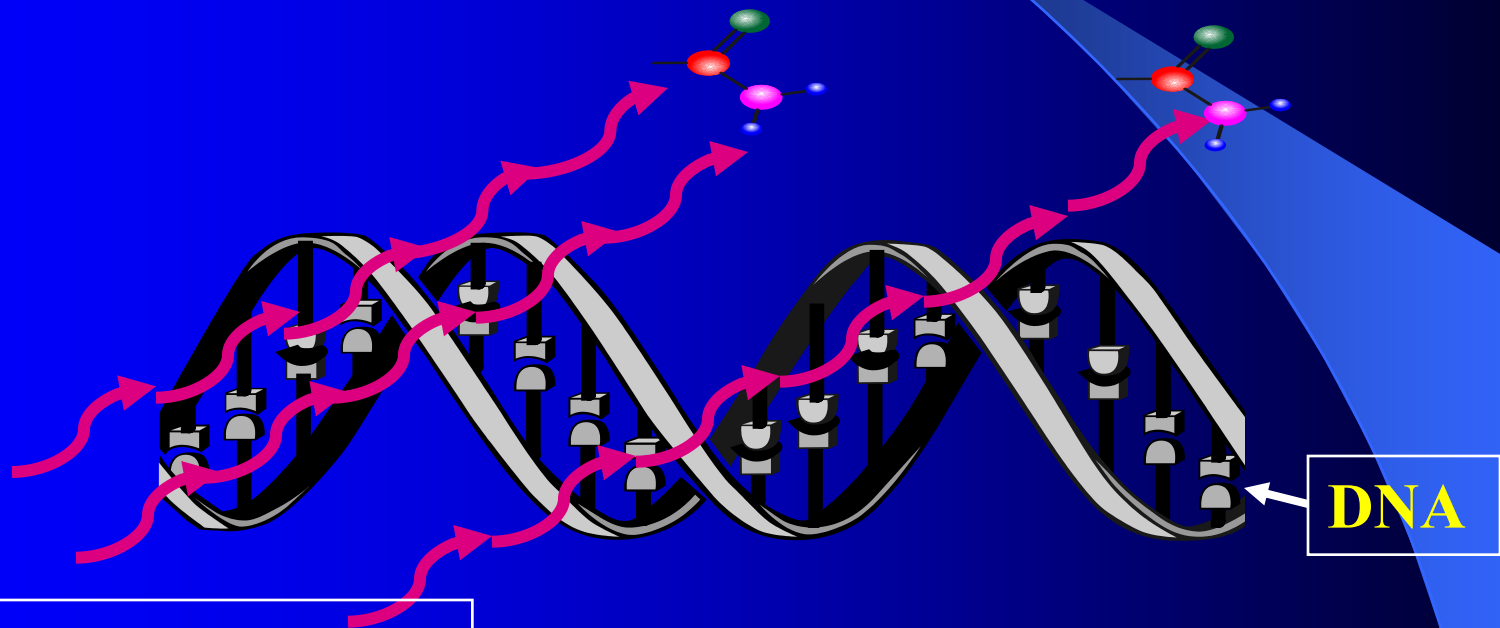
THE MECHANISM OF RADIATION INJURY

- ❑ Basic differences between *nuclear radiation* and commonly encountered radiation, e.g., heat, microwave and light is that the former can cause *Ionization*
- ❑ Cells contain almost 75-85% Water
- ❑ Mechanism of Radiation injury due to
 - *Direct effect* of IR on the cells
 - *Indirect effect* of IR on water molecules producing intermediate radicals and cause molecular damage to chromosomal materials
- ❑ By far the greatest damage to cell due to **byproducts** of water breakdown by IR

***DIRECT vs INDIRECT
EFFECT OF IR***

Direct Effect of IR

Direct interaction of Radiation with chromosomes (DNA) — point mutation, affect mitotic division & repair



α, β, γ or X-rays

Decomposition of H₂O by ionizing radiation



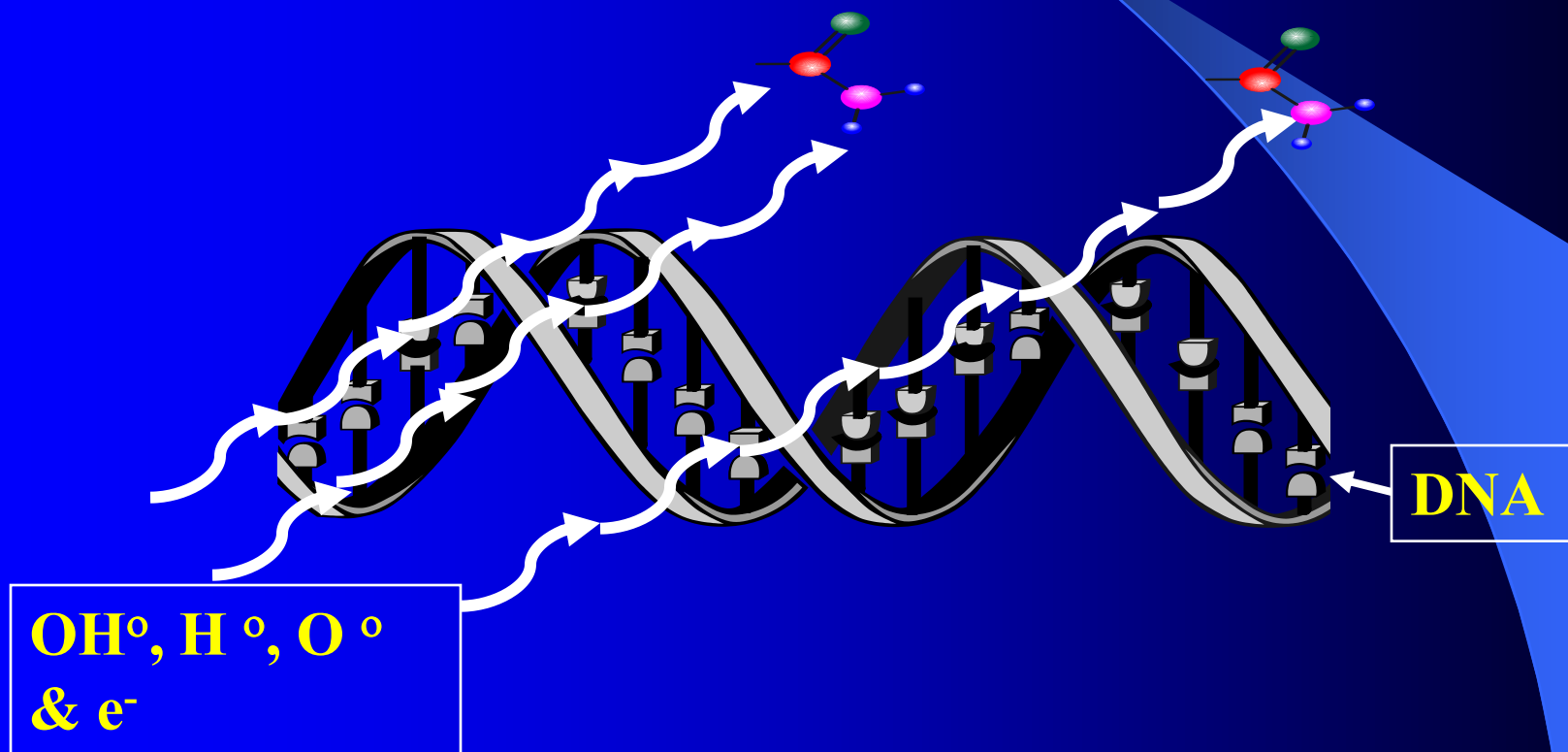
H₂O

Direct Effect

- The breakage of chemical bonding among atoms that forms structure of cells
- Majority of injury caused by high Linear Energy Transfer (LET) radiation such as α and β
- LET amount of energy transferred to traversed media in unit Joules per cm path length.

Indirect Effect of IR

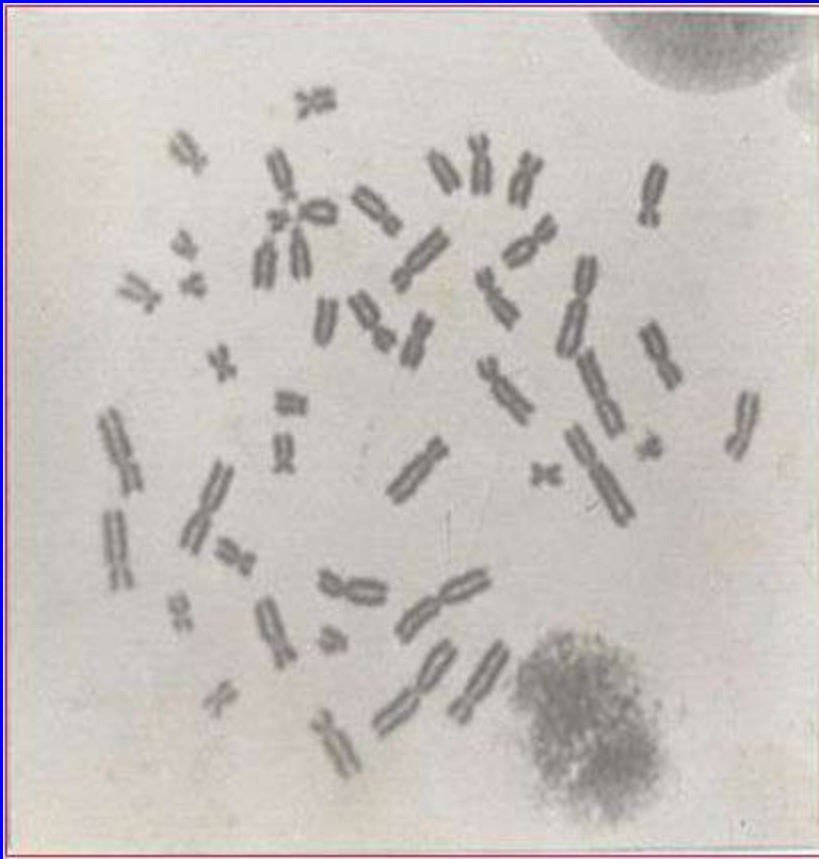
Indirect Effect - Radical Interaction with H₂O



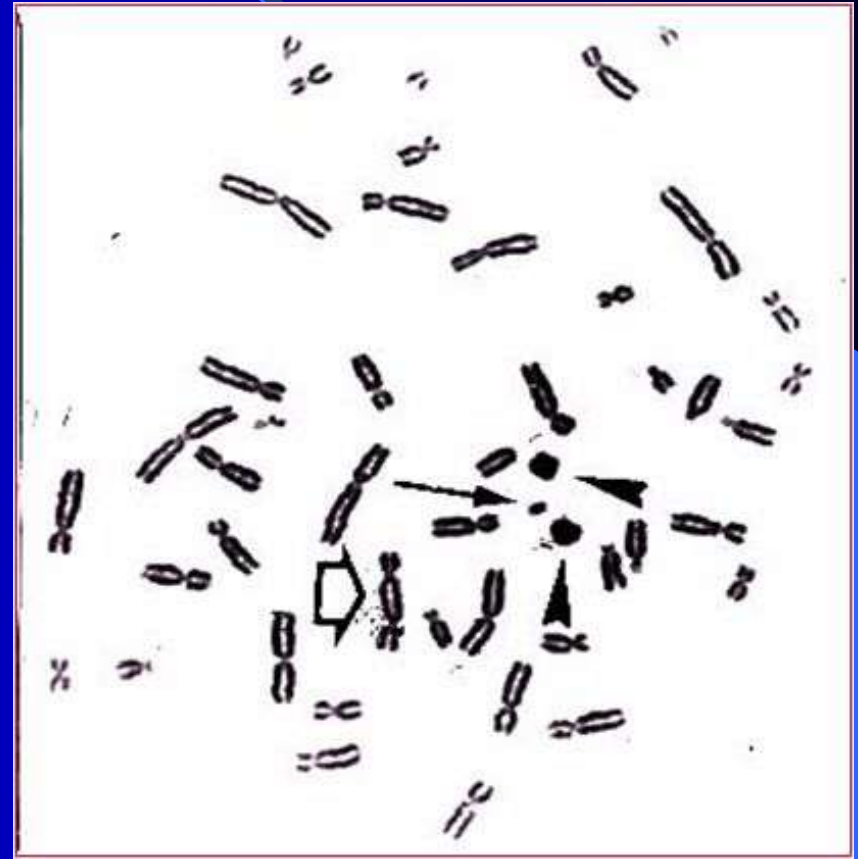
Indirect Effect

- Interaction occur with the water molecules in the cell structure (Water constituted 80% of cell).
- Physico-chemico reaction –generation of radicals
- Chemical reaction – Reaction between the radicals and chemicals in the cells and cell structure
- Biological – Cell damage particularly damage to the cell's nucleus – such as DNA

Chromosomal Structure due to Exposure to Gamma Radiation (e.g.)



Normal Cell



Cell receiving $>50\text{mSv}$

Body respond to radiation

- The effects of radiation on the human body can be classify as either **chronic or acute**
- **Chronic effects** occur **some years** after exposure. E.g. cancer and genetic defects
- **Acute effects** occur **within hours** after exposure due to the radiation's direct physical damage to tissue.

Acute exposure

- **Accidental & non-routine**
- **Large dose**
- **Immediate biological effects**
- **Symptoms**
 - Vomit, low red and white blood cells, bleeding, hair drop, die

Example:
Acute Dosage
>200 RADS
Delivered within a few days or weeks

Chronic Exposure

- ▶ **Routine**
- ▶ **Small dose but continuous (> 14 days)**
- ▶ **Long term biological impact (20 - 30 years)**
- ▶ **Carcinogenic**
 - Specific Cancer
 - Leukemia
 - Affect the body immune system
- ▶ **Non-carcinogenic – cataracts**

CHRONIC DOSE=

20 MREM /a week

delivered over months,
years, or a working lifetime

Units of radiation

- **Activity**
 - SI Becquerel(Bq), Non SI Curie(Ci)
 - $1 \text{ Ci} = 3.7 \times 10^{10} \text{ Bq}$
- **Exposure**
 - SI C/Kg, Non-SI Roentgen(R)
 - $1 \text{ C/kg} = 3876 \text{ R}$
- **Absorbed Dose**
 - SI Gray(Gy), Non SI Rad(rad),
 $1 \text{ Gy} = 100 \text{ rad}$
- **Dose Equivalent**
 - SI sievert(Sv), Non SI rem,
 - $1 \text{ Sv} = 100 \text{ rem}$

UNITS

Microcurie

Becquerel

Rad

Curie

Rem

Millirem

Sievert

International units

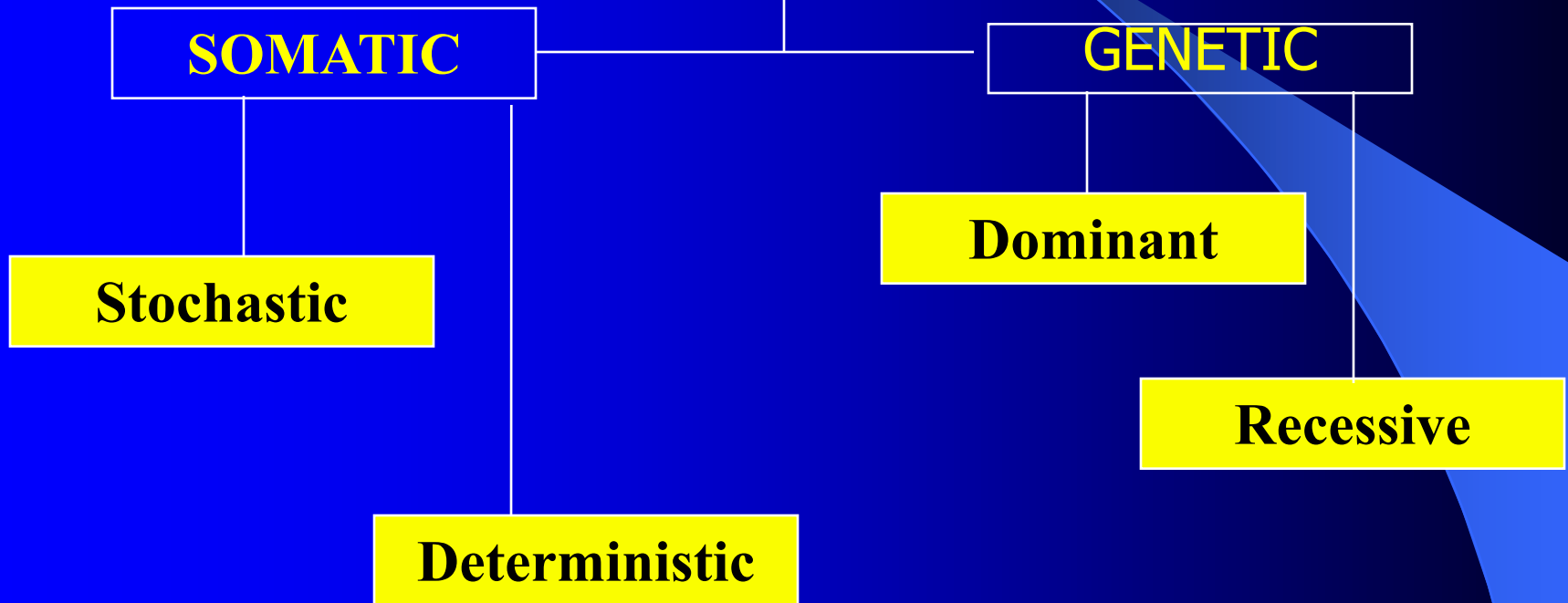
BECQUEREL = Bq

Unit used to measure Activity

SIEVERT = Sv

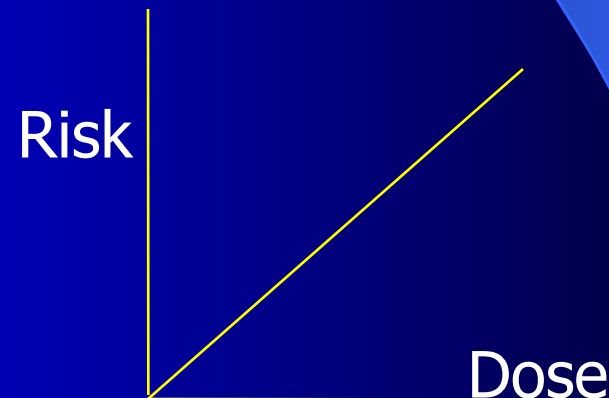
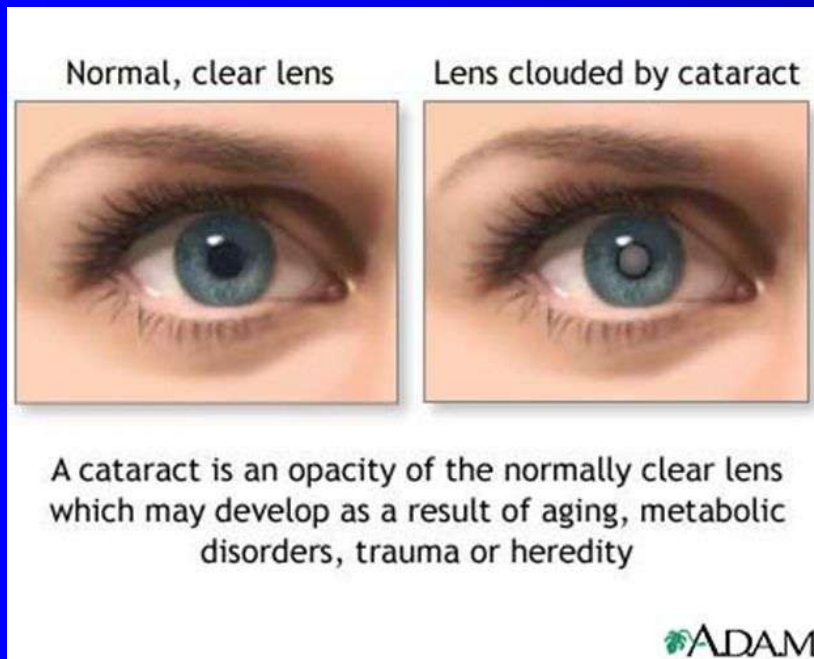
Unit used to measure Dosage

Overview of Biological effects



Stochastic vs Deterministic effects

- *Stochastic* – probability, no threshold, long-term (chronic)/delayed effects, e.g., cancer, cataract



NORMAL

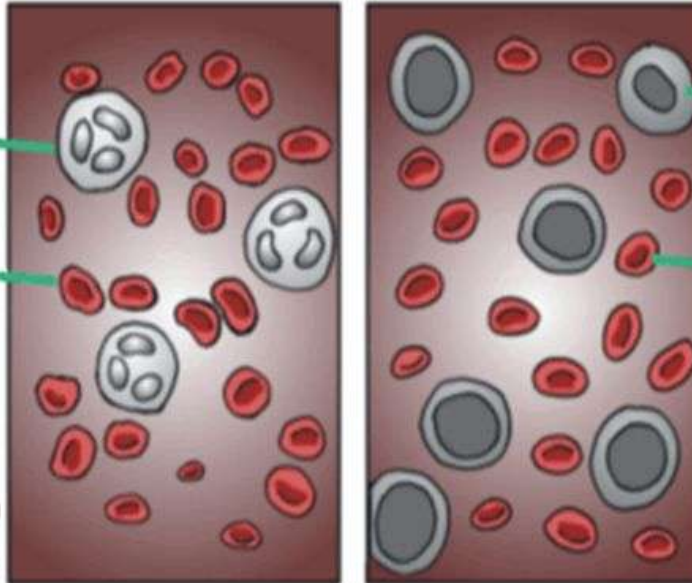
ABNORMAL

White Cell

Red Cell

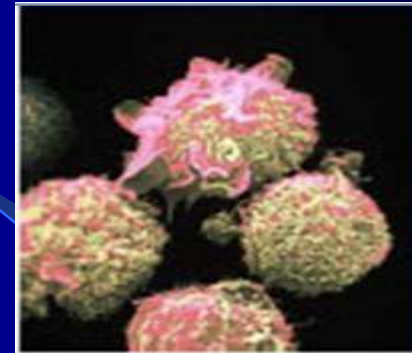
White Cell

Red Cell



Normal Blood (*above left*) contains mostly red cells and small percentage of white blood cells.

A person with chronic lymphocytic leukemia (*above right*), the white cell count is abnormally high.



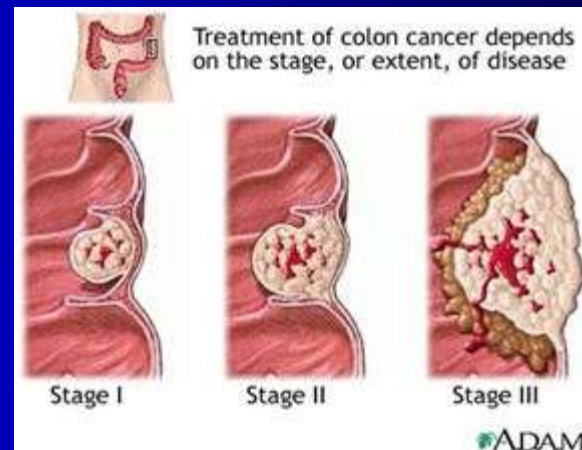
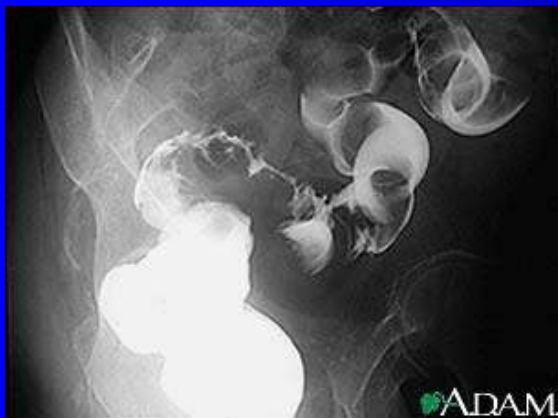
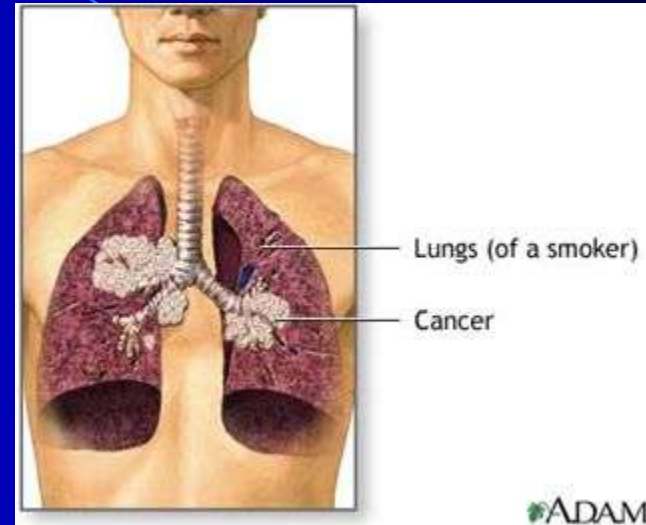
Leukemia

Stochastic Effect

Carcinogenesis

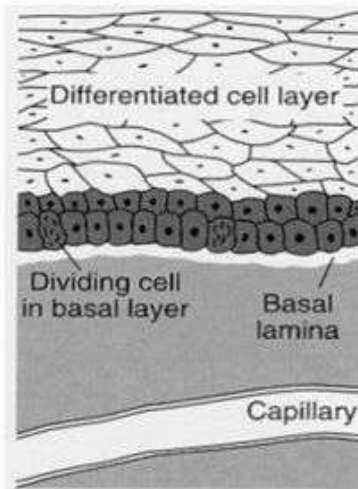
- Carcinogenesis is an example of somatic stochastic effect.
- Carcinogenesis may:
 - Occur after low dose exposure; and
 - The probability of malignancy increases with increase in dose.
- In man there is a **latent period** between **initiation and expression** of effects. Latent period is about 8 years for induced leukemia and 2-3 X longer for solid tumor (eg lung and breast cancers).
- Stochastic effect is influenced by Linear Energy Transfer (LET) and dose rate.

Cancer types (skin, lungs & colon)



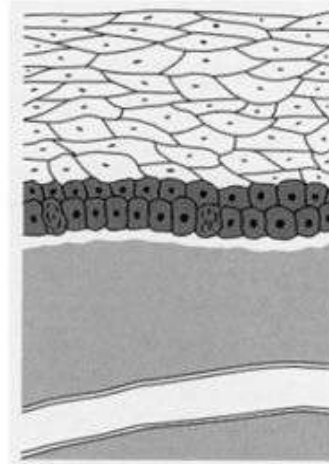
Cancer progression

NORMAL TISSUE



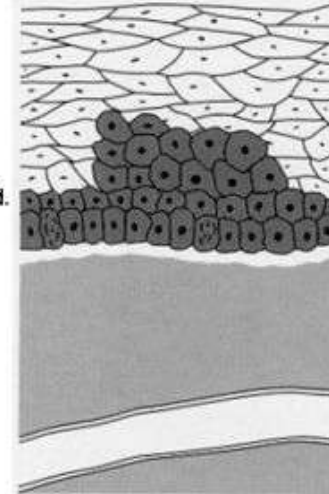
CELL INITIATION

An initiating event
Creates a mutation in
One of the basal cells



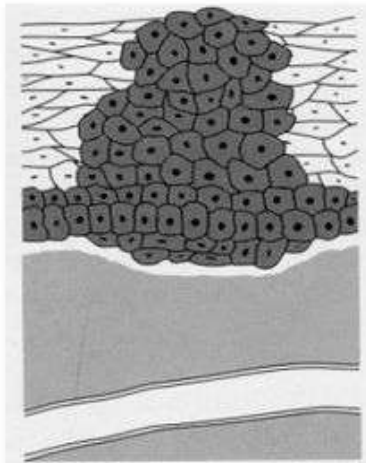
DYSPLASIA

More mutations occurred.
The initiated cell has
gained proliferative
advantages.
Rapidly dividing cells
begin to accumulate
within the epithelium.



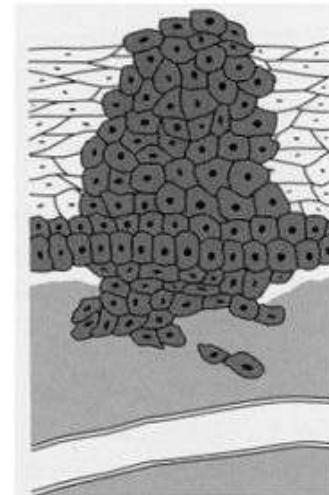
BENIGN TUMOR

More changes within
the proliferative cell
line leads to full
tumor development.



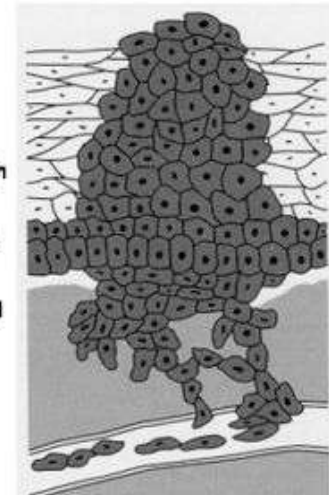
MALIGNANT TUMOR

The tumor breaks trough
the basal lamina.
The cells are irregularly
shaped and the cell line
is immortal. They have
an increased mobility
and invasiveness.



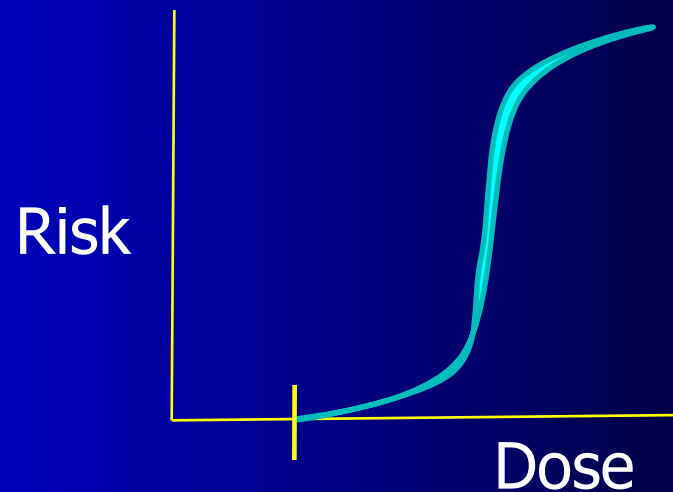
METASTASIS

Cancer cells break trough
the wall of a lymphatic
vessel or blood capillary.
They can now migrate
throughout the body and
potentially seed
new tumors



Stochastic vs Deterministic effects

- *Deterministic* – threshold dose exists (500mSv), severity is proportional to dose after exceeding threshold especially in short term (acute) exposure



Acute Radiation Syndrome (ARS)

- Caused by acute high dose exposure (> 0.5 Sv) to the whole body.
- Usually due to external exposure.
- ARS is divided into three types:
 - Bone Marrow Syndrome;
 - Gastrointestinal Syndrome; and
 - Central Nervous System Syndrome.

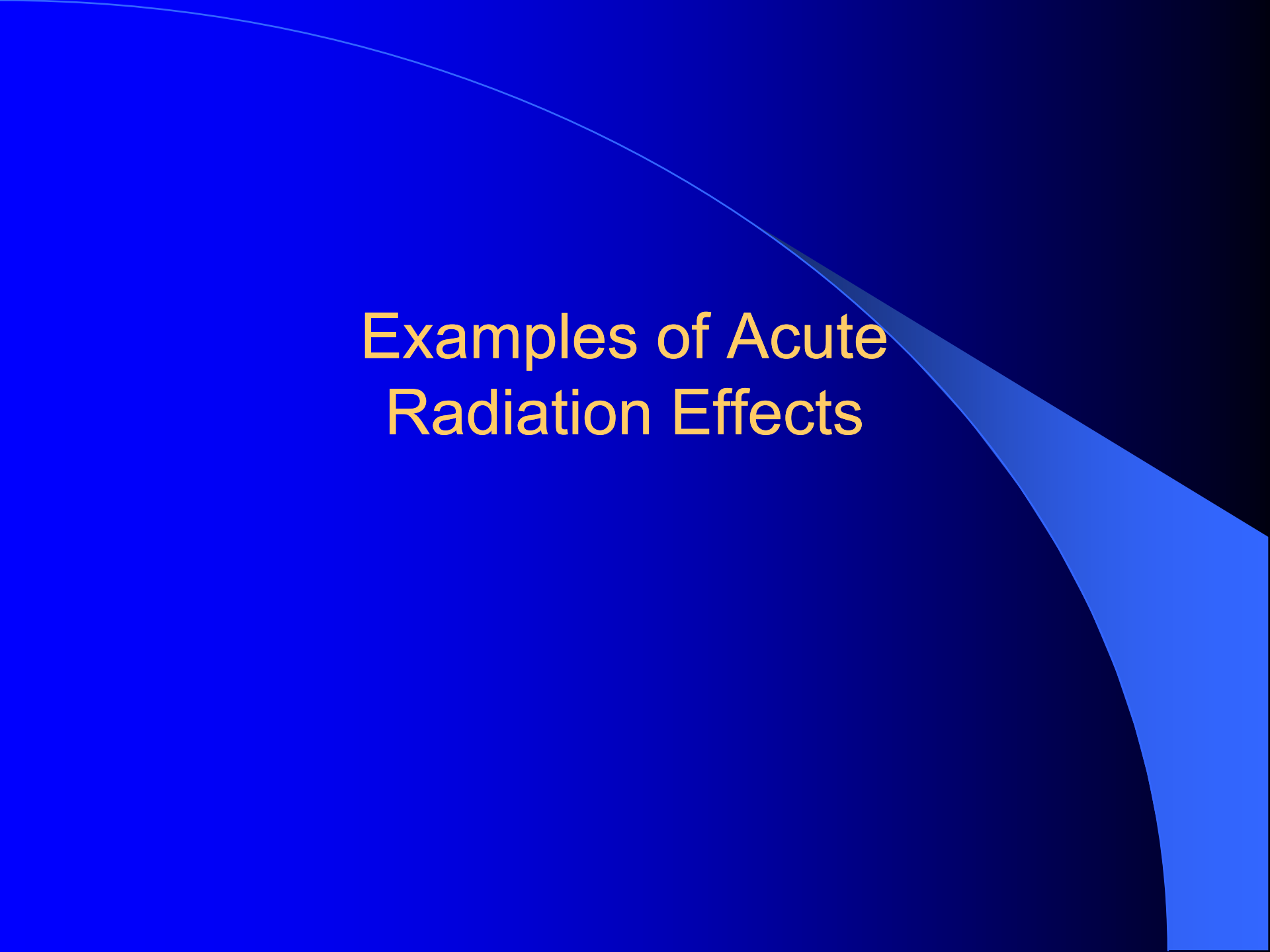
Acute (Short Term) Somatic Effect

- **0.09-0.5 Sv:** No visible effect observed - cause small changes in the composition of blood esp. lymphocyte .
- **0.8-1.2 Sv:** 5-10% of patient experienced vomiting & dizziness for a day. No detrimental effect except weakness of limbs
- **1.3-1.7 Sv:** up to 25% patient experienced vomiting & dizziness within a day & followed by other sign of radiation injury
- **2.7-3.3 Sv:** 1st day - patient experienced vomiting followed by other signs of injuries. About 20% of patient died within 2-6 weeks after exposure

Acute (Short Term) Somatic Effect

- **4-5 Sv** : 1st day - patient vomits & feel dizzy followed by other signs of radiation injury. **50% of patient died** within a period of a month. Death caused by other infection (septicemia) due to lowering of WBC, reduce immune system.
- **5.4 - 5.7 Sv: Vomiting & dizziness in 100%** patient within 4 hours of accidents/exposures followed by other sign of radiation injury. **100% death may occurs.** Survivor can only be confirmed after 6 months.
- **10 Sv: Vomiting and dizziness** in all involved and maybe **none will survive.** This level of radiation can **destroy nervous system completely, basic functions of the body to cease functioning, e.g. brain no longer able to carry out task, breathing no longer controlled etc**

Examples of Acute Radiation Effects





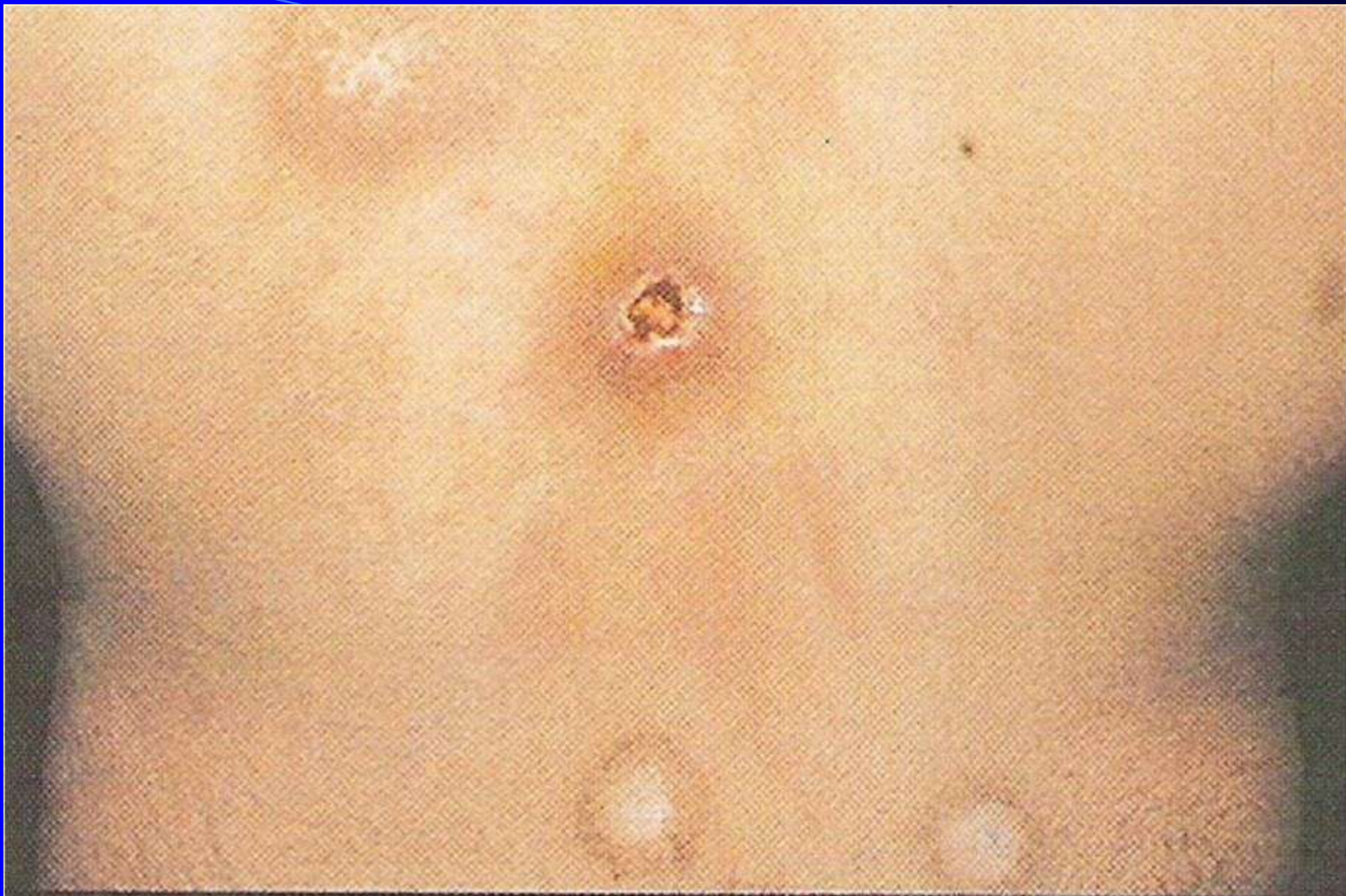
Early erythema in the frontal and antelateral right side of the chest 5 days after the exposure to an iridium-192 source (185 GBq, 5 Ci) mounted in a pen-size source holder for industrial radiography which was placed to the pocket of the worker's overall and kept there for about two hours.



Early erythema 11 days after exposure.



**Desquamation and skin necrosis 21 days after exposure.
Note: the white areas correspond to silver ointment.**



An ulcer in subacute stage and four ulcers following self-healing with depigmentation caused by being unawarely exposed 4-8 months earlier to the same 164 GBq (4.4 Ci) cesium-137 source (placed in a pocket of a trench coat used as a blanket).

Risk of Radiation to Pregnant Women

Exposure to Zygote of pregnant women (1)

- Exposure of **embryo aged 8 days** - death & miscarriage. Estimated risk is 100% at 1 Sv
- **Embryo aged 9-15 days** - mental retardation & physical disability. Estimated risk is 50% per every Sv
- Exposure of **fetus aged 8-15 weeks** - reduction of IQ at the rate of 30 points per every Sv
- Exposure of fetus to radiation at **16 weeks & above** - disturbance of growth of child, increase risk of leukemia/tumor/cancer. Estimated risk of 2% for each Sv
- Risk faced by children to cancer as a result of continuous exposure is estimated to be 2.8×10^{-2} per Sv

Job Exposure of Fertile Women(2)

- **Perlindungan Sinaran Keselamatan Asas 2010** - women who get pregnant suggested not to receive radiation at work place exceeding 1 mSv as compared to radiation workers of 20 mSv) per year

Thank you