CAEN Educational

Guide GD8983

SP5640 GammaEDU

Backpack Radiation Detector

Rev. 3 – 26th November 2024

Purpose of this Guide

This QuickStart Guide contains basic information and examples that will let you use GammaEDU - Backpack Radiation Detector in few steps.

Change Document Record

Date	Revision	Changes
July 2022	00	Initial release.
November 2022	01	Updated **Chap.4** & **Chap.7.** Added New **Chap.5.**
February 2024	02	Updated Android™ references.
November 2024	03	Updated **Chap.5.** Added New **Chap.6.**

Symbols, abbreviated terms and notation

ADC	Analog to Digital Converter
DPP	Digital Pulse Processing
DPP-PHA	DPP for Pulse Height Analysis
OS	Operating System
MCA	Multi-Channel Analyzer
PC	Personal Computer
PMT	Photo-Multiplier Tube
GUI	Graphical User Interface
HVPS	High Voltage Power Supply
APP	Tablet Application Program
DPP	Digital Pulse Processing
PHA	Digital Pulse Processing
DPP-PHA	DPP for Pulse Height Analysis
ROI	Region of Interest

Reference Documents

[RD1] UM3904 – GammaStream User Manual
[RD2] UM3182 – MC2Analyzer User Manual
[RD3] https://scionix.nl/
[RD4] Guidelines for radioelement mapping using gamma ray spectrometry data (IAEA-TECDOC-1363), 2003, International Atomic Energy agency (IAEA).

https://www.caen.it/support-services/documentation-area/

Manufacturer Contacts

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Limitation of Responsibility

If the warnings contained in this manual are not followed, Caen will not be responsible for damage caused by improper use of the device. The manufacturer declines all responsibility for damage resulting from failure to comply with the instructions for use of the product. The equipment must be used as described in the user manual, with particular regard to the intended use, using only accessories as specified by the manufacturer. No modification or repair can be performed

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Disclaimer

The information contained herein has been carefully checked and is believed to be accurate; however, no responsibility is assumed for inaccuracies. CAEN spa reserves the right to modify its products specifications without giving any notice; for up-to-date information please visit www.caen.it.

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 Safety Notices

<u>N.B. Read carefully the "Precautions for Handling, Storage and Installation" document provided with the product before starting any operation.</u>

The following HAZARD SYMBOLS may be reported on the unit:

	Caution, refer to product manual
	Caution, risk of electrical shock
	Protective conductor terminal
	Earth (Ground) Terminal
~	Alternating Current
3~	Three-Phase Alternating Current

The following symbol may be reported in the present manual:

	General warning statement

The symbol could be followed by the following terms:

- **DANGER**: indicates a hazardous situation which, if not avoided, will result in serious injury or death.
- **WARNING**: indicates a hazardous situation which, if not avoided, could result in death or serious injury.
- **CAUTION**: indicates a situation or condition that, if not avoided, could cause physical injury, or damage the product and / or its environment.

To avoid potential hazards, use the product only as specified. Only qualified personnel should perform service procedures.
Avoid Electric Overload. To avoid electric shock or fire hazard, do not power a load outside of its specified range.
Avoid Electric Shock. To avoid injury or loss of life, do not connect or disconnect cables while they are connected to a voltage source.
Do Not Operate without Covers. To avoid electric shock or fire hazard, do not operate this product with covers or panels removed.
Do Not Operate in Wet/Damp Conditions. To avoid electric shock, do not operate this product in wet or damp conditions.
Do Not Operate in an Explosive Atmosphere. To avoid injury or fire hazard, do not operate this product in an explosive atmosphere.
Do Not Operate with Suspected Failures. If you suspect this product to be damaged, please contact Technical Support.

ALL MODELS:

⚠ **THIS DEVICE SHOULD BE INSTALLED AND USED BY SKILLED TECHNICIAN ONLY OR UNDER HIS SUPERVISION**

⚠ **THE SAFETY OF ANY SYSTEM THAT INCORPORATES THE DEVICE IS UNDER THE RESPONSIBILITY OF THE ASSEMBLER OF THE SYSTEM**

Carefulness with Radioactive Sources

Some Physics experiments related to Gamma spectroscopy proposed in this manual need radioactive sources.

There are two radioactive source types for educational purpose: sealed and unsealed sources. In the following experiments, sealed sources have been used. This source type is typically easier to use because the radioactive material is deposited in a plastic disk and sealed inside with a durable epoxy. Problems related to possible spills or decontamination are negligible.

Sealed gamma or beta sources of low activity, such as 0,1 µCi or a little bit more, can be handled directly without significant risk, although it is good practice to utilize tongs. Otherwise, sealed gamma sources with high activity, such as 10 µCi or more, should only be handled with tongs.

Nevertheless, when working with radioactive sources, mitigation of radiation exposures is very important. The basic principles of ALARA can give instructions. ALARA (As Low As Reasonably Achievable) is a radiation safety principle for minimizing radiation doses and releases of radioactive materials by employing all reasonable methods. ALARA is not only a sound safety principle for all radiation safety programs but is a regulatory requirement.

The three main principles are related to:

- Time**:** minimizing the time of exposure is the simplest way to directly reduce radiation exposure;
- Distance: doubling the distance between the radiation source and human body means to reduce radiation exposure by a factor of 4;
- Shielding: using absorber materials, such as lead for X-rays and gamma rays and Plexiglas for beta particles, to reduce the radiation reaching the body from a radioactive source is an effective way to reduce radiation exposures.

The radioactive sources for educational purpose have a low level of activity and them storing is a relatively simple matter. Solid sealed sources can be safely stored in the own plastic containers of shipment and then they can be put together in a locked cabinet, possibly with an additional shielding of lead sheets or bricks.

Important Note: Beta and Gamma Radioactive Sources are not included in the SP5640 Gamma EDU.

2 System Overview

CAEN brings the experience acquired in more than 40 years of collaboration with the High Energy & Nuclear Physics community into the University educational laboratories. Thanks to the most advanced instrumentation developed by CAEN for the major experiments worldwide, together with the University teaching experience at the University of Insubria, a series of experiments covering several applications has been carried out.

CAEN realized different modular Educational Kits. The **GammaEDU**, **SP5640**, is a portable detection backpack for revealing the presence of radioactive materials in the environment. The high efficiency of the scintillation crystal allows to perform a measurement in few minutes. GammaEDU can identify industrial, medical and naturally occurring radioactive isotopes in static and dynamic acquisition.

The GammaEDU detection backpack includes NaI(Tl) scintillator crystal coupled with a Photomultiplier Tube (PMT) and the S2580 – *γstream*, tube base MCA. The *γstream* integrates High Voltage Power Supply, Preamplifier, and digital Multi-Channel Analyzer for scintillation spectroscopy. The GammaEDU has high detection efficiency, low power consumption, and the data taking can be uninterrupted up to 6 hours, very suitable for outdoor gamma radiation measurements. A 10'' tablet including CAEN GammaEDU application is part of the product. With the GammaEDU Android[1] application the students can acquire and analyze in real time a γ-ray spectrum to get the K, U and Th abundances, keep track of the surrounding environment, take the GPS coordinates, and shoot a picture of the on-going measurements. The data are saved in a .kmz file ready to be visualized on Google Earth and shared on Google Drive for producing a radioactivity map of the area.

The GammaEDU comprises:

- Nr.1 NaI(Tl) detector (0.3 L) coupled with S2580 – *γstream*. CAEN *γstream* is a compact and portable system for gamma ray spectroscopy with scintillation detectors, which provides an active Multi-Channel Analyzer (MCA) integrated in a 14-pin photo-multiplier tube (PMT) base. *γstream* fully integrates in a stand-alone device the high voltage to bias the PMT, the preamplifier to shape the signal from detector, and the MCA for a complete online Pulse Height Analysis.
- Nr.1 Tablet Samsung Galaxy A7-10''.
- Nr.1 Ethernet cable.
- Nr.1 Mini USB cable
- Nr.1 External AC/DC stabilized 12V power supplies.
- Nr.1 Quick Start Guide and Documentation
- With GammaEDU Android application the user can acquire and analyse in real time a γ-ray spectrum to get the K, U and Th abundances, keep track of the surrounding environment, take the GPS coordinates and shoot a picture of the on-going measurements. The data are saved in a .kmz file ready to be visualized on Google Earth and shared for producing a radioactivity map of the area.

The detection backpack can be used via the GammaEDU APP directly by placing it on the floor. Alternatively, the detector can be removed from the backpack for gamma spectroscopy measurements in laboratory.

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

[1] Android is a trademark of Google LLC.

CAUTION: to manage the product, consult the operating instructions provided.

When receiving the unit, the user is strictly recommended to:

- Inspect containers for damage during shipment. Report any damage to the freight carrier for possible insurance claims.
- Check that all the components received match those listed on the enclosed packing list. (CAEN cannot accept responsibility for missing items unless we are notified promptly of any discrepancies.)
- Open shipping containers; be careful not to damage contents.
- Inspect contents and report any damage. The inspection should confirm that there is no exterior damage to the unit such as broken knobs or connectors and that the front panel and display face are not scratched or cracked. Keep all packing material until the inspection has been completed.
- If damage is detected, file a claim with carrier immediately and notify CAEN service.
- If equipment must be returned for any reason, carefully repack equipment in the original shipping container with original packing materials if possible. Please, contact CAEN service.
- If equipment is to be installed later, place equipment in original shipping container and store in a safe place until ready to install

DO NOT SUBJECT THE ITEM TO UNDUE SHOCK OF VIBRATIONS

DO NOT BUMP, DROP OR SLIDE SHIPPING CONTAINERS

DO NOT LEAVE ITEMS OR SHIPPING CONTAINERS UNSUPERVISED IN AREAS WHERE UNTRAINED PERSONNEL MAY MISHANDLE THE ITEMS

USE ONLY ACCESSORIES WICH MEET THE MANUFACTURER SPECIFICATIONS

DO NOT PUT THE BACKPACK INTO WATER. ALWAYS KEEP IT AWAY FROM RAIN AND WATER. DOING SO MAY CAUSE DAMAGE OR ELECTRIC SHOCK

3 Hardware Description

As previously mentioned, the GammaEDU backpack includes NaI(Tl) scintillator crystal coupled with a Photomultiplier Tube (PMT) and the S2580 – *γstream* **Fig. 3.1**. To better understand its use, this section provides a brief description of the main components.

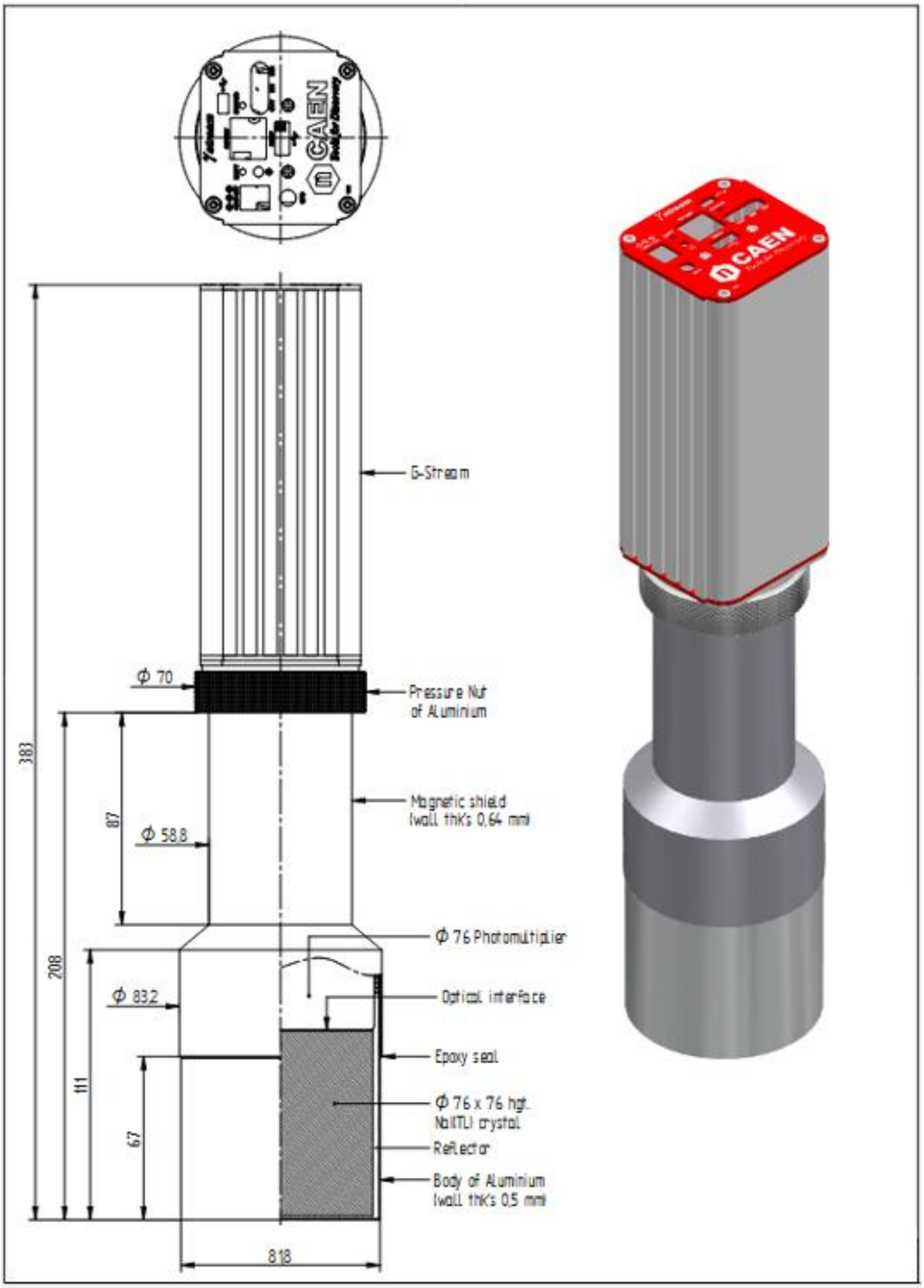
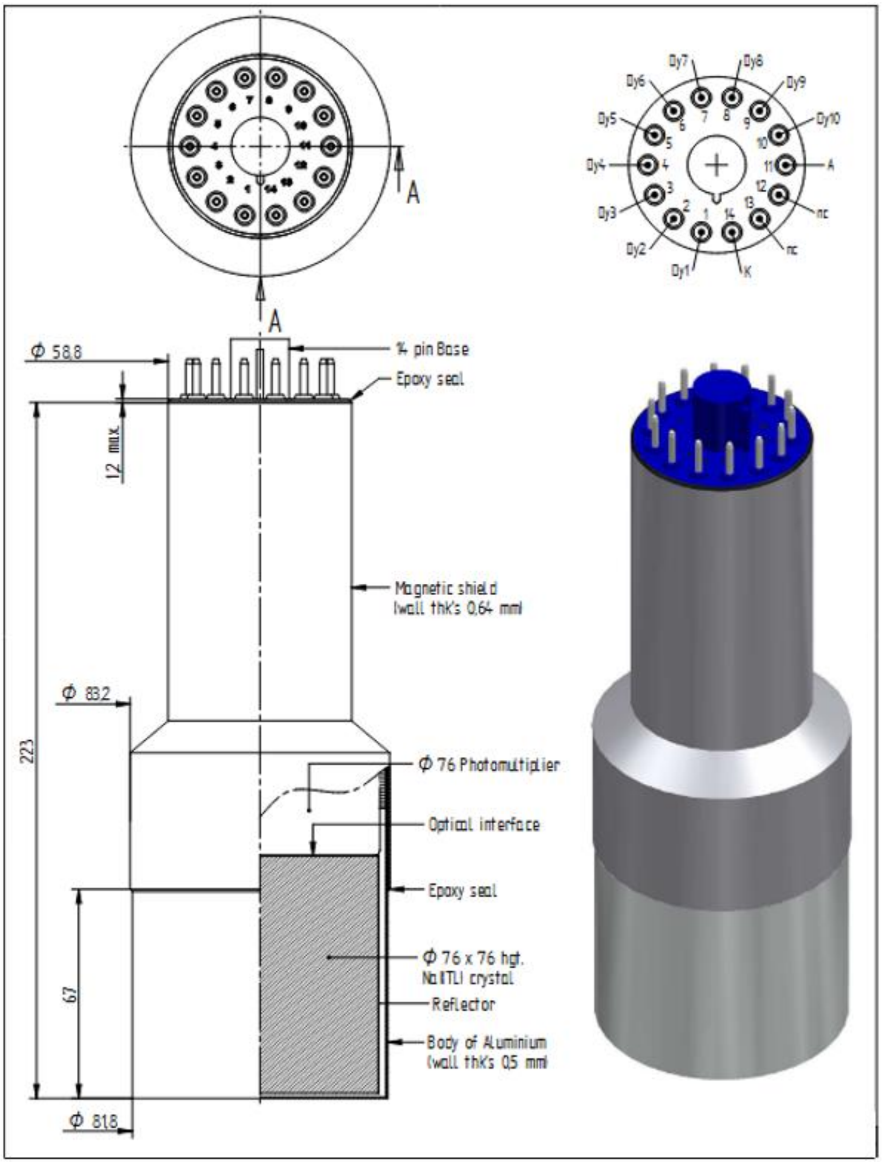


Fig. 3.1: Detector system of GammaEDU backpack.

3.1. Detection System

The GammaEDU detection system is provided by Scionix [RD3] and it is composed of NaI(Tl) scintillator crystal (0.3 L) coupled with a Photomultiplier Tube (PMT). See the following detector sketch.



Single crystal sodium iodide doped with thallium ions NaI(Tl) is the most widely used scintillation material for gamma-ray spectroscopy.
NaI(Tl) scintillators have the greatest light output among all the scintillators and a convenient emission range coinciding with a maximum efficiency of photomultipliers with bialkali photocathodes.
NaI(Tl) crystals have radiation hardness that is quite satisfactory for many applications.
NaI(Tl) scintillator is hygroscopic and is only used in hermetically sealed metal containers to preserve its properties. NaI(Tl) crystals can be grown to large dimensions (400 mm diameter) in ingots of many hundreds of kg. The material can be cut in a great variety of sizes and shapes and cleaved in small diameters.
The wide application of NaI(Tl) crystals is mainly due to the relative simplicity of using and low cost of crystals. Because of physical properties, NaI(Tl) scintillators are widely used in different detecting systems in radiation medicine, in apparatus for monitoring of radionuclides, in nuclear and high energy physics, in time-of-flight measurements, positron lifetime studies, general scintillation counting, environmental monitoring, high temperature use, etc.

Summarizing, NaI(Tl) scintillators:

- are one of the 'brightest' scintillators available

- have good density and a high Z
- have an optical output well match to the maximum sensitivity of commonly available PMTs
- have good "rad hard" properties
- do not glow in the UV
- have an optical output largely independent of temperature
- highly hygroscopic with encapsulation needed

Properties	Value
Peak Scintillation Wavelength (nm)	415
Wavelength Range (nm)	325-550
Decay Time (ns)	230
Light Yield (ptotons/keV)	55
Photoelectron Yield (% of NaI(Tl))	100
Radiation Length (cm)	2.6
Optical Transmission (µm)	0.15 - 12.5
Transmittance (%)	>90 (0.35 - 9 µm)
Refractive Index	1.85 (@415 nm)
Reflection Loss/ Surface (%)	6.8
Density (g cm^{-3})	3.67
Atomic Number (Effective)	56
Melting Point (°K)	924
Thermal Expansion Coeff. (C^{-1})	$47.4*10^{-6}$
Cleavage Plane	<100>
Hardness (Mho)	2
Solubility (g/100g H_20)	TBA (23°C)
Hygroscopic	Yes

Tab. 3.1: NaI(Tl) Scintillator Properties.

Pulses of light emitted by the scintillating material can be detected by a sensitive light detector, often a photomultiplier tube (PMT).
The photocathode of the PMT, placed on the entrance window, converts the light (photons) into electrons, also called photoelectrons.
Electric fields in the PMT accelerate the photoelectrons into another surface called a dynode. The collision of the electron with the dynode releases several new electrons, which are accelerated into another dynode. This process (multiplication process) is repeated several times producing a typical electron gain of $\sim 10^6$. The result is that each light pulse (scintillation) produces a charge pulse on the anode of the PMT that can subsequently be detected and analyzed by the CAEN *γstream*.

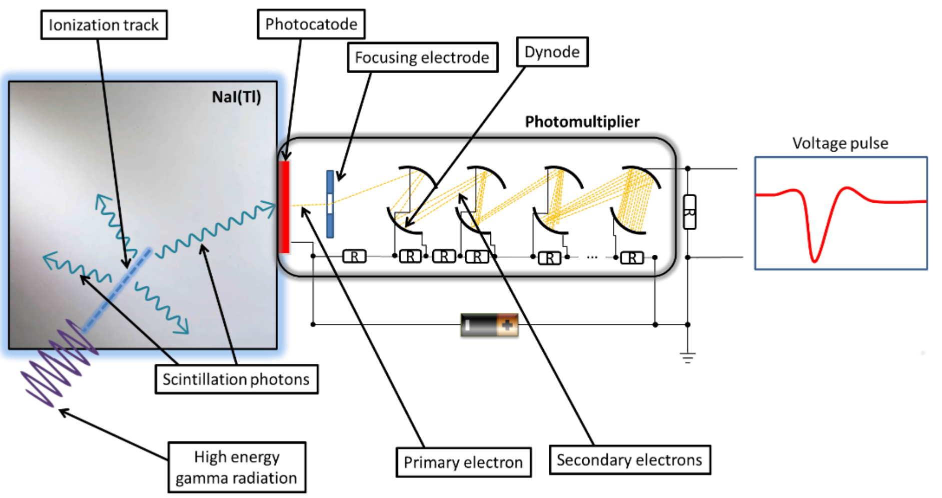


Fig. 3.2: Photomultiplier tube diagram.

3.2. S2580 – γstream

- Fully stand-alone MCA including high voltage power supply, preamplifier, battery and data-storage on SSD
- Compatible with scintillation detectors as NaI(Tl), LaBr3(Ce), and CeBr3, using standard 14-pin and 10-8 stages PMTs
- Different acquisition modes available: signal inspector, time stamped list mode, PHA
- Open access to embedded CPU for custom developments
- Available with embedded GPS for data geo-localization
- Gain stabilizer based on natural or calibration radioactivity
- Wired and wireless connectivity through USB, Ethernet,
- Bluetooth and Wi-Fi
- Front panel cover against dust and rain for outdoor operation
- Front panel auxiliary digital I/O connectors for synchronization, trigger time stamp reset, external trigger, veto
- Supported by CAEN MC^{2}Analyzer software GUI, and Gamma Touch application for smartphones and tablets with Android^{TM} s

CAEN *γstream* [RD1] is a compact and portable system for gamma-ray spectroscopy with scintillation detectors, which provides an active Multi-Channel Analyzer (MCA) integrated in a 14-pin photo-multiplier tube (PMT) base. *γstream* fully integrates in a stand-alone device the high voltage to bias the PMT, the preamplifier to shape the signal from detector, and the MCA for a complete Pulse Height Analysis online.
γstream makes easy the measurements with scintillation detectors, such as NaI(Tl), LaBr3(Ce) and CeBr3, with no need of additional cables. Its socket and voltage divider can supply standard 14-pin and 10-stage (S2580 and S2580G models) or 8-stage (S2580LB and S2580LBG models) PMTs.
γstream has been designed to work stand-alone, with no need of additional devices, cables, nor human assistance. *γstream* features internal rechargeable Li-Ion battery providing long-term duration for unattended on-field acquisitions. Once *γstream* is programmed via computer, tablet or mobile phone, it then acquires and logs data in an internal SSD memory. An embedded CPU, running Linux OS, controls the acquisition and data recording, as well as the supported communication interfaces. Multi-interface communication capability by Ethernet, USB 2.0, Bluetooth or Wi-Fi, makes possible the remote control via computer or smartphone. *γstream* can be fully controlled by the MC2Analyzer software [RD2] running on Windows OS PC. Besides the standard board and spectra configuration, the software features functionalities like spectra calibration, peak search and analysis, etc.
Dedicated S2580G and S2580LBG versions feature an embedded GPS component. Considering that scintillation detectors are usually sensitive to temperature changes, an advanced algorithm for gain stabilization is available. The user can select a specific range where the algorithm recognizes a peak and adjust its position according to the temperature variations.

Advantages using γ*stream*

γstream features make the instrument a ”plug-and-play” device for gamma spectroscopy from scintillation detectors.
The main advantages of the device are:

- **Fully Stand-alone**

  γstream is a compact and portable instrument that provides all-in-one HVPS (High Voltage Power Supply) to bias the PMT, pre-amplification stage, and digital MCA. It is just sufficient to plug the *γstream* socket base into the 14-pin PMT. To ensure the correct alignment, the PMT has a key which mates with the *γstream* keyway. The proper settings and acquisition can be fully managed by software or mobile application, via several communication interfaces, both wired and wireless. In particular, *γstream* can be connected to a PC via wired USB 2.0 and Ethernet connection. Also, wireless connection is available on request via Wi-Fi. Finally, the mobile application running on provided tablet communicates with *γstream* via Bluetooth.

- **Wireless Connectivity**

Wi-Fi or Bluetooth interfaces provide wireless connectivity to *γstream*. The device can therefore work without need of any cable. Bluetooth and Wi-Fi dongles are both provided together with the *γstream* device. Either Bluetooth or Wi-Fi dongle can be plugged into the Host USB connector at a time, thus allowing for a single communication interface at a time. Also, the wired USB communication and Ethernet are mutually exclusive. Refer to Sec. 5.3 of the GammaStream User Manual [RD1] for detailed instructions on how to configure the desired communication interface.

In case the communication is lost during the acquisition, *γstream* will continue the data collection, thus avoiding undesired data losses. Data can be then retrieved by Web Interface [RD1].

- **Multiple Acquisition Modes**

γstream supports the following acquisition modes:

- *PHA Mode*

  In the PHA (Pulse Height Analysis) mode, the energy from radiation detector signals is converted into a digital value through an internal trapezoidal filter. The filter is able to transform the exponential shape from the pre-amplifier into a trapezoid, whose height is proportional to the signal energy. Further details on the trapezoid algorithm are described in [RD2].The energy values are then used to produce an energy spectrum over 2048 (2k) channels. Rebin option of 1024 (1k) channels is supported by MC²Analyzer software. Each channel "*i*" contains the frequency of occurrence of events with energy.$E_i - E_{i-1}$.

- *List Mode*

  In List mode, a time-stamp is associated to each event together with the energy value. The time-stamp reflects the time of occurrence of the event. For more details about the trigger filter, please refer to [RD2]**.** The time stamp is expressed with an accuracy of 16 ns.

- **Gain Stabilization**

Compensation of the detector sensitivity for environmental temperature variations is a feature supported by *γstream*. The device integrates a gain stabilizer based on natural or calibration radioactivity that is managed by the software. The user defines a region of interest in the energy spectrum around a known peak, then the algorithm works by continuously tuning the fine gain (i.e. trapezoidal gain in MC²Analyzer) to keep the peak at the same channel.

- **Digital I/O**

Three general purpose digital I/Os support LVTTL (3.3V) signals. One output connector provides Fast Trigger Detection information; two input connectors are programmed for Veto and Synchronization functionality respectively [RD1].

- **Spectrum Analysis**

MC²Analyzer makes easy interfacing the *γstream* device with a Windows OS personal computer. The user can set the PHA parameters, manage the HV channels configuration, collect the spectra and perform mathematical analysis on them, like energy calibration, peak search, background subtraction, peak fitting, etc..

- **Tablet APP**

GammaEDU software application for Android systems makes *γstream* controllable by personal devices, particularly exploitable if operating in outdoor environment. Running GammaEDU, it is easily possible to acquire and analyse in real time a γ-ray spectrum to get Uranium, Thorium and Potassium abundance, take the GPS coordinates, and shoot a picture of the on-going measurements. The data are saved in kmz file ready to be visualized on Google Earth.

MECHANICAL	**Dimensions** 71.2 W x 66.4 H x 163.8 L mm^3 (including connectors)		**Weigh** 700 g
DETECTOR & PMT	- Scintillation detectors - 14-pin 10-stage PMTs (S2580)		
DIGITAL SIGNAL PROCESSING	- 12-bit and 62.5 MHz ADC - Software selectable coarse gain: x1, x2, x4, x8 - Trapezoidal filter for the energy calculation with software adjustable rise time in the range 0÷16 µs and flat top in the range 0÷16 µs - Trigger threshold software adjustment - Software fine tuning of the Pole-Zero cancellation - Digital fine gain - Automatic gain stabilization - Pile-up rejection and Live Time correction - Baseline restorer with programmable averaging - Time stamp: 16 ns resolution - High frequency noise filter		
DATA STORAGE	Internal SSD memory can guarantee data logging for the whole battery autonomy		
HIGH VOLTAGE POWER SUPPLY	- Output Bias Voltage: 0 ÷ +1500 V - Output Bias Current: 500 µA max. - Output ripple (full load): Typical < 5 mVpp; Maximum < 10 mVpp - Setting resolution: steps of 1 V - Safety alarms (OverVoltage/UnderVoltage, OverCurrent, OverTemperature)		
OPERATING MODES	- PHA (Pulse Height Analysis): pulse height histogram over 1k-2k channels - List mode: pulse height and time stamp for each event - Signal Inspector: input and internal filters waveforms		
TRIGGER MODES	- Stand-alone: triggering based on the channel self-trigger - Correlated: Veto with other *γstream*. - Coincidence/Anticoincidence or Veto with an external trigger(**COMING SOON**) - External: triggering based on an external trigger		
FRONT PANEL DIGITAL I/O	**OUT (LEMO LVTTL 3.3V, Rt = 50 Ohm)** General Purpose Output OUT option: Fast Trigger Discrimination signal	**IN1 & IN2 (LEMO LVTTL 3.3V, Zin = 1000 Ohm)** General Purpose Inputs IN1 option: Veto signal IN2 option: external reset of trigger time stamp	
INDICATORS	Status and battery LEDs		
COMMUNICATION INTERFACE	**Ethernet** 10/100 Mbit interface RJ45 connector **Wi-Fi** USB host port (USB2.0) compliant to the Wi-Fi Micro Adapter included in the kit.	**Bluetooth** USB host port (USB2.0) compliant to the BT dongle included in the kit **USB** Mini-USB client port USB 2.0 compliant Up to 30 MB/s transfer rate	
FIRMWARE	Firmware can be upgraded via USB/Ethernet/WiFi		
SOFTWARE	- Fully controlled by the MC^2 Analyzer spectroscopy software for Windows PC - GammaEDU mobile application for tablets equipped with Android™ OS		
POWER CONSUMPTION	**Blue-Tooth** 300 (typ.) ± 10% mA	**Ethernet** 320 (typ.) ± 10% mA	**WiFi** 330 (typ.) ± 10% mA
	Battery discharging time (HV and acquisition on, list mode continuous dump): about 6 hours		

Tab. 3.2: Technical specifications of S2580 – *γstream*.

3.3. Power Requirements

- **External Power Supply**

  γstream is provided with an external 12V-45W power supply unit deputed to the battery recharge.

Fig. 3.3: External power supply unit and relevant cable.

- **Power Consumptions**

POWER CONSUMPTION	Blue-Tooth 300 (typ.) ± 10% mA	Ethernet 320 (typ.) ± 10% mA	WiFi 330 (typ.) ± 10% mA

Tab. 3.3: Power Consumption table according to the selected communication interface (HV and acquisition ON).

- **Battery Power Supply**

  γstream is equipped with an on-board rechargeable battery pack suitable for stand-alone and on-field operations that is recharged by using the external power supply unit. The following table reports the battery main specifications.

TYPE	Rechargeable, non-extractable Li-Ion 3-cell pack
NOMINAL VOLTAGE	3.6 V (Typ.)
NOMINAL CAPACITY	6750 mAh (Typ.)
MAX. CHARGE VOLTAGE	4.2 V
DURATION	About 6 hours (HV and acquisition on, list mode continuous dump)

Tab. 3.4: Battery Specifications.

Note: For a safe and correct use of the device, pay attention to the following reminders:

- It is recommended to fully charge γstream before using it for the first time.
- The battery charge process starts when the device is connected to an external power supply and powered on.

- **Recharging Process**

  In the battery operating mode, the BATT LED (see **Tab. 3.5**) normally lights on orange. Entering the blinking orange status means that the battery operating time is close to the end. The user can then recharge the battery in few simple steps:

  - Connect the external power supply unit to the net. The green LED on the unit lights on.
  - Plug the jack of the external power supply unit in the *γstream* front panel DC INPUT connector. The BATT LED will be blinking green during the recharging time.
  - As soon as the BATT LED remains on green (i.e. stop blinking), the recharge is over, and *γstream* is ready for new operations. The user can then remove the external power supply unit and the BATT LED will now light back on orange.

DIAGNOSTICS LEDs	
	**BATT** indicates the battery status: BLINKING ORANGE = battery close to discharge; RED = battery discharged (entering the power-off procedure); BLINKING GREEN = battery in charge from external power supply unit; GREEN = battery fully charged and external power supply unit plugged in; ORANGE = battery in discharging progress mode.
	**STATUS** indicates the device status: ORANGE = device is entering the power-off procedure; RED = device is powering ON/OFF; GREEN = device is ready; BLINKING GREEN = device is running.

Tab. 3.5 Diagnostics LEDs (*γstream* front panel).

Note: *γstream* can be operated even while recharging, thanks to the external power supply unit. On the other hand, this will result in a longer recharging time.

4 Getting Started Environmental Gamma Measurements

This chapter will guide you through the first measurements via GammaEDU APP.

4.1. Hardware setup

Before to start an environmental measurements campaign, it a good practice to carry out a preliminary test of the entire system.

- Open the backpack and remove the flexible silicon front cover from the device.
- Open the front pocket of the backpack and the external power supply to charge the first time the *γstream* internal battery.
  The input connector is located on the *γstream* frontal panel [RD1].
- Press the pushbutton to power-on the device.
- The Status LED becomes green and the Battery LED starts blinking green (see **Tab. 3.5** and **Fig. 4.1**).

Fig. 4.1: Initial *γstream* power on.

- Connected the *γstream* to the tablet via Bluetooth.
- Wait the full battery charge (see **Tab. 3.5**).
- Remove the external power supply and close the backpack to start the measurement following the software application instruction in the next section.
- Power-off the device by keeping the button pressed as long as the STATUS LED (see **Tab. 3.5**) becomes orange, then release the button, the STATUS LED will then turn on red and the device will definitely shut down. To force the power-down, keep the button pressed for around seven or eight seconds, until the device will shut down.

4.2. Software Application Description

GammaEDU is a software application for Android™ already installed on the provided 10” tablet, fully compatible with the CAEN *γstream* device. It is designed as an easy-to-use assistant for outdoor operations and allows the user to acquire and analyze in real-time a γ-ray spectrum to get the K, U and T abundances, keep track of the surrounding environment, take the GPS coordinates, and shoot a picture of the on-going measurements. The data are saved in a .kmz file ready to be visualized on Google Earth and shared on Google Drive for producing a radioactivity maps of the area.

Fig. 4.2: Icon of the GammaEDU software application.

Once you have connected the *ystream* to the tablet via Bluetooth, the GammaEDU software application can be launched. As shown in **Fig. 4.3**, the APP allows the user to start a new measurement or upload the old ones.

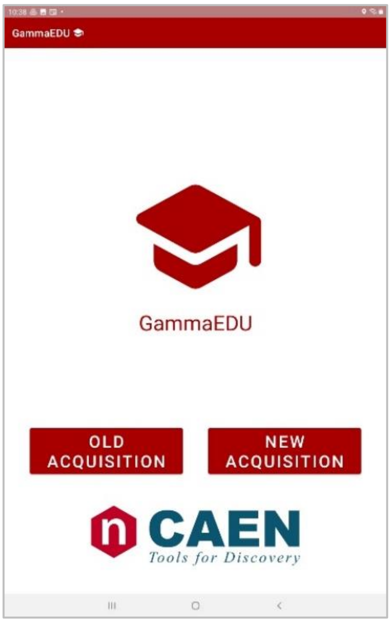


Fig. 4.3: First interface window of the GammaEDU**.**

After the selection of *"NEW ACQUISITION*" label, a new interface appears and allows the user to specify the conditions of the new measurement. All fields must be filled in sequence, including the picture, before entering the acquisition time and selecting the start of the measurement (**Fig. 4.4).**

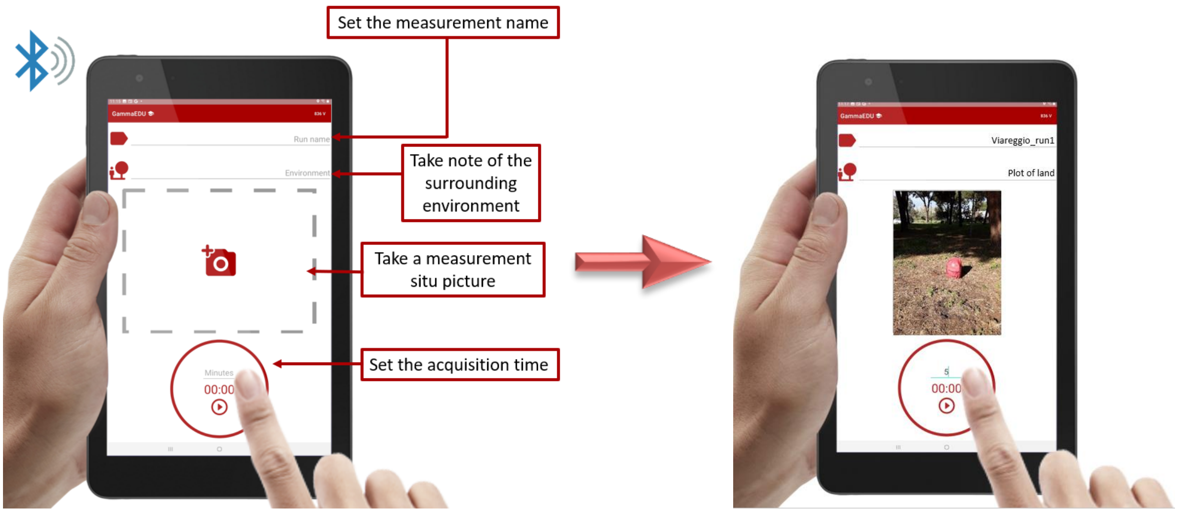


Fig. 4.4: GammaEDU app description.

Select to start the acquisition.

The spectrum starts growing according to the environmental contribution until the end of the acquisition time. After that, an energy auto-calibration of the spectrum is applied, the analysis is performed, and the measurement result is shown (**Fig. 4.5**). Refer to the next section for more details about the calibration method.

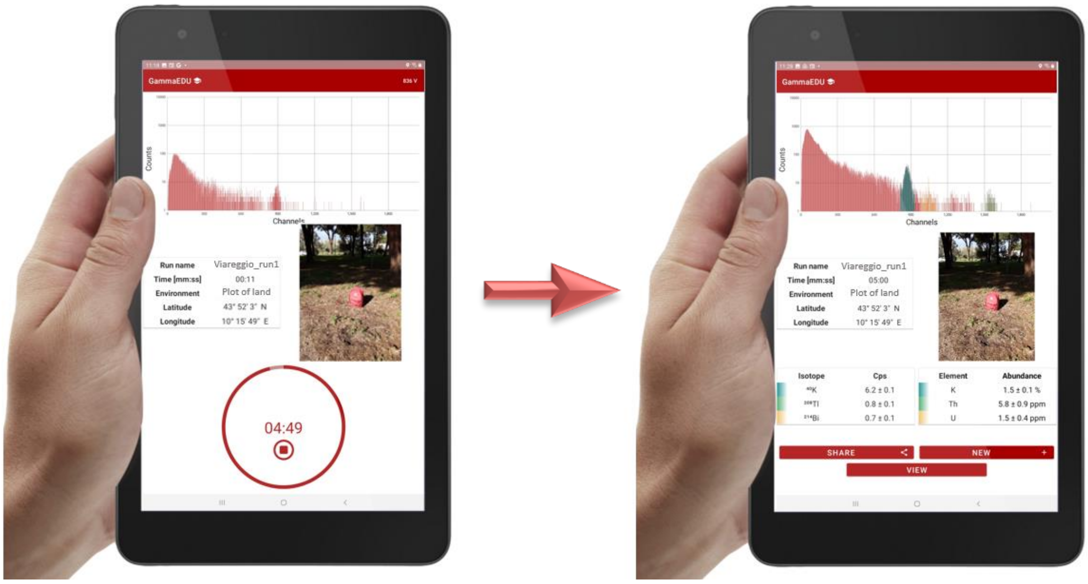


Fig. 4.5: GammaEDU: Measurement result.

The measurement results show the parameters set initially by the user together with the geographical coordinates, the situ picture, the counts per second (cps) of the main natural radionuclides (Potassium - ^{40}K) or their daughters of the radioactive chain decay (Bismuth – ^{214}Bi for Uranium - ^{238}U and Thallium – ^{208}Tl for Thorium – ^{232}Th) and their abundances. From the cps of each element, the abundance of ^{238}U, ^{232}Th and ^{40}K are estimated and expressed in ppm (Parts Per Million), ppm and %, respectively.
The result can be saved on the tablet in JSON format (JavaScript Object Notation), an open standard file format and data interchange format that uses human-readable text to store and transmit data objects consisting of attribute–value pairs and arrays or shared via mail or google drive in .kmz format, a Zip-compressed .KML file that stores map locations viewable in various geographic information systems applications.
The selection of *"SHARE"* label allows the user to save and share .kmz data via mail, Google Drive or Bluetooth.

Note: .kmz files can be opened with various mapping applications for Windows, macOS, Linux, Android™, and iOS. The Google Earth Pro desktop application is a common choice for opening .kmz files.

Note: To share results on Google Drive or Google Maps the tablet must be connected to the WiFi network. The provided tablet does not include a SiM card.

The selection of *"VIEW"* label allows the user to visualize the results via Google Earth APP on the tablet as shown in **Fig. 4.6**.

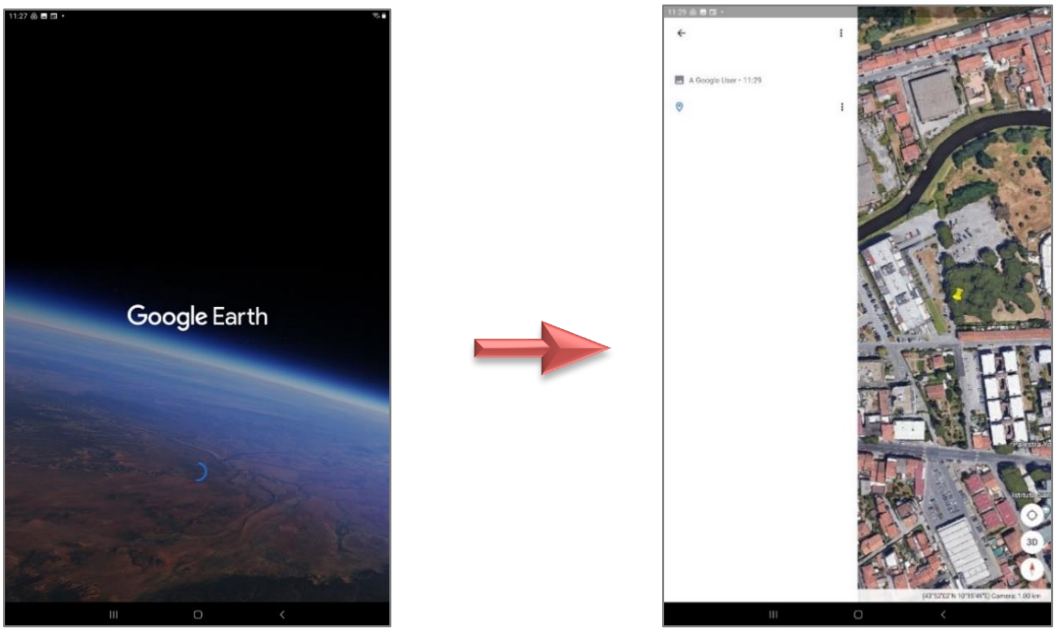


Fig. 4.6: GammaEDU results via Google Earth APP.

By clicking on the yellow marker, the information about the selected measurement is shown (see **Fig. 4.7**).

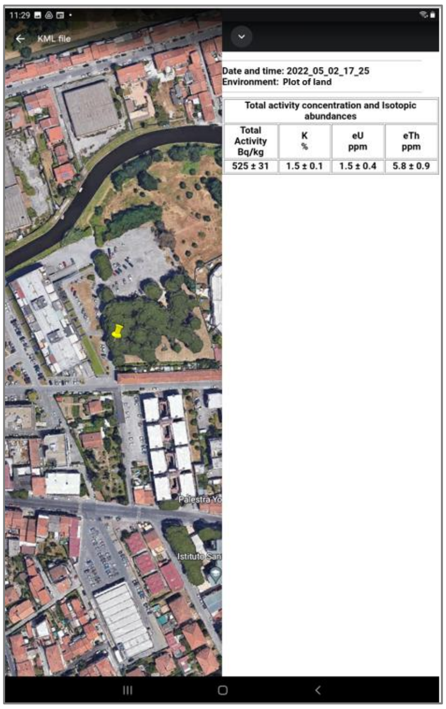


Fig. 4.7: Example of results of environmental radioactivity measurements visualized via Google Earth and obtained by GammaEDU in Viareggio (Tuscany - Italy).

Note: Google Earth APP must be already installed on the tablet before seeing the measurement results obtained via GammaEDU APP.

4.3. Data Analysis

4.3.1 Simulation Notes

The characterization of the system in terms of sensitivity was obtained through simulation, via the Monte Carlo method, of the 3 fundamental spectra that the apparatus would measure in the presence of a concentration unit of the single radioisotope ($1*10^{-2}$ g/g for K, 1 µg/g for eU and 1 µg/g for eTh).
Monte Carlo simulation (MC) is usually adopted to reproduce and numerically solve a problem in which stochastic processes are also involved and whose analytical resolution is very complex.
In the field of nuclear physics, Monte Carlo methods allow user to simulate the behaviour of each individual photon, from emission to detection. In order to reconstruct the experimental spectra acquired by the detection system under various conditions, a Monte Carlo code in C ++ based on GEANT4 (GEometry ANd Tracking) was developed, a platform developed by a collaboration international including CERN for simulating the passage of particles through matter. For the reconstruction of the fundamental spectra in the energy range (0.3 - 3 MeV) the adopted Monte Carlo method was organized into 3 simulation steps of the random interactions between photons and matter: (i) emission of the gamma photon from the ground (ii) propagation through the material up to the detector, (iii) propagation in the material of the apparatus and reconstruction of the energy deposited inside it.

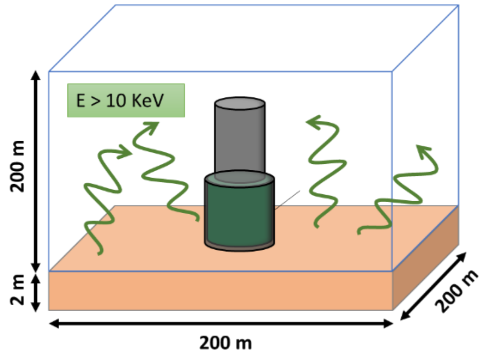


Fig. 4.8: Simulated environment with air density equal to 1,196 kg / m³ and soil density equal to 1545 kg / m³. The detector is in contact with the ground surface with the same geometric configuration that will be adopted during the measurements**.**

The Monte Carlo simulation reproduces the interactions of gamma-rays with matter and consequently, it leads to a certain deposition of energy in the NaI (Tl) crystal. The simulated spectra therefore require the application of the energy resolution of the detector to empirically introduce the main effects that influence the detected signals coming from the conversion mechanisms of the deposited energy in a gamma spectrometer (scintillation process, conversion of light into photoelectrons, etc.).
Once the three fundamental spectra have been obtained, the overall spectrum can be reproduced (**Fig. 4.9**) as the result of the composition of the fundamental spectra produced by potassium (1% abundance), uranium (1ppm abundance) and thorium (1ppm abundance).

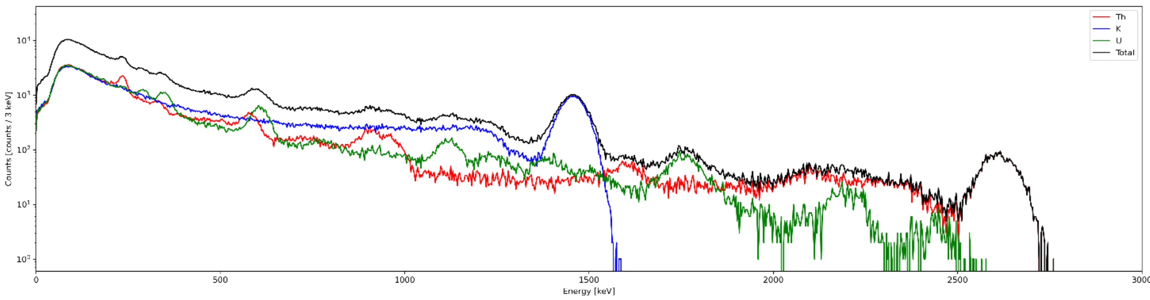


Fig. 4.9: Sum of the simulated fundamental spectra for a unit abundance of K, U and Th.

The overlap of the different components determines the spectrum shape, while the weight of each component is given by the concentration associated with the element itself.
For each channel *i* of the spectrum, the observed number of counts is:

$$N(i) = \sum_{k=1}^{3} C_k * S_k(i)$$

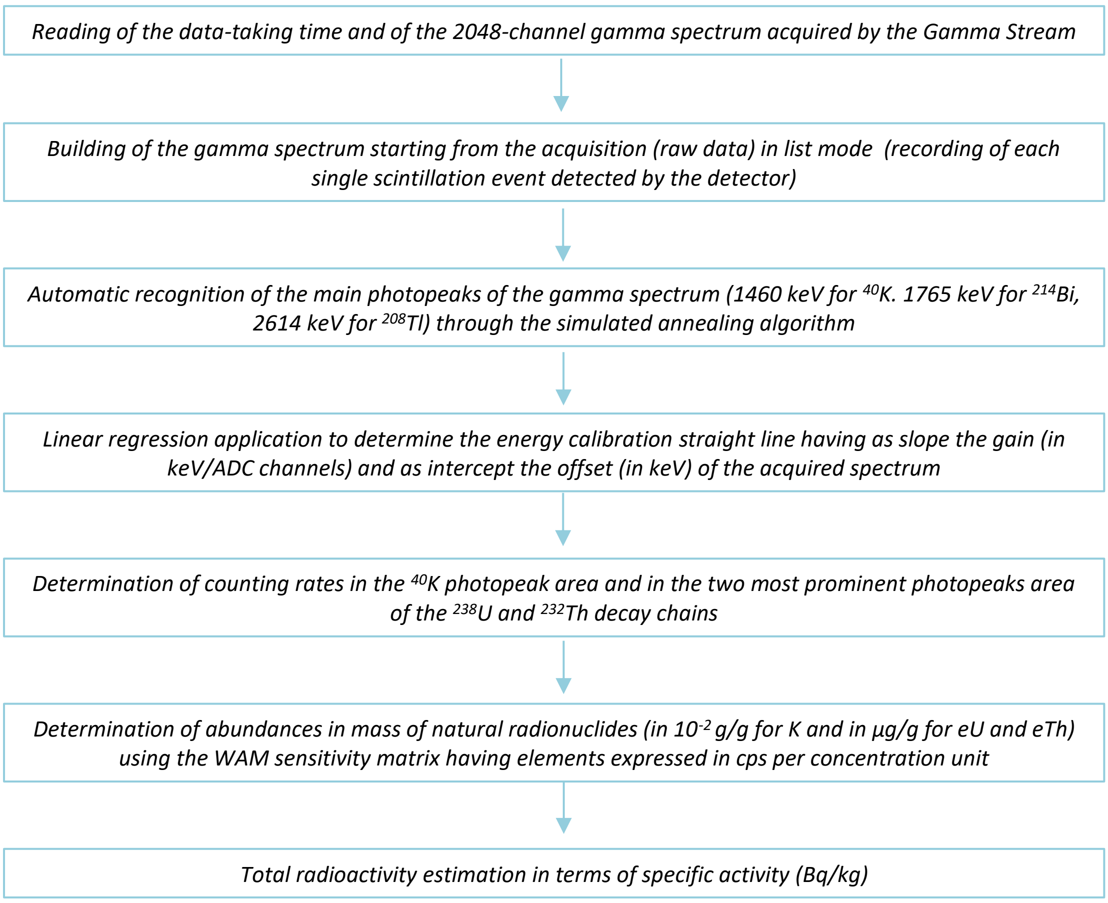
Where,

- *N(i)* = number of counts per second measured in channel *i*;
- C_k = concentration of the *k* element (i.e., *k* = K, U and Th);
- $S_k(i)$ = number of counts per second of the fundamental spectrum referred to the *k* element in channel *i*.

The concentrations of potassium, uranium and thorium are expressed in 10^{-2} g/g, 10^{-6} g/g and 10^{-6} g/g respectively. The fundamental spectrum S_k for the *k*-th element corresponds to the spectrum that the device would ideally measure in the presence of only one concentration unit of the *k-th* element.
The modelling of the fundamental spectra that characterize the sensitivity of the detector to natural radioactivity sources is essential for the analysis of the measurements that will be conducted.

4.3.2 Analysis

For the estimation of the concentrations of natural radionuclides (^{40}K, ^{238}U and ^{232}Th) contained in the soil by performing gamma spectroscopy measurements with the GammaEDU, the conventional approach described in the guidelines of the International Atomic Energy Agency (IAEA) is adopted [RD4].
For this purpose, a radiometric analysis software based on the Windows Analysis Method (WAM) has been developed which analyses the spectrum in the three windows of interest associated with the decay of ^{40}K (1460 keV), ^{214}Bi (1765 keV) in the ^{238}U decay chain and ^{208}Tl (2614 keV) in the decay chain of ^{232}Th.
The implementation of the sensitivity matrix, which links the rate of counts measured in the specific energy windows to the concentrations of K, eU (equivalent Uranium) and eTh (equivalent Thorium), allows the software (executed on the CPU with which the *γstream* is equipped) to be able to determine the abundances and specific activities of natural radionuclides in Bq / kg. Uranium and Thorium mass abundances are generally expressed as equivalent Uranium (eU) and equivalent Thorium (eTh).
The flow chart of the code, developed in C ++, is illustrated here:



- **Windows Analysis Method**

The recognition of the main photopeaks due to the gamma emission associated with the decay of ^{40}K, ^{214}Bi (in the ^{238}U decay chain) and ^{208}Tl (in the ^{232}Th decay chain) occurs via the gamma spectrum acquired by the detector.
The identification of the specific decayed isotope is allowed by the characteristic energy of the photons emitted by the decay.
The evaluation of the potassium concentration takes place by examining the counting rate within the energy windows corresponding to the most intense photopeaks (1460 keV for ^{40}K, 1765 for ^{214}Bi keV, 2614 keV for ^{208}Tl) following the IAEA 2003 guidelines, which suggests using as the energy window within which to evaluate the counting rates, the "Full Width at Tenth Maximum" (defined as the width of the distribution at a level that is 1/10 the maximum ordinate of the peak) or 4.29σ . [1.82 FWHM (Full Width at Half Maximum) since FWHM = 2.35σ] [RD4].

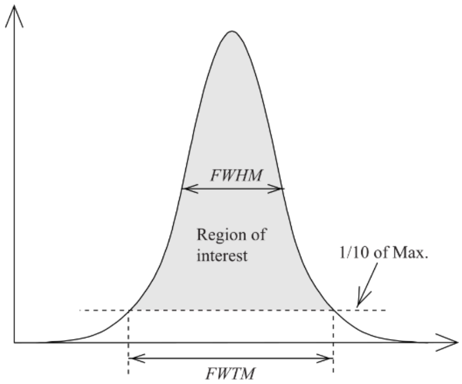


Fig. 4.10: Full Width at Half Maximum (FWHM) and Full Width at Tenth Maximum (FWTM) in the Region Of Interest (ROI).

The photopeaks shape is governed by the intrinsic energy resolution of the NaI(Tl) scintillating crystal, therefore the ROIs corresponding to the three main gamma emission energies (^{40}K (1460 keV), ^{214}Bi (1765 keV) and ^{208}Tl (2614 keV)) can be evaluated as shown in **Tab. 4.1**.

	Radioisotope	Gamma emission energy (keV)	Energy range (keV)
K	^{40}K	1460	1370-1570
U	^{214}Bi	1765	1660-1860
Th	^{208}Tl	2614	2410-2810

Tab. 4.1: Photopeak energy and Region Of Interest for ^{40}K, ^{214}Bi e ^{208}Tl.

The ^{238}U and ^{232}Th mass abundances are indirectly estimated by looking at γ-rays respectively produced by ^{214}Bi and ^{208}Tl. Therefore, the applied approach implicitly assumes that the secular equilibrium condition holds in both decay chains, which is the reason why U and Th mass abundances are generally expressed as equivalent Uranium (eU) and equivalent Thorium (eTh).
The count rates N_K, N_U and N_{Th} linearly depend on the mass abundances (concentration) of K, U and Th according to the following equations:

$$N_K = C_K S_{KK} + C_U S_{UK} + C_{Th} S_{ThK} + B_K$$

$$N_U = C_K S_{KU} + C_U S_{UU} + C_{Th} S_{ThU} + B_U$$

$$N_{Th} = C_K S_{KTh} + C_U S_{UTh} + C_{Th} S_{ThTh} + B_{Th}$$

Where,
- S_{ij} term represents the sensitivity coefficient of the spectrometer for the detection of the *i-th* element in the *j-th* energy window in cps per unit of concentration;

- B_i is the background count rate in the *i-th* energy window (here, these terms are negligible due to the low intrinsic activity of the detector and of its partial collimation).

These equations express the detector answer with respect to the emission of determined energy produced by a unity concentration source.
The three fundamental spectra allow the unique determination of the three unknown sensitivity constants of the three 3 equations. The linear system can be formulated as follows:

$$N = C * S$$

$$\begin{pmatrix} N_{KK} & N_{UK} & N_{ThK} \\ N_{KU} & N_{UU} & N_{ThU} \\ N_{KTh} & N_{UTh} & N_{ThTh} \end{pmatrix} = \begin{pmatrix} C_K & 0 & 0 \\ 0 & C_U & 0 \\ 0 & 0 & C_{Th} \end{pmatrix} \cdot \begin{pmatrix} S_{KK} & S_{KU} & S_{KTh} \\ S_{UK} & S_{UU} & S_{UTh} \\ S_{ThK} & S_{ThU} & S_{ThTh} \end{pmatrix}$$

Where,
- N_{ij} = counts rate of the *i-th* fundamental spectrum in the *j-th* energy window (*i,j* = K, U, Th) (cps);
- C_{ij} = concentration of the radioisotopes (% K, ppm U, ppm Th);
- S_{ij} = detector sensitivity for the detection of the i-th element in the j-th energy window, (cps/concentration unit of the i-th element). It means the response in counts per second that the instrumentation provides in the presence of a unitary concentration of radionuclides.

The square matrix of concentrations C has maximum rank therefore it is invertible. Via Monte Carlo method, it is possible to simulate the presence of a unitary concentration for each radionuclide (1% K, 1 ppm U, 1 ppm Th) to obtain an identity matrix whose inverse (C^{-1}), coinciding with the matrix itself. In this way, the linear system of equations can be solved to derive the sensitivity matrix:

$$S = C^{-1} \cdot N$$

$$\begin{pmatrix} S_{KK} & S_{KU} & S_{KTh} \\ S_{UK} & S_{UU} & S_{UTh} \\ S_{ThK} & S_{ThU} & S_{ThTh} \end{pmatrix} = \begin{pmatrix} C_K & 0 & 0 \\ 0 & C_U & 0 \\ 0 & 0 & C_{Th} \end{pmatrix}^{-1} \cdot \begin{pmatrix} N_{KK} & N_{UK} & N_{ThK} \\ N_{KU} & N_{UU} & N_{ThU} \\ N_{KTh} & N_{UTh} & N_{ThTh} \end{pmatrix}$$

The obtained matrix S allows us to carry out measurements and estimate the value of the concentrations of potassium, uranium and thorium in the investigated soil.

$$S = \begin{pmatrix} 3.448 \pm 0.021 & 0 & 0 \\ 0.287 \pm 0.005 & 0.294 \pm 0.005 & 0.014 \pm 0.001 \\ 0.077 \pm 0.002 & 0.059 \pm 0.002 & 0.126 \pm 0.002 \end{pmatrix}$$

As expected from the physics point of view, the sensitivity matrix has an almost triangular shape: indeed, as ^{40}K decay generates a single gamma with 1.46 MeV energy, ^{40}K does not provide any count rate contribution in the U and Th energy windows, centered at higher emission energies.
The vector of unknown concentrations C is provided by the inverse sensitivity matrix S^{-1} as follows:

$$C = N \cdot S^{-1}$$

Where C is the row vector of the concentration and N the row vector of the counts per seconds associated to the radioelements photopeaks. Therefore, the K, U and Th concentrations C_K, C_U and C_{Th} can be separately estimated as well as properly combined to obtain the overall natural specific activity A in Bq/kg.

$$C_{K[\%]} = N_K S_{KK}^{-1} + N_U S_{UK}^{-1} + N_{Th} S_{ThK}^{-1}$$

$$C_{U[ppm]} = N S_{UU}^{-1} + N_{Th} S_{ThU}^{-1}$$

$$C_{Th[ppm]} = N_{ThTh} S_{ThTh}^{-1} + N_{UU} S_{UTh}^{-1}$$

The concentration-to-activity conversion coefficients are constants which can be determined on the basis of the decay physical parameters.

$$A = 313\ C_K + 12.35\ C_U + 4.06\ C_{Th}$$

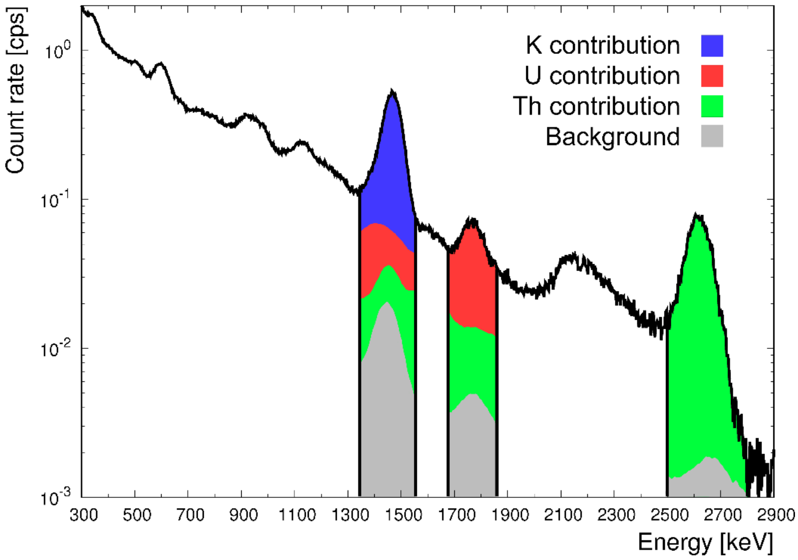


Fig. 4.11: Gamma environmental spectrum. Spectral contributions of potassium (in blue), uranium (in red) and thorium (in green) in the energy windows of ^{40}K, ^{214}Bi and ^{208}Tl.

- **Uncertainty Calculation**

In addition to the intrinsic radioactivity of the detector and the presence of cosmic rays, the main elements affecting the accuracy and precision of the analysis are the variability of the radiation due to atmospheric radon, the environmental characteristics and geometry of the source and the statistical nature of the decay process linked to the acquisition time of the measurement and to the activity of the source.
The statistics uncertainty is the only estimable contribution. Since radioactive decay is a statistical process, the frequency of radioactive decay is ruled by the Poisson distribution.
If N is the number of decay events in time interval *t,* then the standard deviation σ in counting units is given by:

$$\sigma(\bar{N}) = \sqrt{\bar{N}}$$

where N is the expectation value of the number of counts. The relative standard deviation is given by:

$$\frac{\sigma(\bar{N})}{\bar{N}} = \frac{1}{\sqrt{\bar{N}}}$$

Considering the law of uncertainties propagation, for a counting rate *n = N/t (cps*), the standard deviation and the relative standard deviation are respectively given by:

$$\sigma(n) = \frac{\sqrt{\bar{N}}}{t} = \sqrt{\frac{n}{t}} \qquad \frac{\sigma(n)}{n} = \frac{1}{\sqrt{nt}}$$

The introduction of the stripping ratios, i.e. the ratios between the counting rates observed in an energy window and the counting rates observed in the main window of the considered element, is necessary to determine the statistical uncertainty associated with the photopeak counts (see **Tab. 4.2**).
The background contribution, mainly attributable to the Compton events associated with the emission of other radionuclides, can be discriminated by the use of the stripping ratios.
By defining $N_{i(corr)}$ as the net photopeak counts (where *i = K, U, Th*), it is possible to determine the radionuclide abundances only through the diagonal elements of the sensitivity matrix:

$$c_K[\%] = \frac{N_{K(corr)}}{S_{KK}} \qquad c_U[ppm] = \frac{N_{U(corr)}}{S_{UU}} \qquad c_{Th}[ppm] = \frac{N_{Th(corr)}}{S_{ThTh}}$$

Stripping ratios	Description	Sensitivities Ratio	Value
α	Ratio between the counts detected in the uranium window in comparison to those detected in the thorium window of a pure thorium source.	$\alpha = \frac{S_{ThU}}{S_{ThTh}}$	0.472 ± 0.024 (RU=5%)
β	Ratio between the counts detected in the potassium window as compared to those detected in the thorium window of a pure thorium source.	$\beta = \frac{S_{ThK}}{S_{ThTh}}$	0.611 ± 0.027 (RU=4%)
γ	Ratio between the counts detected in the potassium window as compared to those detected in the uranium window of a pure uranium source.	$\gamma = \frac{S_{UK}}{S_{UU}}$	0.977 ± 0.028 (RU=3%)
a	Ratio between the counts detected in the thorium window as compared to those detected in the uranium window of a pure uranium source.	$a = \frac{S_{UTh}}{S_{UU}}$	0.049 ± 0.005 (RU=10%)

Tab. 4.2: Ratios between counts in the different spectral windows defined as stripping ratios and relative uncertainty (RU).

From the equations of the count rates N_K, N_U and N_{Th} and the stripping ratios previously defined, it follows that:

$$N_{Th(corr)} = \frac{nN_{Th} - aN_U}{1 - a\alpha}$$

$$N_{U(corr)} = N_u - \alpha N_{th(corr)}$$

$$N_{K(corr)} = N_K - \beta N_{th(corr)} - \gamma n N_{U(corr)}$$

Where *Ni* represent the total counts in the three spectral windows.
Simply applying the uncertainty propagation laws, the net counts uncertainty can be defined as follows:

$$dN^2_{K(corr)} = dN^2_K + N^2_{th(corr)}(d\beta)^2 + dN^2_{th(corr)}(\beta)^2 N^2_{U(corr)}(d\gamma)^2 + dN^2_{U(corr)}(\gamma)^2$$

$$dN^2_{U(corr)} = dN^2_U + N^2_{th(corr)}(d\alpha)^2 + dN^2_{th(corr)}(\alpha)^2$$

$$dN^2_{Th(corr)} = \frac{(dN^2_{th} + (N^2_U(da)^2 + dN^2_U(a)^2)^2)^2}{\left(1 - a(\alpha)\right)^2} + \frac{(N_{th} - aN_U)^2}{\left(1 - a(\alpha)\right)^4}((\alpha)^2(da)^2 + (a)^2(d\alpha)^2)^2$$

Therefore, the uncertainties associated to the abundances are:

$$dc^2_K = \frac{\left(dN_{K(corr)}\right)^2}{S^2_{KK}} + \frac{N^2_{K(corr)}}{S^4_{KK}} dS^2_{KK}$$

$$dc^2_U = \frac{\left(dN_{U(corr)}\right)^2}{S^2_{UU}} + \frac{N^2_{U(corr)}}{S^4_{UU}} dS^2_{UU}$$

$$dc^2_{Th} = \frac{\left(dN_{Th(corr)}\right)^2}{S^2_{ThTh}} + \frac{N^2_{Th(corr)}}{S^4_{ThTh}} dS^2_{ThTh}$$

For example, the abundances uncertainty of the main environmental radioelements can be estimated by performing a measurement (acquisition time: 5 min) in situ characterized by concentrations typical of the earth's crust and propagating the statistical uncertainty deriving from the measurement time and the Monte Carlo calibration spectra (**Tab. 4.3**).

Due to several environmental perturbations (cosmic rays, atmospheric radon, morphological inhomogeneities and composition inhomogeneities of the investigated surface), the adopted uncertainty is equal to 95% of the confidence level associated with the statistical uncertainty (2σ) for all radioelements (**Tab. 4.4**).

Radioisotopes	N [cps]	$N_{(corr)}$ [cps]	Abundance
K (^{40}K)	7.6 ± 0.2 (RU=3%)	6.0 ± 0.2 (RU=3%)	(1.74 ± 0.05) % (RU=3%)
U (^{214}Bi)	1.5 ± 0.1 (RU=7%)	0.9 ± 0.1 (RU=11%)	(3.1 ± 0.3) ppm (RU=10%)
Th(^{208}Tl)	1.4 ± 0.1 (RU=7%)	1.3 ± 0.1 (RU=8%)	(10.3 ± 0.6) ppm (RU=6%)

Tab. 4.3: Statistical uncertainty propagation for the abundances (K, U and Th) estimation**.**

Radioisotopes	Abundance
K (^{40}K)	(1.74 ± 0.1) % (RU=6%)
U (^{214}Bi)	(3.1 ± 0.6) ppm (RU=20%)
Th(^{208}Tl)	(10.3 ± 1.2) ppm (RU=12%)

Tab. 4.4: Total uncertainty on the K, U and Th abundances measurement.

5 Getting Started Gamma Measurements in Lab

This chapter will guide you through the first gamma spectroscopy measurements via MC^{2}Analyzer software.

5.1. Hardware setup

Before starting gamma spectroscopy measurements in the laboratory, open the backpack and pull out the content entirely. Open the front pocket of the backpack and the external power supply to power ON the *γstream* and/or charge its internal battery.

Fig. 5.1: GammaEDU Backpack radiation content.

Open the Velcro strips to remove the detector from the protective packaging.

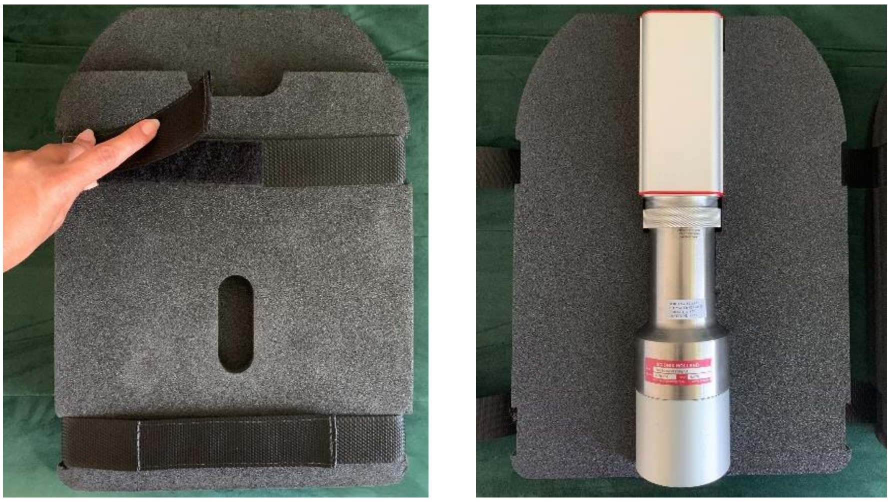


Fig. 5.2: Detector protective packaging.

Set up your experiment by placing the device on the desk laboratory together with the gamma radioactive source under investigation.
To power ON *γstream*, press the ON/OFF button. The input connector is located on the *γstream* frontal panel [RD1].
To power OFF the device, press the ON/OFF button as long as the STATUS LED becomes orange, then release the button, the STATUS LED will then become red and the γstream will definitely shut down. In the case it is needed to force the power down, keep pressed the ON/OFF button for around seven or eight seconds and γstream will shut down (see **Tab. 3.5** and **Fig. 4.1**).

CAUTION: it is strongly recommended not to force the power-down in the common operating, especially if an acquisition is running with the HV powered on!

5.2. MC² Analyzer Software

The Multi-Channel Analyzer (MC²Analyzer) software has been designed as a user-friendly interface to manage the acquisition with pulse height algorithms [RD2].
The software is specifically designed to manage CAEN Gamma stream as well as CAEN digitizers running DPP-PHA firmware.
The DPP-PHA firmware implements a digital trapezoidal filter on the input pulse, which replaces the traditional analog chain of shaping amplifier and peak sensing ADC. The MCA is therefore directly connected to the charge sensitive preamplifier, with no need of additional devices. The PHA algorithm is able to perform online baseline restoration, ballistic effect corrections, and to manage the pile-up for the live time information. PHA and time-stamped list acquisition modes are available.
MC²Analyzer software allows the user to program the relevant DPP-PHA parameters, to manage the HV channels configuration, to collect the spectra and perform basic mathematical analysis, like energy calibration, peak search, background subtraction, peak fitting, etc.

Ethernet Connection to the PC

- Connect the Ethernet cable from γstream to the PC.
- Configure the Ethernet network of your PC.
    - Open the path: Control Panel - Network and Internet - Network and Sharing Center as in **Fig. 5.3**

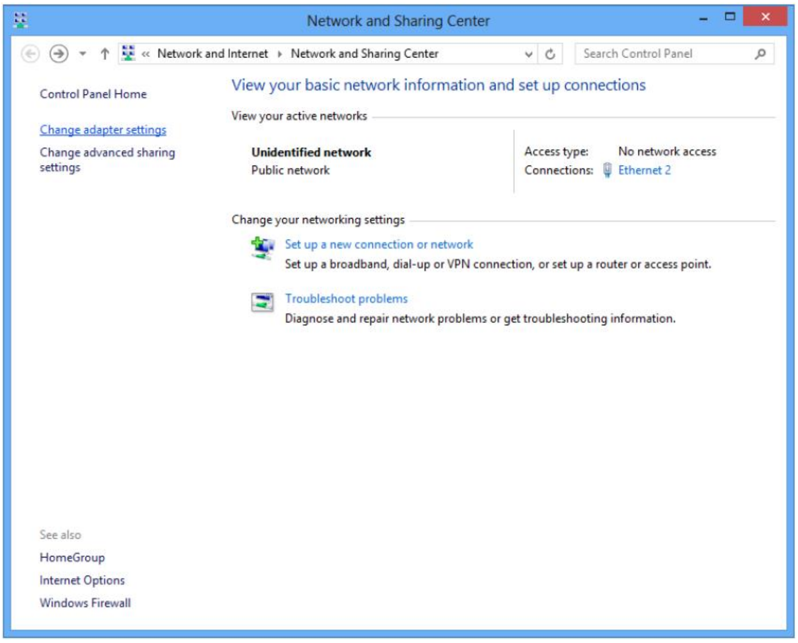


Fig. 5.3: The Network and Sharing Center window.

- Click on ”Change adapter settings”.
- Right click on the Ethernet icon and select ”Properties”, as in **Fig. 5.4.**

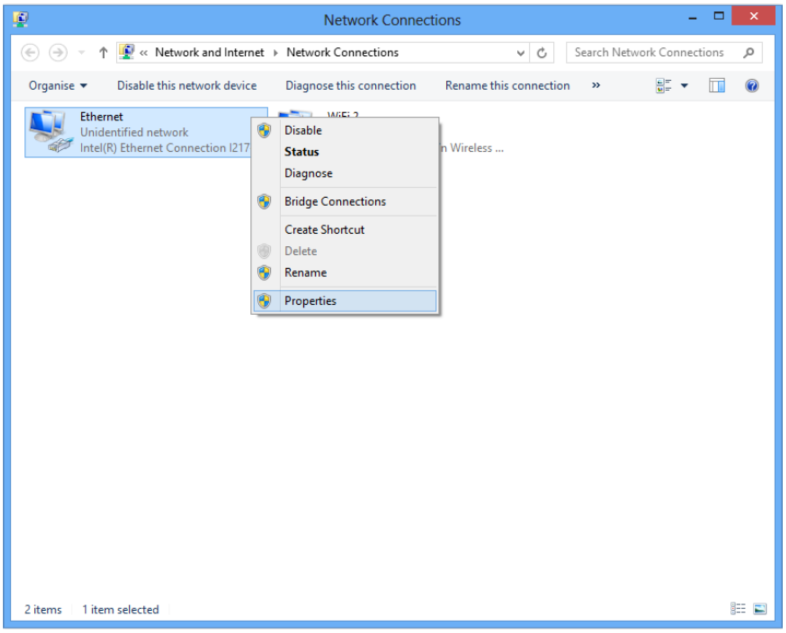


Fig. 5.4: Properties window of the Ethernet network.

- Click on ”Internet Protocol Version (TPC/IPv4)”, and select ”Properties”, as in **Fig. 5.5**.

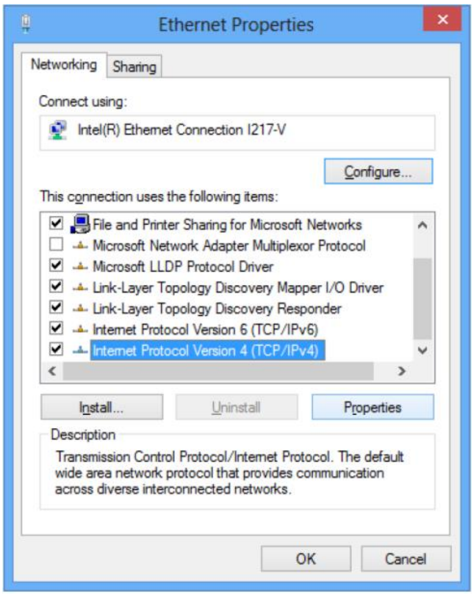


Fig. 5.5: Properties window of the ”Internet Protocol Version (TPC/IPv4)”.

- Copy the following configuration on the ”Internet Protocol Version (TPC/IPv4) Properties” window, as in **Fig. 5.6**.

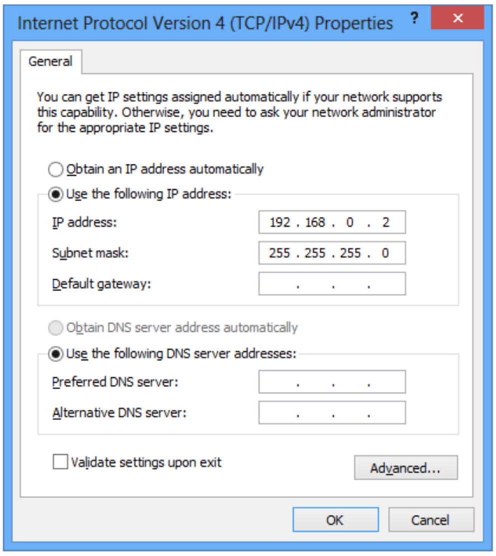


Fig. 5.6: Properties window of the "Internet Protocol Version (TPC/IPv4)".

- Connect *ystream* to the MC^{2}Analyzer software through Ethernet connection.
  - Once you have installed the required driver for the communication interface and the MC^{2}Analyzer software you can launch the MC2Analyzer software and connect it to the *ystream* [RD2].
  - From the main panel of MC^{2}Analyzer software GUI select: "*File-> Add Spectrum*" or press the button  (see **Fig. 5.9**).
  - Select "Online Spectrum" and "New Board Connection" to connect the software to the device (see **Fig. 5.7**).

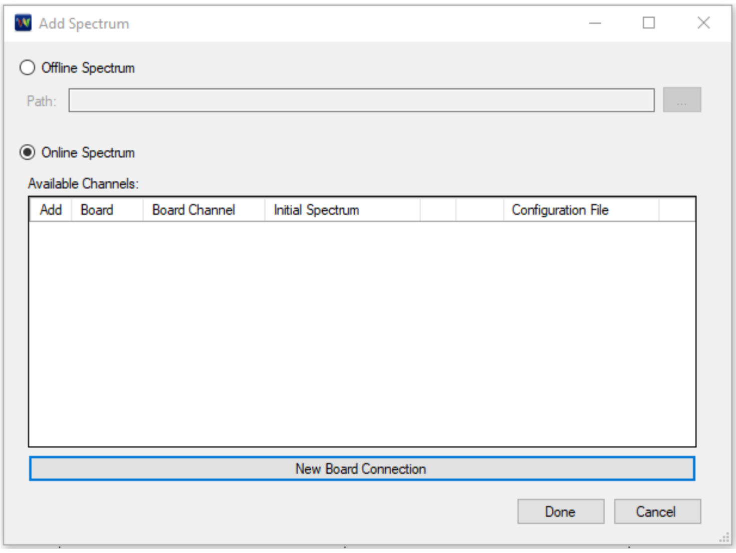


Fig. 5.7: The "Add Spectrum" window to add an offline spectrum from file or an online spectrum from board.

  - Select "Type = Ethernet" on the "Device Connection" window, and write the IP Address of *ystream*. By default, IP Address = 192.168.0.1.
    It is possible to change the IP Address via the web interface [RD1].

Fig. 5.8: Ethernet connection settings of MC^{2}Analyzer.

- The default GUI interface will be then available.

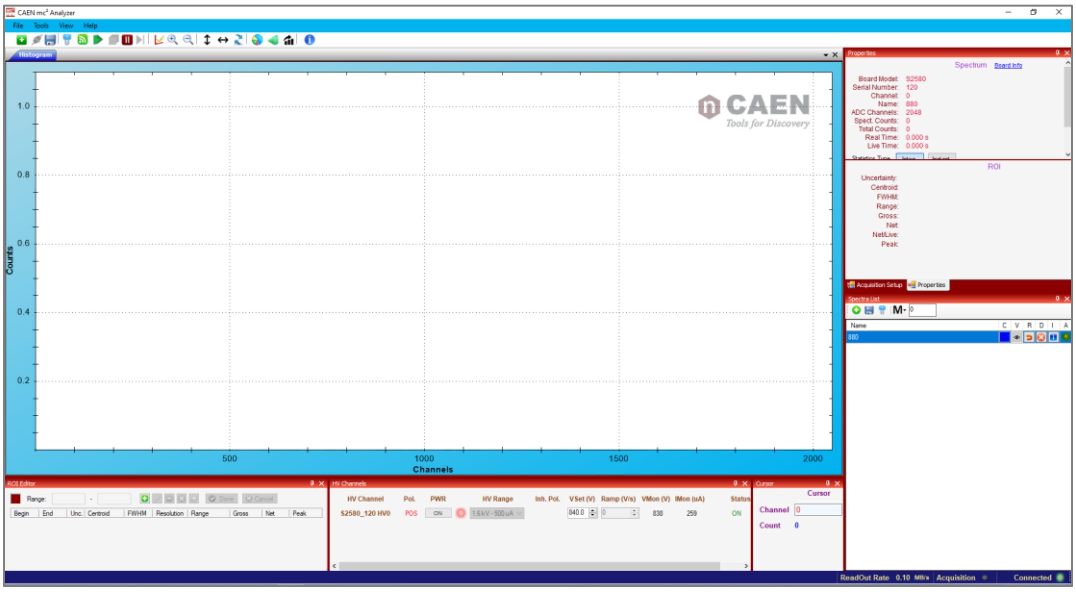


Fig. 5.9: The default GUI at the first connection.

Power ON the HV

- Open the “HV Channels” Window.
- The High Voltage value, VSet, according to your detector specifications is already set (once connected the software automatically reloads the default HV settings). Press ON and check the HV status from the VMon, IMon and Status flags.

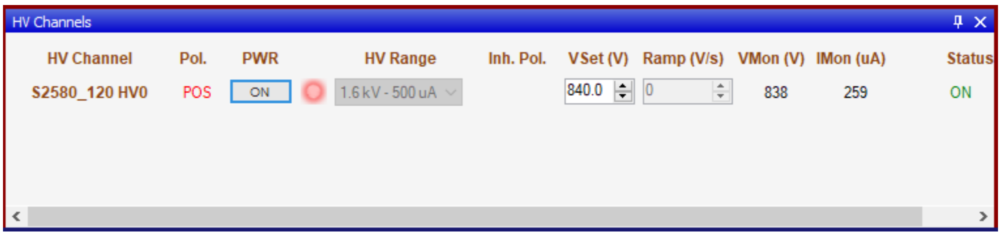


Fig. 5.10: “HV Channels” window for the setting and monitoring of the HV channels of the *ystream*.

The parameters configuration is already applied but to change or verify it, it is necessary to open the “Signal Inspector” window through the icon. Refer to the manuals for more details [RD1][RD2].

Gamma Spectrum Acquisition

Then press PLAY to start the acquisition, STOP to stop it. The spectrum accumulation will appear in the main "Histogram" window. In **Fig. 5.11** it is shown a typical natural background acquisition with the 0.3L NaI(Tl) detector.

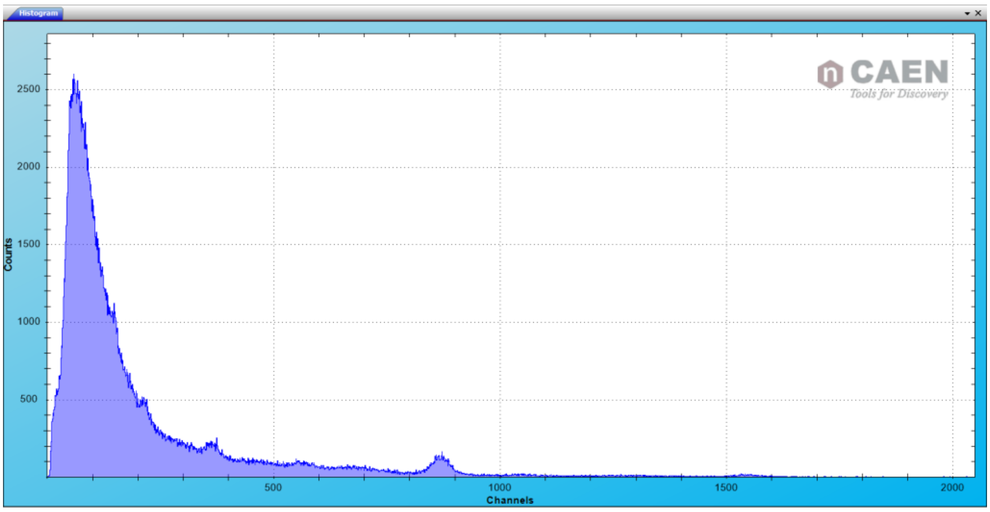


Fig. 5.11: Typical natural background acquisition with GammaEDU.

In **Fig. 5.12** it is shown a typical ^{137}Cs spectrum acquired with the system.

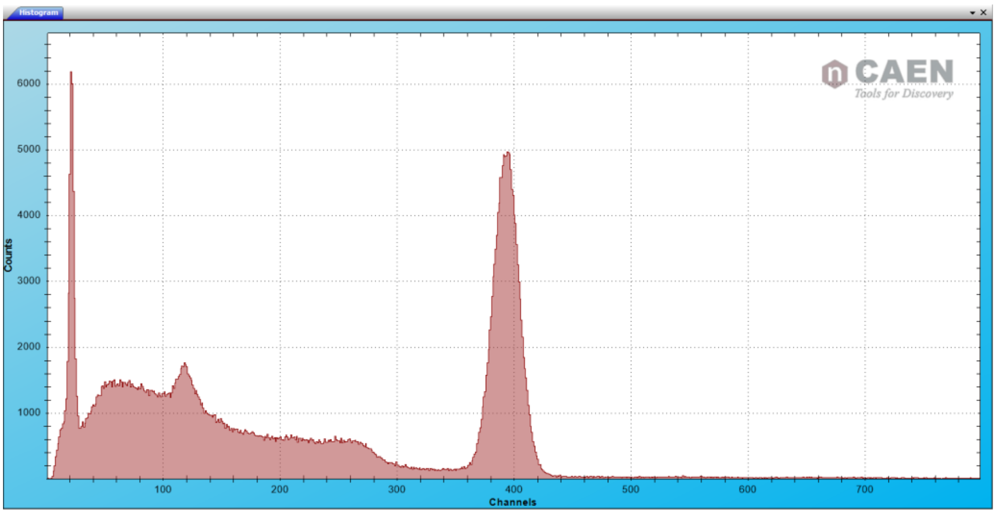


Fig. 5.12: ^{137}Cs spectrum acquired with GammaEDU.

ROI Editor and Spectrum Calibration

From the "Roi Editor" window add a ROI pressing the icon. Then left click on the spectrum window to select the left limit of the ROI and click again to select the right limit of the ROI. It is also possible to write the limits in the "Range" field of the ROI Editor window itself. Press "Done" when ready.

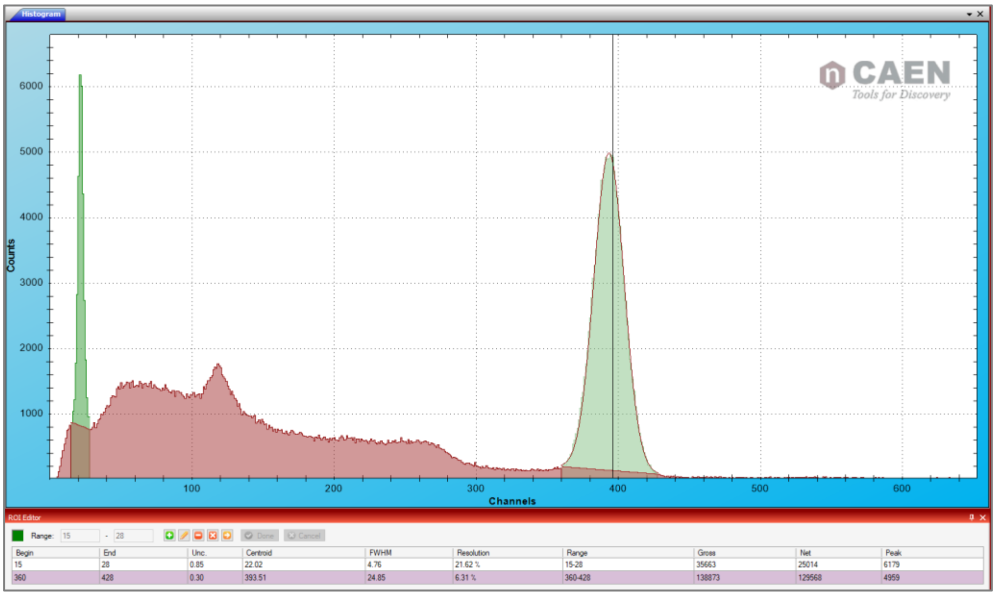


Fig. 5.13: ROI selection in MC²Analyzer software.

The peak is fitted with a Gaussian function, and the background is fitted with a line crossing the two limits of the ROI range. The relevant ROI parameters are shown on the ROI Editor window.

To calibrate the spectrum, press the icon . Write the channel value and the corresponding energy in keV or MeV (see **Fig. 5.14**). It is also possible to select the Centroid of the ROI itself. Press OK to calculate the calibration curve. Then press to enable the calibration.
The resulting spectrum is then calibrated in keV, according to the calibration curve. Also, the ROI settings are converted in keV.

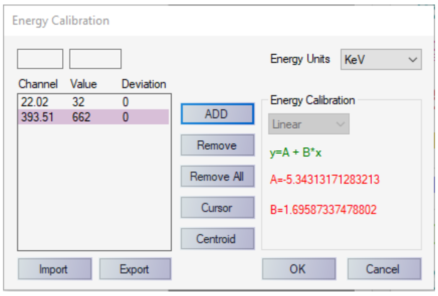


Fig. 5.14: Calibration window. Add points for linear/quadratic calibration.

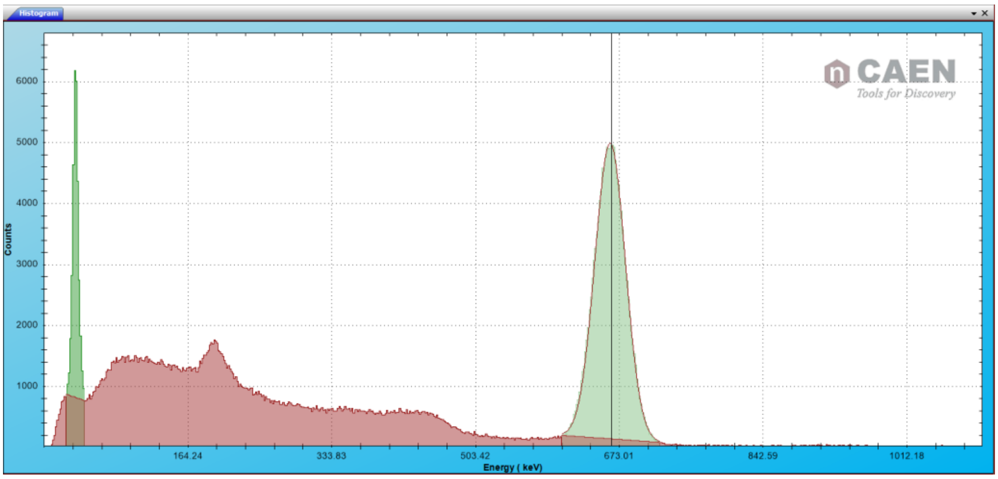


Fig. 5.15: Calibrated ^{137}Cs spectrum in MC²Analyzer software**.**

For a description about data saving, refer to the GammaStream User Manual [RD1], particularly to Sect 6.8.1.

Note: If, after using the equipment with the MC^2 Analyzer software, you intend to reuse it immediately in backpack mode with the GammaEDU App, it is strongly recommended to reboot the GammaStream. This ensures that the default configurations for the 2K spectrum analysis app are restored.

6 GammaEDU Maps

This Chapter is intended to give to the user a complete description of all the functionalities of the GammaEDU Maps software, a standalone executable software tool.
GammaEDU Maps, developed in Python, is an advanced software tool tailored for GammaEDU backpack users, researchers, educators and students who need to analyze and visualize collected environmental radioactivity data. Designed to seamlessly integrate with the GammaEDU app, GammaEDU Maps can process all file formats generated by GammaEDU, offering users flexibility in handling diverse data types for robust data extraction, interpolation, and mapping.
With GammaEDU Maps, users can manage large datasets efficiently, performing tasks such as data interpolation to create activity maps and combining multiple files into a unified, comprehensive dataset. The tool's intuitive interface guides users through easy setup and processing, from folder selection to automated data extraction. By simplifying the workflow of data visualization and analysis, GammaEDU Maps is a powerful resource for anyone working to interpret complex geospatial information on environmental radioactivity.

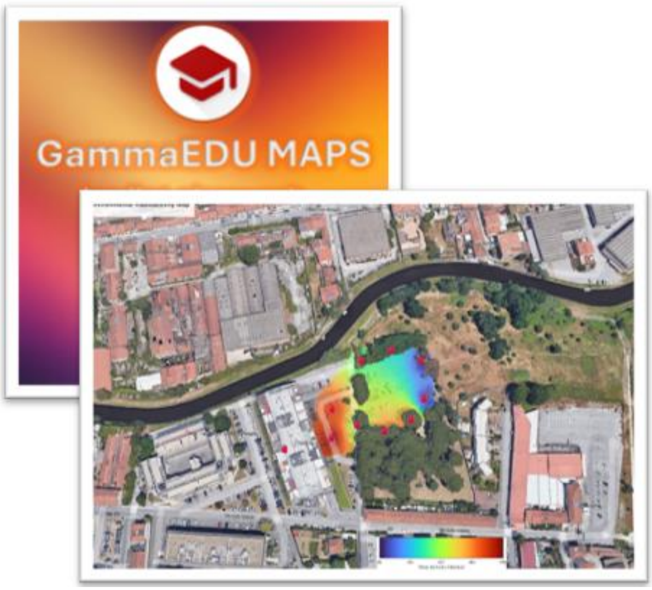


Fig. 6.1: GammaEDU Maps is a standalone executable software tool designed for processing and visualizing geospatial data generated by the Gamma EDU application

Software Installation & Description

Minimum system requirements:

OS	Third-party software required
Microsoft Windows 11 (64-bit)	• Google Earth Pro version 7.1 (or higher)

Tab. 6.1: Host PC requirements for GammaEDU Maps.

Note: To ensure correct visualization of the KMZ files generated by the application, the installation of **Google Earth** is the most reliable solution. This software provides optimal compatibility and performance for viewing KMZ files. Alternatively, users may consider one of the following options for KMZ file visualization:

I. **ArcGIS Earth** (https://www.esri.com/it-it/arcgis/products/arcgis-earth/overview).
II. **QGIS** (https://www.qgis.org/) with the KMLTools Plugin (https://github.com/NationalSecurityAgency/qgis-kmltools-plugin/tree/master).
III. **Google Earth Online** (https://earth.google.com/web/).

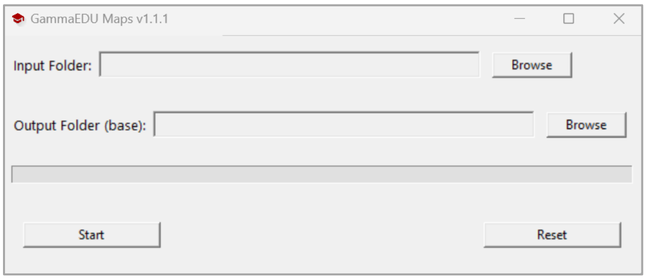
Please, follow the instructions:

I. **Access the CAEN Website:**
   - Visit the GammaEDU webpage.
   - Navigate to the **"Downloads"** section and download the software package from the **Software** tab. *(Login is required before downloading.)*

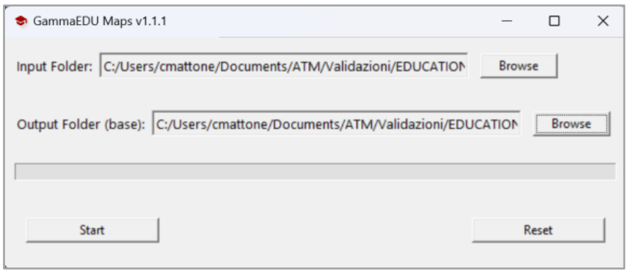
II. **Prepare the Software:**
   - Extract the contents of the downloaded package.
   - Run the executable file (GammaEDU_Maps.exe) with administrator privileges.

III. **Launch the Application:**
   - A splash screen will appear upon launch.

   - Wait for the splash screen to close, revealing the **Gamma EDU_Maps** graphical user interface (GUI).



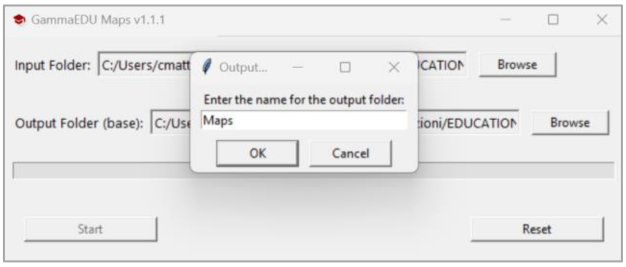
IV. **Set Up the Application:**
   - Use the GUI to select the following:
     - **Input Folder:** The folder containing the data to be analyzed. Select a folder containing at least 10 measurements to process and confirm your choice.
     - **Output Folder:** The destination folder where the processed data will be saved.



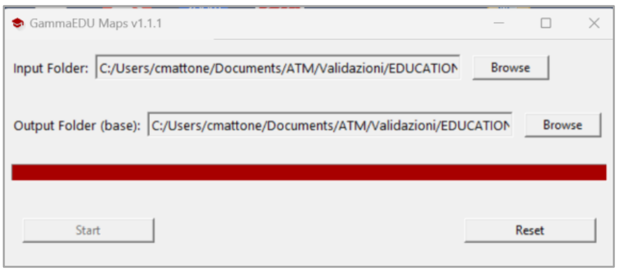
Note: The GammaEDU_MAPS executable software is capable of processing all files generated by the GammaEDU Application.
Specifically, the executable can read files in the following formats: ".KMZ", ".ZIP", ".KML with an associated image", and even files without an extension (as might occur when using the Google Drive for Desktop version). In particular, files shared via Google Drive with a ".zip" extension are actually .KMZ files. A .KMZ file is essentially a ZIP archive that contains a KML file along with resources such as images.
This flexibility ensures compatibility with various file formats and sharing methods, making GammaEDU_MAPS versatile and robust for data processing tasks.

V. **Start Data Processing:**
   - After selecting the folders, click the **Start** button to begin data processing.

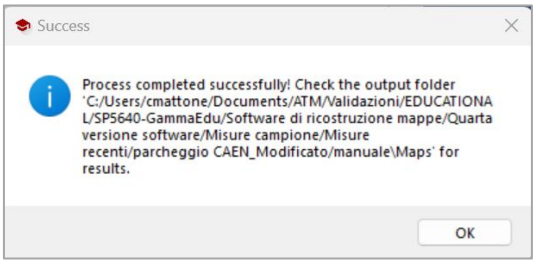
VI. **Output Folder Name:**
   - Upon launch, a dialog box will prompt you to choose the output folder name.



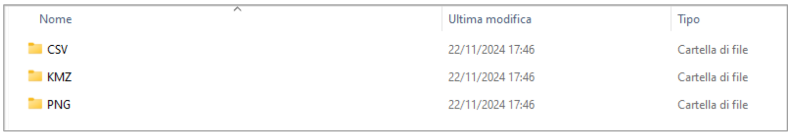
VII. **Data Processing Details:**
   - The software will perform the following tasks:



     - Data extraction.
     - Point filtering.
     - Data interpolation for activity mapping.
     - KMZ file combination.
   - Once processing is complete, the results will be saved in the specified output folder.



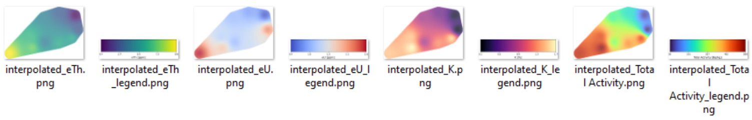
- The output folder will contain three subfolders:



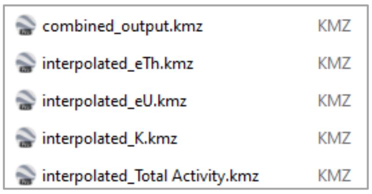
  - **CSV**: contains extracted data from the files in CSV format.

id	latitude	longitude	Total Activity	K	eU	eTh
2024_09_18_15_52_first.kmz	43,8674824	10,2628809	556	1,5	2,6	9,6
2024_09_20_11_53_caen.kmz	43,8677786	10,26327453	522	1,5	1,2	6,4
2024_09_20_12_00_park2.kmz	43,8675851	10,26329702	598	1,7	1,8	7,5
2024_09_20_12_07_park3.kmz	43,86768674	10,26351935	290	0,8	1	3,9
2024_09_20_12_13_park4.kmz	43,86766257	10,26377847	460	1,3	1,3	5,9
2024_09_20_12_20_park5.kmz	43,86775559	10,26401878	531	1,6	1,5	5,8
2024_09_20_12_26_park6.kmz	43,86790602	10,26412382	56	0,1	2,2	2,6
2024_09_20_12_40_park8.kmz	43,8681698	10,26407304	82	0,2	0,4	0,4
2024_09_20_12_46_park9.kmz	43,8682254	10,26377779	223	0,6	0,8	2,9
2024_09_20_12_52_park10.kmz	43,86813318	10,26349925	265	0,8	1	4,3

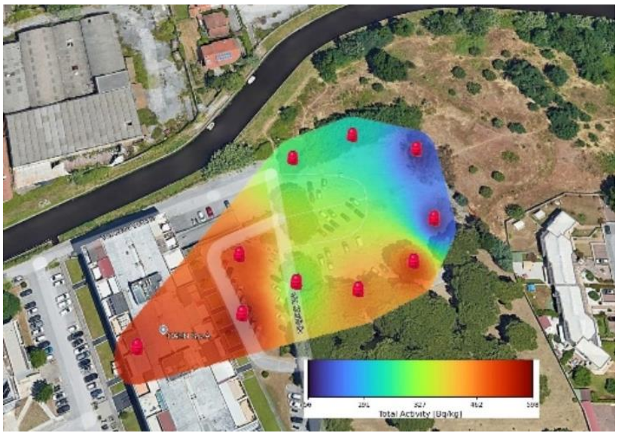
  - **PNG**: contains images of the interpolated activity maps and corresponding legends.



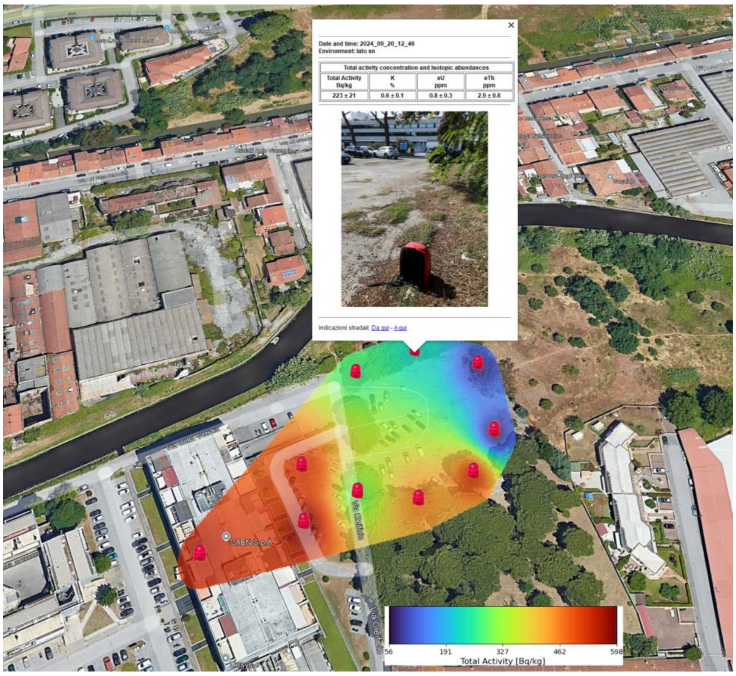
  - **KMZ**: contains KMZ files with activity map overlays and a combined KMZ file of all processed files.



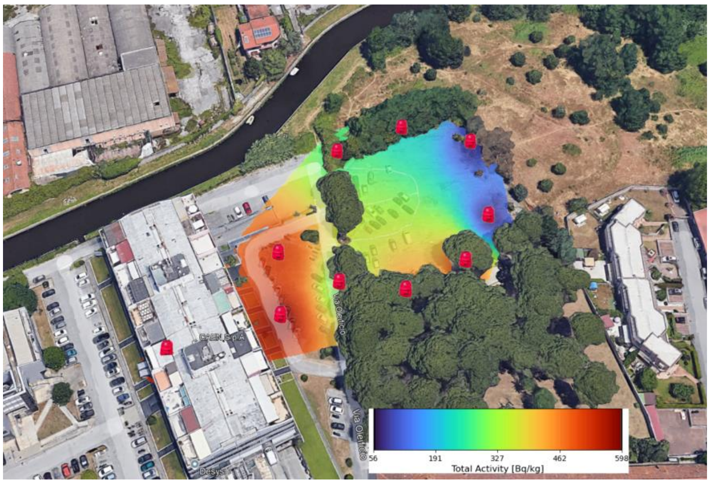
    – The following image shows the complete visualization of the measurement results for the investigated area. This visualization was obtained by opening the "interpolated_Total_Activity.kmz" file in Google Earth Pro, which represents the total radioactivity map (U, Th & K), along with the "combined_output.kmz" file, which highlights the exact measurement points (represented by a red backpack icon).



– As shown in the image below, it is possible to click on the red backpack icon to view the results of the individual measurement.



– The previous visualizations exclude 3D buildings and high grounds in the Google Earth Pro settings. If these features are not disabled, the visualization would appear as follows:



- **KMZ**: contains KMZ files with activity map overlays and a combined KMZ file of all processed files.

Note: When a problem is encountered during file processing (e.g., invalid files or an insufficient number of files), the GUI displays warning pop-ups and resets to its initial state. If the GUI does not automatically reset, the user can manually reset it by clicking the "Reset" button.

7 Educational Experiments

The CAEN GammaEDU detection backpack allows the user to perform experiments concerning naturally occurring gamma radiation.
Despite the idea that radioactivity is something dangerous, related to atomic bombs and nuclear waste diseases only, natural radioactivity is all around us: food, cosmic rays, Earth, and human body even.
GammaEDU backpack allows the user to get acquainted with what concern the gamma environmental radioactivity. Minerals and materials from the earth soil are the most common sources of natural radiation. "Naturally Occurring Radionuclides" stands for radionuclides that occur naturally in significant quantities on earth. The term is usually used to refer to the primordial radionuclides Potassium-40, Uranium-235, Uranium-238 and Thorium-232 (the decay product of primordial uranium-236), their radioactive decay products, and Tritium and Carbon-14 generated by natural activation processes. 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: Naturally Occurring Radioactive Material) can be extracted and potentially contaminate the equipment.

This section represents an overview of the experiments proposed by CAEN using the GammaEDU. 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 website (*https://edu.caen.it/*). 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 for this equipment are listed and highlighted in green in **Tab. 7.1.** Some experiments, identified by (✹) symbol, require extra tools, like low intensity laboratory radioactive source.

Section	Subsection	Reference ID	Experiment	Additional tool
Particle Detector Characterization	**Photomultiplier Tube (PMT)**	6020E	Measurement of Photomultiplier Plateau Curves	✹
Nuclear physics and radioactivity	**Gamma Spectroscopy**	6111E	Detecting γ-Radiation	✹
		6112E	Poisson and Gaussian Distributions	✹
		6113E	Energy Resolution	✹
		6114E	System Calibration: Linearity and Resolution	✹
		6116E	γ-Radiation Absorption	✹
		6117E	Photonuclear cross-section/Compton Scattering cross-section	✹
		6118E	Study of the ^{137}Cs spectrum: the backscatter peak and X-rays	✹
		6119E	Activity of the ^{60}Co	✹
	γ Environmental Radioactivity (outdoor)	6150E	Environmental monitoring in land field	No
		6151E	Ground Coverage Effect on the Environmental Monitoring.	No
		6152E	Human Body Radioactivity	No
		6153E	γ Environmental detection as a function of the soil distance	No
		6154E	Radioactivity maps production	No
		6155E	Radiological evaluation of the building materials	No
		6156E	Mapping of potential radon-prone areas	No
		6157E	Soil water content evaluation with gamma ray spectroscopy	No
		6158E	Geochemical and mineral exploration	No

Tab. 7.1: Physics Experiments performed via the Environmental Kit. If the symbol (✹) is present, extra tools are needed to perform the experiment.

7.1. Measurement of Photomultiplier Plateau Curves (ID.6020E)

Purpose of the experiment:

The goal of this experience is the identification of the working point of a photomultiplier by determining the plateau curve.

Fundamentals:

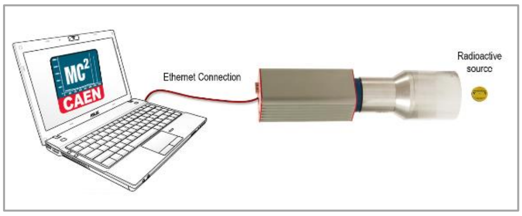
Photomultiplier tubes (often abbreviated as PMT) are widely used Physics, in medical equipment, analytical instruments and industrial measurement systems. The PMTs make use of the photoelectric effect and have good response speed and sensitivity (low-light-level detection). Photomultiplier tubes are usually tested in combination with a ^{137}Cs radiation source and a NaI(Tl) scintillator. There are two characterization measurement methods in scintillation counting. One is the spectrum method which uses a pulse height analyzer to measure an energy spectrum. The other one, described in this experimental activity, is the counting method. Plateau characteristics are measured by setting a threshold value and counting all pulses with amplitudes greater than that value while changing the supply voltage for the photomultiplier tube. The plateau region is such that the count rate will not vary even if the supply voltage is changed within this region. Operating the photomultiplier in the plateau zone is fundamental for correctly using each particle detection apparatus that includes this instrument.

Requirements:

The present experiment was performed using ^{137} CsI source but the background can be use in replacement.

Carrying out the experiment:

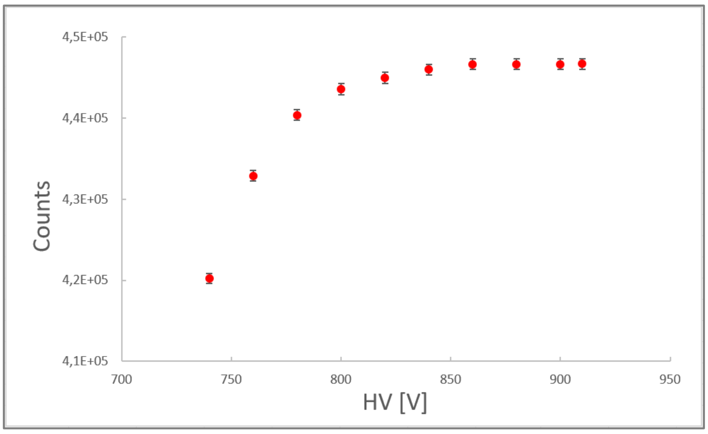
The experiment can be performed both by taking off the instrumentation from the backpack and using the backpack with the open zipper. To power ON γstream, press the ON/OFF button. Take care that the γstream internal battery is charged, otherwise use the external power system. Connect the Ethernet cable from γstream to the PC and configure the Ethernet network of your PC. Connect γstream to the MC^{2}Analyzer software through Ethernet connection. Place the radioactive source close to the scintillator/under the central part of the backpack and run the software. Set the threshold value and keep it fixed for the whole measurement time, by varying the PMT supply voltage.



Experimental setup block diagram for experiment.

Results:

The identification of the working point where the output signals of the photomultiplier are less affected by variations in the power supply voltage.



Example of plateau characteristics.

7.2. Detecting γ-radiation (ID.6111E)

Purpose of the experiment:

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

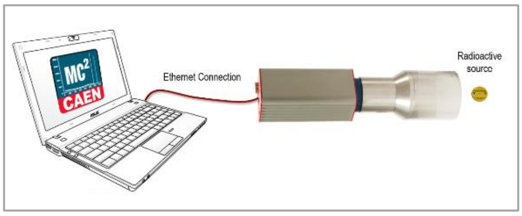
Fundamentals:

Gamma rays interact with matter by three processes: Compton Scattering, Photoelectric Effect and Pair Production (whenever the energy exceeds the 1.022MeV 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 of 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:

Gamma Radioactive Source

Carrying out the experiment:

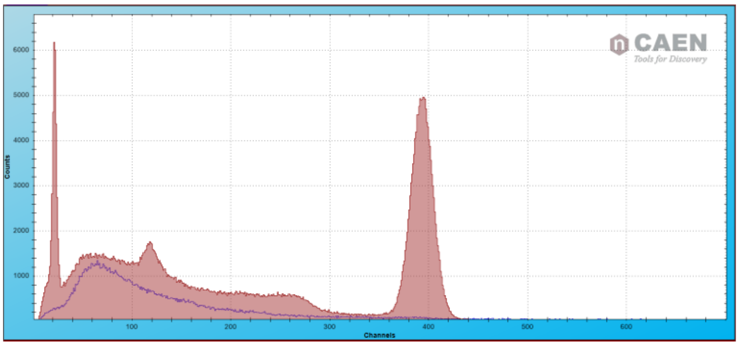


Experimental setup block diagram for experiment.

The experiment can be performed both by taking off the instrumentation from the backpack and using the backpack with the open zipper. To power ON γstream, press the ON/OFF button. Take care that the γstream internal battery is charged, otherwise use the external power system. Connect the Ethernet cable from γstream to the PC and configure the Ethernet network of your PC. Connect γstream to the MC²Analyzer software through Ethernet connection. Run the software, power ON the detector, set the acquisition time and acquire the background spectrum. Place the radioactive source close to the scintillator/under the central part of the backpack and acquire the gamma source spectrum.

Results:

The student may get acquainted with the presence of radioactivity with a simple preliminary measurement, namely comparing the spectra acquired with/without the source. Presuming the source, essentially in contact to the crystal, to be point like with respect to the crystal surface, and assuming its activity is known, the student may estimate for every threshold value the detection efficiency and the signal over noise ratio, building up an efficiency-purity plot. Exemplary results obtained with a ^{137}Cs Source are shown. Moving away the source from the crystal, the law governing the variation of the flux can also be investigated.



Comparison of background spectrum (blu profile) and ^{137}Cs source spectrum (red) acquired by MC²Analyzer software.

7.3. Poisson and Gaussian Distribution (ID.6112E)

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:

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

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_μ (n) is well approximated by a Gaussian distribution:

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

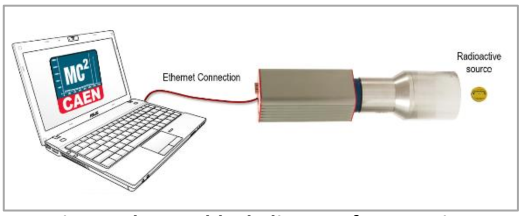
Where $\sigma = \sqrt{\mu}$ is the standard deviation.

Requirements:

Gamma Radioactive Source

Carrying out the experiment:

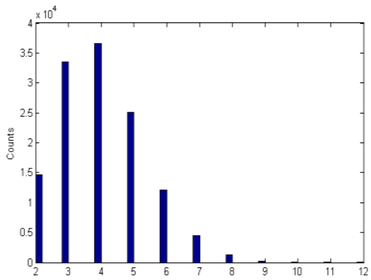
The experiment can be performed both by taking off the instrumentation from the backpack and using the backpack with the open zipper. To power ON γstream, press the ON/OFF button. Take care that the γstream internal battery is charged, otherwise use the external power system. Connect the Ethernet cable from γstream to the PC and configure the Ethernet network of your PC. Connect γstream to the MC^{2}Analyzer software through Ethernet connection. Run the software and power ON the detector. Place the radioactive source close to the scintillator/under the central part of the backpack to perform the experiment.



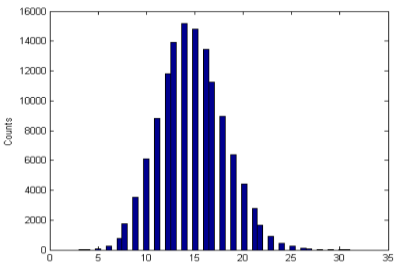
Experimental setup block diagram for experiment.

Results:

Changing the counting window and/or the activity of the source or the threshold, the number of counts changes, with a probability density function moving form a Poissonian to a Gaussian shape. The student may play with the data, fitting them and comparing the expectations to the measurement.



Poissonian distribution.



Gaussian distribution.

7.4. Energy Resolution (ID.6113E)

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.

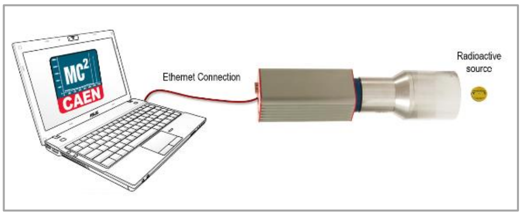
Fundamentals:

For γ-energy less than 2 MeV, 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 NaI crystal coupled to a Photomultiplier Tube. The ^{137}Cs source is particularly interesting due to its low energy X ray line at 33 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.

Requirements:

Gamma Radioactive Source

Carrying out the experiment:



Experimental setup block diagram for experiment.

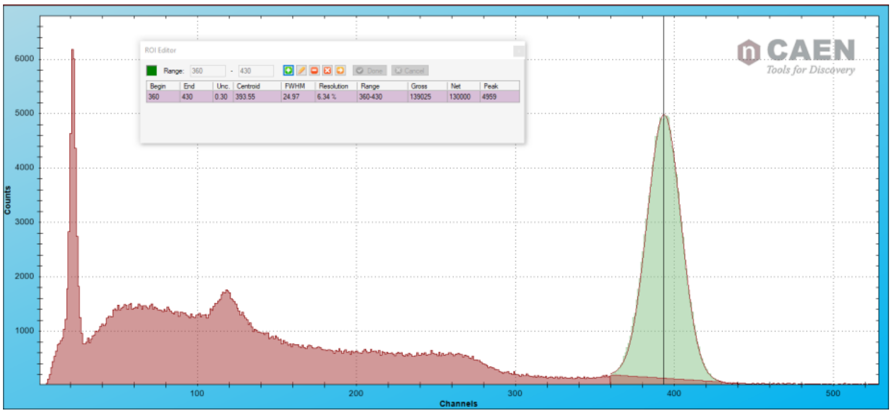
The experiment can be performed both by taking off the instrumentation from the backpack and using the backpack with the open zipper. To power ON γstream, press the ON/OFF button. Take care that the γstream internal battery is charged, otherwise use the external power system. Connect the Ethernet cable from γstream to the PC and configure the Ethernet network of your PC. Connect γstream to the MC²Analyzer software through Ethernet connection. Run the software and power ON the detector. Place the radioactive source close to the scintillator/under the central part of the backpack. Once the radioactive source is properly positioned, the spectrum can be recorded.

Results:

The figure shows a typical gamma spectrum, recorded with a very low energy threshold. The left over from the system noise is clearly visible, as well as the low energy line at 33 keV and the photo-peak. For this specific spectrum, the energy resolution on the 662 keV peak corresponds to

$$\text{Energy Resolution} = \frac{\text{FWHM}_{\text{peak}}}{\mu_{\text{peak}}} * 100 \sim 10\%$$

where $FWHM_{peak}$ and μ_{peak} represent the full width at half maximum of the peak and the channel number of the peak centroid respectively.



The ^{137}Cs spectrum acquired by MC²Analyzer software.

7.5. System Calibration: Linearity and Resolution (ID.6114E)

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 student 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.

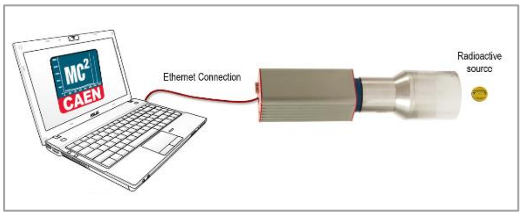
This is following an initial activity on the optimization of the operating parameters by an analysis of the photo-peak position and the resolution for a single isotope.

Requirements:

Gamma Radioactive Sources

Carrying out the experiment:

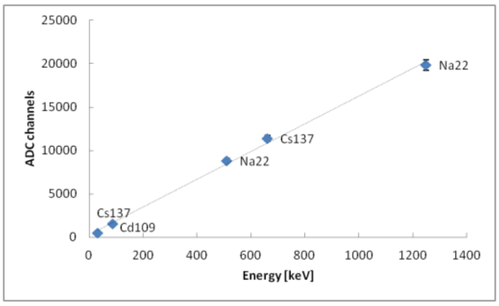
The experiment can be performed both by taking off the instrumentation from the backpack and using the backpack with the open zipper. To power ON γstream, press the ON/OFF button. Take care that the γstream internal battery is charged, otherwise use the external power system. Connect the Ethernet cable from γstream to the PC and configure the Ethernet network of your PC. Connect γstream to the MC^{2}Analyzer software through Ethernet connection. Run the software and power ON the detector. Place the radioactive source close to the scintillator/under the central part of the backpack. Once the radioactive source is properly positioned, the spectrum can be recorded.



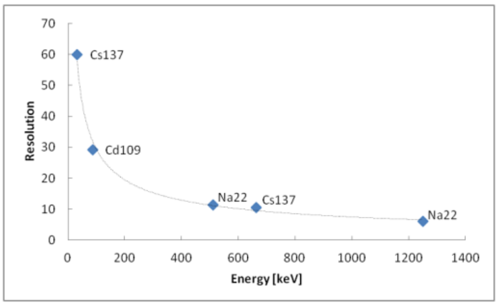
Experimental setup block diagram for experiment.

Results:

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



Energy calibration



Energy dependence of the system resolution

7.6. γ-Radiation Absorption (ID.6116E)

Purpose of the experiment:

The main goal of the experiment is the measurement of the γ radiation attenuation coefficient for different materials and different energies.

Fundamentals:

The attenuation of a γ radiation flux passing through matter is described by the exponential law

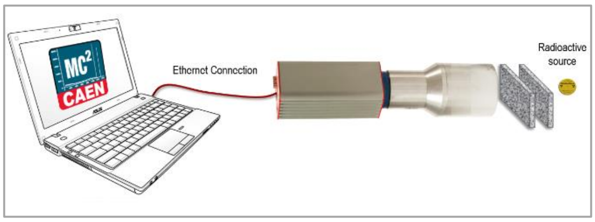
$$I(x) = I_0 * e^{-\mu x}$$

where I_0 is the incident photon flux and I(x) measures the flux of γ rays emerging from a layer x of material without having interacted. The coefficient μ depends on the material properties (atomic number, density) and on the energy of the impinging photon. The student is guided towards the development of complementary measurement techniques based on counting and on the analysis of the spectrum, performing the experiment for different materials (including PMMA, a water equivalent solid state organic material used in medical dosimetry).

Requirements:

Gamma Radioactive Source and Aluminium Absorbers.

Carrying out the experiment:

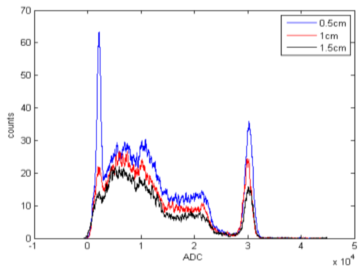


Experimental setup block diagram for experiment.

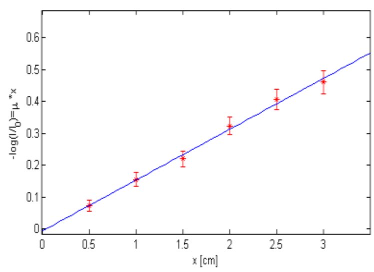
The experiment can be performed both by taking off the instrumentation from the backpack and using the backpack with the open zipper. To power ON γstream, press the ON/OFF button. Take care that the γstream internal battery is charged, otherwise use the external power system. Connect the Ethernet cable from γstream to the PC and configure the Ethernet network of your PC. Connect γstream to the MC²Analyzer software through Ethernet connection. Run the software and power ON the detector. Place the radioactive source close to the scintillator/under the central part of the backpack. Once the radioactive source is properly positioned, the spectrum can be recorded. The experiment can be performed in analysing the spectrum by placing different absorber thicknesses between the source and the detector and measuring the events in the photo-peak for a constant pre-defined time interval.

Results:

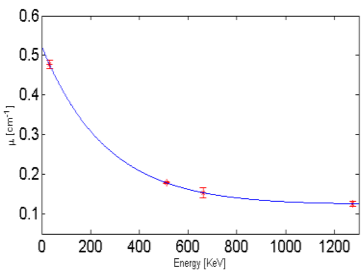
Exemplary results are shown below, reporting the variation of the events in the photopeak for different absorber thickness, a plot verifying the exponential absorption law and the dependence of the absorption coefficient on the energy.



Gamma spectra acquired with different absorber thicknesses



Linear dependence of logarithmic intensity of gamma rays as a function of penetration thickness



Gamma attenuation coefficient as a function of energy

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

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 1MeV energy level

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

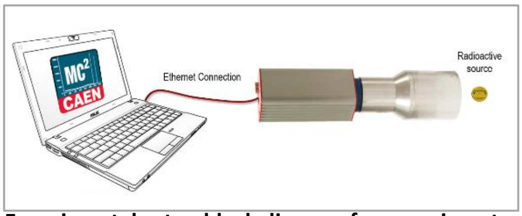
The predominant mode of interaction depends on the energy of the incident photons and the atomic number of the material with which they are interacting. From the acquired γ-spectrum, it is possible to estimate the fraction of events due to Compton scattering and those caused by the photoelectric. The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

Requirements:

Gamma Radioactive Source

Carrying out the experiment:

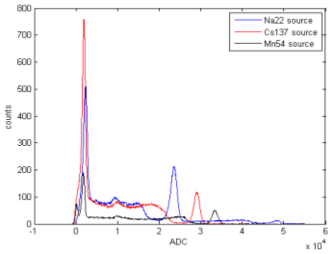
The experiment can be performed both by taking off the instrumentation from the backpack and using the backpack with the open zipper. To power ON γstream, press the ON/OFF button. Take care that the γstream internal battery is charged, otherwise use the external power system. Connect the Ethernet cable from γstream to the PC and configure the Ethernet network of your PC. Connect γstream to the MC^{2}Analyzer software through Ethernet connection. Run the software and power ON the detector. Place the radioactive source close to the scintillator/under the central part of the backpack. Once the radioactive source is properly positioned, the spectrum can be recorded. Once done, change the radioactive gamma source and repeat the measurement.



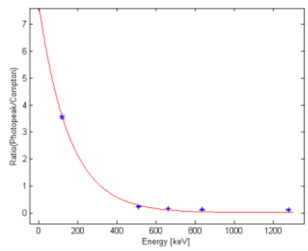
Experimental setup block diagram for experiment.

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.



Spectra of radioactive sources used to estimate the ratio of Photonuclear and scattering Compton cross sections



Behaviour of the ratio between Photo-Peak and Compton contributions as a function of energy

7.8. Study of the ^{137}Cs spectrum: the backscatter peak and X rays (SG6118E)

Purpose of the experiment:

Study the characteristics of the ^{137}Cs spectrum, with special relevance given to the low energy spectrum. The student can learn effects related to the experimental observation of a gamma decay and have basic information about the experimental setup used in gamma spectroscopy. Estimate the energy of the backscatter peak and of the K_α line.

Fundamentals:

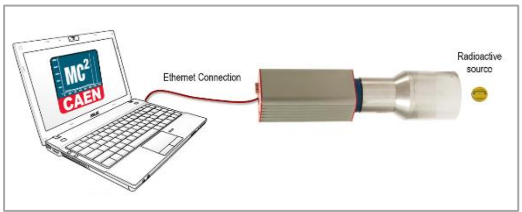
The Compton effect is linked with experimental issues, since it is caused by the interaction of photons with the electrons instrument that measure the gamma radiation. In a real detector setup, some photons can and will undergo one or potentially more Compton scattering processes (e.g. in the housing material of the radioactive source, in shielding material or material otherwise surrounding the experiment) before entering the detector material. This leads to a peak structure, the so-called backscatter peak.
The basic principle for the backscatter peak formation is the following: gamma-ray sources emit photons isotropically, some photons will undergo a Compton scattering process with a scattering angle close to 180° and some of these photons will subsequently be detected by the detector. The result is an excess of counts in the Compton part of the spectrum, the so-called backscatter peak. This peak has an energy approximately equal to the photopeak energy minus the Compton edge energy.

Requirements:

Gamma Radioactive Source: ^{137}Cs

Carrying out the experiment:

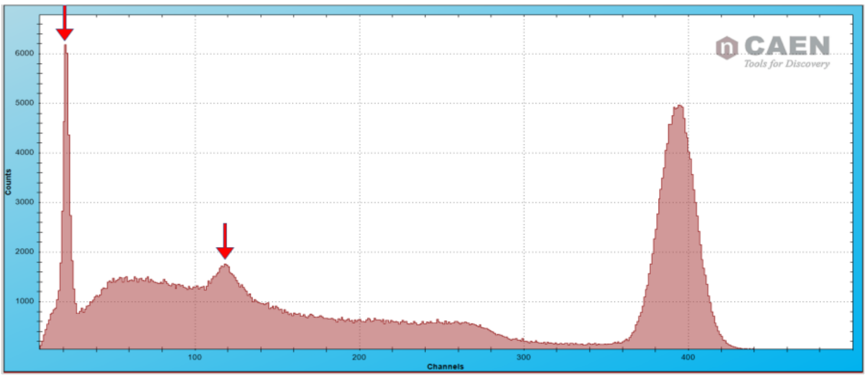
The experiment can be performed by taking off the instrumentation from the backpack. To power ON γstream, press the ON/OFF button. Take care that the γstream internal battery is charged, otherwise use the external power system. Connect the Ethernet cable from γstream to the PC and configure the Ethernet network of your PC. Connect γstream to the MC²Analyzer software through Ethernet connection. Run the software and power ON the detector. Place the radioactive source close to the scintillator. Once the radioactive source is properly positioned, the spectrum can be recorded.



Experimental setup block diagram for experiment.

Results:

The user can calibrate the system by using the spectrum itself. The backscatter peak and the K_α line can be identified. After calibrating the spectrum, it is possible to estimate the energy of the two peaks and compare them with theoretical predictions.



Plot of the ^{137}Cs spectrum acquired by the MCA. The backscatter peak and the Kα line are indicated with the red arrows.

7.9. Activity of the ^{60}Co (SG6119E)

Purpose of the experiment:

Determine the activity of a ^{60}Co source from its gamma spectrum. Learn about the meaning of the sum peak, visible in the spectrum of some radioactive sources.

Fundamentals:

The ^{60}Co spectrum presents two distinct gamma photopeak in its spectrum, respectively corresponding to photons γ1 and γ2 at 1.17 MeV and 1.33 MeV. For the purpose of this experiment, we can assume that each of these gamma rays are isotropically distributed. In other words, if γ1 departs in a particular direction, γ2 can go in any direction that it wishes. There is a certain probability that γ2 will go in the same direction as γ1. If this occurs the energies of γ1 and γ2 will be summed in the detector. Hence a sum peak will show up in the spectrum, at nearly 2.5 MeV.

We can estimate the activity of the source by calculating the counts under the two main peaks and under the sum peak, i.e. calculating their area ∑. For the case of ^{60}Co, we have that the counts under the sum peak can be evaluated as

$$\sum(SUM) = \frac{\sum 1 \sum 2}{A\, t}$$

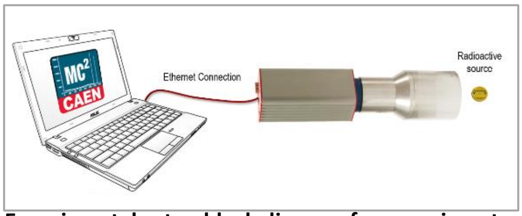
Where A is the activity of the source and t is the acquisition time. Therefore, fitting the peaks with a gaussian and calculating their area, it is possible to estimate the activity of the ^{60}Co source used to record the available spectrum.

Requirements:

Gamma Radioactive Source: ^{60}Co.

Carrying out the experiment:

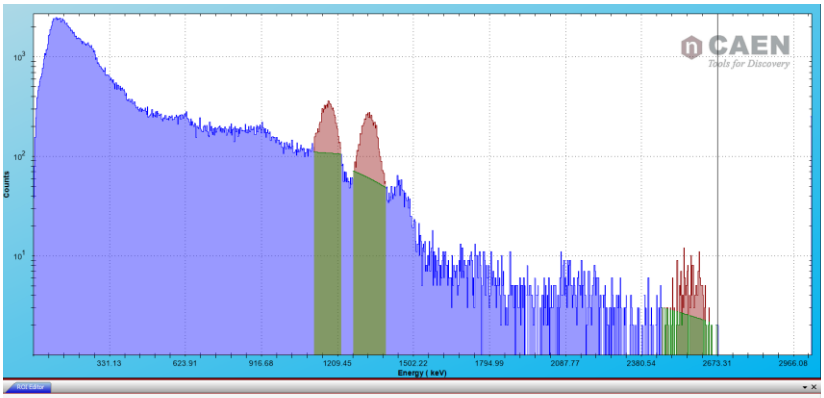
The experiment can be performed by taking off the instrumentation from the backpack. To power ON γstream, press the ON/OFF button. Take care that the γstream internal battery is charged, otherwise use the external power system. Connect the Ethernet cable from γstream to the PC and configure the Ethernet network of your PC. Connect γstream to the MC^2Analyzer software through Ethernet connection. Run the software and power ON the detector. Place the radioactive source close to the scintillator. Once the radioactive source is properly positioned, the spectrum can be recorded.



Experimental setup block diagram for experiment.

Results:

The user should verify that, after the spectrum calibration, the sum peak is nearly at 2.5 MeV. From the formula given above, using the live time in seconds, the student can estimate de activity of ^{60}Co directly in Bq. A calculation made for a spectrum acquired in 100 seconds gives an activity of nearly 264 kBq.



Begin	End	Unc.	Centroid	FWHM	Resolution	Range	Gross	Net	Peak
369	405	2.30	1,172.99 keV	52.59 keV	4.48 %	1,118.69-1,224.09 keV	8758	4885	361
421	464	2.20	1,333.01 keV	55.36 keV	4.15 %	1,270.93-1,396.82 keV	7003	4433	275
827	900	18.10	2,572.08 keV	77.40 keV	3.01 %	2,459.59-2,673.31 keV	253	109	12

The ^{60}Co complete spectrum acquired by MC2Analyzer software.

7.10. Environmental monitoring in land field (ID.6150E)

Purpose of the experiment:

Increase of the familiarity with environmental radioactivity topic via measurements in land field which combine nuclear engineering and computer science to a better the comprehension of basic physics concepts.

Fundamentals:

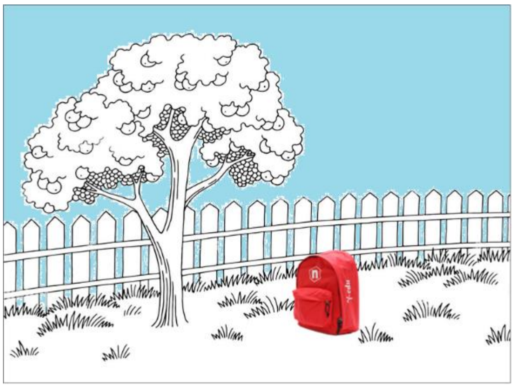
Radioactivity is a physical phenomenon occurring when an unstable nucleus undergoes a transition from one energy state to another. In addition to the cosmogenic radionuclides, natural sources include the so-called primordial radionuclides existing since the Earth formed and that have not completely decayed due to their long half-life (~10^9 years and longer). The most common isotopes in the Earth responsible for the so-called terrestrial radiation are Uranium (^{238}U), Thorium (^{232}Th), and Potassium (^{40}K), together with their multiple daughter products. It is estimated that 80% of the average annual dose for the world's population comes from natural background radiation. While ^{40}K undergoes one single decay, ^{238}U and ^{232}Th produce decay chains that comprise α, β, and/or γ decays.
In the outside environment, especially in case of in-situ γ-ray spectroscopy, there are many variables that could interfere with the measurement, such as the presence of vegetation or buildings and the morphology of the area affecting the field of view of the spectrometer.

Requirements:

No other tool is needed

Carrying out the experiment:

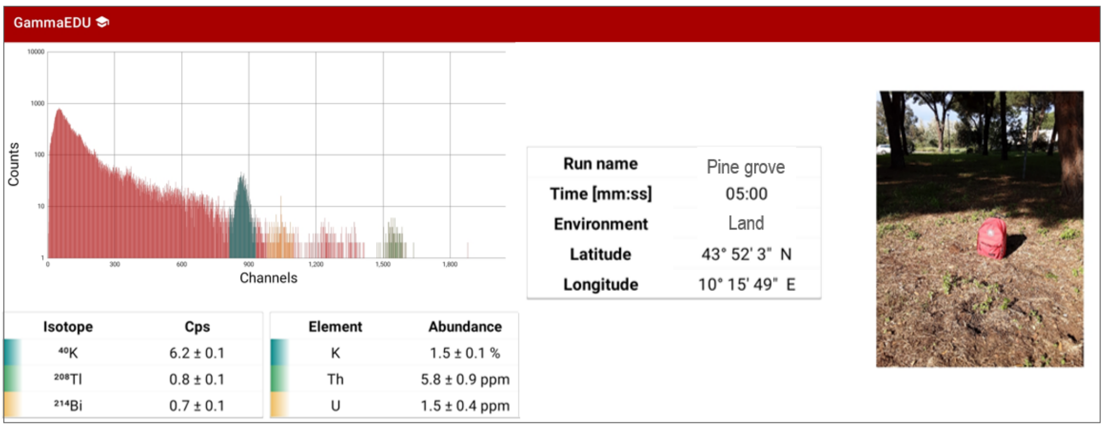
Power on the *γstream* inside the red backpack. Power on the tablet and associate the two devices via Bluetooth.
Take care that the γstream internal battery is charged, otherwise use the external power system.
Start the measurement campaign in land field and place the backpack on the floor almost 1m far from the trees, manhole or other construction. Set the acquisition time to about 5 minutes and see the results. If the statistic is not enough increasing the acquisition time.
It is good practice to repeat the measurement in order to obtain the mean and standard deviation of the result.



Experimental setup block diagram.

Results:

The acquired γ-ray spectra and the experimental results can be analyzed using GammEDU App thus, to obtain a quantitative survey of environmental radioactivity.



Experimental result of in-situ γ-ray spectroscopy taken place in Viareggio, Italy.

7.11. Ground Coverage Effect on the Environmental Monitoring (ID.6151E)

Purpose of the experiment:

The experimental activity aims to give to the user a critical understanding of environmental radioactivity phenomenon.

Fundamentals:

The use of portable gamma-ray spectrometers (NaI) as a probe for exploring the natural radioactivity allows the users to be able to grasp quantitative insights of the spatial distribution of the terrestrial radionuclides (i.e. U, Th and K) in the daily environment.

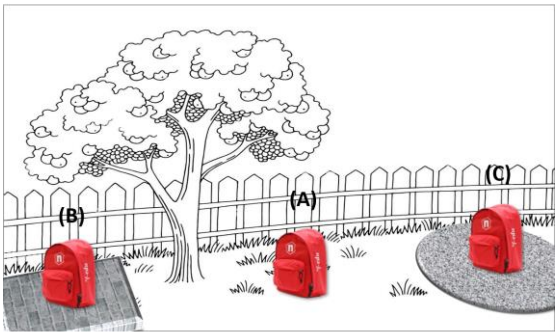
In the specific case of in-situ gamma ray spectroscopy, there are many variables that could interfere with the measurement, such as the presence of vegetation or buildings and the morphology of the area affecting the field of view of the spectrometer. In addition, soil humidity has an attenuating effect on gamma radiation and sources having weak intensities need longer acquisition times. Moreover, the different types of ground coverage (like asphalt, grass, or brick) affect the measurement considerably. It is interesting to observe and understand how some type of ground coverage can be most or least abundant in natural radioactivity terms.

Requirements:

No other tool is needed

Carrying out the experiment:

Power on the *γstream* inside the red backpack. Power on the tablet and associate the two devices via Bluetooth.
Take care that the γstream internal battery is charged, otherwise use the external power system.
Start the measurement campaign in land field and place the backpack on the floor almost 1m far from the trees, manhole or other construction. Set the acquisition time to about 5 minutes and see the results. If the statistic is not enough increasing the acquisition time.
Repeat the measurements for the different types of ground coverage, like asphalt, grass, or brick and compare the results.



Experimental setup block diagram.

Results:

Different ground coverage types are investigated by recording in-situ γ-ray spectra. The mean and standard deviation of the ^{40}K, ^{238}U, and ^{232}Th concentrations can be compared and discussed critically.

Ground Coverage	*Number of Measurements*	*^{40}K [10^{-2}g/g]*	*^{238}U [µg/g]*	*^{232}Th [µg/g]*
Brick	7	0.82 ± 0.19	1.8 ± 0.5	4.1 ± 1.0
Grass	28	2.08 ± 0.32	1.7 ± 0.4	9.5 ± 1.8
Asphalt	7	1.20 ± 0.10	1.9 ± 0.4	5.1 ± 0.7

Mean and standard deviation of the K, U, and Th concentrations that were obtained from the in-situ-ray measurements distinguished according to the different ground coverage types (Data from University of Ferrara)[2].

[2] Training Future Engineers to Be Ghostbusters: Hunting for the Spectral Environmental Radioactivity, Albéri M. et Al., Education Sciences, 9(1), 15 (2019).

7.12. Human Body Radioactivity (ID.6152E)

Purpose of the experiment:

The purpose of the experiment is to become aware of the radioactivity of the human body.

Fundamentals:

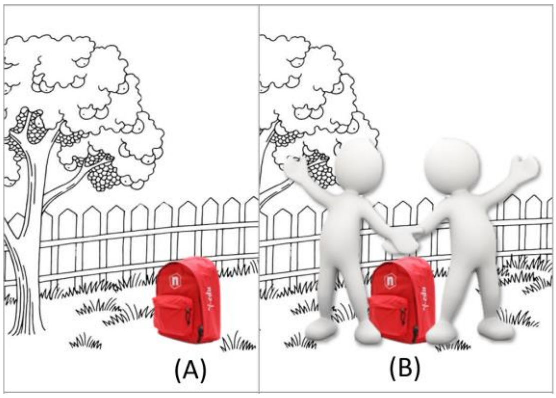
Potassium is essential to all living beings, including humans, where it's found especially in the muscle tissue. It can be found in most soils, building materials, plants and animals and it is typically used in fertilizers.
In nature there are only three isotopes of potassium: ^{39}K (93.3% of weight abundance), ^{41}K (6.7%) and ^{40}K (0.0117%). While ^{39}K and ^{41}K are stable, ^{40}K is a radioactive isotope with a half-life of $1.28 \cdot 10^9$ *years* and it is one of the most common responsible for the so-called terrestrial radiation.
Considering the relative abundance, only twelve of a hundred thousand potassium atoms are actually radioactive, i.e. approximately for 1 *g* of potassium, 31 nuclei decay per second [~ 31 *Bq /g*]. This fact implies that one banana of 150 *g* contains about 525 *mg* of potassium which corresponds to ~16 *Bq* activity, and similarly, an adult man (70 *kg*) has about 140 *g* of potassium which corresponds to ~ 4400 *Bq*.
^{40}K decays 89.3% of the time to the ground state of ^{40}Ca by pure β-emission and 10.7% of the time by electron capture to an excited state of ^{40}Ar which then decays γ reaching the stability. The emitted photon has an energy of 1460.86 *keV* and can be used in order to identify and quantify the activity concentration of ^{40}K in sites of measurement and in the environmental samples.

Requirements:

No other tool is needed

Carrying out the experiment:

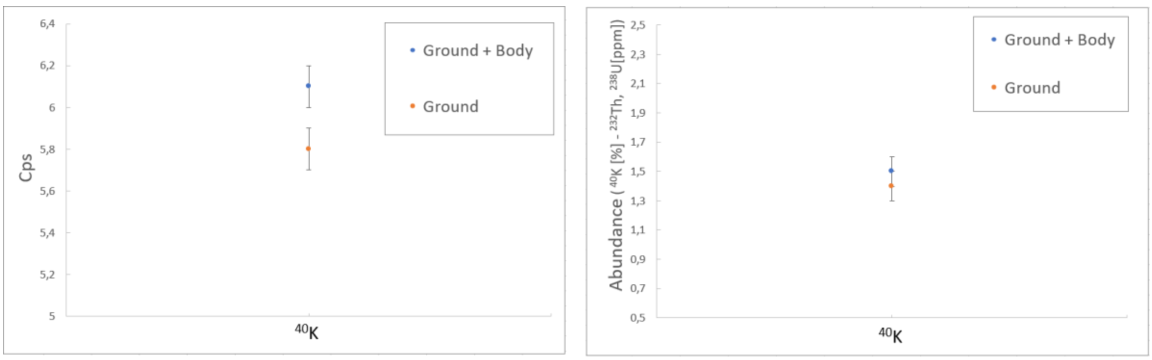
Power on the *γstream* inside the red backpack. Power on the tablet and associate the two devices via Bluetooth. Take care that the γstream internal battery is charged, otherwise use the external power system.
Start the experiment by placing the backpack on the ground and be sure that your presence is far enough from the measure point not to be revealed (A). Set the acquisition time to about 5 minutes and see the results. If the statistic is not enough increasing the acquisition time. Repeat the measurements leaving the backpack in the same position but getting yourself close to the system (B).



Experimental setup block diagram.

Results:

The measurements results show how the detection of the ^{40}K in situ is dependent of the human presence weakly.



Experimental result of in-situ γ-ray coming from ^{40}K [1460 keV] with and without people presence.

7.13. Environmental detection as a function of the soil distance(ID.6153E)

Purpose of the experiment:

The main goal of the experiment is to understand how the measurement of the γ environmental radiation can be affect by the distance of the point of measurement.

Fundamentals:

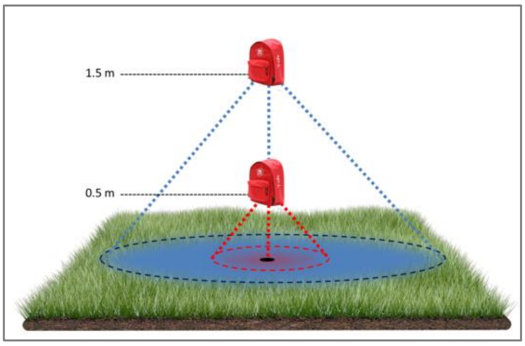
The linear attenuation coefficient of gamma radiation μ represents the inverse of the distance at which the number of photons is reduced by a factor *1/e*, as can be inferred by the following equation: $N = N_0 e^{-\mu x}$, where μ in cm^{-1}. This Equation is the key for understanding the lateral horizon of in-situ gamma ray spectroscopy. The horizontal field of view of a gamma-ray detector expresses the relative contribution to the total signal that is produced within a given radial distance from the detector vertical axis. The lateral horizon depends on the height of the detector: for instance, a spectrometer that was placed at ground level detect gammas coming from the first 25 cm of depth and it receives 90% of the signal from a radius of ~0.5 m. At a height of 0.5 m, 95% of the signal come from a radius of ~8 m and the maximum percentage contribution to the flux comes from the concentric hollow cylinder of soil having a ~0.6 m radius centered at the detector vertical axis. When it's carried on the shoulders of the operator (1.5 m of height) the signal reaches ~95% at ~20 m and the maximum percentage contribution to the flux comes from the concentric hollow cylinder with a radius of ~1.2 m.

Requirements:

No other tool is needed

Carrying out the experiment:

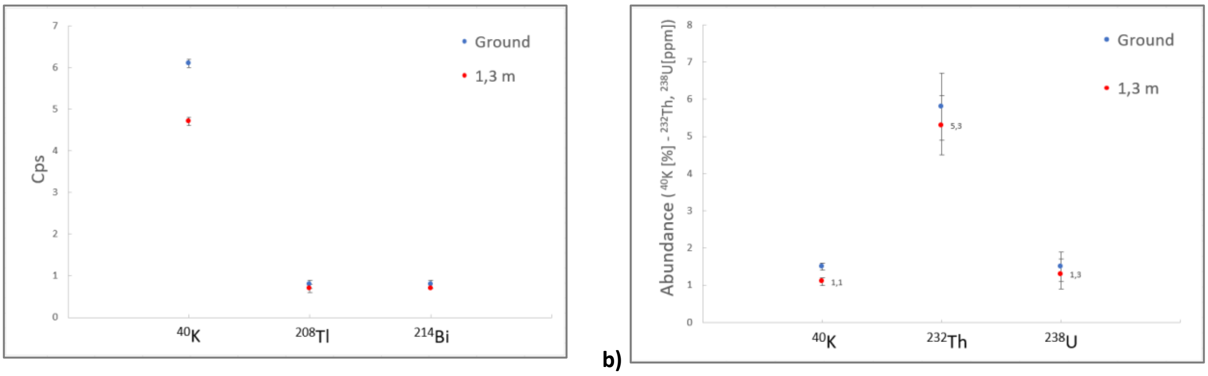
Power on the γstream inside the red backpack. Power on the tablet and associate the two devices via Bluetooth.
Take care that the γstream internal battery is charged, otherwise use the external power system.
Start the experiment by placing the backpack on the floor/soil. Set the acquisition time to about 5 minutes and see the results. If the statistic is not enough increasing the acquisition time.
Repeat the measurements at different heights/distances from soil and pay attention to perform the measurements in the same conditions exactly.



Experimental setup block diagram.

Results:

The measurements results show a gamma detection decrease as a function of the soil distance.



Results of the in-situ γ-ray measurements that were performed at different heights: the counts per second of three isotopes (a) and the abundance (b).

7.14. Radioactivity maps production (ID.6154E)

Purpose of the experiment:

Starting from outdoor spectroscopy measurements to create the map of the natural radioactivity expressed in total specific activity in Bq/kg of the investigated area.

Fundamentals:

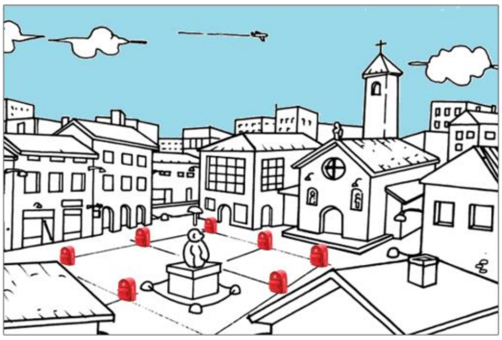
The human population is continuously exposed to ionizing radiation from various natural sources (cosmic and terrestrial ones). Moreover, the exposure to natural sources exceeds that of all artificial, i.e., due to medical use, power generation and associated fuel cycle facilities, radioisotope production waste management and from military ones. In this context, the radiological monitoring of the geographical areas became very important. All over the World, several institutions are missioned to develop collections of maps showing the levels of natural radioactivity caused by different sources (e.g., indoor radon, cosmic radiation, terrestrial gamma radiation, and natural radionuclides in soil and bedrock).

Requirements:

No other tool is needed

Carrying out the experiment:

Power on the γstream inside the red backpack. Power on the tablet and associate the two devices via Bluetooth.
Take care that the γstream internal battery is charged, otherwise use the external power system.
The in-situ survey must be planned to keep in mind the spatial resolution of the desired information: it is important choosing the sampling points in order to cover the surveyed area comprehensively for the different types of ground coverage, like asphalt, grass, or brick.
Start the measurement campaign and place the backpack on the floor almost 1m far from the buildings, manhole or other construction. Set the acquisition time to about 5 minutes and see the results. If the statistic is not enough increasing the acquisition time.



Experimental setup block diagram.

Results:

The results that were obtained during the outdoor experiment in terms of total activity originating from ^{40}K, ^{238}U, and ^{232}Th are visualized via Google Earth. From these data, a natural radioactivity map of the investigated area can be developed.

Maps of the measurement points (yellow triangles) reported in the Google Earth app and the example of the measurement result reporting total activity concentration and Isotopic abundances [Viareggio, Italy].

7.15. Radiological evaluation of the building materials (ID.6155E)

Purpose of the experiment:

The main goal of the experiment is the estimation of the natural radioactivity content in several dwellings and/or buildings representative of the different geological construction materials and commonly used in building constructions.

Fundamentals:

The main contributors on the overall natural indoor effective dose to which population is exposed are ^{222}Rn and ^{220}Rn isotopes of radon gas, by-products of the ^{238}U and ^{232}Th series.
Only a fraction of radon atoms preserves enough kinetic energy to leave the grain of the material where it has been generated and to reach the empty space in the porous materials (emanation process that depends on the material itself). Moreover, only a fraction of the radon atoms reaching the pore volume of the material mass can escape into the air and reaches the spaces where people live (exhalation process).
The study of the natural radionuclides ^{232}Th, ^{40}K, ^{226}Ra, and the radon emanation coefficient and exhalation rate is essential to estimate the actual risk for human health associated to a given natural material used for building construction. The natural radioactivity content of building materials depends on the local geology of each region on Earth. One of the requirements of estimate the radiation hazards in closed spaces, aiming to better protect against natural ionizing radiations exposure, is the assessment of the radiation hazards arising from the use of natural building materials in the construction of dwellings, since the majority of people in the World spend most time in indoor environments.

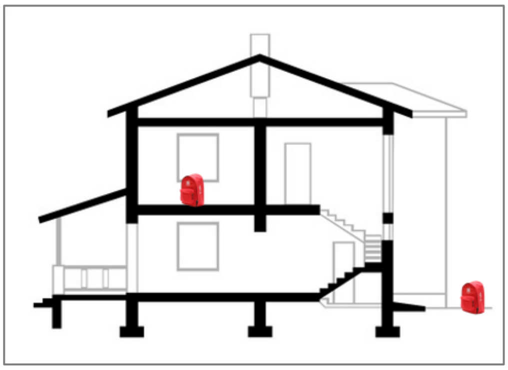
Requirements:

No other tool is needed

Carrying out the experiment:

Power on the *γstream* inside the red backpack. Power on the tablet and associate the two devices via Bluetooth.
Take care that the γstream internal battery is charged, otherwise use the external power system.

Start the measurement campaign and place the backpack on the floor far from the room walls. Set the acquisition time to about 5 minutes and see the results. If the statistic is not enough increasing the acquisition time. Repeat the measurements in a different place where the building material is different and compare the results.



Experimental setup block diagram.

Results:

The measurement results are compared to the reference values in the terrestrial crust. The discrepancy in the reference levels can be explained by the building material, distance from soil and more. This kind of measurement is important for the evaluation of natural radiation exposure from building materials [2013/59/Euratom Directive and by UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation)].

	Isotopic Abundances		
	^{238}eU [ppm]	^{232}Th [ppm]	^{40}K [%]
Reference Values Range	[2 ; 2.5]]	[8 ; 12]]	[2 ; 2.5]]
Tuff Dwelling (4° floor)	10 ± 1	31 ± 1	6.9 ± 0.2
Modern Building (1° floor)	2.8 ± 0.6	8.8 ± 1.1	1.6 ± 0.1
Country House (0° floor)	6.8 ± 0.9	17.6 ± 1.6	3.4 ± 0.2

Isotopic abundances evaluated in buildings located in different places and made with several construction materials.

7.16. Geochemical and mineral exploration (ID.6158E)

Purpose of the experiment:

Large area survey to evaluate the radioactivity concentration of Uranium, Thorium, and Potassium.

Fundamentals:

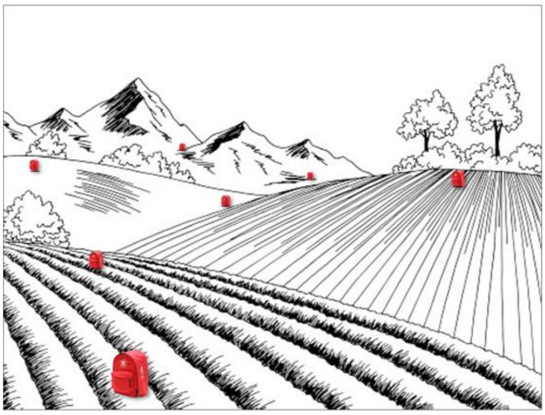
A geochemical exploration campaign aims at locating economic mineral deposits through the recognition of concentrations of chemical components, to be called as geochemical anomaly, in surface materials such as rocks, soils, stream sediments, glacial till, water, plants, and air. The radiological characterization of surface soil, in terms of Uranium, Thorium and Potassium, proves to be also a good tool to direct excavations for mines. The main advantages of using in situ measurements are quick feedback, a large sample size, immediate repeatability of the measurement and low management costs. The areas with an enormous geodiversity have a considerable variety of stone materials that can be used both as building materials and as ornamental elements. This enormous variety also corresponds to considerable variability in the abundance of radionuclides. The world average radioactivity content in the upper continental crust is (33 ± 7) *Bq/kg* for ^{238}U, (43 ± 4) *Bq/kg* for ^{232}Th and (727 ± 60) *Bq/kg* for ^{40}K. Igneous plutonic rocks are characterized by relatively high concentrations of natural radionuclides varying over a wide range of up to 2000 *Bq/kg* for ^{40}K, 600 *Bq/kg* for ^{238}U and 900 *Bq/kg* for ^{232}Th.

Requirements:

No other tool is needed

Carrying out the experiment:

Power on the *γstream* inside the red backpack. Power on the tablet and associate the two devices via Bluetooth. Take care that the γstream internal battery is charged, otherwise use the external power system.
Start the measurement campaign in land field and place the backpack on the floor almost 1m far from the trees, manhole or other construction. Set the acquisition time to about 5 minutes and see the results. If the statistic is not enough increasing the acquisition time.
Repeat the measurements along the survey area.



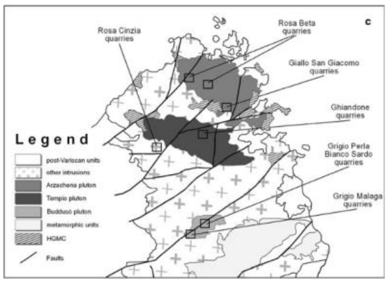
Experimental setup block diagram.

Results:

Exemplary of in situ survey performed by using a portable NaI(Tl) scintillation detector for the determination of the radioactivity concentration of ^{40}K, ^{238}U and ^{232}Th on intrusive granite outcrops in Corsica-Sardinia (FR-IT).[3]

Granite Quarries	^{40}K [*Bq/kg*]	^{238}U [*Bq/kg*]	^{232}Th [*Bq/kg*]
Rosa Beta	1144 ± 120	42.3 ± 7.1	55.0 ± 6.3
Ghiandone	1092 ± 198	56.3 ± 12.7	68.9 ± 10.4
G. San Giacomo	1335 ± 206	50.1 ± 13.8	61.9 ±9.4
Rosa Cinzia	1313 ± 64	56.0 ± 6.8	69.4 ± 3.4
Grigio Malaga	848 ± 121	34.5 ± 4.6	61.1 ± 5.5
Grigio Perla	1222 ± 155	39.1 ±5.2	60.6 ±5.7
Bianco Sardo	1269 ±64	44.8 ±7.1	51.6 ±8.8

Activity concentration of ^{40}K, ^{238}U and ^{232}Th in situ measurements [2].



Position of extractive districts in Sardinia where in situ measurements were performed [2].

[3] *Radiological characterization of granitoid outcrops and dimension stones of the Variscan Corsica-Sardinia Batholith*, Puccini, A., Xhixha, G., Cuccuru, S., Oggiano, G., Xhixha, M. K., Mantovani, F., Alvarez, C. R., and Casini, L., Environmental Earth Sciences, 71, 393-405, (2014).

8 Instructions for Cleaning

The equipment may be cleaned with isopropyl alcohol or deionized water and air dried. Clean the exterior of the product only.
Do not apply cleaner directly to the items or allow liquids to enter or spill on the product.

Cleaning the Touchscreen

To clean the touchscreen (if present), wipe the screen with a towelette designed for cleaning monitors or with a clean cloth moistened with water.
Do not use sprays or aerosols directly on the screen; the liquid may seep into the housing and damage a component. Never use solvents or flammable liquids on the screen.

Cleaning the air vents

It is recommended to occasionally clean the air vents (if present) on all vented sides of the board. Lint, dust, and other foreign matter can block the vents and limit the airflow. Be sure to unplug the board before cleaning the air vents and follow the general cleaning safety precautions.

General cleaning safety precautions

CAEN recommends cleaning the device using the following precautions:

1) Never use solvents or flammable solutions to clean the board.
2) Never immerse any parts in water or cleaning solutions; apply any liquids to a clean cloth and then use the cloth on the component.
3) Always unplug the board when cleaning with liquids or damp cloths.
4) Always unplug the board before cleaning the air vents.
5) Wear safety glasses equipped with side shields when cleaning the board

9 Device decommissioning

After its intended service, it is recommended to perform the following actions:

- Detach all the signal/input/output cable
- Wrap the device in its protective packaging
- Insert the device in its packaging (if present)

THE DEVICE SHALL BE STORED ONLY AT THE ENVIRONMENT CONDITION SPECIFIED IN THE MANUAL, OTHERWISE IT WILL NOT BE GUARANTEED PERFORMANCE AND SAFETY

10 Disposal

The disposal of the equipment must be managed in accordance with Directive 2012/19 / EU on waste electrical and electronic equipment (WEEE).

The crossed bin symbol indicates that the device shall not be disposed with regular residual waste.

11 Technical Support

CAEN makes available the technical support of its specialists for requests concerning the software, hardware, and eventually board repair. To access the support platform, please follow the steps below:

1. Login at www.caen.it or register a new account.
2. On the MyCAEN+ area, from the “Dashboard” section (www.caen.it/mycaen/dashboard), register your boards
3. From the “Support” section (www.caen.it/mycaen/support) open a ticket request for the issue you have found.
4. In case of product repair, a CAEN operator will enable the RMA (Return Merchandise Authorization) form directly from the support ticket.

Note: only MyCAEN+ accounts can request technical support. If you have a basic account, please insert your institutional email: if the domain is in our whitelist, the account is automatically updated to MyCAEN+, otherwise an operator will take care of the validation within 48 hours.

Appendix A

Calculation of the K concentration-to-activity conversion factor [4]

Let's assume to have a unitary concentration of K in the soil, corresponding to 10^{-2} g/g, i.e. m_K = 10 g of potassium in 1 kg of soil.

Provided the:

- Avogadro number N_A=6.023 * 10^{23} atoms/mol
- K molar mass M_K = 39.098 g/mol
- ^{40}K isotopic composition $i_{^{40}K}$= 1.17 * 10^{-4} ^{40}K atoms/K atoms

We can estimate the number of ^{40}K atoms (nuclei) as:

$$N_{^{40}K} = \frac{m_K}{M_K} N_A \, i_{^{40}K} = \frac{10\ g}{39.098 \frac{g}{mol}} 6.023 * 10^{23} \frac{atoms}{mol} * 1.17 * 10^{-4} \frac{K\ atoms}{K\ atoms} = 1.80 * 10^{19}\ {}^{40}K\ atoms$$

The general formula A = N / τ can be applied to derive the activity of 10 g of K, knowing that the ^{40}K mean life is:

$$\tau = 1.83 * \ 10^9\ yr = 1.83 * \ 10^9 yr * 365.24 \frac{day}{year} * 23.93 \frac{hour}{day} * 3600 \frac{seconds}{hour} = 5.76 * 10^{16} seconds$$

$$A = \frac{N_{^{40}K}}{\tau} = \frac{1.80 * 10^{19} nuclei}{5.76 * 10^{16} seconds} = 313 \frac{decays}{second}$$

[4] https://www.fe.infn.it/radioactivity/educational/analysis.html

CAEN SpA is acknowledged as the only company in the world providing a complete range of High/Low Voltage Power Supply systems and Front-End/Data Acquisition modules which meet IEEE Standards for Nuclear and Particle Physics. Extensive Research and Development capabilities have allowed CAEN SpA to play an important, long term role in this field. Our activities have always been at the forefront of technology, thanks to years of intensive collaborations with the most important Research Centres of the world. Our products appeal to a wide range of customers including engineers, scientists and technical professionals who all trust them to help achieve their goals faster and more effectively.

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