RH ELECTRONICS

Gamma Spectrometer

NUCLEAR PIONEER MCA

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MCA TECHNICAL DESCRIPTION

The **Nuclear Pioneer RIID MCA** can work as a robust portable Gamma Spectrometer and as a Scintillation Counter Survey Meter. It compatible with small size 25x25mm or with big size 63x63mm NaI(Tl) crystal probe. The MCA has high count rate performance for spectrum mode. It allows you to test high activity samples and to perform gamma spectrum acquisition with CPS up to 10000.

For samples with weak activity you can use real time Background subtract mode for the emphasis of the detected gammas.

The MCA can detect Gaussian shape peaks in real time. It has Peak Data sidebar showing peak energy information.

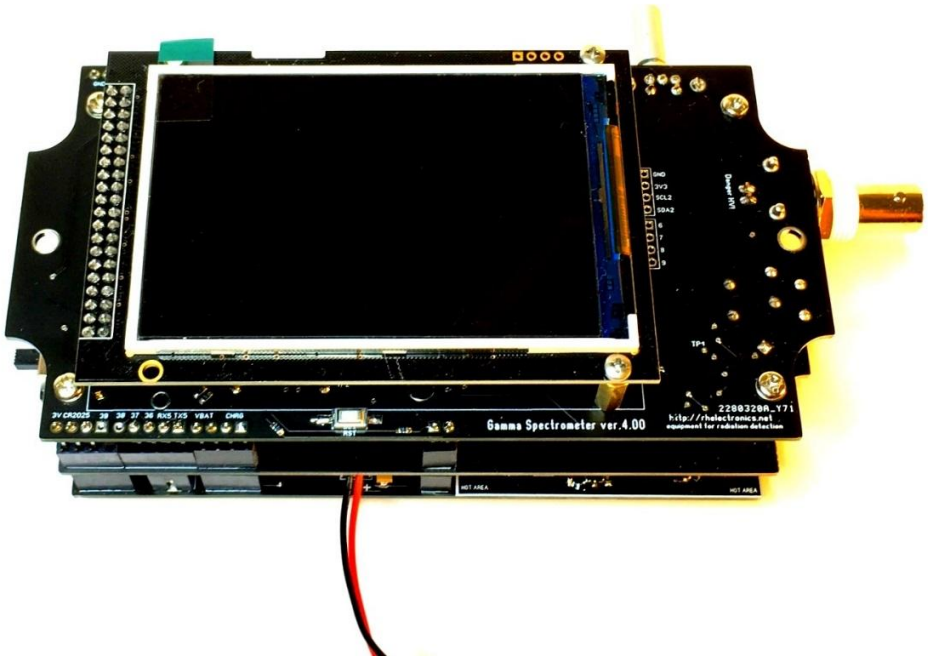
Dose rate reading is energy compensated and normalized to Cs-137 662keV response of the scintillator. For better performance it's recommended to use the MCA with large size NaI(Tl) crystals like 2x2" or 63x63mm.

The board has regulated & filtered positive polarity high voltage for a photomultiplier tube. You can adjust PMT HV in range of 600V-1000V. Secondary internal high voltage allows to connect any 400V Geiger-Muller tube sensor.

Analog circuit of the MCA pulse amplifier has default preset gain ratio. If required, you can re-adjust the pulse amplifier gain with oscilloscope. In case of wrong settings, you always can return to the default ratio as described below in this manual.

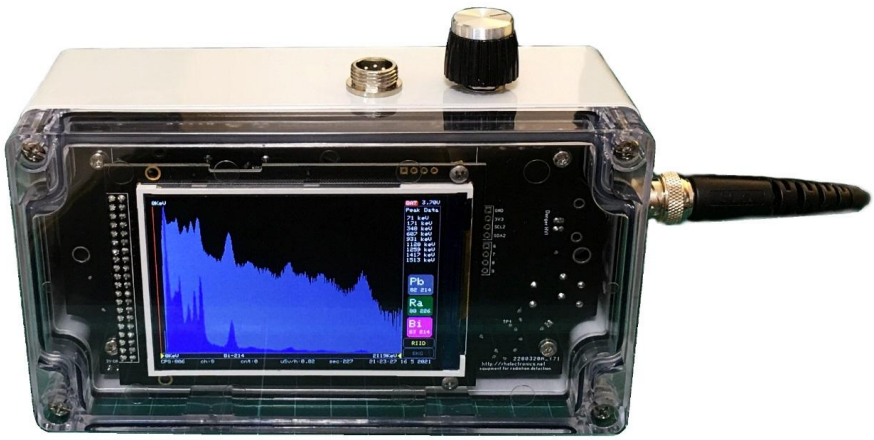
Computer communication is full speed 12Mbit/sec USB port that allows to transfer full spectrum instantly. You can calibrate the unit with simple serial commands or to adjust channel-to-energy scale from MCA unit menu.

Any further firmware update is available to perform with friendly and save-to-use teensy USB bootloader application. It does not require a special hardware programmer; you only need a computer with USB connection to upload the latest firmware file.



MCA Technical specifications 4.16 firmware:

- ARM Cortex-M4 microprocessor
- 12-bit 4096 channels ADC
- TFT LCD 3.5” 480x320 with adjustable backlight level
- Rotary Encoder for controls
- 600V-1000V adjustable high voltage for photomultiplier probe
- 400V high voltage for an internal Geiger Counter
- Adjustable gain & pulse shape pre-amplifier for photomultiplier
- Gamma Spectrometer Mode with RIID (recommended up to 10.000 CPS)
- Automatic Radioisotope Identification library
- Scintillation Counter Mode with PMT and GM Sensor
- Waterfall histogram in Scintillation Mode
- Easy Channel to Energy scale calibration with selectable scheme
- Real time background subtract mode for gamma spectrometer
- Real time Gaussian peak detection
- Activity calculator
- Linear or Logarithmic spectrum viewer
- Energy compensated dose rate calculation
- 0.30 uSv/h doserate alert and 2-sigma CPS alert in scintillation counter mode
- CPS standard deviation calibration for scintillation counter mode
- Sound Mute / Alert / Clicking on every n-particle in scintillation counter mode
- Spectrum LCD zoom 512-4096 channels
- Micro SD card socket for CSV files storage
- RTC (require CR2032 battery for date and time keeping)
- Internal / External temperature sensor configuration
- Adjustable temperature correction
- Oscilloscope menu
- Bluetooth BLE
- 12Mbit USB port for programming, calibration or data downloading
- Easy firmware update via USB and friendly bootloader
- Power supply: 3.7V LiPo battery, battery current consumption 100mA-350mA
- 3.7V LiPo battery charger included in circuit, low battery alert



ENCODER AND BUTTON CONTROLS

Metal Pushbutton or Slide Switch: Power On/Off.

Encoder Short Button Press: In MCA mode it will toggle between Pointer Position scrolling or Spectrum scrolling. In Scintillation mode short press on the button will toggle Sound mode.

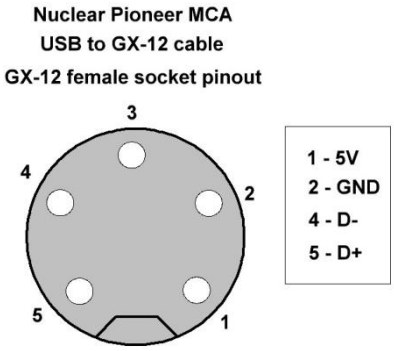
Encoder Long Button Press: will open Menu or confirm selection.

Encoder Scroll: in MCA mode Encoder rotation moves the Pointer or change LCD first channel position. Scroll the red line Pointer Position several turns toward 0keV to change color theme of the spectrum.

In Menu, encoder rotation scrolls between selectable items.

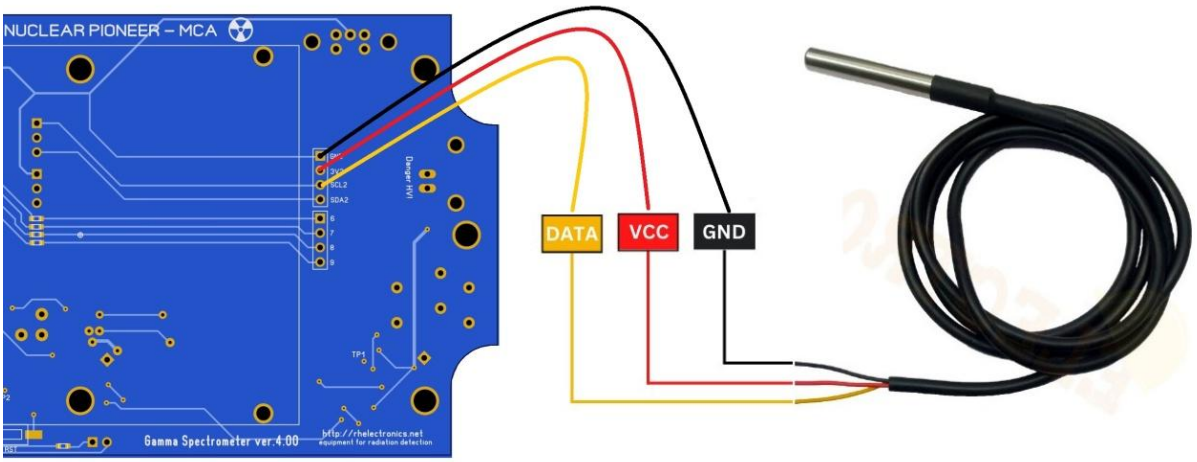
CONNECTORS

USB Port or 5-pin Connector: for charging the battery, firmware updates, communication with PC. Your unit can be with the standard USB port jack or with custom GX-12 cable. For GX-12 version cable is included.



BNC Jack: for connecting scintillation probe, positive high voltage.

External DS18B20 temperature sensor: you can wire an external temperature sensor for scintillation detector as shown on the diagram. Recommended part number: Adafruit 381, Sparkfun SEN-18367 or similar. Default 4.7K resistor is already included on the Pioneer board. However, if the probe is too long you may need to solder additional 2.2K resistor between DATA and VCC.



HARDWARE ADJUSTMENT

Please note, MCA does not support hot plug of the probe! Connect / disconnect the probe only after the MCA is powered off and at least 10 seconds passed to allow HV capacitors discharge!

The document describes calibration process for the hardware and for the software of the MCA you may need to perform, if you change a NaI(Tl) probe, or if you want to set up the non-calibrated MCA unit.

All Scintillation Crystals always has some light output brightness difference. Any photomultiplier tube from the same batch can come with noticeable gain tolerance even on the same high voltage bias. If you are using an old stock or surplus-sale probe, settings and resolution for similar probes can vary. The performance of the gamma spectrometer is strictly depending on your NaI(Tl) scintillation probe specifications and hardware/software calibration of the unit.

For hobby and education people often uses old stock or surplus-sale items to assemble their own detectors, that makes project specifications unpredictable.

On the first review, make sure your NaI(Tl) probe has compatible wiring and divider total resistance ~100 Mega ohm. The MCA supports 2-wire configuration wiring for positive high voltage:

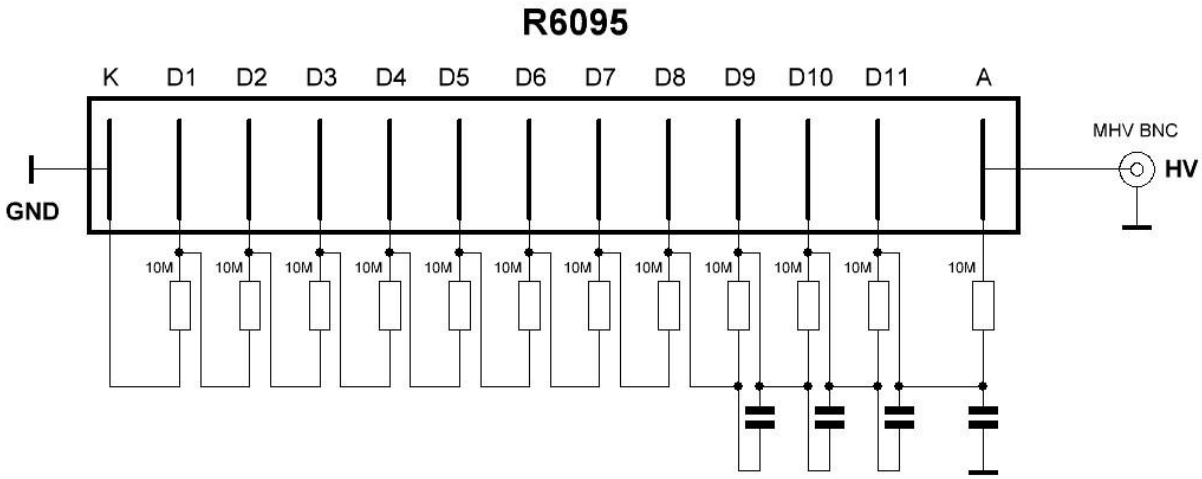


Fig.1

One of the possible wirings is shown on the Fig.1, a typical example for R6095 Hamamatsu tube. Capacitors are 10nF-47nF 2kV, resistors are 12x10Meg. Metal enclosure and magnetic shield are recommended for the probe. In some circumstances mu-metal and probe enclosure must pass degaussing treatment to release magnetization of the metal caused by long-term storage.

The MCA high voltage output can be adjusted to 600V-1000V and it fit low-voltage range PMT tubes. Please avoid shorting high voltage on BNC socket and do not use hot plug of the probe because HV arcing across the BNC jack can ruin sensitive electronics. Recommended BNC cable part number CT2942-100. Recommended BNC jack for probe is 31-221-RFX.

For complete calibration prepare multimeter, computer, set of isotopes for channel-to-energy calibration, patience☺

It's recommended to obtain an oscilloscope 500Msa/s or better, just to verify you get correct pulse shape and low noise. If you don't have oscilloscope, don't worry – you can use default settings for the gain potentiometers as described below and an internal oscilloscope menu.

Limitation of one Coaxial HV Cable.

Nuclear Pioneer uses one BNC cable connection to supply HV bias and read a low current short photomultiplier pulses. One cable wiring method choice was made only for wide compatibility and easy replacement of the probes. Within professional instruments one cable wiring used rather for scintillation counters. When it used for gamma spectroscopy, where electronics needs precisely read weak unbuffered signal from the anode, you have to remember that the HV BNC cable is also your signal path! Cable is the integral part of your detector. Every coaxial has serial resistance and stray capacitance acting as a RC filter. When you adjust pulse shape and gain, it adjusted for your probe and for your cable at once. That's why if later you exchange the cable, or if the cable is low quality, then the gain calibration become out of range.

Pulse & Gain adjustment.

Pulse shape must meet compatibility requirements of the MCA analog to digital converter. Signal gain and tube HV bias can be adjusted with multiturn potentiometers. Connect an oscilloscope to the **TP1** with ground reference to **Analog GND**. Set scope for 2uS time base and 200mV resolution. Connect the NaI(Tl) probe wired with high impedance divider.

The pair of 2pcs 3006P multiturn potentiometers on the upper board are controlling amplifier gain ratio. Default preset for the first is ~6K, default preset for the second is ~108K as shown on the Fig.2. **Recommended to start with these default values.** Please set 6K-108K before you power up the MCA. The ratio of these multiturn potentiometers controls signal gain.

Small 2K 3362P potentiometer under the LCD module comes with default preset on the middle tap. It helps to filter out low energy noise and normalize ADC response in low energy range <200keV.

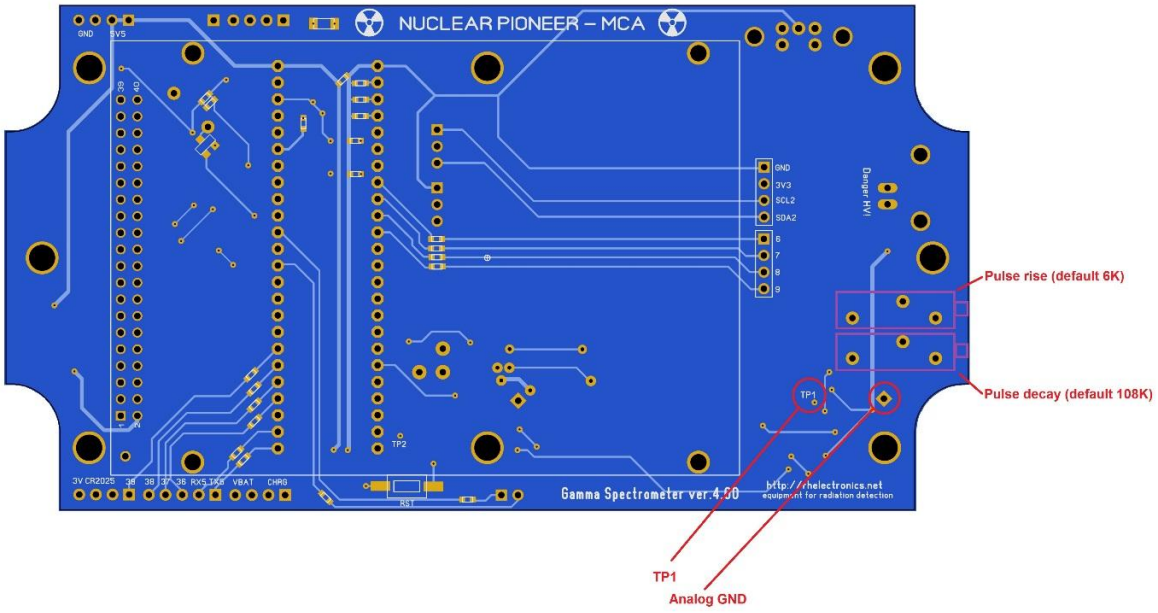


Fig.2

High voltage is adjusted with the 3006P multiturn potentiometer on the bottom board. Clockwise rotation will reduce HV, anti-clockwise rotation will rise HV.

Apply Cs-137 or Ra-226 source on the probe and turn on the MCA. Set LCD ZOOM X to 4096.

If you don't see any spectrum on the LCD check pulses on TP1 with scope, check PMT probe wiring is correct and slowly rise high voltage bias. Adjust high voltage / gain ratio to set 662keV Cs-137 or 609keV Ra-226 peak to amplitude ~ 800mV (or ~channel #1000). Suggested mV value is not mandatory, total gain ratio settings depends on optimal energy range for your NaI(Tl) probe. Some probes will work fine with 12K/60K gain ratio, others gives good signal with higher gain ratio like 6K/150K.

Each time during calibration when you adjust HV or gain ratio, you also need to restart the spectrum to see immediately if the peak location shifted to the desired channel.

To check photopeak channel number, you can scroll the red line pointer with encoder over the LCD.

Verify that you can get on spectrum 32keV from Cs-137 or 26keV-59keV from Am-241. You can set zoom=512 from the menu to view the spectrum in details.

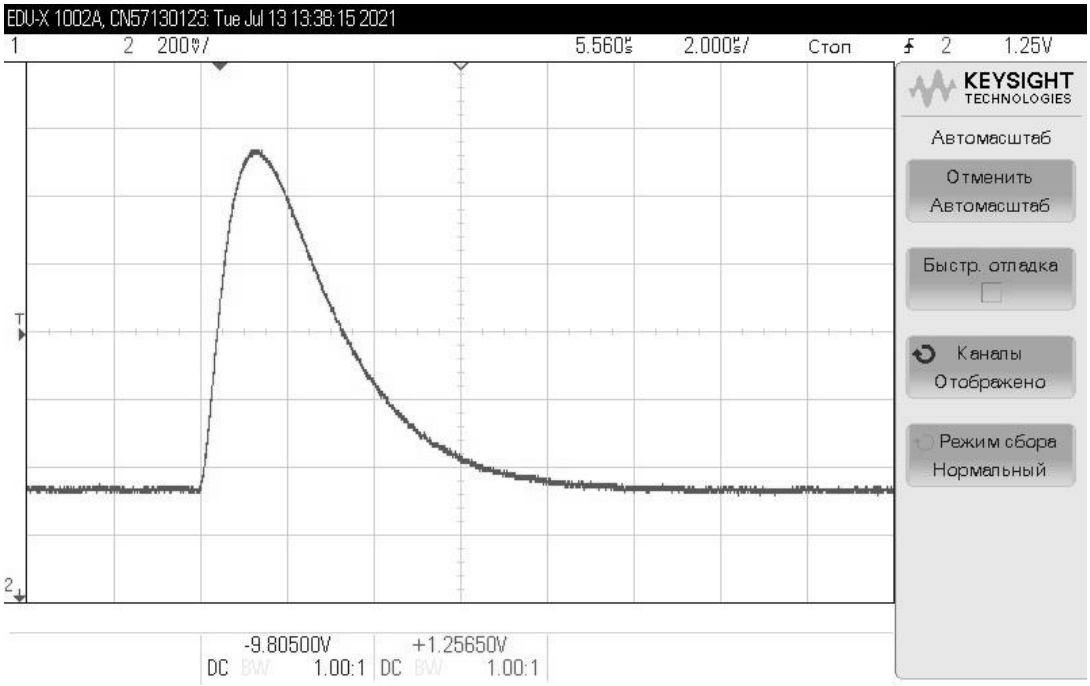


Fig.3a

If you have an oscilloscope you can read pulses on TP1. Typical pulse shape is shown in Fig.3a. Amplitude of a random pulse will depend on detected photon energy. Normally, Am-241 59keV needs to be in range of 70mV-100mV max. amplitude. Pulse rise time recommended below <5us. Pulse decay time has to be short as possible <20us. If you have a slow scintillator like CsI(Tl) then you may need to switch the ADC into slow mode with service serial command **s102** as described in Serial Commands chapter.

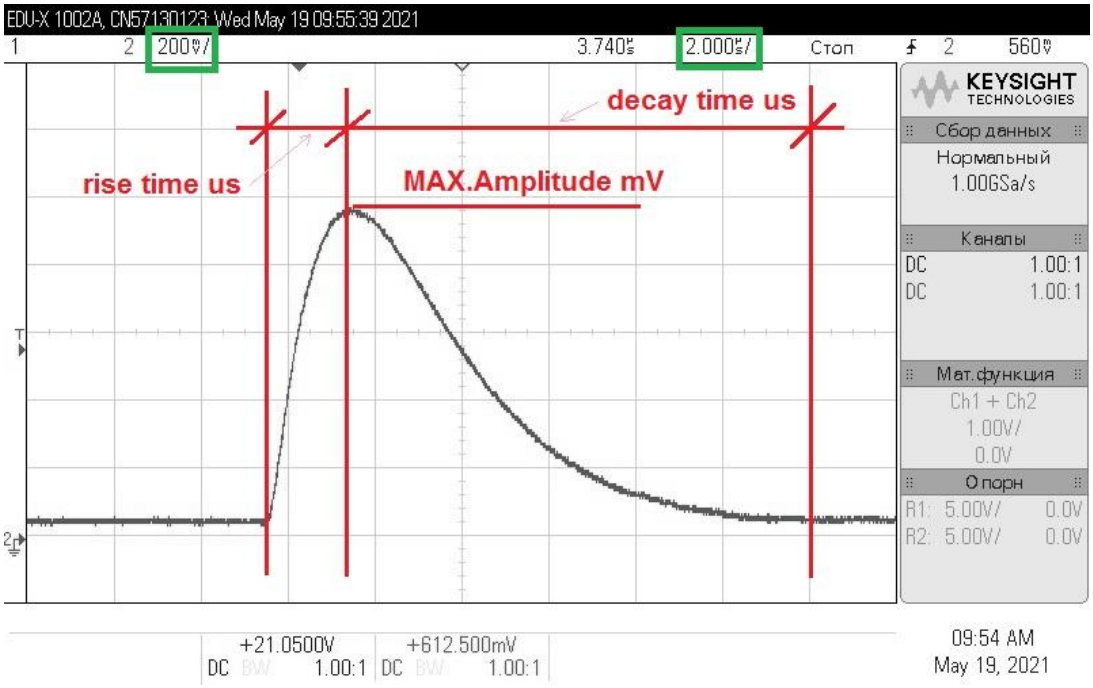
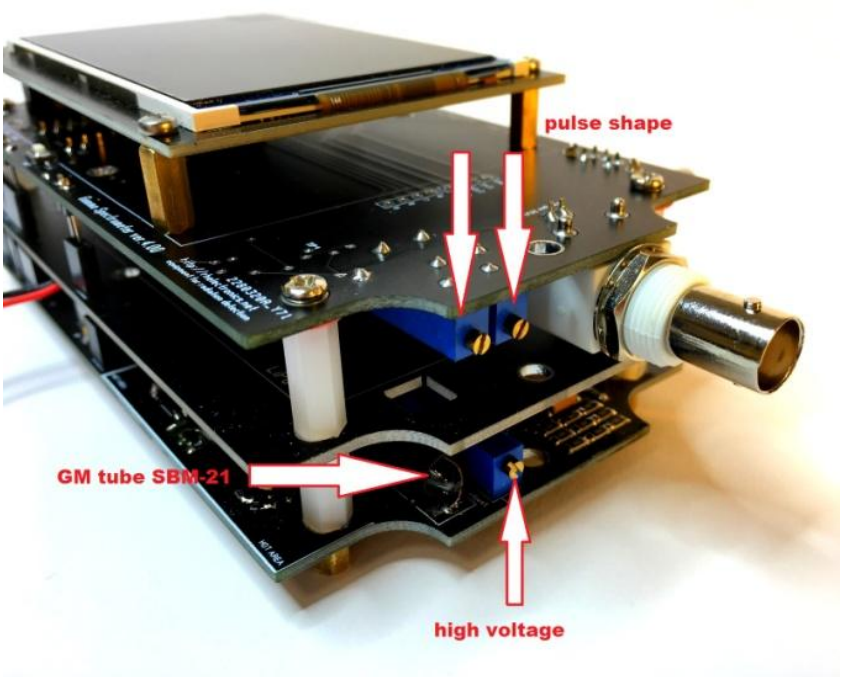


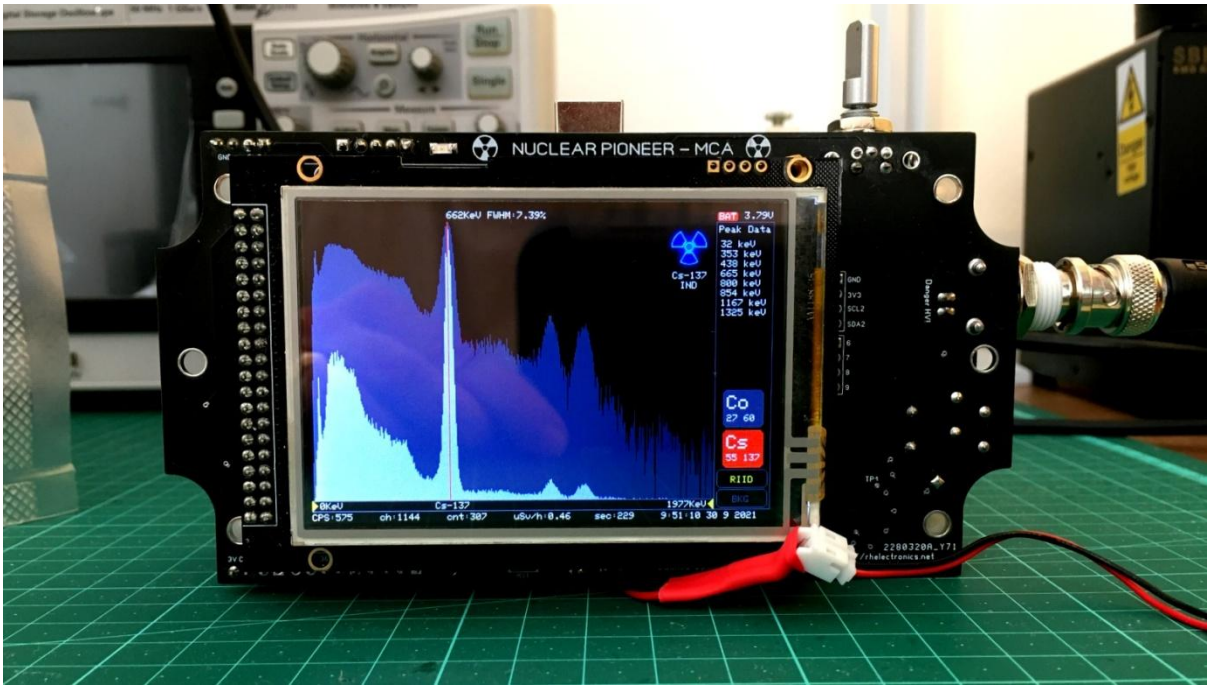
Fig.3b

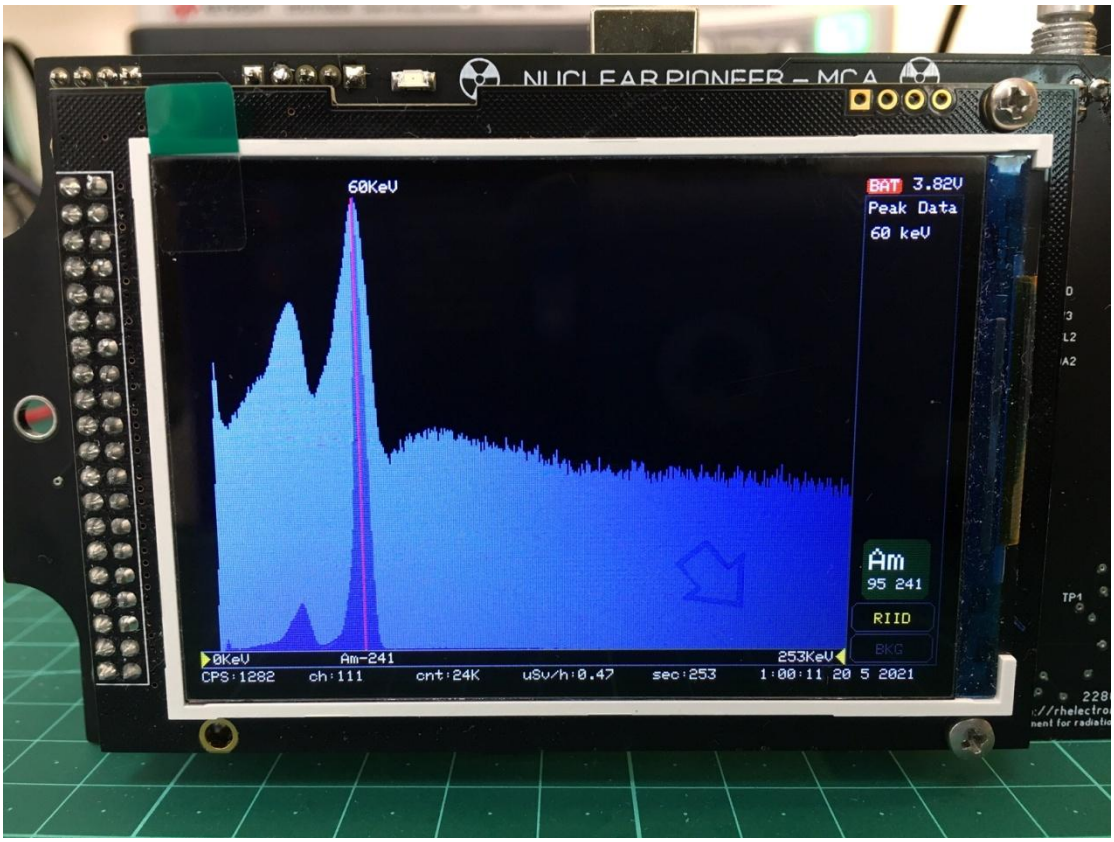
Before you can continue with software calibration, it suggested to verify that you can get good shape low and high energy spectrum on the LCD. For low energy spectra use Am-241 and make fine tuning of small 2K potentiometer under the LCD to get rid of unwanted noise. For high energy spectrum checklist, you can use Co-60, Th-232, Ra-226 or Eu-152 to verify the gain settings has good linearity.

Different BNC cables can decrease total gain of the signal or add large stray capacitance to the signal path or to introduce noise or add a high voltage leakage. That's why is suggested to use high quality cable or to use recommended part number CT2942-100. Remember that BNC cable is actually the same path for HV bias and for low current PMT signal.



If the amplifier gain, hardware noise level and PMT HV bias are adjusted correctly you'll be able to get good quality spectra like on the following photos:

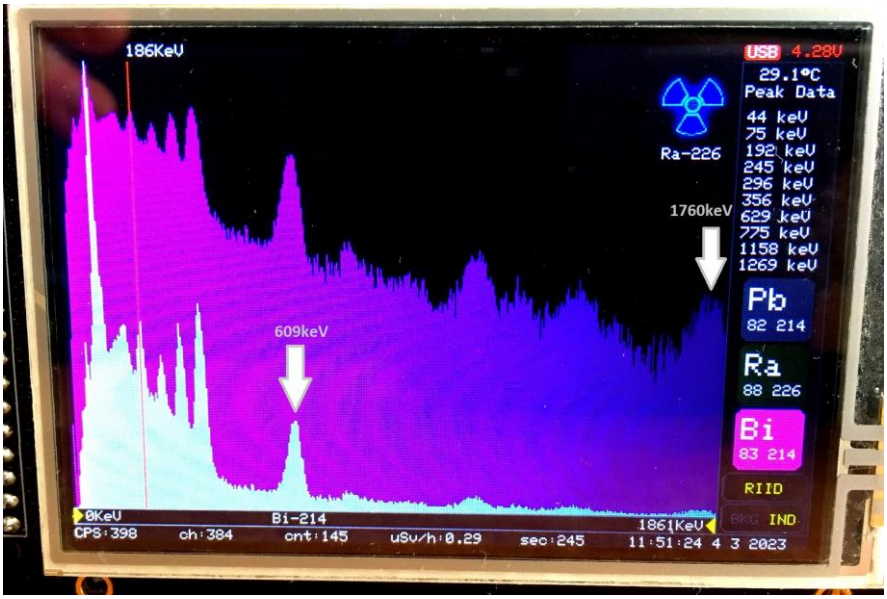




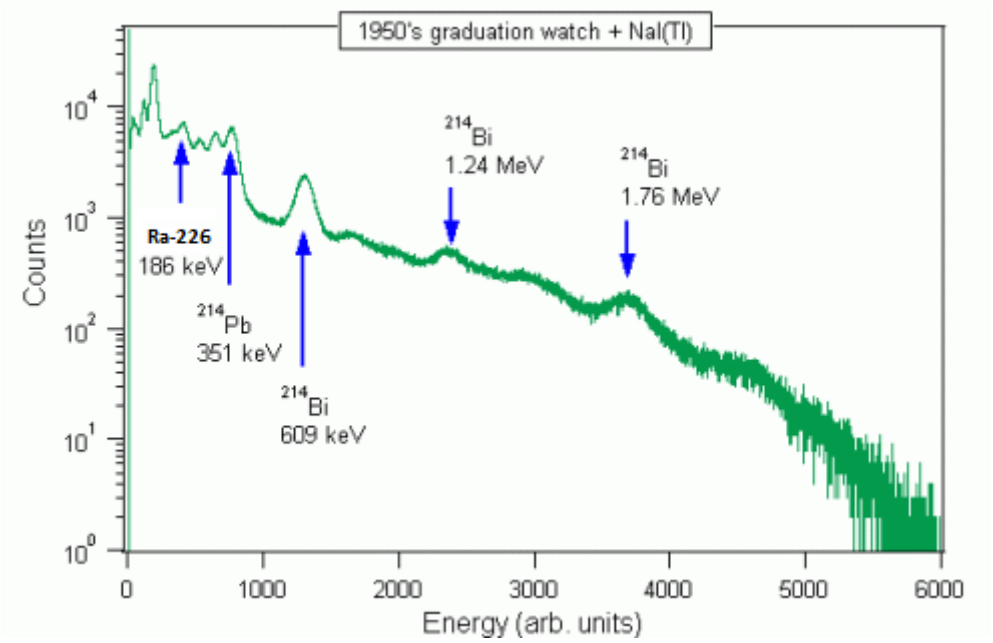
Fine tuning of the **2K** potentiometer under the LCD module can help to improve low energy response of the ADC and to get rid of the low energy parasitic noise <200keV. The best way to test low energy spectrum response is to use Am-241 sample and to set ZOOM X=512 in **LCD ZOOM X**.

While adjusting amplifier gain and HV bias, you need to place centroid of the 59keV Am-241 at about ~100 channel bin of the ADC. If you less interested in energy >1500keV, then total gain can be set even higher to archive an emphasis of the low energy region. Usually, most common region of the spectrum interest is located below 2MeV

For hardware gain calibration with Ra-226 you need to set the total gain to allow 3 peaks appears visible on the LCD: 186keV, 609kev and high energy 1760keV (when **LCD ZOOM X** set to 4096). While adjusting HV bias and total gain with Ra-226 it suggested to set Bi-214 (609keV) above the bottom line mark "cnt:" (~1000 channel bin of the ADC); and the highest peak's centroid of 1760keV has to be visible on the right side of the spectrum. The highest energy peak like 1760keV usually visible in log scale only.



The following picture demonstrates the typical Ra-226 spectrum in case you are not sure about peaks related energy:



MENU

- RETURN – return from menu to current working mode display
- RESTART – restart a new spectrum
- SAVE SPECTRUM – will safe CSV file to uSD card with name XXXXXXXX.CSV
- VIEW SPECTRUM – load CSV file from uSD card
- LCD ZOOM X – change LCD spectrum zoom 512-4096 channels
- LCD DRAW MODE – toggle between spectrum draw mode (line/bar)
- BACKGROUND – set or turn on/off background subtract mode
- UNLOCK CALIBRATION – allows to unlock 3-points channel-to-energy calibration and to select calibration scheme. Allows to enter 3+1 point sub-menu.
- SPECTRUM TIME – set time in seconds for spectrum acquisition
- BACKLIGHT – change LCD backlight level
- RIID f(x) icon – open RIID tolerance menu
- BLE icon (on/off) – power on/off internal Bluetooth module (optional)
- SIGMA icon (on/off) – activate CPS standard deviation calibration for scintillation mode
- LAMDA icon (on/off) – activate activity calculator, enter activity menu to select geometry
- PLST f(x) icon – open Oscilloscope and Temperature correction menu
- MCA icon – toggle gamma spectrometer mode
- SCI icon – toggle scintillation counter mode
- GM Tube icon – toggle internal Geiger Counter circuit (active in SCI mode only)

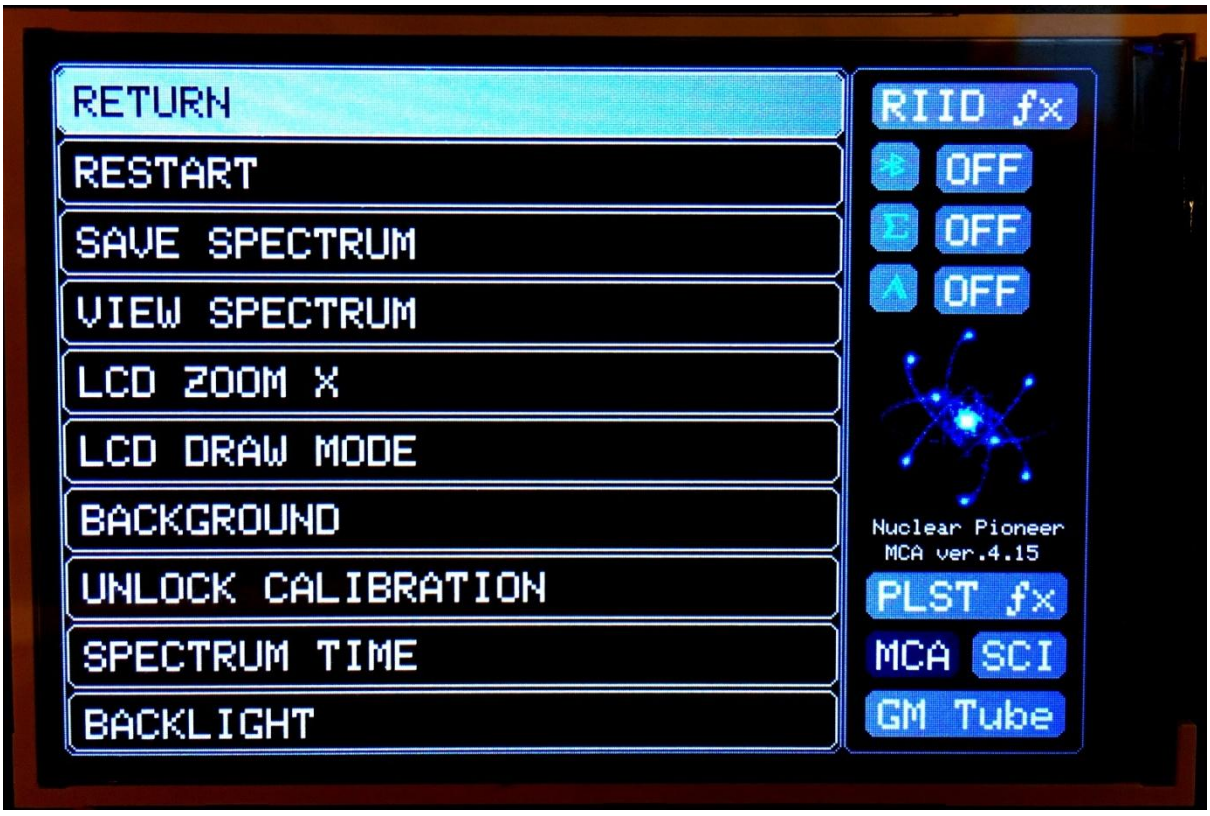


Fig.4

INTERNAL OSCILLOSCOPE

Enter **PLST f(x)** sub menu to open built-in oscilloscope. The scope window allows to observe sampled pulsed and to estimate pulses amplitudes. If you don't have an oscilloscope for pulse shape calibration on TP1, then internal scope can definitely help checking if you are within the recommended limits for pulse's timing and amplitudes. Correctly adjusted NaI(Tl) pulse shape will result as an almost ideal trapezoid sample as shown below.

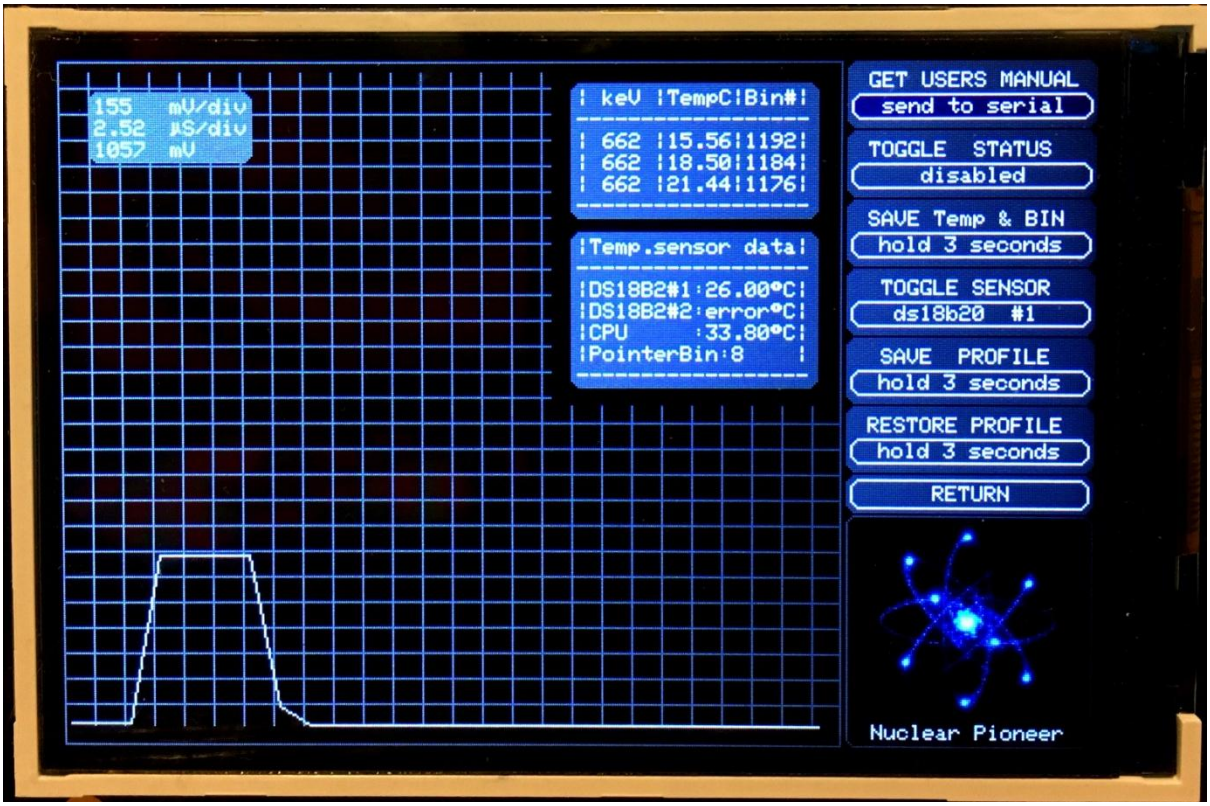


Fig.5

Very long pulse decay tail, or longer than 5us pulse rise time may result distortion in the sampled pulse shape. If you are using a slow scintillator like CsI(Tl) it strongly recommended to verify signal on TP1 with real oscilloscope and maybe to switch the ADC into slow mode.

TEMPERATURE CORRECTION MENU

- GET USER MANUAL – sends temperature correction instruction to serial monitor
- TOGGLE STATUS – turn on/off software temperature correction
- SAVE Temp&BIN – used for temperature correction calibration procedure
- TOGGLE SENSOR – set internal or external temperature sensor as the main sensor
- SAVE PROFILE – create file on SD card with current temperature correction profile and energy scale calibration
- RESTORE PROFILE – restore previously saved profile. If SD card is missing or profile file does not exist on SD, it will restore default temperature profile from a factory setup.

Please note, default factory profile is not intended to work correctly with your probe. It only allows restoring the values if you mess with the calibration steps. To set temperature correction to ENABLE you have to perform the full calibration as described in the **GET USER MANUAL** instruction!

SOFTWARE CALIBRATION

ENERGY SCALE CALIBRATION

Before starting energy calibration, choose for you the preferred scheme: Cs-137 K40, Ra-226 or Eu-152 and make spectrum acquisition to locate channel number for the following energy peaks. You can move red pointer line over the LCD right-left with the encoder.

3-point energies are used in the default schemes:

- **Cs-137 K40 scheme:** 32keV, 662keV, 1460keV
- **Ra-226 scheme:** 186keV, 609keV, 1760keV
- **Eu-152 scheme:** 122keV,344keV, 1408keV
- **Co-57 I-131 scheme:** 122keV,364keV, 637keV

Write your note with channel number for 3 calibration points, depending on your preferred scheme. In our example we use Cs-137 K40 scheme. Enter menu **UNLOCK CALIBRATION** and select your scheme. Return to the spectrum. You will see 3 triangles in the upper screen line. Each triangle and dashed line indicates channel position of single a calibration point.

For example, if you selected Cs-137 K40 scheme, move the red pointer to the centroid of the first 32keV photopeak and shortly press the button. It will save to the memory the channel bin number for the first peak. Repeat marker positioning for the second and for the third energy. If done correctly, you will hear confirmation melody and the MCA will re-calibrate the scale by auto with all new values. If you made a mistake, then just start over the energy calibration process.

When calibration process is unlocked, you can see yellow “unlocked” message on the bottom line. Important to perform energy scale calibration procedure because RIID detection and dose rate calculation are dependable on this data.

On the photo below we just picked the first 32keV peak and moving the pointer toward next 662keV peak. The third 1460keV peak usually visible only in dark blue log scale, but it enough for you to locate the approximate centroid bin. Video instruction available here: https://youtu.be/1jUABb_zQsE

Fig.6

3+1 ENERGY SCALE CALIBRATION

Firmware 4.16 added an option to perform energy scale calibration by four points. In Pioneer it called 3+1 method and it allows to keep backward compatibility with calibration points saved before 4.16 firmware. After making the standard 3-points calibration with the selected scheme, you can enter **4-rd POINT** sub-menu and set additional point manually. To enter 4-rd point menu navigate:

MENU -> UNLOCK CALIBRATION -> 4-rd POINT

Why it required? NaI(Tl) and CsI(Tl) crystals are known as having bigger non-linearity region in low energy range, compared with high energy region. That's why the simple 3-points polynomial calibration not always allows to get the best scale fit in both regions. Fourth data point allows to fit the scale better to the scintillator response close to the scale edges. On the photo below shown **Ra-226 scheme calibration** (**e1**=186keV, **e2**=609keV, **e3**=1760keV) with picked 26keV from the Am-241 as a 4-rd **e4** point:

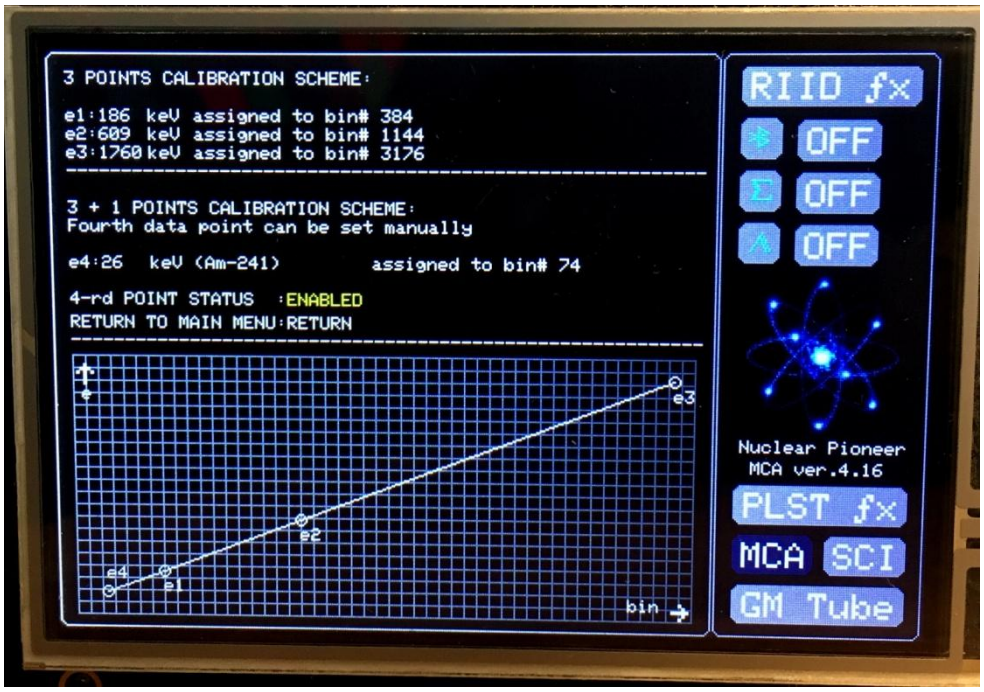


Fig.7

Fourth data point can be selected from the pre-defined list according your calibration scheme: 26keV (Am-241), 46keV (Pb-210), 122keV (Co-57 or Eu-152), 186keV (Ra-226), 1460keV (K-40). A point that matches energy to your current 3-point scheme is excluded from the list automatically.

You need to select the **e4** energy and set manually channel **bin#** (ADC bin) where this peak is located on your spectra. The point can be ENABLED / DISABLED / changed any time. If you cannot set ENABLE status means that you set probably out of range value and the Pioneer will prompt you about the error with 3 low tones.

SERIAL COMMANDS LIST

During MCA load screen, if one of calibration parameters is detected as out of range value, you will hear several low tone alerts. You may need to re-check and set all calibration parameters to be sure MCA operates correctly.

For the next following parameters adjustment, you can use Arduino IDE Serial Monitor with Teensyduino. Usually all these parameters are rarely changed and calibrated just once for your probe.

https://www.pjrc.com/teensy/td_download.html

Following parameters can be changed by sending serial monitor command:

- set RTC time and date
- set factor for energy compensated doserate calculation
- set factor for direct cps->doserate conversion
- set LLD lowest level detection ADC channel
- set HLD highest level detection ADC channel
- set crystal size
- set BLE module type
- set Geiger tube model
- set ADC mode for fast/slow pulse
- execute service commands

RTC time and date:

send first command: **T**

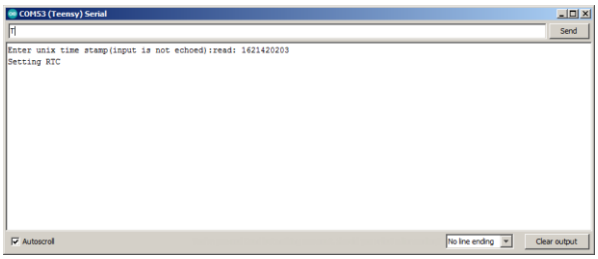
send second command Epoch timestamp like a: **1620750120**

You can send the command in one line like: "**T1621420203**".

use https://www.unixtimestamp.com/ or https://www.epochconverter.com/ to generate timestamp value long int number. You need to take care of time zone when generating time stamp in the website.

After first command T sent, serial monitor has 5 seconds time out to accept the new time stamp.

Epoch timestamp: 1621420203
Timestamp in milliseconds: 1621420203000
Date and time (GMT): Wednesday, 19 May 2021 year., 10:30:03



The doserate energy compensation function by default is programmed for 51x51mm NaI(Tl) crystal. If you are using a different crystal volume then it's recommended to set crystal size. Send crystal volume command through serial:

C1 – will set 51x51mm crystal

C2 - will set 25x25mm crystal

C3 - will set 10x40mm or 15x25mm crystal

C4 - will set 63x63mm crystal

C5 - will set 40x40mm crystal

Please note, you also can select your crystal size in Activity Menu when selecting the geometry for the test. The crystal selection in the Activity Menu will be saved to the memory of the device same as C command.

It's important to set the size of the crystal to get correctly calculated energy compensated doserate! If your crystal volume not in the list then you can set the closest volume from the C list. With a big crystal selected, particle counter beeper in SCI mode will make a beep for every n=50 detected particle. With a small crystal – for every n=15 particle.

Energy compensated doserate factor:

send first command: **D**

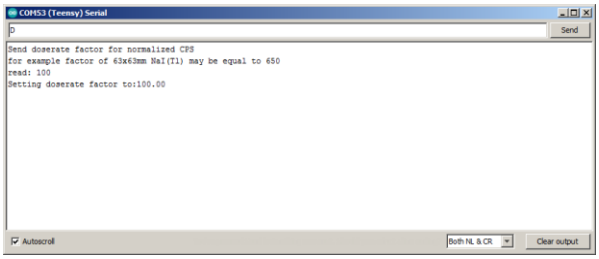
send number in format like: **650**

You can send the command in one line like: "**D650**"

Factor depend on your NaI(Tl) crystal volume. Serial monitor return accepted value. You can repeat the command to change the value again. Big crystal requires higher value, for example 63x63 may require 600-700 factor. Small crystal like 25x25 may requires factor equal to 100-150. Check on normal background level that you get 0.05-0.07 uSv/h doserate reading while a non-compensated reference dosimeter with GM counter read as 0.10-0.12 uSv/h. **Energy compensated doserate takes into account the energy of every detected photon**. That's why compensated normal background will result a little bit smaller uSv/h numbers than a typical reference dosimeter with Geiger Muller detector. It because GM dosimeters are calibrated with 662keV Cs-137 while the natural background is mostly below 300keV.

In some areas you may need to use a reference energy compensated dosimeter to get a known background level.

If you have high activity Cs-137 calibration source and calculated doserate value for known crystal geometry&distance, then you can easily find the correct factor with it by placing the probe at the correct distance. For calibration with a reference source it required to use high activity sample with known activity larger than 10uCi, or better >100uCi. That source is able to create a uniform field inside the whole volume of the crystal at the distance of 30-100cm.



Not compensated direct doserate factor:

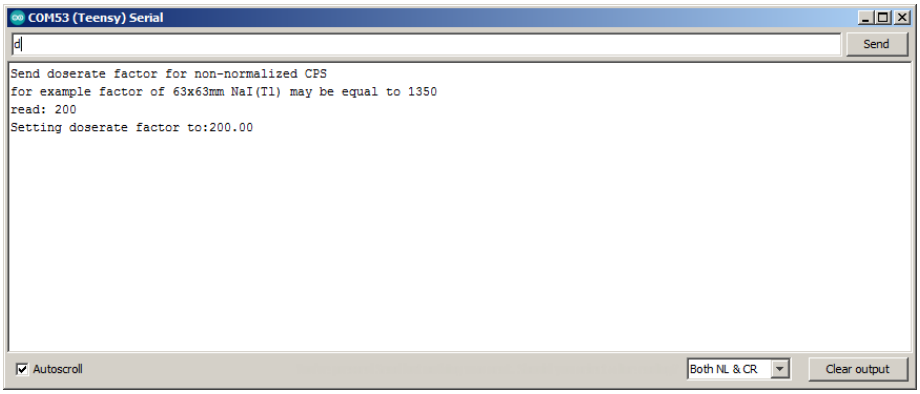
send first command: **d**

send number in format like: **1350**

You can send the command in one line like: "**d1350**".

Factor value depend on your NaI(Tl) crystal size. Serial monitor return accepted value. You can repeat the command to change the value again.

Non compensated Doserate = CPS / d factor. The d factor can be easily extracted from this formula.



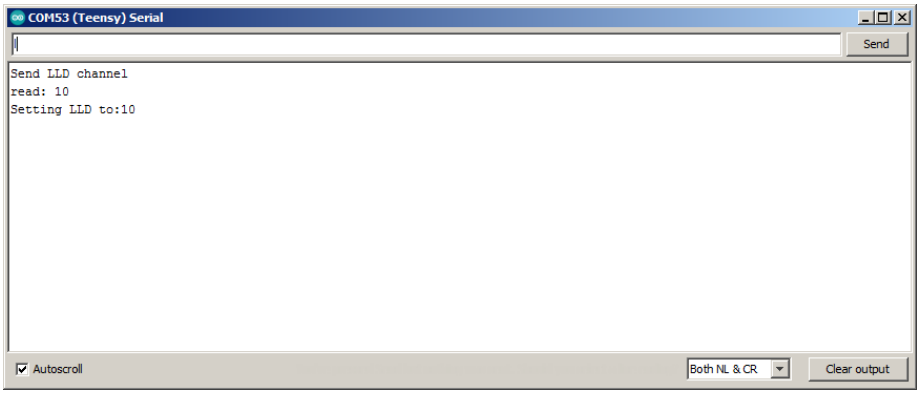
LLD lowest level detection:

send first command: **l**

send number like: **10**

You can send the command in one line like: "**l10**".

The lowest channel number for ADC to detect. Helps to filter out noise caused by PMT dark current or HV ripple. In some applications, you can use it to set required energy range starting point to detect only a specific region. Minimum allowed value is 10.



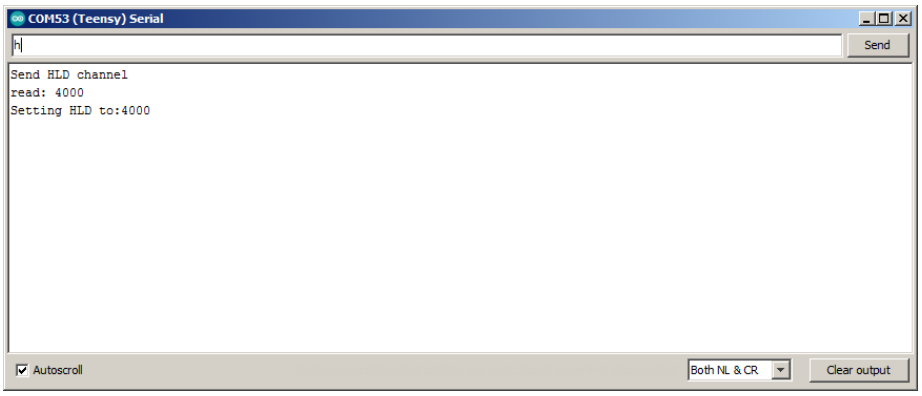
HLD highest level detection:

send first command: **h**

send number like: **4000**

You can send the command in one line like: "**h4000**".

The highest channel number for ADC to detect. Helps to filter out cosmic muons. In some applications, you can use it to set required energy range end point to detect only a specific region. Maximum allowed value is 4095.



Additional USB Serial terminal commands:

The MCA has additional serial commands unrelated to calibration. It can be used to download CSV data to computer or to erase a file from SD card.

G – will trigger complete spectrum download to computer

If you need to download a specific CSV file to computer, you can load the required spectrum into memory from **VIEW SPECTRUM** menu and after that use Serial Monitor "**G**" command to send out the whole spectrum data to computer. Or you can use "**G**" command during normal spectrum acquisition at any moment.

R – will trigger spectrum restart.

e – command to erase a single CSV file from SD card. Followed by **e** you need to send file name to erase. For example, **e12012215** will erase file with name timestamp 12 Jan 22:15

r – command to send out SD file's names list to the Serial monitor.

RIID Training command:

Command to create a training spectra for your probe / geometry for Cs-137, Ra-226, Am-241,Th-232. The data will help to identify these isotopes faster with your probe. To train the MCA for one of the isotopes make a good spectrum with correct channel-to-energy calibration. When the spectrum is ready send following commands through serial:

A1 – for creating Cs-137 data file

A2 – for creating Am-241 data file

A3 – for creating Ra-226 data file

A4 – for creating Th-232 data file

A new file will overwrite an old, if it exists. If a file was made by mistake you can delete any of these files by sending commands:

E1 – delete Cs-137 data file

E2 – delete Am-241 data file

E3 – delete Ra-226 data file

E4 – delete Th-232 data file

LCD Backlight PWM frequency:

b – command to set backlight PWM frequency. Followed by b you need to send the frequency in Hz, for example **b1000** will set the PWM frequency to 1000Hz. Default is 1000Hz.

Service commands:

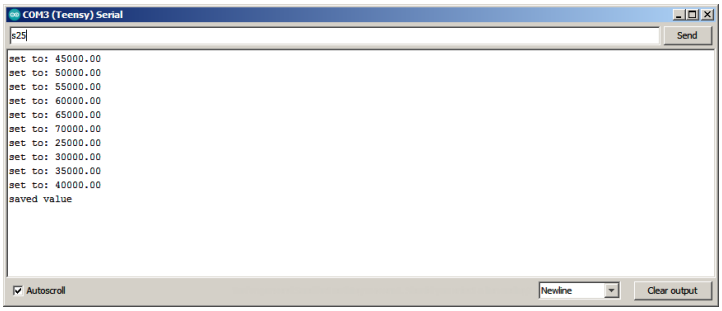
s101 – will set the ADC for fast pulses.

s102 – will set the ADC for slow pulses with long tail >20us.

When working with slow scintillators like CsI(Tl) or an external SiPM pulse shape pre-amplifier you may not able to adjust the pulse shape to meet MCA specifications because of the long decay tail of the CsI(Tl). In this circumstance you need to switch the MCA software to work with slow pulse. If your pulse decay time is longer than 20us it's recommended to toggle s102 command via serial monitor prior using and calibrating the device.

s2 – will toggle Compton HIDE parameter. Function operates with an abstract units; you can set it in range of 25000-70000 with step of 5000. Default value for 63x63 8% resolution crystal is 50000. If your crystal is small and has 7% resolution then you can try to reduce the value down to 35000-40000. To see influence of the settings changes, just restart or reopen a spectrum file with Compton HIDE active mode.

s25 – will save the new preset for Compton HIDE that previously was set with s2 commands. If you do not send s25 command after toggling numbers with s2, then new setting will not be saved into settings memory.



s10 – will set BLE module type for BM71BLE / RN4871 (see BLE section for more details).

s11 - will set BLE module type to BT4502 (see BLE section for more details).

s12 – will return processor board type Teensy 3.5 or Teensy 3.6. Since 4.13 firmware we have added support for Teensy 3.6 boards. If you are not sure what type of the processor board your unit have installed, please use this command to verify and use the correct HEX file for download.

s13 – will toggle Geiger Muller type and will change the doserate factor for GM sensor. Following GM sensors are supported: SBM-21, SBM-20, LND-7312, Si29-BG. Send this command via serial monitor several times to toggle the GM sensor type. The command returns GM tube name as set.

s57 – will restore default initial table of temperature correction points.

s1818 – will turn on live spectrum logging for https://spectrum.nuclearphoenix.xyz/

More service commands maybe added in the next updates.

RADIOISOTOPE IDENTIFICATION DEVICE RIID F(X)

Radioisotope Identification Device (RIID) is an instrument that designed to determine the identity of radioactive materials by measuring the energy of the emitted gamma rays. Identification made by automatic algorithm according library of the isotopes included in the device memory.

Firmware 4.16 includes following nuclides in the library: Cs-137, Ra-226, Th-232, Bi-214, Ba-133, U-235, N.O.R.M., Am-241, Lu-177, Lu-176, Eu-152, K-40, Co-60, Co-57, I-131, F-18, Tc-99m.

The accuracy and performance of the RIID side bar is strongly depending on energy calibration function accuracy, probe linearity and crystal volume. It's recommended to use 2x2" NaI(Tl) crystal for better performance of the RIID. If the energy scale calibration was completed correctly, the RIID will start to identify isotopes in real time automatically according selected library type: **Industrial and N.O.R.M or Medical**.

False positive can happen, and it usually caused by wrong channel picked during energy calibration, small integration time for a given crystal volume, too complicated spectrum with Compton overlay, noise or low linearity of a photomultiplier, limitations of the algorithm and the library, uncompensated temperature drift.

Video demonstration of the RIID performance:
Nuclear Pioneer RIID with 63x63mm probe: https://youtu.be/HJWBur8yqVU
Nuclear Pioneer RIID with 51x51mm probe. Mixed sources: https://youtu.be/mQOOVvGnjcg
Nuclear Pioneer RIID with tiny 6x6x30mm crystal: https://youtu.be/r843jDDyRSc

To set your RIID you'll need to do: energy scale calibration; set correct crystal volume; if required, adjust tolerance in RIID f(x) menu. If you are using small crystal size then it also recommended to make spectrum training with serial command (refer page #16).
In **RIID f(x)** menu you can toggle library type, turn on/off Compton hide function and set detection tolerance for every isotope in the library. Default settings for tolerance are all 0%. Tolerance is bounded with crystal size, that's why if you get too much false positive or low response rate then first check if you have set correct crystal volume.

To reduce false positive rate for a specific isotope reduce tolerance %. To increase detection rate of a specific isotope increase tolerance %. Normally you may set tolerance for your probe in range -25% to +25%. If you get correct RIID response only with a higher % then we recommend to contact technical support to check the reason.

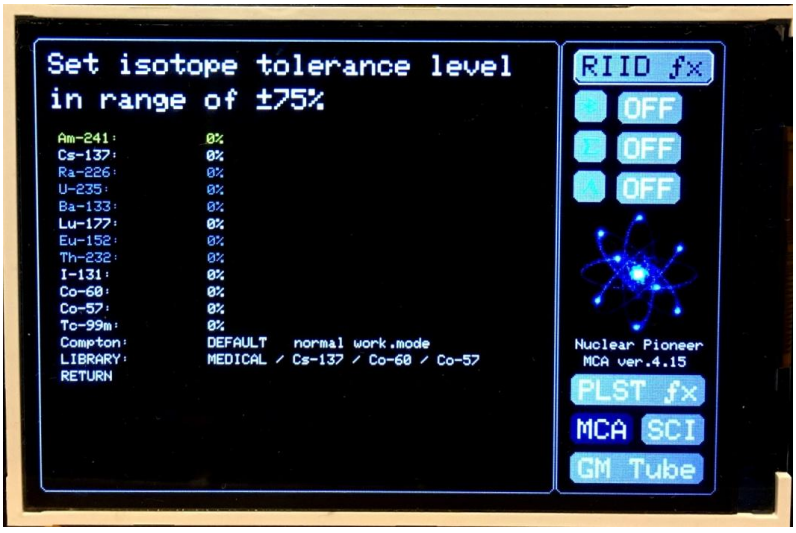


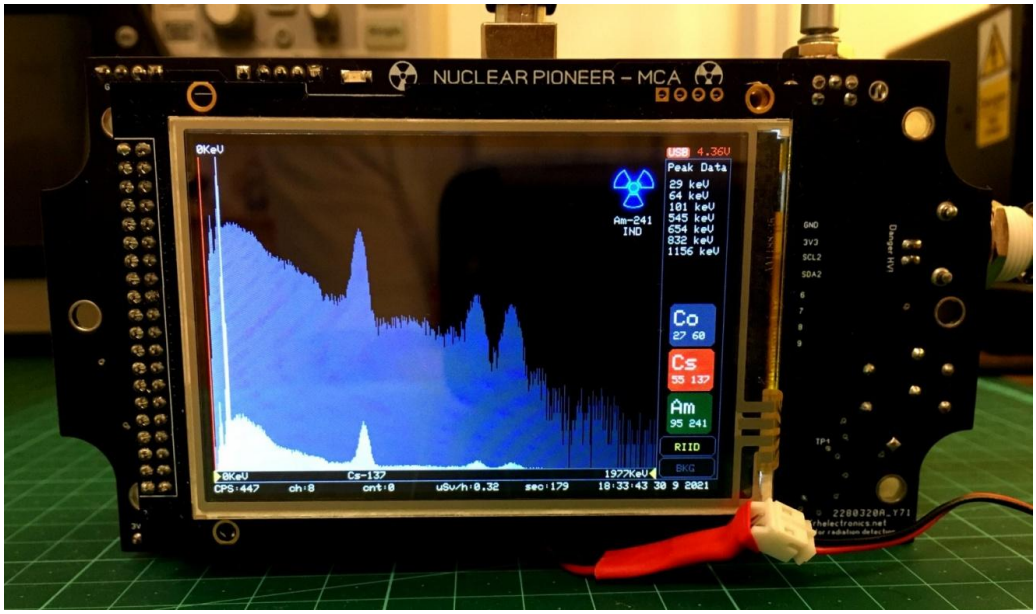
Fig.7

Compton HIDE offers software algorithm for removing Compton continuum from the spectrum. Hide mode can be useful for analyzing N.O.R.M. spectrum in situ when the source is shielded by the environment (walls, soil, constructions). Hide mode mostly useful for ore, natural minerals or geological samples. Hide mode also can help to detect radon Rn-222 daughters behind natural background or to identify very low activity Ra-226.

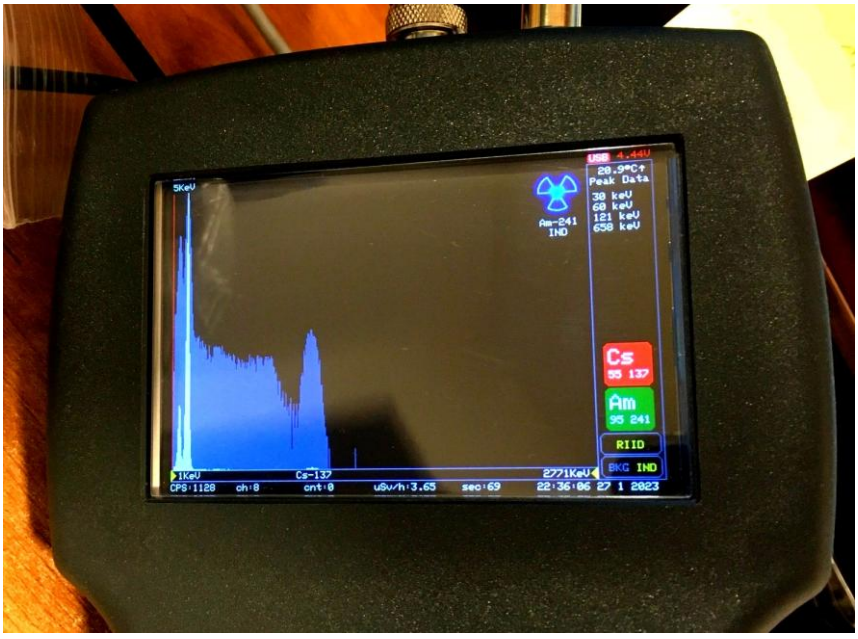
Compton HIDE with shielded uranium ore sample: https://youtu.be/C_afj5UNHNg

Examples of Nuclear Pioneer RIID results in different conditions:

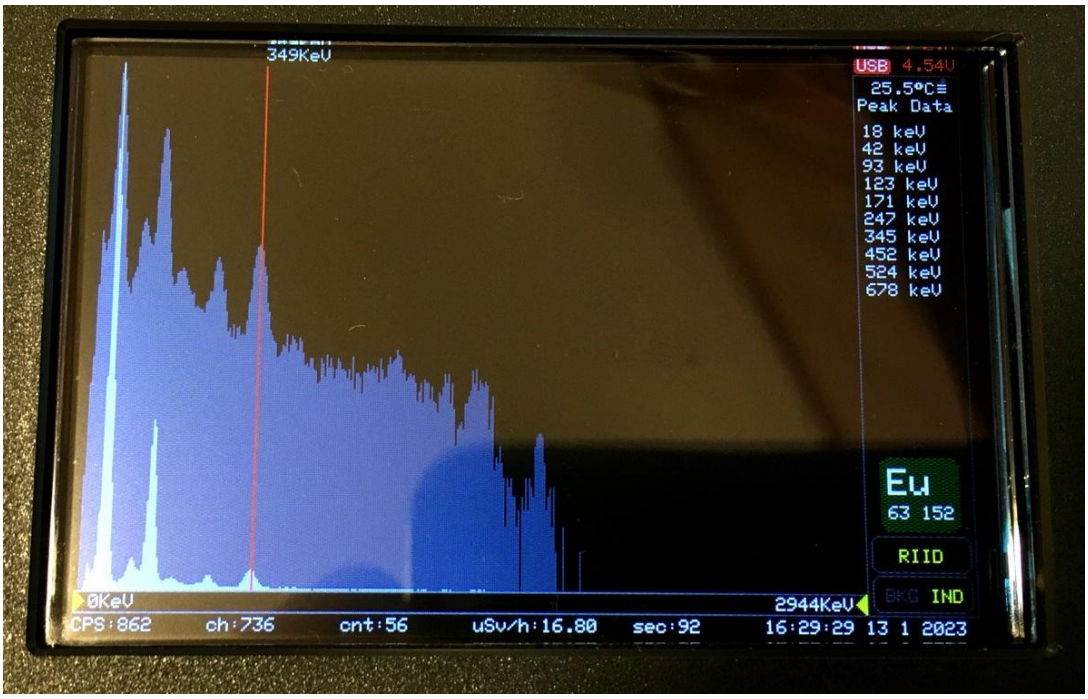
Mixed Am-241, Cs-137, Co-60; 63x63mm crystal:



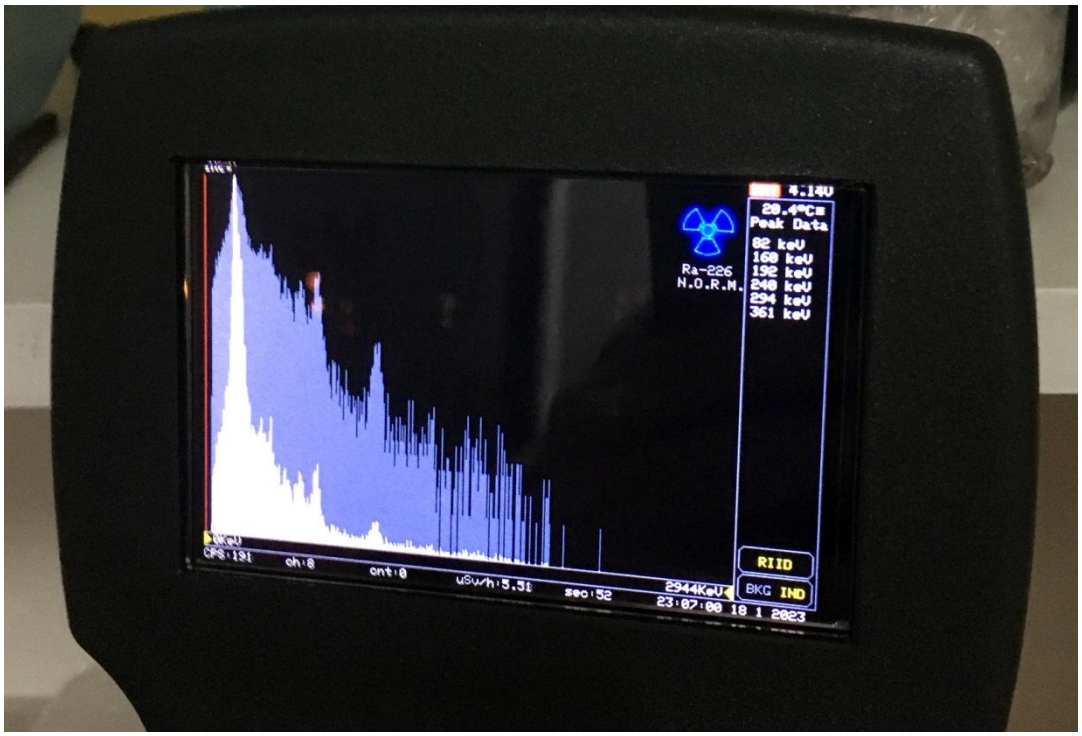
Mixed Am-241, Cs-137; 25x25mm crystal:



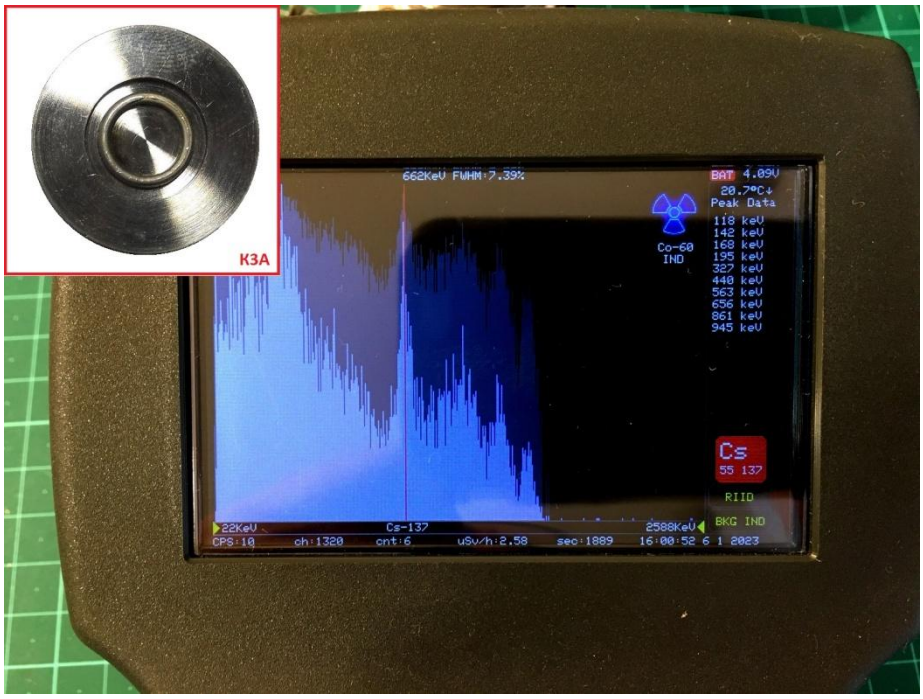
Eu-152 with tiny 6x6x30mm crystal:



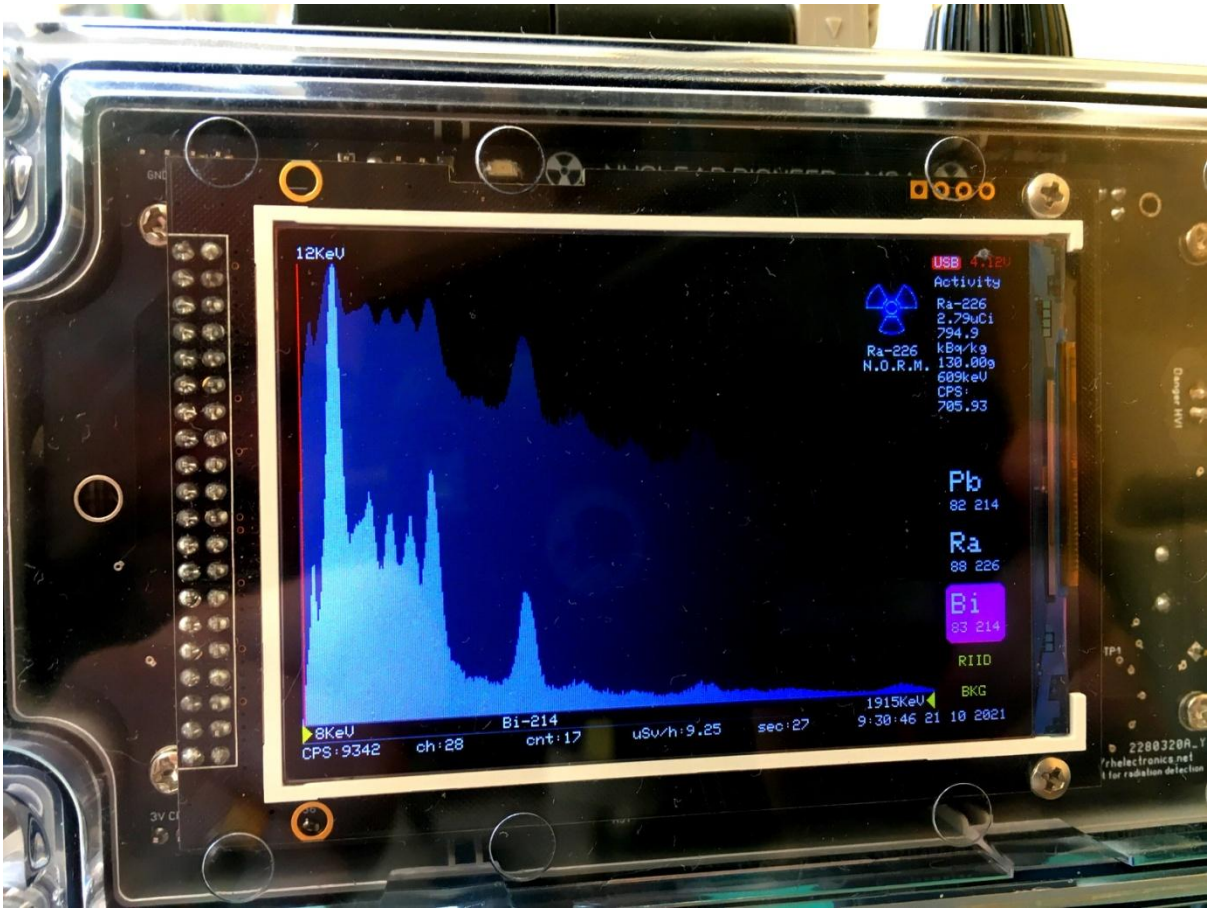
N.O.R.M. with tiny 6x6x30mm crystal, Rn-222 daughters detected:



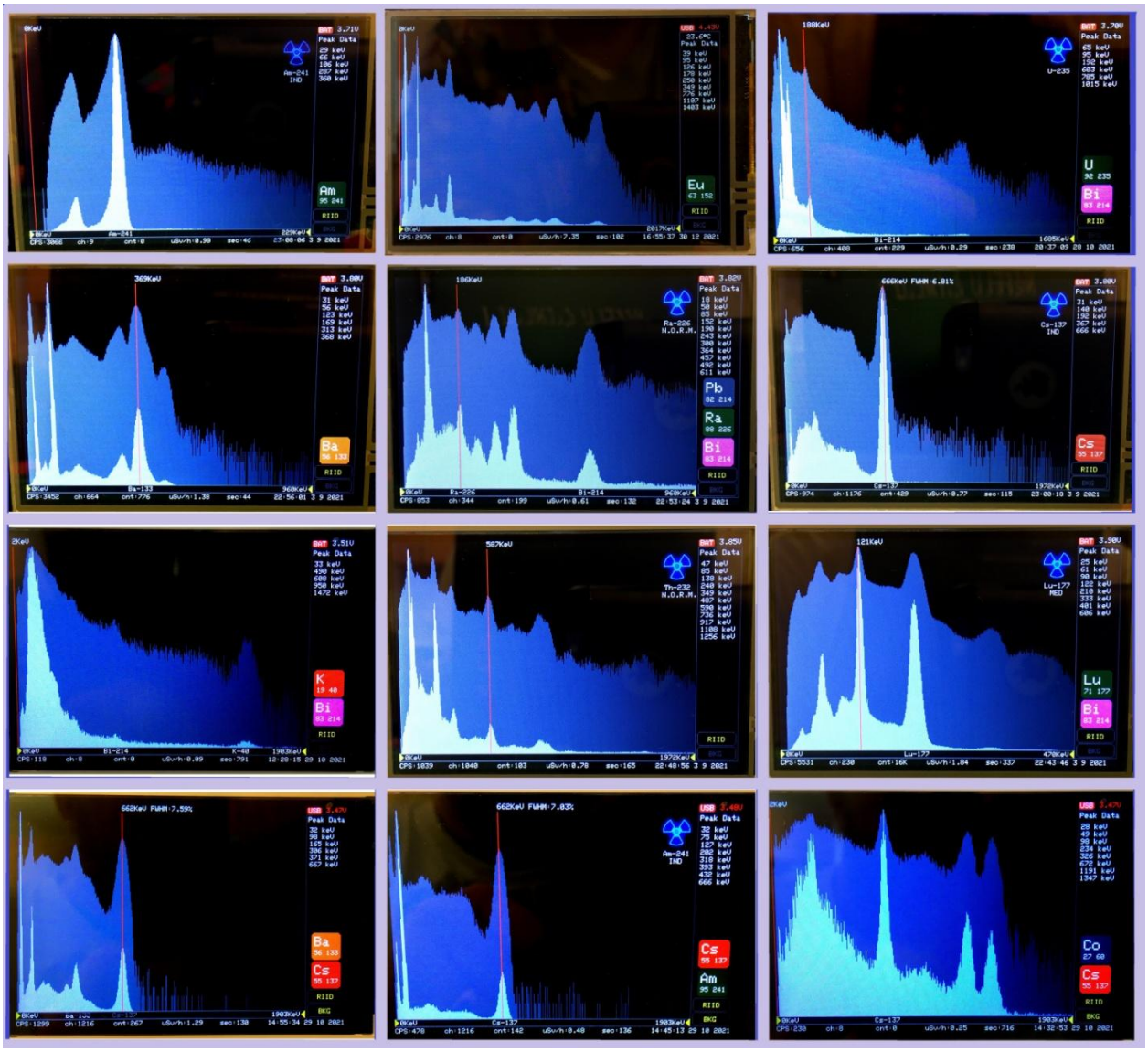
Weak Co-60 Cs-137 K3A with tiny 6x6x30mm crystal, background subtracted:



N.O.R.M. sample with 51x51mm crystal, Rn-222 daughters detected:

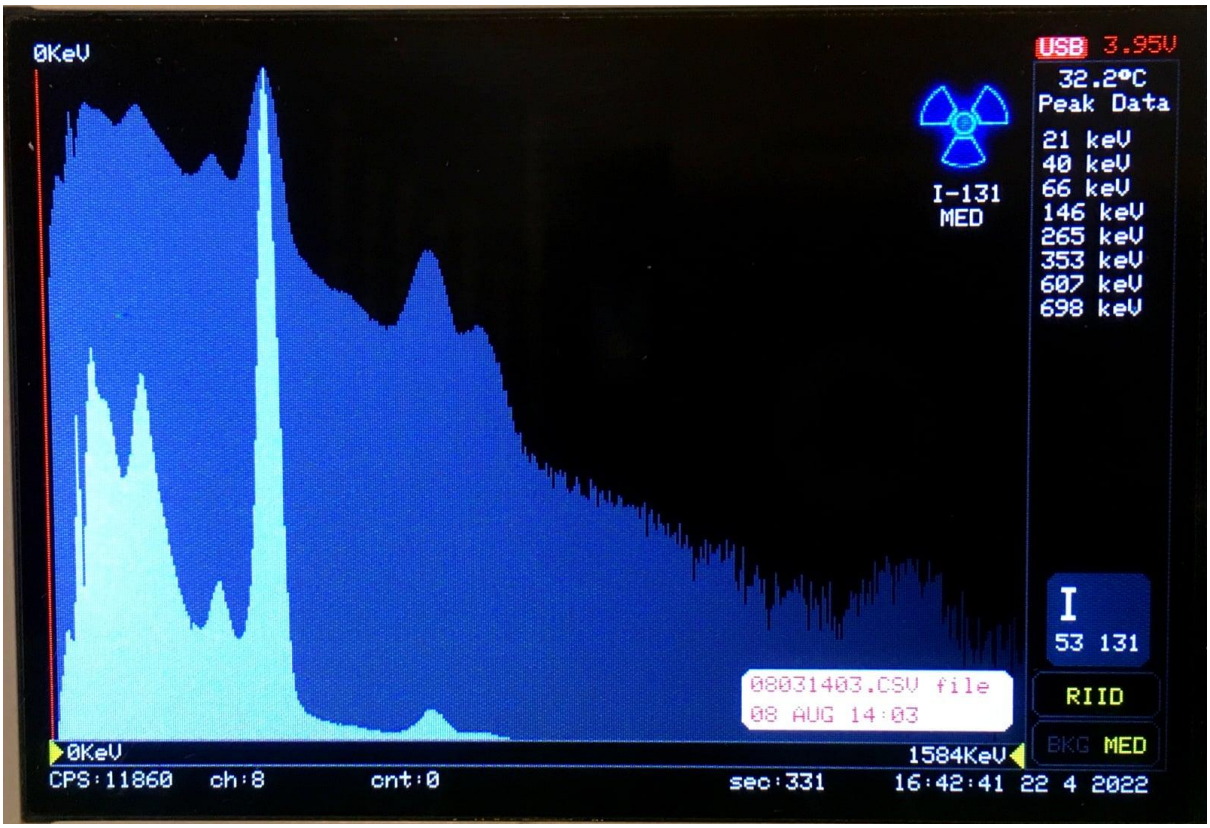


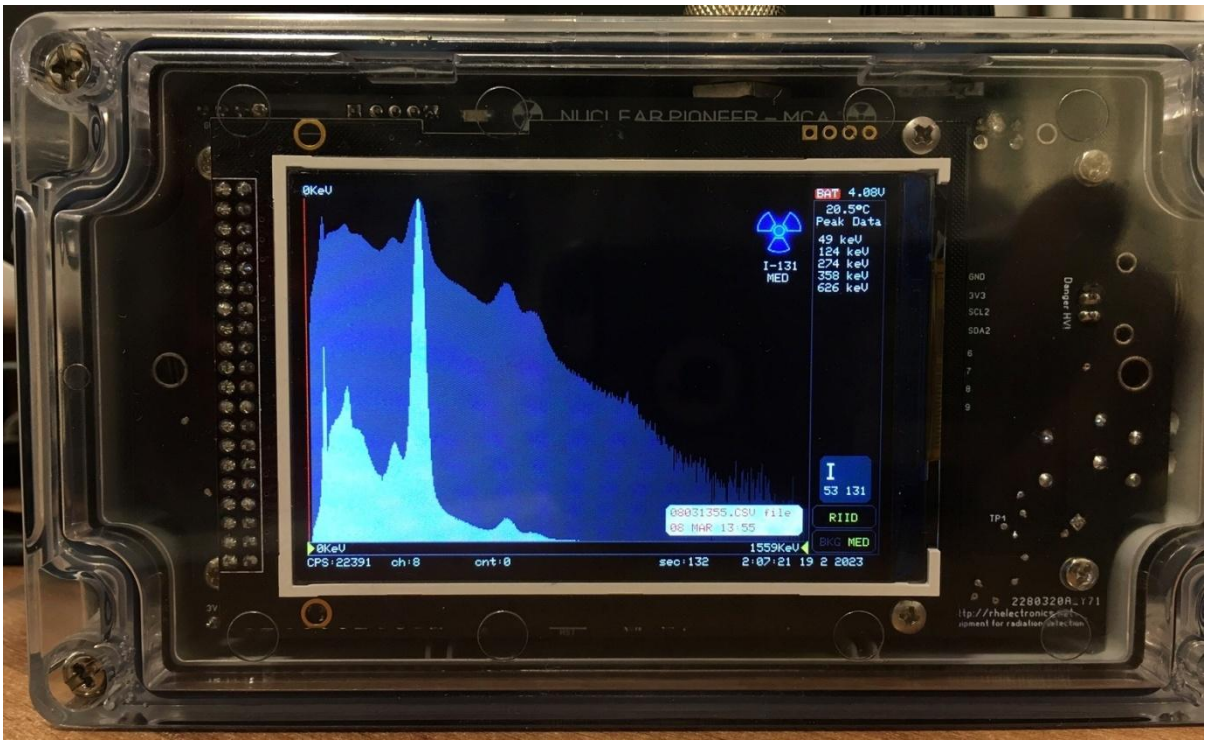
Various samples with 63x63mm crystal:



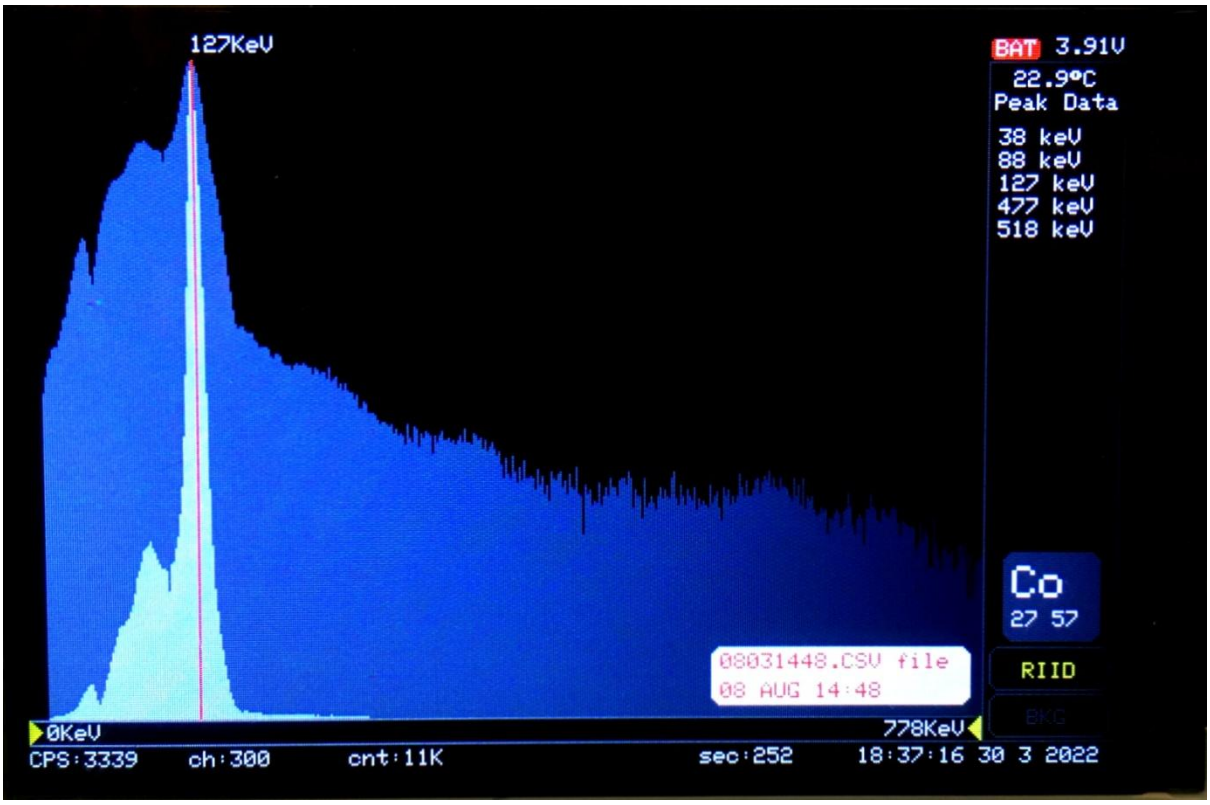
Syringe with medical F-18 51x51mm crystal:

Medical sample of I-131 63x63mm crystal:

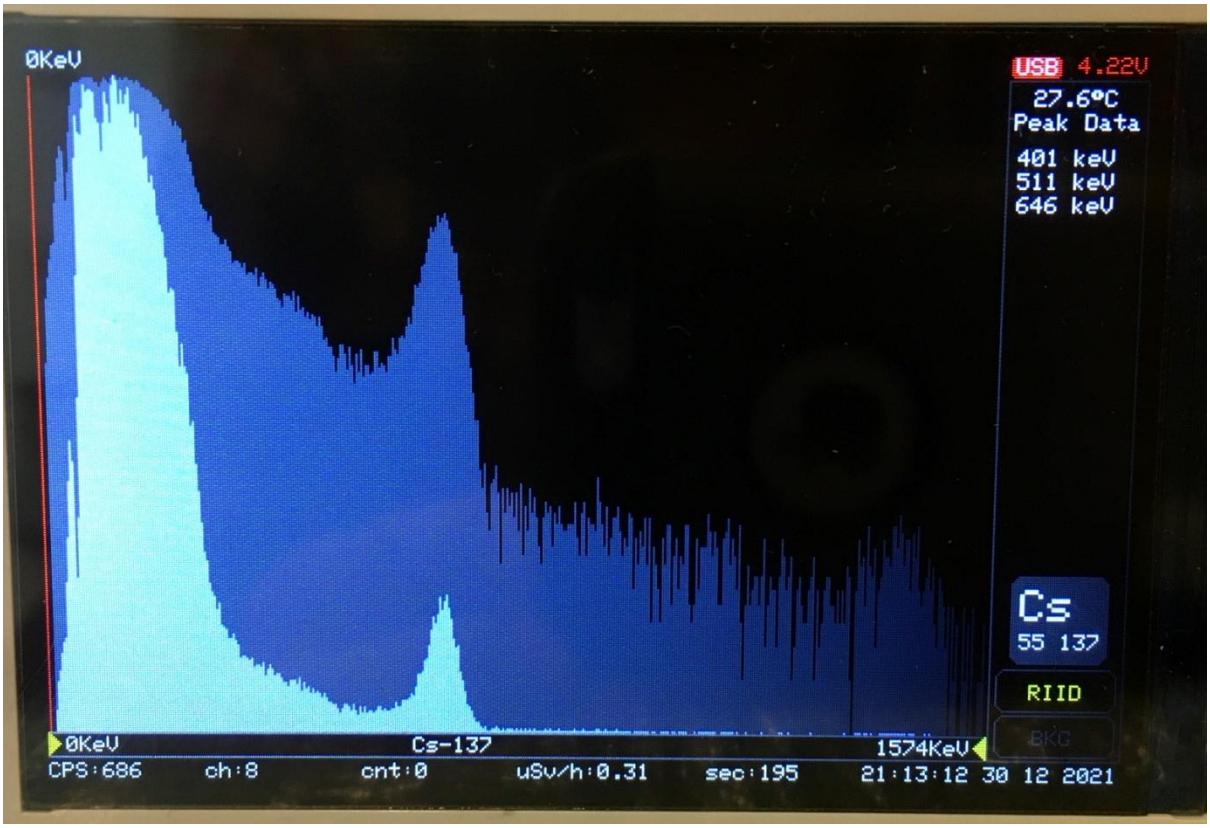




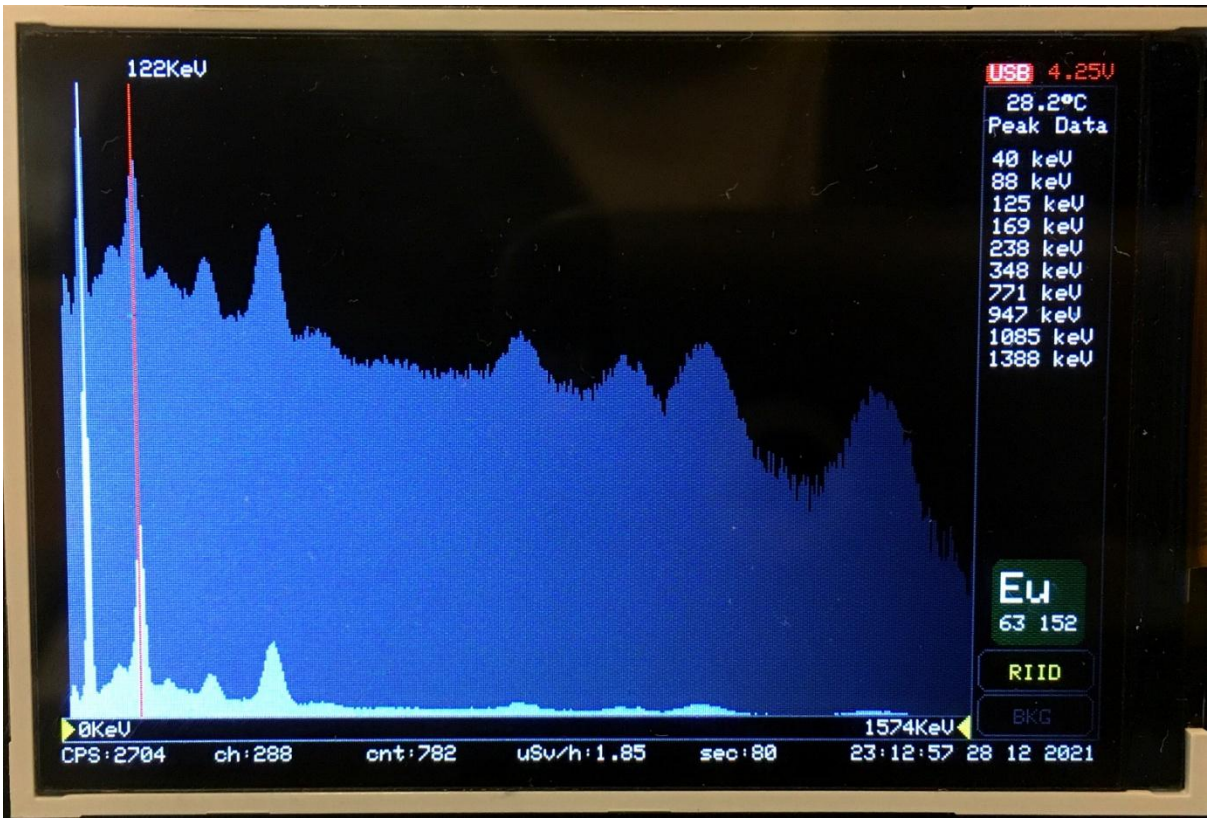
Co-57 63x63mm crystal:



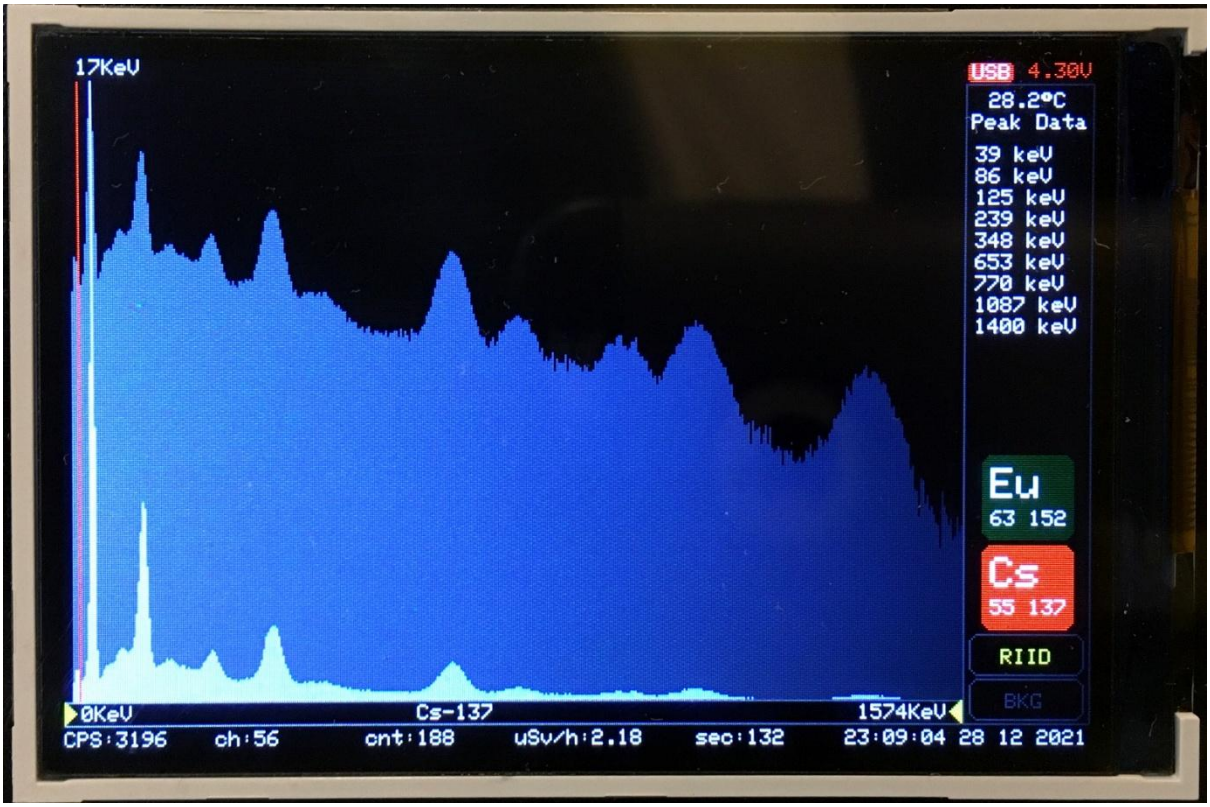
75uCi Cs-137 shielded by concrete, 51x51mm crystal:



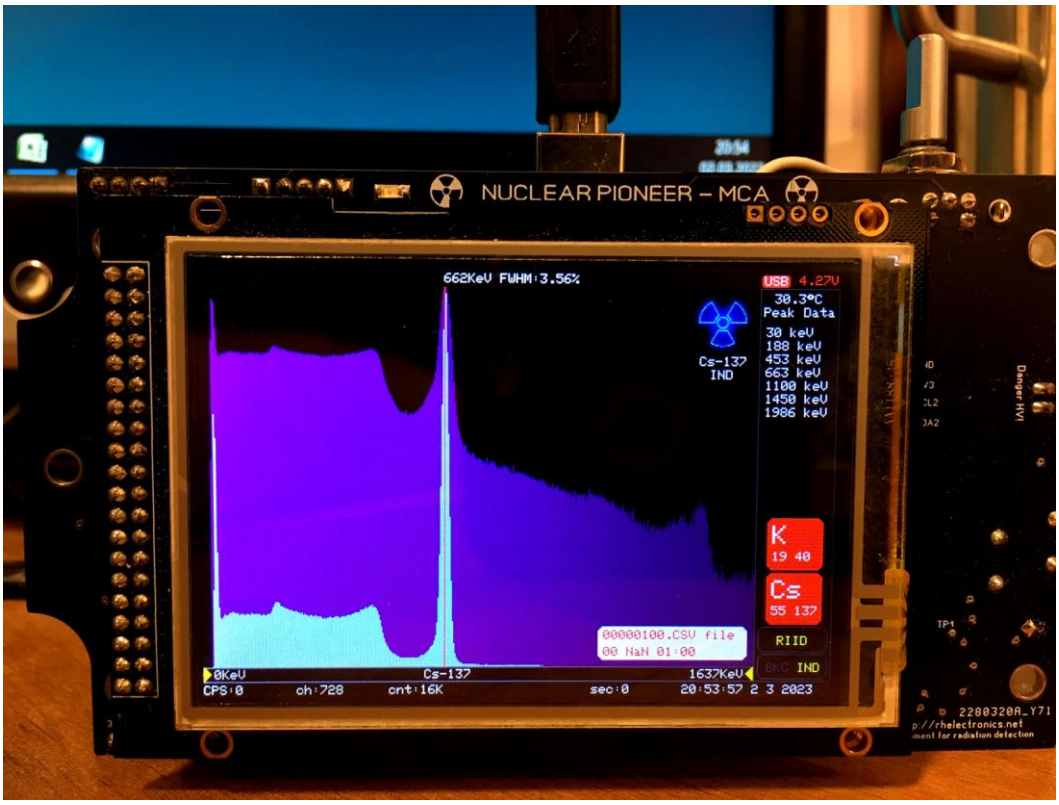
Eu-152 51x51mm crystal:



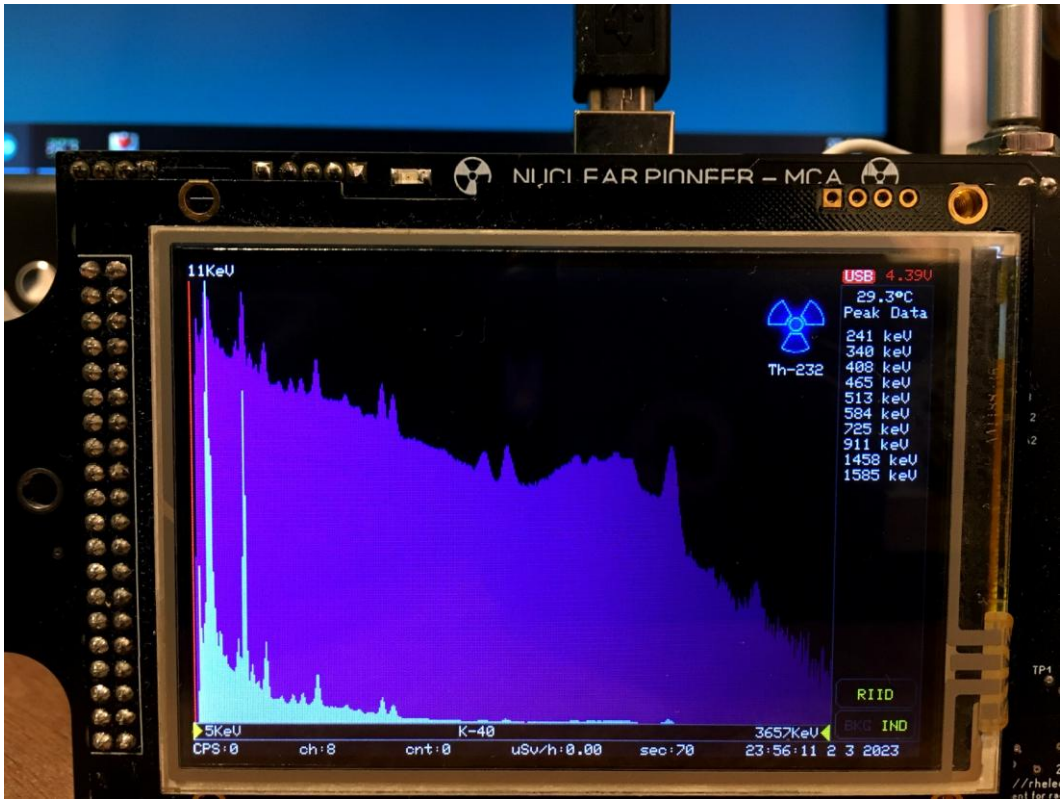
Eu-152 and Cs-137 51x51mm crystal:



Cs-137 25x25mm LaBr crystal:



Th-232 25x25mm LaBr crystal:



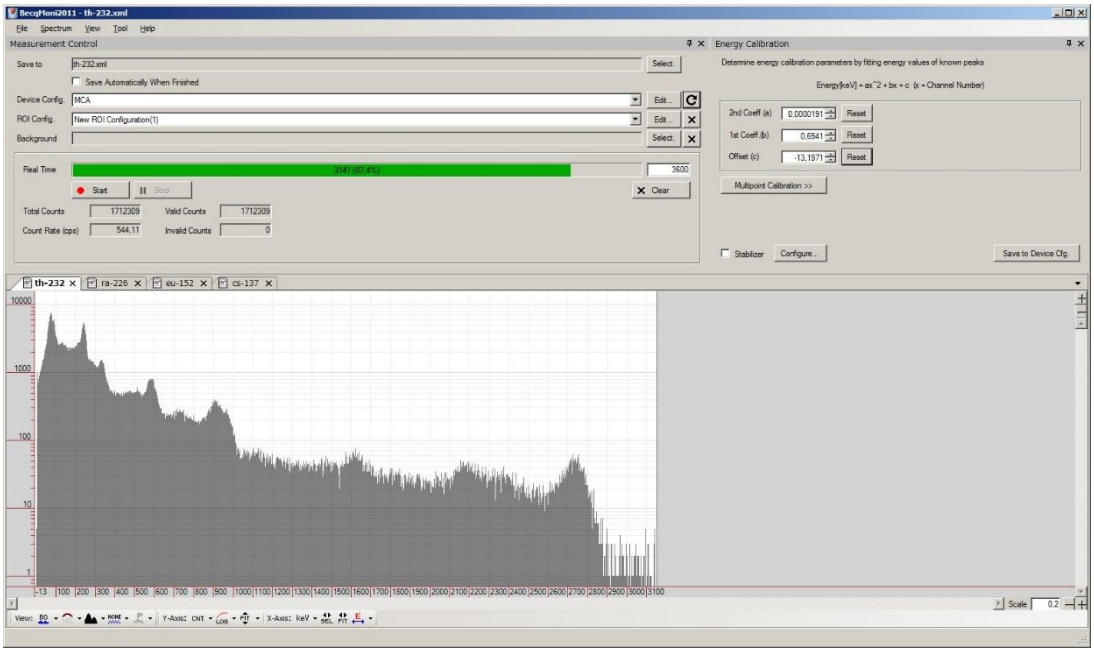
EXPORTING CSV SPECTRA

DOWNLOADING CSV TO PC

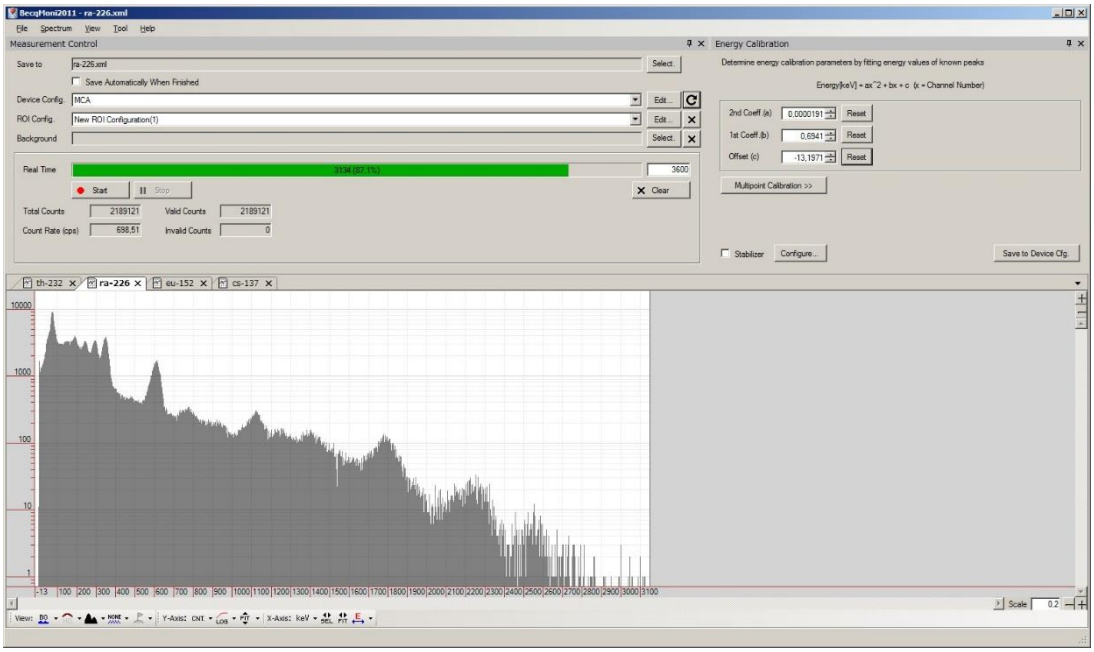
You can download the whole 4096 channels spectrum to your computer via USB serial command and save the file as CSV. Freeware Notepad++ software can be really useful for copy - pasted data edit when you are using Arduino IDE Serial Monitor commands. From Arduino IDE serial monitor send "**G**" command to get the spectrum that currently opened or recording.

Here are several typical spectra for 2x2" NaI(Tl) crystal with resolution ~7.5% at 662keV. CSV files are imported into freeware BecqMoni2011 software for detailed view.

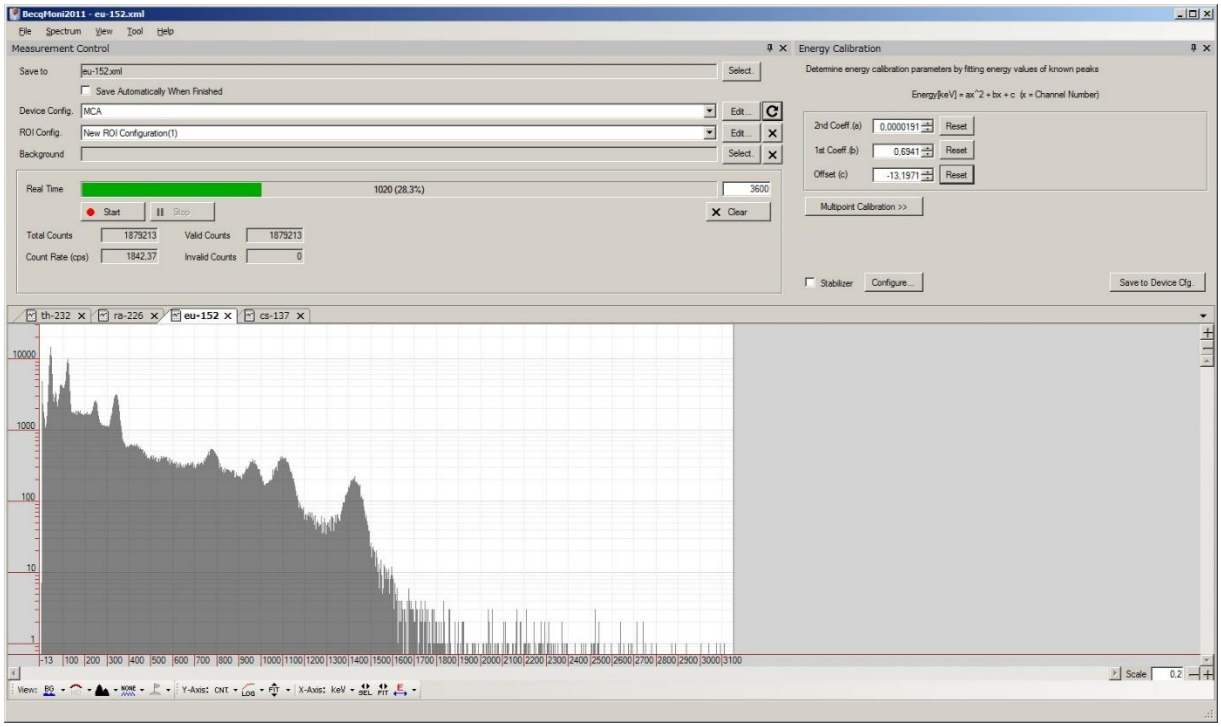
Lantern Mantle Th-232 Gamma Spectrum:



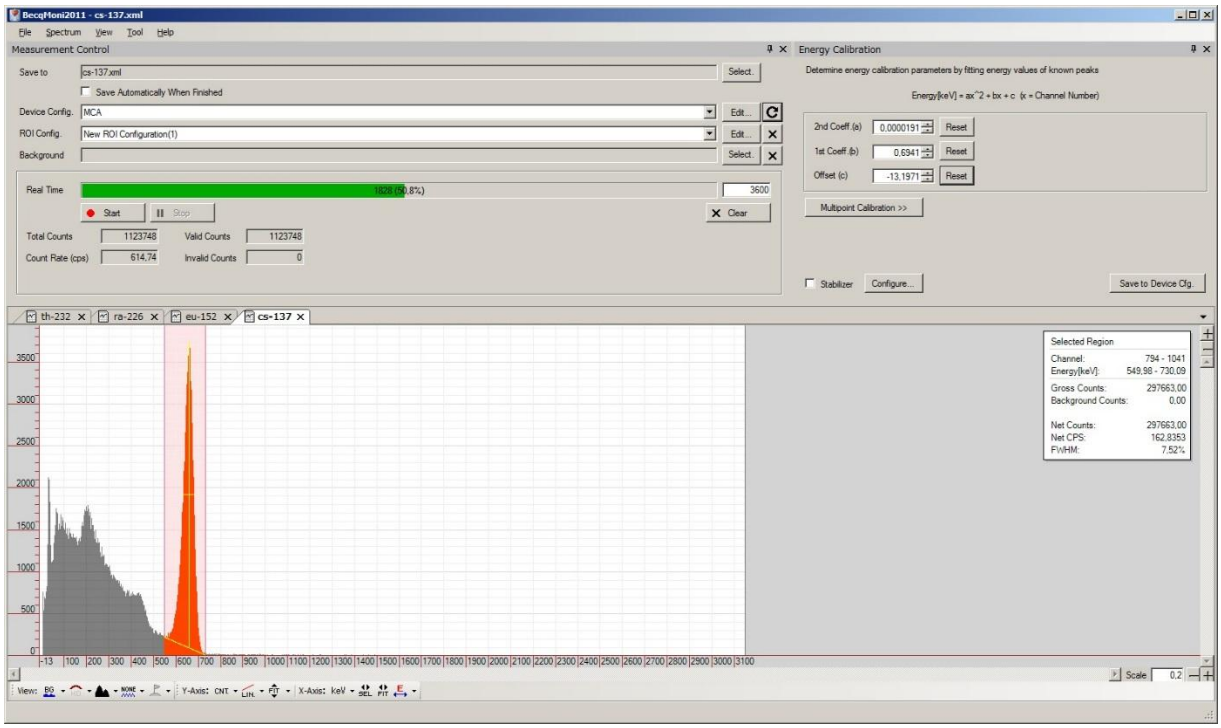
Ra-226 paint Gamma Spectrum:



Eu-152 Gamma Spectrum:



Cs-137 Gamma Spectrum:

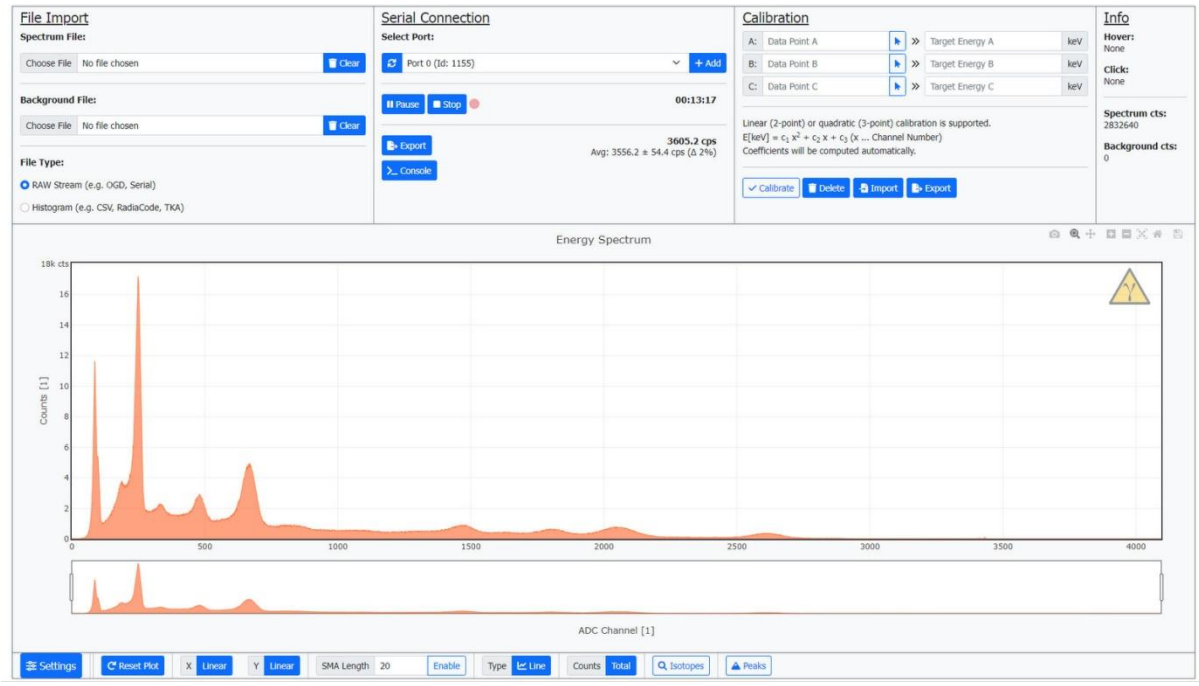


GAMMA MCA NUCLEARPHOENIX

Nuclear Pioneer supports Nuclear Phoenix browser MCA that allows getting live spectrum data through serial USB connection. Please visit developer website for more details:

https://spectrum.nuclearphoenix.xyz/

To toggle data stream open **<_Console** in the browser application and send **s1818** command to the Nuclear Pioneer. The Pioneer uses " **;** " delimiter for separating pulses data.



SD CARD

Nuclear Pioneer utilize uSD card as an internal hard drive to store recorded spectra and back-up setup settings. In 4.15 firmware maximum allowed stored spectra files quantity limited up to 500.

Normally SD card have to stay connected, when you can download or remove the files with serial monitor commands. Or you can use **VIEW SPECTRUM** menu to open requested file.

SD card is located on the main CPU printed circuit board. To remove / install the card you may need to detach the upper board from the stackable pin header. LCD module may also have SD socket, but the MCA uses SD socket on the CPU board, be sure you are using correct slot.

If you remove SD card to open it on PC, please note that first 5 bins of every spectra recorded to SD card may contain a technical data and it should be ignored or set to zero.

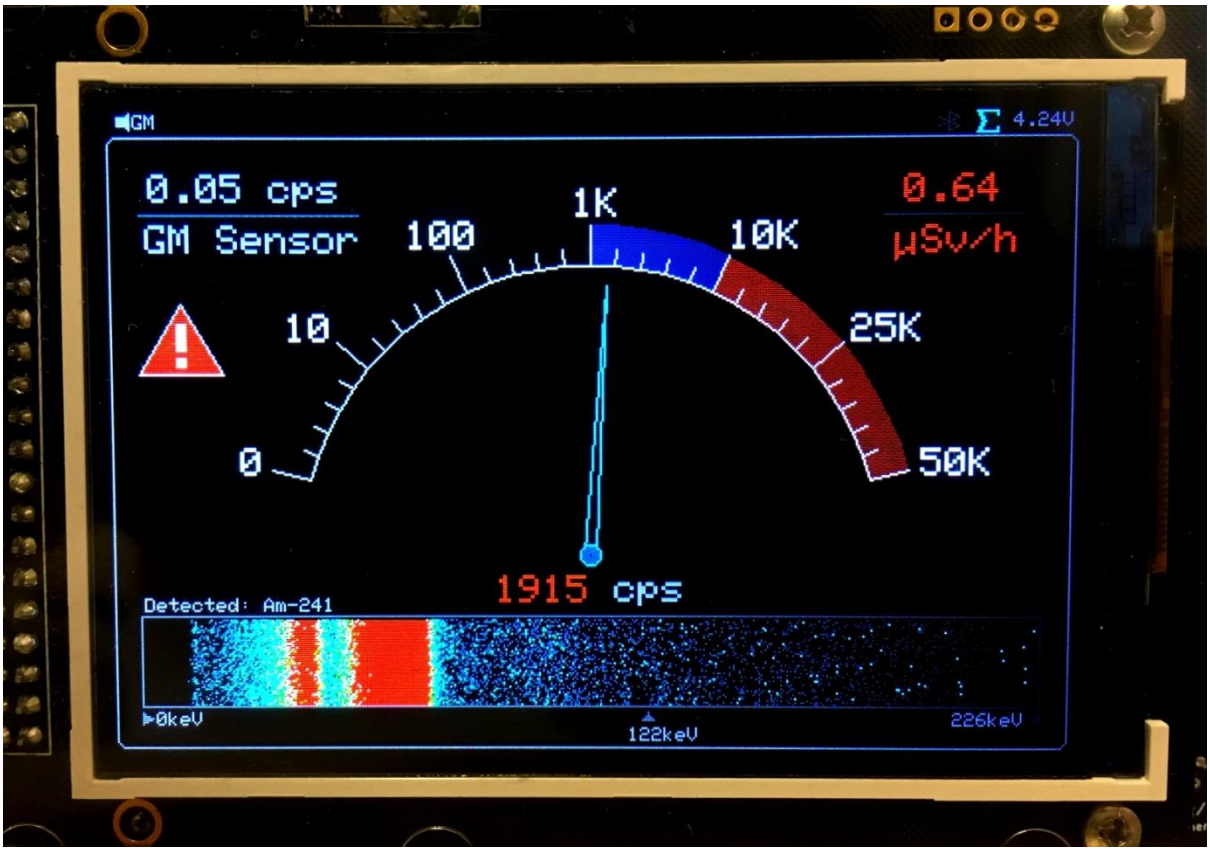
Current CSV format for spectra contains 4096 lines with bin,counts data in every line.

SCINTILLATION MODE

To enter Scintillation Mode set **SCI** icon in Menu to **ON** and press on **RETURN**.

To switch back to Spectrum Mode set **MCA** icon in Menu to **ON** and press on **RETURN**.

In scintillation mode software calculates energy compensated doserate. You can connect / disconnect the internal Geiger counter circuit by setting **GM Tube** icon in Menu.



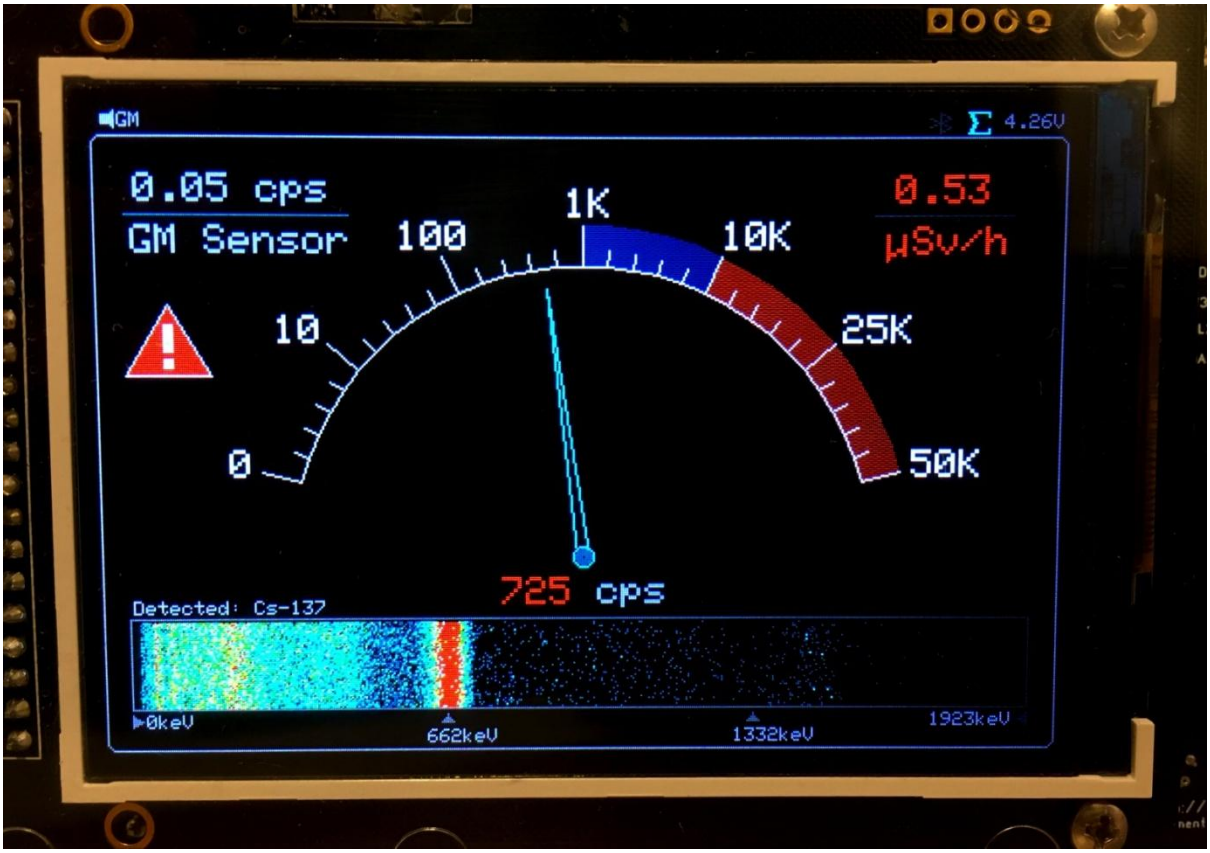
During initial setup and calibration with your probe, you have to toggle sigma **Σ** icon in Menu to **ON**. It will trigger the software to recalculate a new standard deviation for your probe when you enter Scintillation Mode.

Place the probe on normal background without any radioactive sample around it. Enter scintillation mode and wait until you still read message: "standard deviation is in progress, please wait..."

After ~1 minute you can start using the scintillation mode. Standard deviation calibration is required only once, or you can redo it at any moment if you change the probe or need searching with reference higher than natural background.

To toggle sound modes, use short press on the button when you are in scintillation mode screen. **Default doserate alert is 0.30uSv/h.** Default CPS alert exclamation symbol is 2xSigma for fast search. The counter will click on every n=50 particle for 63x63mm and 51x51mm crystal, or on every n=25 for 25x25mm crystal, or on every n=15 for 10x40mm crystal, or on every n=35 for 40x40mm crystal.

Please note, when in scintillation mode, some Menu items related to gamma spectroscopy are not active.



Waterfall histogram:

Since 4.14 firmware scintillation mode comes with Waterfall histogram. It shows energy distribution and CPS intensity of the detected pulses for the last 45 seconds. RIID functions are limited in scintillation mode, and will work only for basic identification of Cs-137. Ra-226 and Am-241.

Zoom of the x-axis in Waterfall is set with **LCD ZOOM** Menu.

Geiger-Muller tube:

Nuclear Pioneer has dedicated 400V/500V power supply for biasing GM tube sensor. Tiny 400V SBM-21 GM sensor can be installed on the bottom PCB. If you have space in the enclosure, you can install a bigger size GM sensor. Keep GM sensor wires short as possible. Geiger Counter is useful in high activity where scintillation counter will be saturated. Pancake GM tube can be useful for detecting alpha and beta sources. Latest PCB editions can support 500V GM tubes. Contact support prior ordering if you need the board with 500V bias voltage.

You can toggle GM sensor type through serial monitor service command. The software is supporting following GM sensors: SBM-21, SBM-20, LND-7312, Si29-BG. The accuracy of the GM tube CPS counter is 0.05 CPS.

To turn on GM clicks or turn on the GM tube circuit just press on the button shortly until you get symbol “GM” in front of the sound icon.

When Scintillation probe is physically disconnected, the doserate value will be calculated with GM tube CPM, that's why it important to set the correct GM sensor type through serial port command. Full period to update the CPM for Geiger tube is 60 seconds. The doserate calculated with GM sensor is not energy compensated, when doserate calculated with Scintillation probe is energy compensated.

Nuclear Pioneer calculates GM sensor doserate only when scintillation probe is disconnected. In that case the software uses the simple direct Geiger CPM to doserate conversion. GM tube doserate typical coefficient is programmed for Cs-137 sensitivity of the tube.

For small size tube like SBM-21, 60 seconds measurement period is not enough to get reliable doserate reading on background low level radiation, however 60 seconds measurement window acceptable for high activity sources.

BACKGROUND SUBTRACT

Real-time background subtract can be helpful when sample activity is low, and when you don't have a lead castle available to filter natural background. The function is mathematically subtracting previous saved background file **00000000.CSV** from the actual spectrum in real time; i.e. it takes into account the spectrum duration as a time basis for subtract. That's why the background file **00000000.CSV** has to be longer or equal in duration compared with the working file **xxxxxxxx.CSV**.

You need to prepare background data file prior using subtract function. Set **SPECTRUM TIME** to 1000 – 7200 seconds and make background acquisition. The file will be saved by auto on SD card when timer roll over the defined spectrum time. File name will be in format of **xxxxxxxx.CSV** according date and time as any other CSV on SD. Check that the file is saved correctly through opening it from **VIEW SPECTRUM**. **Be sure the file remains opened before converting it to 00000000.CSV**.

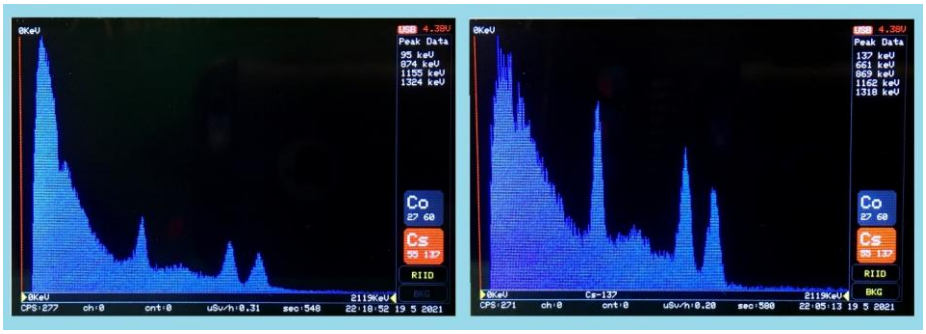
Go to **BACKGROUND** menu and select "**Save**". The software will create a new file (or re-write an old) on SD card with the name **00000000.CSV**. Now It's your background data that can be used for the real time subtract. Acquisition time must be smaller or equal to the background spectrum duration. The good idea is just to keep SPECTRUM TIME unchanged.

To be sure you set correct file as **00000000.CSV** you can just reopen the **00000000.CSV** through **VIEW SPECTRUM** menu.

To activate the subtract go to **BACKGROUND** again and select "**Subtract**". Now you can make **RESTART** and to view real time spectrum without background. To stop using the subtract go to **BACKGROUND** and select "**Unload**".

Once file **00000000.CSV** was created on SD, you can activate the subtract function anytime by setting "**Subtract**" from the BACKGROUND menu. If you need to change or replace **00000000.CSV** then re-make it as described above.

Photo example of the same spectrum with and without background. The sample is very weak Co-60 & Cs-137 source that barely show up above the 63x63mm crystal background spectra without lead castle due to relativity high background count rate of the crystal. The peaks are much better visible when background is filtered out. Left spectrum is data as is, right spectrum is with subtract:



Step by step subtract background instruction:

1. Insert micro SD card or verify you have one installed.

2. In the menu set **SPECTRUM TIME** to the 1000-7200 seconds, depend how long you want to get background spectrum duration.

3. Run spectrum acquisition on natural background without any source around, when spectrum timer roll to the SPECTRUM TIME preset it will save the file automatically on SD card. The file will get name formed with date and time, for example 16021040.CSV

4. Now navigate to **VIEW SPECTRUM** and open the file it just saved. You will see your natural background on the LCD.

5. Go to menu **BACKGROUND** when last file is still loaded to memory, select **SAVE** and press button. Wait a second until you hear beep.

At this step the software takes the last file you loaded into RAM memory and put it into **00000000.CSV** to SD. That's why it important to be sure you opened a correct file with background!

6. After you got ready **00000000.CSV** you can check yourself by simple opening this file in **VIEW SPECTRUM** to be sure the background saved correctly.

7. Now go to **BACKGROUND** menu and select **SUBTRACT**. This command tells the software take **00000000.CSV** from SD and uses it as background. You need to wait a second until you hear confirmation beep. If **00000000.CSV** contain a random spectrum, then subtract function will not work correctly!

8. Now you can press **RESTART** and make a spectrum of the source you want to view without background counts.

9. If you want to return to normal mode, enter **BACKGROUND** and select **UNLOAD** .

Next time you power off/on the MCA you can start from step#7 to subtract the background again. Not need to make a new **00000000.CSV** if you have not changed high voltage or pulse shape potentiometers for your detector.

ACTIVITY CALCULATOR

The initial function is programmed for 51x51mm NaI(Tl) crystal and 3 types of geometries: point source with selectable distance, sample bottle 60mm, Marinelli Beaker MB500-92-116L.

In 4.08 firmware added point source geometry for 63x63mm, 10x40mm, 25x25mm and 40x40mm.

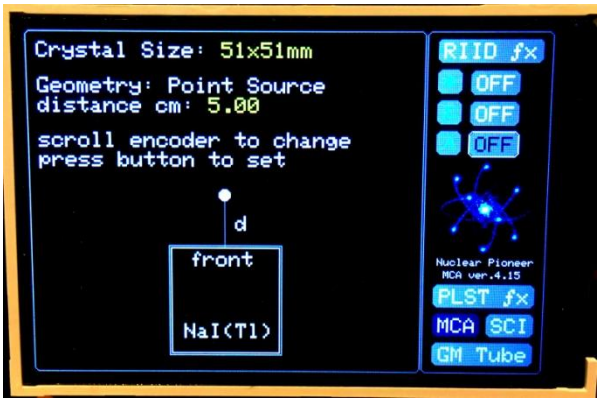
Efficiency function is calculated with Monte Carlo method.

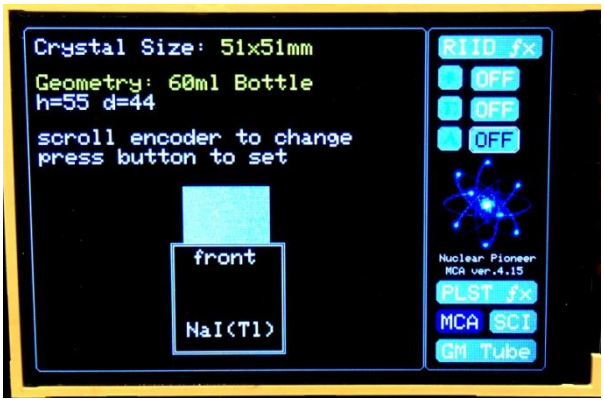
To enter activity menu, set **ON** for Δ Lamda symbol in the main Menu.

It will open the geometry selection menu page where you need to scroll and select the correct geometry for your test. **Please note, point source distance is between the source and the crystal encapsulation surface.** Some probes may have additional 3mm-15mm internal gap with foam insulation between the crystal encapsulation and the front cap. While testing very low activity <1uCi even the 0.5mm positioning difference has the impact on the results.

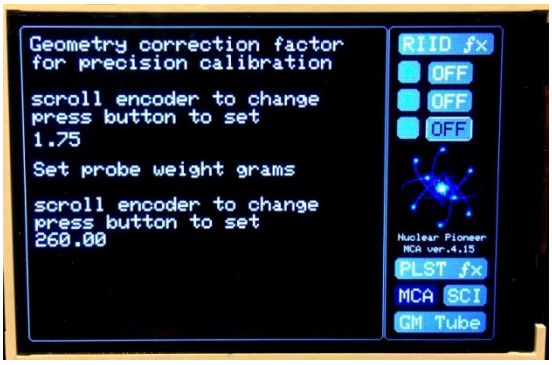
Bottle geometry uses 60ml sample collection container. Marinelli geometry uses MB500-92-116L container. It has no selectable distance to source, but you need to set sample weight [g].

After selecting the geometry, you need to set correction linear factor that fit your detector. You can set 0.01-9.99. The factor is intended to compensate the differences for random detector due to enclosure materials and crystal encapsulation wall's depth. The factor will be unique. **The best way to find the correct factor for your detector is to use reference Cs-137 source 0.1uCi -1.0uCi to validate the resulted activity returns correct value.** If the resulted activity will be higher than the real activity of calibration Cs-137 sample, then you need to set the factor higher than 1.0. If the resulted activity is smaller than real activity of the calibration source then you need to set the factor less than 1.0. Selected factor will be saved to the device memory and can be used with further measurements of activity.

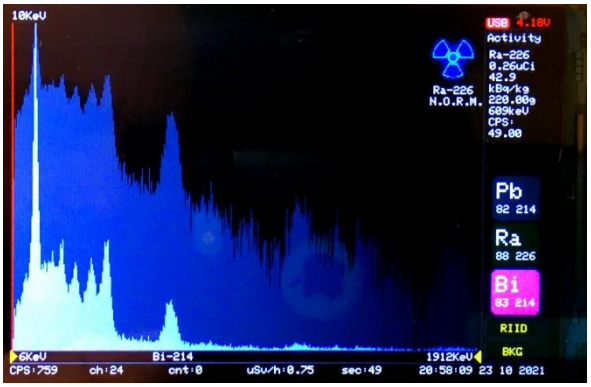




Setting correction factor and sample weight:



You can press **RESTART** new spectrum acquisition or **RETURN** to already recording spectra with activity calculation Lamda **ON**. In the side bar of the spectrum the activity results will appear after several tens of seconds for Cs-137, or Ra-226, or Ba-133, or Am-241. Calculation time depends how fast the device can gather the required statistics for peaks. Usually it can take 1-5 minutes.



If very low activity samples are under test, it's recommended to activate background subtract function in menu prior starting activity test.

Video instruction how to use Activity Calculator: https://youtu.be/zxtRZKI4MFU

BLE BLUETOOTH

The board is electrically compatible with BM71BLE or RN4871 or BT4502 module. The module is soldered on the middle board of the MCA. The BLE communication is under development. By default, current software can send out doserate and CPS data to a smartphone or to receive commands through BLE terminal.

You can download and install freeware application like **Microchip Bluetooth Data (MBD)** from Apple Store.

https://www.microchip.com/en-us/products/wireless-connectivity/bluetooth-low-energy

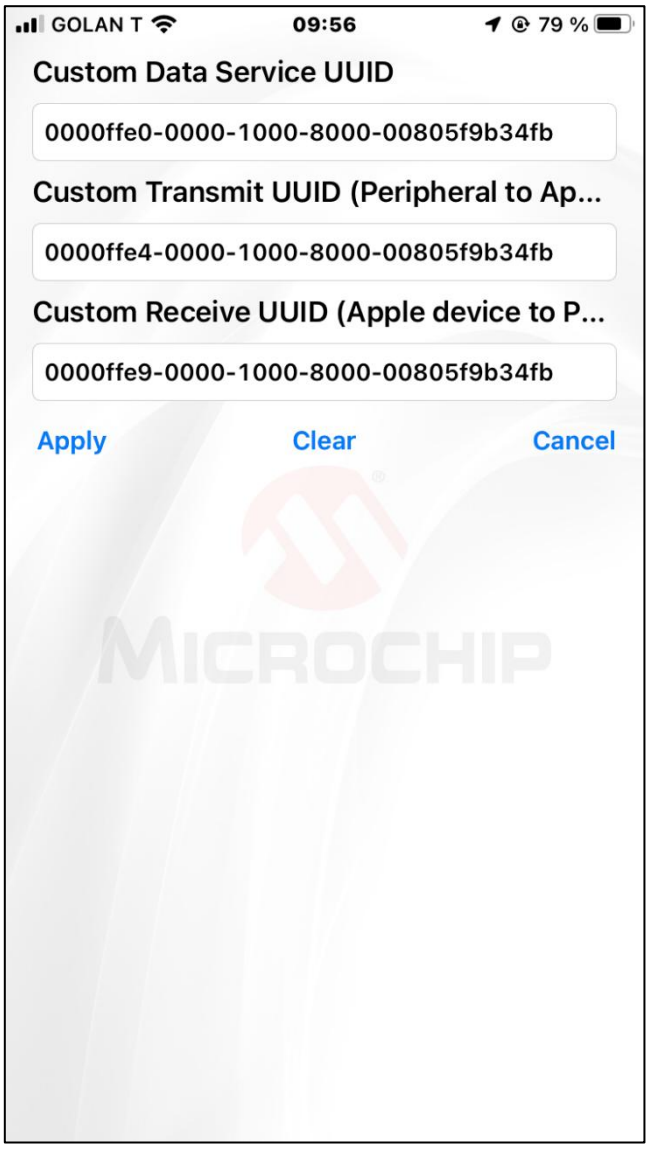
In the application select BM70/BM71 or BM78 BLE UART, connect to the MCA module, select Transparent UART mode and tick “Display Data”.

Fig.10

If you cannot connect with MBD application, it means your hardware comes with BT4502 module that require custom UUID. Download and install **Bluetooth Smart Data** by Microchip:

https://apps.apple.com/us/app/bluetooth-smart-data/id1004033562

Open the application and enter UUID menu. Manually set as shown on the screenshot below and press Apply:



Connect with Nuclear Pioneer and get CPS and doserate data in the console.

BLE commands list (since firmware 4.01):

You can set following commands through BLE console to control the MCA.

R – 0x52 restart the spectrum

Z – 0x5A toggle zoom factor

M – 0x4D toggle between line / bar draw mode

0 – 0x30 toggle turn off/on BLE cps logging, suggested to turn off data logging before sending calibration instructions

Dxxx – instruction to set energy compensated doserate factor. For example, D650 will set the factor to 650

dxxx – instruction to set doserate factor for non-compensated dose, for example d1350 will set the factor to 1350

lxxx – instruction to set LLD level, for example l10 will set the LLD to 10

hxxx – instruction to set HLD level, for example h4000 with set the HLD to 4000

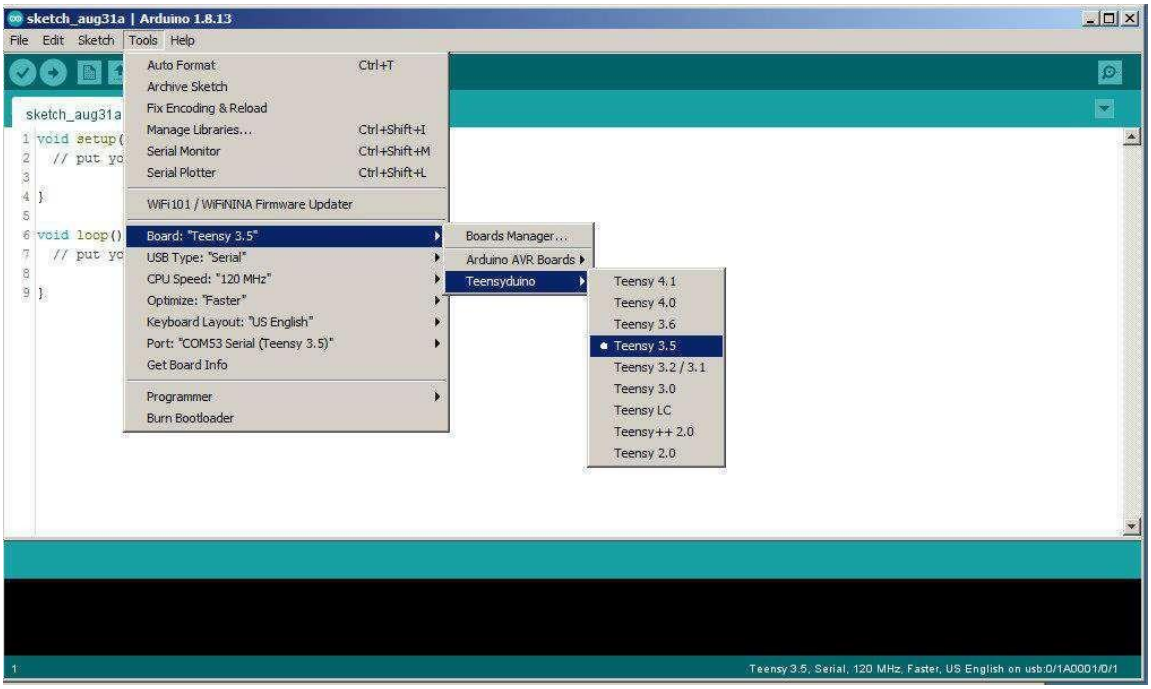
C – 0x43 toggle and save Compton HIDE parameters, can be useful in situ

More commands are expected in further firmware updates!

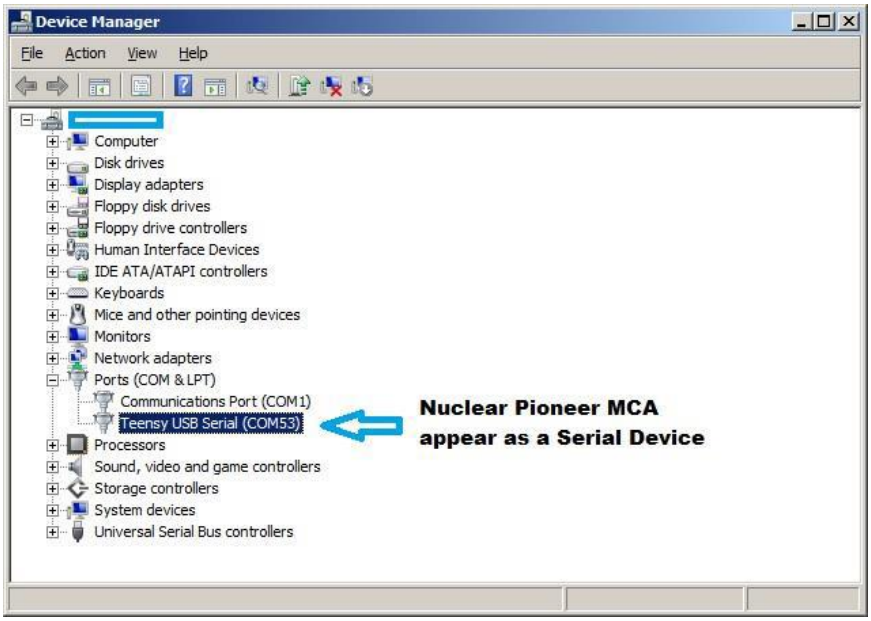
FIRMWARE UPDATE

Nuclear Pioneer Programming Instruction for Windows OS

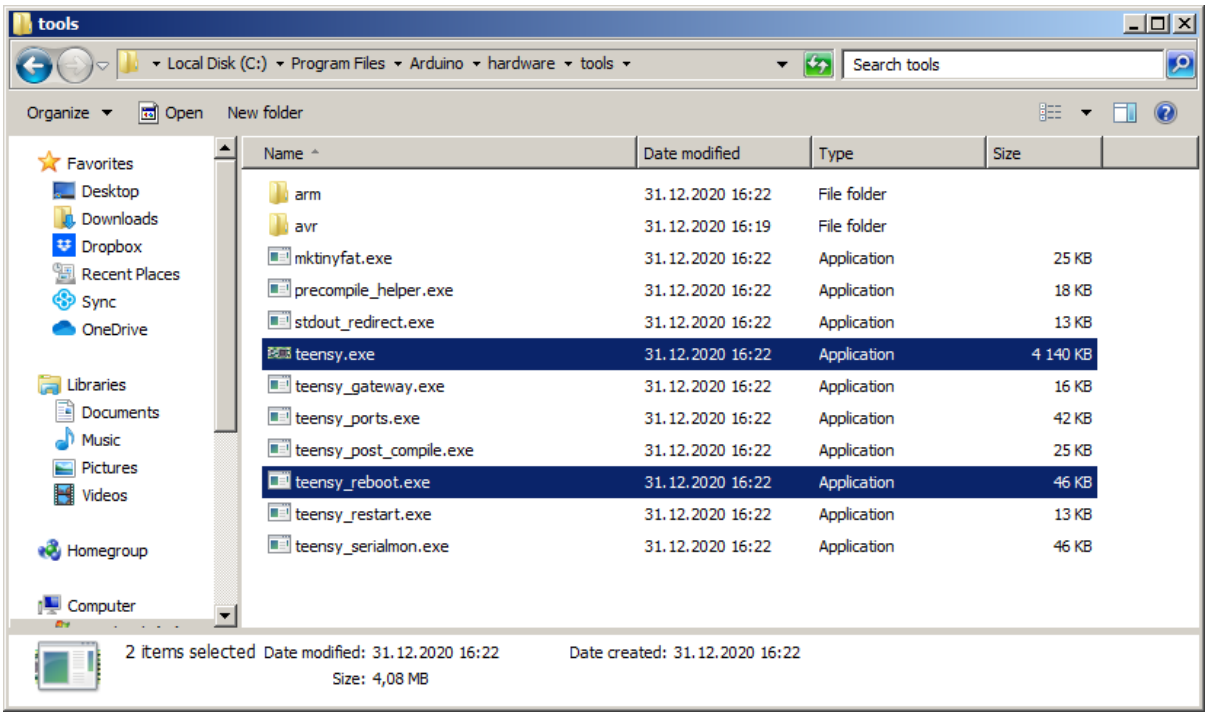
1. Install Arduino IDE and Teensyduino addon. It will add all required drivers for your PC https://www.pjrc.com/teensy/td_download.html
2. Download the latest firmware HEX file from rhelectronics website
3. Allow the firewall exception in the Windows OS for Arduino IDE. Usually firewall will ask about the exception at the first time you open the IDE.
4. In the IDE select board Teensy 3.5



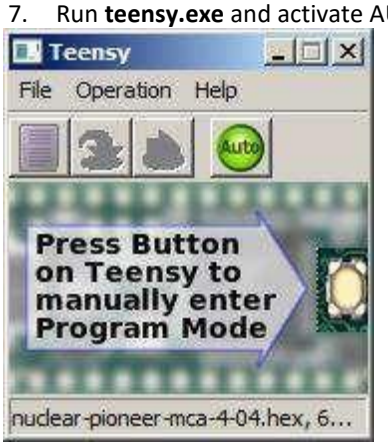
5. Connect Nuclear Pioneer MCA to the computer with USB cable and check in Windows Device Manager it detected as a Serial Com Port device. Be sure you are not using any USB hub. Be sure the USB cable has data lines, some cheap cables comes with only charging function.



6. Open folder path **C:\Program Files\Arduino\hardware\tools**



7. Run **teensy.exe** and activate AUTO mode (green button)



8. Press File -> Open HEX file and select the firmware file
9. Run **teensy_reboot.exe** file

Now you'll see the programming process started with progress bar. After firmware uploading finished, the MCA will automatically restart.

The **teensy_reboot.exe** application causing the MCA to enter programming mode and will force the **teensy.exe** to upload the HEX file into the device by auto without pressing the physical reset button on the PCB.

Troubleshooting:
When first time programming Nuclear Pioneer on a computer it may happen, that teensy board enters bootloader and not listen to USB port. The LCD screen stay black and device seems to be in constant reset. It may happen when first time firmware uploading interrupted by USB device driver installation or any other interrupt on USB port. In this case automatic entry to USB programming mode is not possible. **Teensy loader will ask you manually press the button on Nuclear Pioneer**.

This small program button is located on the top PCB board right under the LCD module. If short pressing the program button does not help and device still stay in bootloader reset mode even after power reset, then make following procedures:

1. Power of Nuclear Pioneer with main power button
2. Disconnect USB cable and wait several seconds until internal capacitors will discharge.
3. Open teensy loader teensy.exe, select the HEX firmware file and set the loader into AUTO mode (green auto)
4. Open teensy loader folder and find teensy_reboot.exe (but do not click on it yet)
5. Press and hold the program RTS button on Nuclear Pioneer board
6. Power on Nuclear Pioneer with the main power switch
7. Insert USB cable, the loader will start to upload the firmware by auto.
8. If Auto upload is not started, then run teensy_reboot.exe manually

To avoid this troubleshooting, it's recommended that when you program the device for the first time on the computer please use the manual program button and wait for the driver installation was finished.

Teensy bootloader is stored in a dedicated chip. The physically separate chip keeps Teensy's bootloader separate from the firmware code and prevents flash programming from being able to damage or erase the original bootloader.

www.pjrc.com/teensy/loader_win10.html

BATTERY MANAGEMENT

Nuclear Pioneer supports 3.7V LiPO battery. Recommended capacity >2200mAh. Minimum charging time is 7 hours. Charging current 350mA.

You can charge it with 5V USB Wall Adapter or with computer USB.

Recommended LiPO batteries with supported connector polarity:

https://www.adafruit.com/product/328

https://www.sparkfun.com/products/13855

https://www.sparkfun.com/products/13856

Battery connector type and polarity: LiPo 3.7V JST 2.0mm Sparkfun PRT-08670 or compatible. Wrong polarity of the battery connector can burn charging IC immediately and will require replacing of the SOT-23-5 part.

CONTACT DETAILS

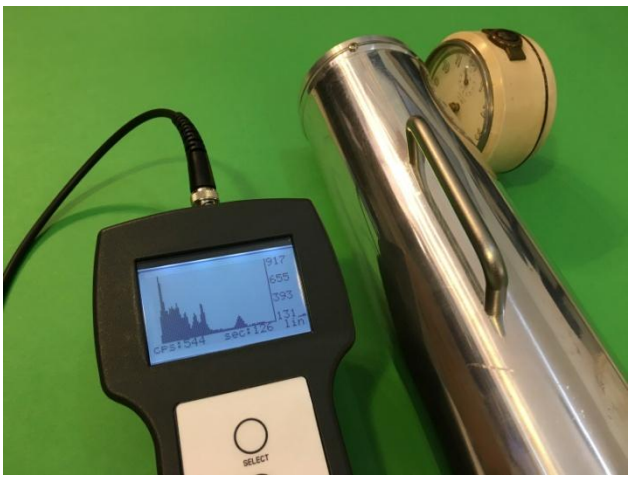
You can send your enquiry or contact technical support by email: support@rhelectronics.net

PROJECT BACKGROUND

This chapter not contains any necessary technical data for the unit calibration. But it may help you to understand the project background, initial goals and further perspectives.

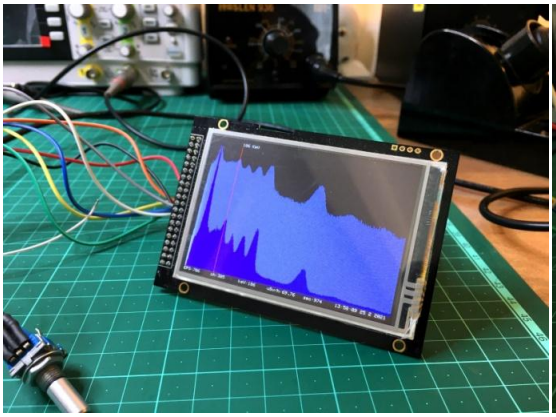
Since 2015 I was experimenting with the DIY Hobby Gamma Spectroscopy hardware. As many other hobbyists, I have used PRA, Theremino and Becquerel-Monitor computer software and a different sets of my DIY boards I have prototyped to learn the basis. Actually, I never had someone I can ask in person or someone who helped me with the subject. The only one way to understand how things works was to learn physics and electronics on my own, experimenting with dozens of prototype boards, search and read scientific papers and datasheets, learn embedded programming.

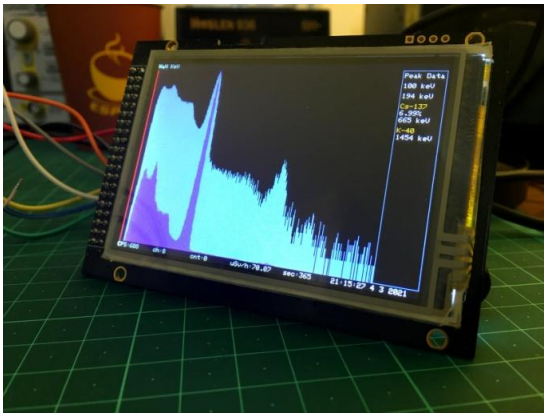
Every new puzzle opened a way to a new terra incognita where every time I understood that I know nothing ahead and have only little knowledge behind.



I had a dream to make portable DIY Spectrometer that can be fast as Berkeley Nucleonics SAM 940(RIID) and can be assembled and programmed by me from scratch. The challenge was more complicated than a hobby board development. Because of single person resources limitation and requirements to take care of hardware and software at once. It took me a while to select IDE environment that helps me to focus on the essence without struggling with every byte in CPU configuration. Finally I found **pjrc.com** website with amazing Teensy platform and chose main CPU board that able to handle 32-bit floating point math for all ideas and algorithms I expected to try.

For old school 8-bit nerd with byte-by-byte ASM PIC instructions it was a huge technology jump to C++ programming world. As a project, Nuclear Pioneer started at the beginning of 2021, after I exported my PIC18 MCA ver.3 to the Teensy CPU.





Nuclear Pioneer electronics was never optimized as a typical commercial mainstream product where it naturally expected to cut costs to the lowest few cents and order 1000pcs batch PCB's assembled by a machine. Meanwhile I'm the machine and an enthusiast who enjoys spending for project more cash than it can gives me back. The units are soldered and assembled manually in a small batch production.

If I could have a budget to order 100pcs units production batch, then the costs of every unit could be cheaper by 30% and would make the device available for wider community of hobbyist and students. However, I can see it happen only with a third side support.

And if we come back to the commercial project re-design and optimization for profit, then today it tends to end up with another low-cost and low detection efficiency gadget for smart phone. Marketing always compromises quality. I'm sure it possible to create a nice low-cost gadget based on Nuclear Pioneer, but it's not the initial concept of the Pioneer.

No matter how you turn it, detector's efficiency and resolution it's the key to the fascinating world of gamma spectroscopy. And when you have an excellent detector you also need an excellent MCA.

What makes Nuclear Pioneer special?

- Hardware module that can be calibrated for a different scintillation probes.
- High performance Gamma Spectrometer that can analyze up to 20000 pulses per second.
- Automatic and fast Radioisotope Identification Device (RIID) that able to identify nuclides in 1 second.
- RIID automatically supports wide range of crystal's resolution from 3% to 12%
- Configurable and adaptive software. You can use 63x63mm crystal as well as tiny 10x40mm.
- Verified low noise electronic circuit.
- An option to calibrate and use temperature correction.
- Portable and desk application.
- Oriented for DIY community, researchers, students and educators.

If you want to help to improve Nuclear Pioneer, you are welcome to send your spectra data in any format you have: CSV, TXT, PRA export, RAW, Theremino, XML and etc. Please include your detector specification like crystal size and scintillation material.

In further firmware updates it planned to make the device closer to IEEE/ANSI N42.34 standard. Of course you have to remember that Nuclear Pioneer is still stay amateur educational device, but adopting few good things from the world of the professional standards can make it just better.

CREDITS

I want to give special credits for the contribution to the community education:

- Marek Dolleiser (PRA)
- Theremino Team
- GeigerCounterEnthusiasts Yahoo group
- Paul Stoffregen

I want to give special credits for gathering and sharing their spectra data to:

Hemi Avraham, Mike Wall, Cornelius Donat, Jay Howson.