Radiation dosimetry

Radiation quantities and units

- The basic radiation quantities are:
- exposure dose
- absorbed dose
- equivalent dose
- effective dose
- integral dose

Exposure = ionization air

- The old unit to measure exposure is ***roentgen (R)***, which is defined in terms of the amount of ionization produced in air. The unit for exposure is based on change/mass of air (C/kg) (columb),
- where $1R = 2.58 \times 10^{-4}$ C/kg

Absorbed dose = energy/mass

- When ionizing radiation interacts with the human body, it gives its energy to the body tissues. The amount of energy absorbed per unit weight of the organ or tissue is called ***absorbed dose*** and is expressed in units of gray (Gy).

- One gray dose is equivalent to one joule radiation energy absorbed per kilogram of organ or tissue weight.

- ***Rad*** is the old and still used of absorbed dose.

One gray is equivalent to 100 rads.

1Gy =100 rads

Equivalent dose

- The third important radiation quantity is the dose equivalent.
- Equal doses of all types of ionizing radiation are not equally harmful. Alpha particles produce greater harm than do beta particles, gamma rays and x rays for a given absorbed dose.

- To account for this difference, radiation dose is expressed as ***equivalent dose*** in units of ***sievert (Sv).***

- The dose in SV is equal to ***"absorbed dose" multiplied by a "radiation weighting factor"*** (***Wr*** – see table 1 below). Prior to 1990, this weighting factor was referred to as Quality Factor (***QF***).

Table 1

Recommended Radiation Weighting Factors

Types and energy range	Radiation weighting factor, WR
Gamma rays and x rays	1
Beta particles	1
Neutrons, energy < 10 keV >10 keV to 100 keV >100 keV to 2 MeV >2 MeV to 20 MeV >20 MeV	5 10 20 10 5
Alpha particles	20

- Equivalent dose is often referred to simply as “dose” in energy day of radiation terminology. The old unit of “dose equivalent” or “dose” was ***rem***.

- ***Dose in Sv = Absorbed Dose in Gy x radiation weighting factor (WR)***
- ***Dose in rem = Dose in rad x QF***

- ***1Sv = 100 rem***

- ***1 rem = 10 mSv*** (millisievert = one thousandth of a sievert)
- ***1Gy air dose equivalent to 0.7 Sv tissue dose***
- ***1 R (roentgen) exposure is approximately equivalent to 10 mSv tissue dose***

What effects do different doses of radiation have on people?

- One sievert is a large dose. The recommended ***Threshold Limit Values (TLV)*** is average dose of 0.05 Sv (50 mSv).
- The effects of being exposed to large doses of radiation at one time (acute exposure) vary with the dose.

- **Here are some examples:**

- 10 Sv – Risk of death within days or weeks
- 1 Sv – Risk of cancer later in life (5 in 100)
- 100 mSv – Risk of cancer later in life (5 in 1000)
- 50 mSv – TLV annual dose for radiation workers in any one year
- 20 mSv – TLV for annual average dose, averaged over five years

What are the limits of exposure to radiation?

- The Threshold Limit Values (TLVs) published by the ACGIH (American Conference of Governmental Industrial Hygienists) are used in many jurisdictions occupational exposure limits or guidelines:
- **20 mSv** – TLV for average annual dose for radiation workers, averaged over five years
- **1 mSv** – Recommended annual dose limit for general public (ICRP – International Commission on Radiological Protection).

What is the relationship between SI units and non-SI units?

- Table 2 shows SI units (International System of Units or System International quantities), the corresponding non-SI units, their symbols, and the conversion factors.

Table 2 Units of Radioactivity and Radiation Dose

Quantity	SI unit and symbol	Non-SI unit	Conversion factor
Radioactivity	becquerel, Bq	Curie, Ci	1 Ci = 3.7x10^{10} Bq =37 Gigabecquerels (GBg) 1 Bq = 27 picocurie (pCi)
Absorbed dose	gray, Gy	rad	1 rad = 0.01 Gy
“Dose” (Equivalent dose)	sievert, Sv1	rem	rem= 0.01 Sv1 rem = 10 mSv

What is “committed dose?”

- When a radioactive material is gets in the body by inhalation or ingestion, the radiation dose constantly accumulates in an organ or a tissue. The total dose accumulated during the 50 years following the intake is called the ***committed dose***. The quantity of committed dose depends on the amount of ingested radioactive material and the time it stays inside the body.

What is an effective dose?

- The effective dose is the sum of weighting equivalent doses in an all the organs and tissue of the body.

- **Effective dose = sum of (organ doses x tissue weighting factor)**

- Tissue weighting factors (Table 3) represent relative sensitivity of organs for developing cancer.

Table 3 **Tissue Weighting Factor for Individual Tissues and Organs**

Tissue or Organ	Tissue Weighting Factor (WT)
Gonads (testes or ovaries)	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
Oesophagus	0.05
Thyroid gland	0.05
Skin	0.01
Bone surfaces	0.01
Remainder**	0.05
Whole body	1.00

- ** The remainder is composed of the following additional tissues and organs:

- adrenal
- brain
- upper large intestine
- small intestine
- kidney
- muscle
- pancreas
- spleen
- thymus
- uterus

Integral dose

- Integral dose is the radiation quantity that is equal to the total energy absorbed by the body.

- The SI unit for integral dose is the ***joule*** (the standard unit of energy), and the conventional unit is *the* ***gram-rad***.

Measuring radiation by ionization methods

- Common types of wearable dosimeters for ionizing include:

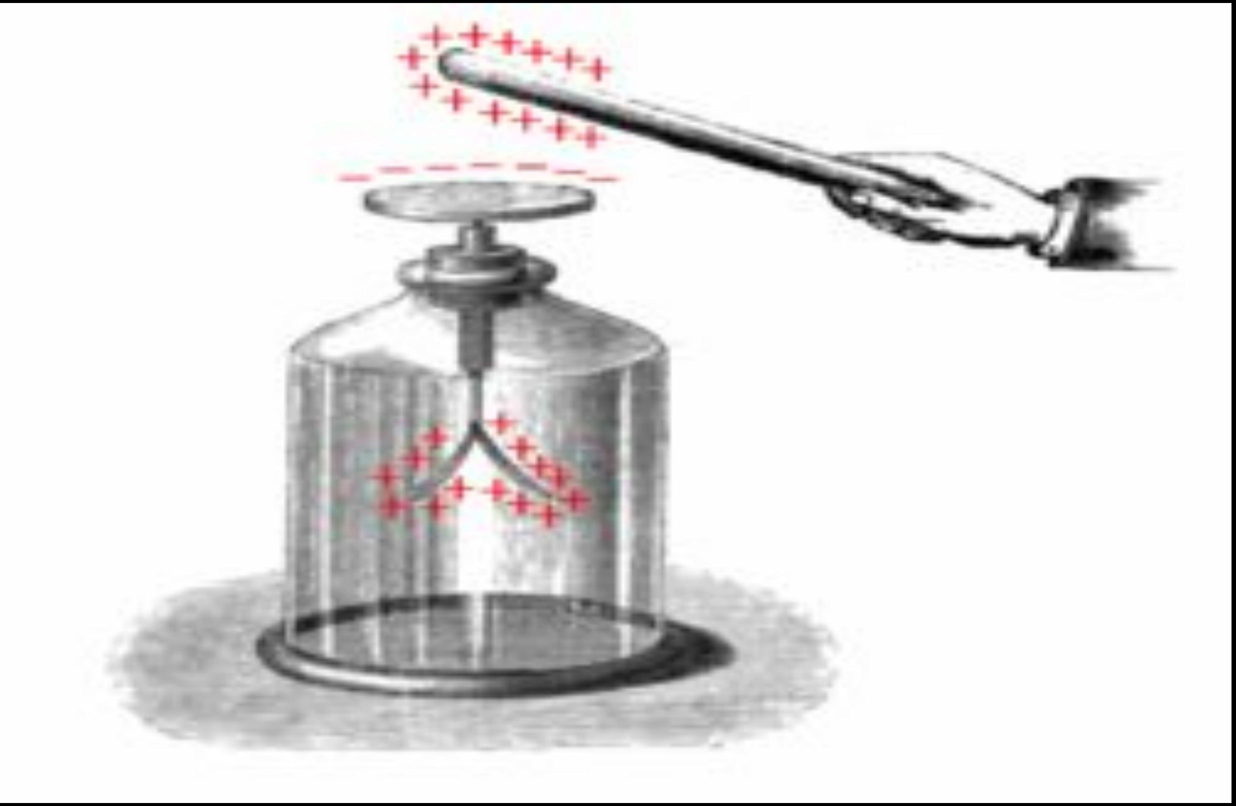
- film badge dosimeter
- thermoluminescent dosimeter
- quartz fiber dosimeter

Quartz fiber dosimeter

- A quartz fiber dosimeter, sometimes simply called a pocket dosimeter, is a pen like device that measures the dose of ionizing radiation.
- The oldest accurate technique for measuring radiation involves measuring the charge produced by the radiation. This can be done in two different ways.

- If the radiation is more or less constant, it is possible to measure the ionizing current. This is a dose rate meter. The results will be given in R/hour or a similar unit. If the exposure is short, as in the case of an X-ray exposure, all of the ionization charge is collected and measured. This is called an "integrating dosimeter".

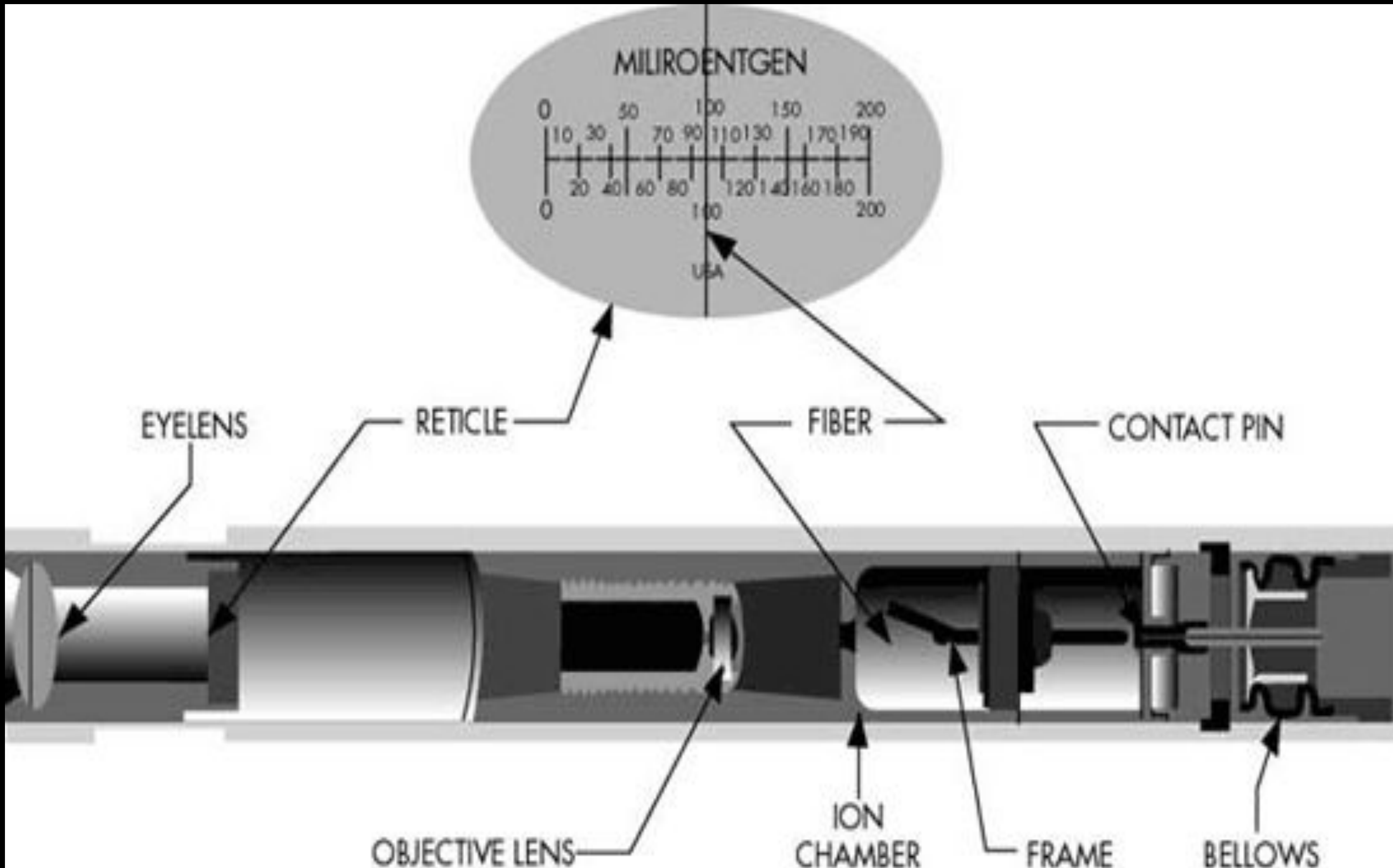
- A simple dosimeter of this type is a pocket or pen dosimeter. A capacitor is charged to about 400 volts. As the air in the chamber is ionized by the radiation, the ions produced are collected and discharge the capacitor. The charge loss on the capacitor during a given time is a measure of the radiation exposure.
- Most pen dosimeters include a simple electroscope to measure the remaining charge. They include a scale which indicates zero when fully charged. As it discharges, the scale shows the remaining voltage. The scale is calibrated to read directly in milliroentgens (mR).



- Gold leaf electroscopeGold leaf electroscope showing principle of fiber dosimeter. When ionizing radiationGold leaf electroscope showing principle of fiber dosimeter. When ionizing radiation penetrates the inner gasGold leaf electroscope showing principle of fiber dosimeter. When ionizing radiation penetrates the inner gas of the electroscope, ionsGold leaf electroscope showing principle of fiber dosimeter. When ionizing radiation penetrates the inner gas

Quartz fiber dosimeter

Quartz fiber dosimeter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USA
EYELENS
RETICLE
FIBER
CONTACT PIN
OBJECTIVE LENS
ION CHAMBER
FRAME
BELLOWS

Dosimeter charger

Essential for recharging quartz fibre dosimeters.

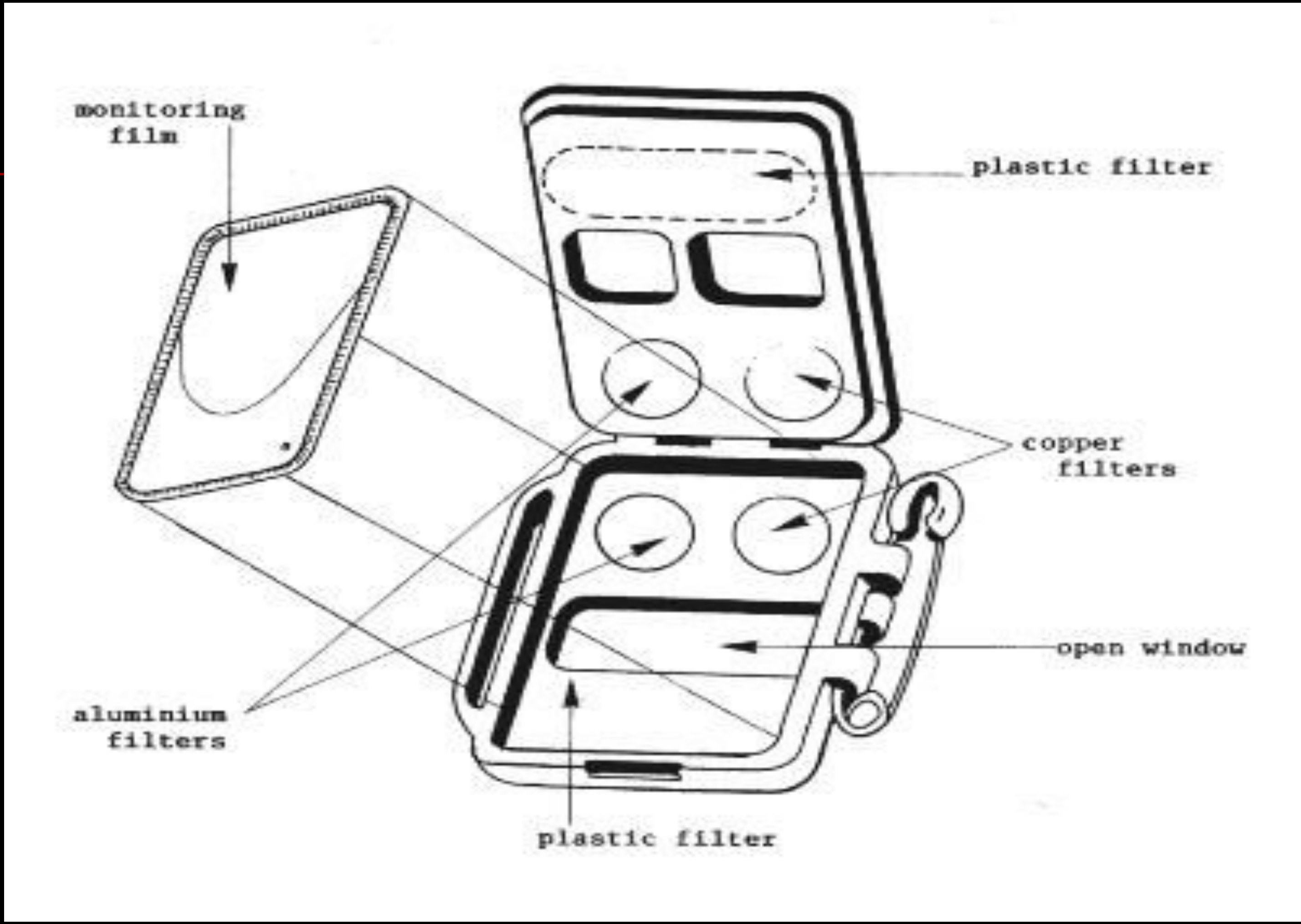
Film badge dosimeter

- Film badge dosimeter, is a dosimeter used for monitoring exposure to ionizing radiation.

- The badge consists of two parts:
- photographic film
- holder

- The film is removed and developed to measure exposure.
- The film is sensitive to radiation and, once developed, exposed areas in optical density (i.e. blacken) in response to incident radiation. One badge may contain several films of different sensitivities or, more usually, a single film with multiple emulsion coatings. The combination of a low – sensitivity and high-sensitivity emulsion extends the dynamic range to several orders of magnitude. Wide dynamic range is highly desirable as it allows measurement of very large accidental exposures without degrading sensitivity to more usual low level exposure.

- ***Advantages:***
- The film badge has several advantages over other types of dosimetry:
- permanent record of exposure
- radiation type detection – use of multiple filters allows separate measurement of beta and gamma exposure.


monitoring film
plastic filter
copper filters
open window
aluminium filters
plastic filter

Film badge dosimeter

Thermoluminescent Dosimeter

- Thermoluminescent dosimeters (TLD) are often used instead of the film badge. Like a film badge, it is worn for a period of time (usually 3 months or less) and then must be processed to determine the dose received, if any. Thermoluminescent dosimeters can measure doses as low as 1 millirem, but under routine conditions their low-dose capability is approximately the same as for film badges. TLDs have a precision of approximately 15% for low doses. This precision improves to approximately 3% for high doses.

- ***Advantages***:
- The advantages of a TLD over other personnel monitors are its:
- linearity of response to dose
- relative energy independence
- sensitivity to low doses
- it is also reusable, which is an advantage over film badges
- However, no permanent record or re-readability is provided and an immediate, on the job readout is not possible.

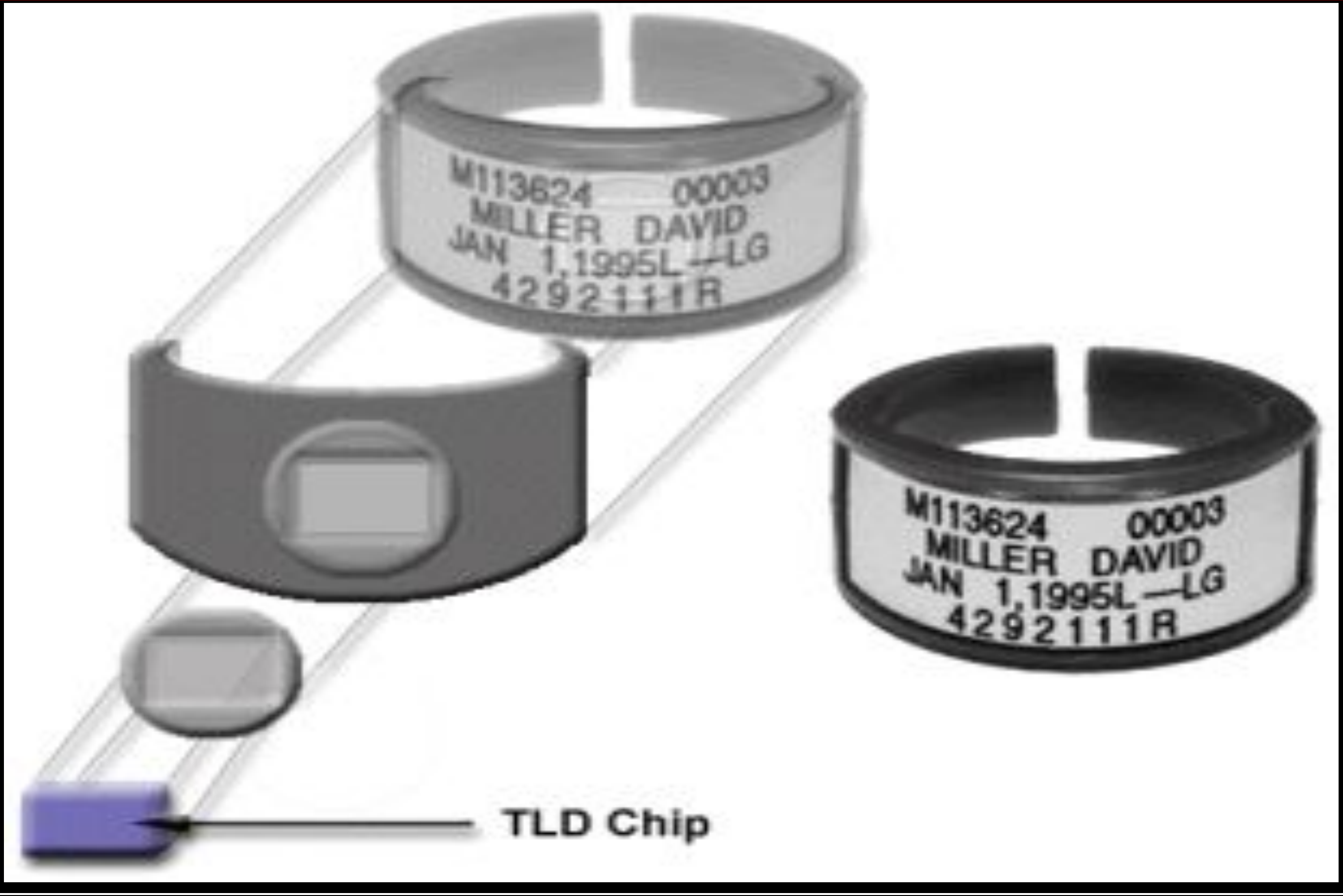
How it works

- A TLD is a phosphor, such as lithium fluoride (LiF) or calcium fluoride (CaF), in a solid crystal structure. When a TLD is exposed to ionizing radiation at ambient temperatures, the radiation interacts with the phosphor crystal and deposits all or part of the incident energy in that material. Some of the atoms in the material that absorb that energy become ionized, producing free electrons and areas lacking one or more electrons, called holes. Imperfections in the crystal lattice structure act as sites where free electrons can become trapped and locked into place.

- Heating the crystal causes the crystal lattice to vibrate, releasing the trapped electrons in the process. Released electrons return to the original ground state, releasing the captured energy from ionization as light, hence the name thermoluminescent. Released light is counted using photomultiplier tubes and the number of photons counted is proportional to the quantity of radiation striking the phosphor.

- Instead of reading the optical density (blackness) of a film, as is done with film badges, the amount of light released versus the heating of the individual pieces of thermoluminescent material is measured. The "glow curve" produced by this process is then related to the radiation exposure. The process can be repeated many times.

Thermoluminescent Dosimeter



Thermoluminescent Dosimeter

Dosimeter-radiometer

- The **dosimeter-radiometer**, which has many unique qualities:
- a thin graphical display, which shows the information with maximum clarity.
- the dosimeter’s measuring capabilities range from the natural background level up to 0.1 Sv/h; additional tests confirmed dose tolerance of «Swift» to up to 10 Sv/h!;
- detects two radiation types – beta and gamma;

- the dosimeter-radiometer generates sound signals to indicate the following events:
  - — one or several particles detection;
  - — exceeding the regulation threshold – dose, dose rate or flux density;
  - — the battery is getting low;
  - — the key is pressed;
- convenient functions of light and dynamic (vibration) threshold alarm;
- continuous monitoring of performance and residual capacity of batteries;

Dosimeter-radiometer

The effects of radiation on the cell at the molecular level

- When radiation interacts with target atoms, energy is deposited, resulting in ionization or excitation.
- The absorption of energy from ionizing radiation produces damage to molecules by:
- direct actions
- indirect actions

- For direct actions, damage occurs as a result of ionization of atoms on key molecules in the biological system. This causes inactivation or functional alteration of the molecule.
- Indirect action involves the production of reactive free radicals whose toxic damage on the key molecule results in a biological effect. Free radicals readily recombine to electronic and orbital neutrality

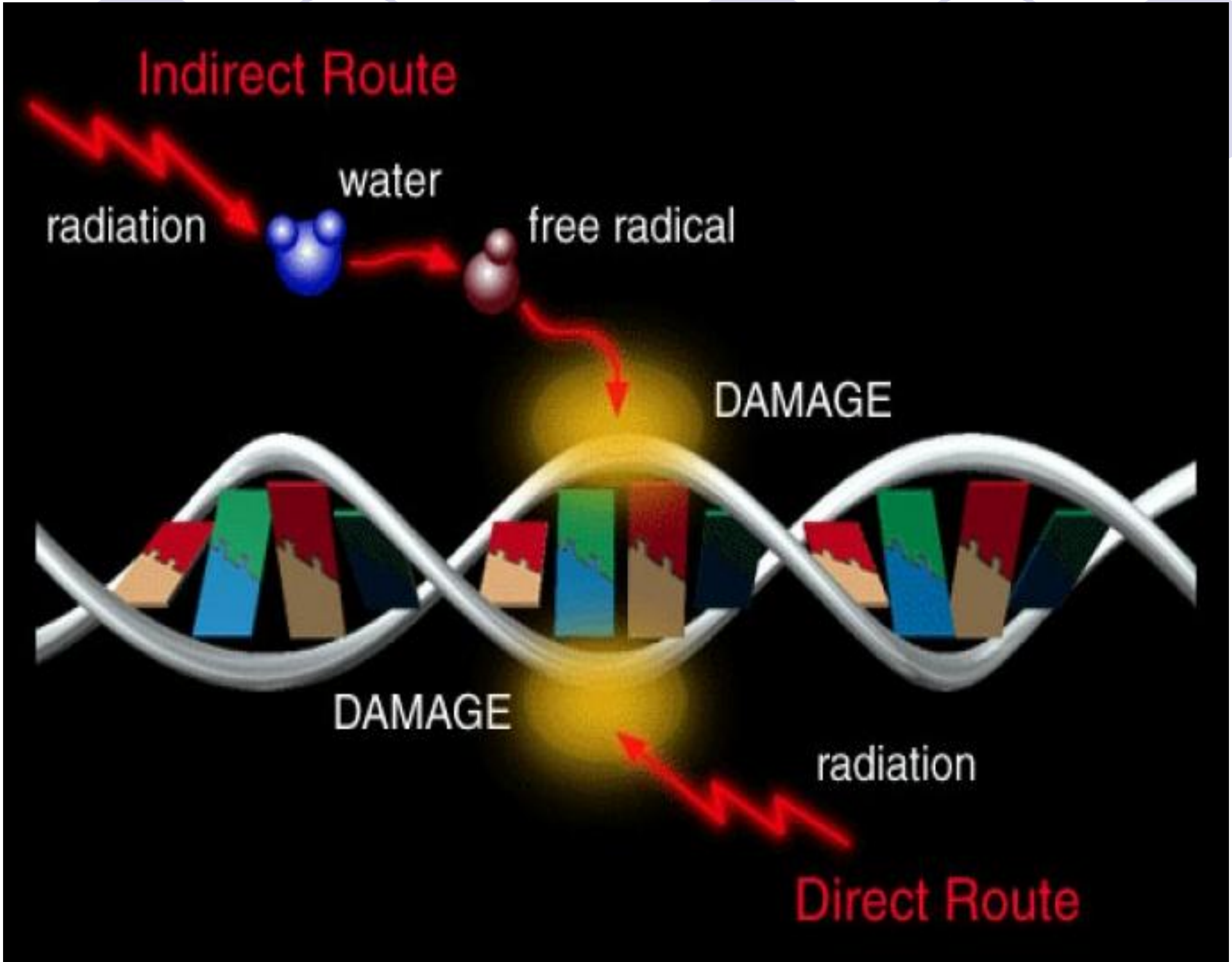
- However, when exist, as in high radiation fluence, orbital neutrality can be achieved by:

- hydrogen radical dimerization (H_2)
- the formation of toxic hydrogen peroxide (H_2O_2)
- the radical can also be transferred to an organic molecule in the cell

Ionizing radiation DNA damage

- active enzymatic repair processes exist for the repair of both DNA base damage and strand breaks, in many cases breaks in the double-strand DNA can be repaired by the enzymes, DNA polymerase, and DNA ligase
- the repair of double strand breaks is a complex process involving recombinational evens, depending upon the nature of the initial break

- residual unrejoined double strand breaks are lethal to the cell, whereas incorrectly recoined breaks may produce important mutagenic lesions, in many cases, this DNA disrepair apparently leads to DNA deletions and rearrangements; such large-scale changes in DNA structure are characteristic of most radiation induced mutations


Indirect Route
water
radiation
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DAMAGE
DAMAGE
radiation
Direct Route

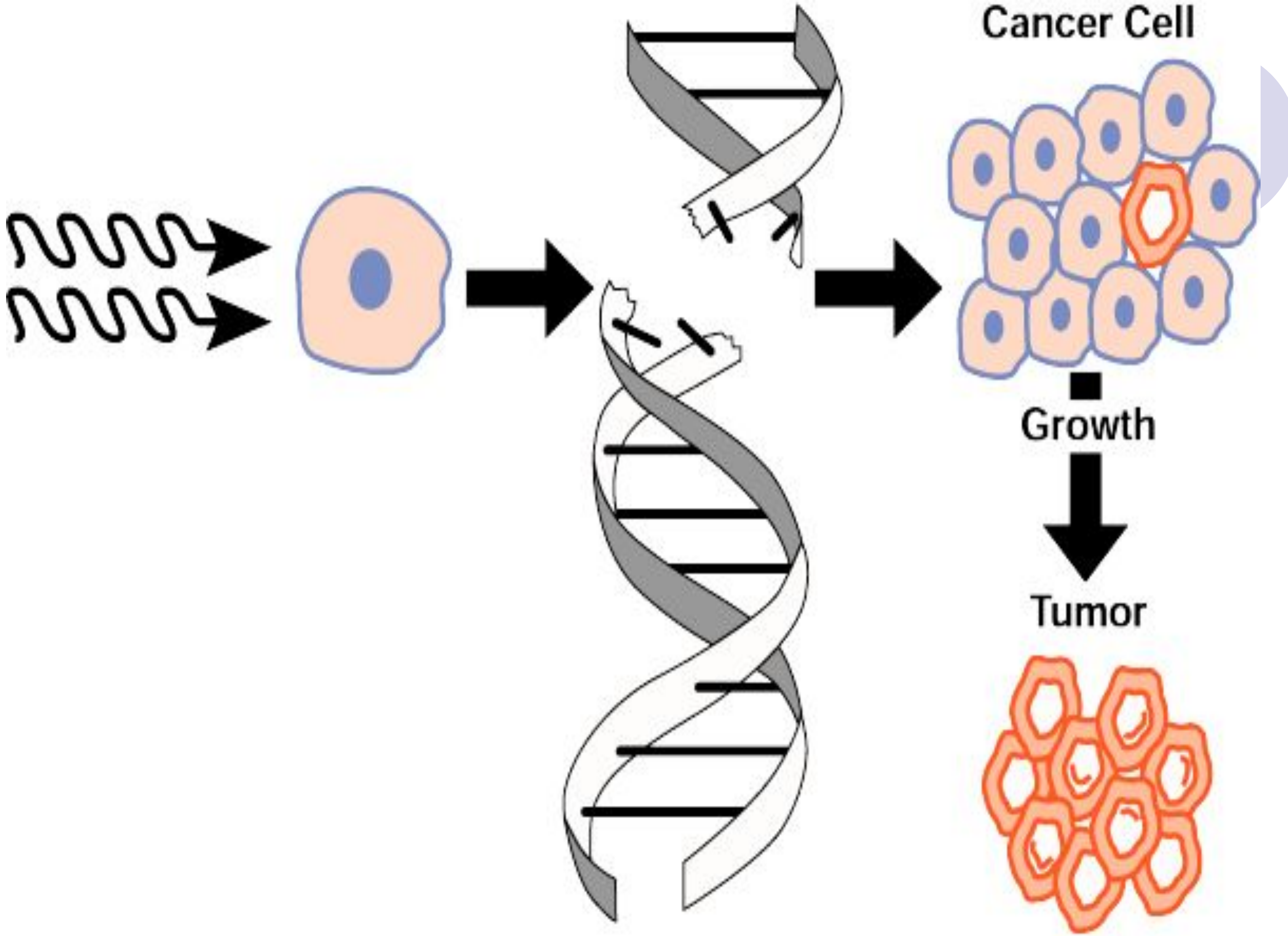


Figure 1. Development of cancer from mutation produced by ionizing radiation.

Stochastic effects

- Stochastic effects are those that occur by chance and consist primarily of cancer and genetic effects. Stochastic effects often show up years after exposure. As the dose to an individual increases, the probability that cancer or a genetic effect will occur also increases. However, at no time, even for high doses, is it certain that cancer or genetic damage will result. Similarly, for stochastic effects, there is no threshold dose below which it is relatively certain that an adverse effect cannot occur. In addition, because stochastic effects can occur in individuals that have not been exposed to radiation above background levels, it can never be determined for certain that an occurrence of cancer or genetic damage was due to a specific exposure.

- ***In summary, stochastic effects are:***

  - totally random (occur by chance)
  - appear in non-exposed persons as well as exposed persons
  - no threshold – any dose can cause an effect
  - the likelihood of an effect increases as the radiation dose increases, but a single photon can cause an effect
  - the severity of the response is independent of the dose (the severity of cancer is not associated with the amount of dose received. You are more likely to get cancer if you receive a higher dose, but the severity of the disease is not based on the dose)

Non stochastic effects (acute)

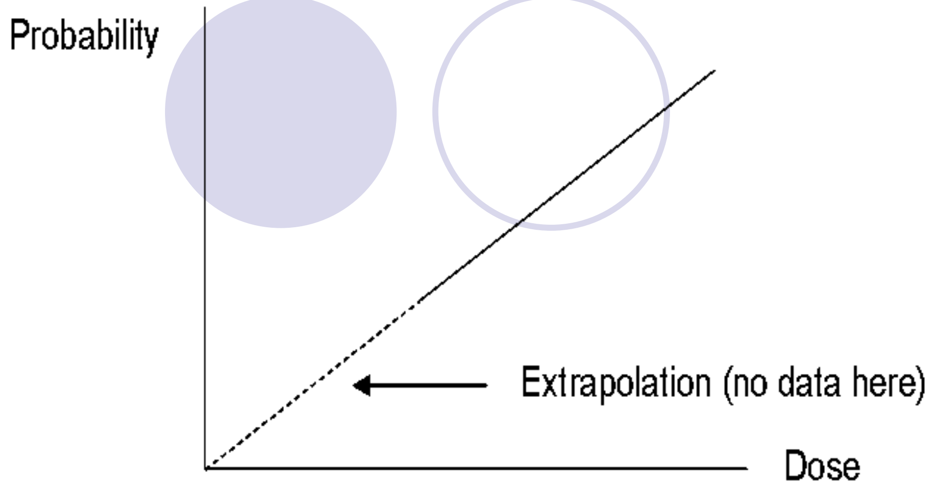
- Unlike stochastic effects, non stochastic effects are characterized by a threshold dose below which they do not occur. In other words, non stochastic effects have a clear relationship between the exposure and the effect. In addition, the magnitude of the effect is directly proportional to the size of the dose. Non stochastic effects typically result when very large dosages of radiation are received in a short amount of time. These effects will often be evident within hours or days.

- ***Examples of non stochastic effects include:***

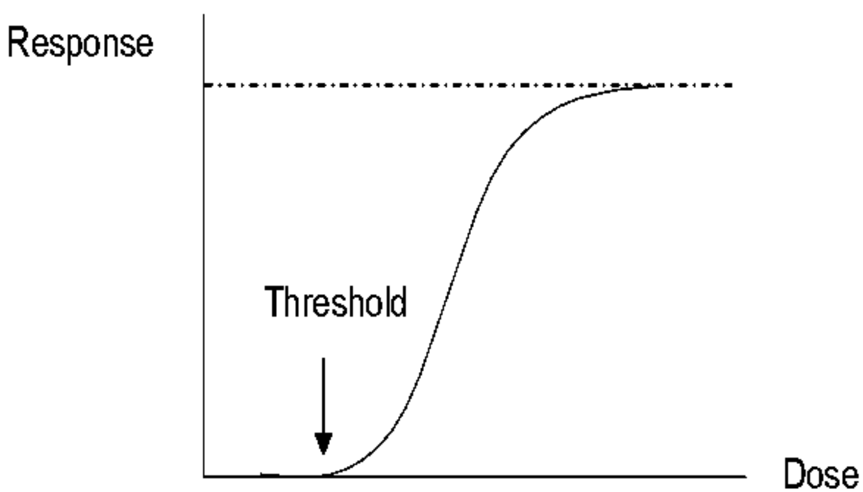
- erythema (skin reddening)
- skin and tissue burns
- cataract formation
- radiation sickness
- Death

- Each of these effects differs from the others in that both its threshold dose and the time over which the dose was received cause the effect.

- ***Summary of non stochastic effects:***
  - Threshold – a certain minimum dose must be exceeded before the particular effect is observed. Because of this minimum dose, the non stochastic effects are also called Threshold Effects. The threshold may differ from individual to individual.
  - The severity of the effect increases with the size of the dose received by the individual. More dose more severe effect)
  - There is a clear relationship between exposure to radiation and the observed effect on the individual.



Stochastic effects. As the dose increases, so does the probability of occurrence of a stochastic effect (e.g. cancer)



Deterministic effects. As the dose increases, so does the severity of a deterministic effect, e.g. skin reddening. Note the threshold dose for deterministic effects.

Threshold for deterministic effects (Gy)

	Effects	One single absorption (Gy)	Prolong absorption (Gy-year)
Testis	Permanent infertility	2.5 - 6.0	2
Ovary	Permanent infertility	2.5 - 6.0	>0.2
Lens of eyes	Milky of lens cataract	0.5 – 2.0 5.0	>0.1 >0.15
Bone marrow	**Blood forming deficiency**	0.5	>0.4

Teratogenic effects

- Teratogenic effects are effects from some agent that are seen in the offspring of the individual who received the agent. The agent must be encountered during gestation period.

Somatic effects

- Somatic effects are effects from some agent, like radiation that are seen in the individual who receives the agent.

Genetic effects

- Genetic effects are effects from some agent that are seen in the offspring of the individual who received the agent. The agent must be encountered pre-conception.

This chest burn was produced when a powerful radiation source was placed in a shirt pocket.

This damage was caused by handling a powerful radiation source, without protection.

These burns are on the legs of a fireman who was involved in the aftermath of the Chernobyl accident, and were caused by beta radiation.