Rev. 0 - September 24th, 2021

SP5630EN

Environmental kit for gamma radiation

CAEN Educational

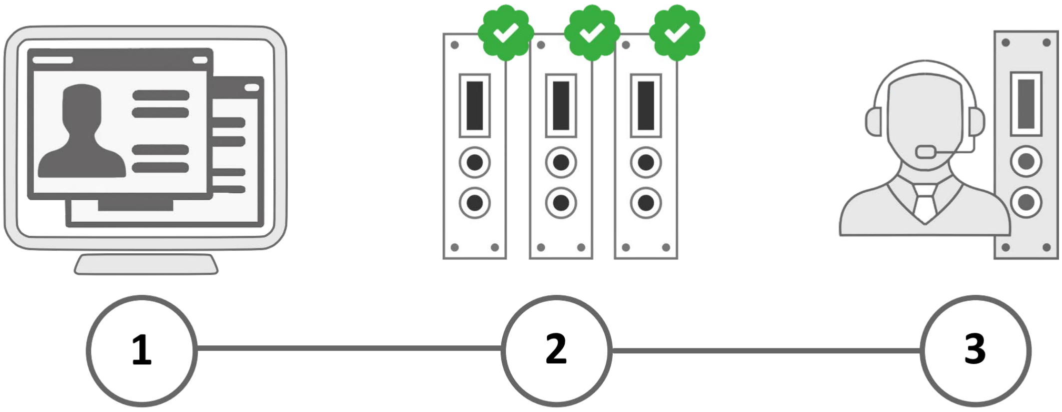
Guide

GD8359

Register your device

Register your device to your **MyCAEN+** account and get access to our customer services, such as notification for new firmware or software upgrade, tracking service procedures or open a ticket for assistance. **MyCAEN+** accounts have a dedicated support service for their registered products. A set of basic information can be shared with the operator, speeding up the troubleshooting process and improving the efficiency of the support interactions.

MyCAEN+ dashboard is designed to offer you a direct access to all our after sales services. Registration is totally free, to create an account go to https://www.caen.it/become-mycaenplus-user and fill the registration form with your data.



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Purpose of this Guide

This QuickStart Guide contains basic information and examples that will let you use the Environmental kit for gamma radiation measurements in few steps.

Change Document Record

Date	Revision	Changes
September 24th, 2021	00	Initial release

Symbols, Abbreviated Terms and Notation

GUI	Graphical User Interface
MCA	Multichannel Analyser
PMT	Photomultiplier Tube
SiPM	Silicon Photomultiplier
DC	Direct Current
OS	Operating System
USB	Universal Serial Bus

Reference Documents

[RD1] GD6745 – iSpector family Quick Start Guide

[RD2] EPA 402/K-10/005 "Consumer's Guide to Radon Reduction", March 2013, www.epa.gov/radon

[RD3] United States Environmental Protection Agency (EPA), "Indoor radon and radon decay product measument protocols", EPA 520-1/89-009, March 1989

[RD4] P. Jekins, "A critique of the "EPA Methos" for analyzing and calibrating charcoal canisters for radon measurements, 2002 International Radon Symposium Proceedings

All CAEN documents can be downloaded at: www.caen.it/support-services/documentation-area/

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MADE IN ITALY: We remark that all our boards have been designed and assembled in Italy. In a challenging environment where a competitive edge is often obtained at the cost of lower wages and declining working conditions, we proudly acknowledge that all those who participated in the production and distribution process of our devices were reasonably paid and worked in a safe environment (this is true for the boards marked "MADE IN ITALY", while we cannot guarantee for third-party manufactures).

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1. Introduction

Despite the idea that radioactivity is something dangerous, related to atomic bombs and nuclear waste diseases only, radioactivity is all around us and, with the correct handling and understanding, it can be used for peaceful human purposes. For this reason, we try to spread a better understanding of the physical processes of nuclear physics. The Environmental kit SP5630EN can show to users the behaviour of gamma radiation, which is produced from material of common use, like soil samples, camping lanterns, etc.

1. The kit is based on the i-Spector Digital **[RD1]**, the SiPM photomultiplier base with digital MCA from CAEN, coupled with a CsI(Tl) scintillation detector to reveal the gamma radiation and produce an energy spectrum from it. See also Sec. **Getting Started** for more details.
2. A holder is provided to house the i-Spector Digital and the sample material during the energy spectrum acquisition. The holder features a fan for cooling the i-Spector Digital and stabilize the operating temperature.
3. The kit comes with five samples of material to be analysed with the i-Spector Digital device:
    - Rock sample;
    - Fertilizer sample;
    - LYSO(Ce) (Cerium-doped Lutetium Yttrium Orthosilicate) scintillating crystal sample;
    - Active carbon samples;
    - Test sample, to be identified;
4. An additional empty box is added in the kit to perform a custom measurement with material collected by the user.
5. All the samples are sealed and labelled with the corresponding date of sealing and weight. The empty box can be sealed with scotch type and weighted with a scale which is included in the kit case.

The different building blocks of the kit can be assembled in a customized configuration, according to the specific application and the user’s requirements.

The purpose of this guide is to provide a hands-on primer on the use of the essential functionalities of the kit.

Code	Description
WSP5630ENXAAA	SP5630 – Environmental kit

Tab. 1.1: Table of models and related items.

2. Physics Pills

What is an atom?

The atom consists of a nucleus and a cloud of electrons. The nucleus is made of protons (positively charged) and neutrons (neutrally charged). The positive charge of a single proton is equal to the negative charge of a single electron. Having an equal number of protons and electrons, the atom has usually a net charge equal to zero. Atoms are the building blocks of the matter around us.

What is radioactivity?

Atoms can be stable or unstable when the forces among the particles of the nucleus are balanced or unbalanced. In case of unstable atoms, there is an excess of internal energy or either neutrons or protons, and the unstable atom will attempt to reach a more stable level by ejecting nucleons (protons or neutrons), as well as other particles, or by releasing energy in other forms.

Radioactivity is therefore the property of some unstable atoms (radionuclides) to spontaneously emit nuclear radiation, usually alpha (Helium nucleus), beta (electrons) particles, or gamma-rays (photons). The nucleus of the radioactive atom undergoes radioactive decay and it is converted into a different isotope, which can be either radioactive or stable. The process occurs until a stable radioisotope is reached.

What is a radioactivity decay chain?

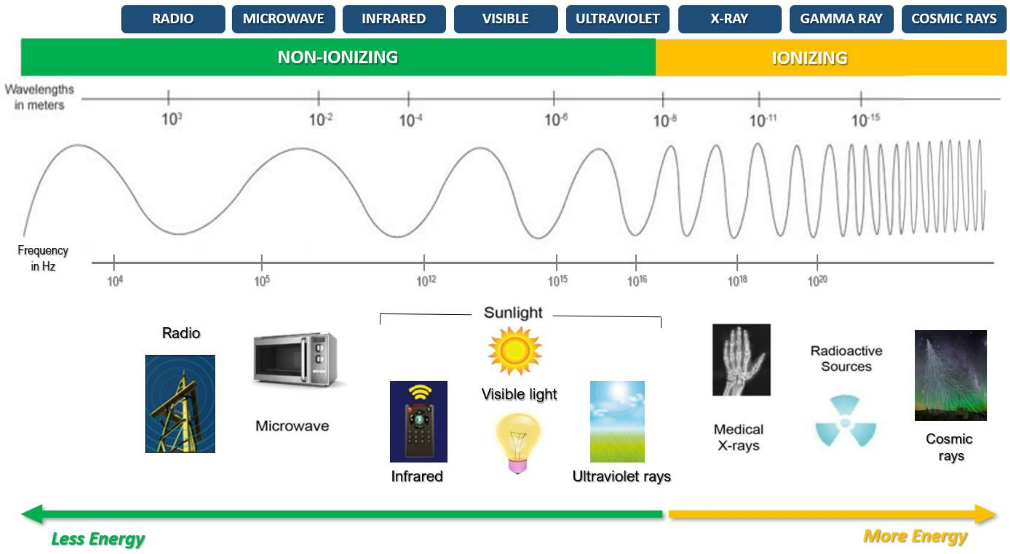
As the nucleus emits radiation or disintegrates, the radioactive atom (radionuclide) transforms to a different nuclide. This process is called radioactive decay. It will continue until the forces in the nucleus are balanced. For example, as a radionuclide decays, it will become a different isotope of the same element if it gives off neutrons.

The series of transformations that a radionuclide goes through to reach stability and the type of radiation produced is characteristic of the radionuclide and the stages form a decay series.

What is radiation?

Radiation is the process of emitting energy as either waves or particles. It is usually referred as ionizing radiation, where the emitter particle/wave has enough energy to let electrons escape from atoms or do lower-energy damage such as breaking chemical bonds in molecules. Non-ionizing radiation is able to transmit heat energy and raise the temperature of the hit object, like for example in the case of microwave cook.

The following diagram shows non-ionizing and ionizing radiation in the scale of electromagnetic energy. In our discussion we are going to consider mostly gamma radiation.



What is gamma radiation?

Gamma radiation (or gamma ray) is a packet of electromagnetic photons emitted by the nucleus due to radioactive decay. Gamma rays have the highest energy among the other electromagnetic radiations.

Where to find gamma radiation?

Radioactive material is quite common in nature. The human body got used to natural radiation, which is generally harmless in this state. Here follow some examples to understand how common radiation around us is:

- *Food*: Bananas contains a high amount of Potassium, and therefore a high amount of Potassium-40, a radioactive isotope. Other common foods containing radioactive elements include carrots, white potatoes, lima beans which also contain radon-224, Brazil nut which contains radium. Radioactivity levels are extremely low and not considered harmful. For example, the fat contained in the nuts can be more dangerous than the radiation.
- *Cosmic rays*: Radiation can come from the sun, where there are continuously nuclear reactions, and from outside the solar system. Most of the cosmic rays are intercepted and absorbed by the Earth's magnetosphere and the ozone layer, however, they make about 13% of the total annual background radiation a person is exposed to over the course of a year. This exposure rate is slightly increased by living at higher altitudes, and even more by air travel. For example, flight crews on long-distance, high-altitude flights tend to accumulate about 30% more annual radiation exposure than the average person.
- *Earth*: Minerals and materials from the earth soil are the most common sources of natural radiation, like potassium-40, uranium-238, and thorium-232. There are few cases where this kind of radioactivity can become a problem for human being, like in the case of radon, a gas which comes from the decay chain of U-238, which can radiate from some of the house materials and accumulate in rooms with poor ventilation, and in case of mining industries, where radioactive material (called NORM) can be extracted and potentially contaminate the equipment.
- *Human body*: human body is made up of many of the same atoms and elements that are found in the rest of the terrestrial environment, some of them are radioactive. Most common are Carbon-14, which is used for radiocarbon dating of organic material, and Potassium-40, which is an important part of DNA molecules.

Can radiation be produced by humans?

There are man-made processes that can produce radioactive material. Usually the radioactivity levels are low, and they can be compared with natural radioactivity. Here some examples of products of man-made processes.

- *Granite, dishes, etc.*: man-made products, furniture, etc. which contain naturally radioactive materials. For example, granite for countertops contains uranium, as well as old dishes from the 40s-60s, where uranium glaze was used to give brilliant colors.
- *Nuclear plants*: man-made nuclear plants use the fission of uranium-235 to generate electricity. The radiation exposure to workers and to public is very limited, and it is comparable with the natural radioactivity. Coal-burning power plants are usually more polluting also in terms of radioactivity, since the fly ash from coal burning might contain Uranium and Thorium.
- *Terrorism, disaster, war*: The atomic bombs at Hiroshima and Nagasaki, nuclear weapons tests of from 50s to 80s, the explosion at the Chernobyl nuclear power plant in 1986 are some of the examples which contributed to global levels of atmospheric radioactive material and had higher impact in the immediate areas.

How radiation can be used to human being?

The use of radiation in the workplace is a normal and required part of many occupations. For example, radiation is used widely in the health sector to diagnose or treat patients, the mining industry in the processing of minerals and ores and in technology used to power our homes and devices.

3. Power Requirements

The module is powered by the external AC/DC stabilized power supply provided with the SP5630EN and included in the delivered kit.

Note: Please, use only the power supply shipped with this instrument and certified for the country of use.

Input: 100-240 VAC, 47-63 *Hz*; Output: 5.0 *V*, 2.4 *A*.

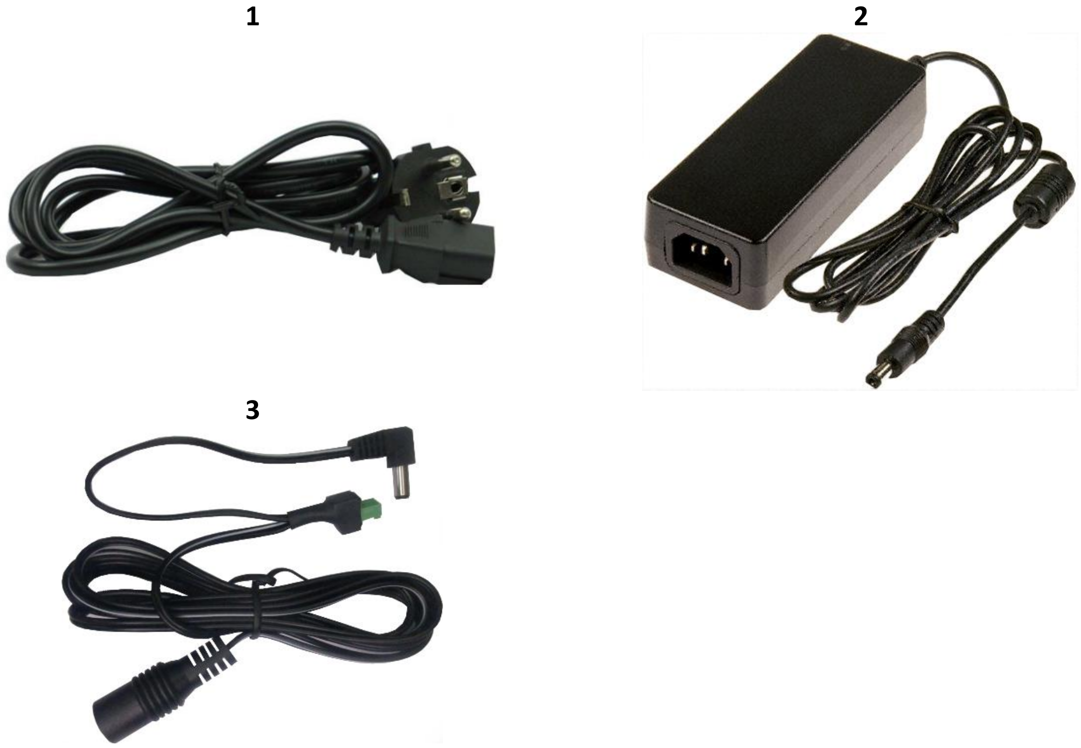


Fig. 3.1: AC/DC power supply provided with the Environmental Kit – SP5630EN.

4. Getting Started

This Chapter describes the first steps to be done to power the i-Spector Digital available in the Environmental Kit, how to connect it to computer, and how to start a measurement.

What is the i-Spector Digital

The i-Spector Digital provided in the SP5630N kit is a fully-integrated tube-base Gamma Spectrometer designed to operate as a complete radiation detection system, with integrated MCA, and Ethernet connectivity.

i-Spector Digital is based on a SiPM area of 18x18 mm^2 coupled with a CsI(Tl) crystal. It hosts a preamplifier stage, an integrated power supply for SiPM biasing with temperature feedback loop, a shaper, and a MCA based on 80 MSps, 12-bit ADC and digital charge integration algorithm.

i-Spector Digital can be easily controlled through its dedicated web graphical user interface, with no needs to install a dedicated software. The user can configure the module and visualize the acquired spectrum.

The web interface displays the spectrum on an interactive plot with analysis tools: cursors and ROI can be added to the spectrum to perform real-time fitting and linear background estimation. For each fitted peak, the centroid, the FWHM, counts and other statistics are automatically calculated. It is also possible to perform energy calibration of the bin axe using linear and higher-order fit models.

Thanks to the internal circular memory buffer, i-Spector module is able to store up to 1 hour of output data consisting in voltage, current and sensor temperature samples. The last 1-hour recording can then be downloaded by the web interface.

Here follows a summary of the key features of the i-Spector Digital provided in the SP5630EN. More details can be found in **[RD1]**.

- All-in-one detector, electronics, and MCA for Gamma Spectroscopy
- Based on a SiPM area of 18x18 mm^2
- 20-80 V Integrated High Voltage for SiPM biasing
- Assembly with CsI scintillator of 18x18x30 mm^3
- 9.3 mm distance from CsI crystal to the i-Spector face
- Resolution @ 662 keV < 6 %
- Ethernet connectivity
- Web-based interface with spectrum analysis tools
- Compact form factor: Ø 60 mm, h 121 mm

GENERAL	**Form Factor** Portable Ø 60 mm, h 121 mm, >500 g	**Operating Temperature** -20 … +50 °C
POWER CONSUMPTION	3W max.	
SUPPLY VOLTAGE	8-13 V (12 V typ.)	
SiPM	Area made of Hamamatsu S14160-60520HS 18x18 mm^2	

HIGH VOLTAGE **for SiPM biasing**	Range: 20-80 V (10 mA) Accuracy : 1 mV Thermal Feedback Accuracy: 0.01 °C – 1mV	
FRONT-END STAGE	Preamp Gain : x5 Bandwidth : > 1GHz Shaping time: 180 ns	
ANALOG OUTPUT	-4 …. +4 V , 170 mA on the OUT LEMO connector	
TIMING RESOLUTION	50 ps @ rate <20 kpcs 5 ns @high rates	
MCA	12-bit @ 80 MS/s ADC Nr. of channels: 4096 Resolution @ 100 kpcs : < 0.2% Processing Algorithm: Digital Charge Integration	**Performances** **with CsI(Tl) crystal (18x18x30 mm^3)** Energy range : 30 keV to 30 MeV Energy resolution @ 662 keV : < 6% Non-linearity: < 0.1%
COMMUNICATION INTERFACE	Ethernet 100 Mbps	
SOFTWARE	Graphical web interface	

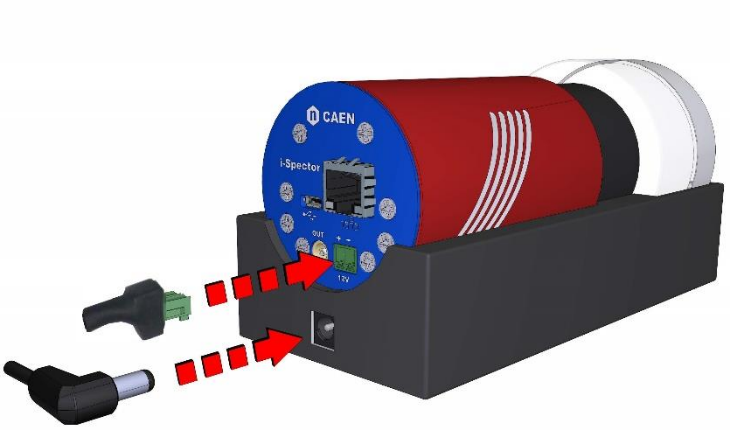
Tab. 4.1: Technical specifications of i-Spector Digital.

Cable connection

1. Place the i-Spector Digital and a sample into the base holder.

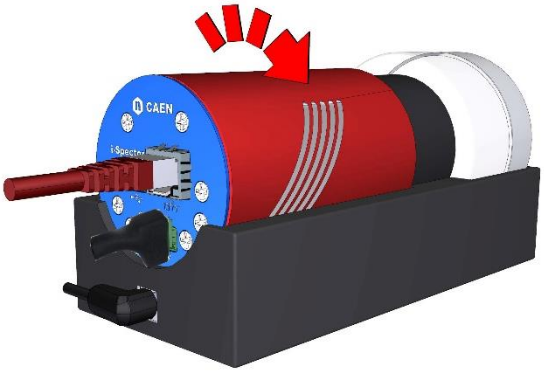
2. Connect the three power supply cables available in the kit following the order shown in the picture below.

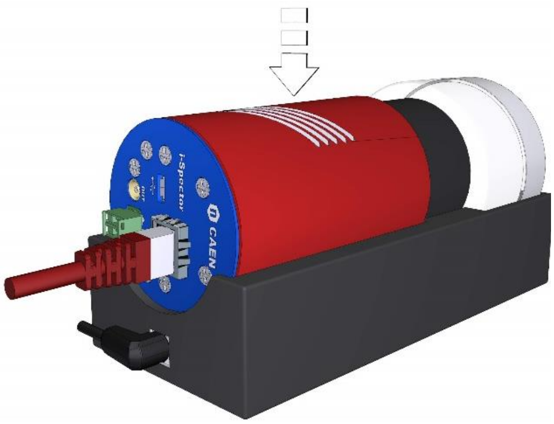
3. Connect the last two connectors to the i-Spector Digital (green plug) and to the base holder (black plug). The i-Spector Digital will power on as soon as it is connected to the power supply.



4. Connect the Ethernet cable to the Ethernet connector of the i-Spector Digital.

5. Rotate the i-Spector to match the holes of the outer casing with the fan in the base. The holes shall be visible in the top view of the i-Spector (left picture).

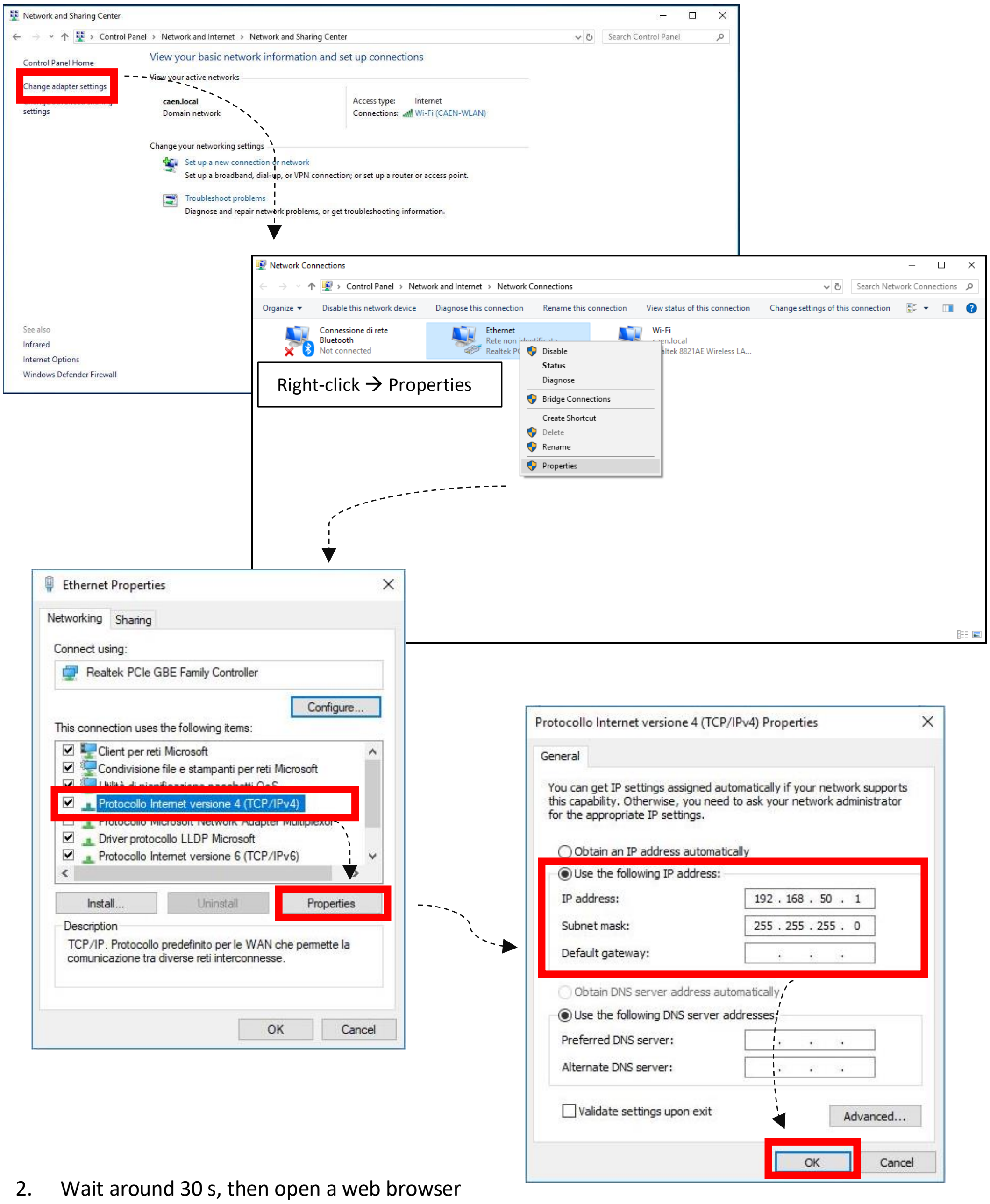




Ethernet Connection to the PC

Note: the **default IP address** of the i-Spector for Ethernet connection is **192.168.50.2**

1. Configure the Ethernet network of your PC from the “Network and Sharing Center”, as shown below.



Ethernet Properties – Connect using: Realtek PCIe GBE Family Controller

This connection uses the following items:

- ☑ Client per reti Microsoft
- ☑ Condivisione file e stampanti per reti Microsoft
- ☑ Utilità di pianificazione pacchetti QoS
- ☑ Protocollo Internet versione 4 (TCP/IPv4)
- ☑ Protocollo Microsoft Network Adapter Multiplexor
- ☑ Driver protocollo LLDP Microsoft
- ☑ Protocollo Internet versione 6 (TCP/IPv6)

Description: TCP/IP. Protocollo predefinito per le WAN che permette la comunicazione tra diverse reti interconnesse.

Protocollo Internet versione 4 (TCP/IPv4) Properties – General:

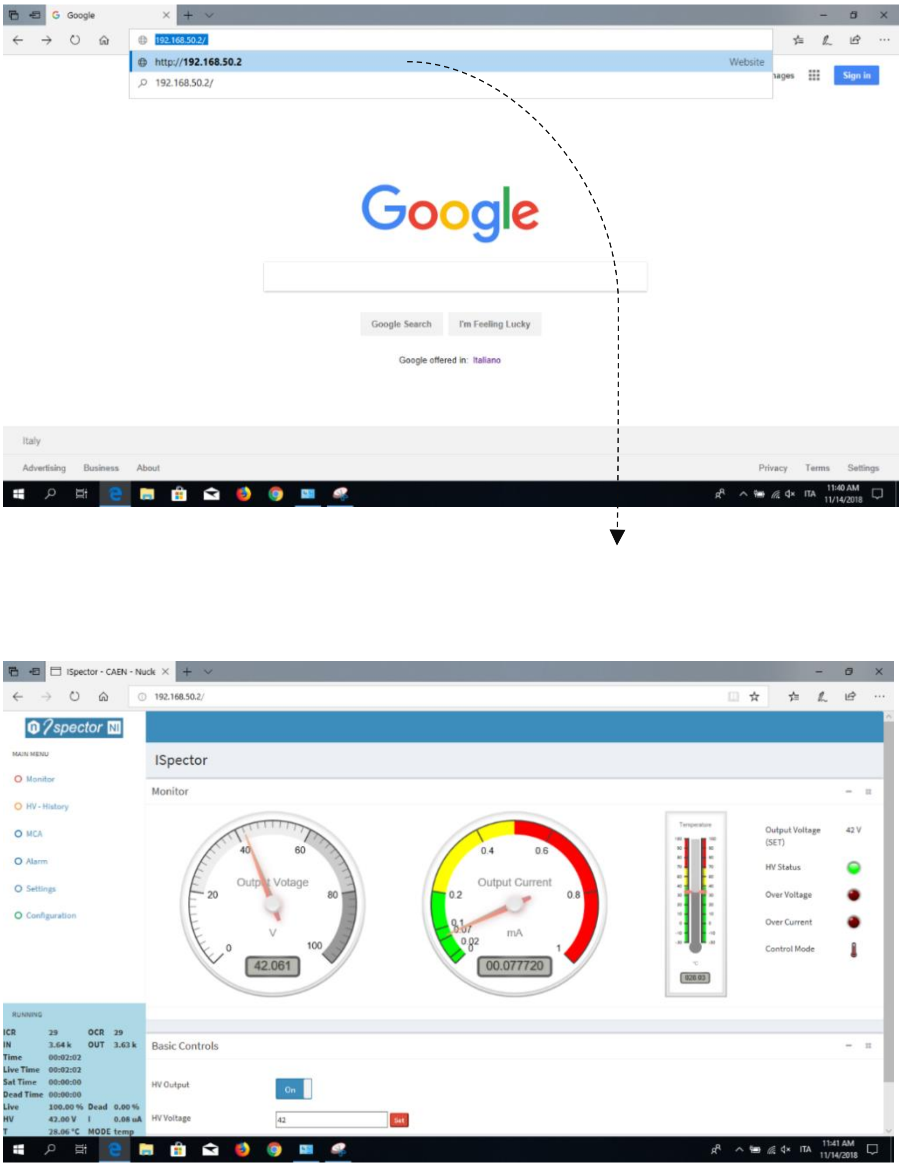
You can get IP settings assigned automatically if your network supports this capability. Otherwise, you need to ask your network administrator for the appropriate IP settings.

○ Obtain an IP address automatically
● Use the following IP address:
IP address: 192 . 168 . 50 . 1
Subnet mask: 255 . 255 . 255 . 0
Default gateway: . . .

○ Obtain DNS server address automatically
● Use the following DNS server addresses:
Preferred DNS server: . . .
Alternate DNS server: . . .

☐ Validate settings upon exit

2. Wait around 30 s, then open a web browser (Microsoft Edge browser is suggested) and enter the web address **192.168.50.2**. The homepage of the graphical web interface will open.



RUNNING

ICR	29	OCR	29
IN	3.64 k	OUT	3.63 k
Time	00:02:02		
Live Time	00:02:02		
Sat Time	00:00:00		
Dead Time	00:00:00		
Live	100.00 %	Dead	0.00 %
HV	42.00 V	I	0.08 uA
T	28.06 °C	MODE	temp

3. Now you are ready to use your i-Spector!

Web interface

Note: This section reports the main features of the i-Spector Digital, in particular, those features that are useful for the use of the Environmental kit. For advanced settings please refer to **[RD1]**.

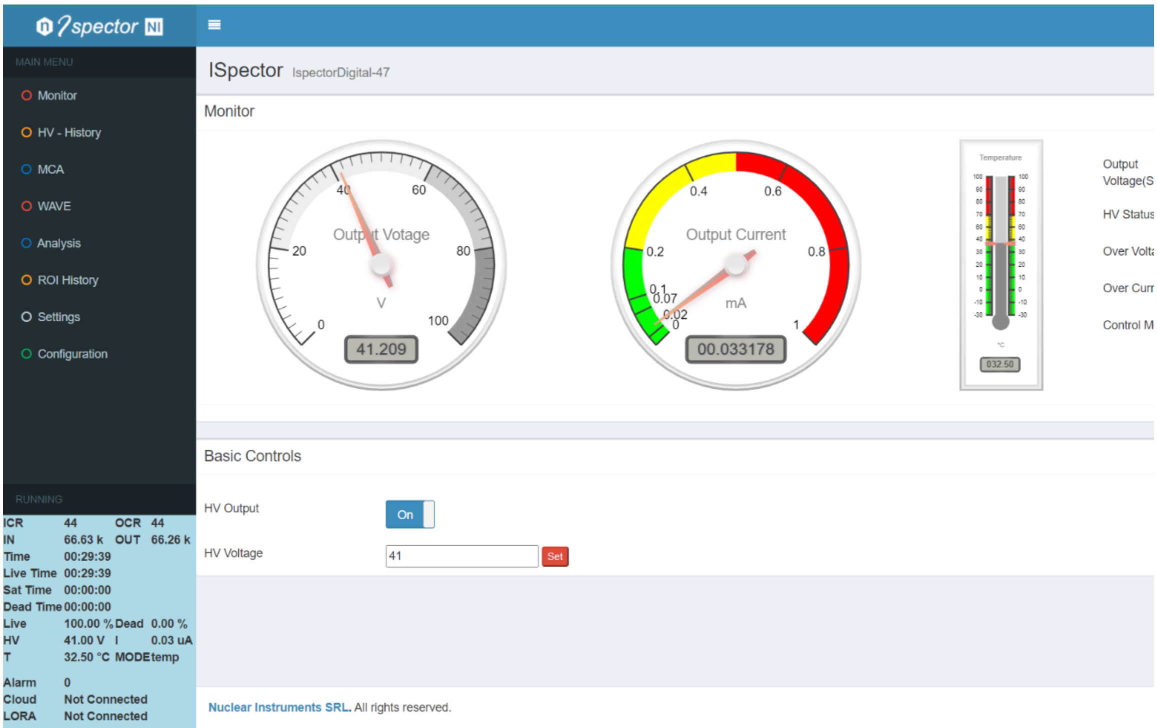
Setting the High Voltage

When powering the i-Spector, the High Voltage (HV) goes automatically ON, so it is not necessary to modify the voltage level, unless specifically required.

After opening the Web Interface, the Monitor Tab will appear, showing the measured High Voltage parameters (Output Voltage and Current) and the Temperature value used for the HV feedback loop. The temperature sensor is placed very close to the SiPM, so that this temperature can be considered as the real temperature of the sensor.

Note: the maximum measured output current is **1 mA**

Note: the Output Voltage and the relative temperature feedback loop are pre-set with the optimal values for the SiPMs installed on the i-Spector, namely **Hamamatsu S14160-60520HS** (18x18 mm^2).



HV Output: On

HV Voltage: 41 Set

RUNNING

ICR	44	OCR	44
IN	66.63 k	OUT	66.26 k
Time	00:29:39		
Live Time	00:29:39		
Sat Time	00:00:00		
Dead Time	00:00:00		
Live	100.00 %	Dead	0.00 %
HV	41.00 V	I	0.03 uA
T	32.50 °C	MODE	temp
Alarm	0		
Cloud	Not Connected		
LORA	Not Connected		

Fig. 4.1: the *Monitor* tab of the i-Spector Web Interface

Other basic monitor parameters are shown on the right top part of the window, like the Voltage set point, the HV status, the occurrence of Over Voltage/Over Current conditions and the feedback Control Mode (temperature or digital).

The Output Voltage can be changed manually using the "Basic Controls" to set the voltage set point and switch on the High Voltage module.

⚠ WARNING: if changing the Output Voltage set point, please pay attention not to damage the SiPMs. Read carefully the SiPMs datasheet for maximum allowed voltage and check the advanced HV Control parameters in the Settings tab.

More advanced settings can be done using the "HV Control" menu in the *Settings* tab. Refer to **[RD1]** for more details.

Note: verify that the temperature is **below 40 °C.** The i-Spector performances degrade for temperature higher than 40 °C.

Note: all the parameters for the "HV Control" menu, are pre-set with the optimal values for the SiPMs installed on the i-Spector. It is possible to change these settings and define them as default by storing the values on flash. Only expert user must perform this kind of operations.

How to set the waveform

The *Wave* tab can be used as an embedded oscilloscope to check waveforms and digital traces like trigger, integration gate, pile-up inhibit, etc. Moreover, in this tab it is possible to modify the acquisition parameters according to the given input exponential signals. The *Configuration* menu includes the following:

- *Trigger Threshold* (LSB): threshold for the derivative trigger
- *Post Trigger Inhibit* (ns): set the time after a trigger for which any other trigger is inhibited
- *Pre Integration* (ns): set how much time before the trigger the charge integration is started
- *Integration* (us): set the charge integration gate
- *Gain*: set the energy digital gain to be applied to the spectrum
- *Pileup Inhibition* (us): set the time after the integration gate for which the acquisition of any other event acquisition is inhibited
- *Pileup Penality* (us): set the trigger inhibition gate to be opened after a pile up
- *Baseline Inhibition* (us): set the time after the integration gate for which the baseline is not calculated
- *Baseline Length* (samples): set the number of samples used to calculate the baseline

- *Target Mode*: set the acquisition mode as Free Running or with a targe in Time (ms) or Counts
- *Target Value*: set the target value in time or counts, accordingly to the Target Mode

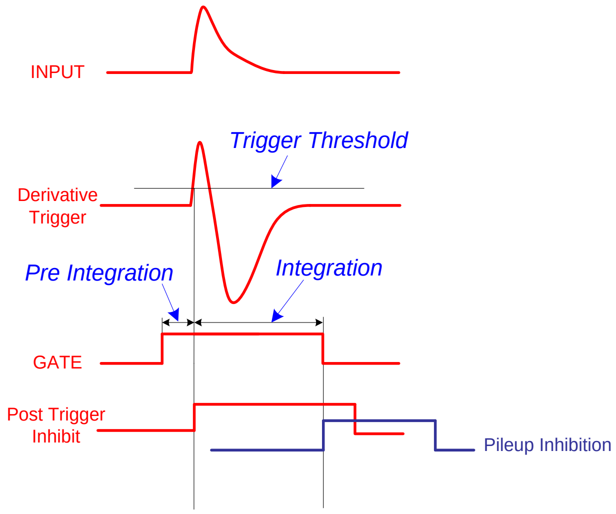
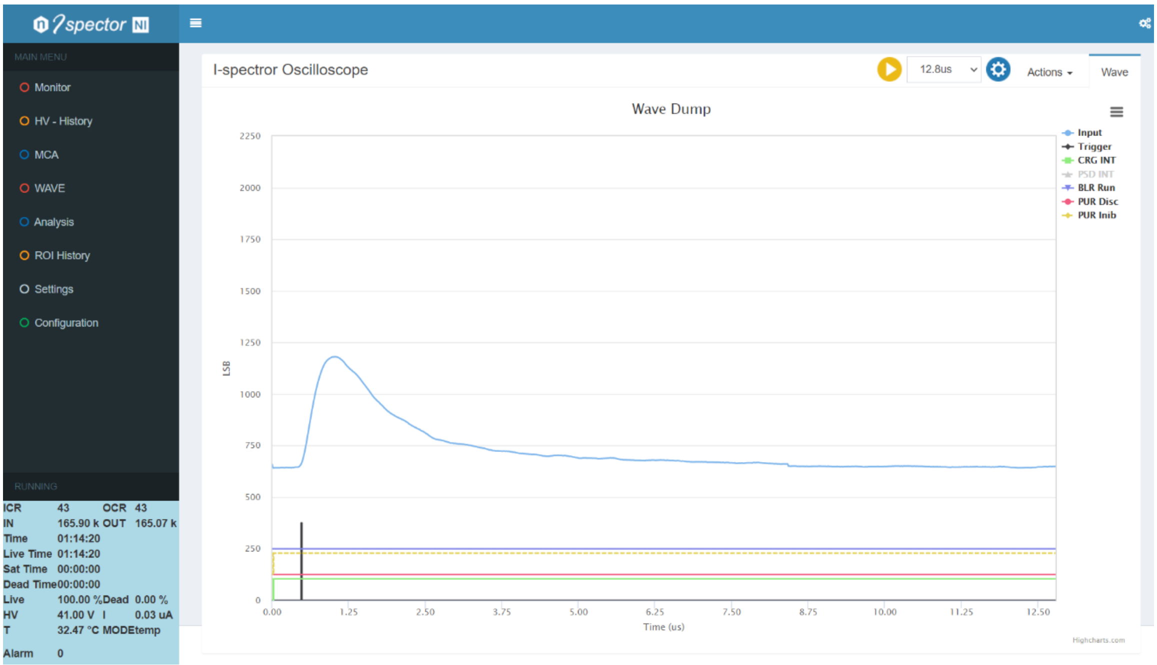


Fig. 4.2: diagram summarizing the most important parameters of the charge integration algorithm

Note: the i-Spector comes with a pre-set optimal configuration. The pre-set parameters should allow to immediately see waveforms and digital traces, and, in principle, there is no need to change them.

1. Place the i-Spector in front of your radioactive source/samples
2. Power On the module and connect to the Web Interface
3. Surf into the *Wave* tab
4. Choose the desired record length time in the top bar (from 12.8 µs to 52.4 ms)
5. You should see an exponential analog signal and the related digital traces (like Trigger, CRG INT, …) as shown in **Fig. 4.3**.



```
ICR       43       OCR  43
IN        165.90 k OUT  165.07 k
Time      01:14:20
Live Time 01:14:20
Sat Time  00:00:00
Dead Time00:00:00
Live      100.00 %Dead  0.00 %
HV        41.00 V  I    0.03 uA
T         32.47 °C MODEtemp

Alarm     0
```

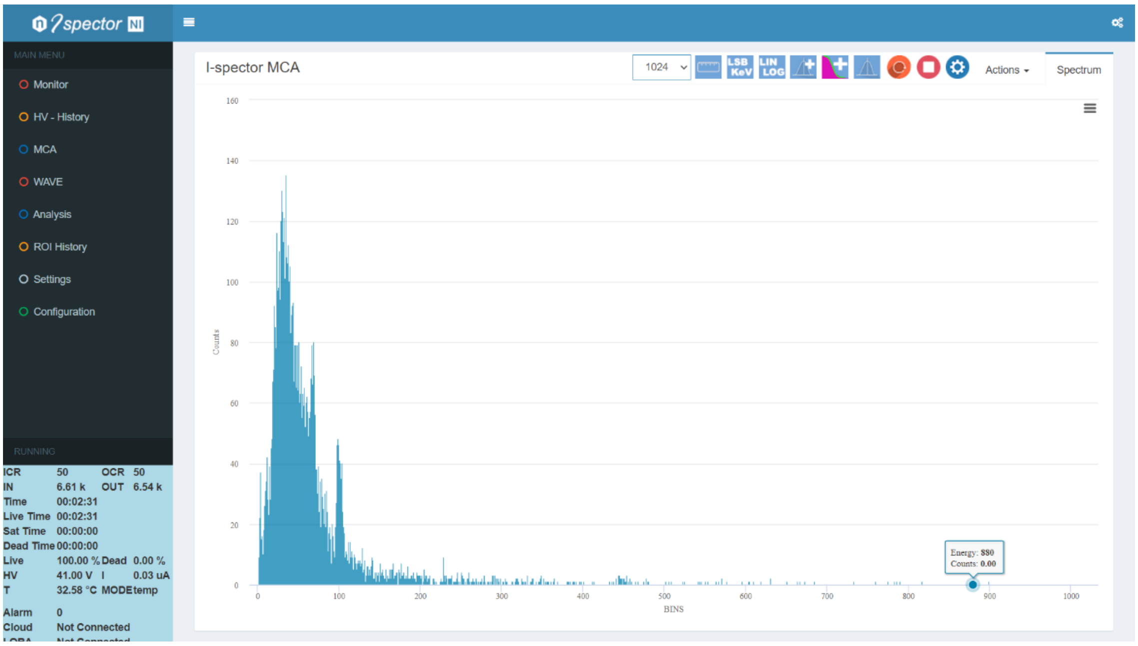
Fig. 4.3: the *WAVE* tab of the i-Spector Web Interface

How to acquire a spectrum

The *MCA* tab is completely dedicated to the energy spectrum acquisition with i-Spector Digital.

Note: when coupled to a crystal, the i-Spector comes with a pre-set optimal configuration. The pre-set parameters should allow to immediately see waveforms and digital traces, and, in principle, there is no need to change them.

1. Place a radioactive source in front of the i-Spector, like for example, the LYSO sample
2. Power On the module and connect to the Web Interface
3. Surf into the *MCA* tab
4. You should see a spectrum growing up, as shown in **Fig. 4.4.**

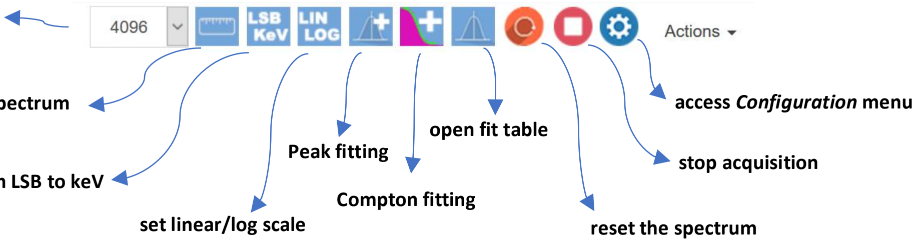


ICR 50 OCR 50
IN 6.61 k OUT 6.54 k
Time 00:02:31
Live Time 00:02:31
Sat Time 00:00:00
Dead Time 00:00:00
Live 100.00 % Dead 0.00 %
HV 41.00 V I 0.03 uA
T 32.58 °C MODE temp
Alarm 0
Cloud Not Connected

Energy: 880
Counts: 0.00

Fig. 4.4: the *WAVE* tab of the i-Spector Web Interface

The Web Interface allows to:



rebin the spectrum

calibrate in energy the spectrum

switch the x-axis from LSB to keV

set linear/log scale

Peak fitting

Compton fitting

open fit table

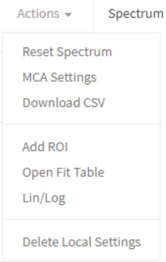
reset the spectrum

stop acquisition

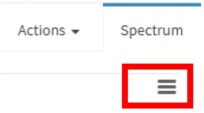
access *Configuration* menu

Moreover, it is possible to access two additional menus:

- **Actions** (self-explicative)

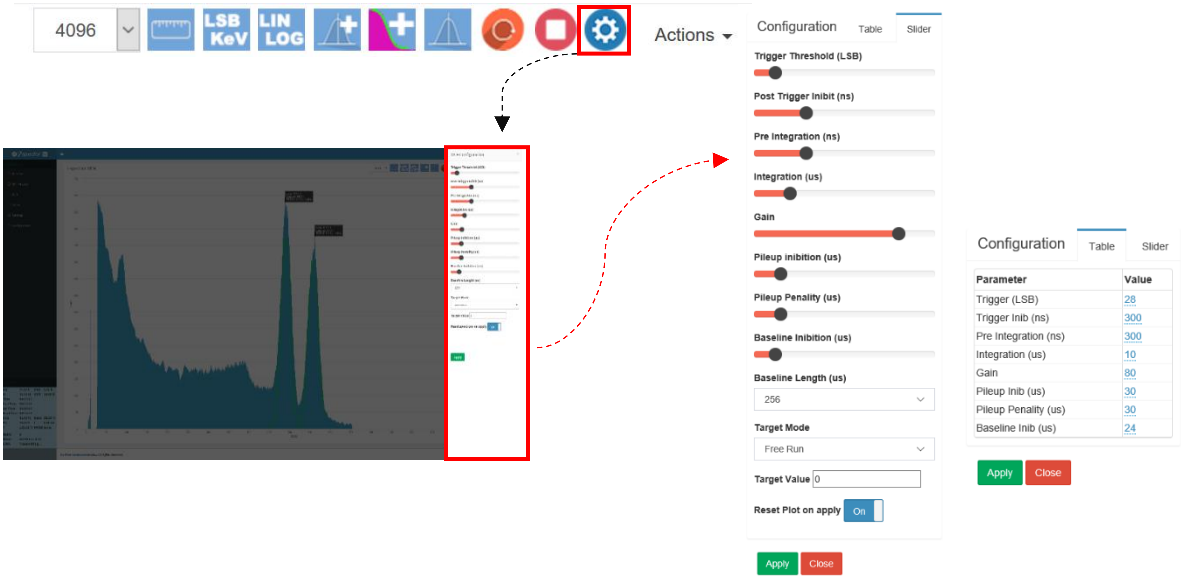


- **Export:** allows the user to export the spectrum as image or data



The ***Configuration*** menu can be accessed by clicking on the **gear icon** in the top bar (see **Fig. 4.5**). Refer to the previous section for a complete description of parameters meaning.

The parameters are set after pressing the *Apply* button. It is possible to reset the spectrum when pressing *Apply,* by enabling the relative option.



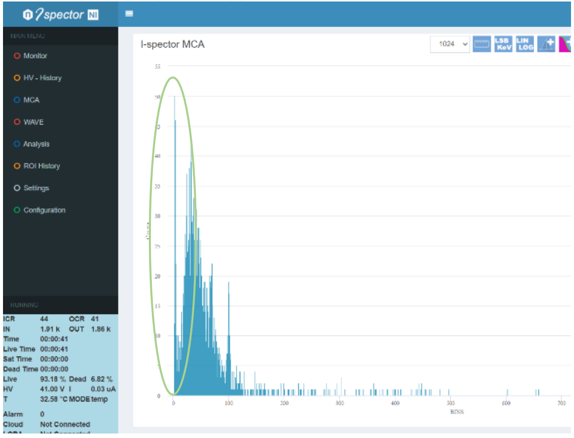
Trigger Threshold (LSB)
Post Trigger Inibit (ns)
Pre Integration (ns)
Integration (us)
Gain
Pileup inibition (us)
Pileup Penality (us)
Baseline Inibition (us)
Baseline Length (us): 256
Target Mode: Free Run
Target Value: 0
Reset Plot on apply: On

Parameter	Value
Trigger (LSB)	28
Trigger Inib (ns)	300
Pre Integration (ns)	300
Integration (us)	10
Gain	80
Pileup Inib (us)	30
Pileup Penality (us)	30
Baseline Inib (us)	24

Fig. 4.5: the MCA configuration menu (in *Slider* or *Table* mode), to adjust the MCA settings and the Charge Integration algorithm parameters.

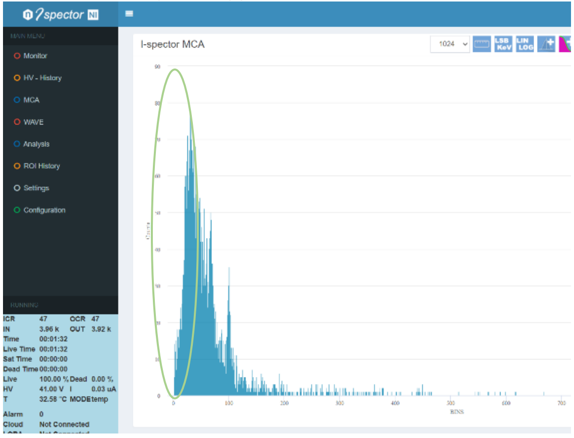
Note: If you see a peak close to zero, this means that those events are noise and must be rejected by increasing the trigger threshold from the Configuration menu. See pictures below.

Example: Trigger Threshold = 49 LSB



```
ICR        44        OCR   41
IN         1.91 k    OUT   1.86 k
Time       00:00:41
Live Time  00:00:41
Sat Time   00:00:00
Dead Time  00:00:00
Live       93.18 %   Dead  6.82 %
HV         41.00 V   I     0.03 uA
T          32.58 °C  MODE  temp

Alarm      0
Cloud      Not Connected
```

Example: Trigger Threshold = 53 LSB



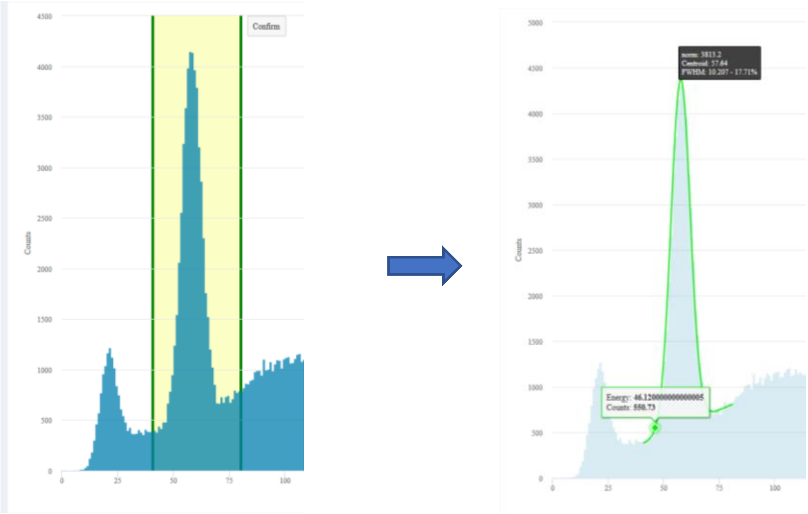
```
ICR        47        OCR   47
IN         3.96 k    OUT   3.92 k
Time       00:01:32
Live Time  00:01:32
Sat Time   00:00:00
Dead Time  00:00:00
Live       100.00 %  Dead  0.00 %
HV         41.00 V   I     0.03 uA
T          32.58 °C  MODE  temp

Alarm      0
Cloud      Not Connected
```

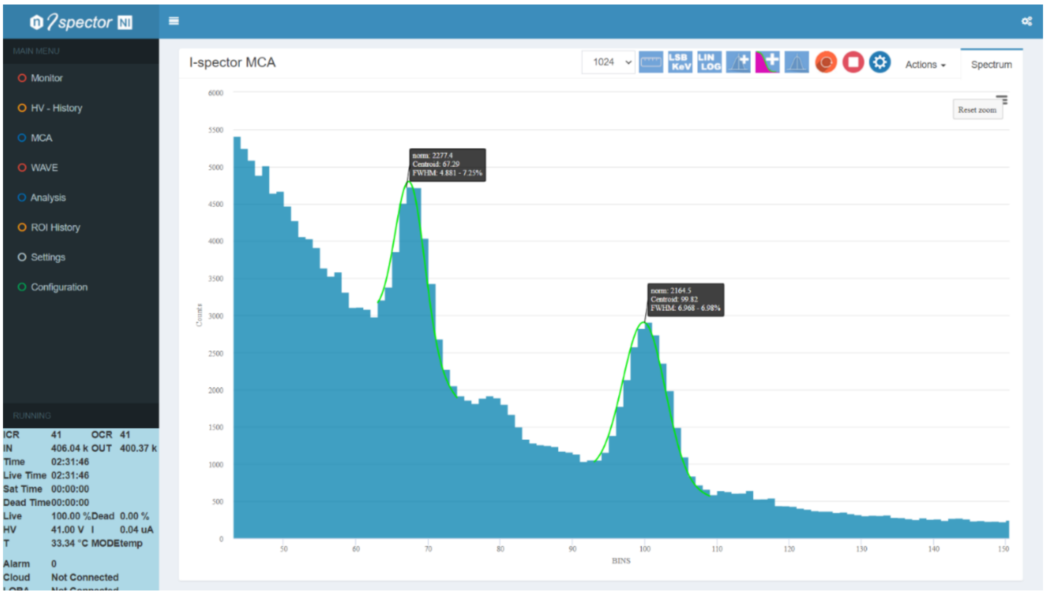
How to set a ROI

After you are satisfied with the MCA settings and the acquired spectrum, you can create a ROI to fit, for example, a peak of interest with a Gaussian shape or a Compton edge with its special fitting tool.

Here we show the procedure to fit a peak with a Gaussian shape. To do this, follow the procedure given below:

- Press to add a ROI on the spectrum
- Use the mouse to **drag and resize** the ROI to suit the peak of interest
- Once you are satisfied, **click *Confirm*** button near the ROI. The fitting Gaussian curve and a label reporting the main fitting parameters (**normalization, centroid** and **FWHM)** will appear for each defined ROI, as shown below.





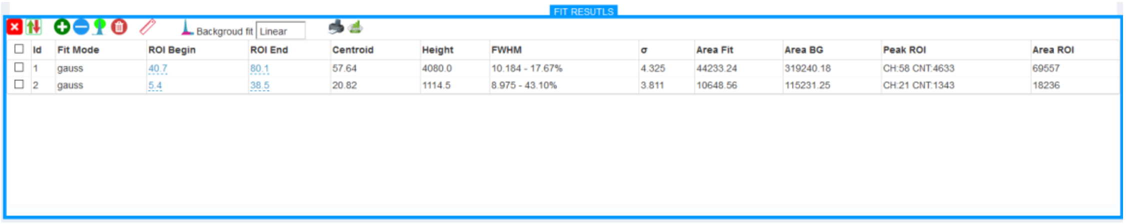
ICR 41 OCR 41
IN 406.04 k OUT 400.37 k
Time 02:31:46
Live Time 02:31:46
Sat Time 00:00:00
Dead Time 00:00:00
Live 100.00 % Dead 0.00 %
HV 41.00 V I 0.04 uA
T 33.34 °C MODE temp

Alarm 0
Cloud Not Connected

Fig. 4.6: LYSO crystal spectrum with fitted peaks.

Note: the fitting procedure is automatically performed with an algorithm based on Gaussian fitting and the background subtraction selected from the Fit Table (see **Fig. 4.7:**).

The complete **fit table**, reporting the fitting parameters for each ROI, is shown by clicking on *Actions* → *Open fit table.*



☐	Id	Fit Mode	ROI Begin	ROI End	Centroid	Height	FWHM	σ	Area Fit	Area BG	Peak ROI	Area ROI
☐	1	gauss	40.7	80.1	57.64	4080.0	10.184 - 17.67%	4.325	44233.24	319240.18	CH:58 CNT:4633	69557
☐	2	gauss	5.4	38.5	20.82	1114.5	8.975 - 43.10%	3.811	10648.56	115231.25	CH:21 CNT:1343	18236

Fig. 4.7: the fit table with two Gaussian peaks fitted with Linear background subtraction.

The fit table is reporting, in each line the paramters of a ROI, including the parameters of the fit.

From the fit table top bar, it is possible to:

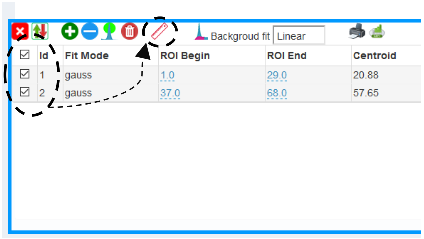
- Stack the fit table below the spectrum
- Add manually a ROI
- Delete a group of selected ROIs
- Perform peaks autodetection. This is alternative to the manual ROI selection and fitting. The found peaks are automatically fitted and included in the fit table.
- Delete all ROIs
- Perform energy calibration
- Show background fit on spectrum plot. The background is highlighted in magenta.
- Backgroud fit | Linear Select background fit type: *constant, linear, quadratic, cubic, 4th order, 5th order*
- Print the current fit table
- Save the current fit table in .csv format

Note: the **ROIs and fit parameters are saved in the user web browser**. Even if the browser is closed, the data are saved in a special web browser storage and retrieved at the following connection to the instrument. It is possible to delete the local settings by clicking *Action* → *Delete Local Settings*

How to calibrate the spectrum in energy

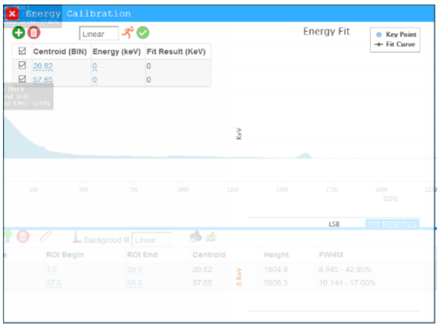
After one or more ROIs are set, it is possible to easily calibrate the spectrum x-axis in energy. To do this, follow the procedure below:

- Open the fit table and check the ROIs to base the calibration on. After checking, press



☑	Id	Fit Mode	ROI Begin	ROI End	Centroid
☑	1	gauss	1.0	29.0	20.88
☑	2	gauss	37.0	68.0	57.65

- The calibration window will open, reporting the centroid of the selected ROIs. Enter the corresponding energy in KeV.



☑	Centroid (BIN)	Energy (keV)	Fit Result (KeV)
☑	20.82	0	0
☑	57.65	0	0

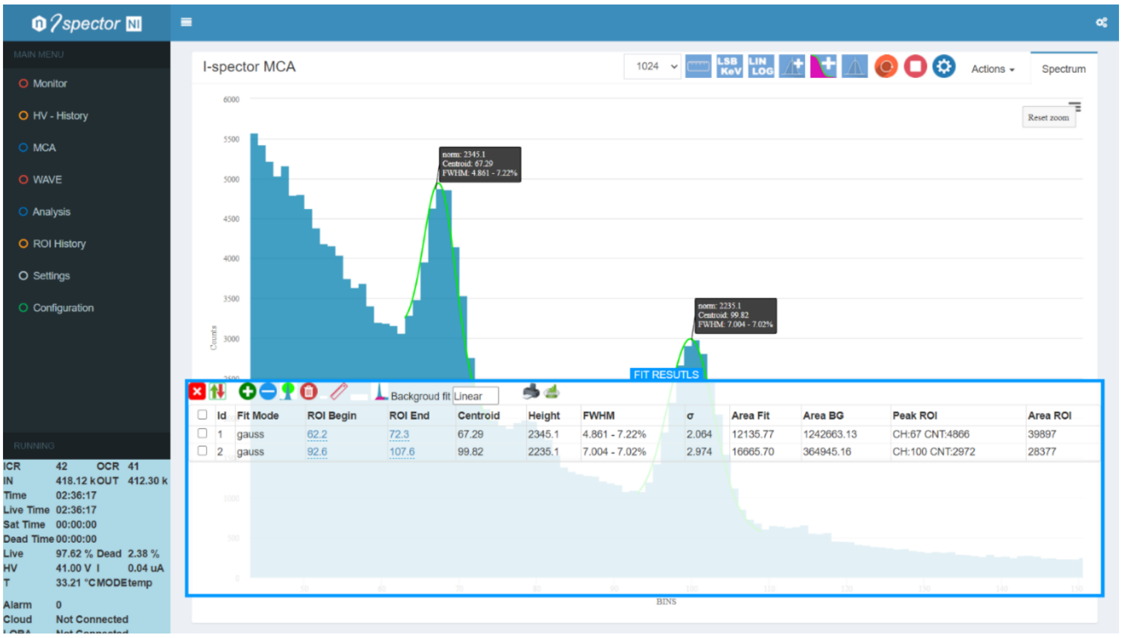
- Choose the fit mode (linear, quadratic , cubic, 4th order, 5th order) Linear ▼

- Run the calibration procedure by pressing . The fit results will be shown in a plot.

☑	Centroid (BIN)	Energy (keV)	Fit Result (KeV)
☑	20.82	10	10.00
☑	57.65	60	60.00

- Apply the calibration ✓. The window will be closed and a message of successful calibration is shown in the bottom part of the web browser

- It is now possible to visualize the x-axis of the spectrum in keV. It is possible to switch from keV to LSB and vice versa by pressing the icon LSB KeV



☐	Id	Fit Mode	ROI Begin	ROI End	Centroid	Height	FWHM	σ	Area Fit	Area BG	Peak ROI	Area ROI
☐	1	gauss	62.2	72.3	67.29	2345.1	4.861 - 7.22%	2.064	12135.77	1242663.13	CH:67 CNT:4866	39897
☐	2	gauss	92.6	107.6	99.82	2235.1	7.004 - 7.02%	2.974	16665.70	364945.16	CH:100 CNT:2972	28377

ICR	42	OCR	41
IN	418.12 k	OUT	412.30 k
Time	02:36:17		
Live Time	02:36:17		
Sat Time	00:00:00		
Dead Time	00:00:00		
Live	97.62 %	Dead	2.38 %
HV	41.00 V	I	0.04 uA
T	33.21 °C	MODE	temp
Alarm	0		
Cloud	Not Connected		

norm: 2345.1
Centroid: 67.29
FWHM: 4.861 - 7.22%

norm: 2235.1
Centroid: 99.82
FWHM: 7.004 - 7.02%

Fig. 4.8: a LYSO crystal spectrum calibrated in energy. The parameters in the fitting labels and in the fit table are expressed in energy.

Note: the **energy calibration is saved in the user web browser**. Even if the browser is closed, the data are saved in a special web browser storage and retrieved at the following connection to the instrument. It is possible to delete the local settings by clicking *Actions* → *Delete Local Settings*

5. Experiments

The CAEN Environmental kit allows the user to perform experiments concerning naturally occurring gamma radiation.

Gamma rays are emitted from radioactive decay, which can be found in common material surrounding us. The SP5630EN contains samples of common material, like rock, fertilizer, etc. An empty sample is also available, to be filled with the material to be analysed by the user.

The user will learn how to build an energy spectrum through the embedded MCA, how to perform the background subtraction, how to calibrate the spectrum with known sources.

This section represents an overview of the experiments proposed by CAEN using the Environmental kit. Each experiment has its own identification code (reference ID). For each ID, a step-by-step guide that includes a detailed description to perform the experiment is available on the CAEN Educational web page. The experiments address the essence of the phenomenon as well as exemplary illustrations of their use in different application fields, complemented by basic and advanced statistical exercises.

The main experiments proposed by CAEN are listed and highlighted in green in **Tab. 5.1** and some of them, identified by (✹) symbol, require extra tools, like low intensity laboratory radioactive source.

Section	Reference ID	Experiment	Additional tool
Nuclear physics and radioactivity	6111	Detecting γ-Radiation	No
	6112	Poisson and Gaussian Distributions	No
	6113	Energy Resolution	No
	6114	System Calibration: Linearity and Resolution	No
	6117	Photonuclear cross-section/Compton Scattering cross-section	✹
	6140	Energy calibration of System based on LYSO crystal and Fertilizer sample	No
	6141	Background Measurements	No
	6142	Fertilizer and photopeak identification	No
	6143	Soil sample identification	No
	6144	Samples Comparison	No
	6145	Test sample Identification	No
	6146	Radon passive measurement	No

Tab. 5.1: Physics Experiments performed via the Environmental Kit. If the symbol (✹) is present, extra tools are needed to perform the experiment.

Detecting γ-Radiation (ID.6111)

Purpose of the experiment:

Gamma radioactivity detection by using a system composed of a scintillating crystal coupled to a photon detector.

Fundamentals:

Gamma rays interact with matter by three processes: Compton Scattering, Photoelectric Effect and Pair Production (whenever the energy exceeds the 1.022 MeV threshold corresponding to the e^+e^- rest mass). The cross section of each process depends on the energy of the gamma ray.

The Compton Effect is the inelastic scattering between the incoming photon and an atomic electron. In the Photoelectric Effect, the incident gamma ray transfers all its energy to a bound electron which acquires a kinetic energy equal to the incoming gamma energy decreased by the binding energy.

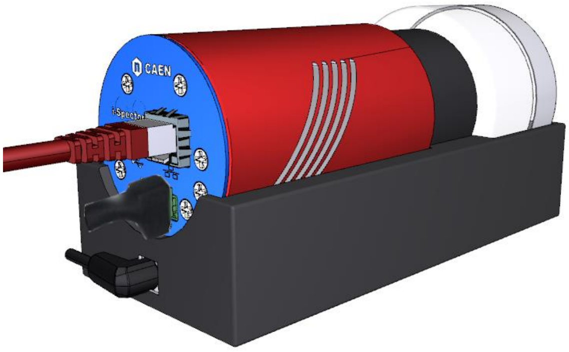
These processes convert, totally or partially, the gamma ray energy into kinetic energy of electrons (or positrons, in case of pair production). The interaction of the charged particles with the atomic and molecular systems of the medium results in excited states whose decay, possibly mediated, leads to light in the visible or UV region, eventually detected by the light sensor. A wide range of scintillator products is available today, differing for the light yield, the material properties, the time characteristics of the scintillation light and, last but not least, cost. The choice of the scintillator is essentially dependent on the specific targeted application.

Requirements:

No other tool is needed.

Carrying out the experiment:

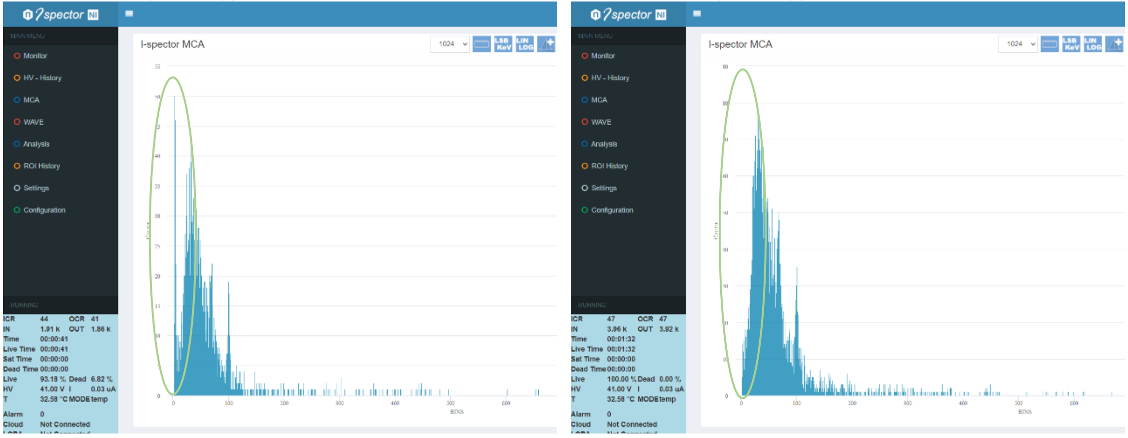
Put the i-Spector digital into the base. Power the i-Spector and connect the Ethernet cable. Wait until the temperature is stable from the web interface (it can take half an hour from power on). Check the waveform, modify the threshold and gate width, if needed, then start a spectrum acquisition. Save the result and compare it with a spetrum acquired in presence of a radioactive sample. Place the radioactive source, like, for example, the LYSO scintillating crystal which is provided as calibration source and start the measurement of the energy spectrum.
Take for example 10 minutes of acquisition with the LYSO crystal sample by setting the corresponding acquisition time. Repeat the experiment by modifying the threshold value.



Experimental setup block diagram.

Results:

The energy spectrum will appear in the MCA tab of the i-Spector web interface. Verify the implication of modify the trigger threshold into the energy spectrum. For example, decrease the threshold until the peak at zero appears (corresponding to noise), then slightly increase it until the peak at zero disappear.
Note: threshold value may vary from kit to kit, find the corresponding value for your own kit.



Example: Trigger Threshold = 49 LSB

ICR 44 OCR 41
IN 1.91 k OUT 1.86 k
Time 00:00:41
Live Time 00:00:41
Sat Time 00:00:00
Dead Time 00:00:00
Live 93.18 % Dead 6.82 %
HV 41.00 V I 0.03 uA
T 32.58 °C MODE temp
Alarm 0
Cloud Not Connected

Example: Trigger Threshold = 53 LSB

ICR 47 OCR 47
IN 3.96 k OUT 3.92 k
Time 00:01:32
Live Time 00:01:32
Sat Time 00:00:00
Dead Time 00:00:00
Live 100.00 % Dead 0.00 %
HV 41.00 V I 0.03 uA
T 32.58 °C MODE temp
Alarm 0
Cloud Not Connected

Energy spectra with different threshold value of the internal discriminator of i-Spector

Poisson and Gaussian Distributions (ID.6112)

Purpose of the experiment:

Study the statistical distribution of the counting rates of a gamma radioactive source. Comparison of the data to the Poisson distribution, turning into a Gaussian as the mean number of counts grows.

Fundamentals:

The number of radioactive particles detected over a time Δt is expected to follow a Poisson distribution with mean value µ. It means that for a given radioactive source, the probability that n decays will occur over a given time period Δt is given by:

$$P_{\mu}(n) = (\mu^{n} / n!) \cdot e^{-\mu}$$

Where µ is proportional to the sample size and to the time Δt and inversely proportional to the half-life $T_{1/2}$ of the unstable nucleus. As long as µ grows, the probability $P_{\mu}(n)$ is well approximated by a Gaussian distribution:

$$P(n) = \frac{1}{\sqrt{2\pi\sigma}} e^{\frac{-(n-\mu)^2}{2\sigma^2}}$$

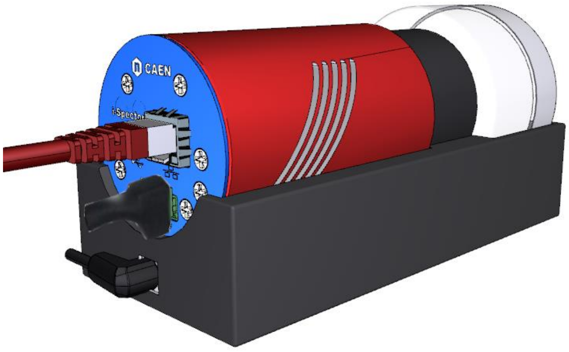
Where $\sigma = \sqrt{\mu}$ is the standard deviation.

Requirements:

No other tool is needed

Carrying out the experiment:

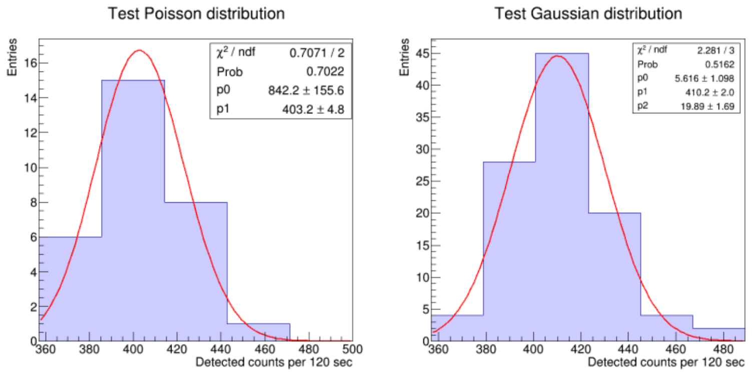
Put the i-Spector digital into the base and place the radioactive sample, like, for example, the LYSO crystal which is provided as calibration source. Power on the i-Spector and connect the Ethernet cable. Wait until the temperature is stable from the web interface (it can take half an hour from power on). Check the waveform, modify the threshold and gate width, if needed, then start the measurement of the energy spectrum.
Take for example 2 minutes of acquisition with the LYSO crystal sample by setting the corresponding acquisition time. Select the ROI peak at 303 keV, then check the value reported in the ROI area. Repeat the experiment many times and report the ROI area.



Experimental setup block diagram.

Results:

Changing the counting window and/or the activity of the source or the ROI, the number of counts changes, with a probability density function moving from a Poissonian to a Gaussian shape. The user may play with the data, fitting them and comparing the expectations to the measurement. The results below have been acquired with 100 consecutive measurements, where the first 30 were used for the Poissonian distribution.



Poissonian distribution [Fit: $y = p0 * (p1^{x}/x!) * e^{-p1}$] on the left, Gaussian distribution on the right.

[Fit: $y = p0 \cdot \left(\frac{1}{\sqrt{2\pi} \cdot p2}\right) \cdot e^{-\frac{(x-p1)^2}{2 \cdot p2^2}}$]

Energy Resolution (ID.6113)

Purpose of the experiment:

The analysis of the spectrum of the deposited energy by a γ ray in a detector discloses the essence of the interaction of high energy photons with matter and allows to learn by doing the detector related effects.

Fundamentals:

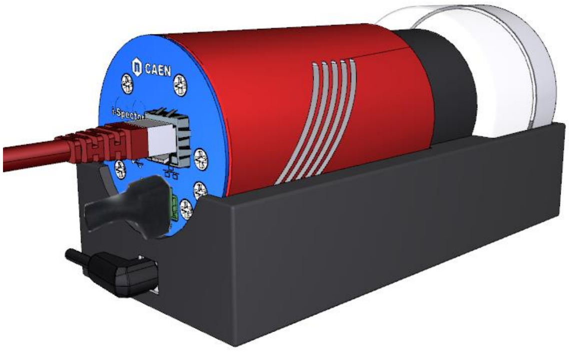
For γ-energy less than 2MeV, the interaction with matter is dominated by Compton scattering and Photo-absorption. The analysis of the Compton continuum of the deposited energy and of the photo-peak conveys information on the characteristics of the decaying isotope as well as the effects due to the system noise, the detected photon statistics, the stochastic terms in the detector and the intrinsic resolution of the scintillator. The experiment presumes to use ^{137}Cs with its decays detected by a CsI scintillating crystal coupled to a Silicon Photomultiplier. The ^{137}Cs source is particularly interesting due to its low energy X ray line at 30 keV and the high energy gamma emission at 662 keV. The former is relevant to optimize the lower detection limit of the system; the latter is a standard to evaluate the energy resolution. The use of the 2 lines and the analysis of the Compton spectrum characteristics allow to perform a rough measurement of the linearity with a single isotope. The same activity can be done with LYSO scintillating crystal as well.

Requirements:

^{137}Cs laboratory low intensity or LYSO crystal sample.

Carrying out the experiment:

Put the i-Spector digital into the base and place a radioactive source into the empty box (*you can use biadesive tape to fix the source into the box*). You can use the LYSO crystal sample, if the ^{137}Cs is not availble. Power on the i-Spector and connect the Ethernet cable. Wait until the temperature is stable from the web interface (it can take half an hour from power on). Check the waveform, modify the threshold and gate width, if needed, then start the measurement of the energy spectrum.
Take for example 2 minutes of acquisition with the ^{137}Cs source sample by setting the corresponding acquisition time. Select the ROI peak, then check the values reported in the FWHM and Centroid fields.



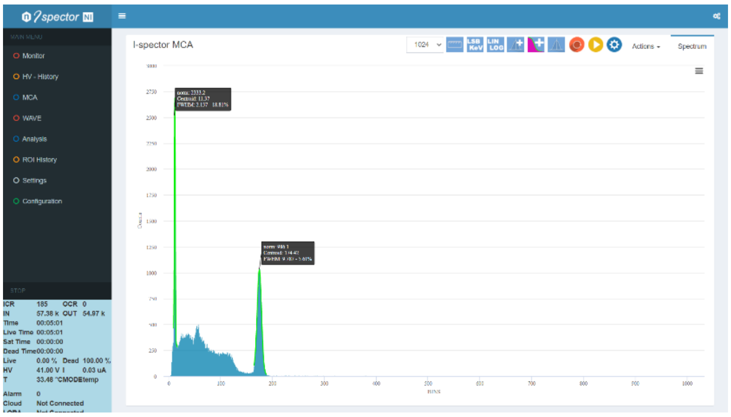
Experimental setup block diagram.

Results:

The figure shows a typical gamma spectrum, recorded with a very low energy threshold. The low energy line at 32 keV and the photopeak are clearly visible. For this specific spectrum, the energy resolution on the 662 keV peak corresponds to:

$$R = \frac{FWHM_{peak}}{\mu_{peak}} \cdot 100 = \frac{9.79}{174.4} \cdot 100 \sim 5.6\%$$

Where $FWHM_{peak}$= full width at half maximum of the peak, μ_{peak}= channel number of the peak centroid.



ICR 185 OCR 0
IN 57.38 k OUT 54.97 k
Time 00:05:01
Live Time 00:05:01
Sat Time 00:00:00
Dead Time 00:00:00
Live 0.00 % Dead 100.00 %
HV 41.00 V I 0.03 uA
T 33.48 °C MODE temp
Alarm 0
Cloud Not Connected

Energy spectrum with ROI and fit results.

System Calibration: Linearity and Resolution (ID.6114)

Purpose of the experiment:

Recording and comparing the γ energy spectra of several radioactive sources is the main goal of the experiment. The photo-peaks are used to calibrate the response of the system and to measure the energy resolution.

Fundamentals:

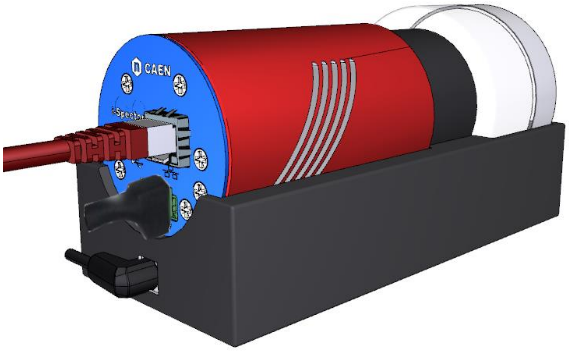
Linearity and energy resolution are the main figures of merit of a spectrometric system. In the proposed experiment, based on a scintillating crystal coupled to a Silicon Photomultipliers, deviations in the linearity may be due to the sensor or the front-end electronics saturation. The user is guided through the analysis of the response curve using a series of isotopes up to the MeV energy by a ^{60}Co source and to disentangle the different effects. At the same time, the energy resolution of the system is measured by the width of the photo-peaks and the results compared to what is expected by the fluctuations in the number of detected scintillation photons, the system noise, the sensor stochastic effects, the intrinsic resolution of the scintillator. This is following an initial activity on the optimization of the operating parameters by an analysis of the photo-peak position and the resolution for a single isotope. The same activity can be done with the radioactive samples provided in the SP5630EN kit as well.

Requirements:

^{60}Co laboratory low intensity or a couple of radioactive samples of the SP5630EN kit.

Carrying out the experiment:

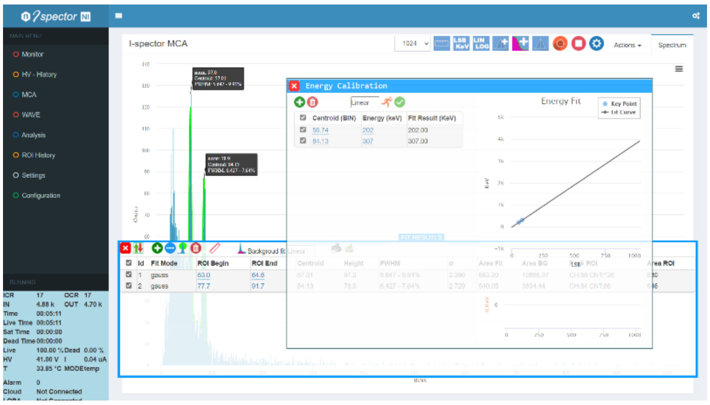
Put the i-Spector digital into the base and place a radioactive source into the empty box (*you can use biadesive tape to fix the source into the box*). You can use the LYSO crystal sample, if the ^{60}Co is not availble. Power on the i-Spector and connect the Ethernet cable. Wait until the temperature is stable from the web interface (it can take half an hour from power on). Check the waveform, modify the threshold and gate width, if needed, then start the measurement of the energy spectrum.
Acquisition for a time which can vary according to the source or sample activity. Select the ROIs and use the calibration tool to calibrate the spectrum.



Experimental setup block diagram.

Results:

By fitting the photo-peaks with a Gaussian curve, the system linearity as a function of energy is verified. The peak widths determine the energy resolution. At more advanced level, the interpretation of the results accounting for the system properties may be performed.



	Centroid (BIN)	Energy (keV)	Fit Result (KeV)
☑	56.74	202	202.00
☑	84.13	307	307.00

	Id	Fit Mode	ROI Begin	ROI End	Centroid	Height	FWHM	σ	Area Fit	Area BG	Peak ROI
☑	1	gauss	53.0	64.6	57.01	97.0	5.647 - 9.91%	2.398	583.20	10886.37	CH:58 CNT:126
☑	2	gauss	77.7	91.7	84.13	78.9	6.427 - 7.64%	2.729	540.05	3894.44	CH:84 CNT:86

ICR 17 OCR 17
IN 4.88 k OUT 4.70 k
Time 00:05:11
Live Time 00:05:11
Sat Time 00:00:00
Dead Time 00:00:00
Live 100.00 % Dead 0.00 %
HV 41.00 V I 0.04 uA
T 33.85 °C MODEtemp
Alarm 0
Cloud Not Connected

Linear dependency in the Energy Calibration.

Photonuclear cross-section / Compton Scattering cross-section (ID.6117)

Purpose of the experiment:

Determination of the ratio of the effective cross-sections due to Compton and Photoelectric effects as a function of photons energy.

Fundamentals:

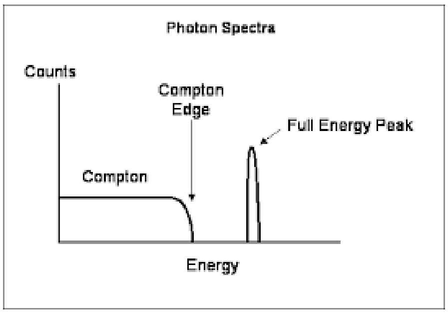
In the energy range up to 2 MeV, gamma rays interact with matter by two processes:

- Photoelectric Effect, dominant at energy less than 100 KeV. In this process the photon energy is completely transferred to atomic electron bounded

$$\gamma + \text{atom} \rightarrow \text{ion} + e^{-}$$

- Compton Scattering, linked to the elastic collision between electrons and photons and relevant at 1 MeV energy level

$$\gamma + e- \rightarrow \gamma' + e^{-\prime}$$



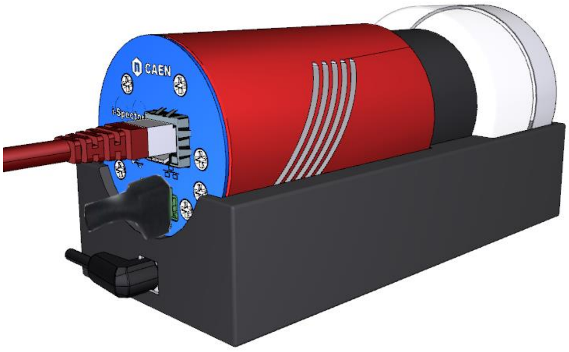
The predominant mode of interaction depends on the energy of the incident photons and the atomic number of the material with which they are interacting. From the acquired γ-spectrum, it is possible to estimate the fraction of events due to Compton scattering and those caused by the photoelectric. The ratio of the event fractions is used to determine the ratio of the two effective cross-sections that depends on the detector size.

Requirements:

^{137}Cs and ^{22}Na γ radioactive sources

Carrying out the experiment:

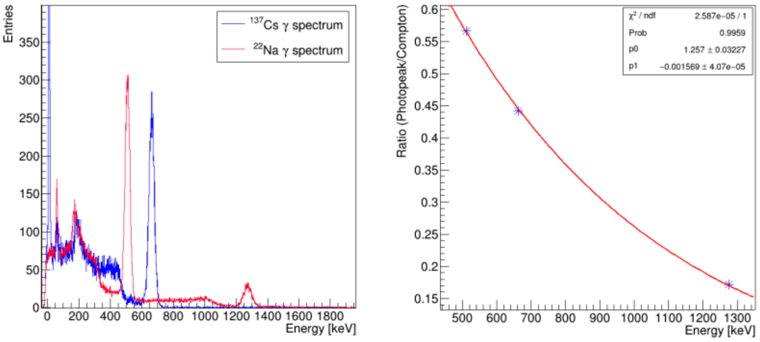
Put the i-Spector digital into the base and place a radioactive source into the empty box (*you can use biadesive tape to fix the source into the box*). Power on the i-Spector and connect the Ethernet cable. Wait until the temperature is stable from the web interface (it can take half an hour from power on).
Check the waveform, modify the threshold and gate width, if needed, then start the measurement of the energy spectrum.
Take few minutes of acquisition according to the source activity



Experimental setup block diagram.

Results:

By using several radioactive sources, the energy dependence of the ratio between the cross-sections of two phenomena can be examined, by verifying that the Photoelectric Effect cross section decreases with increasing energy compared to the Compton Scattering cross section for the used detector size.



^{137}Cs and ^{22}Na energy spectrum on the left and the ratio between Photopeak and Compton exponential trend.

Energy calibration of System based on LYSO crystal and Fertilizer sample (ID.6140)

Purpose of the experiment:

Recording γ energy spectra of several radioactive sources and detecting the photo-peaks to calibrate the response of the system is the main goal of the experiment.

Fundamentals:

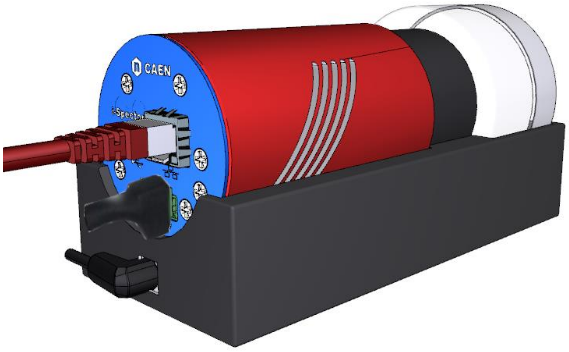
The calibration of the spectrum is the first step to be done in a typical experiment. The settings, like the trigger threshold, gate width, etc., used in the calibration should be used in the following measurements proposed in the Environmental kit. It is usually convenient to use radioactive sources with a wide range of energies, from hundreds keV to MeV. In the proposed experiment we take advantage of the LYSO(Ce) (Cerium-doped Lutetium Yttrium Orthosilicate) crystal (202 keV and 307 keV) and the Fertilizer sample (1468 keV) to have a calibration curve for the full spectrum range. The LYSO is also a scintillator material which can be coupled with SiPM or PMTs to detect gamma rays. See for example the SP5600C and SP5600AN kits.

Requirements:

No other tool is needed

Carrying out the experiment:

Put the i-Spector digital into the base and place, one at a time, the radioactive sources to be used for the calibration, like, for example, the LYSO crystal and the Fertilizer to have two/three points for calibration. Power on the i-Spector and connect the Ethernet cable. Wait until the temperature is stable from the web interface (it can take half an hour from power on).
Check the waveform, modify the threshold and gate width, if needed, then start the measurement of the energy spectrum.
Take for example 5 minutes of acquisition with the LYSO crystal sample and 30 minutes of acquisition with the Fertilizer. Acquisition time with laboratory radioactive sources can be reduced according to the source activity. Select the ROIs and use the calibration tool to calibrate the spectrum.



Experimental setup block diagram.

Results:

By fitting the photo-peaks with a Gaussian curve, the system linearity as a function of energy is verified. The final calibration function is used for the consecutive activities.

☑	Centroid (BIN)	Energy (keV)	Fit Result (KeV)
☑	56.74	202	200.20
☑	91.13	307	308.87
☑	374.14	1460.8	1460.63

☑	Id	Fit Mode	ROI Begin	ROI End
☑	1	gauss	53.0	61.8
☑	2	gauss	77.7	81.7
☑	3	gauss	[illegible]	[illegible]

```
ICR        13        OCR   13
IN         9.80 k    OUT   9.73 k
Time       00:13:41
Live Time  00:13:41
Sat Time   00:00:00
Dead Time  00:00:00
Live       100.00 %  Dead  0.00 %
HV         41.00 V   I     0.03 uA
T          33.49 °C  MODE  temp
Alarm      0
Cloud      Not Connected
```

Linear dependency in the Energy Calibration.

Background Measurements (ID.6141)

Purpose of the experiment:

Measurement of the background radioactivity to be subtracted from the energy spectra of the samples.

Fundamentals:

The main contributors to the background energy spectrum are the gamma radiations that originate from naturally occurring radioactive isotopes dispersed in the environment and the materials that surround the detector, and the radiations whose origin can be traced to cosmic rays. To properly identify the radioactive source and its activity, the background must be acquainted. The background spectrum is obtained by removing the radioactive source and must be acquired in the same conditions of the desired spectra. A possibility is to use lead blocks to cover the system and reject as much as possible environmental radioactivity that could hide interesting peaks.

Requirements:

No additional tool is required

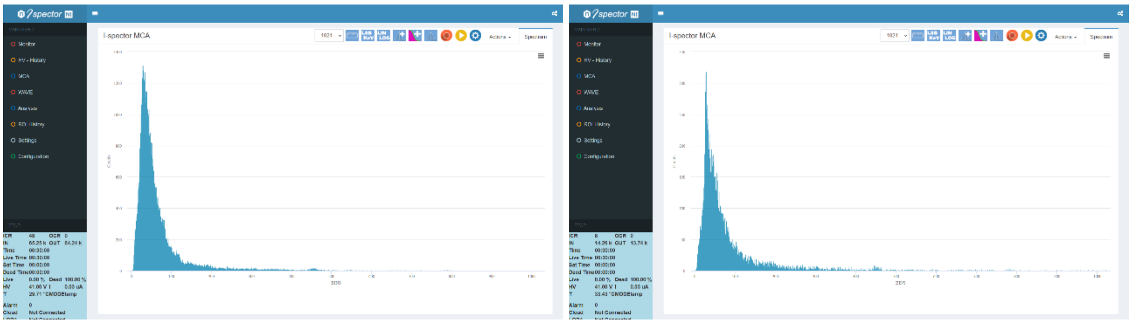
Carrying out the experiment:

Decide whether or not to use the Lead blocks to cover the system. The entire system can be covered by lead blocks, as shown in the figure below, just taking care to leave air flow for the i-Spector base fans. In any case, it is important to make all the measurements on the same conditions of the background one, so that the background subtraction can be made easily. The same software settings must be applied as well, including the acquisition time, so that the background subtraction can be done bin-by-bin in the energy spectrum. Put the i-Spector digital into the base. No sample is required in this experience. Power on the i-Spector and connect the Ethernet cable. Wait until the temperature is stable from the web interface (it can take half an hour from power on). Check the waveform, modify the threshold and gate width, if needed, then start the measurement of the energy spectrum. Take for example 30 minutes of spectra acquisition.

Experimental setup block with Lead blocks covering the active scintillator of i-Spector digital.

Results:

The user can easily check how lead blocks reduce the gamma radioactivity, by comparing the spectra with and without lead blocks (left and right respectively). A factor of 4 in the background reduction is visible when using the Lead blocks.



Environmental background acquired without Lead blocks (on the left) and with Lead blocks (on the right). Note the different scale on the y-axis. The radioactivity is reduced by a factor of about 4 when using the blocks.

Fertilizer and photopeak identification (ID.6142)

Purpose of the experiment:

Record the energy spectrum of Fertilizer sample and identify the Potassium peak. The experience will guide the user to select a ROI and perform a Gaussian fit on the peak. This sample can be used also as a reference for the spectrum calibration.

Fundamentals:

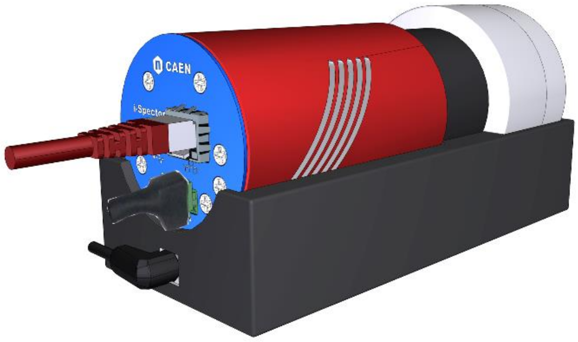
Potassium is a natural element whose radioactive isotope ^{40}K is widely available on Earth, especially in food and in human bodies. It plays a key role in geologic fields for the dating samples and rocks. Indeed, one of the main decay is in ^{40}Ar, which remains locked up in minerals. Knowing the decay time of ^{40}K into ^{40}Ar, and measuring the ratio between the two elements, it is possible to give a precise estimate about the origin of that material.

Another interesting application is the so-called Banana Equivalent Dose (BED), a “user-friendly” unit to measure radioactivity. Bananas naturally contains ^{40}K and 1 BED corresponds to 0.1 μSi of equivalent dose. To understand the proportions, consider that a dental X-ray corresponds to eating 50 bananas, an average daily dose of natural background is 100 BED, a fatal dose is 100 million bananas. This quantity has been introduced to get users familiar with natural low-radioactive objects.

Requirements:

No other tool is needed

Carrying out the experiment:

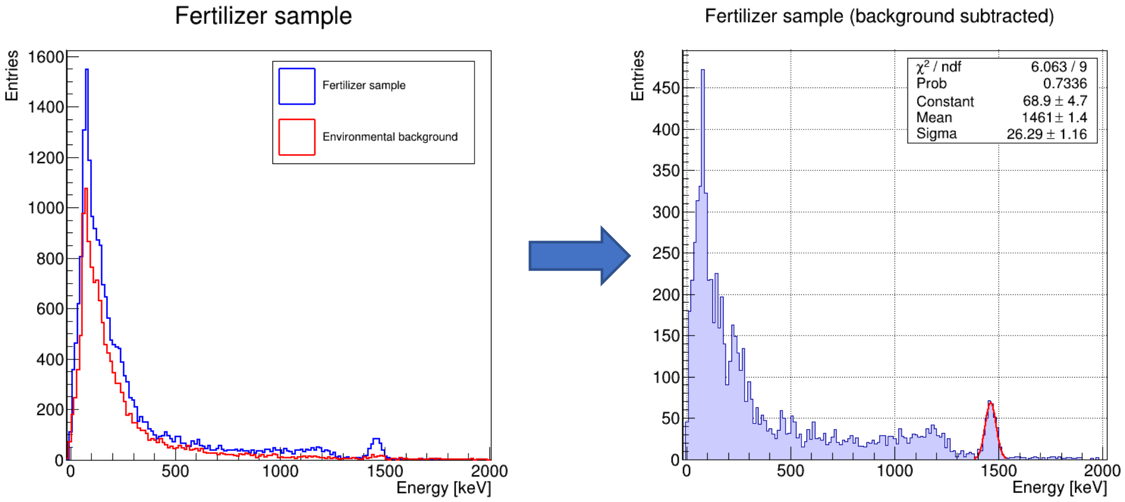


Experimental setup block diagram.

Put the i-Spector digital into the base and place the Fertilizer box into the place-holder. Power on the i-Spector and connect the Ethernet cable. Wait until the temperature is stable from the web interface (it can take half an hour from power on).
Check the waveform, modify the threshold and gate width, if needed, then start the measurement of the energy spectrum.
Take 30 minutes of acquisition with the Fertilizer.
NOTE: in case of background measurement, settings and acquisition time must be the same. Lead blocks could help in distinguish a clearer peak but they must be used if just employed in background measurement only.

Results:

Several steps can be done in this experiment. First, the background subtraction by saving the .csv of the two and by making a bin-by-bin subtraction of the two spectra. A small portion of the ^{40}K peak can be seen in the background spectrum too. The ^{40}K peak can be then selected through a ROI and fitted by means of a Gaussian function. The peak can be used together with the LYSO crystal for the energy calibration of the system (ID.6140)



Fertilizer sample: total contribution and background on the left; background subtracted on the right with a Gaussian fit on the ^{40}K peak. The mean value is in agreement with the expected value of 1460.8 keV

Soil sample identification (ID.6143)

Purpose of the experiment:

Record the energy spectrum of the Soil sample and identify the peaks, after the energy calibration, by knowing the decay chain of Thorium and Uranium.

Fundamentals:

Natural radioactivity has several sources that can be classified into two broad categories: high energy cosmic rays incident on the Earth's atmosphere and releasing secondary radiation (cosmic contribution); and radioactive nuclides generated during the formation of the Earth and still present in the Earth's crust (terrestrial contribution).

The terrestrial contribution is mainly composed of the radionuclides of the uranium and thorium decay chains together with radioactive potassium. In most circumstances, radon, a noble gas produced in the radioactive decay of uranium, is the most important contributor to radiation exposure.

Natural radionuclides, both terrestrial and cosmogenic, migrate in the environment through different pathways: air, water, rock, soil, and the food chain. Radionuclides may then enter the human body through ingestion (food and drinking water) and inhalation giving the so-called internal exposure. External exposure is due to cosmic radiation and radiation from terrestrial radionuclides present in soil, rocks, and building materials.

Requirements:

No other tool is needed.

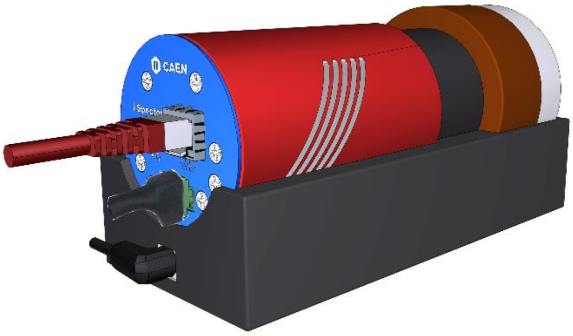
Carrying out the experiment:

Put the i-Spector digital into the base and place the Soil box into the place-holder. Power on the i-Spector and connect the Ethernet cable. Wait until the temperature is stable from the web interface (it can take half an hour from power on).

Check the waveform, modify the threshold and gate width, if needed, then start the measurement of the energy spectrum.

More than 30 minutes of acquisition need with the Soil sample.

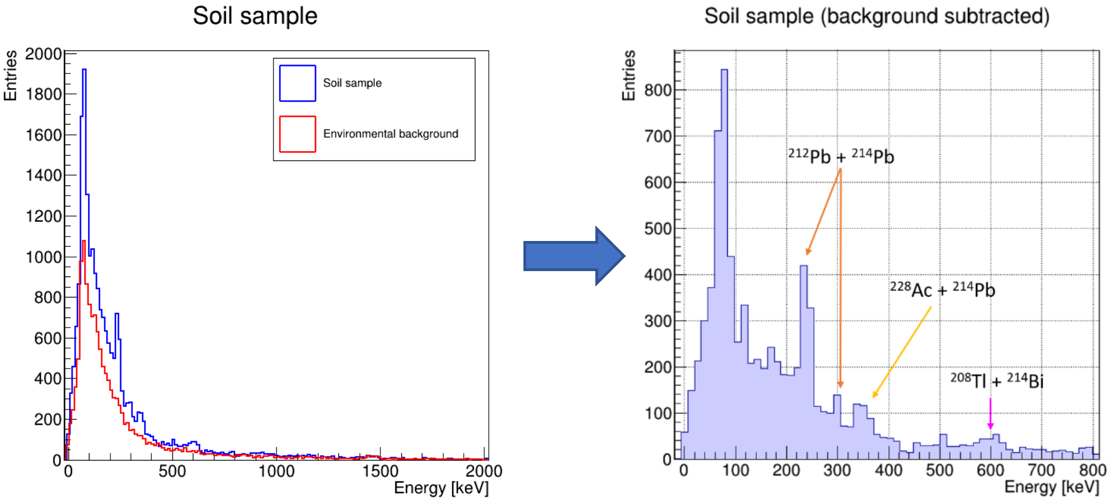
NOTE: in case of background measurement (ID.6141), settings and acquisition time must be the same. Lead blocks could help in distinguish clearer peaks but they must be used if just employed in background measurement only.



Experimental setup block diagram.

Results:

After the background subtraction, it is possible to recognize peaks coming from the Uranium or Thorium chain, as shown in the picture below.



Soil sample: total contribution and background on the left; background subtracted on the right. The visible peaks from the ^{238}U and ^{232}Th are highlighted in the spectrum.

Samples Comparison (ID.6144)

Purpose of the experiment:

This activity shows how to compare different spectra together.

Fundamentals:

Spectra comparison is a very common procedure in statistics and physics and consist of the superposition of different spectra, taken in the same conditions, or normalized to a common state. For example, radioactive sample and background spectra can be superimposed to visually show the differences and highlight the signal contribution.

Different sample spectra can be superimposed too, like for example the Soil and Fertilizer samples to see how in the same amount of time the two samples emitted. In the case of comparison of radioactive samples with a big activity difference, the normalization could be done for the total number of events.

Another possible comparison is by using a different detector, like the High Purity Germanium detector (HPGe), or a different system, like the GammaEDU backpack SP5640, composed of photomultiplier tube (PMT) coupled to a NaI scintillating crystal (0,3L).

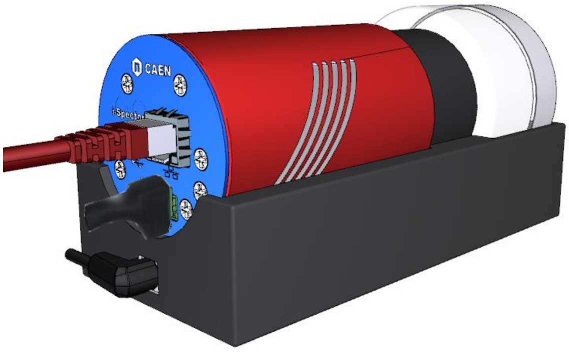
Requirements:

No other tool is needed.

Carrying out the experiment:

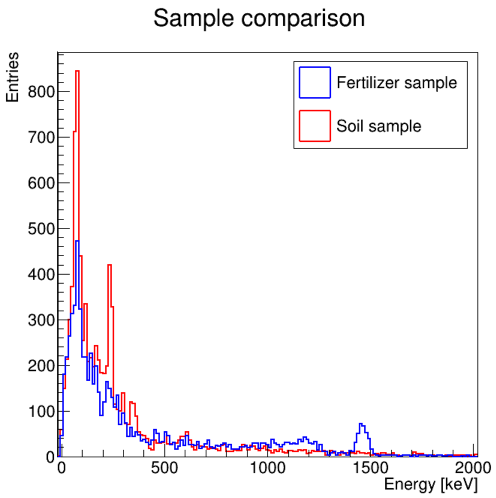
Put the i-Spector digital into the base and place the Soil box into the place-holder. Power on the i-Spector and connect the Ethernet cable. Wait until the temperature is stable from the web interface (it can take half an hour from power on).
Check the waveform, modify the threshold and gate width, if needed, then start the measurement of the energy spectrum.
Take 30 minutes acquisition with the Soil sample and then repeat the measurement by using Fertilizer sample.

NOTE: Settings and acquisition time must be the same. Lead blocks could help in distinguish clearer peaks but they must be used if just employed in background measurement only.



Experimental setup block diagram.

Results:
Superimpose the Fertilizer and Soil spectra in the same histogram. The different contributions are clearly visible on the left plot below, where the Uranium and Thorium peaks are visible in the region 200-400 keV of the Soil sample, while no contribution appears in the Fertilizer sample, and viceversa, the ^{40}K peak with its Compton edge is visible in the Fertilizer sample, with no contribution in other energy areas.



Sample comparison: two samples taken with the same i-Spector in the same experimental conditions.

Test Sample Identification (ID.6145)

Purpose of the experiment:

Record the energy spectrum of the Test sample and identify the peaks, after the energy calibration, by knowing the decay chain of Thorium and Uranium.

Fundamentals:

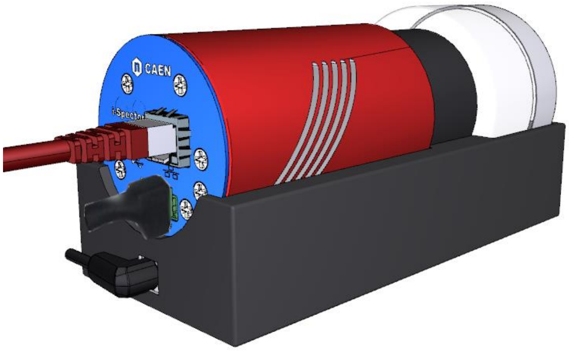
Naturally occurring radiative material (NORM) is material found in the environment that contains radioactive elements of natural origin (uranium, thorium, and potassium). NORM is often found in its natural state in rocks or sand but it can also be present in consumer products, including common building products (like brick and cement blocks), granite counter tops, glazed tiles, phosphate fertilizers, and tobacco products. Moreover, there are some of the materials and products sitting around your house could be emitting low levels of radiation. In the past, radioactive materials were employed by humans in objects of common use, like ceramics dishes (once uranium oxides were used to create a bright red-orange dinnerware), drinking glasses (glassmakers widely used uranium to color glasses a transparent yellow or yellow-green), clocks (glow in the dark with radium in the paint), camping lanterns (white light due to thorium), etc.
The test sample available in the kit contains old objects containing radioactive elements. The user can acquire the energy spectrum and try to recognize the source by knowing the decay products of Thorium and Uranium.

Requirements:

No other tool is needed

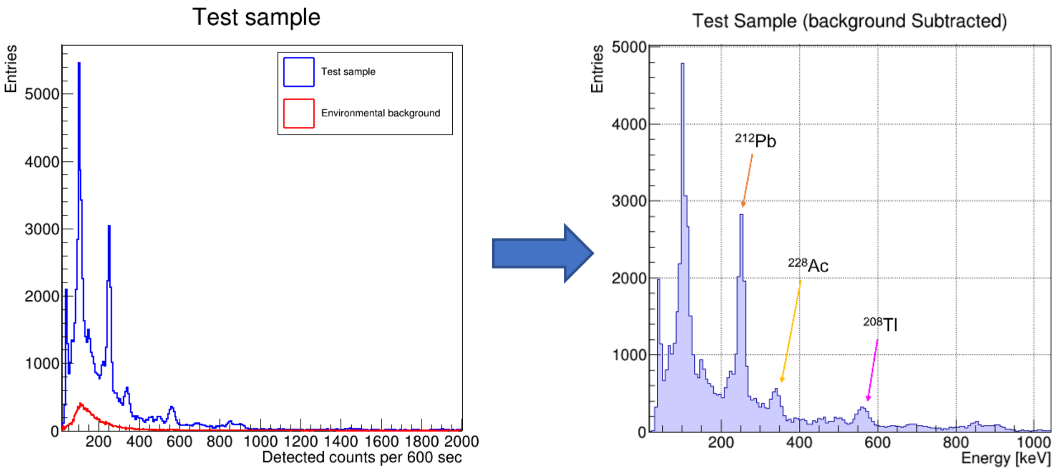
Carrying out the experiment:

Put the i-Spector digital into the base and place the Test sample box into the place-holder. Power on the i-Spector and connect the Ethernet cable. Wait until the temperature is stable from the web interface (it can take half an hour from power on).
Check the waveform, modify the threshold and gate width, if needed, then start the measurement of the energy spectrum.
Take few minutes of acquisition according to the sample activity
NOTE: in case of background measurement, settings and acquisition time must be the same. Lead blocks could help in distinguish clearer peaks but they must be used if just employed in background measurement only.



Experimental setup block diagram.

Results:
The background subtraction can be made with the background spectrum. After that, it is possible to recognize peaks and identify the source, either Thorium, Uranium, or both, as shown in the picture below. The user can identify which source is contained in the Test sample by knowing the product decay of the two elements.



Test sample: total contribution and background on the left; background subtracted on the right. The visible peaks are highlighted in the spectrum.

Radon passive measurement (ID.6146)

Purpose of the experiment:

Get familiar with radon passive measurements by taking care of the proper sample preparation and exposure, as well as of acquiring the spectrum to calculate the Radon concentration.

Fundamentals:

Radon is a naturally occurring radioactive gas produced by the breakdown of uranium in soil, rock, and water. Radon can be dangerous since it accumulates inside houses or buildings. Air pressure inside your home is usually lower than the pressure in the soil around the building foundation. Because of this difference in pressure, the building acts like a vacuum, drawing radon in through foundation cracks and other openings. Additionally, building materials — such as granite and certain concrete products — can give off radon.
It is usually recommended to make screening measurements to have a quick estimate of the highest concentration and take action in case the measurement exceeds 4 pCi/L (or 100 Bq/m^3), which is the limit for a non-dangerous exposure to this element.

Requirements:

No other tool is needed

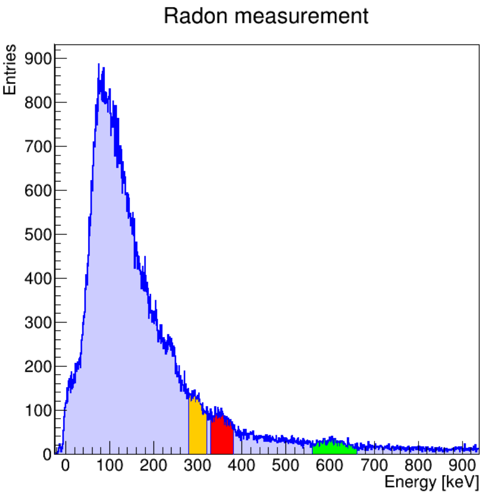
Carrying out the experiment:

Detailed instructions for this activity are reported in Sec. **Appendix A: Radon measurement**. Check the expiration date of the charcoal sample; if expired, or if the sample has already been used, bake it for some hours. Acquire the background spectrum with the i-Spector. Before starting the acquisition, make sure that the temperature is stable from the web interface. Once done, expose the sample for about 5-6 days, following the requirements of the closed house, and far away from wall, windows, etc., according to the Radon measurement procedure. Once ready, seal again the sample, wait at least three hours, and acquire the energy spectrum. Take few hours of acquisition with the exposed sample in the same condition of background acquisition.

Experimental setup block diagram.

Results:

After the energy calibration and background subtraction, it is possible to select the region of interest (ROI) of the ^{214}Pb and ^{214}Bi decay products at 295 keV, 352 keV, and 609 keV. The counts can be used together with the calibration curves to calculate the Radon concentration. On request, Excel® spreadsheets examples can be provided to customers.



Radon spectrum: counts of the three ROI are summed and combined with the calibration curves. The result is 124 ± 85 Bq/m^3. Longer acquisition time will improve the measurement resolution.

Appendix A: Radon measurement

CAEN SP5630EN kit contains two canisters of active charcoal for the indoor Radon measurement. Radon is a naturally occurring radioactive gas produced by the breakdown of uranium in soil, rock, and water. It is well known that radon can accumulate inside the house, and it has been identified as the second cause of lung cancer after smoking.

Air pressure inside your home is usually lower than pressure in the soil around the building foundation. Because of this difference in pressure, the building acts like a vacuum, drawing radon in through foundation cracks and other openings. Radon also may be present in well water and can be released into the air when water is used for showering and other household uses. In most cases, radon entering the home through water is a small risk compared with radon entering your home from the soil. In a small number of homes, the building materials — such as granite and certain concrete products — can give off radon, although building materials rarely cause radon problems by themselves **[RD2]**.

The radon concentrations in houses may vary greatly over time and over different rooms, showing highest concentrations in building's basements, cellars, or ground floors, i.e. in areas of the house close to the underlying soil.

It is usually recommended to make screening measurements to have a quick estimate of the highest concentration and take action in case the measurement exceeds 4 pCi/L (or 100 Bq/m^3), which is the limit for a non-dangerous exposure to this element. In case of high concentration of Radon, it is recommended to perform long-term integrated radon measurements to determine the annual average radon concentration.

There are several methods for measuring Radon, which include active and passive methods, like alpha-track detectors, activated charcoal, electret ion chambers, etc. In the CAEN Educational kit, the measurement with activated charcoal is proposed, since the gamma rays emitted by the absorbed radon can be easily measured by the i-Spector digital included in the kit. The method discussed in this manual is based on the technique reported in **[RD3]**.

The charcoal canister consists of a circular, 6-to-10 cm diameter containing approximately 2.5 cm deep filled with 25 to 100 grams of activated charcoal. One side of the container is fitted with a screen that keeps the charcoal in and allows air to diffuse into the charcoal. In some cases, the canister contains a diffusion barrier over the canister opening which improves the uniformity of the response to variations of radon concentration with time for longer exposures.

Charcoal canisters are passive devices requiring no power to function. The passive nature of the activated charcoal allows continual adsorption and desorption of radon. During the measurement period, the adsorbed radon undergoes radioactive decay, so the technique does not uniformly integrate radon concentrations during the exposure period. The average concentration calculated using mid-exposure time is subject to error if the ambient radon concentration varied during the adsorption period.

Before starting the measurement: check the expiring date of the charcoal. If it is expired, then it is required to regenerate the charcoal by baking the canister in an oven at 120°C for several hours. Make sure to remove the lid and the sealing tape before baking. Repeated purging of the canisters with heated air does not alter their adsorption capacity.

Before starting the measurement: choose the appropriate location to measure the Radon concentration. The "closed-house" conditions must be respected as much as possible, i.e. a closed building with a minimum level of ventilation. It is preferred to perform the measurement in wintertime, so that windows and doors are not left opened for long time.

The canister will not be disturbed during the measurement. The selection of the location must include the following requirements:

- The canister should not be placed near drafts caused by heating, ventilation, air conditioning vents, doors, windows, and fireplaces.
- No near heat, sunlight, no high humidity.
- No in kitchens and bathrooms.
- No near exterior house walls to reduce the effect of ventilation through cracks in the walls.
- Sampling locations should be at least 10 cm from other objects and at least 75 cm above the floor to reduce possible effects of drafts near the floor.

Once ready, follow the steps for the Radon concentration measurement.

1. Register the weight of the canister, including the lid, and sealing tape.
2. Open the canister and leave it opened in the selected location for a time duration from 2 to 6-7 days. As can be seen from **Fig. A.1:**, after that period the amount of decaying particles will overcome the radon adsorption, and it is not therefore convenient to leave it for more than 6-7 days.
3. Seal the canister with the same sealing tape.

4. Weight the canister at the end of the exposure. Any weight increase is attributed to water adsorbed on the charcoal. The weight of water gained is correlated to a correction factor for the analytical results.
5. Start and end exposure time should be registered.

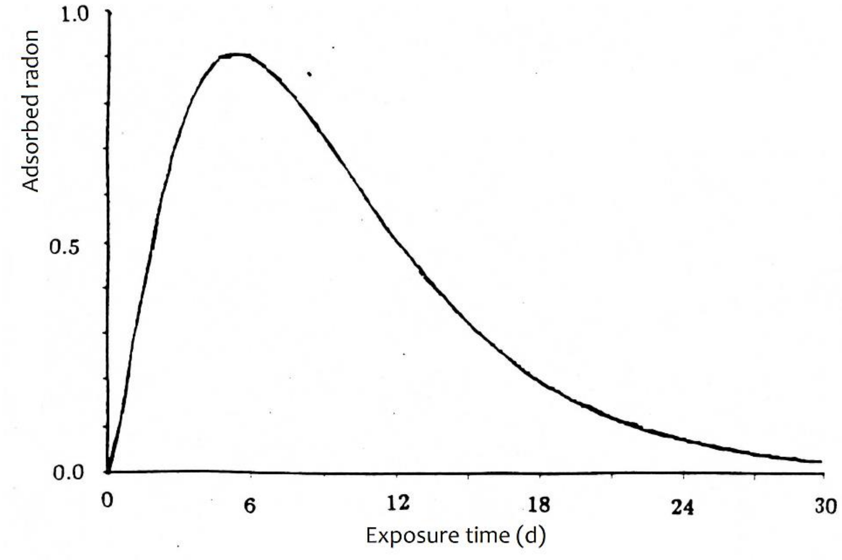


Fig. A.1: After 6-7 days the amount of decaying particles is greater than the amount of radon that could be accumulated for adsorption.

The formula to get the concentration of radon is:

$$C_{Rn} = \frac{Net\ Count\ Rate}{T_S \cdot DF \cdot \varepsilon \cdot CF}$$

Where:

- $Net\ Count\ Rate$ is the expressed in cpm and corresponds to sum of net events of **^{214}Pb** and **^{214}Bi** decay products at **295 keV**, **352 keV**, and **609 keV**.
- T_S is the exposure time (min) of the canister in air.
- DF is the Decay Factor from the midpoint of the exposure to the beginning of the counting. $DF = e^{-\lambda(T_D+T_S)/2}$, where $\lambda = \frac{\ln(2)}{t_{1/2}}$ is the decay constant for Rn (1/min), $t_{1/2}$ is the half-life of Rn, T_D is the time from the end of the exposure to the beginning of the counting (min).
- ε is the efficiency evaluated with a standard sample of ^{222}Rn (cpm/pCi) of known activity.
- CF is the calibration factor, which depends on calibration curves with respect to reference values of 48 h of exposure.

$$CF(\Delta m, Ts) = CF(\Delta m, 48h) \cdot \frac{AF(\Delta m, Ts)}{AF(48h)}$$

Where Δm is the mass difference of the canister after and before the exposure, and *AF* is a correction factor which takes into account the humidity gain over time, according to some calibration curves made in three humidity steps (20%, 50%, 80%). The calibrations are made with several samples exposed in a Radon and humidity-controlled chamber.

According to the gain in mass, the following curves must be chosen:

Δm < 1.0 g -> 20% *AF* curve

1.0 g < Δm < 4.0 g -> 50% *AF* curve

Δm > 4.0 g -> 80% *AF* curve

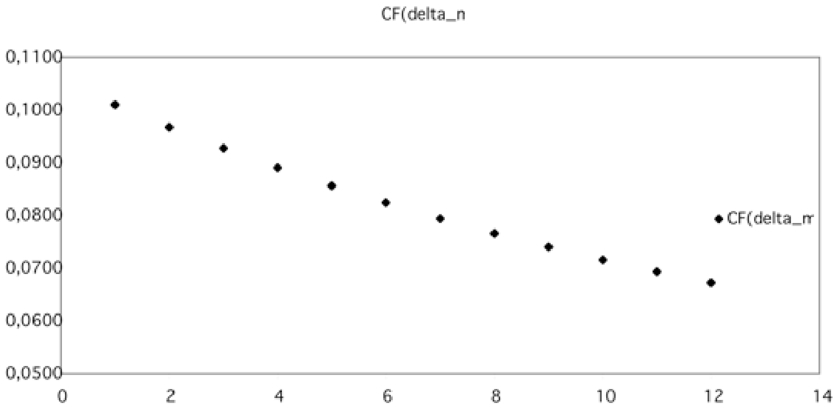


Fig. A.2: Calibration Factor (CF) as a function of the canister mass variation before and after the exposure.

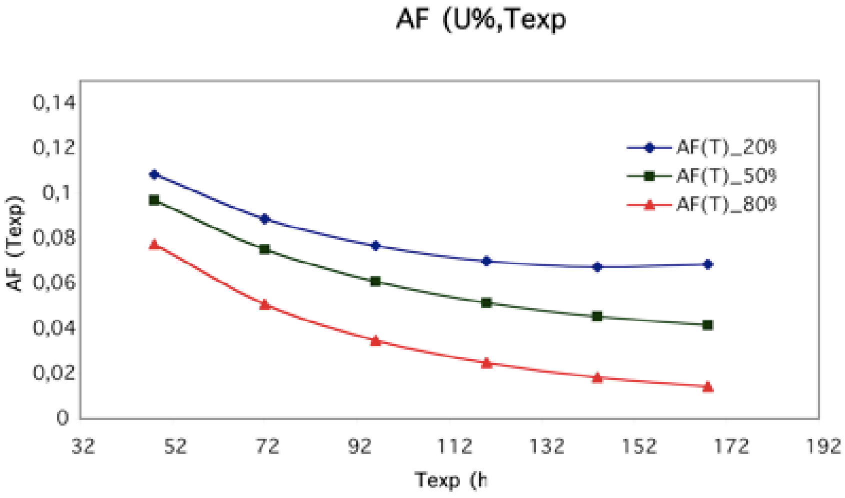


Fig. A.3: Correction Factor (AF) as a function of the exposure time (Ts). Values are reported for the three reference humidity levels

An example of CF and AF curves are reported in **Fig. A.2** and **Fig. A.3**, with the same samples type used in the SP5630EN kit. Other tabled values are reported in various documents, like **[RD3]** and **[RD4]**.

6. Wait a minimum period of three hours after the end of exposure to reach the equilibrium and start the measurement with the i-Spector. The canisters should be analyzed before about 10 days from the exposure.
7. Put the canister in from of the i-Spector and start taking the spectrum acquisition. Acquire also the background spectrum without the canister sample. It is recommended to acquire for several hours to get enough statistics.

Appendix B: ^{232}Th decay chain series

Isotope	half-life	gamma energies (KeV)
Th232	1.405 x 1010 years	63.8 (0.267%)
Ra228	6.7 years	------
Ac228	6.13 hours	57.7 (0.487%) 99.5 (1.28%) 129.0 (2.42%) 154.0 (0.737%) 209.3 (3.88%) 270.2 (3.43%) 328.0 (2.95%) 338.3 (11.3%) 409.5 (1.94%) 463.0 (4.44%) 772 (1.50%) 794.9 (4.36%) 835.7 (1.61%) 911.2 (26.6%) 964.8 (5.11%) 969.0 (16.2%) 1588.2 (3.27%)
Th228	1.91 years	84.4 (1.22%)
Ra224	3.64 days	241.0 (3.97%)
Rn220	55 seconds	550 (0.07%)
Po216	0.15 seconds	------
Pb212	10.64 hours	238.6 (43.6%) 300.0 (3.34%)
Bi212	60.6 minutes	39.9 (1.1%) 727.3 (6.65%)
64.06% 35.94% Po212 Tl208	 304 nsec 3.1 minutes	 ------- 277.4 (6.31%) 510.77 (22.6%) 583.2 (84.5%) 763.1 (1.81%) 860.6 (12.4%)
Pb208	stable	-------

Appendix C: ^{238}U decay chain series

Isotope	half-life	gamma energies (KeV)
U238	4.468 x 10^9 years	----
Th234	24.1 days	63.3 (4.47%) 92.38 (2.60%) 92.80 (2.56%)
Pa234m	1.17 minutes	765 (0.207%) 1001 (0.59%)
99.8% 0.13% Pa234	6.75 hours	100 (50%) 700 (24%) 900 (70%)
U234	2.47 x 10^5 years	53.2 (0.123%)
Th230	8.0 x 10^4 years	67.7 (0.373%)
Ra226	1602 years	186.2 (3.50%)
Rn222	3.823 days	510 (0.076%)
Pc218	3.05 minutes	------
99.98% 0.02% Pb214 At218	26.8 minutes 2 seconds	53.2 (1.1%) 242.0 (7.46%) 295.2 (19.2%) 351.9 (37.1%) 785.9 (1.09%) -----
Bi214	19.7 minutes	609.3 (46.1%) 768.4 (4.89%) 806.2 (1.23%) 934.1 (3.16%) 1120.3 (15.0%) 1238.1 (5.92%) 1377.7 (4.02%) 1408.0 (2.48%) 1509.2 (2.19%) 1764.5 (15.9%)
99.98% 0.02% Po214 Tl210	164 microsec 1.3 minutes	799 (0.014%) 296 (80%) 795 (100%) 1310 (21%)
Pb210	21 years	46.5 (4.05%)
Bi210	5.01 days	------
Po210	138.4 days	803 (0.0011%)
Pb206	Stable	------

6. Technical Support

CAEN makes available the technical support of its specialists for request concerning the software and the hardware. Use the support form available at the following link:

https://www.caen.it/support-services/support-form/

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