5) Measurement of Nuclear Radiation (1)

Registration of interactions between nuclear radiation and matter
Universal principle: Measurement of the ionisation

Measurement of the ionisation
- measurement of the dose, equivalent dose etc.
- important for the radiation protection

Measurement of gamma spectra
- gamma spectrometry
- specific nuclide analytics

Measurements of neutrons by indirect methods
- nuclear reactions produce radioactive nuclides (fission products, neutron capture products)
- measurement of the radioactivity of the products

5) Measurement of Nuclear Radiation (2)

Units

Activity

$$\text{Activity} = \frac{\text{Number of Disintegrations}}{\text{time}}$$

Volume of air	Natural Activity in Bq (Mean values)
1 m^3	50
62,5 m^3 (appartment 5 m · 8 m · 2,5 m)	3125
240 m^3 (class room 10 m · 8 m · 3 m)	12 000
6000 m^3 (sports hall 20 m · 30 m · 10 m)	300 000
1 human	≈ 7 400

SI Unit:
1 Bq (Bequerel) = 1/s

Old unit:
Ci (Curie)
1Ci = 3.7 x 10^{10} Bq

Specific activity

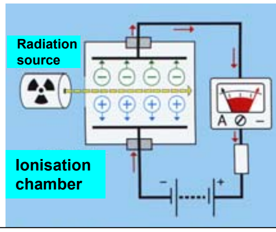
Activity per mass, Bq/g; area or Bq/cm^2; volume Bq/cm^3

5) Measurement of Nuclear Radiation (3)

Units
Ion dose

$$\text{Ion dose} \quad I = \frac{\text{produced charges}}{\text{Mass of irradiated air}}$$

$$I = \frac{\Delta Q}{\Delta m}$$



- Measurement of the ionisation in an ionisation chamber
- gasfilled container with a window of thin material
- electric current is produced by ions which are produced by the influence of radiation

SI Unit:

$$I = \frac{C(As)}{kg} = 6{,}25 \cdot 10^{18} \frac{\text{Ion pairs}}{\text{kg air}}$$

Old unit:

R (Roentgen)

$$1R = \frac{2{,}58 \cdot 10^{-4}\,C}{\text{kg air}} \qquad 1\frac{C}{\text{kg air}} = 3{,}88 \cdot 10^{3}\,R$$

5) Measurement of Nuclear Radiation (4)

Units
Energy dose

$$D = \frac{\text{absorbed radiation energy}}{\text{mass}} \qquad D = \frac{\Delta W}{\Delta m}$$

- the formation of 1 ion pair requires 34 eV
- with this information we have a direct information about the transfered energy

SI Unit:

1 Gy (Gray)

1 Gy = 1 J/kg

Old unit:

rd (rad)

1rd = 10^{-2} Gy

5) Measurement of Nuclear Radiation (5)

Units

Equivalent dose

Damage of organic material (tissue) can only be expected when the energy is absorbed by the tissue (Interactions radiation -matter)

The bigger the absorption is, the bigger is the impact

Highly ionising radiation have a higher impact than weakly ionsing **(α > n > β, γ, X-ray)**

Energy dose exclusively reflects the pure energy value (not the impact)

Equivalent dose $\mathbf{H = D \cdot W}$

W = Weighting factor of the radiation

SI Unit:

1 Sv (Sievert)

1 Sv = 1 J/kg

Old unit:

1 rem

1 Sv = 100 rem

5) Measurement of Nuclear Radiation (6)

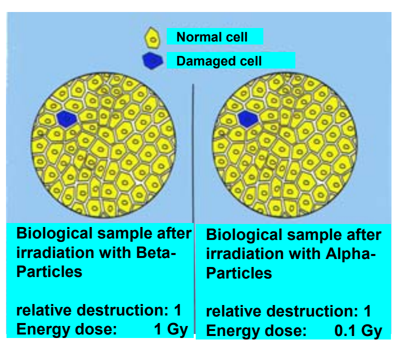
Units

Equivalent dose

Equivalent dose $\mathbf{H = D \cdot W}$

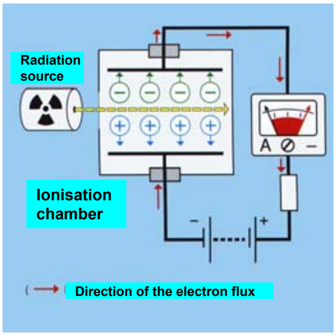
W = Weighting factor of the radiation

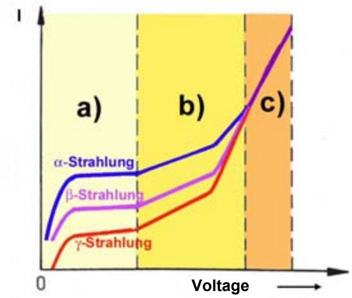
Radiation types	W
X-rays, γ- and ß-radiation	1
Neutron radiation	between 5 and 20
α - radiation	20



5) Measurement of Nuclear Radiation (7)

Principle of a gas-filled detector





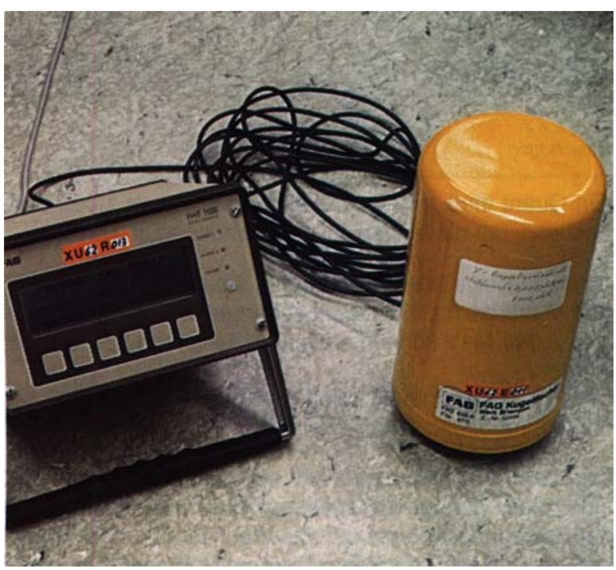
- Ionisation of gas atoms/molecules by radiation
- three detector types are possible depending on the voltage applied
  a) **Ionisation chamber** (current/signal depends on type and intensity of the radiation)

  b) **Proportional counter** (signal amplification by a factor of about 1000, secondary ionisation, signal is proportional to the energy of the radiation)

  c) **Geiger-Mueller counter** (any radioactive particle or quant leads to a cascade of ions, signal in independent of type and energy of the radiation)

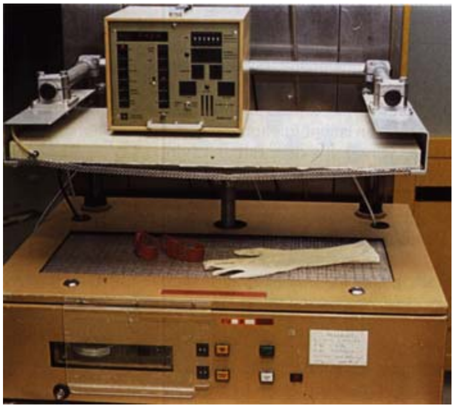
5) Measurement of Nuclear Radiation (8)

Ionisation Chamber



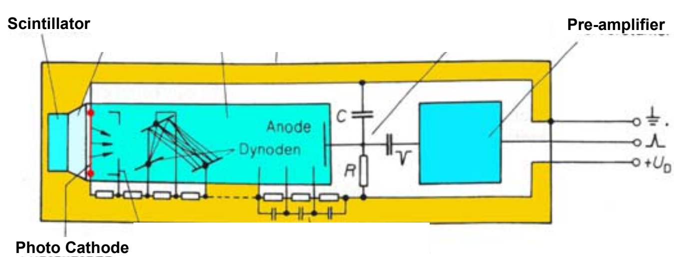
5) Measurement of Nuclear Radiation (9)

Various Geiger-Mueller Counters



5) Measurement of Nuclear Radiation (10)

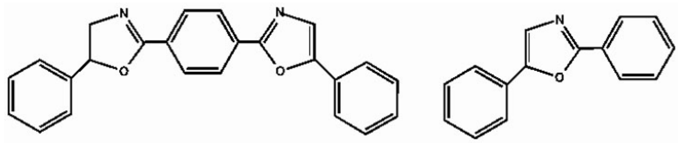
Scintillation detector



- Production of light impulses in a light-sensitive material (scintillator)
- Appropriate scintillator materials Na(Tl)I, Cs(Tl)I, Zn(Ag)S, anthracen etc.
- Amplification of the signals by a photo-multiplier
- Measuring range: 1 nSv/h ... 10 mSv/h

5) Measurement of Nuclear Radiation (11)

Liquid Scintillation

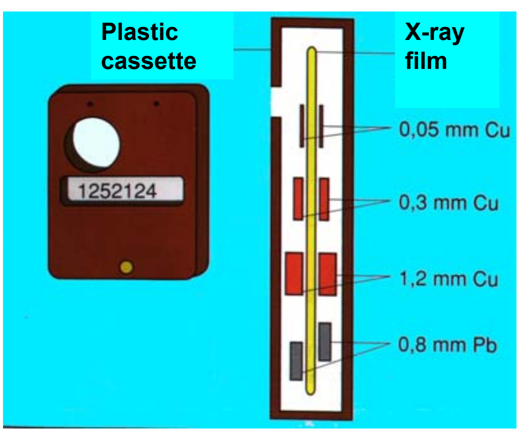


1,4-Bis-(5-phenyl-2-oxazolyl)benzol (POPOP) 2,5-Diphenyloxazol (PPO)

- Scintillator material is an organic molecule which is dissolved in an appropriate solvent
- The same principle as solid state scintillation measurements
- highly sensitive method for the determination of trace amounts of ß-radiation
- Low-level measurements down to 1 Bq

5) Measurement of Nuclear Radiation (12)

Chemical Detectors



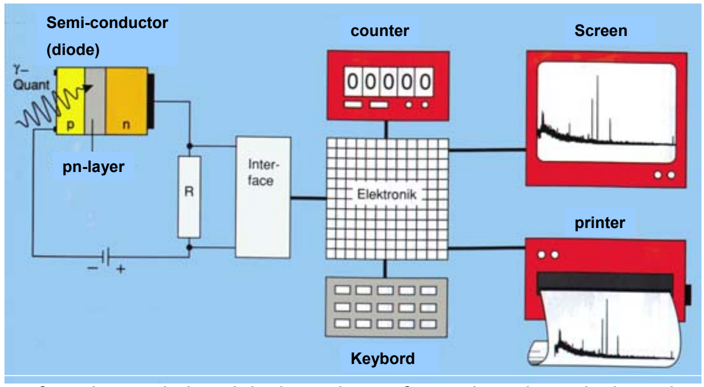
Simple Principle:

- Darkening of an X-ray film
- Energy dependence due to different absorber materials

- Measuring range: 0,2 mSv ... 10 Sv

5) Measurement of Nuclear Radiation (13)

Gamma Spectrometry

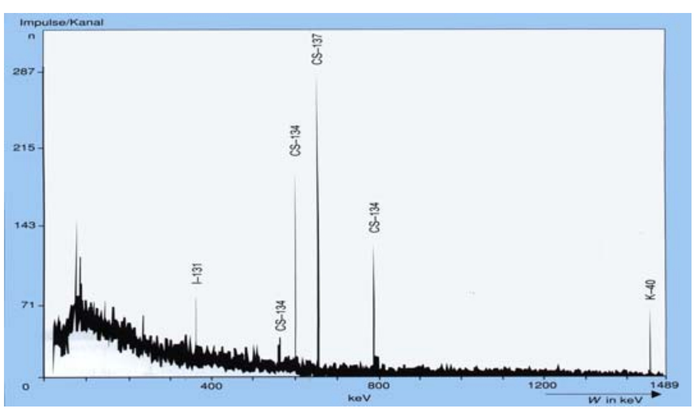


- Formation of an electron-hole pair in the pn layer of a semi-conductor by incoming γ -quants
- registration of the electric signal
- impulse amplitude is proportional to the intensity
- multichannel solution allows resolution of the energy (gamma spectrum)
- very sensitive method
- often used for the measurement of environmental radioactivity

5) Measurement of Nuclear Radiation (14)

Gamma Spectrometry Example 1

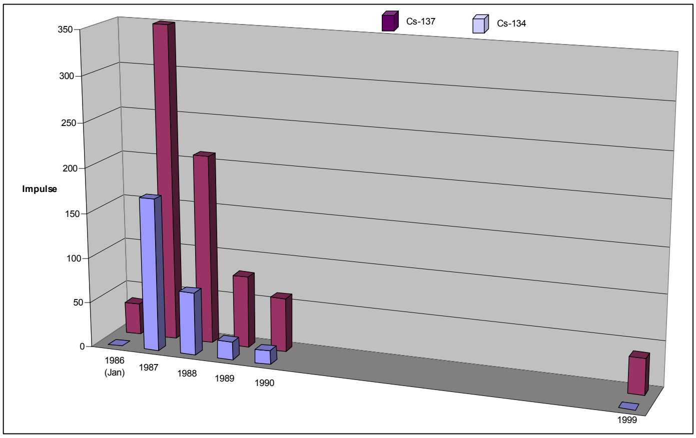
Gamma-spectrum of cheese (Hamburg, 26.6.1986)



Tschernobyl desaster: 26. April 1986 !!!

5) Measurement of Nuclear Radiation (15)

Gamma Spectrometry Example 2



Monitoring of persons:

Body counting of a co-worker of the Radiochemistry group of the FU Berlin

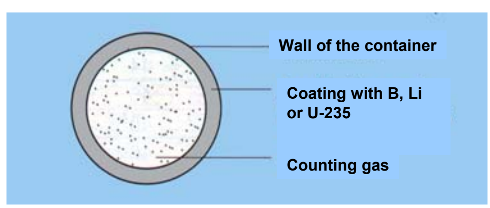
Tschernobyl desaster: 26. April 1986 !!!

5) Measurement of Nuclear Radiation (16)

Instruments for neutron counting

- counting facility is desingned in a way that ionising radiation can be produced as a results of nuclear reactions

- possibilities: coating of the container with boron, lithium or uranium-235 or use of bortrifluoride (BF_3) as counting gas



Nuclear reactions:

$$^{10}_{5}B + ^{1}_{0}n \rightarrow ^{7}_{3}Li + ^{4}_{2}He$$

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{236}_{92}U \rightarrow ^{144}_{56}Ba + ^{89}_{36}Kr + 3\ ^{1}_{0}n$$