

# Radiation safety for users of neutron facilities

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# History

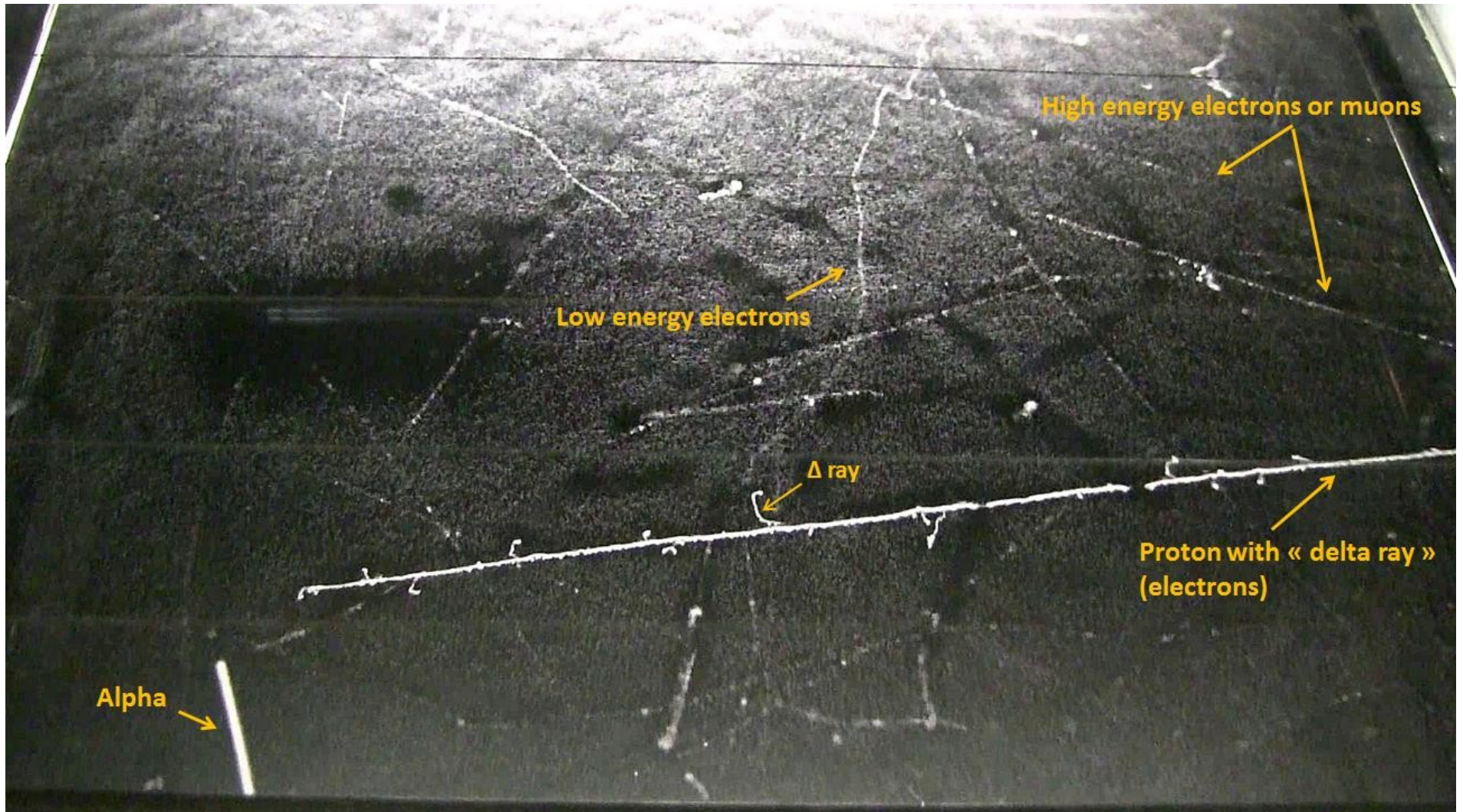
- 1895 – Wilhelm Röntgen discover the X-rays while experimenting with vacuum tubes
- 1896 – Becquerel discovers natural radioactivity in uranium containing salts
- 1897 – Thomson discovers the electrons
- 1898 – Marie and Pierre Curie isolates polonium and radium
- 1902 – Rutherford and Soddy discover the chemical change of alpha and beta emitting materials
- 1911 – Rutherford suppose the existence of the nucleus
- 1914-1918 Röntgen automobiles in WW I.
- 1928 – Müller discovers that mutations can be induced by X-rays in flies
- **1928 – Establishment of the first organization for radiation safety (predecessor of ICRP: International Commission of Radiation Protection)**
- 1931 – Walter Boethe and Herbert Becker found a penetrating radiation when bombarding light elements with alpha particles. Originally thought as X-rays.
- **1932 – James Chadwick discovers the neutrons (beryllium bombarded with alpha particles from polonium)**

# History

- 1938 – Otto Hahn, Fritz Strassman and Lise Meitner discover the fission of nuclei
- 1939 – Leo Szilárd patents the nuclear chain reaction
- **1942 – Fermi starts Chicago Pile-1, the first critical system**
- 1945 – Hiroshima, Nagasaki
- 1956 – First nuclear power station (Calder Hall, UK)
- 1956 – Establishment of International Atomic Energy Agency (IAEA)
- **1959 – Budapest Research Reactor went critical**
- 1967 – ILL was founded
- 1979 – Accident in the Three Mile Island nuclear power station (marginal contamination released to the environment)
- 1986 – Chernobyl: due to the absence of containment high amount of radioactive isotopes was released
- 2011 – Fukushima

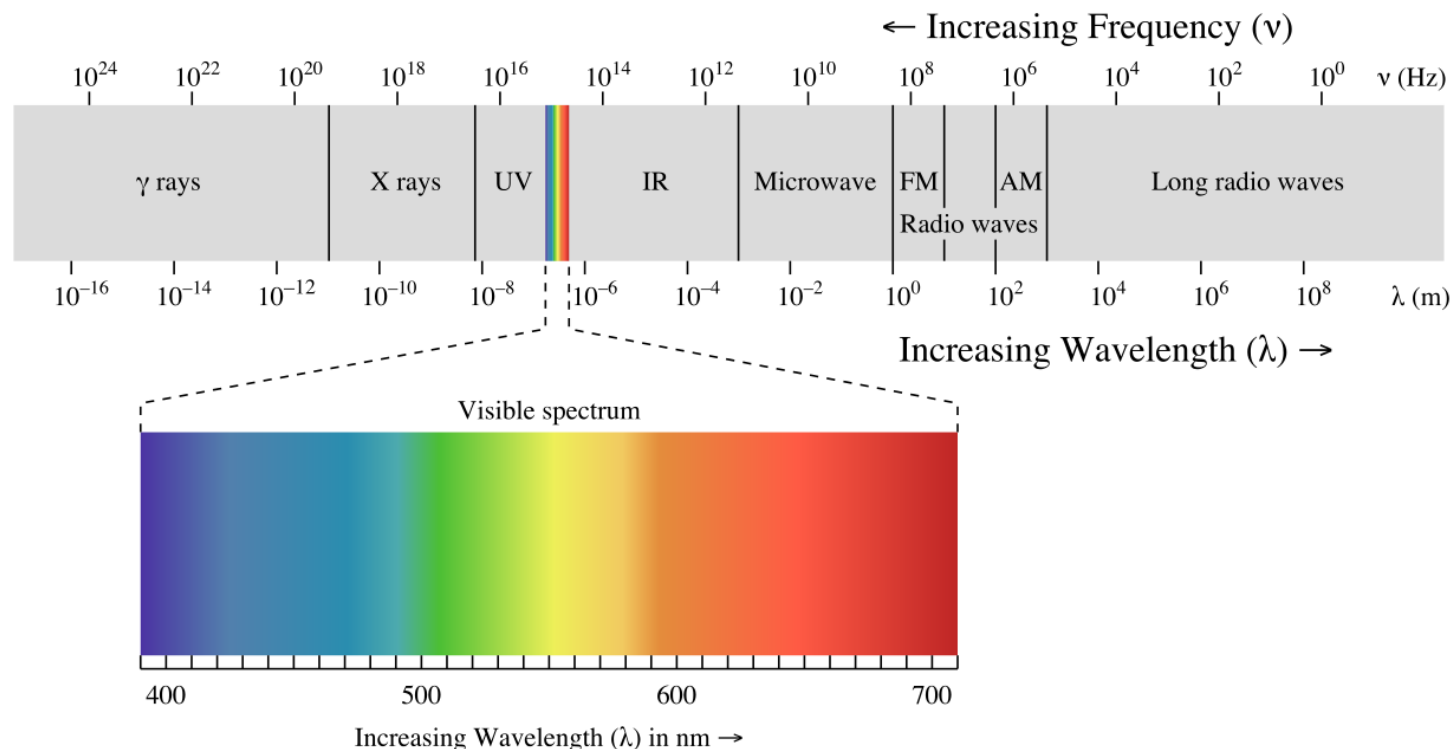
# Radiation types

Different radiations in a cloud chamber:



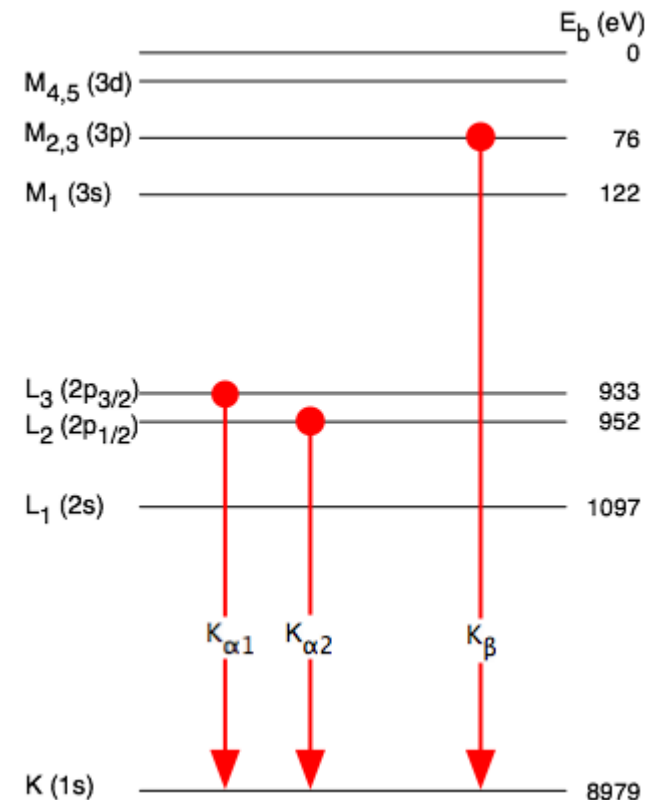
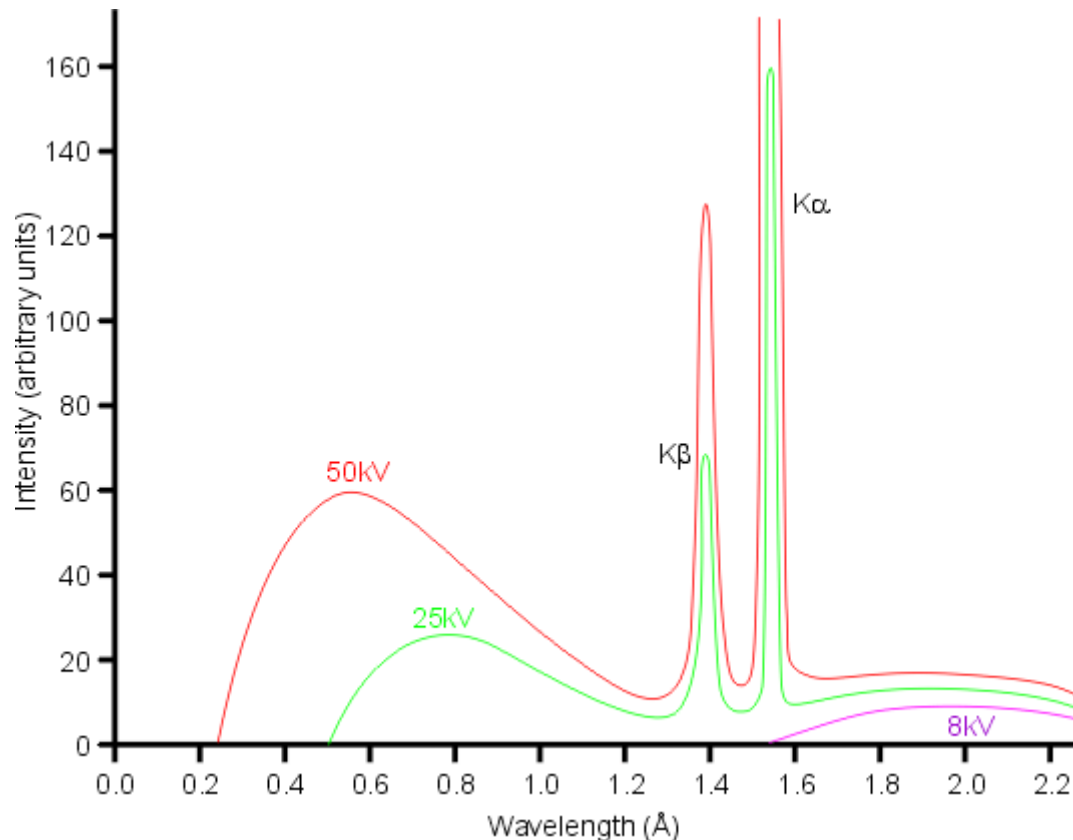
# X-ray and gamma-radiation

- Parts of the electromagnetic spectrum.
- Separation by energy or source:
  - X-rays: 1keV – 100 keV; emission from electrons outside the nucleus
  - Gamma-rays:  $E > 100$  keV; emitted from the nucleus

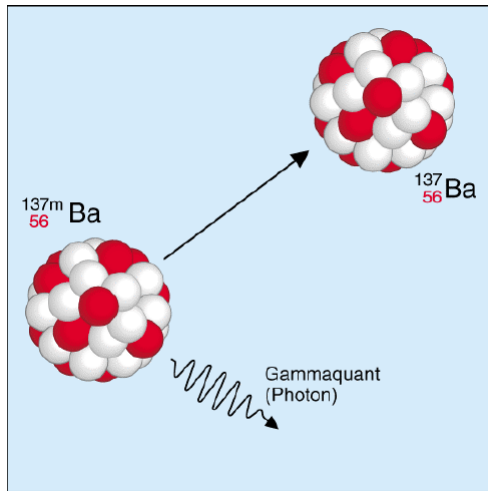




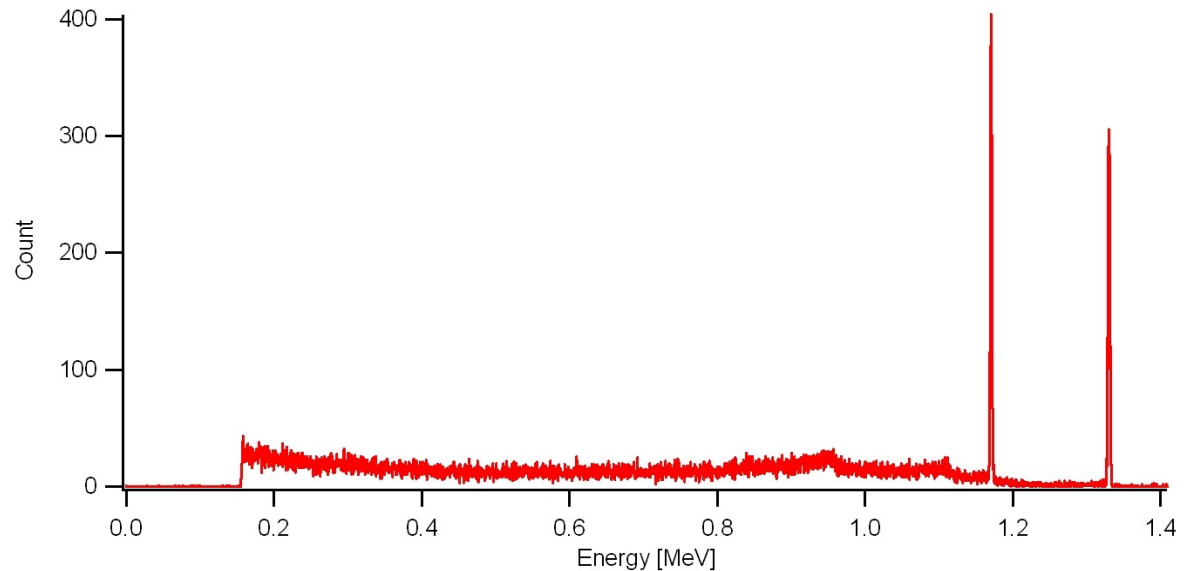
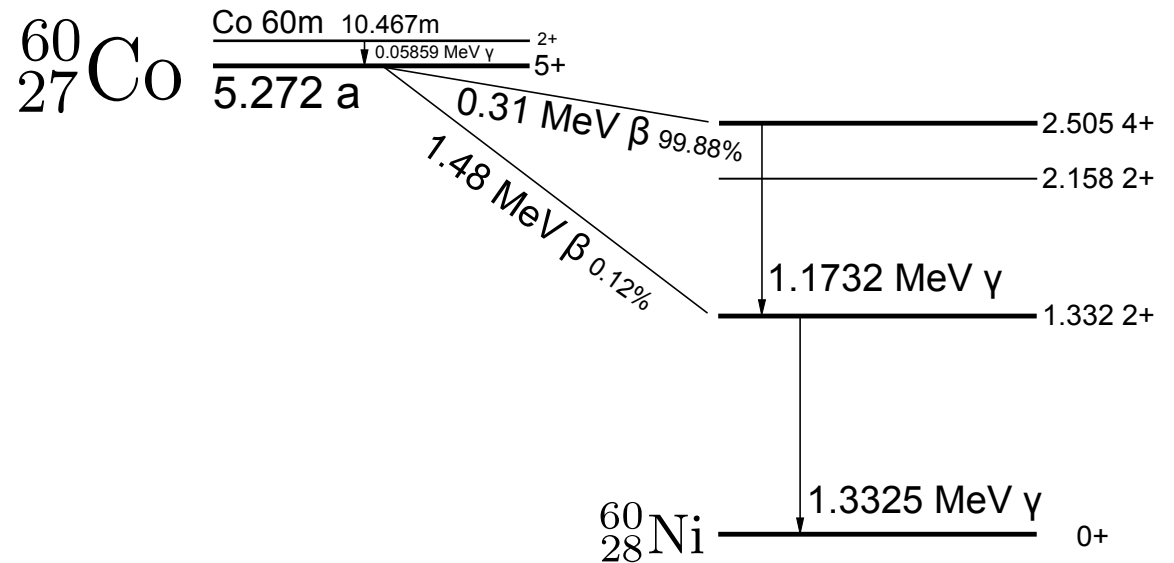
- **X-rays** are generated when energetic electrons hit a metal target and slow down (X-ray tubes)
  - Bremsstrahlung: Continuous spectrum
  - Fluorescent radiation: an electron is kicked out from an inner shell and the hole is filled by an outer electron



- **Gamma radiation** is emitted when an excited nucleus change the energy level
  - Characteristic energy



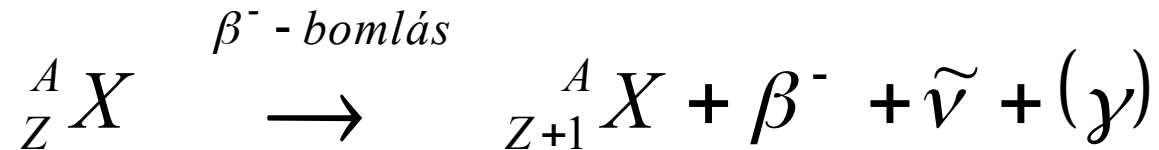
**Shielding:**  
Elements with high  
atomic number: Pb, W



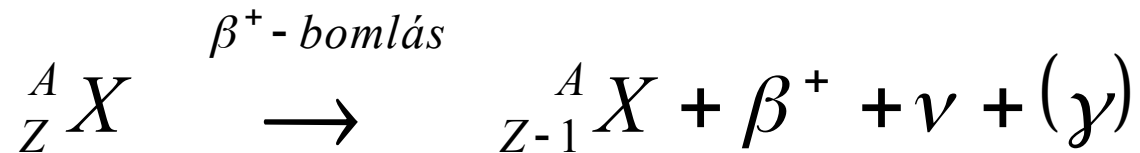


# Beta radiation

**Beta decay:** A neutron in the nucleus is transformed to a proton; an energetic electron and an antineutrino is released:



**Positive beta decay:** A proton of a nucleus is transformed to a neutron; an energetic positron and a neutrino is released:



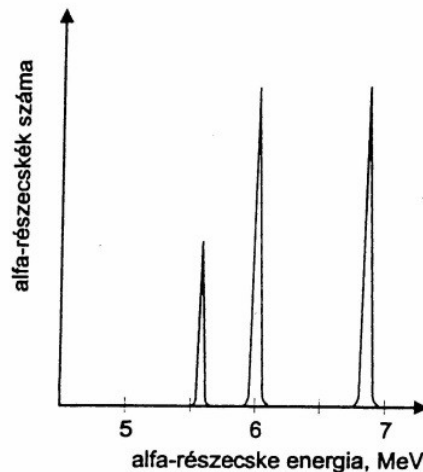
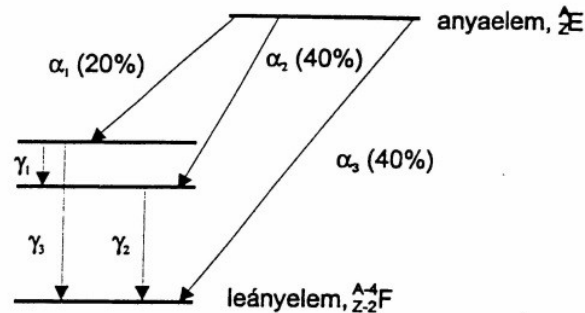
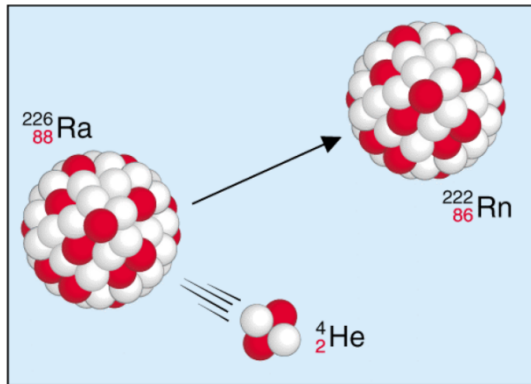
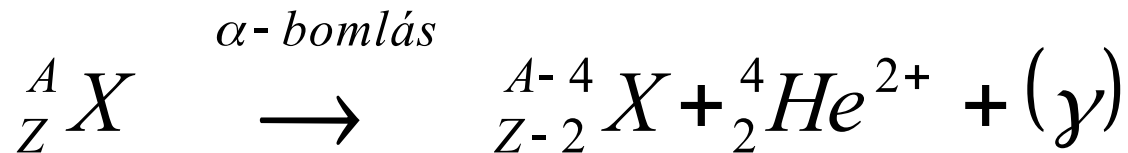
- Often, the nucleus remains in an excited state -> gamma emission!
- Spectrum is continuous because of the (anti)neutrino

## Shielding:

- Short free path in condensed matter
- Shielding with low-Z metals e.g. Al (Pb generate Bremsstrahlung)

# Alpha radiation

**Alpha decay:** Heavy elements decay by the emission of a  ${}^4\text{He}$  nucleus



Egy jellegzetes alfa-bomlás séma és energia spektrum

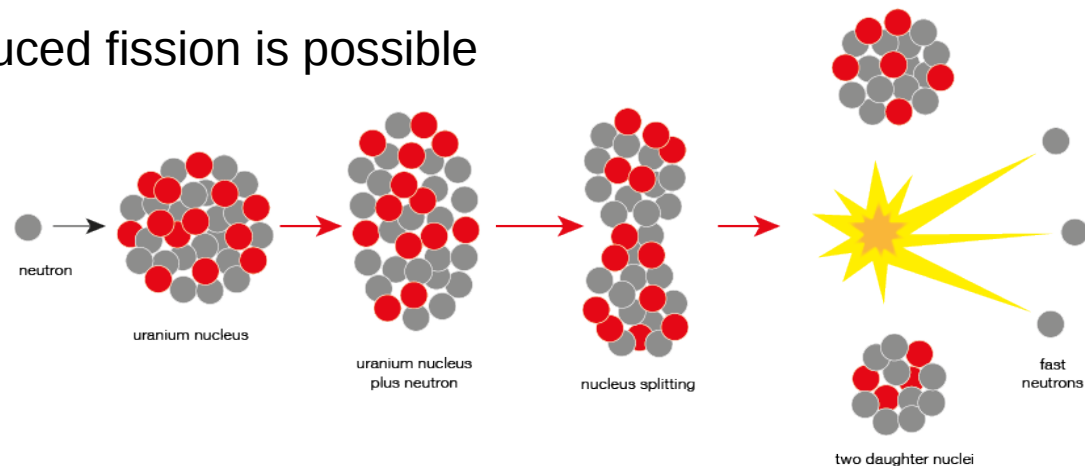
## Shielding:

- Very short free path
- Thin condensed matter stops the alpha-particle e.g. a sheet of paper

# Neutron radiation

**Neutron decay:** E.g.  $^{13}\text{Be}$  decays by ejecting a neutron, but in practice, fission reactions are more common sources of neutron radiation.

**Fission:** Spontaneous or induced fission is possible



**Spallation:** A heavy nucleus emit neutrons after collision with high energy protons.

**Shielding:** Neutron adsorbing materials are: *Cd, B, Gd, Li*

- Additional shielding of the produced gamma radiation may be necessary
- Shielding of fast neutrons may need the use of hydrogen containing material to slow down the neutrons to thermal energy.
- (Heavy)Concrete is a good material for neutrons and gamma photons

# Activity

The strength of a source is described by its activity.

$$A = \frac{dN}{dt}$$

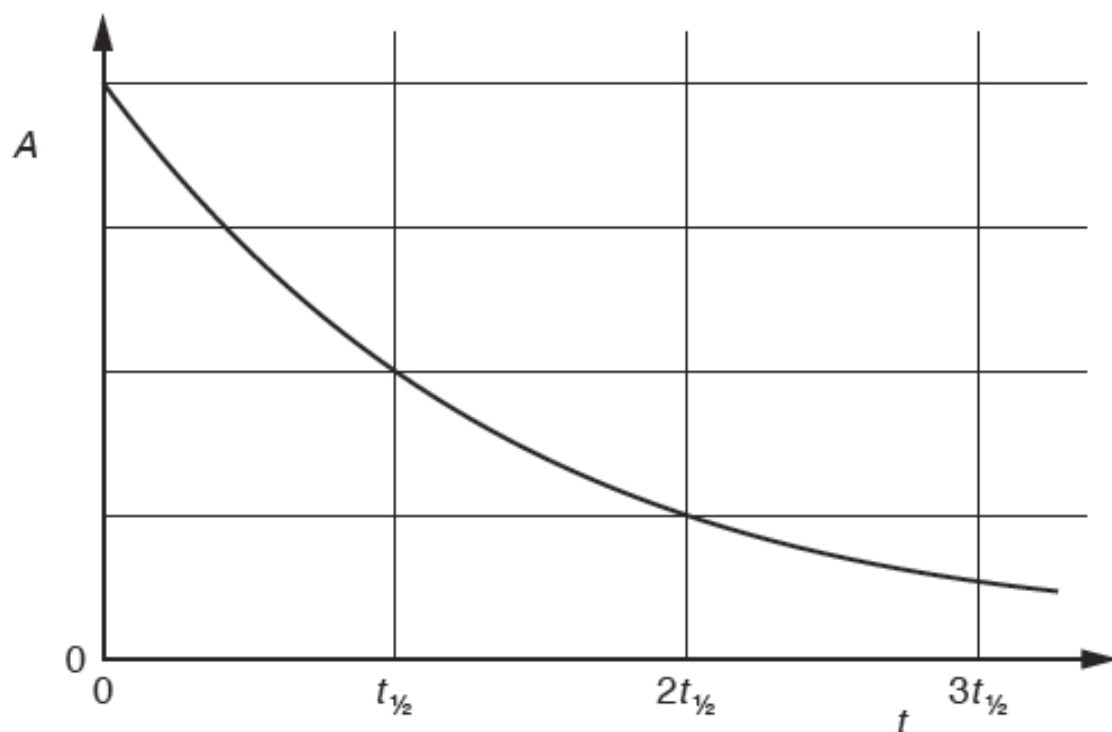
1Becquerel [Bq] = 1 decay / second

Activity in the function of time:

$$A = A_0 e^{-\lambda t}$$

$$\lambda = \frac{\ln 2}{T_{1/2}}$$

Rule of thumb: Activity drops below 1%  
in 7 half lives



# Measures of dose

Activity describe the source only, the various dose quantities can be connected to health effects.

## Absorbed dose:

$$D = \frac{dE}{dm} [Gy] \qquad 1 Gy = \frac{1 J}{1 kg}$$

- Radiation type is not taken into account!

**Equivalent dose:** Takes into account the type of radiation because the efficiency for ionization is different

$$H_T = \sum_R w_R D_{T,R}$$

Radiation weight factor

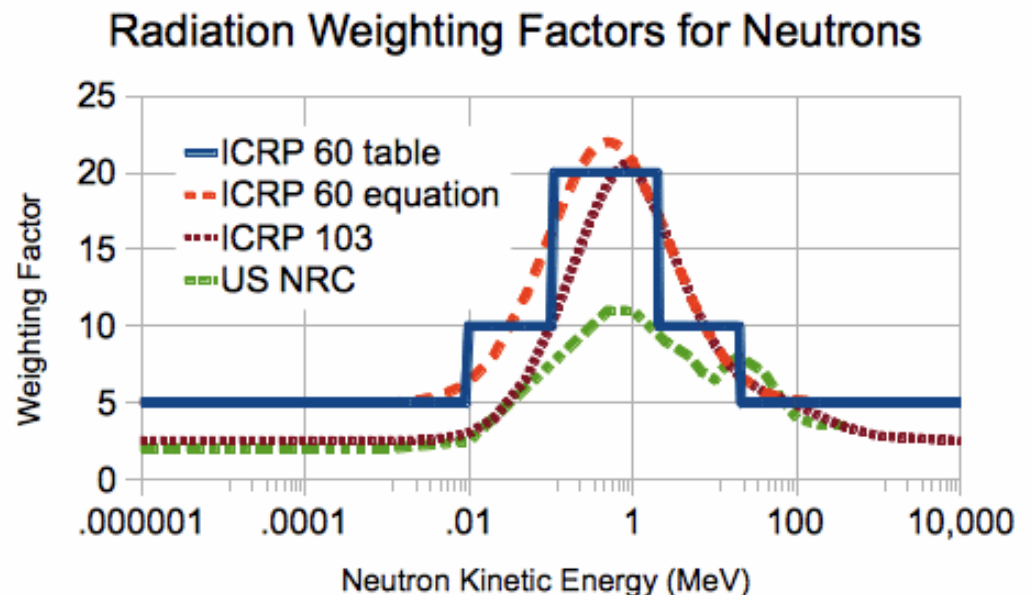
Absorbed dose of radiation R, in tissue T

# Measures of dose

Radiation type and energy	Weight factor $w_R$
Gamma photons, X-rays, electrons, muons	1
Neutrons: <1 MeV	$2.5 + 18.2 \cdot \exp(-[\ln(E)]^2/6)$
1-50 MeV	$5 + 17 \cdot \exp(-[\ln(2E)]^2/6)$
>50 MeV	$2.55 + 3.25 \cdot \exp(-[\ln(0.04E)]^2/6)$
Protons	2
Alpha particles, fission products, heavy nuclei	20

ICRP 103, (2007)

Equivalent dose can be used if the whole body is irradiated!



# Measures of dose

The **effective dose** has to be used if the organs are not uniformly irradiated and the damage has to be described by one number.

$$E = \sum_T w_T H_T [Sv]$$

Organ	w <sub>T</sub>	Organ	w <sub>T</sub>
Gonads	0.08	Oesophagus	0.04
Red Bone Marrow	0.12	Thyroid	0.04
Colon	0.12	Skin	0.01
Lung	0.12	Bone surface	0.01
Stomach	0.12	Salivary glands	0.01
Breasts	0.12	Brain	0.01
Bladder	0.04	Remainder of body	0.12
Liver	0.04	<b>TOTAL</b>	<b>1.00</b>

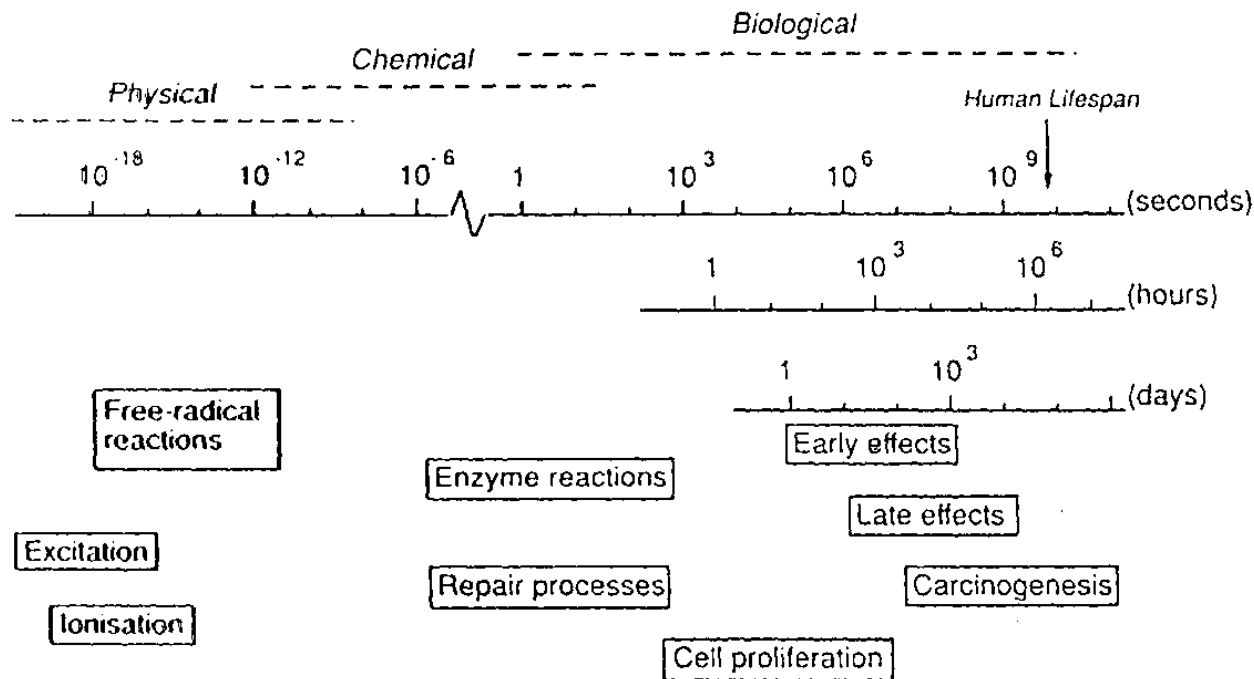
Equals to the effective dose distributed uniformly which has the same risks as the risk of the irradiation of tissues.



# Effects of ionizing radiations

- Ionizing radiation can be found everywhere in nature.
- The body has mechanisms to repair the radiation damage.
- Ionizing radiation transfer energy to the tissues like radiating heat but due to the high energy concentration chemical changes are possible
- Ionization, production of free radicals
- Damage of the DNA molecule

THE TIME-SCALE OF RADIATION EFFECTS



# Risks of radiations

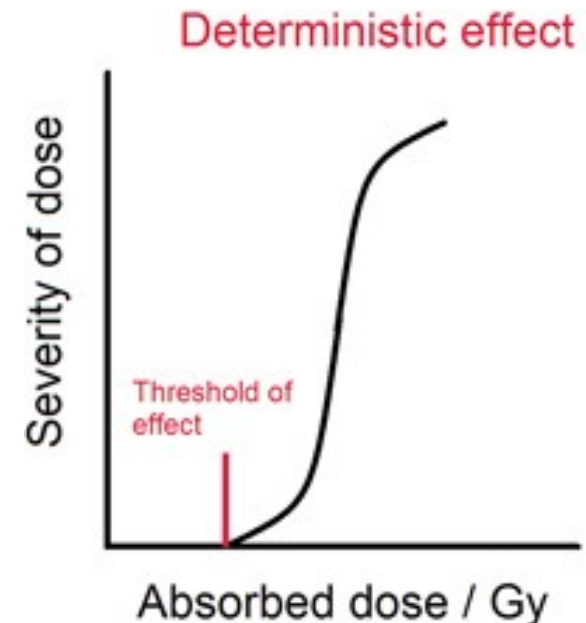
Effects of radiations can be divided into two categories by the probability of effects:

## Deterministic effects:

- Significant number of cells is killed leading to functional loss of an organ
- Functional changes in nervous system, digestive system, blood system

Connection with dose:

- Cells can be replaced to some extent → threshold dose
- After exceeding the threshold, the severity of consequences increase
- When dose limits are exceeded considerably
- 50% lethality in 30 days: 3-5 Gy (whole body)
- Used in radiotherapy



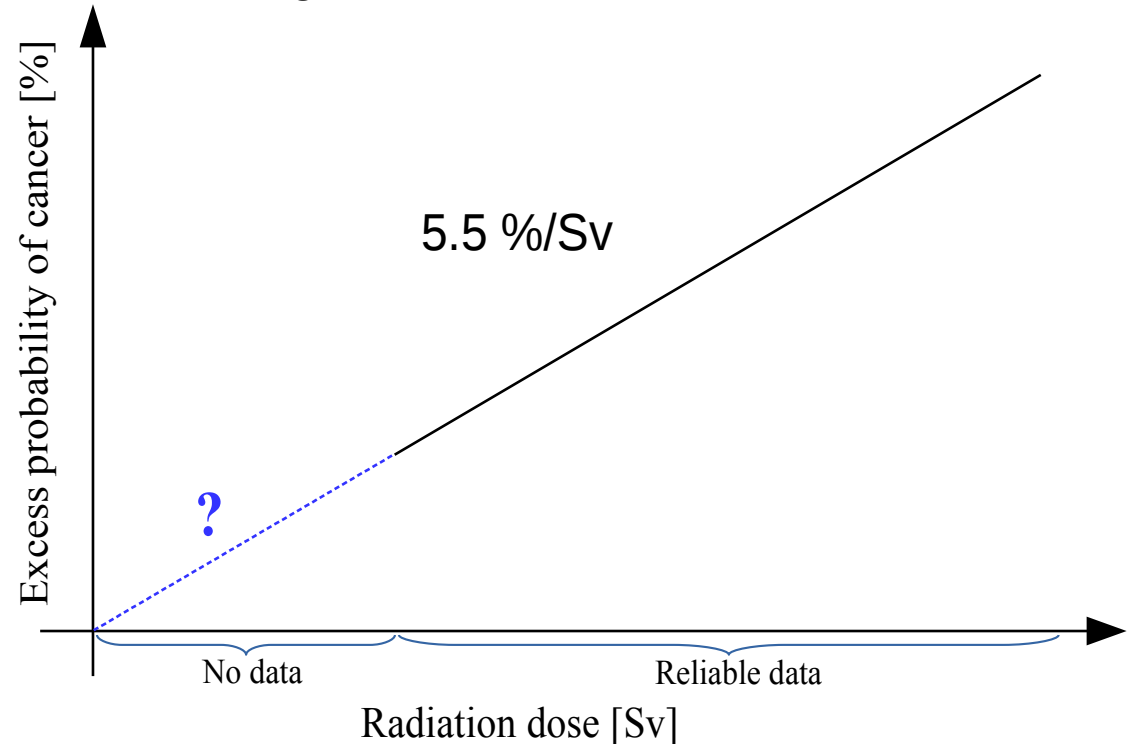
# Risks of radiations

## Stochastic effects:

- Changes in the DNA of one cell
- Cancer if the repair mechanisms of the body fail to detect and kill the cell

## Connection with dose:

- Difficult to measure the effects of low doses
- Consensus is that no threshold exist
- The probability of the effect depends linearly on dose, the severity not
- Risk of cancer: 5.5%/Sv, risk of heritable changes: 0.2%/Sv



# Natural and artificial background

Sources:

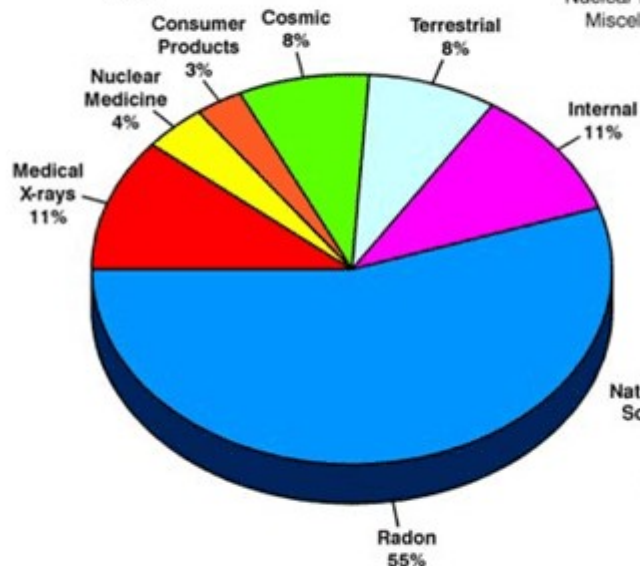
- Earth (uranium, thorium)
- Cosmic radiation
- Internal (mainly 40-K)
- Artificial

2.4 mSv/year  
3  $\mu$ Sv/hour

## Ionizing Radiation Exposure to the Public

Man Made Radiation Sources – 18%

Medical X-rays  
Nuclear Medicine  
Consumer Products  
Other

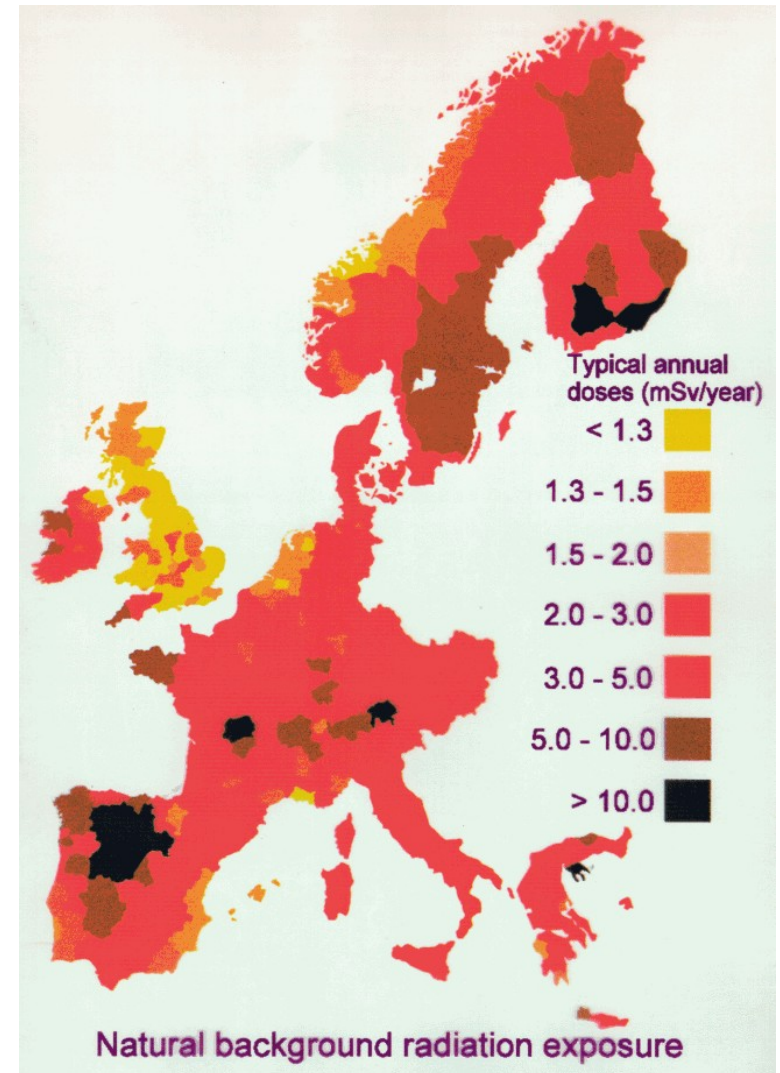


Other – <1%  
This Includes:  
Occupational – 0.3%  
Fallout – <0.3%  
Nuclear Fuel Cycle – 0.1%  
Miscellaneous – 0.1%

Natural Radiation  
Sources – 82%  
Radon  
Internal  
Terrestrial  
Cosmic

The above chart is taken from the National Council on Radiation Protection and Measurements (NCRP) Report No. 93, "Ionizing Radiation Exposure of the Population of the United States," 1987.

This chart shows that natural sources of radiation account for about 82% of all public exposure while man-made sources account for the remaining 18%.



Artificial sources: 0.6 mSv/year world average, in developed countries 3 mSv can be reached!!

# Principles of radiation protection

3 principles: justification, optimization, limitation

**Principle of justification:** The application has to have more benefit for the exposed individual or the society than the detriment of the exposition and all costs, including radiation protection. Example: bone X-ray

**Principle of optimization:** If the use of ionizing radiation is justified then the excess dose due to the application and the release of radioactive materials has to be reduced by applying all reasonable methods.

The dose is optimized if: As Low As Reasonably Achievable (ALARA)

**Principle of limitation:** Effective dose of individuals must remain below the recommended dose limits (but ALARA has to be applied):

- Public: 1 mSv
- Radiation workers: 20 mSv averaged in 5 years but not exceeding 50 mSv in any one year period

Exception: radiotherapy and emergency situations.

# Protection

## **TIME**

- Dose is proportional to time of exposition
- Rehearsal with inactive sample
- Only those activities are allowed which can not be done elsewhere
- Cheap way but hard to gain orders of magnitudes

## **DISTANCE**

- Dose rate  $\sim 1/r^2$  for a point source
- Pair of pincers, manipulators
- Forbidden to hold sources in hand

## **SHIELDING**

- Must be designed for the radiation characteristics (type, intensity)
- Neutrons: sandwich-type

# Rules at Budapest Research Reactor

## **General:**

- The safety of the experiments is the responsibility of the leader of the experiment.
- Visitors are obliged to follow the instructions of the supervisor.
- When leaving the reactor hall and the reactor building contamination has to be checked with the installed instruments at the gates.

## **Clothing:**

- Trousers, closed shoes!
- Lab coat and overshoes in the Reactor Hall.

## **Open/close the beam ports:**

- Red, white and green lamps show the status of beam shutters.
- Beams can be opened after permission is given from the radiation safety group
- GREEN: shutter closed
- GREEN and WHITE: shutter closed permission is given
- WHITE: opening of the beam is in progress
- RED: beam opened, entry is forbidden

## **Activation:**

- Samples can be activated in the neutron beam.
- Usually decay is fast
- Check with GM counter, call radiation safety group if unsure.
- Always check samples before taking them home!!



Thank you for your attention!