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A light weight multichannel analyser and γ-ray spectroscopy system: Application to estimate ^{40}K content in some potassium salts and building materials

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Abstract. A γ-ray spectroscopy system based on a $1'' \times 1''$ NaI(Tl) detector and $1.5''$ photomultiplier tube has been developed at IUAC for teaching laboratory applications involving radioactive sources. Following along the lines of the Phoenix and Expeyes hardware developed in the laboratory earlier, a low-cost, light weight multichannel analyser also has been developed. Here the details about the same are presented. The detector–analyser system has been used as a part of the postgraduate curriculum for measuring ^{40}K content in some potassium salts and common building materials like brick, cement, concrete and sand.

Keywords. ^{137}Cs γ-rays; light weight multichannel analyser; radioactivity; ^{40}K content; potassium salts; building materials.

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1. Introduction

A programme for developing computer-based hardware and software for improving experimental physics teaching and research in Indian universities has been started at the Inter University Accelerator Centre, New Delhi. The idea was to make available such systems at affordable prices to the universities. Phoenix [1] and Expeyes [2] are two such devices. The objective of the project is to provide a low-cost but advanced tool for students to learn science by exploring and experimenting. Following along similar lines, two of the authors (SV and BPA) have developed a low-cost γ-ray spectroscopy system including a light weight multichannel analyser [3]. Essential details of the set-up are presented in the next section. The set-up has been used to investigate the radioactve ^{40}K content in common potassium salts and some building materials. Results of the studies are also presented.

2. Experimental set-up

2.1 *Hardware*

A $1'' \times 1''$ NaI(Tl) detector supplied by M/s Saint-Gobain Crystals, Bangalore, was used for γ detection. The detector has been optically coupled to a ten-stage, Hamamatsu $1.5''$ PMT (R980 with socket E678-12A). The detector crystal and PMT are packed in an aluminium canister and provided with a 'mu' metal shielding. The electronic modules are placed within the die-cast aluminium box with an opening for radiation to enter the scintillation crystal. A high voltage bias network supplies the anode with +550 V through a load resistor of 2.2 MΩ. The divider network is fabricated on a PCB with SMD components and socket mounted for easy assembly. A charge-sensitive preamplifier having a charge sensitivity of −1 mV/MeV routes the signals from the anode of the PMT. At present no provision has been made to tap the signal from lower dynodes. The block diagram of the signal processing electronics is shown in figure 1.

The signal from the preamplifier is further shaped and amplified with a low noise, operational amplifier. Coarse gain selection is done in this stage. Further fine amplification as well as overload recovery is effected in the next stage which also helps to recover the amplifier quickly from pile-up of events at the input due to increased radiation intensity. The signal is shaped for a desired time constant (2 μs) with two stages of second-order low pass filters in the cascade. The slow varying baseline or DC offset is corrected in the following stage with twin diode

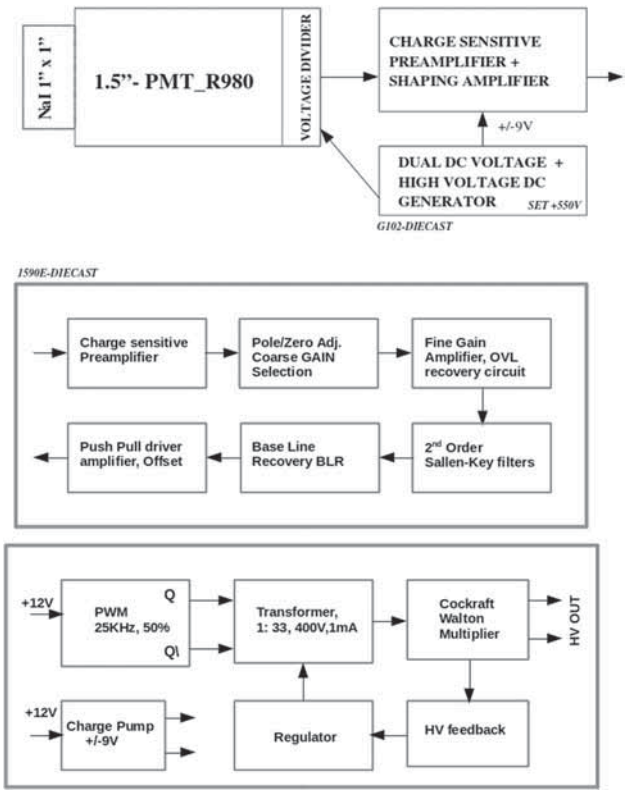

Figure 1. Block diagram of the signal processing electronics.

Robinson baseline recovery circuit [4]. Further, the signal is amplified and buffered for an optimum load in the last stage.

The high voltage power supply is an independent unit, as shown in figure 1. A dual DC voltage supply (charge pump) circuit, required for signal processing electronics is also incorporated in the same PCB. The high-voltage DC generator works on Cock Croft–Walton principle. A six-stage Cock Croft–Walton half bridge high voltage multiplier circuit generates the required high output voltage (550–600 V). The output voltage is sampled through a high ohmic resistor chain to generate negative feedback voltage for an on-board regulator (LM723). The output voltage is set to +550 V, and can be adjusted within ±5% with control provided on PCB. The rms ripple voltage at the output is measured to be 14 mV (less than 0.003%) when it is fully loaded. The high voltage power supply is capable of more than +700 V, and if required the same can be adjusted on the PCB. The currently set high voltage +550V is optimised for better resolution.

The multichannel analyser (MCA) part is enclosed in a separate aluminium housing. A threshold detector, peak detector, and a microcontroller with built-in ADC are the basic components of the MCA. The input pulse is in the 0–5 V range. Any pulse exceeding the

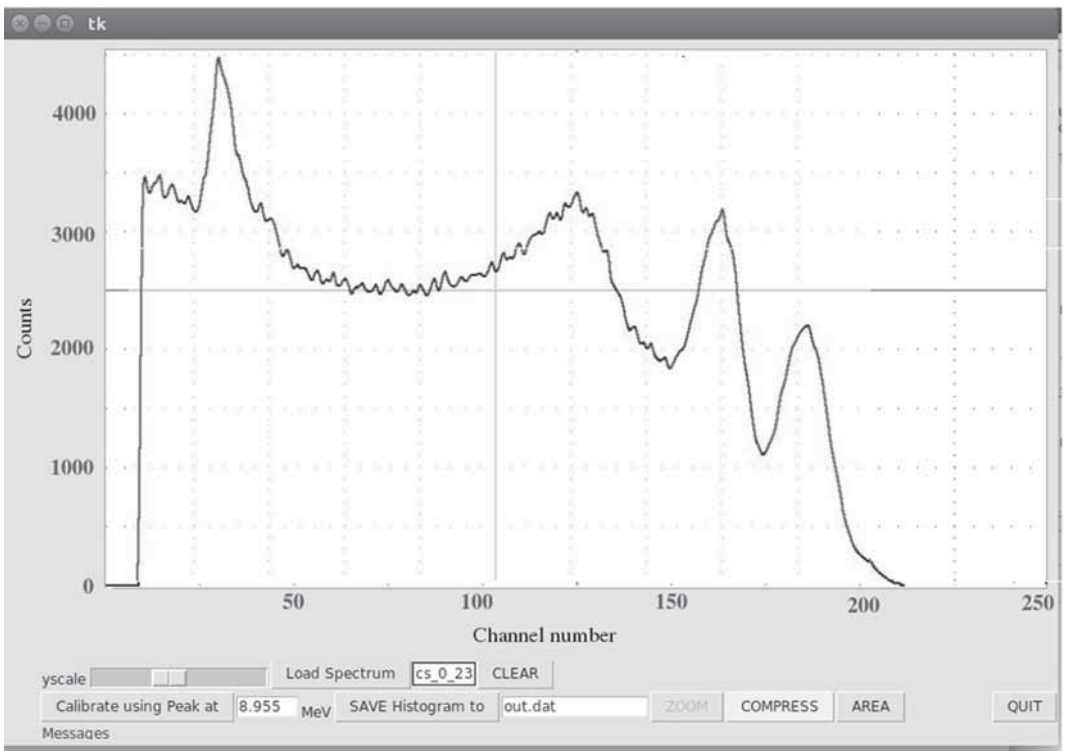

Figure 2. GUI window of the light weight MCA showing ^{60}Co spectrum.

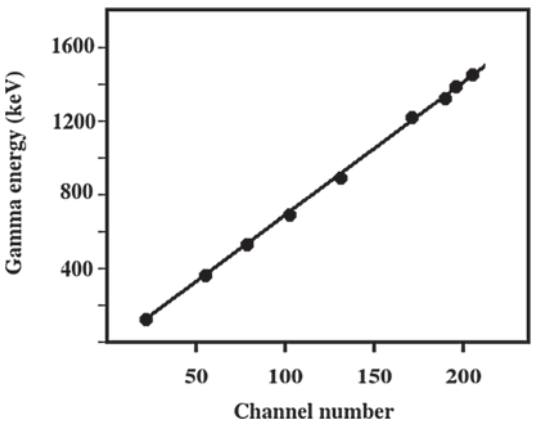

Figure 3. Energy calibration plot.

threshold activates the peak sensing circuit and interrupts the microcontroller unit (MCU). The pulses are then digitised by the MCU. The spectrum is generated in the local memory. It is subsequently sent to the PC as and when requested by the light MCA programme running on the PC.

2.2 *Software*

The software for data acquisition and analysis using the MCA is written in python programming language. It presents a user friendly GUI, shown in figure 2. It has provisions for starting/stopping the spectrum acquisition, pre-defined acquisition time, zooming and clearing the spectrum, saving the spectrum etc. Two markers can be used for selecting a region for zooming as well as for obtaining integrated counts. There is also provision to select online or offline mode. In the offline mode, a previously saved spectrum can be loaded and analysed.

2.3 *Details of the experiment*

The γ-ray spectrometer was initially calibrated using the standard γ-ray sources ^{133}Ba, ^{137}Cs, ^{54}Mn, ^{22}Na, ^{60}Co and the 1.46 MeV line of ^{40}K. A typical spectrum obtained using ^{60}Co source is reproduced in figure 2. The calibration curve is shown in figure 3. It can be seen that there is reasonably good linearity.

For measuring the ^{40}K radioactivity content, the required samples were kept on the axis of the detector at a distance of 5 cm from the detector face. Spectra were collected to get reasonably good statistics. A representative spectrum from the KI sample is shown in figure 4. The 1.46 MeV γ line from ^{40}K is seen prominently.

The background spectrum was separately measured for the same time interval as used for the sample runs.

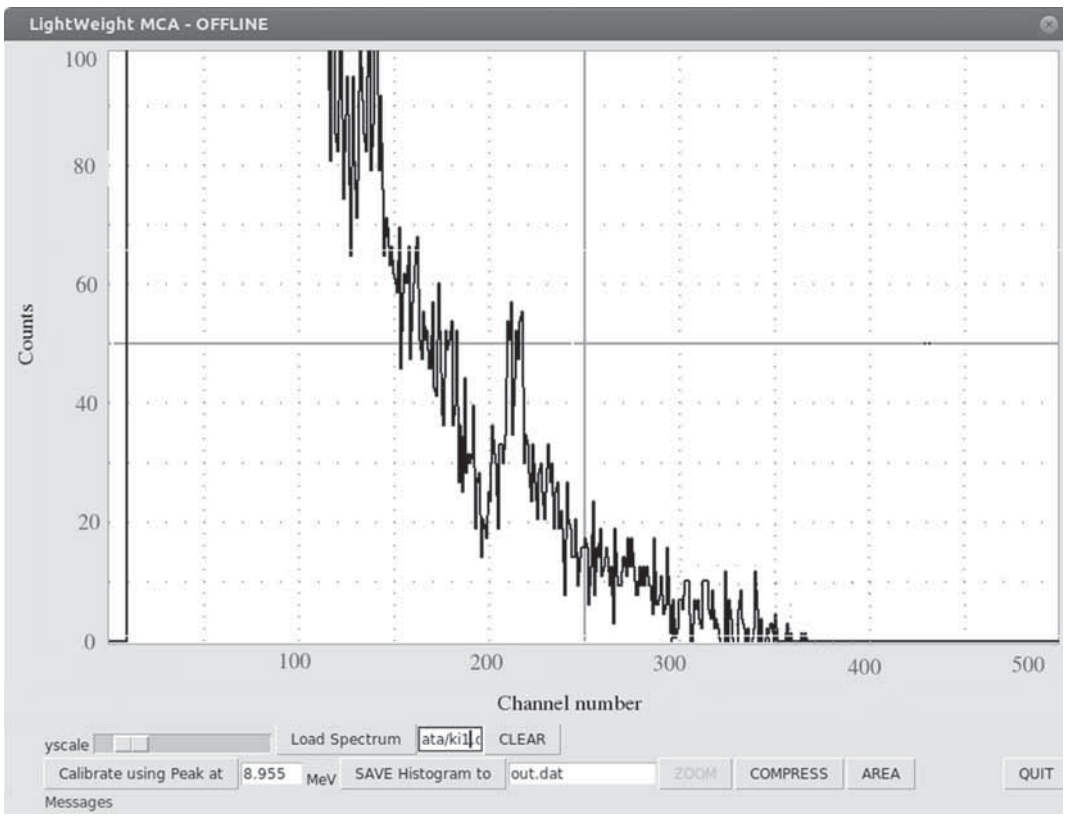

Figure 4. Spectrum from a KI sample, showing the 1.46 MeV γ line.

Table 1. Radioactive ^{40}K content in the analysed samples.

Sample	^{40}K content (Bq/kg)	
	Present experiment	Standard/calculated
Potassium iodide	121 ± 7	101
Potassium hydroxide	294 ± 16	280
Potassium sodium tartarate	34 ± 3	35
Potassium chloride	187 ± 12	204
Cement	460 ± 26	Varies
Concrete	149 ± 10	in the
Brick	52 ± 6	range
Sand	115 ± 8	50–800

The area under the ^{40}K γ photopeak is determined using a separate Gaussian + linear background peak fitting programme. The measured background counts under the photopeak agreed, within the statistical uncertainties, with the estimated counts obtained in the fitting procedure. From the photopeak counts, the radioactive ^{40}K content in the sample is calculated after correcting for the photopeak to total ratio, attenuation inside the sample and the finite solid angle and total efficiency of the detector. A 'C' code was used for calculating the mentioned corrections.

3. Results and discussion

Table 1 lists the results of the measurements. The uncertainties quoted are basically due to the counting statistics, and to a lesser extent to the error in the mass measurements. For comparison, the works of Estokova and Palascakov [5] and Chong and Ahmed [6] give ^{40}K contents varying between 50 and 800 Bq/kg in different samples of building materials in foreign countries. The work of Nain *et al* [7] quote similar ranges for samples from India. Kadum *et al* [8] have compared the results for samples from various countries.

The present results for the potassium salts are more or less agreeing with the calculated values, which were extracted from the known masses of the salts used, assuming the natural abundance of ^{40}K. For the building materials the results lie within the limits quoted by other authors and depend on the source of the materials.

4. Conclusions

We have demonstrated the capabilities of the new low-cost light weight γ spectrometer MCA system, which is affordable to many Indian universities. The set-up has been used to determine the radioactive ^{40}K content in some potassium salts and in some common building materials. The results are consistent with the expected values. The low-cost set-up can be used for routine postgraduate teaching laboratory experiments on γ-ray interactions as well as in research experiments in a limited way.

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