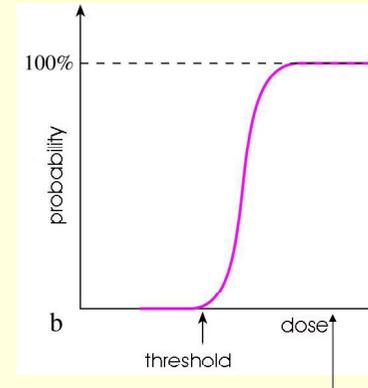


## Types of damages

*Deterministic damages*

*Stochastic damages*

## Deterministic damages



**Gy**

**Under threshold:  $p=0$**

## Deterministic damages

A threshold dose exists - No risk below threshold doses.

Above threshold severity depends on the dose.

Appear soon after exposition.

Must not be induced during diagnostic procedures.

e.g. erythema, epilation, cataract

\*1% lethal 60 days after exposition

Dose (Gy) (whole body)	Biological effect
< 0,15-0,2	No observable effect
0,5	Slight blood changes – limit of detection by hematological methods.
0,8	Critical dose – threshold of acute radiation syndrome
2,0	Minimal lethal dose (LD1/60)*
4,0	Half lethal dose (LD50/60)
7,0	Minimal absolute lethal dose (LD99/60)

Chest X-ray: cc 160  $\mu$ Gy in the skin

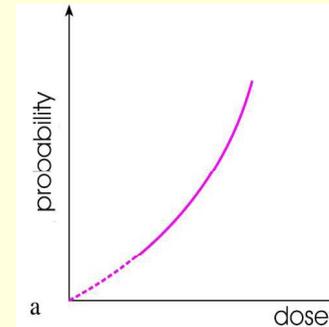
## Variations in threshold values

Depend on dose delivery mode:

- single high dose most effective
- fractionation increases threshold dose in most cases significantly
- decreasing the dose rate increases threshold

Threshold may differ person by person

## Stochastic damages



The probability of stochastic damage depends on the dose.

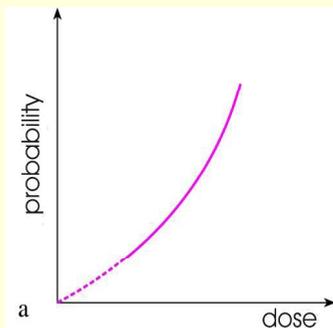
Severity (e.g. cancer) independent of the dose.

Delayed biological effects.

NO threshold!

e.g. tumours, hereditary diseases

## Stochastic damages



$H_T$  (equivalent dose) and  $E$  (effective dose) provide a basis for *estimating the probability of stochastic effects* for doses below the threshold of deterministic effects.

Dose range is under the threshold of deterministic damages.

**Sv**

## Stochastic damages

Irradiated cell is modified rather than killed

Severity is not effected by the dose

With increasing dose only the probability\* increases

\*1 gamma photon: the probability to cause cancer is  $3 \times 10^{-16}$  (1: 3,000 billion, but this is the Russian roulette!)

examination	Approximate effective doses mSv
Chest X-ray	0,04
Chest CT	7,8
Cranial CT	1,8
Abdominal X-ray	1,2
Abdominal CT	7,6
X-ray of the dorsal vertebrae	1,0
X-ray of the lumbar vertebrae	2,1
Barium enema with fluoroscopy	8,7

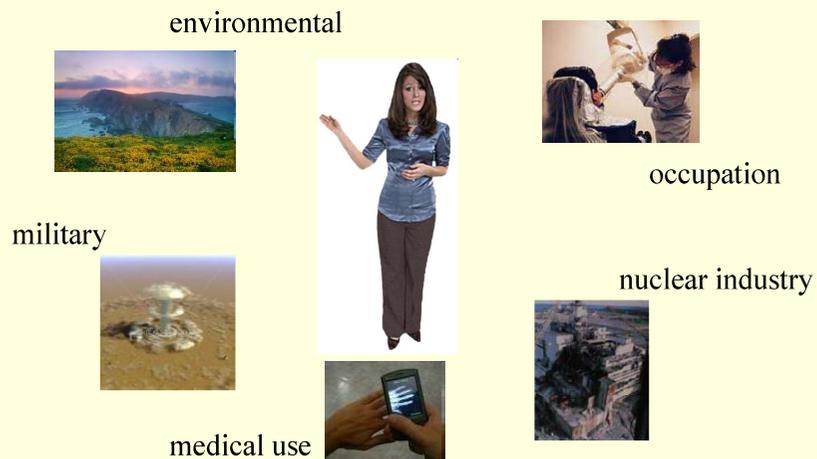
## Radiotherapy

Irradiation results *deterministic effects* (tumour cell kill)  
- in this context some deterministic effects and stochastic effects must be tolerated ( side effects)

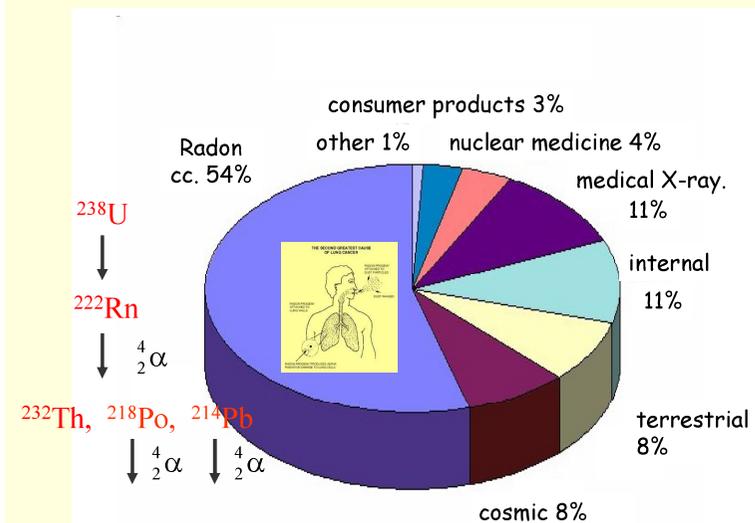
## Radiation protection

The aim is to *exclude deterministic effects*  
and  
*minimize* the risk of *stochastic effects*.

Estimated average of annual dose from natural background and man-made sources is 3.6 mSv.



## Distribution of annual dose among sources



## Sources of natural background



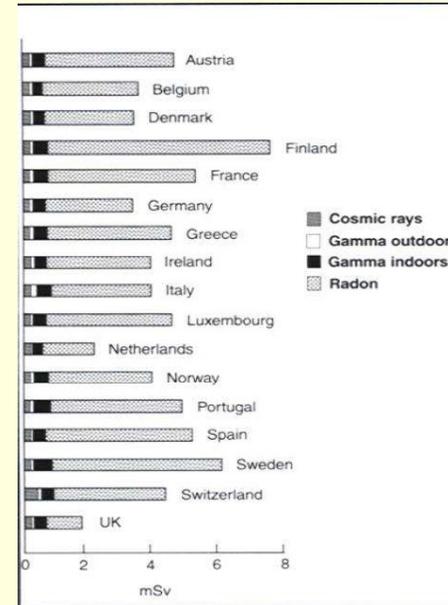
radon: cc. 1,8 mSv/year



cosmic radiation  
~ 0,4 mSv/year



potassium: cc 0,1 mSv/year



Distribution of naturally occurring background levels of radiation in Europe

The highest known level of background radiation is in Kerala and Madras States in India where a population of over 100,000 people receive an annual dose rate which averages 13 millisieverts.

## Risk – loss of life expectancy

### Days of average life expectancy lost

Being unmarried male	3500
Smoking (pack/day)	2250
Being unmarried female	1600
Being a coal miner	1100
25% overweight	777
Alcohol abuse	365
Being a construction worker	227
Driving motorcycle	207
1 mSv/year effective dose for 70 years	10
Coffee	6

## Relative risk of dying: 1 in a million odds

- Smoking 1.4 cigarettes (lung cancer)
- Eating 40 tablespoons of peanut butter
- Eating 100 charcoal broiled steaks
- 2 days in New York City (air pollution)
- Driving 40 miles in a car (accident)
- Flying 2500 miles in a jet (accident)
- Canoeing for 6 miles
- Receiving 0.10 mSv radiation dose (cancer)

# Radiation protection

## Aims of radiation protection:

Prevention from deterministic effects (except in radiotherapy those that are intentionally produced)

Keeping the occupational risk of the users of the sources at the level of occupational risk of other professionals.

Keeping the public risk from ionising radiation sources at the level of public risk of other civilisation related harms.

*Radiation protection lies on the following principles:*

Optimization: All exposures should be kept As Low As Reasonable Achievable (ALARA)

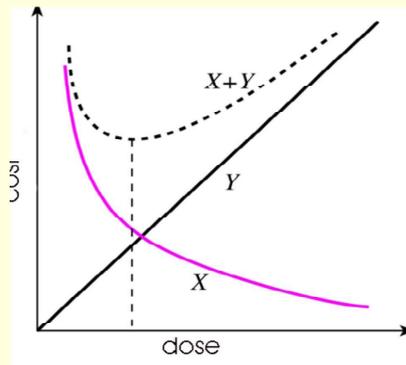
Justification: no practice shall be adopted unless it produces a positive net benefit

Limitation: the effective dose (E) to individuals shall not exceed the limits recommended by the ICRP (maximum permitted doses)

## Optimization of radiation protection

### ALARA-principle

As Low As Reasonably Achievable



X : cost of radiation protection

Y : cost of treatment

X+Y: total cost

**Optimum is the minimum**

## Dose limits in radiation protection



	Occupational (mSv/year)	Population (mSv/year)
Effective dose	20*	1
Dose equivalent (eye lens)	150	15
Dose equivalent (limb/skin)	500	50

\* Over the average of 5 years but maximum 50 mSv/year

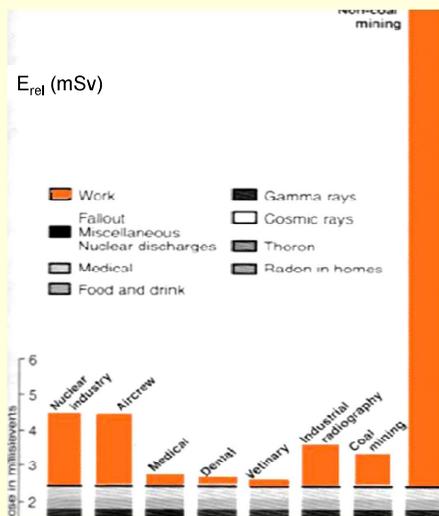
## Average individual annual radiation exposure dose in nuclear workers in 15 countries

Country	Average length of employment (years)	Average individual cumulative dose (mSv)	Average individual annual dose (mSv)
Australia	11.0	6.1	0.55
Belgium	14.3	26.6	1.86
Canada	8.6	19.5	2.27
Finland	6.7	7.9	1.18
France CEA-COGEMA	13.4	3.8	0.28
France EDF	15.8	15.8	1.00
Hungary	12.7	5.1	0.40
Japan	7.8	18.2	2.33
South Korea	7.0	15.5	2.21
Lithuania	8.3	40.7	4.90
Slovak Republic	10.7	18.8	1.76
Spain	11.7	25.5	2.18
Sweden	7.2	17.9	2.49
Switzerland	11.0	62.3	5.20
UK	12.2	20.7	1.70
U.S. Hanford	11.3	23.7	2.10
U.S. Idaho National Laboratory	10.5	10.0	0.95
U.S. NPP	11.4	27.1	2.38
U.S. Oakridge National Laboratory	12.7	15.2	1.20
Total	10.5	19.4	1.85

## Cosmic ray contributions to dose rate as the function of the altitude



## Relative risk of various professions



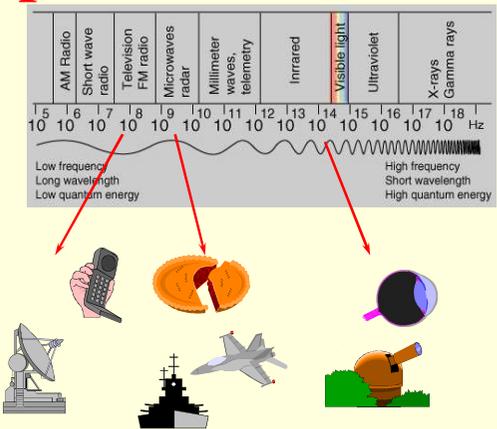
## Detection of radiation - dose measurement

- What?  $\alpha^{++}$   $p^+$   $(n)$   $\beta$   $\gamma$   $\nu$

- How much energy?

- How much intensity?

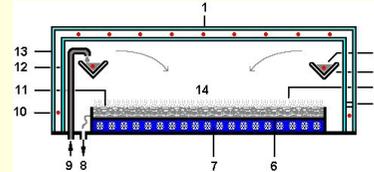
- How good accuracy?



## Measuring devices

Alteration of a physical parameter ~ absorbed dose

### Detection of particles

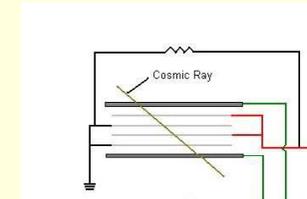


- **Cloud chamber**  
supersaturated vapor of water or alcohol

- **Spark chamber**

high voltage wires

- **Bubble chamber**
  - superheated transparent liquid (H<sub>2</sub>, Ar, Xe)
  - entire chamber is subject to a constant magnetic field



## Dose and dose rate measuring devices

\* electronic detectors – absorbed energy generates free charges

**gas-ionization detectors** – prompt and/or delayed evaluation

**scintillation detectors**

**semi-conductor detectors** –

\* Chemical detectors – based on radiochemical alterations

**film** – follow-up evaluation

\* Solid materials – based on physical parameters of solid materials

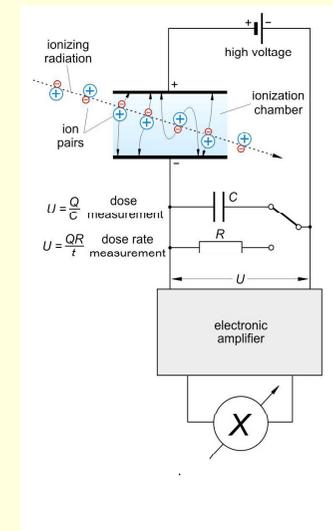
**thermoluminescent detector – TLD** (LiF, CaF<sub>2</sub>, BeO, Al<sub>2</sub>O<sub>3</sub>)

## Electronic Dosimeters

### Ionization chambers

**Dose measurement:** the voltage  $U$  that is produced by collected charge  $Q$  on the capacitor  $C$  is proportional to the total amount of the separated charges.

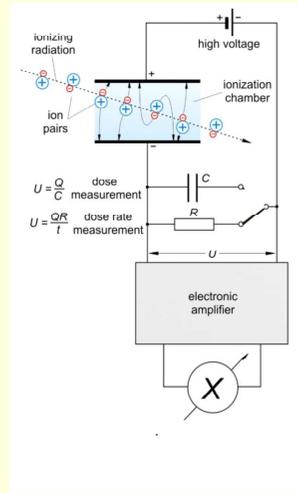
$$U = \frac{Q}{C} \sim X$$



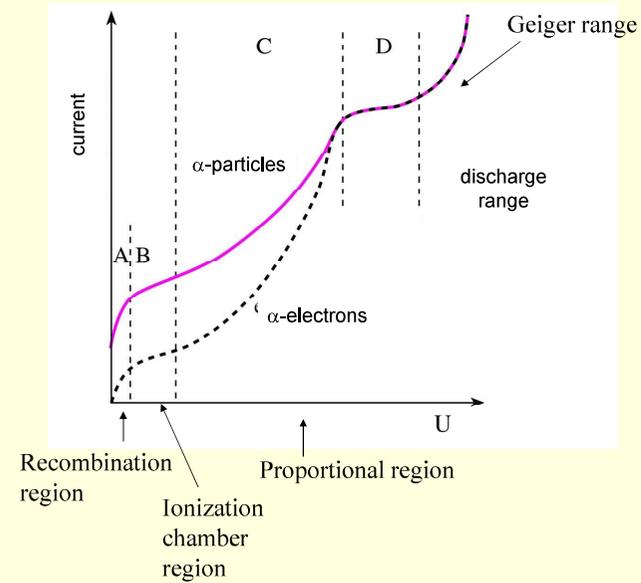
## Ionization chambers

**Dose rate measurement:** the potential drop is measured on a large resistance R, that is proportional to the charge Q that flows through at unit time.

$$U = \frac{QR}{t} \sim \frac{X}{t}$$



## Ionization chambers



The dependence of ionization on voltage

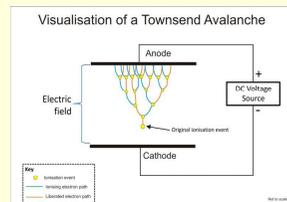
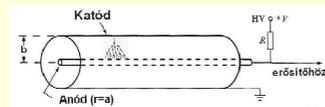
## Ionization chambers— Geiger-Müller counter

- Inert gas filling
- High accelerating voltage



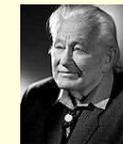
Avalanche effect between electrodes

**Current pulse**



*Number of current pulses ~ number of ionising particles*

## Multiwire chamber



Nobel prize in Physics 2002

**Georges Charpak**  
1924-2010

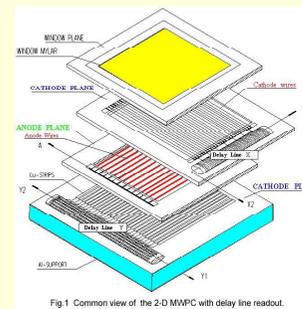
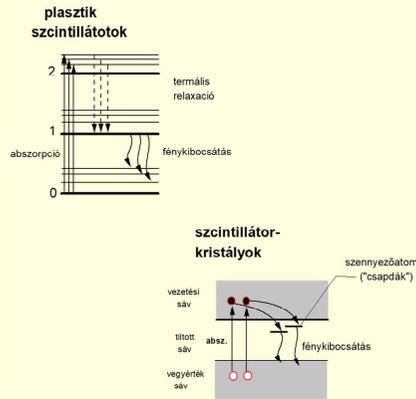


Fig.1 Common view of the 2-D MWPC with delay line readout.

- electric current proportional to the energy of the detected particle
- localised cascade of ionization
- spatial sensitivity!

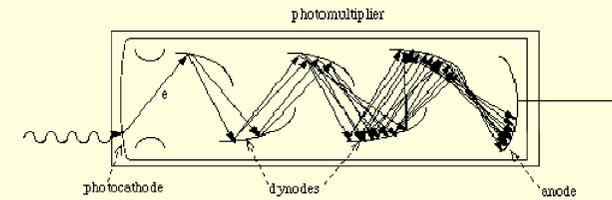
## Scintillation detectors



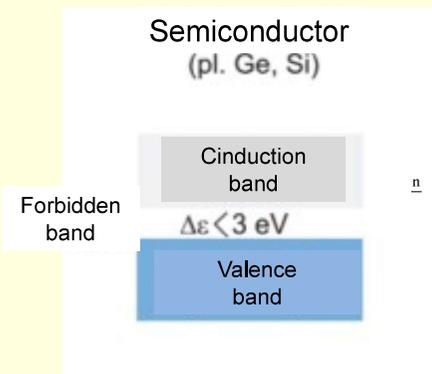
- Liquid scintillator
  - Solution of fluorescent compounds
  - Primary excitation of solvent and follow-up excitation of diluted compound
  - Light emission
- Plastic scintillator
  - Solid materials
- Inorganic crystals
  - Primary excitation of crystal, follow-up excitation of luminescent atoms

## Scintillation detectors

- scintillator → visible light
- Photoelectric effect
- Generation of electric signal
- Multiplication of free electrons



## Semiconductor detectors



$$\frac{n}{n_0} = e^{-\frac{\Delta\epsilon}{kT}}$$

$$\sigma \approx e^{-\frac{\Delta\epsilon}{2kT}}$$

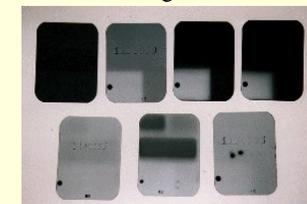
Conductivity ~ number of excitations

## Chemical processes

### Film badges

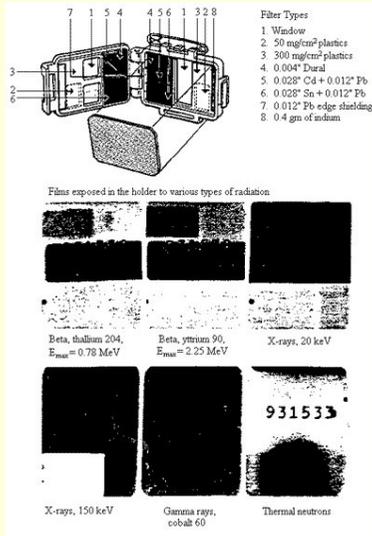


It measures darkening of the developed photographic film that was exposed to ionizing radiation.

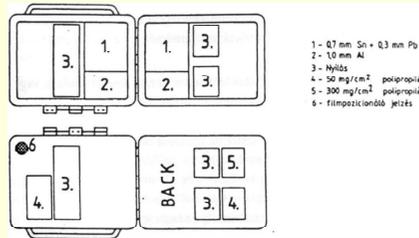


Darkening of the developed photographic film is proportional to the dose rate of the ionizing radiation and to the irradiation time.

## Film badges



Darkening depends on the type and energy of radiation, and the thickness and material of absorber.

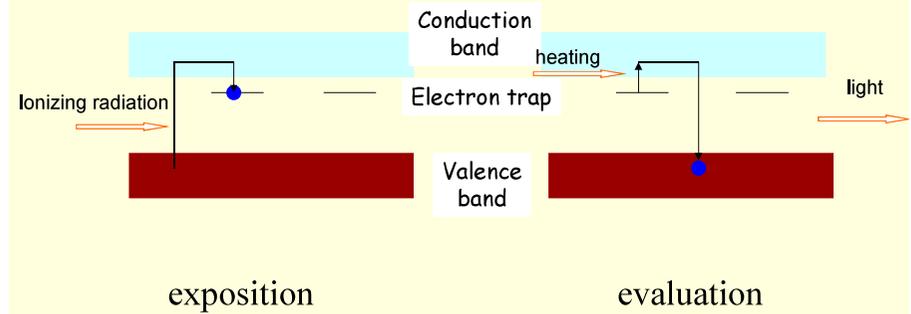


## Solid phase detectors

### Thermoluminescent dosimeter



### Band structure on electronic transitions



## Calculation of the dose in case of $\gamma$ - radiation

The absorbed dose in air ( $D_{\text{air}}$ ) for any  $\gamma$  - radiating isotope

$$D_{\text{air}} = K_{\gamma} \frac{\Lambda t}{r^2}$$

izotop	$\gamma$ -energy (MeV)	$K_{\gamma}$
<sup>24</sup> Na	2,754; 1,369	444
<sup>52/59</sup> Fe	0,5; 1,3; 1,1	160
<sup>60</sup> Co	1,33; 1,17	305
<sup>131</sup> I	0,364; 0,08; 0,723	54
<sup>137</sup> Cs	0,661	80

$\Lambda$ : activity of the isotope preparation

t: time of exposition

r: distance from the source

$K_{\gamma}$ : dose constant  
(specific  $\gamma$  - ray constant)

$$[K_{\gamma}] = \frac{\mu\text{Gy} \cdot \text{m}^2}{\text{h} \cdot \text{GBq}}$$

Someone works at 30 cm distance from a <sup>24</sup>Na isotope preparation of 75 MBq. Calculate the thickness of the lead shielding that reduces the dose rate to 15  $\mu\text{Gyair/h}$  at the working place.

$$\left(\frac{D}{t}\right)_0 = K_{\gamma} \frac{\Lambda}{r^2} \quad \left(\frac{D}{t}\right)_0 = 444 \frac{75 \cdot 10^{-3}}{0,3^2} = 370 [\mu\text{Gy} / \text{h}]$$

$$\left(\frac{D}{t}\right) = \left(\frac{D}{t}\right)_0 e^{-\mu_m x_m}$$

$$x = 5,7 \text{ cm}$$

Question of the week

Which voltage range(s) of ionization chamber can be used in dose measurements? Why?

*Damjanovich, Fidy, Szöllösi: Medical Biophysics*

II. 4.

4.1

4.2

4.3

4.4

4.5

In the frame: 184. 186.

*Manual :Dosimetry*