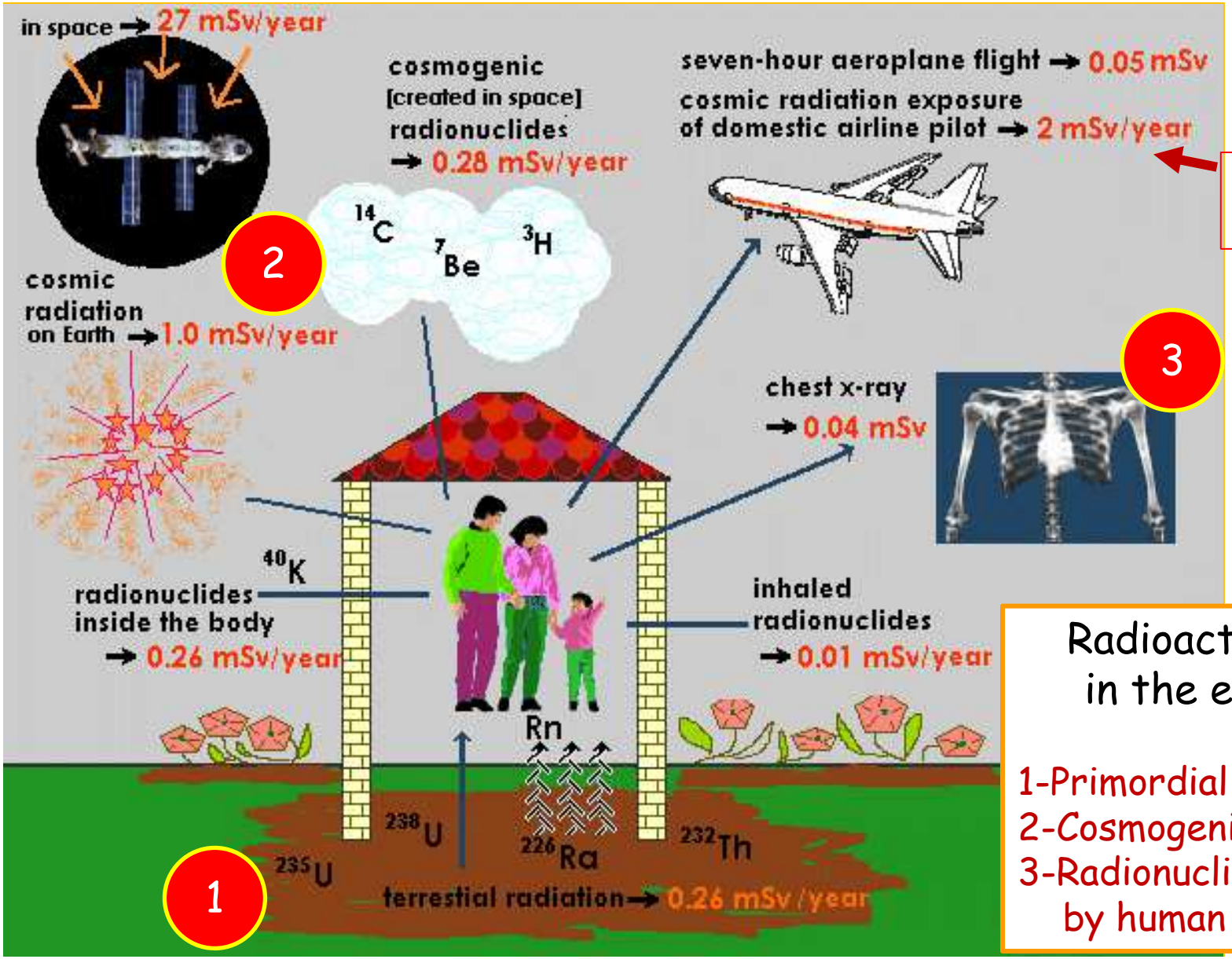
Measurement of environmental radiation (by gamma spectroscopy)

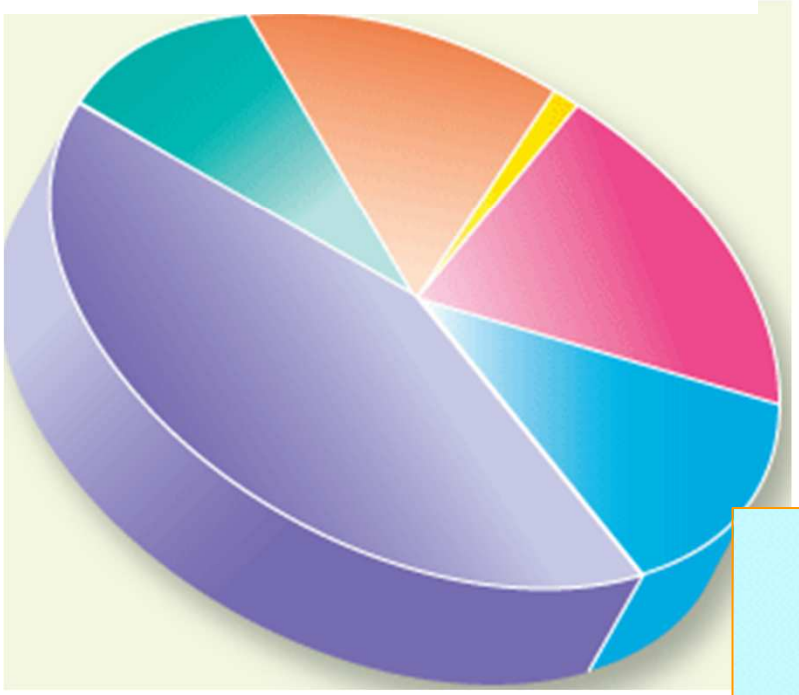


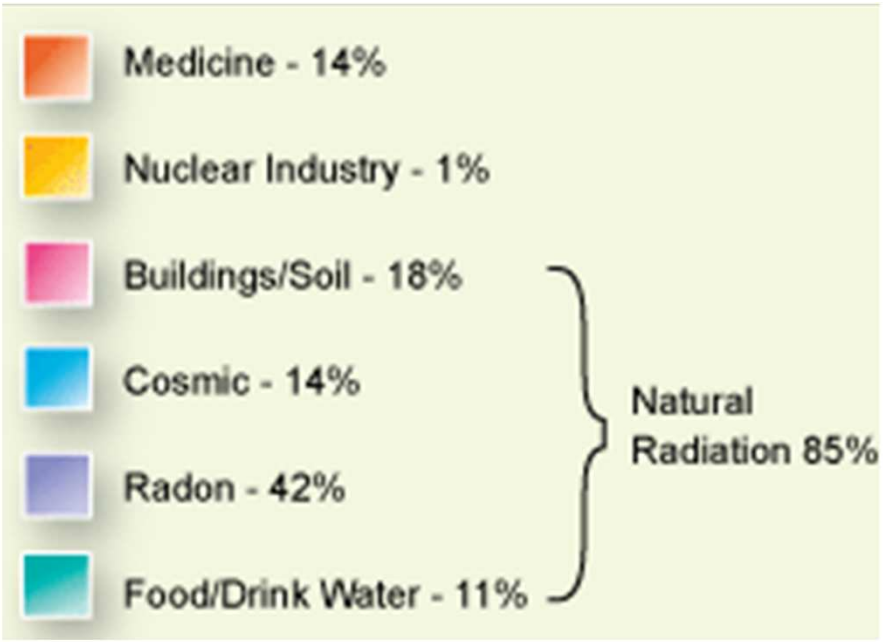
Dose unit of measure

Radioactive isotopes in the environment

1-Primordial radionuclides
2-Cosmogenic radionuclides
3-Radionuclides produced by human action

Sources of radioactivity natural and artificial

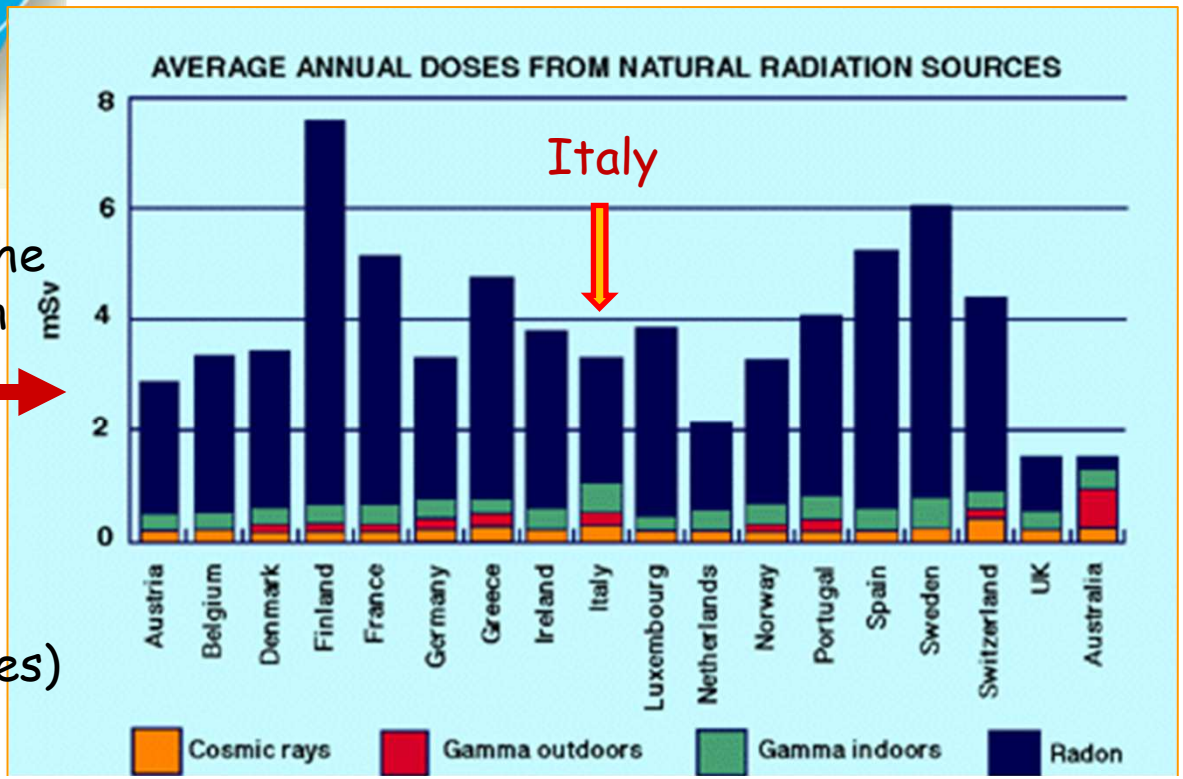




The average dose absorbed by the human body for natural radiation is ≈ 2.4 mSv/yr

But it really depends on places

It can go from 1 to 10 mSv / yr (with peaks of 50 in specific cases)



Units of measure

	Radioactivity	Absorbed Dose	Dose Equivalent	Exposure
Common Units	curie (Ci)	rad	rem	roentgen (R)
SI Units	becquerel (Bq)	gray (Gy)	sievert (Sv)	coulomb/kilogram (C/kg)

From the emission...

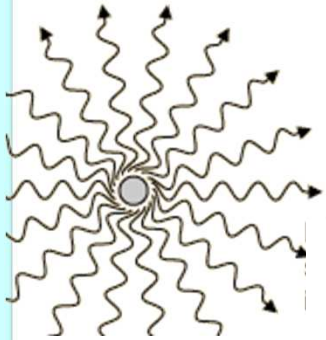
Radioactive source
Activity → Becquerel, Curie

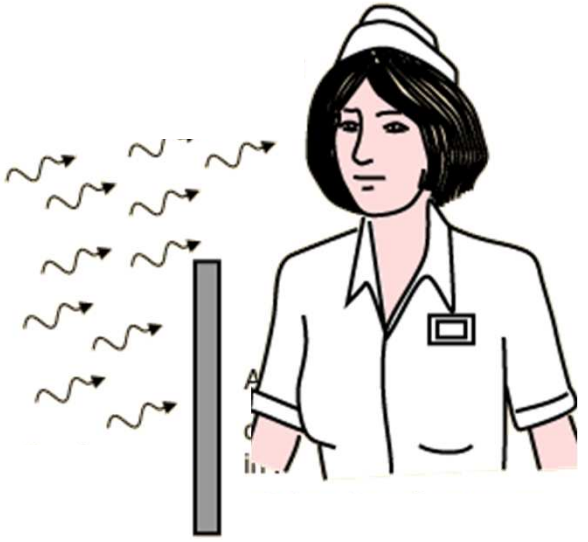
Absorption
Absorbed dose → Gray, rad

Biological damage
Equivalent dose
→ Sievert, rem

...to the absorption

Activity'
(Becquerel)





1 Becquerel (Bq) =
1 decay per second

1 Curie (Ci) =
1 g di ^{222}Ra=37 GBq

Absorbed dose

Dose absorbed

Dose = absorbed energy for mass units

$D = \Delta E / \Delta m$

m = mass of the absorber material, not of the radiation

International system unit

SI → Gray = 1 J/1 Kg

practical → rad = 100 erg/g

1 Gray = 100 rad

Problem: the same dose
due to different radiation
and / or absorbed by different materials
produces different effects / damages

Equivalent dose

Equivalent dose

The absorbed dose D measures the amount of energy absorbed by a unit mass. The equivalent dose is linked to the biological effects of radiation organism. Different types of radiation can be more or less harmful for the body. The equivalent dose is obtained by multiplying the absorbed dose for an adimensional factor of weight (or quality factor) that indicates the hazard of the type of radiation.
Standard radiation with weight 1 is that of x or gamma with an energy of 250 keV.

1 Sv = 100 rem

Unit of measure
SI → Sievert = QF · Gray
practical → rem = QF · rad

quality factor QF which takes into account the global effect of ionization

Radiation	QF
photons, electrons	1
protons	5
neutrons (various energies)	5-20
α, heavy nuclei	20

e.g.. 1 Gray (α) = 20 Sievert
1 Gray (γ) = 1 Sievert

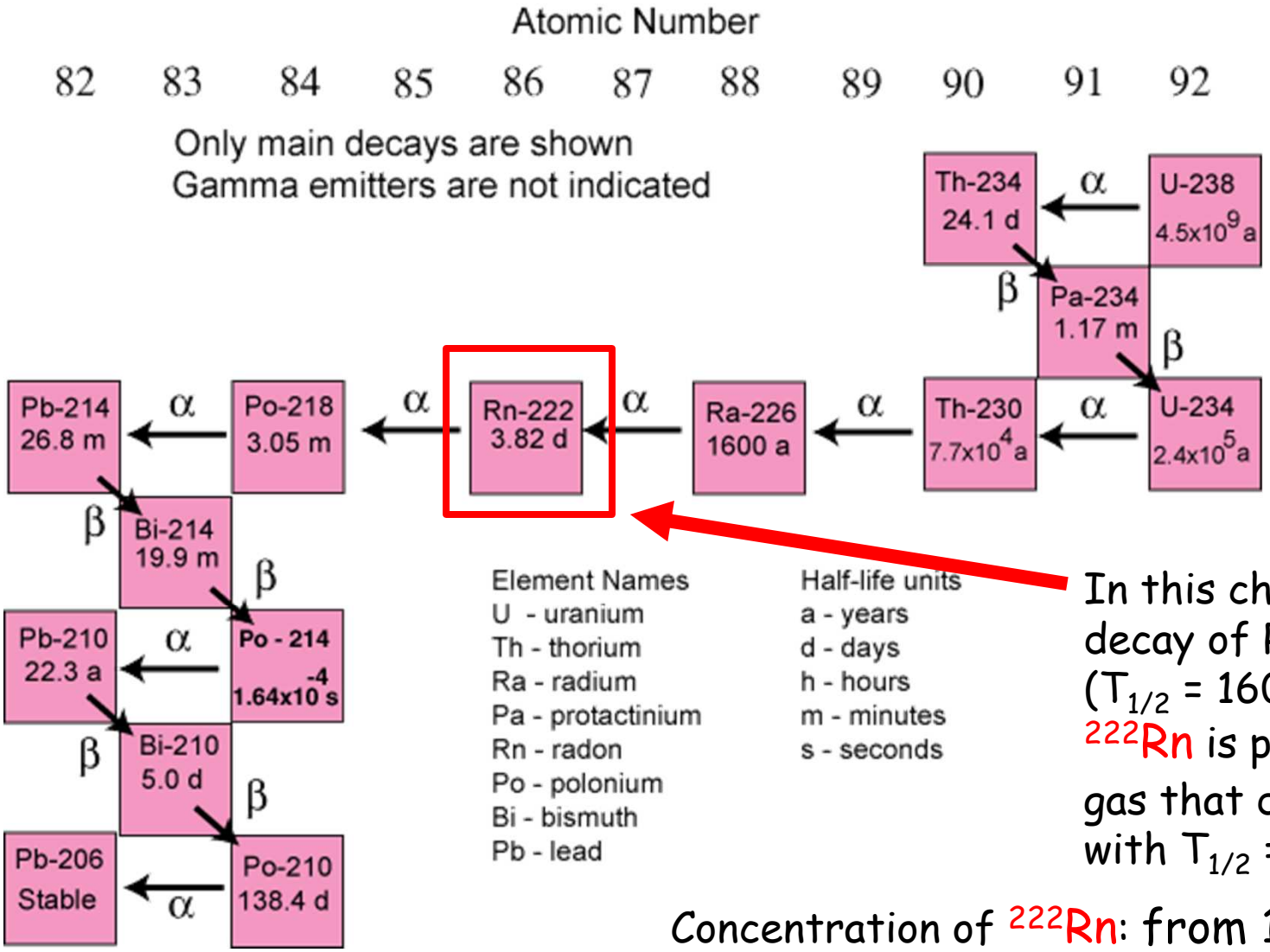
Exposure limits beyond the natural background :
- Public: 1 mSv/year
- Classified workers: 6 – 20 mSv/year

1 Natural Radioactivity: some primordial nuclides

Radionuclide	Simbol	Decay type	$T_{1/2}$	
Uranium 235	^{235}U	α, SF	$7.04 \cdot 10^{8}$ yr	0.72% of natural Uranium
Uranium 238	^{238}U	α, SF	$4.47 \cdot 10^{9}$ yr	99.3% of natural Uranium
Thorium 232	^{232}Th	α, SF	$1.41 \cdot 10^{10}$ yr	Average value in Earth's crust 11 ppm
Potassium 40	^{40}K	β-, β+	$1.28 \cdot 10^{9}$ yr	Present in the ground 0.037-1.1 Bq/g

Other important radionuclides (Radon, Radium) are present because continuously produced in the decay chains of Uranium and of the Thorium

The ^{238}U decay chain

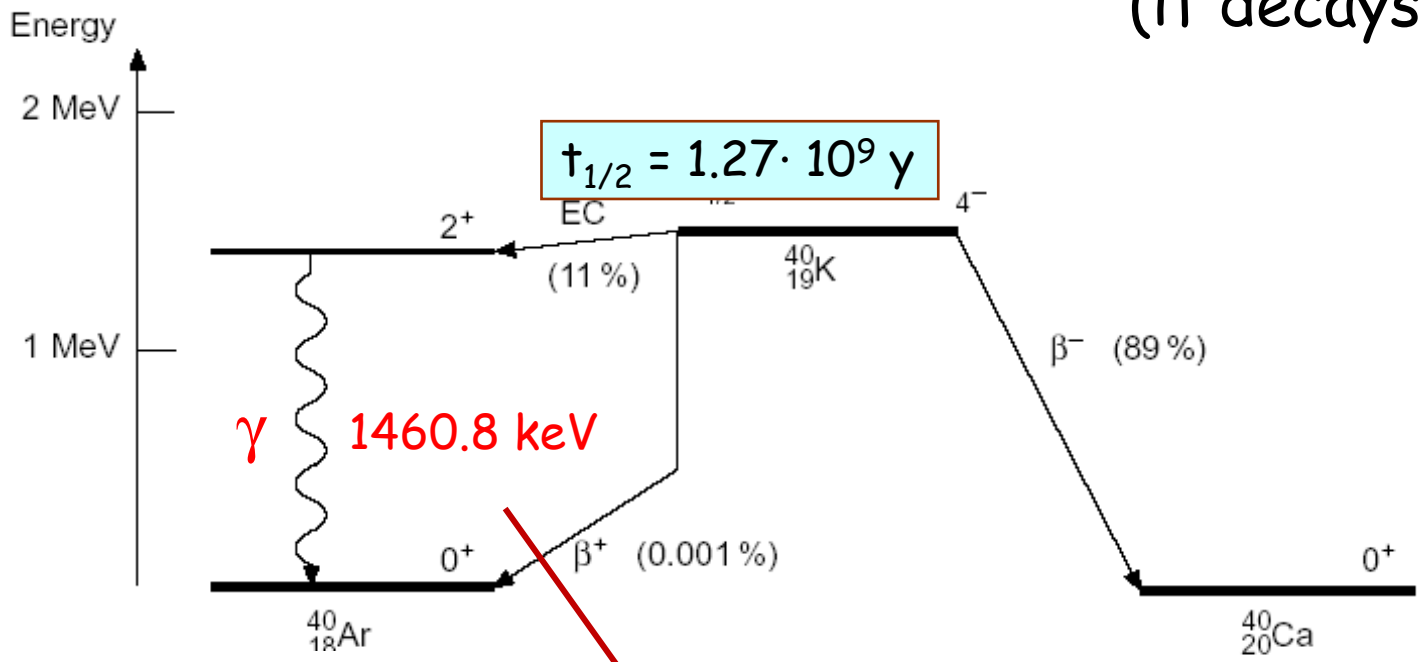


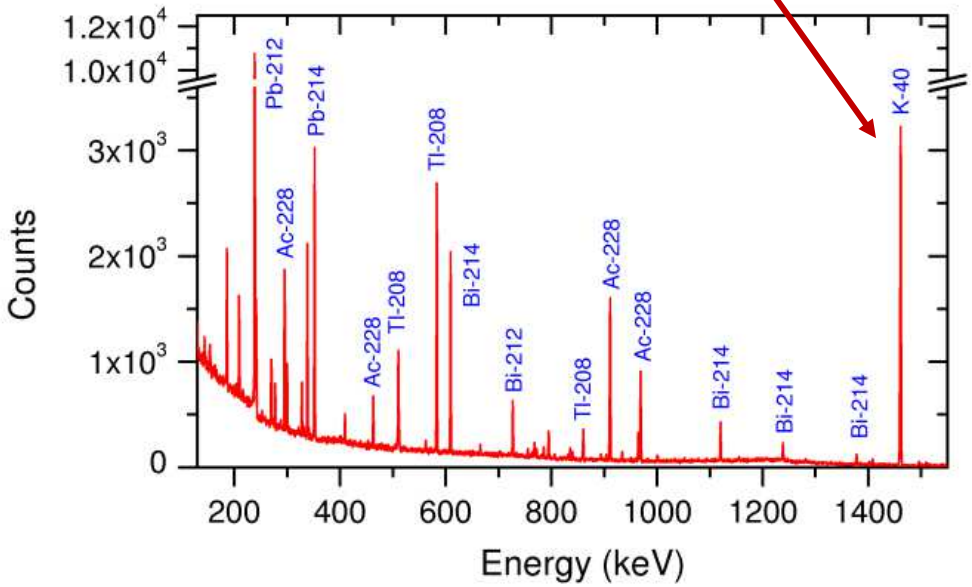
In this chain, from decay of Radium 226 ($T_{1/2}$ = 1600 years) the ^{222}Rn is produced. It is a gas that decays α, with $T_{1/2}$ = 3.82 days.

Concentration of ^{222}Rn: from 1 to 100 Bq/m^3 in air but it can reach 20-2000 Bq/m^3 in unpaved environments, mines, quarries, ...

Another very common primordial nuclide, the ^{40}K

(it decays β^- e β^+)





Gamma spectrum from a soil sample

2 Natural radioactivity: some cosmogenic nuclides

(Produced in the atmosphere from the cosmic rays)

Radionuclide	Symb.	Decay	$T_{1/2}$	Production method	Natual Activity
Carbon 14	^{14}C	β^-	5730 yr	$^{14}N(n,p)^{14}C$	0.22 Bq/g* in organic materials
Tritium	^{3}H	β^-	12.3 yr	$^{14}N(n,^{12}C)^{3}H$	$1.2 \cdot 10^{-6}$ Bq/g*
Berillium 7	^{7}Be	EC	53.29 days	Spallation on N o O	10^{-5} Bq/g*

* These values represent the average activity due to that particular element in a gram of material! One gram of pure Tritium, for example, has a much larger activity

$$A(t) = \lambda \cdot N_0 e^{-\lambda t} \quad N_0 = \frac{1}{3} N_A = \frac{1}{3} 6.02 \cdot 10^{23}$$

$activity_{Tritium} \approx 3.7 \cdot 10^{14}$ Bq/g

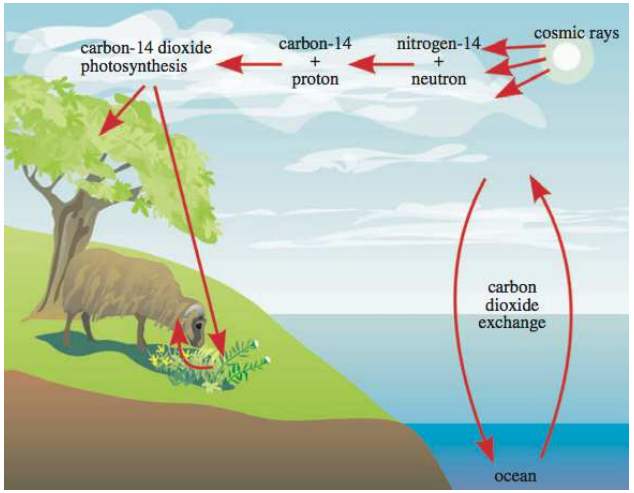
3 Radionuclides produced by human action

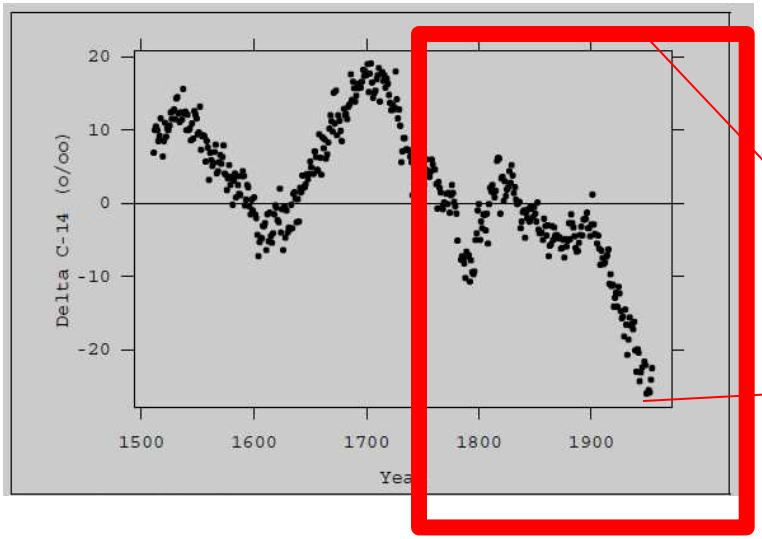
present in the environment

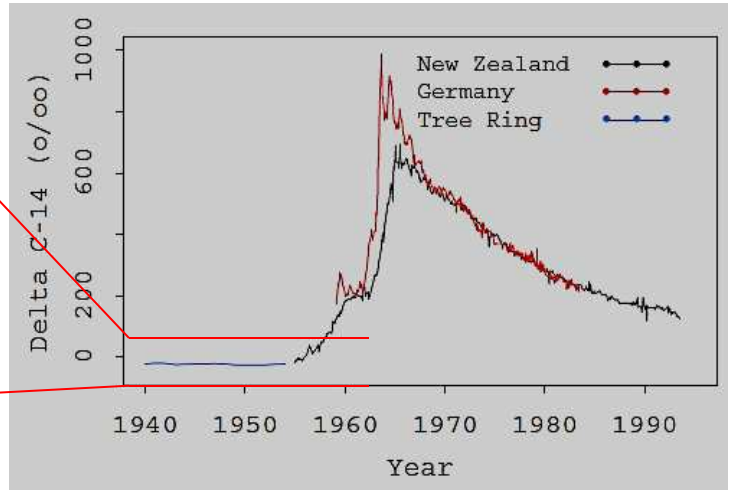
Radionuclide	Symb.	$T_{1/2}$	Origin
Tritium	^{3}H	12.3 yr	Nuclear Explosions and Fission Reactors
Iodine 131	^{131}I	8.04 days	Nuclear Explosions and Fission Reactors. Used in medecine.
Cesium 137	^{137}Cs	30.17 yr	Nuclear Explosions and Fission Reactors. Chernobyl
Strontium 90	^{90}Sr	28.78 yr	Nuclear Explosions and Fission Reactors.
Technetium 99	^{99}Tc	$2.11 \cdot 10^{5}$ yr	Nuclear Explosions and Fission Reactors.
Plutonium 239	^{239}Pu	$2.41 \cdot 10^{4}$ yr	Neutron capture on ^{238}U ($^{238}U+n \rightarrow {}^{239}U \rightarrow {}^{239}Np+\beta \rightarrow {}^{239}Pu+\beta$)

Example: **Chernobyl** reactor explosion residues are still present in our atmosphere

Natural / artificial radioactivity: ^{14}C





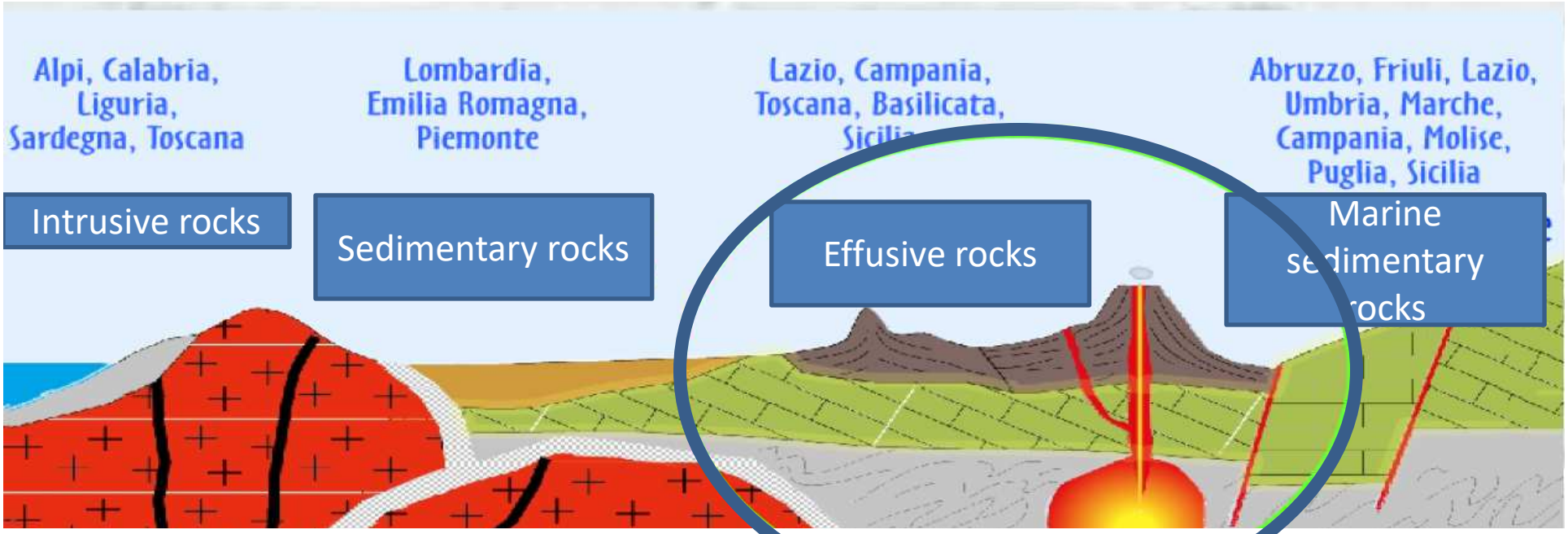


Fossil ^{14}C

(Industrial Revolution)

Atmospheric Atomic Test

Radon from the rocks



The heterogeneous distribution of **radon progenitors** in different types of rocks cause uneven radon production. At the climbing points of rock material, from the mantle to the crust, the highest concentrations are found.

Radon emitted is quickly dispersed outdoors, where it is in generally low concentrations (0-20 Bq/m^3); when it is present in the closed (diffused by soil or building materials), because of the decreased air exchange it tends to concentrate (up to hundreds of Bq/m^3)

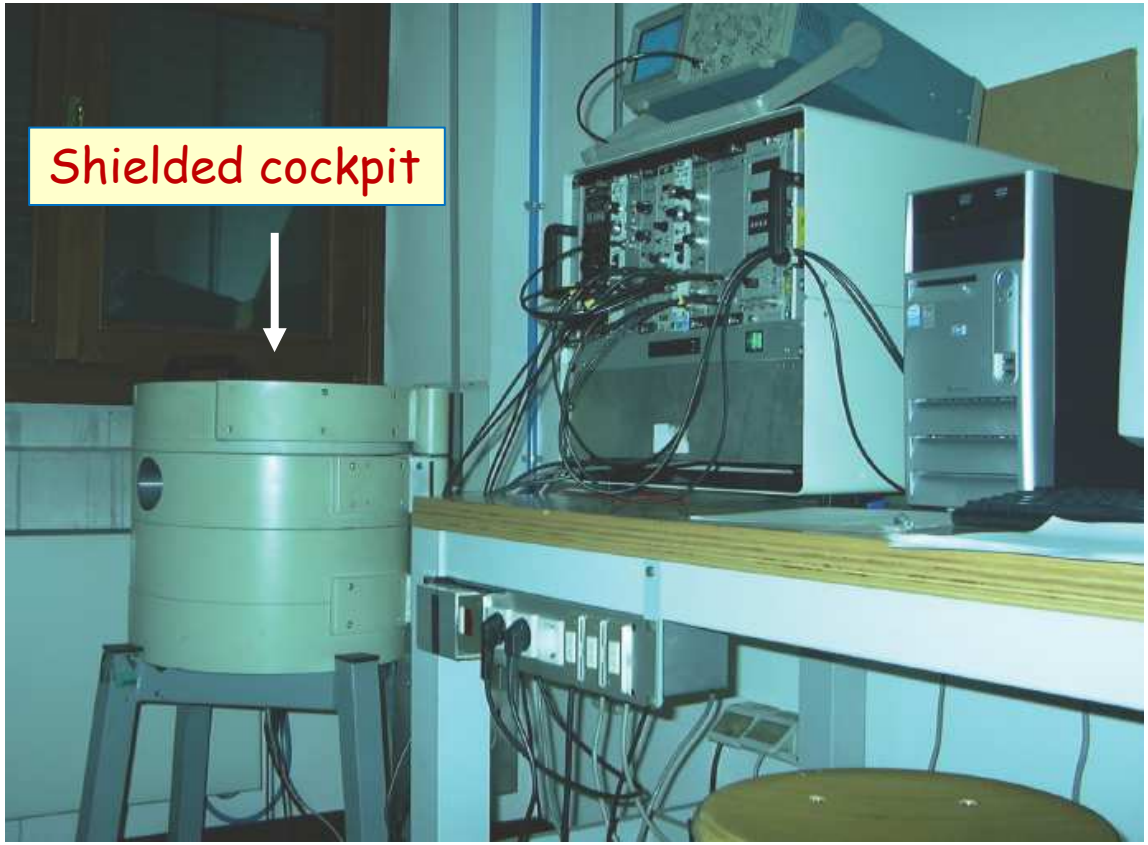
http://www.fe.infn.it/italrad/

The objective of the project ITALRAD (ITALIAN RADIOACTIVITY PROJECT) is to make paper of the natural radioactivity of the **Italian territory through gamma spectroscopy measures**.
The radioisotopes content natural (^{238}U, ^{232}Th, ^{40}K) in rocks and in Italian soils it is investigated by measures in laboratory, in-situ and airbone.

TOTAL NATURAL RADIOACTIVITY MAP OF VENETO (ITALY)

Strati V.[a,b], Baldoncini M.[a,c], Bezzon G.P.[b] Broggini C.[d], Buso G. P.[b], Caciolli A.[d], Callegari I.[e], Carmignani L.[e], Colonna T.[e], Fiorentini G.[a,b,c], Guastaldi E.[e], Kaçeli Xhixha M.[f], Mantovani F.[a,c], Menegazzo R.[d], Mou L.[b], Rossi Alvarez C.[d], Xhixha G.[a,c], Zanon A.[b]

Apparatus used
(in our laboratory)
for measurements of
environmental
radioactivity



The samples of that will be measured are entered in the cockpit. The gamma activities will be measured with two detectors

Scintillator NaI(Tl) 3"x3"
Hyper pure Germanium HPGe

Measurements

1- Energy calibration and efficiency of the two detectors NaI (Tl) and HPGe

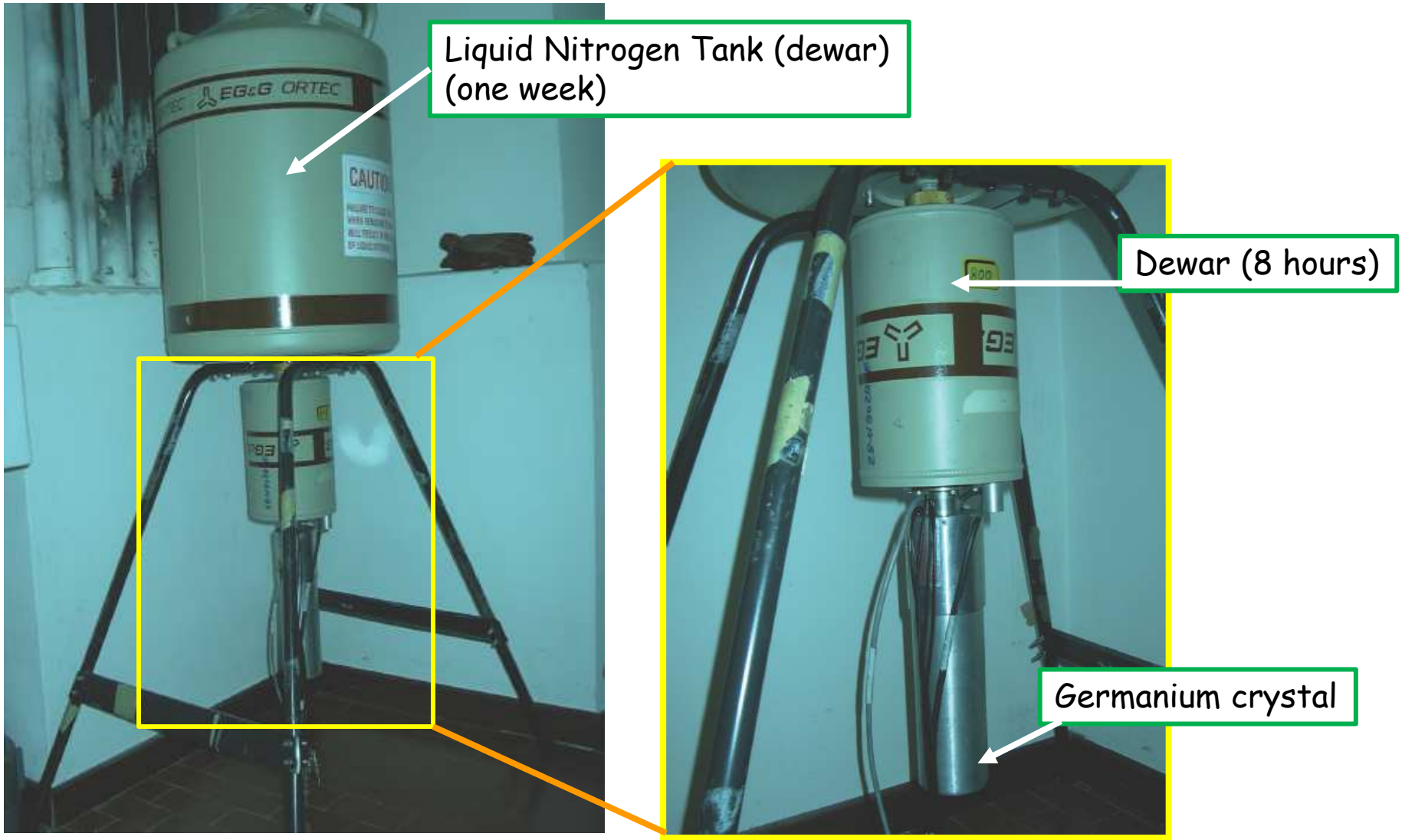
2- Environmental **background** measurement

3- Measurement of natural radioactivity from a series of **samples**

4- Measurement of **Radon indoor**

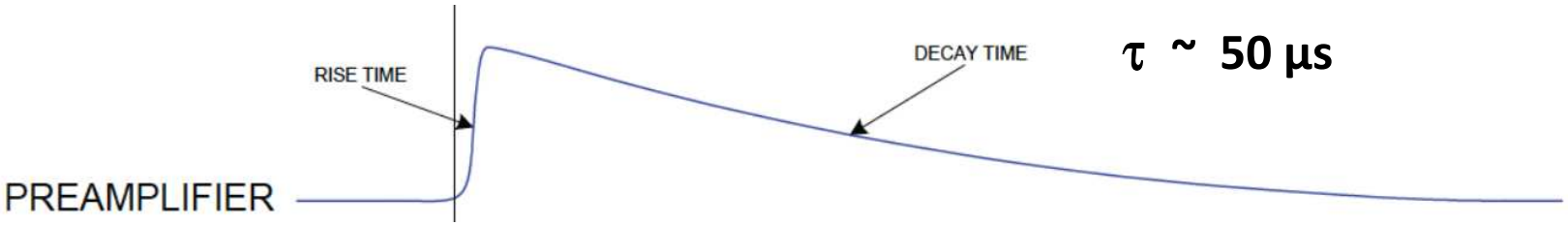
HPGe detector

(it works at liquid nitrogen temperature, 77 Kelvin)

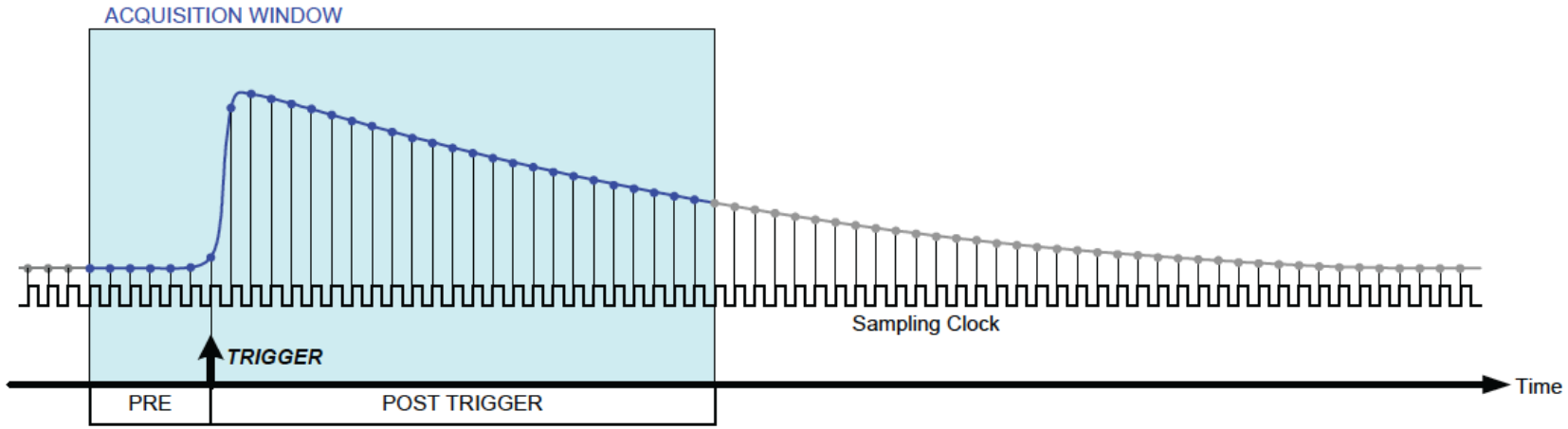


Digitization

Preamplifier output:



Digitized:

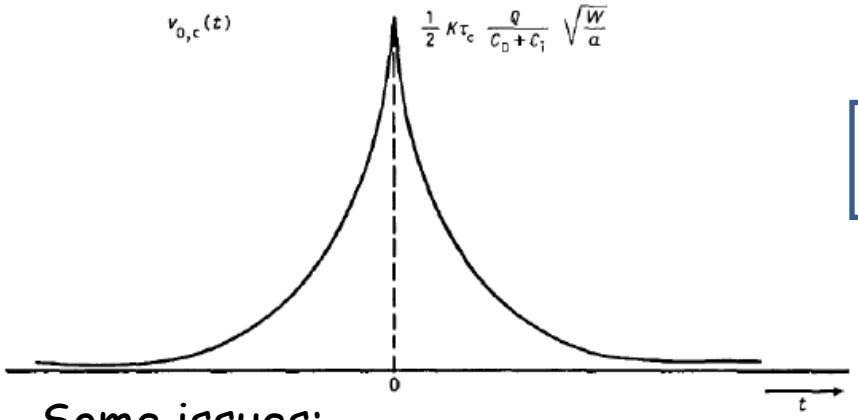


The amplitude provides the information on the energy deposited. We need somehow to calculate an "average" the signal amplitude to filter out noise. We need to do it with a moving window algorithm.

Noise filtering

Typical noise is **not white**. Type of noise should guide the choice of the filter.

For reasonable assumptions it can be demonstrated that the "optimum processing" consists in a **convolution with a proper kernel** to transform the exponential signal in an **infinite exponential cusp**:



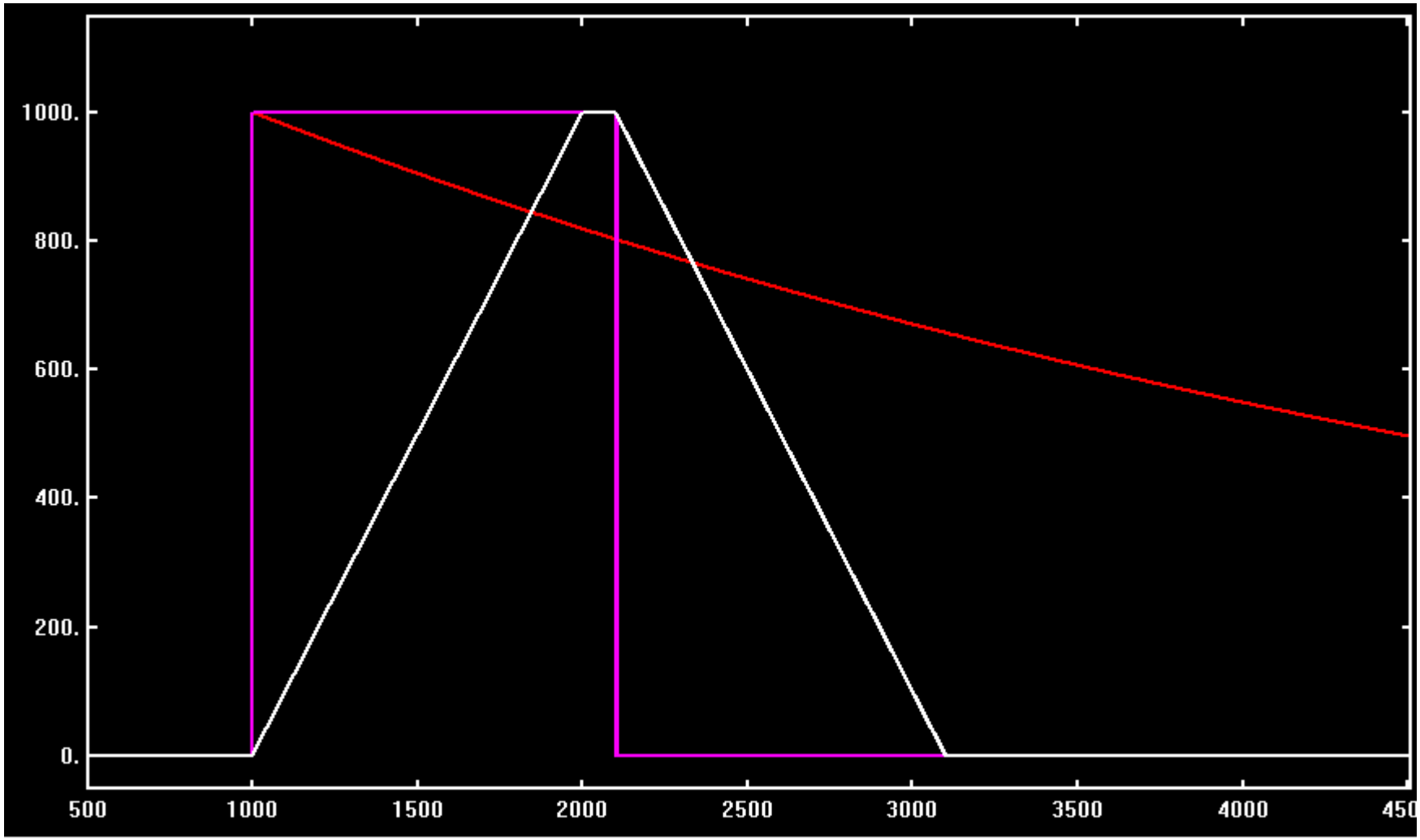
Some issues:
- usually collection time not zero!
- maximum retained for zero time! difficult to measure
- need infinite time to develop

analogue

Forced to suboptimal choices

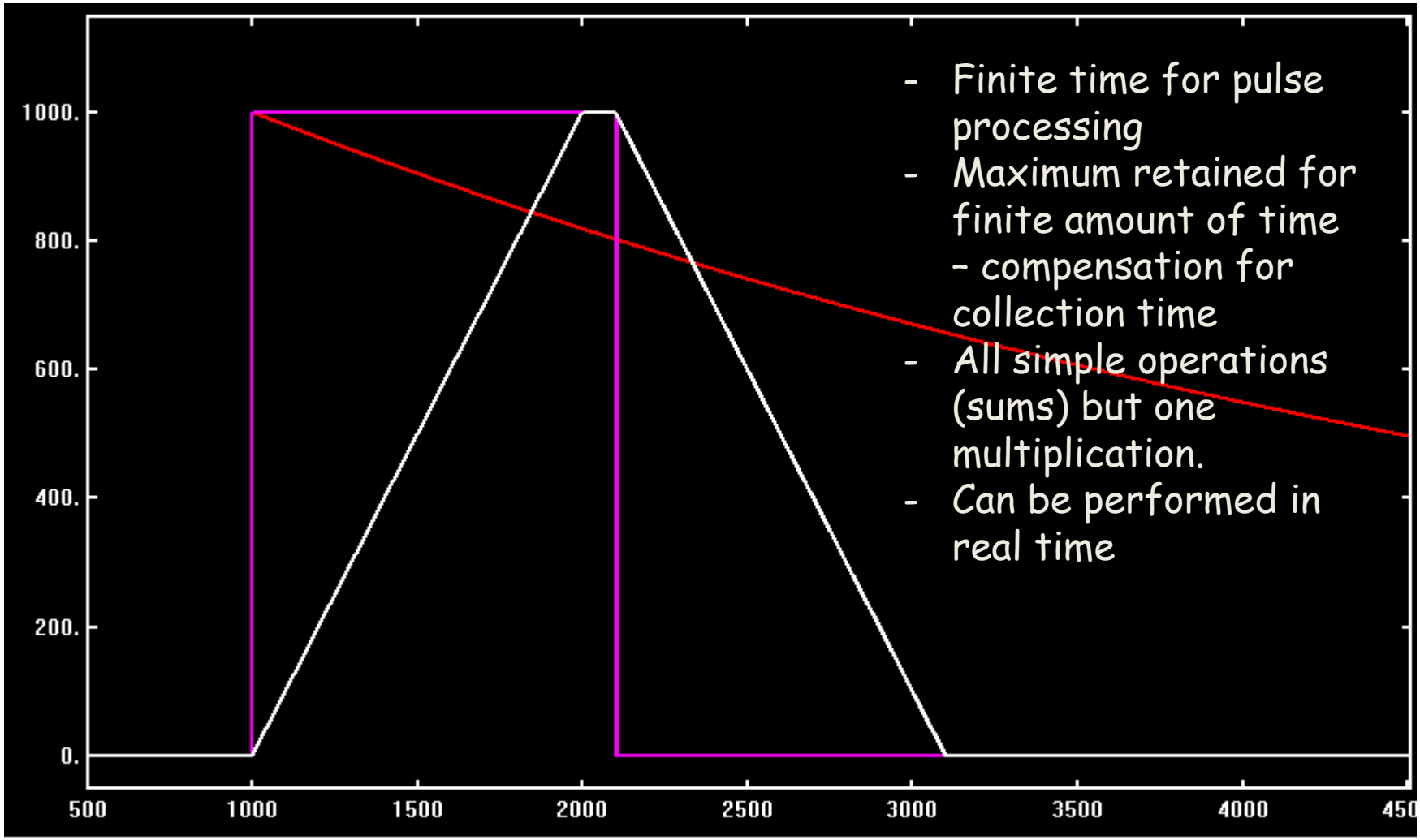
Pulse Shape		Relative 'Noise'
	Cusp	1.00
	Triangle	1.08
	Gaussian	1.12
	CR,nRC	1.36 n=1 1.22 n=2 1.18 n=3 1.12 n=∞
	Double CR,RC	1.88
	Delay Line DL,RC	1.10 - 1.41

Deconvolution and shaping: ideal exponential



D. Bazzacco

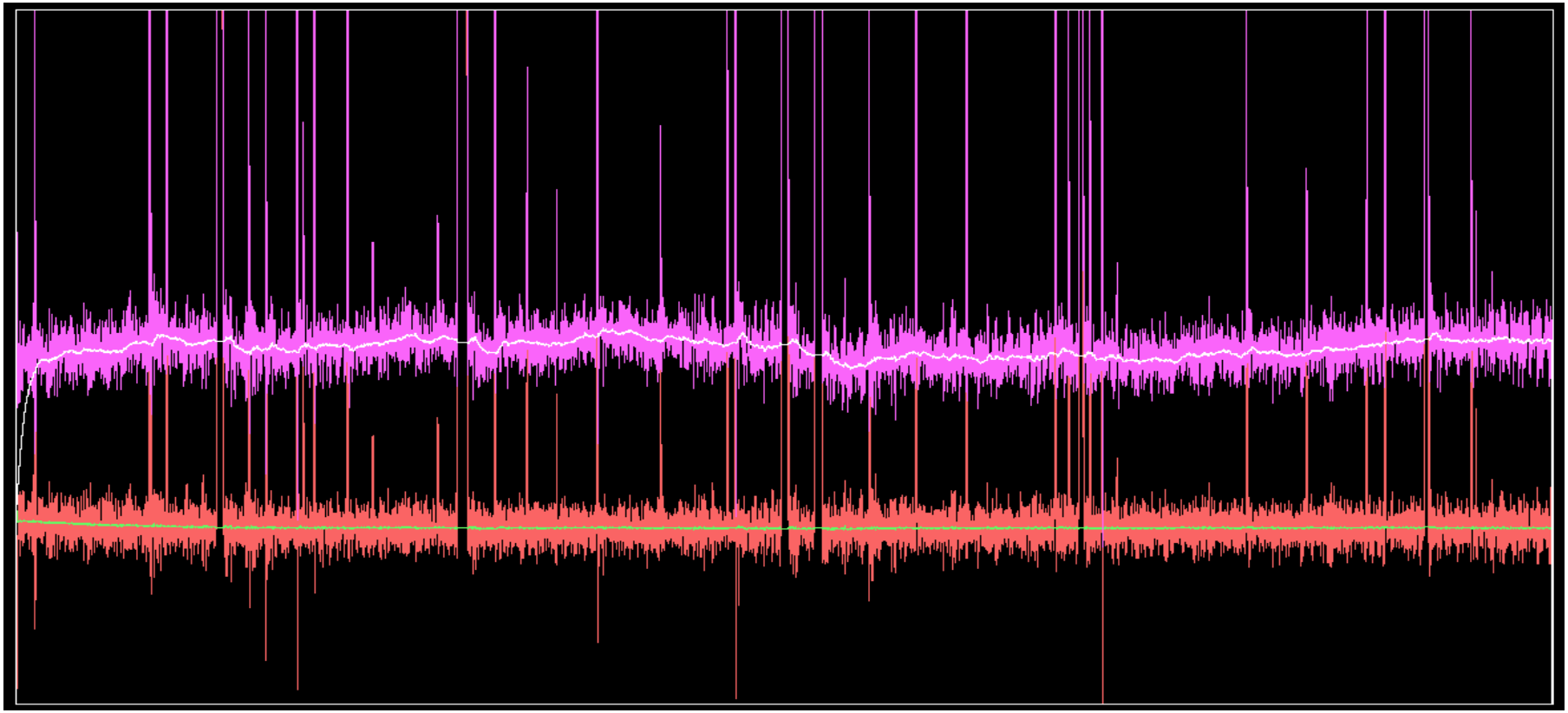
Deconvolution and shaping: ideal exponential



D. Bazzacco

Base-line stabilisation

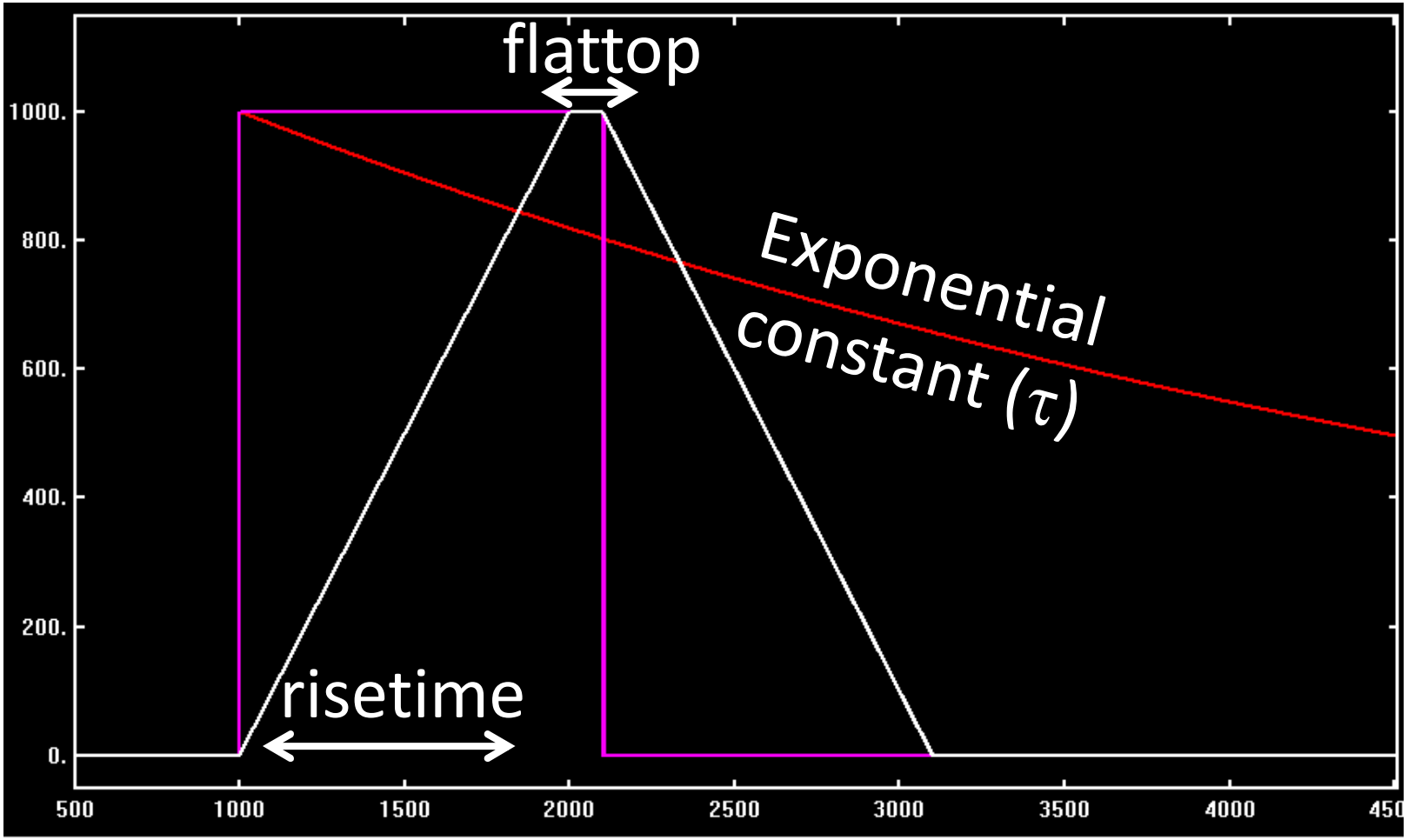
- continuous average of baseline
- automatic detection of pulses based on variance



Upper part → without feedback
Lower part → with feedback

D. Bazzacco

Noise filtering



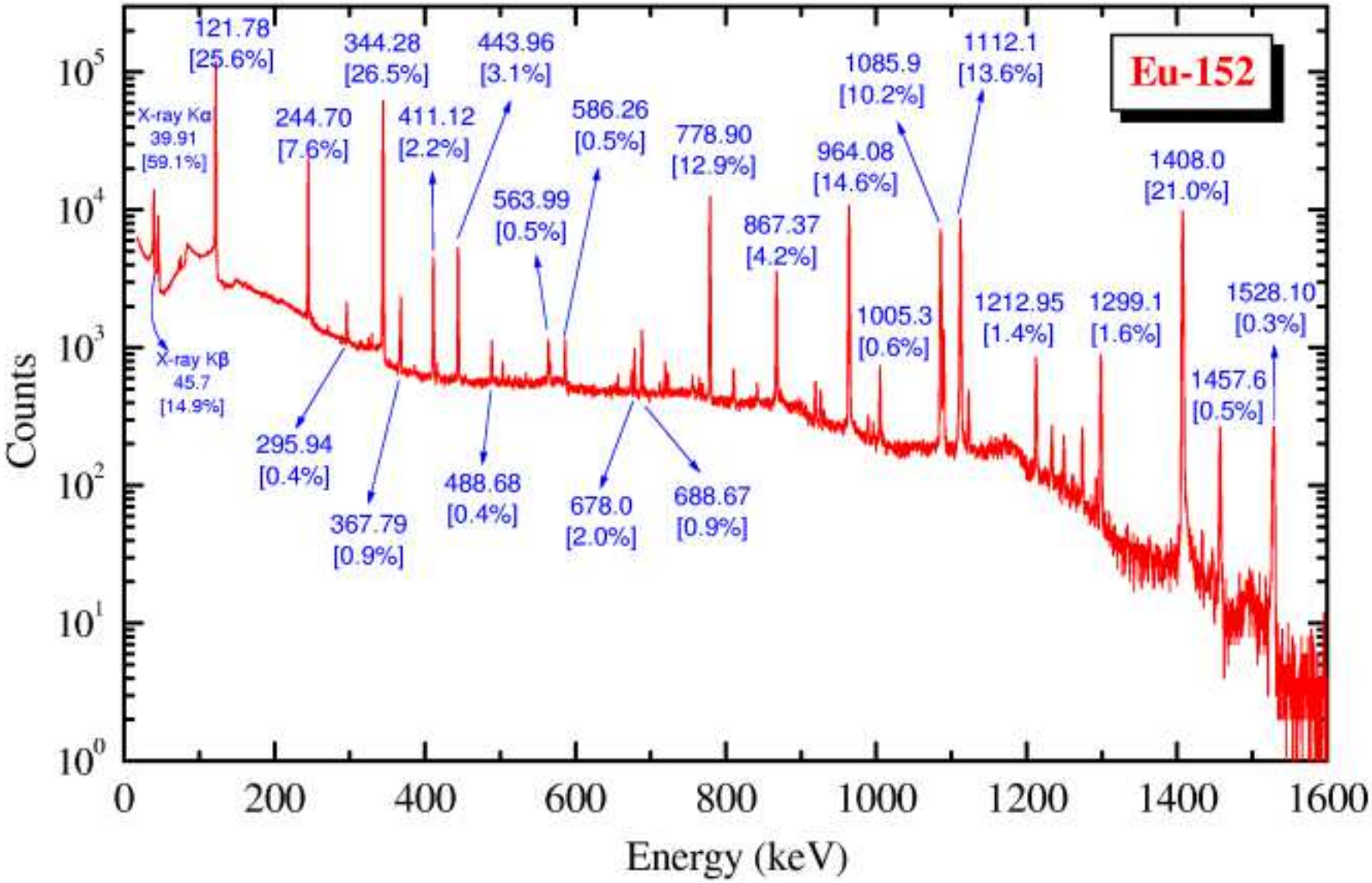
Your **goal is the best resolution**:

- Exponential constant (τ)
- Risetime
- Flattop
- Threshold

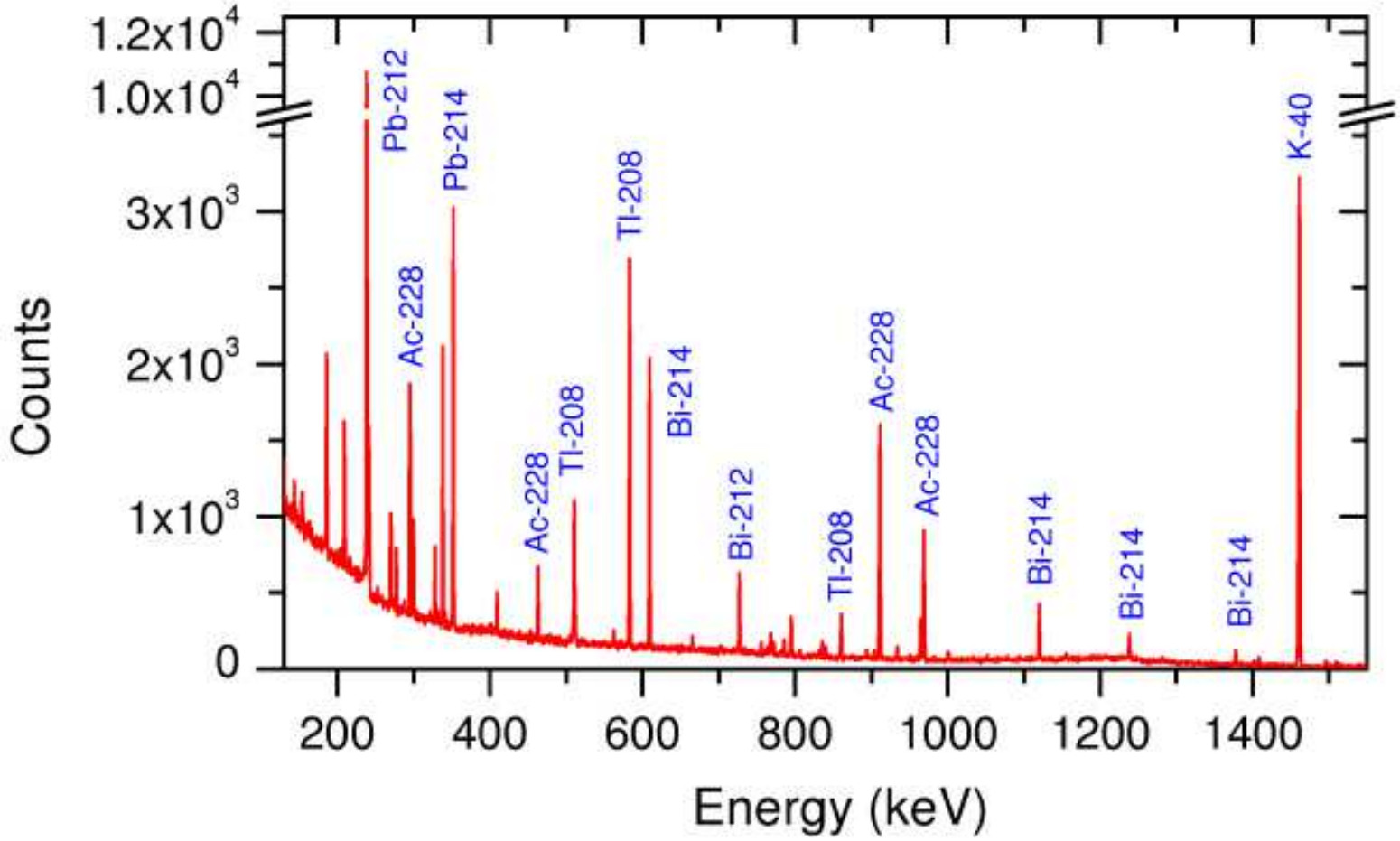
Calibration in efficiency and energy of the detectors

a) absolute efficiency measurement with calibrated sources of ^{22}Na (gamma of 511 e 1275 keV), with ^{241}Am (59 keV) and with ^{60}Co (1173 e 1333 keV)

b) relative efficiency measurement of the HPGe detector with a source



Environmental background measurements: HPGe detector



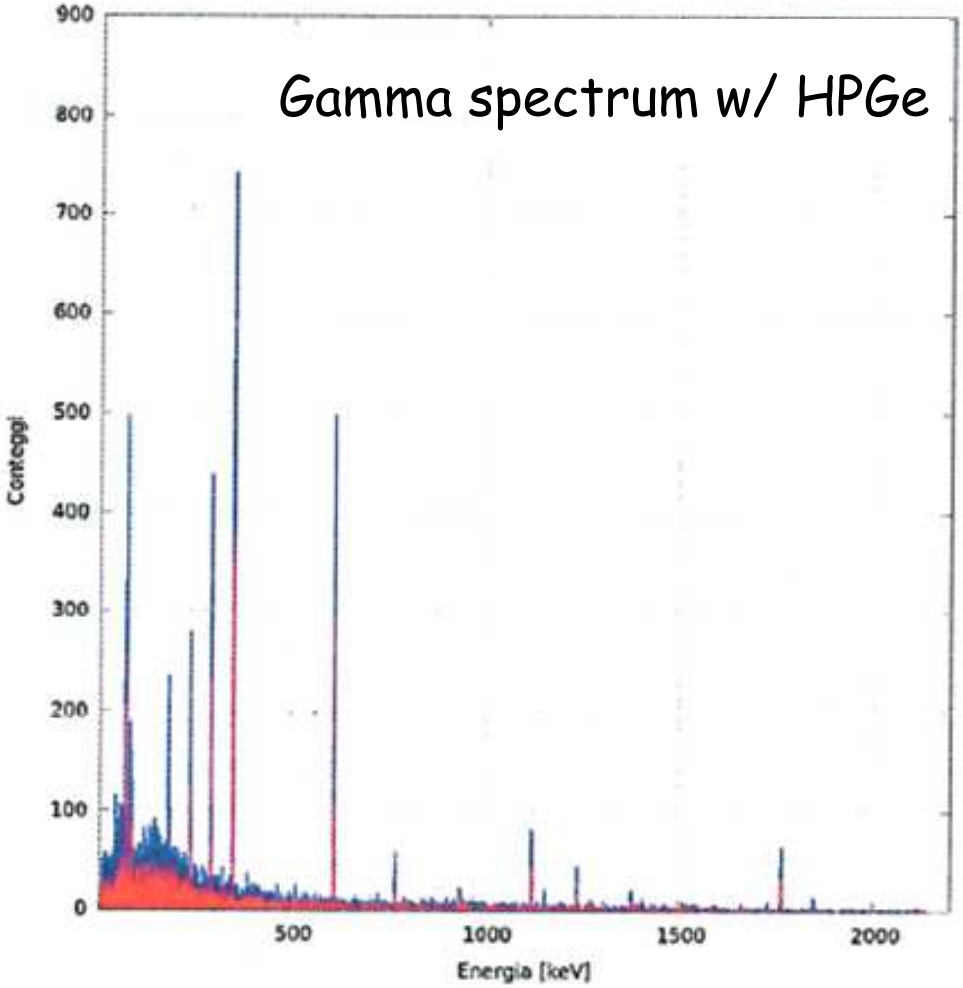
Typical gamma spectrum of a germanium detector measuring a sample of soil. Measurement time ≈ 10 hors. The gamma peaks corresponding to the most important radionuclides are labelled.

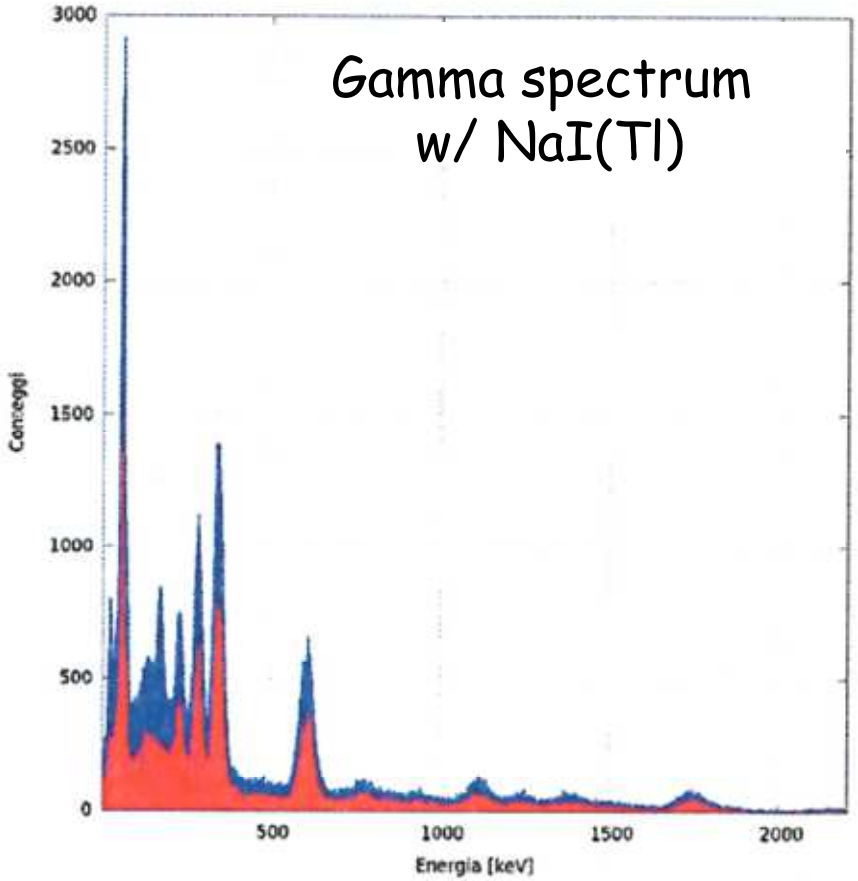
The measurement of indoor Radon in the laboratory

Determination of the radon activity present in an inhabited building

- Standard techniques are used, identifying the gamma transitions from the decay of nuclei from the radon-derived chain.
- Radon present in a given environment is **absorbed into special "canister"** to the activated carbons that are left exposed for two days. The gamma emitted by the nuclei caught in the "canister" can then be counted with the available gamma detection apparatus.
- The calculation of radon activity per liter of air will be carried out following the EPA's **(Enviromental Protection Agency) standards**, USA.
- On the session (1st day) the **canister is weighed** and then exposed in the locale chosen within the Polo Didattico in Via Loredan.
  On the 3rd day the canister is recovered, closed and sealed with the original adhesive tape and repacked. The weight difference found (**water gain**) is due to vapor absorption.

Measurement of radon activity in the environment





Comparison of gamma spectra of exposed canister (**blue**) and not exposed canister (**red**)

Summarizing:

1- Energy resolution via **trapezoidal filtering.**
Energy calibration and efficiency of the two detectors **NaI (Tl) and HPGe.**

2- Environmental **background** measurement.

3- Measurement of natural radioactivity from a series of **samples.**
Measurement of **Radon indoor.**