

Chapter 7

Experiment # 5

MEASUREMENT OF ENVIRONMENTAL RADIATION with gamma spectroscopy techniques



7.1 Introduction to natural radioactivity

Radioactivity is part of our world since the birth of the planet. More than 60 radionuclides, i.e. radioactive isotopes, are present in nature, classified as:

1. Primordial radionuclides, i.e. created by nucleosynthesis cycles that generated all the isotopes present on earth.
2. Cosmogenesis product, i.e. formed by the interaction of cosmic rays with the atmosphere.
3. Artificial: products by human action both as a creation of a new isotope as well as human contribution to the part created by natural effects.

Radionuclides are not only found in the air, water, and soil, but they are also part of the human body as we continuously inhale or ingest the material containing such isotopes.

The importance of natural radioactivity can be demonstrated in Table 7.1 below, where the average annual dose distribution for the population in the US is reported.

Source	Equivalent dose (annual average) (μSv)
Inhalation (Radon and decay products)	2000
Other radionuclides deposited internally to the human body	390
Terrestrial environmental radiation	280
Cosmic rays	270
Cosmogenic radioactivity	10
Annual average dose from natural sources	3000
Annual average dose from artificial sources	600
Total	3600

Table 7.1: Average annual dose due to environmental radioactivity for the US population.

It should be noted that about 80% of the average dose (which amounts to 3600 $\mu\text{Sievert} / \text{year}$) is due to environmental radioactivity and almost half is due to the inhalation of Radon or its decay products.

Primordial radionuclides were yielded during nucleosynthesis processes. They are isotopes characterized by a very long half-life, often of the order of hundreds of millions of years, which allows them to be revealed in measurable quantities in our days. In general, radionuclides that have been populated in the past for an equivalent time of about thirty half-lives are no longer measurable.

Table 7.2 provides some information on the most important primordial radionuclides.

Some nuclei such as the ^{232}Th have a particularly complex decay chain $^{232}\text{Th} \rightarrow ^{228}\text{Ra} \rightarrow ^{228}\text{Ac} \rightarrow ^{228}\text{Th} \rightarrow ^{224}\text{Ra} \rightarrow ^{220}\text{Rn} \rightarrow ^{216}\text{Po} \rightarrow ^{212}\text{Pb} \rightarrow ^{212}\text{Bi} \rightarrow ^{212}\text{Po} \rightarrow ^{208}\text{Pb}$ (stable). Other primordial radionuclides are: ^{50}V , ^{87}Rb , ^{113}Cd , ^{115}In , ^{123}Te , ^{138}La , ^{142}Ce , ^{144}Nd , ^{147}Sm , ^{152}Gd , ^{174}Hf , ^{176}Lu , ^{187}Re , ^{190}Pt , ^{192}Pt , ^{209}Bi .

Radionuclide		Half-life	Features
Uranium 235	^{235}U	$7.04 \times 10^8 \text{ yr}$	0.72% natural abundance
Uranium 238	^{238}U	$4.47 \times 10^9 \text{ yr}$	99.27% natural abundance; it is present with concentrations of 0.5 - 4.7 ppm in common rocks
Thorium 232	^{232}Th	$1.41 \times 10^{10} \text{ yr}$	1.6 - 20 ppm in common rocks. Average concentration in the earth's crust 10.7 ppm

Radium 226	^{226}Ra	1.60×10^3 yr	16 Bq/kg in limestone and 48 Bq / kg in lava stones
Radon 222	^{222}Rn	3.82 days	Noble Gas; annual average concentration: from 0.6 Bq/m ³ to 28 Bq/m ³
Potassium 40	^{40}K	1.28×10^9 yr	In the ground with concentration 0.037-1.1 Bq/g

ppm means part per million

Table 7.2: Primordial Radionuclides

The continuous bombardment of the high altitude part of the Earth's atmosphere by cosmic rays (see Chapter 4 of these lecture notes) produces some radioactive nuclei that are referred to as **Cosmogenic Radionuclides**. The main ones are listed in Table 7.3.

Nuclide		Half-life	Reaction	Natural activity
Carbon 14	^{14}C	5730 yr	$^{14}\text{N}(\text{n},\text{p})^{14}\text{C}$	0.22 Bq/g nei materiali organici
Tritium	^3H	12.3 yr	Interaction of cosmic rays with N and O, spatial reactions induced by cosmic rays, reaction $^6\text{Li}(\text{n}, \text{alpha})^3\text{H}$	$1.2 \cdot 10^{-6}$ Bq/g
Beryllium 7	^7Be	53.28 days	Interaction of cosmic rays with N and O	10^{-5} Bq/g

Table 7.3: Cosmogenic Nuclides.

Other cosmogenic radionuclides are: ^{10}Be , ^{26}Al , ^{36}Cl , ^{80}Kr , ^{14}C , ^{32}Si , ^{39}Ar , ^{22}Na , ^{35}S , ^{37}Ar , ^{33}P , ^{32}P , ^{38}Mg , ^{24}Na , ^{38}S , ^{31}Si , ^{18}F , ^{39}Cl , ^{38}Cl , ^{34m}Cl .

Another series of radionuclides are created by human activities as a consequence of the use of radioactive materials in many applications (see Table 7.4). Such radionuclides in some cases sum up with a natural yielded component. In particular the release of radioactive isotopes into the atmosphere by nuclear weapon testing is significantly decreased in recent years after the Russian and US and the international community agreed to stop such tests.

Isotope		Half-life	Source
Tritium	^3H	12.3 yr	Yield in nuclear explosions and fission reactors, nuclear fuel reprocessing plants and nuclear weapons preparation sites.
Iodine 131	^{131}I	8.04 days	Fission product released by nuclear weapons and reactors. It is used in medicine.
Iodine 129	^{129}I	1.57×10^7 yr	Fission product released by nuclear weapons and reactors.
Cesium 137	^{137}Cs	30.17 yr	Fission product released by nuclear weapons and reactors.
Strontium 90	^{90}Sr	28.78 yr	Fission product released by nuclear weapons and reactors.

Technetium 99	^{99}Tc	$2.11 \times 10^5 \text{ yr}$	Decay product of ^{99}Mo , used in nuclear medicine.
Plutonium 239	^{239}Pu	$2.41 \times 10^4 \text{ yr}$	Yield by neutron bombardment of ^{238}U $(^{238}\text{U} + n \rightarrow ^{239}\text{U} \rightarrow ^{239}\text{Np} + \beta \rightarrow ^{239}\text{Pu} + \beta)$

Table 7.4: Radionuclides produced by human action.

Tables 7.5–7.8 shows some representative values of the natural radioactivity in the Earth's oceans (*1971 Radioactivity in the Marine Environment, USA*), food, human body and some building materials. These values were taken from: Handbook of Radiation Measurement and Protection, Brodsky, A. CRC Press 1978 and Environmental Radioactivity from Natural, Industrial and Military Sources, Eisenbud, M and Gesell T. Academic Press, Inc. 1997.

Soil		Sea water	
Nuclide	Estimated activity	Nuclide	Activity
Uranium	25 Bq/kg	Uranium	33 mBq/l
Thorium	40 Bq/kg	Potassium 40	11 Bq/l
Potassium 40	400 Bq/kg	Tritium	0.6 mBq/l
Radium	48 Bq/kg	Carbonium 14	5 mBq/l
Radon	10 kBq/m ³	Rubidium 87	1.1 Bq/l

Tabella 7.5: Radioactivity in soil and sea water

In Table 7.6 the natural radioactivity values are reported for some foods. The most common radionuclides are potassium (^{40}K), radium 226 (^{226}Ra), uranium 238 (^{238}U) and the associated decay products.

Food	^{40}K Bq/kg	^{226}Ra Bq/kg
Bananas	10	0.27×10^{-2}
Brazil nuts	15	2.7-18.9
Carrots	9	$0.2-0.5 \times 10^{-2}$
Potatoes	9	$0.27-0.67 \times 10^{-2}$
Beer	1	---
Meat	8	0.13×10^{-2}
Beans	12	$0.5-1.3 \times 10^{-2}$
Drinking water	---	$0-5 \times 10^{-4}$

Table 7.6: Natural radioactivity in some foods.

Nuclide	Quantity	Total activity	Daily intake
Uranium	90 µg	1.1 Bq	1.9 µg
Thorium	30 µg	0.11 Bq	3 µg
Potassium 40	17 mg	4.4 kBq	0.39 mg
Radium	31 pg	1.1 Bq	2.3 pg
Carbonium 14	22 ng	3.7 kBq	1.8 ng
Tritium	0.06 pg	23 Bq	0.003 pg
Polonium	0.2 pg	37 Bq	~0.6 fg

Table 7.7: Natural radioactivity in the human body for a 70kg adult (ICRP 30 data).

Material	Uranium		Thorium		Potassium	
	ppm	mBq/g	ppm	mBq/g	ppm	mBq/g
Granite	4.7	63	2	8	4.0	1184
Sandstone	0.45	6	1.7	7	1.4	414
Cement	3.4	46	5.1	21	0.8	237
Limestone Concrete	2.3	31	2.1	8.5	0.3	89
Sandstone Concrete	0.8	11	2.1	8.5	1.3	385
Drywall	1.0	14	3	12	0.3	89
Chalk processing waste	13.7	186	16.1	66	0.02	5.9
Natural plaster	1.1	15	1.8	7.4	0.5	148
Wood	-	-	-	-	11.3	3330
Clay bricks	8.2	111	10.8	44	2.3	666

Table 7.8: Natural radioactivity in some building materials (data from NCRP 94, 1987).

7.2 The radon problem

Radon is a noble gas present in nature with the isotopes ^{219}Rn , ^{220}Rn and ^{222}Rn . Considering the isotopic abundances and half-lives, the largest contribution to the activity is given by the ^{222}Rn isotope. The natural abundance of the Rn element is 4×10^{-13} mg/kg in the earth's crust and 6×10^{-16} mg/l in sea water.

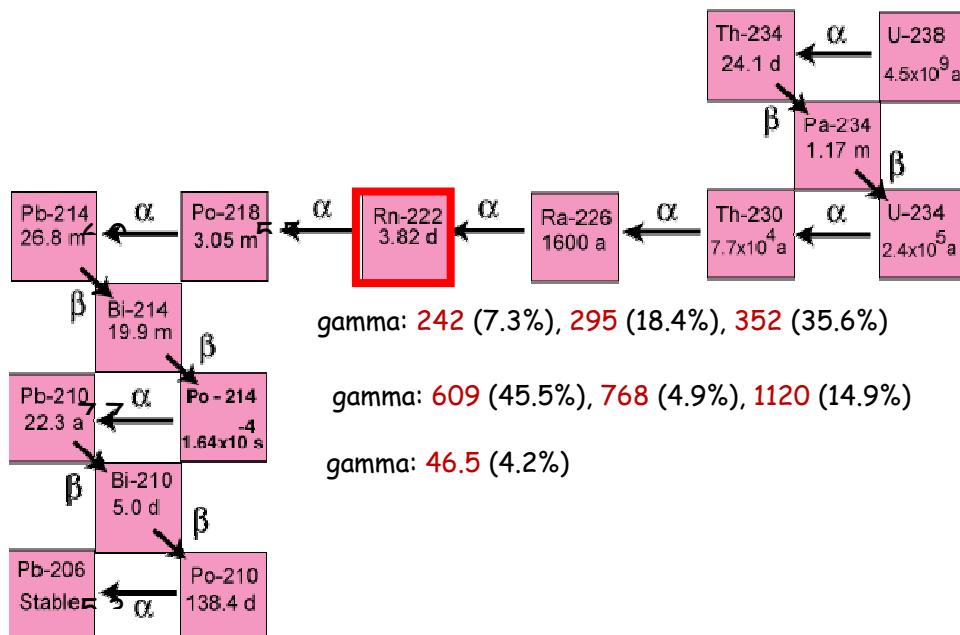


Fig. 7.1 Population and decay chain of ^{222}Rn . The gamma energy is in keV.

The decaying chain that populates the ^{222}Rn is shown in Fig.7.1, where also the decay products, gamma transitions and alpha particles are indicated.

Radon is normally generated in rocks or soil or is emitted by building materials and moves freely by reaching the air through the porosity of the material. Radon movement occurs in the fluids by molecular diffusion, while in the solids (soil) a fluid (air or water) is needed to transport it. If emitted from the ground in an open environment, radon disperses rapidly, thus not generating significant concentrations. Conversely in unventilated and closed environments significant concentrations can be reached. In the case of houses, besides the direct emission from the ground, the concentration of radon can also increase due to internal - external pressure gradients, even though minimal, due to the action of atmospheric agents and the presence of heating. As shown in Table 7.1, the greatest contribution to the total population exposure to ionizing radiation comes from the isotope ^{222}Rn (Radon) and its decay products. Radon exposure normally occurs in closed environments where a high concentration of such gas is present. Epidemiological studies conducted on Uranium miners have shown a correlation between exposure to radon and lung cancer. However, it is not safe to extrapolate these epidemiological studies to radon risk in buildings (see pg.209 of the volume Air Quality Guidelines for Europe, Second Edition, WHO, European series, No. 91, available at www.euro.who.int/_data/assets/pdf_file/0005/74732/E71922.pdf). Epidemiological studies have led to a linear correlation between the level of Radon (in Bq/m^3) and the fraction of lung cancer attributable to this cause, as shown in Fig.7.2

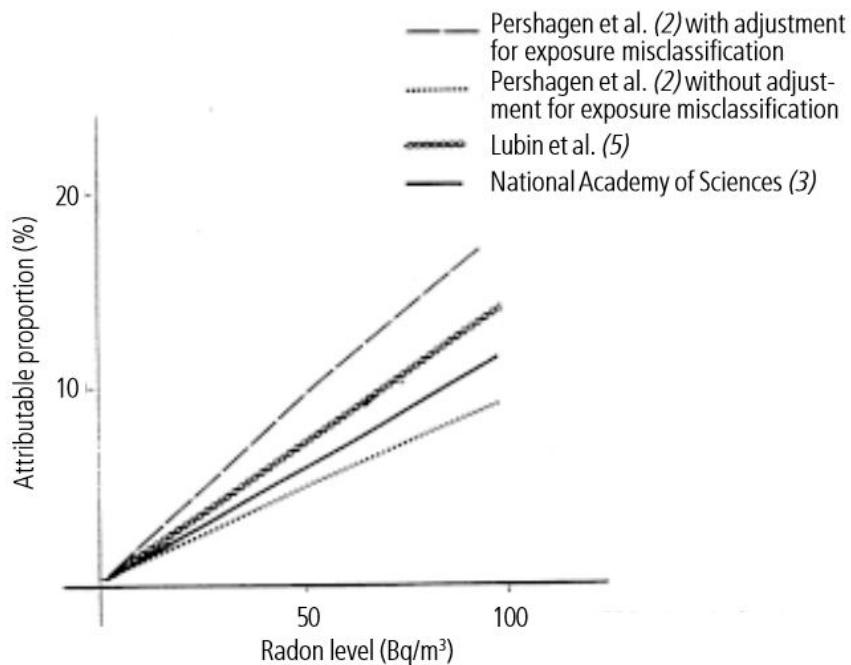


Fig. 7.2 Correlation between the percentage of cases of lung cancer and Radon concentration (from Air Quality Guidelines for Europe, Second Edition, World Health Organization).

More detailed statistics about such correlation are reported from the same document in Table 7.9.

	Concentration		
	High	Medium	Low
<i>Radon concentration</i>			
Arithmetic mean (Bq/m ³)	100	50	25
> 200 Bq/m ³	15%	1.5%	0.75%
> 400 Bq/m ³	5%	0.5%	0.25%
<i>Proportion of all lung cancers attributable to the exposure</i>			
Total	9–17% ^b	5–9%	2–5%
> 200 Bq/m ³	4–6%	0.4–0.6%	0.2–0.3%
> 400 Bq/m ³	2–3%	0.2–0.3%	0.1–0.15%
<i>Excess lifetime lung cancer deaths (per million)^c</i>			
Total	2700–5100	1500–2700	600–1500
> 200 Bq/m ³	1200–1800	120–180	60–90
> 400 Bq/m ³	600–900	60–90	30–45

Table 7.9: Relationship between lung cancer and exposure to radon at various concentrations.

As we can see for an average exposure of 100 Bq/m³ we expect an increase of 2700–5100 units per million of deaths due to lung cancer. Epidemiological studies also show that, for such pathology, the effects of Radon sum to other sources of risk (such as smoking).

Measuring campaigns have been conducted in Italy to determine the level of radon in houses. These campaigns were implemented at regional level by the Regional Agencies for Environmental Prevention. The results of such surveys on the Veneto Region can be found at the website of ARPAV (<http://www.arpa.veneto.it>). Some regional survey results are shown in Fig.7.3. The measured average doses depend on the different types of dwellings, building materials and the year of construction. The largest concentrations were found in single-family houses built before 1900 with the use of stone materials. The greatest concentration is obviously found on the ground floor. The geographical distribution of the sites where Radon has a high presence in the dwellings shows a prevalence of mountainous areas, while it is much lower in the flat land and along the coast. This distribution reflects the effect of the geological conformation on the presence of radon.

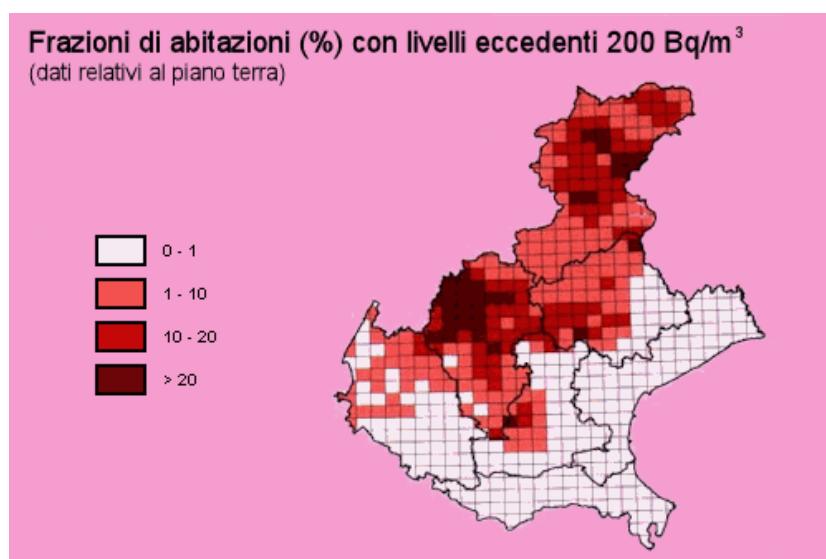


Fig.7.3 Results of the radon level survey in Veneto's dwellings.

In Veneto the average values found are about 60 Bq/m^3 , slightly below the national average of 75 Bq/m^3 . By estimating the average time spent in indoor environments by the population, Radon's average concentration in Italy corresponds to a dose of 1.5 mSv/year , below 2 mSv/year reported in Table 7.1.

In Italy regulations for houses are lacking while instead there is a decree limiting the maximum value of radon concentration in the working environments to 500 Bq/m^3 . There exist guidelines for radon concentration monitoring in environments where countermeasures have been applied. A typical example is shown in Fig.7.4 in which the radon concentration in a room is shown to depend on whether the ventilation systems are switched on.



Fig. 7.4: Radon concentration in dwellings as a function of ventilation.

This laboratory experience is devoted to environmental radioactivity measurements in samples of different origin and to a direct measurement of radon concentration in closed environments located within the Department of Physics.

7.3 Experimental setup

The experimental apparatus for low background measurements consists of a shielded well equipped with two detectors for gamma spectroscopy: a NaI(Tl) scintillation detector and a HPGe detector (hyper-pure germanium detector) operated at the liquid nitrogen temperature. The open shielding with the NaI(Tl) detector and the sample centering rings are shown in Fig.7.5.



Fig. 7.5: Shield for low-background measurement. The NaI(Tl) is visible along with the sample centering rings. The HPGe detector can be inserted from a devoted opening of the shield.

The NaI(Tl) detector can be used without any time constraints, allowing to perform high statistical measurements at night. Instead the liquid nitrogen dewar of the HPGe detector allows the operation of this detector at the measuring station for a maximum of 8 hours. As a consequence the detector can be used only during the laboratory session. The description of the NaI(Tl) scintillation detectors and the general characteristics of the semiconductor detectors can be found in Chapter 12.

The NaI(Tl) scintillator is a cylinder of dimensions 7.5 cm x 7.5 cm and it is coupled to a photomultiplier (PMT), connected to a base with a voltage divider that supplies the power to the dynodes and the anode. The output signal is derived directly from the anode (Time Signal, used for time measurements) or is formed by a pre-amplifier contained in the base (Energy Signal, for spectroscopy measurements) connected to the last dynode. The detector is operated at the fixed voltage of HV = + 700 Volt.

The measuring station is also equipped with HPGe detector type GMX with a 25% efficiency (relative to a standard 3 "x 3" standard NaI(Tl) scintillator). When not in use, the detector is connected to a large dewar containing liquid nitrogen sufficient to keep the detector at the cryogenic temperature for a week. By gravity, liquid nitrogen flows continuously from the large dewar to the detector reservoir. The system is shown in Fig.7.6



Fig. 7.6: The HPGe detector connected to main dewar.

Before the start of each laboratory shift, the detector is placed in the shielding and connected to the electronics so that students find the system ready to use. The HPGe detector works at a voltage HV = -2000 Volt. The voltage of the detector and its shutdown is a process that needs to be done slowly, to avoid the risk of damaging the semiconductor. The detector can then be used from 2 pm to 6 pm on each day.

The first stage of amplification of the HPGe consists in the FET plus feedback network that are mounted nearby the germanium crystal in the same vacuum capsule at liquid nitrogen temperature. The FET output is sent to the preamplifier which is as well mounted on the detector but outside the vacuum and in the warm part of the detector. The preamplifier provides two outputs. One of the preamplifier output will be connected to the input of the digitizer (CAEN) for energy measurement.

You will find the electronics already wired and you will have to check the signals at the oscilloscope before starting the experience.

The NaI(Tl) detector will be used for quantitative sample activity measurements, while the HPGe detector will be used to study the gamma spectrum in detail and identify the isotopes that are present. It is therefore necessary to calibrate the energy detectors and determine the efficiency of the system.

In order to obtain an estimation of the energy a trapezoidal filter will be used. Fig. 7.7

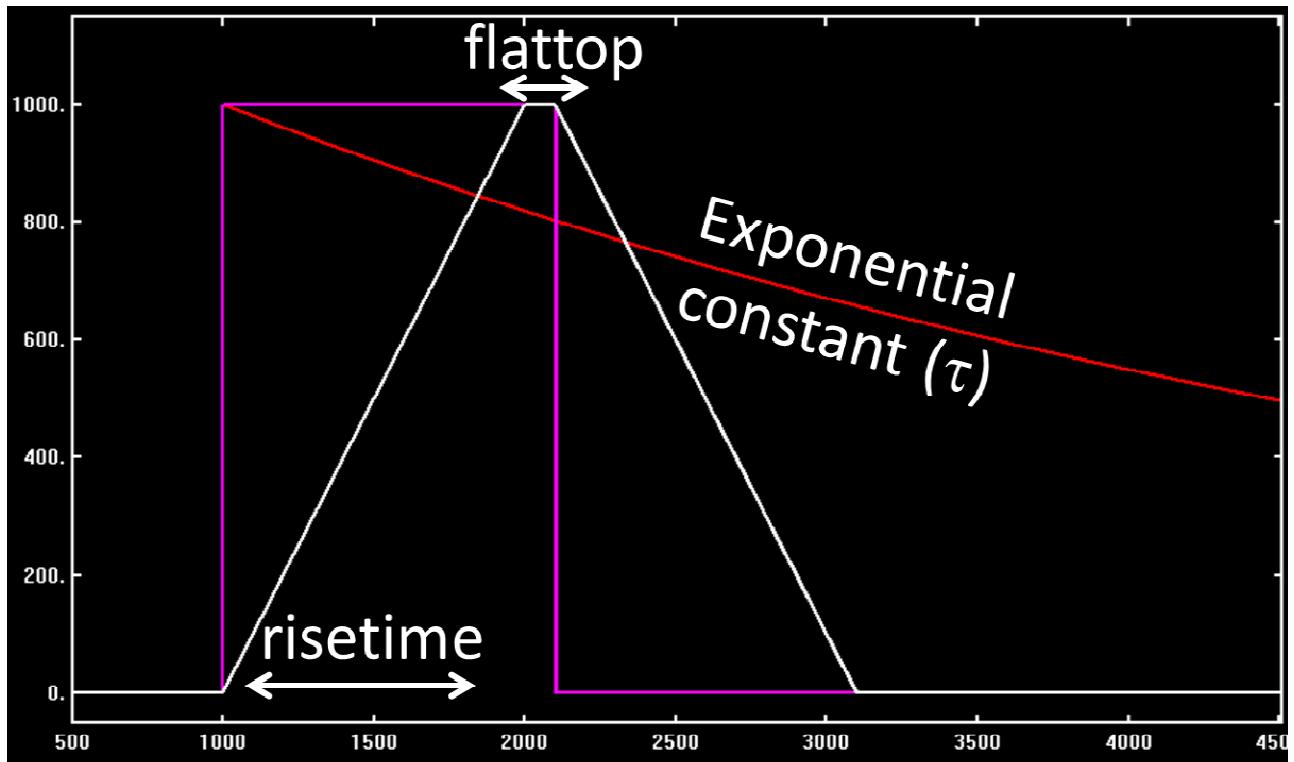


Figure 7.7 The trapezoidal filter implemented in the DT5780 Caen digitizer and the name of the parameters

7.4 Charachterization of the detectors

At the beginning of the experience (first session) the measurement of the efficiency of the detectors is taken using known activity sources of ^{22}Na with γ lines at 511 keV and 1275 keV or ^{60}Co with γ lines at 1.17 MeV and 1.33 MeV depending on the availability in the lab, and ^{241}Am with a line at 59 keV. These sources will be mounted by the lab personnel on a support so as to be at a known distance form the surface of the NaI(Tl) detector and on the axis of that detector. By this way, from the knowledge of geometry and the nominal activity of the source, it is possible to determine the absolute efficiency of the NaI(Tl) detector at the energies of the measurement.

A second determination of the overall efficiency of NaI(Tl) for photons emitted in the decay of radon will be carried out using a calibrated canister (see description of the Radon Counting measurement). The preliminary characterizations of the detector are needed in order to determine the activity of the different samples that will be measured later on.

For the characterization of the HPGe detector a first measurement will be made with the sources of ^{241}Am and ^{22}Na conveniently positioned at a distance known by the detector. This will allow to have a direct estimate of the detector's efficiency. Moreover a ^{152}Eu source will be used decays both β^+ and β^- to the daughter nuclei of ^{152}Gd and ^{152}Sm . Since both the energy and the relative intensities of the gamma transitions produced by that source (as reported in Tab. 7.10 and

Fig.7.9) are well known, it will be possible to obtain both the energy calibration and the relative efficiency curve of that detector. These data are needed to identify the gamma emitters identified in the spectrum and evaluate the relative weight.

121.8	141.0 ± 4.0
244.7	36.6 ± 1.1
344.3	127.2 ± 1.3
367.8	4.19 ± 0.04
411.1	10.71 ± 0.11
444.0	15.00 ± 0.15
488.7	1.984 ± 0.023
586.3	2.24 ± 0.05
678.6	2.296 ± 0.028
688.7	4.12 ± 0.04
778.9	62.6 ± 0.6
867.4	20.54 ± 0.21
+964.0	70.4 ± 0.7
1005.1	3.57 ± 0.07
1085.8	48.7 ± 0.5
1089.7	8.26 ± 0.09
1112.1	65.0 ± 0.7
1212.9	6.67 ± 0.07
1299.1	7.76 ± 0.08
1408.0	100.0 ± 1.0
1457.6	2.52 ± 0.09

Tab. 7.10: Energy and relative intensity of the γ lines emitted from a ^{152}Eu source.

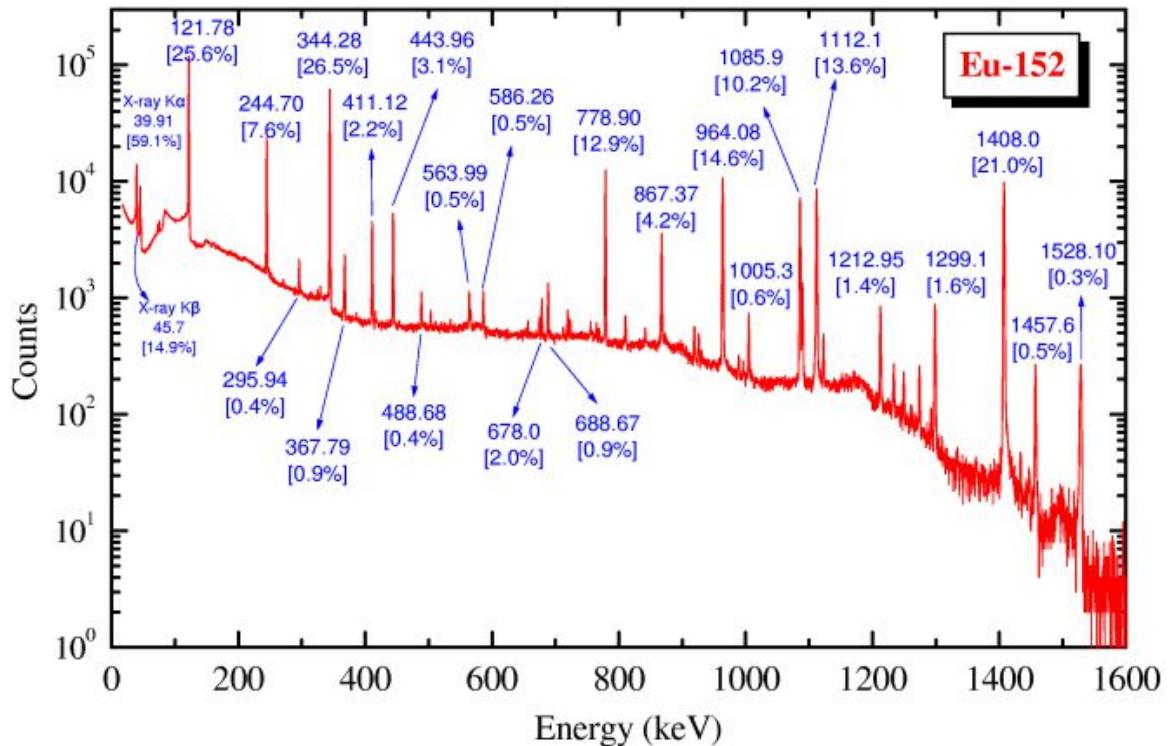


Fig. 7.8: Typical γ spectrum of a ^{152}Eu source measured with a HPGe detector.

7.5 Radon Counting

We want to determine the activity of radon naturally present in an environment with standard techniques that use the observation of gamma transitions emitted in the decay of nuclei produced in the chain originating from radon. The nuclei involved, the types of decay and the corresponding half-lives are shown in Figure 7.1.

Part of the radon gas present in a given environment will be absorbed into "canister" of activated charcoal that will be left open for 48 hours.

The gamma emitted by radioactive nuclei caught in the canister will then be counted with the gamma spectroscopy apparatus described above. The calculation of radon's activity per liter of air will be done according to the EPA's standard (Environmental Protection Agency - USA).

In the first session of the experiment, the canister is weighed and then exposed open in a specific locale within the Polo Didattico building. At the beginning of the third session, the canister will be retrieved, sealed with the original adhesive tape and weighted again. The increase in weight is due to the absorption of water vapor, the so-called "water gain". If the water gain in 48h is less than one gram, it is conventionally established that the average humidity during the exposure was 20%. If the water gain is greater than 1.0 g and less than 4.0 g, the humidity is fixed at 50%; Finally, if the water gain is greater than 4.0 g, it is set to 80%. These values are used to determine the appropriate calibration factors CF and AF (Figures 7.9 and 7.10) used in the following. Depending on the laboratory calendar, the canister may be exposed from a minimum of 2 days to a maximum of 5 days. To obtain the relative humidity value it is possible to normalize the water gain to a 48-hour exposure.

Water Gain, Average Humidity and T_s Exposure Time are used to calculate the CF calibration factor (liters / minute) which indicates how many liters of air are presumably filtered per minute from the canister during the exposure.

The CF is generally calculated for a number n of days of exposure as follows:

$$CF = CF(2) \times AF(T_s) / AF(2)$$

where $CF(2)$ is the calibration factor for a two-day standard exposure and AF are moisture-dependent "adjustment" factors that relates CF for two-day to the CF relative to the actual exposure time. To calculate the $CF(2)$ from Fig. 7.9 remember to use the 48-hour normalized water gain (in grams).

Data have to be taken for the standard radium source, for an unopened canister (bottom) and for the exposed canister. It is suggested to acquire each spectrum for about 30 minutes. The gamma spectrum has to be from the standard sources has to be understood using at the high resolution data of the HPGe detector. It is possible to define the area of interest (i.e. the range of gamma energy) for quantitative measurements with the NaI (Tl) scintillator. It is suggested to consider a range of energy that includes all major gamma transitions.

If E is the net number of counts per week (background subtracted using the background canister) per pCi for the standard calibration source in the energy region of interest (summing up all the gamma transitions present in the area of interest) and N is the corresponding net number of counts obtained for the exposed canister (background subtracted as in the previous case).

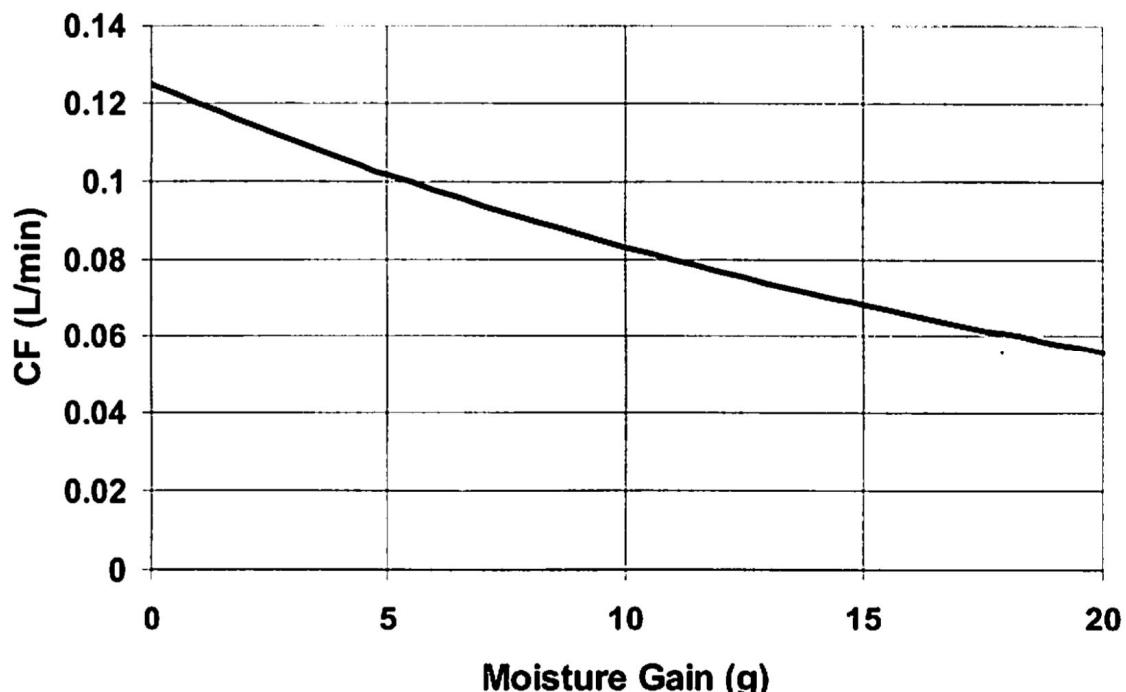


Fig. 7.9: Calibration factor CF (see text) as a function of "water gain".

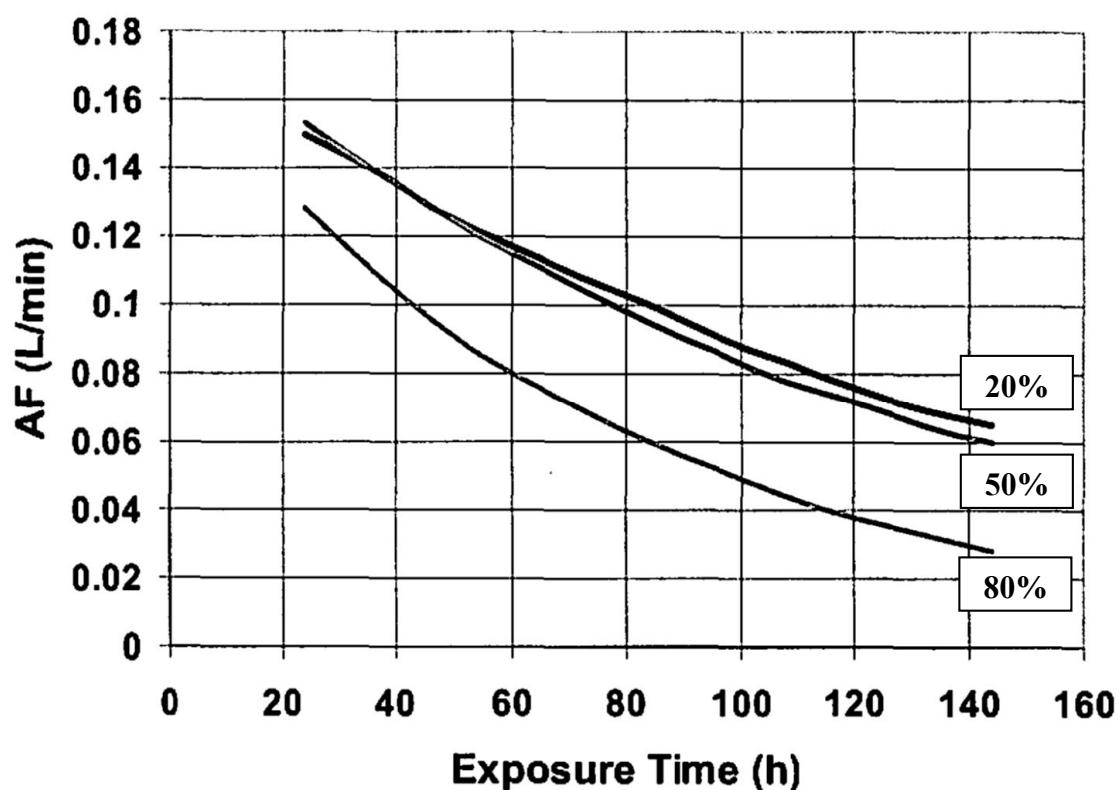


Fig. 7.10: AF calibration factor (see text) depending on the exposure time.

We calculate the DF decay factor that takes into account that part of the trapped radon in the canister can decay before being counted:

$$DF = \text{EXP}(-0.693 t) / (\text{T}_{1/2} \text{ of Radon})$$

$$DF = \text{EXP}(-0.693 t) / (5501)$$

Where t is the time in minutes from half of the exposure period of the canister to when its activity is measured.

6) The radon activity per liter of air (RN) is calculated as:

$$RN = N / (DF \times E \times CF \times T_s)$$

with T_s in minutes.

7.6 Experimental Protocol

The purpose of the Environmental Radioactivity Experiment is:

- a) Obtain the best possible energy resolution for both the HPGe detector and the NaI(Tl) detector adjusting the parameters of the trapezoidal energy filter.
- b) Calibrate in energy and efficiency the low background detector system available in the laboratory.
- c) Measure the ambient background spectrum and identify the origin of transitions in the gamma spectrum.
- d) Measure environmental radioactivity in samples (chosen by students) of different organic or inorganic materials.
- e) Perform an "indoor" radon measurement for a room of the Polo didattico building.

The experimental protocol is subdivided in the three afternoons available for the experiment. The temporal structure of the experiment works as a guidance to the activity and can be varied by the students.

First session: calibrartion of the detectors

At the beginning of the first session weigh the canister for the Radon Counting experience, place it in the chosen room for measurement and open it. Record the weight and time of the canister opening.

Next step is the calibration of the gamma detectors. Open the cover of the low-backgorund shielding.

- a) Connect to the Caen DT5780 module and control the HV panel. Bias the HPGe detector to -2000V and the NaI(Tl) phototube to +700V.
- b) Place the ^{22}Na source on the supporting stick and check the distance between the source and the center of the detector.
- c) Connect the outputs of the NaI(Tl) detector and HPGe detector to the two channels of the oscilloscope.
Record the characteristics of the two signals on the measurement protocol (risetime, amplitudes).
- d) Now connect the cable of both the detectors to the digitizers and observe the trapezoidal filter that you obtain. In order to make the "flattop" to be flat you have to adjust the decay time between 50 and 100 μs .
- e) Disable the recording of the waveform on disk. This is needed in order to not to fill the disk of the acquisition machine. If you forget to disable them your data will be deleted to make space for the other students.
- f) Measure the resolution for different values of the risetime (between 50 and 500 samples, equivalent to 0.5 to 5 μs) till you optimize the resolution for both the detectors.
- g) Measure the resolution for different values of the flattop (between 10 and 100 samples, equivalent to 0.1 to 1 μs) till you optimize the resolution for both the detectors.
- h) Write the parameters you optimized into the file `~/Desktop/Verdi/student_config.cfg` so that all the next times you will start Verdi you will have the proper parameters loaded.
- i) Acquire a calibration spectrum for 10 minutes by saving it to files. Fit the peaks with gaussian and report the values on the protocol.
- j) Replace the source of ^{22}Na with that of ^{241}Am and acquire a spectrum for 10 minutes (save the file). Perform the gaussian peak fit and record the values on the protocol
- k) Calculate the calibration coefficients using the three energy values.

- l) Place the source of ^{22}Na at about 20 cm from the HPGe detector, measure the distance and then connect the cables of this detector as in step b) and perform the controls in step c).
- m) Acquire a calibration spectrum for 10 minutes by saving the gaussian fit files and return the values.
- n) Replace the source of ^{22}Na with that of ^{241}Am and also get a 10-minute spectrum (and save the files) in this case. Perform gaussian fit and record the values.
- o) Calculate the calibration line using the three energy values.
- p) Now place the ^{152}Eu source. Get a spectrum for 20 minutes. Save the file.
- q) Remove all radioactive sources and place them in the safe (as far as possible). Acquire a spectrum of the ambient background for at least 30 minutes.

Hints for data analysis:

1) Measurement of the intrinsic efficiency of the detectors using the ^{22}Na ed ^{241}Am sources

The intrinsic efficiency of a detector is defined as the ratio between the number of recorded events divided by the number of γ that hit the detector. In our case it is also interesting to calculate intrinsic efficiency of the full-energy peak, defined as the ratio between the number of events in that peak divided by the number of γ that hit the detector.

The number of events in a peak can be determined by Gaussian fit by subtracting the background. To determine the number of γ that hit a detector, it is necessary to know the number of decays per second of the source, the fraction of decays that produces a given gamma transition, the measurement time and the solid angle fraction covered by the detector. The first quantity is derived from available sources data by estimating activity at the date of laboratory measurements. The second is derived from the decay scheme. The measurement time can be read directly from the data acquisition. To measure the solid angle covered it is possible to use the distance source / front surface of the detector and the detector area (75 mm diameter for the NaI (T1) scintillator and area 1200 mm² for the HPGe detector).

Plot the efficiency versus the energy of the photon.

2) Measurement of the relative efficiency curve of the HPGe with a ^{152}Eu source

As shown in Table 7.10, the relative yield data are normalized assuming that the transition of 1408 keV of the ^{152}Eu source has yielded 100%.

Analyze the gamma spectrum using fitting with a gaussian the peaks for each gamma transition (subtracting the background). Normalize the areas of the peaks in order to have a nominal value of 100 for the transition to 1408 keV. Dividing the experimental values for the tabulated ones you can get a relative efficiency curve. The figure shows a normalized efficiency curve at value 1 for the transition to 344 keV. Plot the relative efficiency measured versus the energy of the transition.

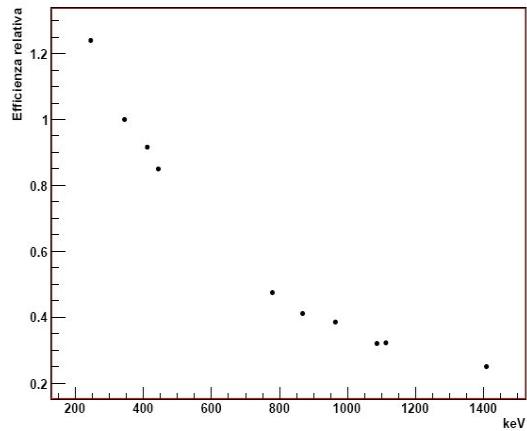


Fig. 7.11: Relative efficiency of the HPGe detector as a function of energy.

ENVIRONMENTAL RADIOACTIVITY EXPERIMENT
SETUP AND CALIBRATION OF THE DETECTOR
NaI(Tl)

Group..... Padova.....

Source.....

Characteristics of the pre-amplified signal

Vmax	Rise time (ns)	Noise level (mV)

CALIBRATION SPECTRUM

Source detector distance:.....cm

SourceActivity.....in date.....

Measurement time.....s

Spectrum saved as

Analsyis of the spectrum

Peak #	Energy (keV)	Centroid	Sigma	Integral
1				
2				

Energy resolution@..... keV

Energy resolution @..... keV

Efficiency@..... keV

Efficiency @..... keV

CALIBRATION SPECTRUM II

Source detector distance:.....cm

SourceActivity.....in date.....

Measurement time.....s

Spectrum saved as

Analsyis of the spectrum

Peak #	Energy (keV)	Centroid	Sigma	Integral
1				

Energy resolution@..... keV

Efficiency@..... keV

CALIBRATION SPECTRUM III

Source detector distance:.....cm

SourceActivity.....in date.....

Measurement time.....s

Spectrum saved as

Analsysis of the spectrum

Peak #	Energy (keV)	Centroid	Sigma	Integral
1				

Energy resolution@..... keV

Efficiency@..... keV

**ENVIRONMENTAL RADIOACTIVITY EXPERIMENT
SETUP AND CALIBRATION OF THE DETECTORHPGe**

Group..... Padova.....

Source.....

Characteristics of the pre-amplified signal

Vmax	Rise time (ns)	Noise level (mV)

CALIBRATION SPECTRUM

Source detector distance:.....cm

SourceActivity.....in date.....

Measurement time.....s

Spectrum saved as

Analsysis of the spectrum

Peak #	Energy (keV)	Centroid	Sigma	Integral
1				
2				

Energy resolution@..... keV

Energy resolution @..... keV

Efficiency@..... keV

Efficiency @..... keV

CALIBRATION SPECTRUM II

Source detector distance:.....cm

SourceActivity.....in date.....

Measurement time.....s

Spectrum saved as

Analsysis of the spectrum

Peak #	Energy (keV)	Centroid	Sigma	Integral
1				

Energy resolution@..... keV

Efficiency@..... keV

CALIBRATION SPECTRUM III

Source detector distance:.....cm

SourceActivity.....in date.....

Measurement time.....s

Spectrum saved as

Analysysis of the spectrum

Peak #	Energy (keV)	Centroid	Sigma	Integral
1				

Energy resolution@..... keV

Efficiency@..... keV

CALIBRATION SPECTRUM OF ^{152}Eu

Source detector distance:.....cm

SourceActivity.....in date.....

Measurement time.....s

Spectrum saved as

Analysysis of the spectrum

Peak #	Energy (keV)	Centroid	Sigma	Integral
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

ENVIRONMENTAL BACKGROUND SPECTRUM
NaI(Tl)

Measurement time.....s
Spectrum saved as

Analysys of the spectrum

Peak #	Energy (keV)	Centroid	Sigma	Integral
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

ENVIRONMENTAL BACKGROUND SPECTRUM
HPGe

Measurement time.....s
Spectrum saved as

Analysys of the spectrum

Peak #	Energy (keV)	Centroid	Sigma	Integral
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

Second session: samples analysis.

- 1) Recheck the energy calibrations by briefly taking a spectrum with the source of ^{22}Na .
- 2) Select some samples from the available ones: use at least one inorganic sample (concrete) and an organic sample. In Fig. 7.11 the sample spectrum of the Zirconium Oxide sample is reported as an example. There are also two low background activity samples that can be used as standard to measure the activity of other samples: a sample of 8 g of nominal activity 12 Bq of KCl for the emission of the 1.4 MeV photon and a sample of 500 g of water with a certified activity of 0.0188 Bq/g of ^{137}Cs (total activity 8 Bq).
- 3) Measure the environment background spectrum for about 15 minutes and then measure each sample for 15 minutes.
- 4) Analyze the spectra obtained and fill in the tables of the experimental protocol. Estimate activity in Bq/kg for the different radionuclides identified in each sample.

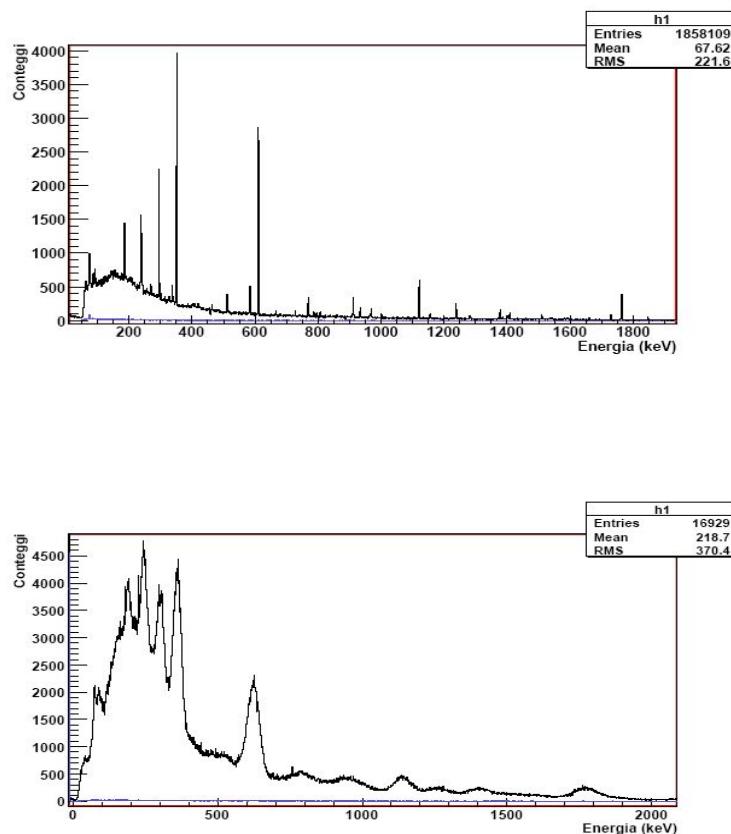


Fig. 7.11 Gamma spectra of a Zirconium Oxide sample measured with the HPGe detector (above) and the NaI(Tl) detector (below)

Hints for data analysis

1) Determining samples activity.

The presence of a given radionuclide is verified by the presence in the gamma spectrum (of HPGe and NaI (Tl)) of a peak at the expected energy. After determining the area of the peak by gaussian fit and subtracting the appropriate background in the gamma spectrum. Given the known duration of the measurement it is necessary to determine the efficiency of the detection system. You need to determine the absolute efficiency, which is a function of the gamma transition energy.

For the NaI(Tl) detector during the first day, the values of the intrinsic full energy efficiency values were determined at the energies 59, 511 and 1275 keV (^{241}Am and ^{22}Na). For each energy transition identified in the sample, the intrinsic efficiency can be obtained by interpolation or extrapolation of the measured values. The intrinsic full-energy efficiency can then be used to correct the measured values and get the number of photons that hit the detector. To obtain a correct estimation of the number of photons emitted by the sample the solid angle is needed. For the estimation of the solid angle it is possible to consider the source of the photons as pointlike and placed at the center of the extended sample you used. This way you can determine the number of decays per second and then the value of Bq/kg.

For the HPGe detector a relative efficiency curve is available (measured with the Europium source) and the absolute values measured with the sources of ^{241}Am and ^{22}Na . You can normalize relative efficiency curve to the measured absolute efficiency values and use this curve to have the absolute efficiency at the energy of interest.

For each sample, verify and discuss the difference between the activity in Bq/kg determined with the NaI (Tl) and HPGe detectors.

SAMPLE.....

Diameter.....cm

Thickness of the material.....cm

Weight.....kg

NaI(Tl)

Measurement time.....s

Spectrum saved as

Peak #	Energy (keV)	Centroid	Sigma	Integral	Origin	Activity (background subtracted) Bq/kg
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						

HPGe

Measurement time.....s

Spectrum saved as

Peak #	Energy (keV)	Centroid	Sigma	Integral	Origin	Activity (background subtracted) Bq/kg
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						

SAMPLE.....

Diameter.....cm

Thickness of the material.....cm

Weight.....kg

NaI(Tl)

Measurement time.....s

Spectrum saved as

Peak #	Energy (keV)	Centroid	Sigma	Integral	Origin	Activity (background subtracted) Bq/kg
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						

HPGe

Measurement time.....s

Spectrum saved as

Peak #	Energy (keV)	Centroid	Sigma	Integral	Origin	Activity (background subtracted) Bq/kg
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						

SAMPLE.....

Diameter.....cm

Thickness of the material.....cm

Weight.....kg

NaI(Tl)

Measurement time.....s

Spectrum saved as

Peak #	Energy (keV)	Centroid	Sigma	Integral	Origin	Activity (background subtracted) Bq/kg
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						

HPGe

Measurement time.....s

Spectrum saved as

Peak #	Energy (keV)	Centroid	Sigma	Integral	Origin	Activity (background subtracted) Bq/kg
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						

SAMPLE.....

Diameter.....cm

Thickness of the material.....cm

Weight.....kg

NaI(Tl)

Measurement time.....s

Spectrum saved as

Peak #	Energy (keV)	Centroid	Sigma	Integral	Origin	Activity (background subtracted) Bq/kg
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						

HPGe

Measurement time.....s

Spectrum saved as

Peak #	Energy (keV)	Centroid	Sigma	Integral	Origin	Activity (background subtracted) Bq/kg
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						

SAMPLE.....

Diameter.....cm

Thickness of the material.....cm

Weight.....kg

NaI(Tl)

Measurement time.....s

Spectrum saved as

Peak #	Energy (keV)	Centroid	Sigma	Integral	Origin	Activity (background subtracted) Bq/kg
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						

HPGe

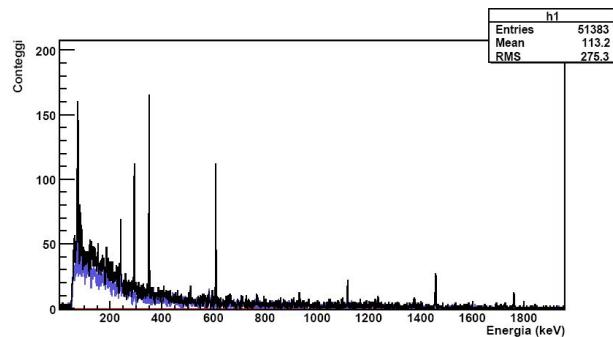
Measurement time.....s

Spectrum saved as

Peak #	Energy (keV)	Centroid	Sigma	Integral	Origin	Activity (background subtracted) Bq/kg
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						

Third session: RADON COUNTING.

- 1) Retrieve the canister. Seal it with the original adhesive tape and weigh it. Determine the water gain as the difference in weight. Identify the proper AC and AF correction coefficients in the tables.
- 2) Check the calibrations in energy using a short data taking of a spectrum with the ^{60}Co source.
- 3) Insert the calibrated canister into the measuring system, acquire a spectrum for 30 minutes.
- 4) Now enter the canister you have exposed. Get a spectrum for 30 minutes.
- 5) Insert a non-exposed canister for the background measurement. Take background spectrum for 30 minutes.
- 6) Following the procedure described in these notes determine the activity of the sample and then the presence of radon in the environment where the measurement was performed. The overall activity of the sample must be determined, do not measure just the relative activity of the individual transitions.
- 7) Measure the Autunite sample and determine the activity.



]

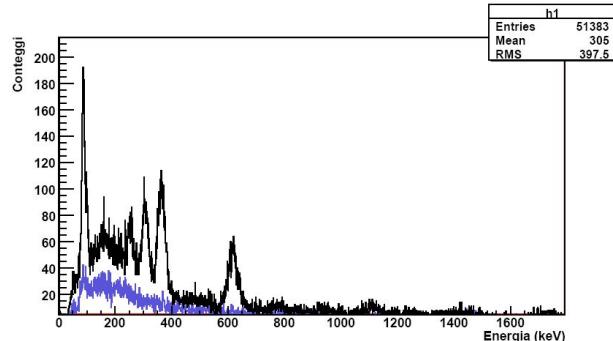


Fig. 7.12 Typical spectra obtained with the exposed canister (black) compared to the background spectrum (blue) for both detectors.

Hints for data analysis

In the specific case of the Radon measurement, a calibrated sample with the same geometry is available. Such sample is made of the same material of the canisters used to collect the radon. The determination of sample activity can be done simply using a fixed energy window to determine the number of counts in the three spectra, both with NaI (Tl) and with the HPGe detector. In the case of Autunite you can use the same energy window but correct for the different sample-detector distance.

RADON COUNTING

EXPOSED CANISTER

Measurement time.....s
Spectrum saved as

NaI(Tl)

Peak #	Energy (keV)	Centroid	Sigma	Integral	Origin
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					

HPGe

Peak #	Energy (keV)	Centroid	Sigma	Integral	Origin
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					

RADON COUNTING
NON-EXPOSED CANISTER (BACKGROUND)

Measurement time.....s
Spectrum saved as

NaI(Tl)

Peak #	Energy (keV)	Centroid	Sigma	Integral	Origin
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					

HPGe

Peak #	Energy (keV)	Centroid	Sigma	Integral	Origin
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					

RADON COUNTING
REFERENCE CANISTER

Measurement time.....s
Spectrum saved as

NaI(Tl)

Peak #	Energy (keV)	Centroid	Sigma	Integral	Origin
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					

HPGe

Peak #	Energy (keV)	Centroid	Sigma	Integral	Origin
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					

RADON COUNTING

AUTUNITE SAMPLE

Measurement time.....s

Spectrum saved as

NaI(Tl)

Peak #	Energy (keV)	Centroid	Sigma	Integral	Origin
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					

HPGe

Peak #	Energy (keV)	Centroid	Sigma	Integral	Origin
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					