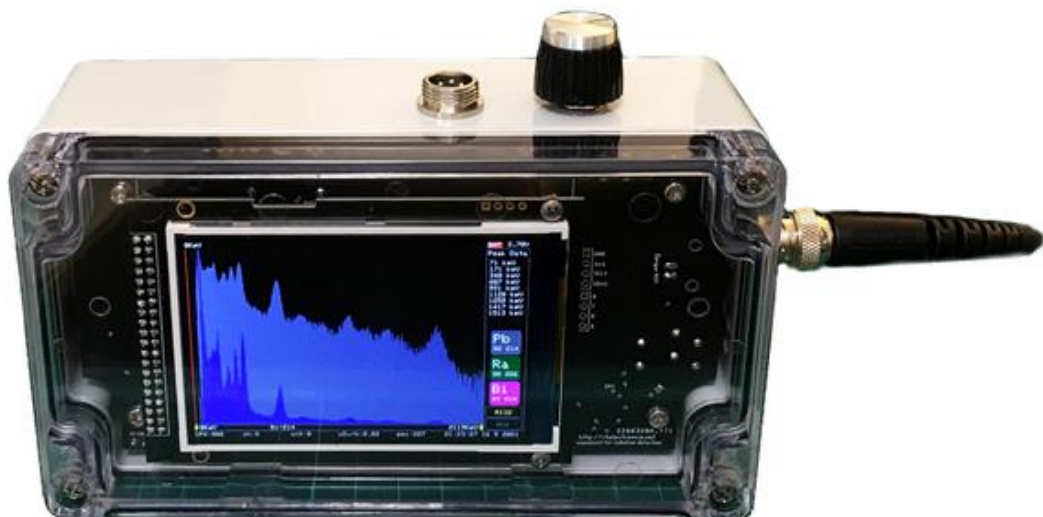




Gamma Spectrometer

## NUCLEAR PIONEER MCA



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The **Nuclear Pioneer 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 visual emphasis of the detected gammas.

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

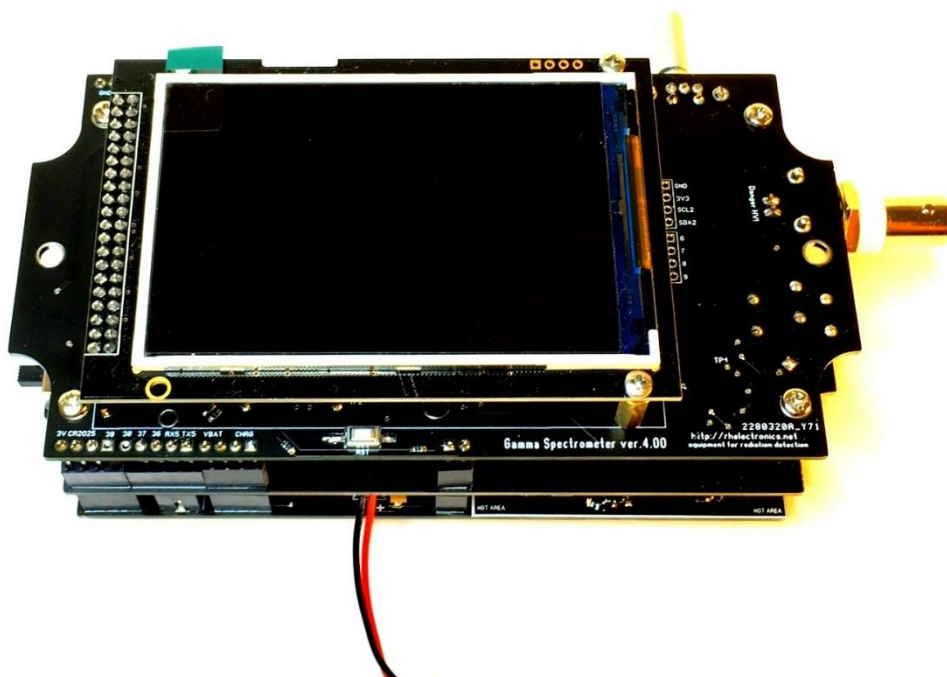
Dose rate reading is energy compensated and normalized to Cs-137 662keV response of the scintillator. For better performance it's recommended to use the MCA with large size NaI(Tl) crystals like 2x2" or 63x63mm.

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.

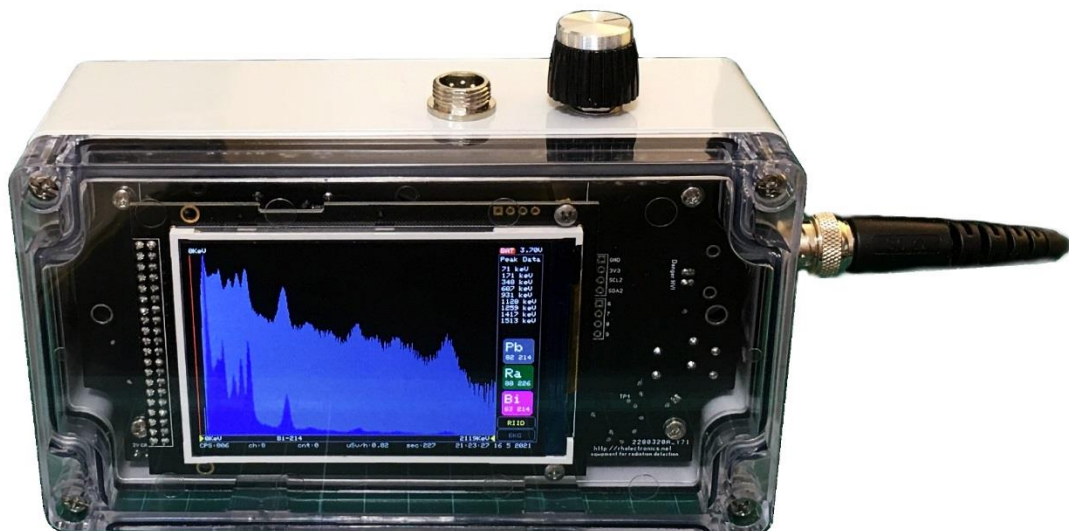
Computer communication is full speed 12Mbit/sec USB port that allows to transfer full spectrum instantly. You can calibrate the unit with simple commands or to adjust channel-to-energy scale from MCA unit menu.

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:**

- 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 (tested up to 10.000 CPS)
- Scintillation Counter Mode with PMT and GM Sensor
- Easy Channel to Energy calibration with selectable scheme
- Real time background subtract mode for gamma spectrometer
- Real time gaussian peak detection
- Linear or Logarithmic spectrum viewer
- Energy compensated dose rate
- 0.30 uSv/h doserate alert and 2-sigma CPS alert in scint.mode
- CPS standard deviation calibration for scint.mode
- Mute / Alert / Clicking on every n-particle in scint.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 temperature sensor
- Bluetooth BLE communication (optional)
- 12Mbit USB port for programming, calibration or data transfer
- Easy firmware update via USB and friendly bootloader
- Power supply: 3.7V LiPo battery, battery current consumption 250mA-350mA
- 3.7V LiPo battery charger included in circuit, low battery alert





**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 setup the non-calibrated MCA device.

Any scintillation crystal 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 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:

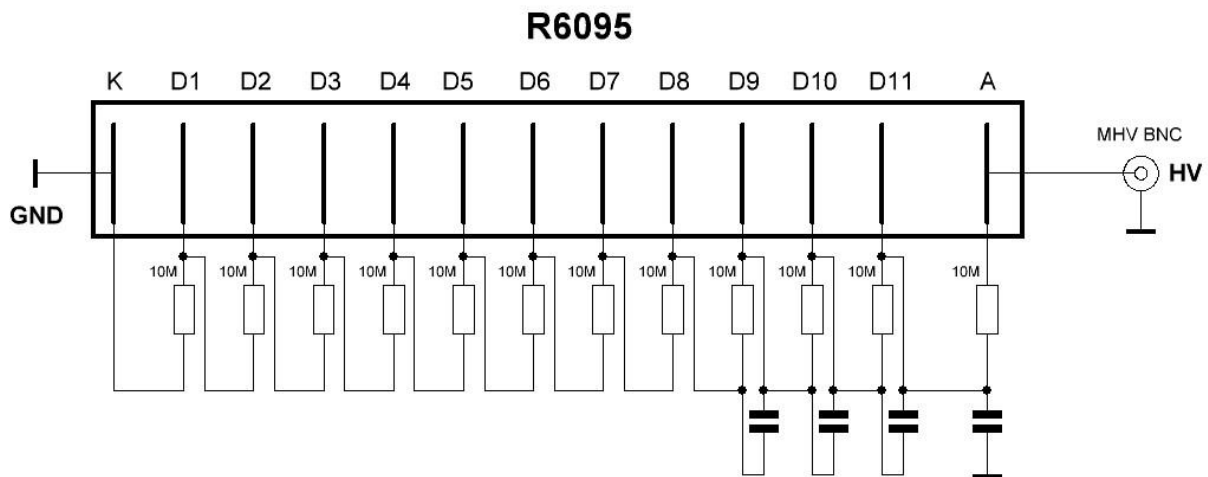


Fig.1

One of the possible wirings is shown on the Fig.1 for R6095 Hamamatsu tube. Capacitors are 10nF-100nF 1kV, resistors are 12x10Meg. Metal enclosure and magnetic shield are recommended for 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 a oscilloscope 500Msa/s or better, just to verify you get correct pulses and low noise. If you don't have oscilloscope, don't worry – you can use default settings for the gain potentiometers as described below.

### 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.

Two 3006P multiturn potentiometers on the upper board are controlling amplifier gain. 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 check and set 6K-108K before you power up the MCA.

Small 3362P potentiometer under the LCD module comes with default preset of 10mV-15mV on the middle tap, or ~180ohm from the middle tap to ground.

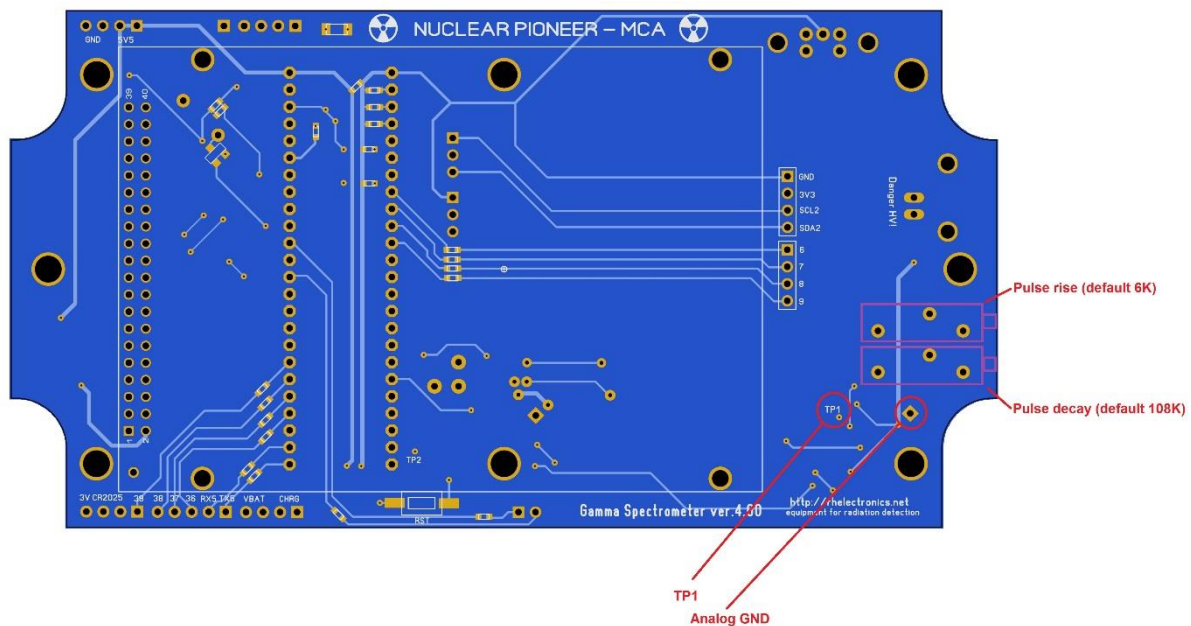


Fig.2

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 rise high voltage bias. Adjust high voltage to set 662keV Cs-137 or 609keV Ra-226 peak to an amplitude ~ 800mV (or ~channel #1000). Visually the photopeak of Cs-137 662keV must be located on the 1/3 position of the LCD from the left side like shown on Fig 6. Suggested mV value is not mandatory, total gain settings depends on optimal energy range for your NaI(Tl) probe.

Each time during calibration when you adjust HV, 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 spectrum, or you can scroll the red line pointer with encoder over the LCD. Short pressing on the encoder button will toggle scroll modes. Longer pressing on the encoder button will open Menu.

Verify that you can see 32keV from Cs-137 or 59keV from Am-241. You can zoom the LCD from menu to view the spectrum in detail.

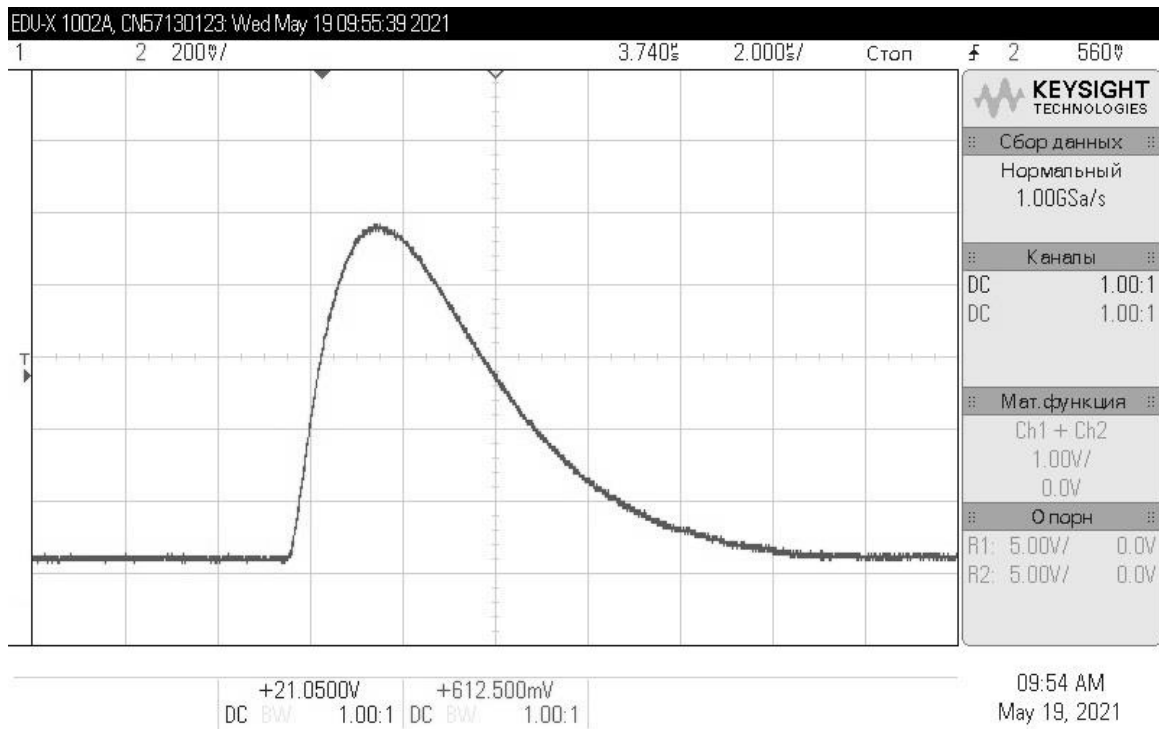
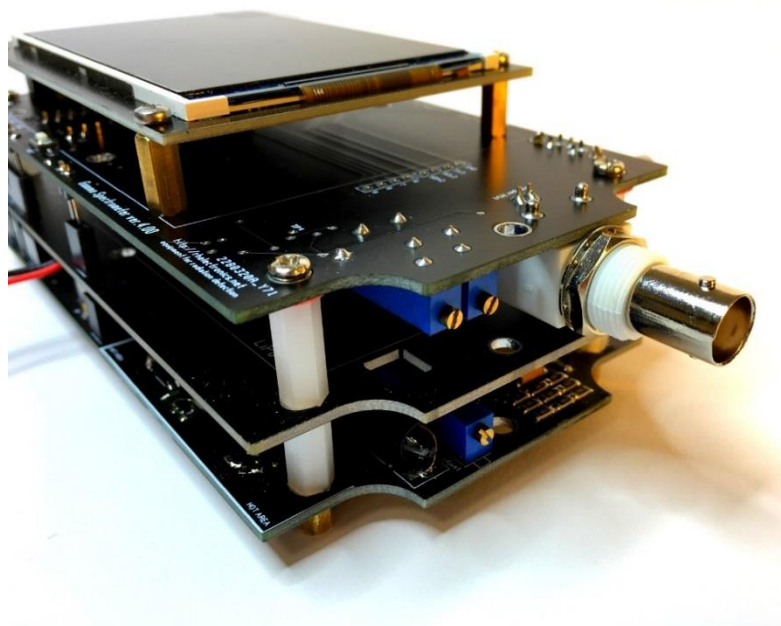


Fig.3

If you have an oscilloscope you can read pulses on TP1. Typical pulse shape is shown in Fig.3. Amplitude of a random pulse will depend on detected photon energy. Normally, Am-241 59keV need to be in range of 70mV-80mV max. amplitude.

Before you can continue with software calibration, it suggested to verify visually that you can get good shape low and high energy spectrum on the LCD. For high energy spectrum checklist, you can use Co-60, Th-232, Ra-226 or Eu-152.

Low quality BNC cable can decrease total gain of the signal or add stray capacitance to the signal path or introduce high voltage leakage. That's why is suggested to use high quality cable or to use recommended part number CT2942-100.

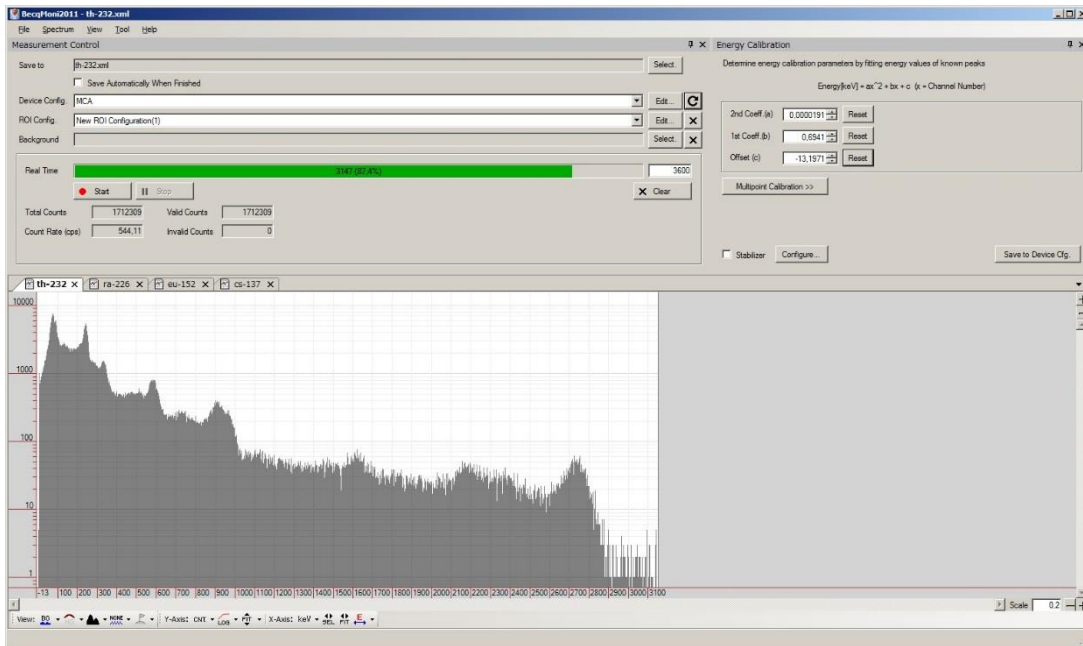


## Exported CSV files:

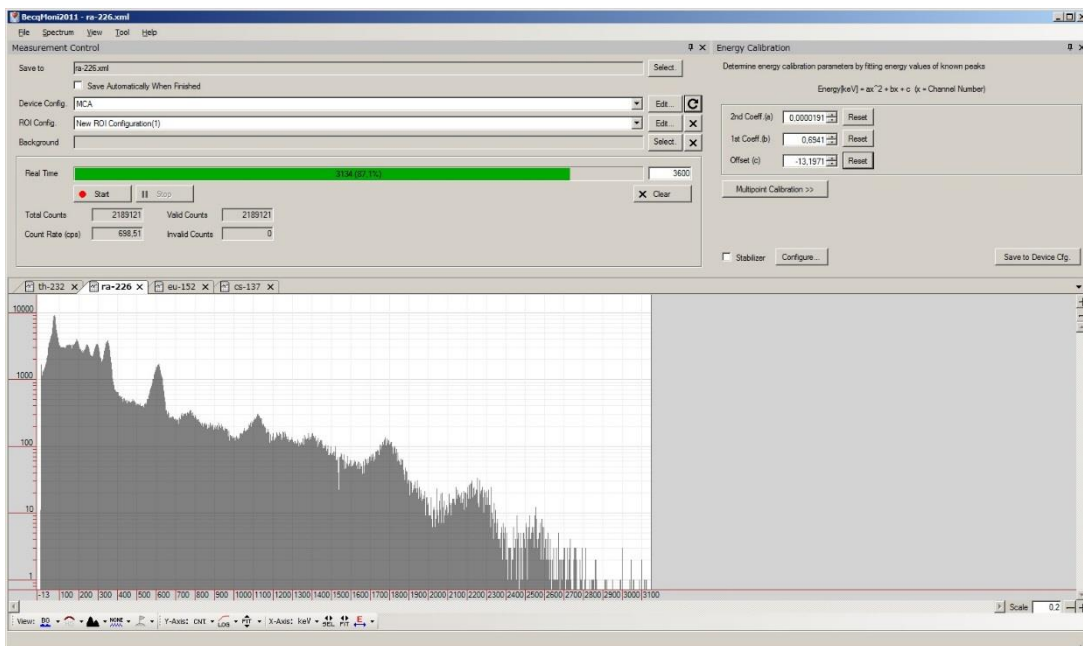
You can download the whole 4096 channels spectrum to your computer via USB command and save the file as CSV. Freeware Notepad++ software can be really useful for copy-pasted data edit when you are using Arduino IDE Serial Monitor commands. Please refer page 14 for serial monitor commands description.

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.

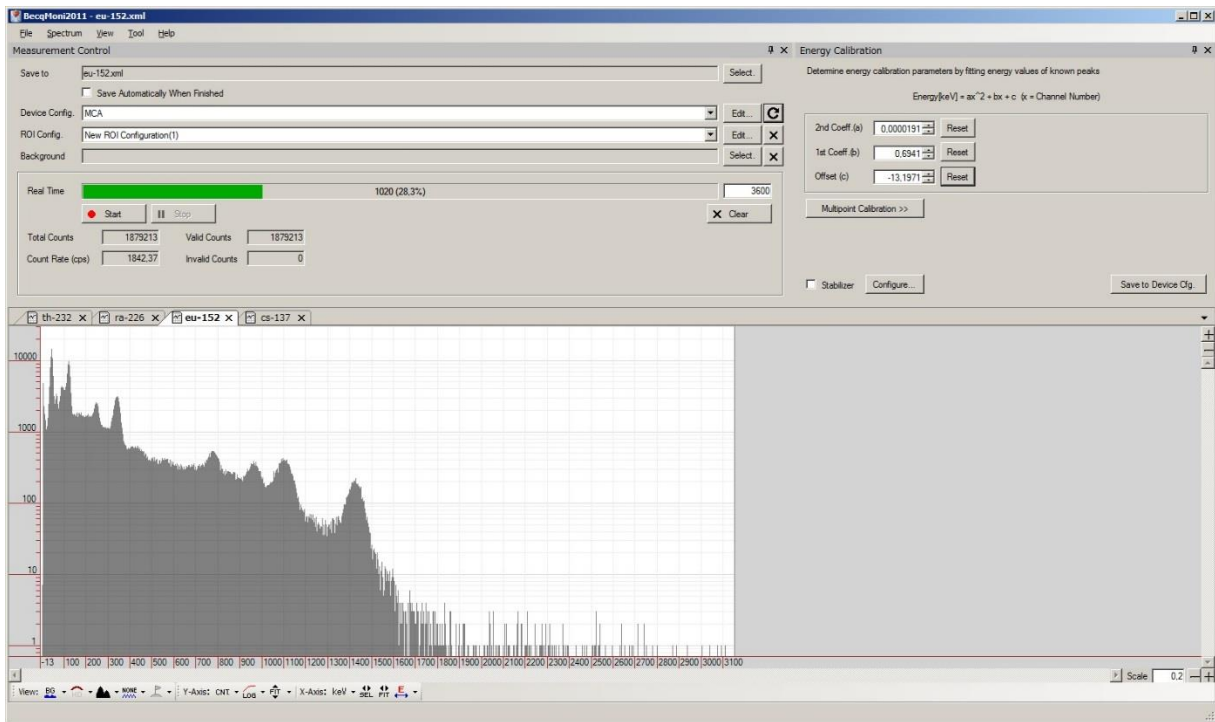
### Lantern Mantle Th-232 Gamma Spectrum:



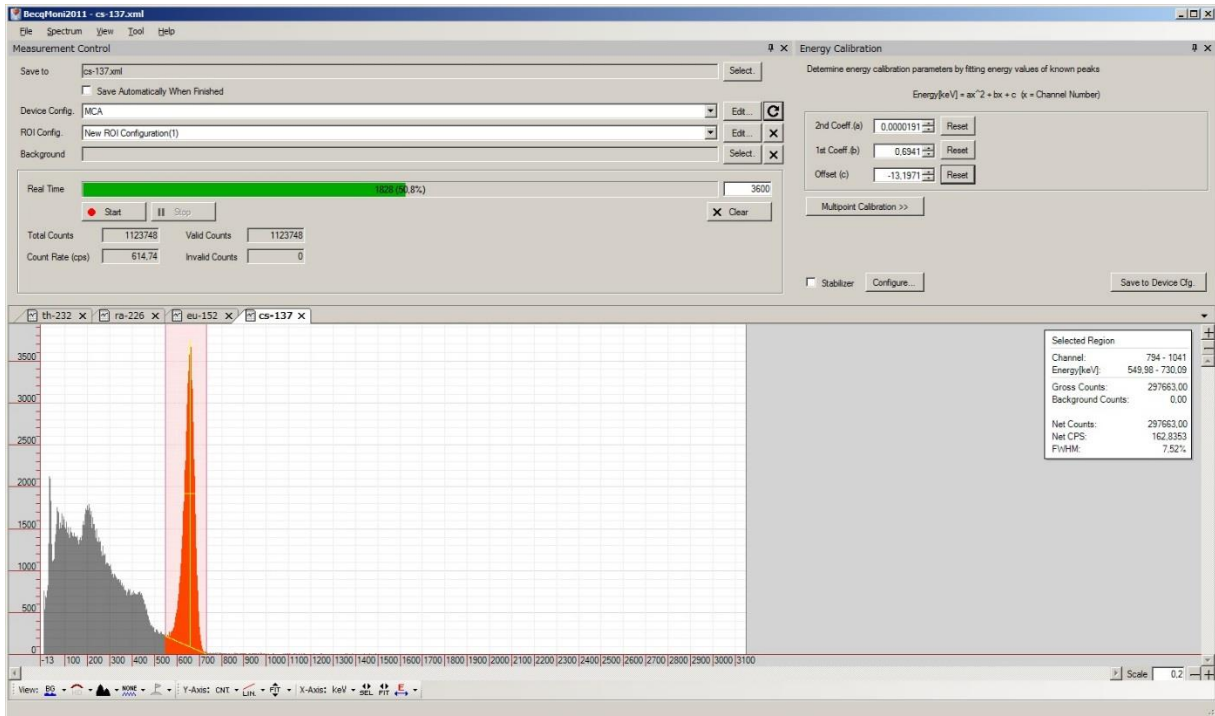
### Ra-226 paint Gamma Spectrum:



### Eu-152 Gamma Spectrum:



### Cs-137 Gamma Spectrum:





## Software Calibration:

### Menu description:

- RETURN – return from menu to current working mode display
- RESTART – restart a new spectrum
- SAVE SPECTRUM – will save 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 SCALE Y – toggle between linear and linear+log scale
- 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
- SPECTRUM TIME – set time in seconds for spectrum acquisition
- BACKLIGHT – change LCD backlight level
- BLE icon (on/off) – power on/off internal Bluetooth module (optional)
- SIGMA icon (on/off) – activate CPS standard deviation calibration for scintillation mode
- 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)

During MCA device start up, if one of a calibration parameter is detected as out of range value, you will hear several low tone alerts. However, no low tone alert is not meaning that everything is calibrated correctly, you need to check and set all calibration parameters to be sure MCA operates correctly.

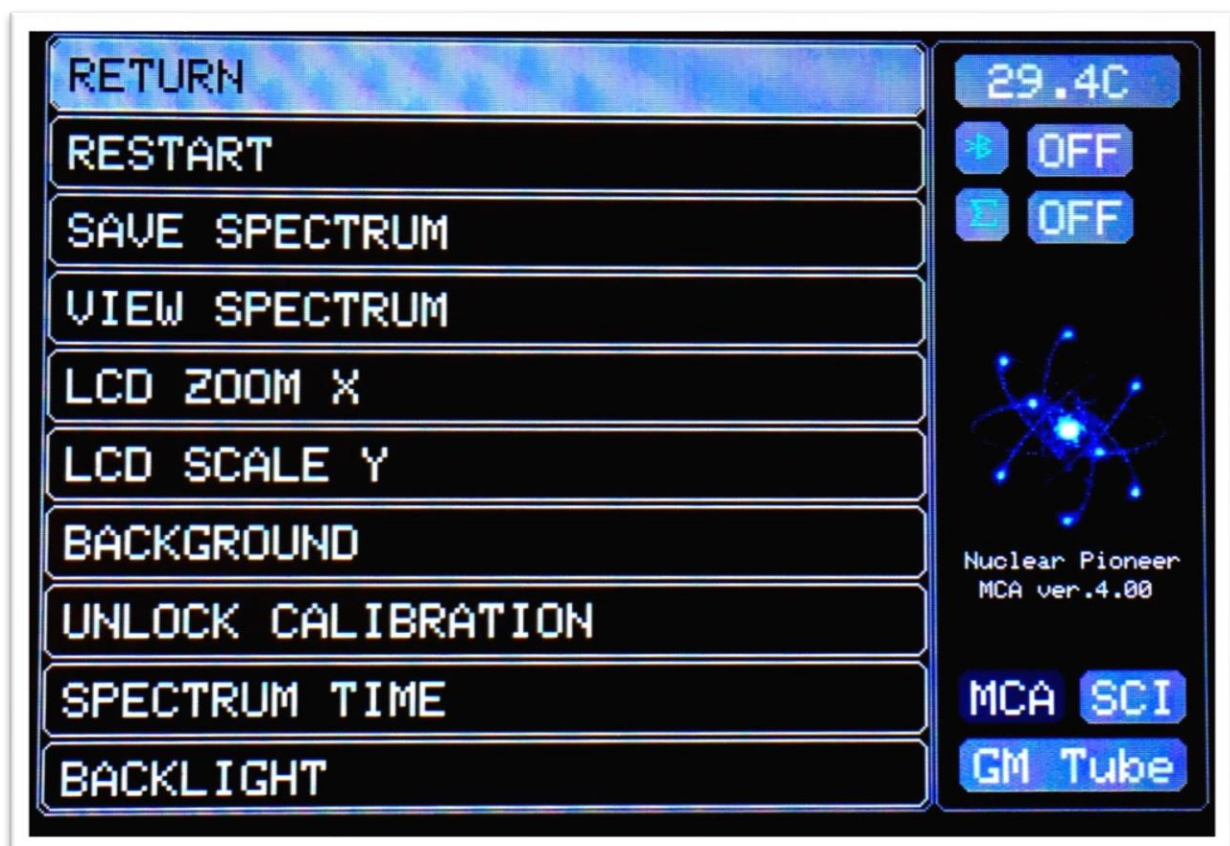


Fig.4

**Channel-to-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 or move all spectrum over the LCD right-left with the encoder. Short pressing on encoder button allows to toggle between moving pointer state. Longer pressing on the encoder button open the menu.

3-point energies used in default schemes:

- **Cs-137 K40 scheme:** 32keV, 662keV, 1460keV
- **Ra-226 scheme:** 186keV, 609keV, 1760keV
- **Eu-152 scheme:** 122keV,344keV, 1408keV

Write your note with channel number for 3 calibration points, depending on your preferred scheme. In my example I 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 line. Each triangle position is indicating channel position of a calibration point.

- Yellow triangle – first point 32keV
- Green triangle – second point 662keV
- Blue triangle – third point 1460keV

Move the pointer red line to set it on channel position of the first 32keV peak and make short press on the button. For example, if you selected Cs-137 K40 scheme, then move the pointer to the position of the first 32keV photopeak. You should see the triangle marker now placed exactly above the correct first peak location. Repeat marker positioning for the second and for the third energy. If done correctly, you will hear confirmation melody and MCA will re-calibrate the scale by auto with all new values. If you made a mistake, just start over energy calibration process.

When calibration process is unlocked, you can see yellow “unlocked” message on the bottom line. It very important to perform energy calibration procedure because peak detection and dose rate functions are using this data.

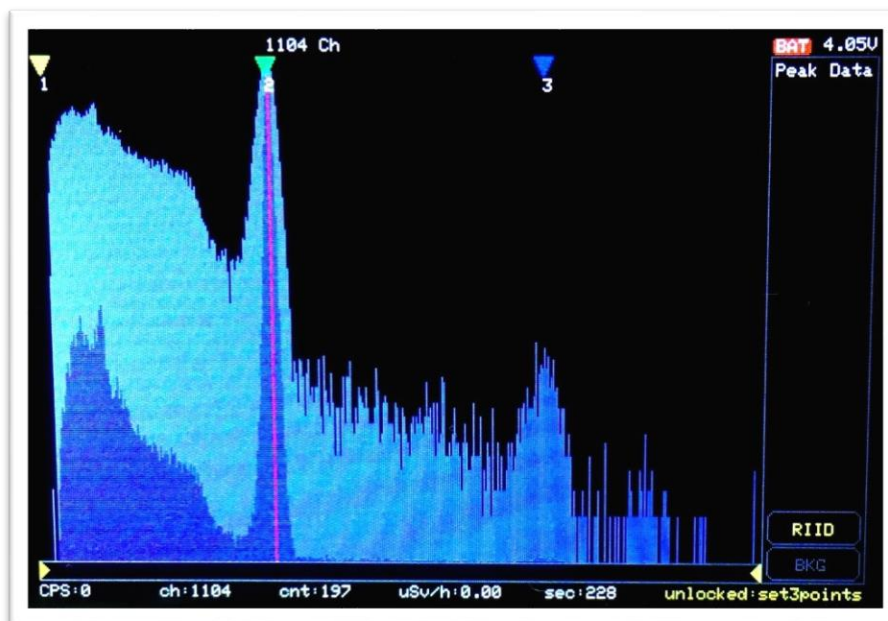


Fig.5

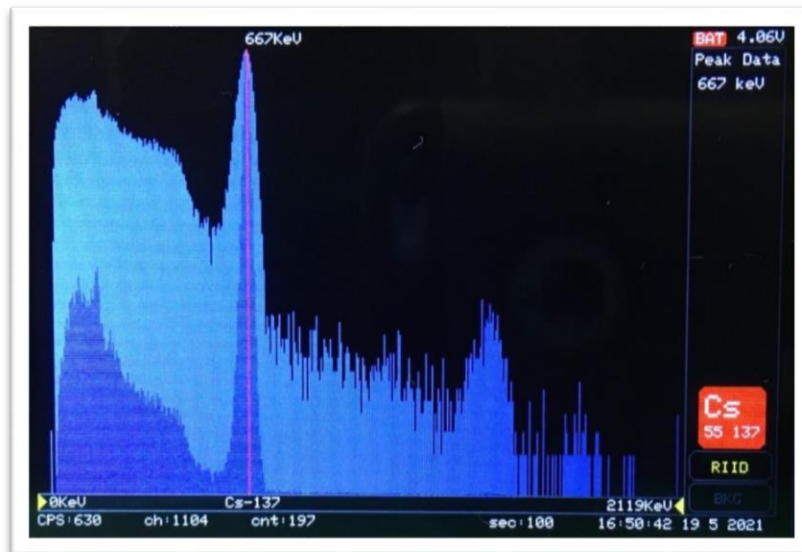


Fig.6

After energy calibration done, Peak Data side bar will appear to work correctly. The accuracy and performance of the RIID side bar is strongly depend on energy calibration function accuracy, probe linearity and crystal volume. It's recommended to use at least 2x2" NaI(Tl) crystal for better performance of the MCA.

**False detection 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, artifacts or low linearity of a detector, limitations of the algorithm and the library, uncompensated temperature drift.

Current isotope library includes detection only for the following elements:

Am-241, Cs-137, K-40, Co-60, Ra-226

Gaussian peaks are detectable over the whole range of the spectrum. You will see detected peaks energies in Peak Data side bar table. That can help to identify other elements in a sample.

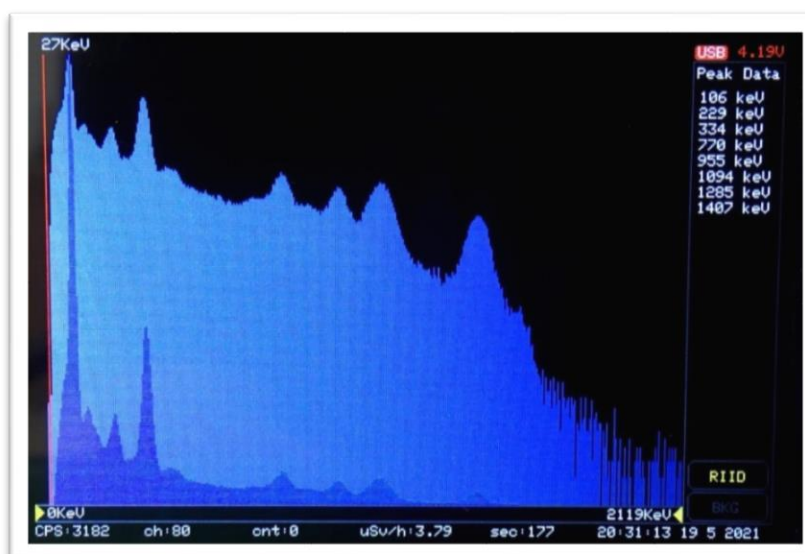


Fig.7

**Additional parameters calibration:**

For the next following parameters adjustment, you can use any Serial Com Port software for sending calibration commands if it supports 12Mbit baud rate speed.

You can use Arduino IDE Serial Monitor with Teensyduino addon.

[https://www.pjrc.com/teensy/td\\_download.html](https://www.pjrc.com/teensy/td_download.html)

Following parameters can be changed by sending command:

- set RTC time and date
- set doserate factor for energy compensated calculation
- set doserate factor for direct calculation
- set LLD lowest level detection channel
- set HLD highest level detection channel

Open Serial Monitor and send following calibration commands sequence for each parameter.

**RTC time and date:**

One way to update RTC time in internal Teensy RTC is just to re-upload sketch from the Arduino IDE, but if you replaced CR2032 battery or cannot use the IDE sketch compile, then use serial monitor command.

send first command: **T**

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

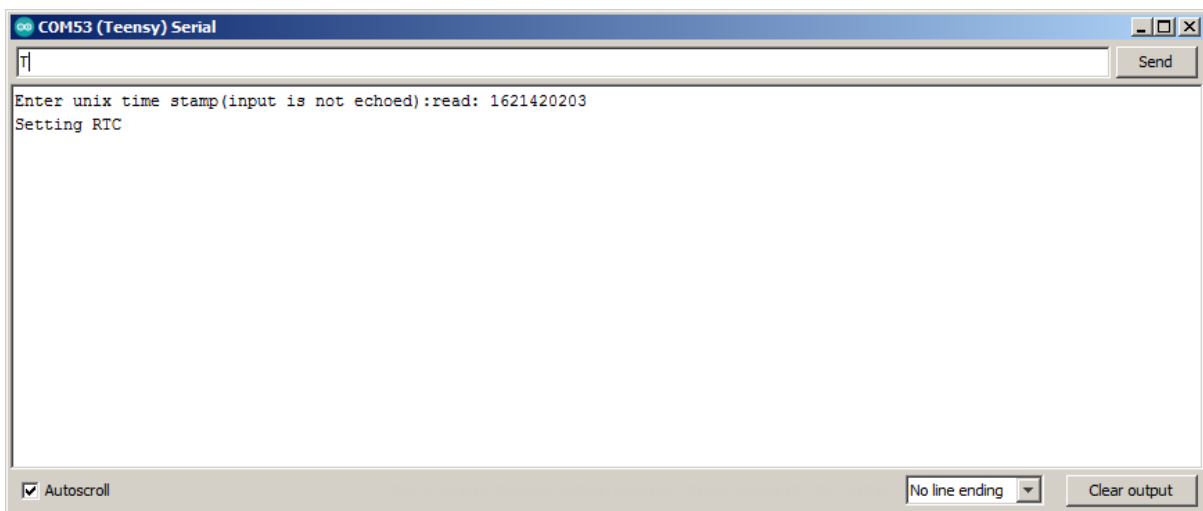
use <https://www.unixtimestamp.com/> or <https://www.epochconverter.com/> to generate timestamp value long number. You need to take care of time zone when generating time stamp in the website.

After first command T sent, serial monitor has 5 seconds time out to accept the new time stamp. You can send the command in one line like: “T1621420203”

**Epoch timestamp:** 1621420203

Timestamp in milliseconds: 1621420203000

**Date and time (GMT):** Wednesday, 19 May 2021 year., 10:30:03

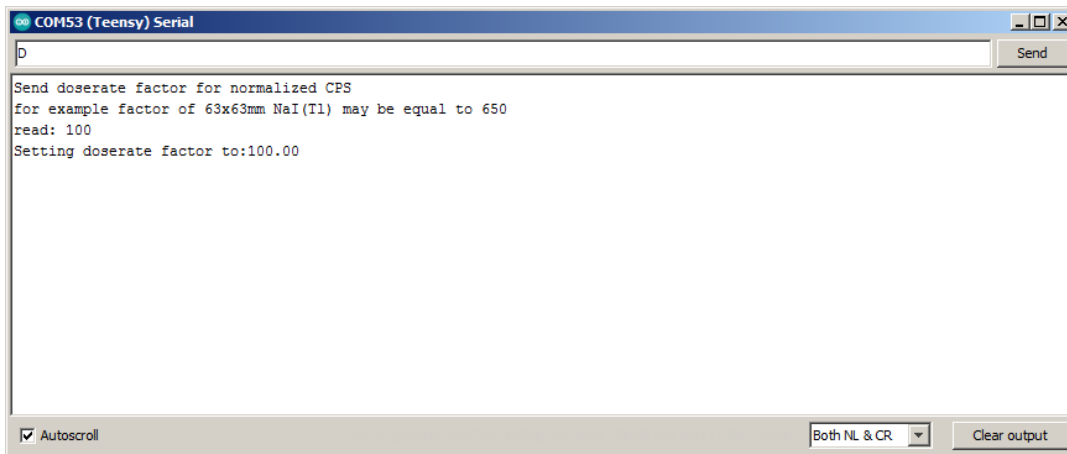


**Energy compensated doserate factor:**

send first command: **D**

send number like: **650**

Factor value depend on your NaI(Tl) crystal volume. Serial monitor return accepted value. You can repeat the command to change the value again. Big crystal require higher value, for example 63x63 may require 600-700 factor. Small crystal like 25x25 may require factor equal to 100-150. Check on your background level that you get 0.07-0.10 uSv/h doserate reading on normal background. In some areas you may need to use a reference dosimeter to get known background level. If you have Cs-137 calibration source and doserate value for known crystal geometry, then you can find the correct factor with it. You can send the command in one line like: “D650”



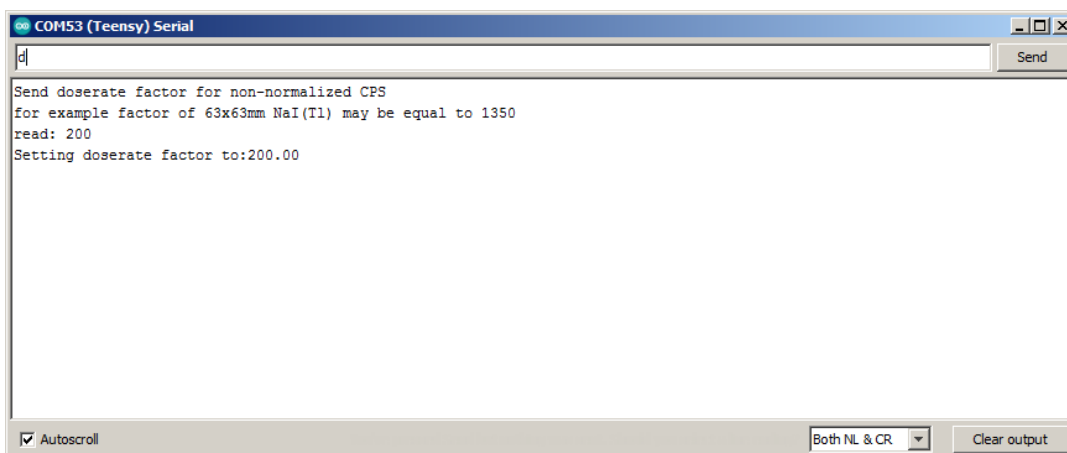
**Not compensated direct doserate factor:**

send first command: **d**

send number like: **1350**

Factor value depend on your NaI(Tl) crystal size. Serial monitor return accepted value. You can repeat the command to change the value again. **The factor used only when background subtract is active in spectrometer mode.** It works as direct CPS to doserate conversion without reference to energy of a detected particles. You can send the command in one line like: “d1350”

Doserate = CPS / factor.

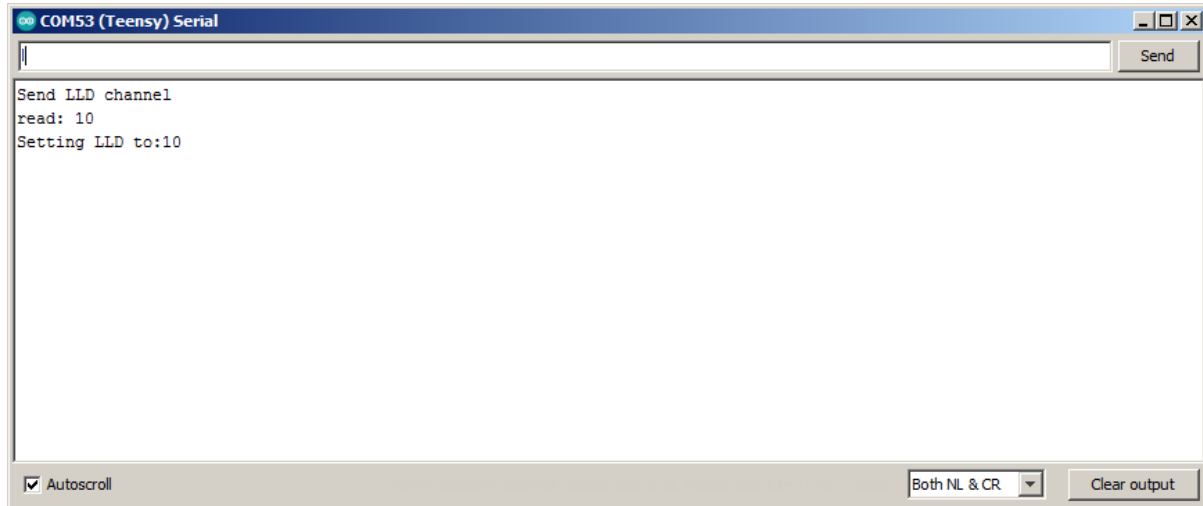


**LLD lowest level detection:**

send first command: **l**

send number like: **10**

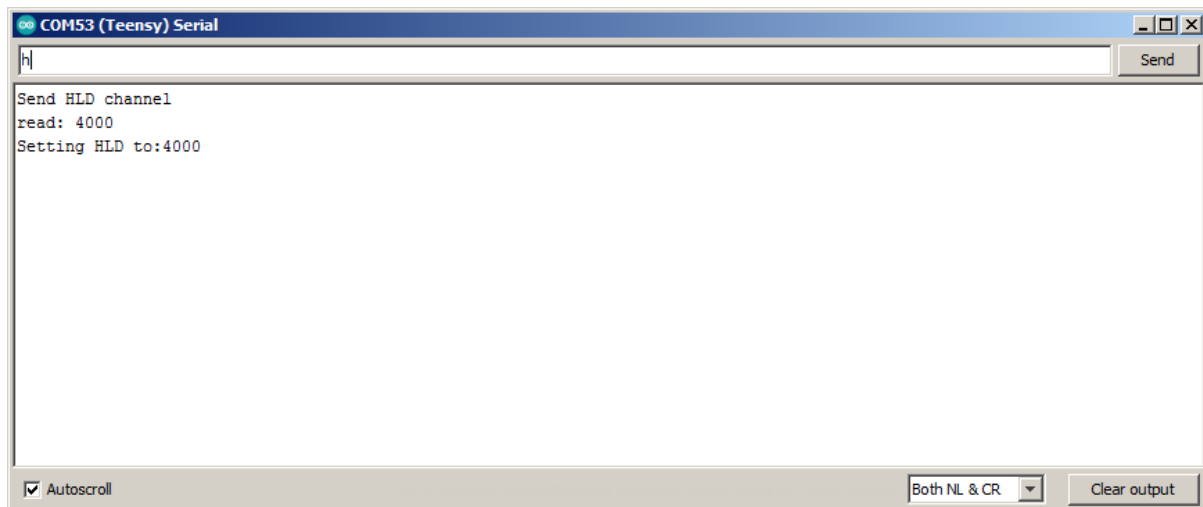
The lowest channel number for ADC to detect. Helps to filter out noise caused by PMT dark current or HV ripple. In some applications, you can use it to set required energy range starting point to detect only a specific peak. Minimum allowed value is 10. You can send the command in one line like: "l10"

**HLD highest level detection:**

send first command: **h**

send number like: **4000**

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 peak. Maximum allowed value is 4095. You can send the command in one line like: "h4000"



### 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

**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

More commands will be added with further firmware updates.

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.

### Replacing micro SD card:

The MCA was tested with micro SD cards 4Gb-16Gb. Insert formatted micro SD card into the socket under upper board. To remove / install the card you may need to detach the upper board from the stackable pin header. LCD module also has SD socket, but the MCA use it own SD socket, be sure you are using correct one.

### Scintillation Mode:

You can toggle scintillation mode by setting **SCI** icon to active. In scintillation mode software calculate energy compensated doserate. You can connect / disconnect the internal Geiger counter circuit by setting **GM Tube** icon.



Fig.8

During initial setup and calibration, you need to toggle Sigma icon in menu to ON. It will trigger the software to recalculate a new standard deviation for your probe. Place the probe on normal background without any radioactive sample around it. Enter scintillation mode and wait until you see: "standard deviation is in progress, please wait..."

To toggle sound modes, use short pressing on the button. Default doserate alert is 0.30uSv/h. Default CPS alert exclamation symbol is 2xSigma for fast search and locate. The counter will click on every  $n=100$  particle. Default CPS averaging time for Geiger Counter is 3 minutes.

Tiny SBM-21 GM sensor can be installed on the bottom PCB. If you have space in the enclosure, you can install a bigger size 400V GM sensor. Keep GM sensor wires short as possible. Geiger Counter is mostly useful in high radiation zones where scintillation counter will be saturated by high activity.

In scintillation mode, some menu items related to gamma spectroscopy are not active.

### Subtract Background:

Real time background subtract can be helpful when sample activity is low, and you don't have a lead castle to filter natural background. The function is mathematically subtracting previous saved background **0000000.CSV** from the actual spectrum.

You need to prepare background data file prior using subtract function. Set SPECTRUM TIME to 1000 - 7200 and make background acquisition. The file will be saved by auto on SD card when timer roll over the defined spectrum time. Check that the file is saved correctly through opening it from VIEW SPECTRUM. **Be sure the file remains opened before continuing.**

Go to BACKGROUND menu and select "Save". The software will create a new file (or re-write the old) on SD card with the name **0000000.CSV** It's your background data that can be used now for the real time subtract. Acquisition time must be smaller or equal to the background spectrum time. The good idea is just to keep SPECTRUM TIME unchanged.

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 viewer go to BACKGROUND and select "Unload".

If you have **0000000.CSV** file on SD card, next time you can just activate the function by selecting "Subtract" from the BACKGROUND menu.

Photo example of the spectrum with and without background subtract. 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 relatively high background count rate of the crystal. The peaks are much better visible when background is filtered out.

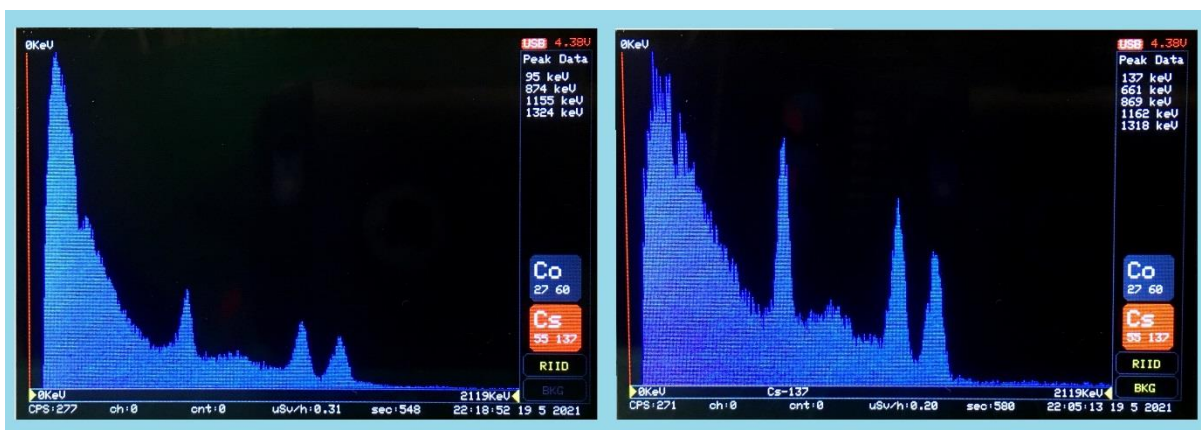


Fig.9

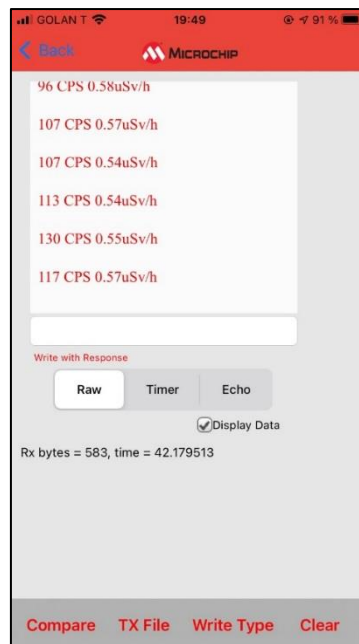
left no subtract, right with subtract



**BLE Bluetooth:**

The board is electrically compatible with BM71BLES1FC2 or RN4871 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. In the application select BM70/BM71 BLE UART, connect to the MCA module, select Transparent UART mode and tick “Display Data”.



**Fig.10**

**Further Software Updates:**

Further software updates can be made through bootloader application. <https://www.pjrc.com/teensy/loader.html>

Open teensy.exe, select the new hex file and press Program in the bootloader application. The MCA board has RST button to enter program mode in case it does not happen by auto from teensy loader. It’s recommended to install Arduino IDE with Teensyduino addon to get all required drivers.

When any update is ready, it will be posted on <https://rhelectronics.net> website for download.



The bootloader is stored in a dedicated chip preventing flash programming from being able to damage or erase the bootloader.

The controller will fully erase its non-volatile memory if the program RST button is held between 13 to 17 seconds. After erasure, the flash memory contains no code which can respond to the automatic program entry request on the USB port. Another press of the RST button is needed to again enter programming mode.

**Temperature Correction:**

Because of the NaI(Tl) nature, any scintillation detector has temperature drift. Try to keep probe temperature stable as possible and make energy scale recalibration if required. Internal temperature sensor provides electronic board temperature and can be used only as a reference sensor for environmental temperature.

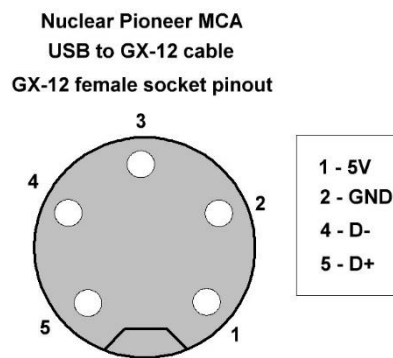
The MCA further firmware update is planned to implement automatic gain software correction.

**Low battery Alert.**

When voltage on the LiPo is drop below minimum 3.15V level, the device will prompt you constantly about low battery level. Please power off the MCA and connect 5V USB for charging. Full charge time for 2000mAh capacity can take about 7 hours. If battery is empty, you still can use the MCA powered by USB cable, but it will slow down charging time of the LiPo.

**GX-12 to USB cable pinout.**

If you purchased Nuclear Pioneer assembled into enclosure, please refer GX-12 cable female socket pinout as shown on Fig.11.



**Fig.11**

**Technical support and contact:**

With any question or request you can contact RH Electronics and the developer by email: [support@rhelectronics.net](mailto:support@rhelectronics.net)