GAMMA-SPECTROMETRIC MODULE BASED ON HPGe DETECTOR FOR RADIATION PORTAL MONITORS

by

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The appearance of small-sized and powerful enough electric cryocoolers of various types on the market, has opened the perspective of HPGe detectors application, cooled by such coolers, in radiation portal monitors. The first results of a spectrometric module based on HPGe detector with relative efficiency of 45% cooled by a Stirling-cycle cryocooler, are presented. The spectrometer has provided energy resolutions of less than 0.95 keV and 1.95 keV at energies of 122 keV and 1332 keV, respectively. The deterioration of the energy resolution of HPGe detector cooled by electric cryocooler in comparison to the resolution with liquid nitrogen cooling was about 8% at the energy of 1332 keV. With the use of activated filters to suppress pulses produced by the mechanical vibrations, the energy resolution of the spectrometer was 0.8 keV and 1.8 keV, respectively, however, the detector relative efficiency at the energy of 1332 keV has dropped to 39 %.

Key words: HPGe spectrometry, radiation measurement, radiation portal monitor, electrical cryocooling

INTRODUCTION

The detection of the fissionable substances and radioactive materials at the illicit traffic has been the object of intense studies in the recent years [1-4]. One of the methods to resist the nuclear and radiation terrorism is the radiation board control by stationary radiation portal monitors (RPM) – passive detection systems for γ and neutron radiation from the radioactive substances and nuclear materials [5].

RPM based on plastic scintillators are widely applied, since they are rather inexpensive detectors, and they provide the non-proliferation of nuclear and radioactive materials by being installed checkpoints (boarder, airports, railway crossing, *etc*). The sensitivity of these modern monitors to γ radiation is rather high.

However, these RPM, manufactured with plastic scintillators and having poor energy resolution could only provide the primary diagnostic, *i. e.*, monitoring a certain level of radioactive materials presence. The next phase is a detailed analysis of the obtained information with semiconductor detectors or scintillation spectrometers.

Having a perfect energy resolution and high efficiency of gamma-radiation registration, HPGe semiconductor detectors, are over decades, are the undeniable leaders amongst all detector types for precision gamma spectrometry [6]. However, to provide their perfect performance, HPGe detectors should be cooled to liquid nitrogen temperature, which restrains their application in the set of passive RPM. Recently, the appearance of small-sized and at the same time powerful enough electric cryocoolers (ECC) of various types, on the market, has opened the perspective of the present task solution [7, 8].

The present manuscript provides the first development results of spectrometric module based on HPGe detector with electric cryocooling, which could be applied as in RPM as well as in other spectrometric equipment based on HPGe detectors.

HPGe DETECTOR AND ELECTRIC CRYOCOOLER

The spectrometric module is made as a monoblock unit of L699 mm W399 mm H520 mm and is easily installed into a standard cabinet of 19" for RPM. The spectrometric module comprises HPGe detector, its electric cryocooler (ECC) and electronics. The external view of the module with opened front cover is shown in fig. 1.

Coaxial HPGe detector is made by a standard technology from p-type crystal of 80 mm diameter and

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Figure 1. Spectrometric module for RPM (with opened front cover)

35 mm height [9]. Relative efficiency of the detector is ~45 %. In technological cryostat, cooled by liquid nitrogen, the energy resolution of the detector was 0.8 keV and 1.8 keV at the energies of 122 keV and 1332 keV, respectively.

In the module, the detector is installed into a cryostat with aluminum cap of 100 mm in diameter and thickness of the front wall of 0.5 mm. The cryostat with the detector is placed in a lead shield of 30 mm thickness around the detector cap and with 50 mm on the backside of the detector to cut off the background radiation and improve the background performance of the detector.

The Stirling-cycle cryocooler LSF9340 with built-in cryocontroller was applied for cooling the detector [10]. At the power consumption of 170 W, the cryocooler provides up to 9W of cooling power at 80 K. The cryocooler compressor is a double-cylinder with antiphased balancing and the, maximum vibration level is 6N. The vibration level on the cold finger is less than 1.5N, which is provided with a special compensator built-in the head. The manufacturer estimates the average mean time between failures (MTBF) of 45 000 hours. It should provide 5-6 years of continuous operation.

ELECTRONICS AND SOFTWARE

Electronics comprises the preamplifier of the detector signals, digital multichannel analyzer (MCA), and microprocessor device to control the module in the set of RPM as well as data transfer to PC. The input stage of preamplifier is placed in the vacuum chamber of the cryostat, for cooling by electrical cryocooler. Non-cooled part of the preamplifier is outside of the vacuum volume in a separate hermetically sealed section.

Digital multichannel analyzer (16 K) is based on a processor board MCA-527 [11]. The main problem for application of ECC with HPGe detectors is the influence of their mechanical vibrations to the detectors energy resolution. That is why, additionally to all means to reduce this influence, in the present development we have applied the special electronic-software filter in the set of MCA to suppress the pulses of the mechanical vibrations.

Low frequency rejection is a special triple differentiating spectroscopic filter for the use in environments with strong low frequency noise components, *e. g*., microphonics with HPGe. Principally this filter does not only evaluate the voltage step, but also the slope of the baseline before and after the voltage step. Because of this, the low frequency sensitivity is so low that pole zero adjustment is not necessary. However, as this filter is triple differentiating, the amount of high frequency noise is increased, even as this filter is optimized for the lowest error. The filter gives the best results with twice or triple as high shaping times, so throughput may be a bit limited with this. Resolution can be almost as good as with the standard filters in a quiet environment. In a noisy environment, the low frequency filter can yield orders of magnitude better results and be invaluable when forced to work in such environments.

Microprocessor device based on WAGO Ethernet controller ECO 750-852 controls the operation of Stirling-cycle cryocooler in two modes – manual and automated with the program "Cooling control" software. The recommended mode is automated one when the cooling is made in two stages prompt at increased power of 100-110 W until the temperature reaches –190 °C and after that, switches to the economy mode of 50-60 W to maintain the temperature of –195 °C.

When the specified radiation level from the monitoring object is exceeded, the spectrometric module produces an alarm signal. That signal allows the operator to stop the object for spectrum acquisition, the software automatically identifies radionuclides and, calculates their activities. The obtained data provides classification of the character of the detected radioactive object and definition of the further actions by the personnel to operate with it. Identification is performed according to software library of the radionuclides. Count rates are calculated automatically with background deduction. The various commands give the opportunity to compile the scenarios, which realize the complex variants for measurement and data processing, their transfer to databases and executive devices.

PERFORMANCE INVESTIGATIONS

As it was underlined in the introduction, precisely the ability to cool HPGe detectors up down to the working temperature without liquid nitrogen has

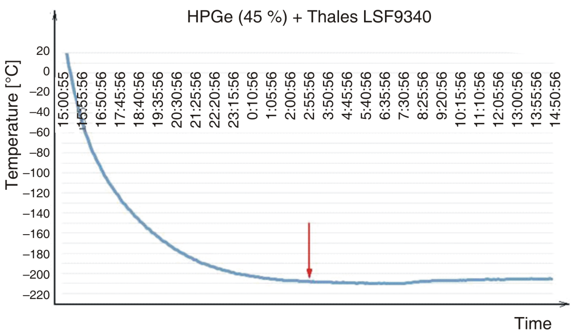

Figure 2. Time dependence of the HPGe detector temperature in the developed module

provided their application in the RPM. The time when HPGe detector achieves its working temperature depends on its weight and ECC power. Figure 2 shows the temperature *vs*. time dependence for HPGe detector with 45 % relative efficiency, cooled by electric cryocooler Thales LSF9340 in the developed module. As it is seen from the figure, the detector reaches the working temperature in about 12 hours after the supply is turned ON.

Spectrometric performance of the developed module was investigated at working temperature of HPGe detector. Figures 3 and 4 show the spectra of the radionuclides Co-57 and Co-60, registered by the developed module. The test results demonstrate that spectrometric module had provided energy resolution less than 0.95 keV and 1.95 keV for energies 122 keV and 1332 keV, respectively. The deterioration of the energy resolution of the detector, cooled by ECC in comparison to the resolution at liquid nitrogen cooling was about 8 % at the energy of 1332 keV.

At the filters, activated in multichannel analyzer, to suppress the pulses of the mechanical vibrations, the energy resolution of the spectrometer was 0.8 keV and 1.8 keV for energies of 122 keV and 1332 keV, respectively, *i. e*., the same values that have been obtained by

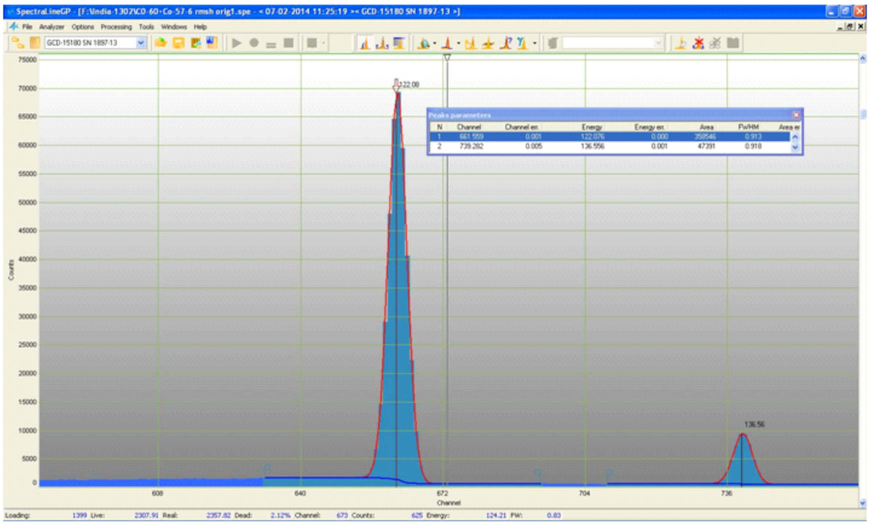

Figure 3. Spectrum of Co-57, detected by the developed module

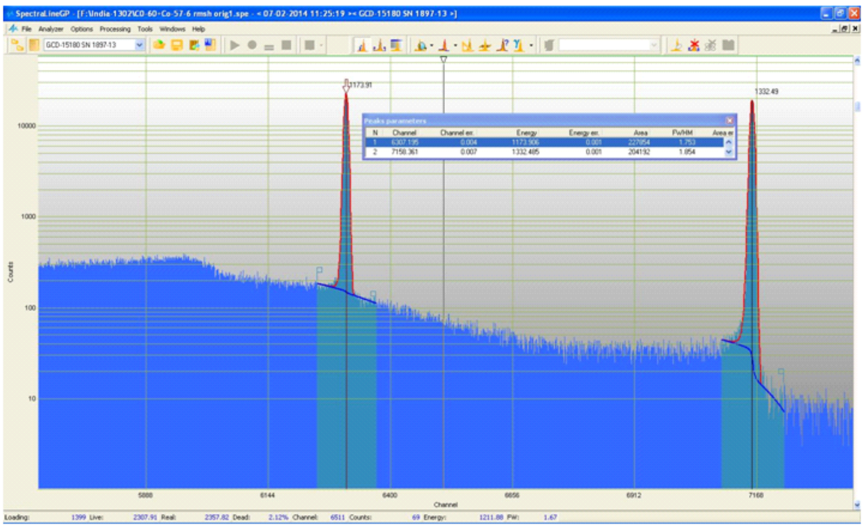

Figure 4. Spectrum of Co-60, detected by the developed module

cooling with liquid nitrogen. However, the relative efficiency at energy 1332 keV has decreased to 39 %. The necessary electronics operation mode – with filter or without – could be selected in dependence on the current task and the optimum performance that should be provided – the best energy resolution or higher relative efficiency.

CONCLUSIONS

The presented results demonstrate the capability to develop the precision spectrometric equipment, based on HPGe detectors, without the liquid nitrogen. Energy resolution of the spectrometric module with HPGe detector of 45 % relative efficiency cooled by Stirling-cycle cryocooler was less than 0.95 keV and 1.95 keV for energies 122 keV and 1332 keV, respectively. The deterioration of the detector energy resolution, cooled by ECC, in comparison to the resolution with liquid nitrogen cooling, was about 8 % at the energy of 1332 keV. The developed module could be applied in the radiation portal monitors as well as in other spectrometric equipment based on HPGe detectors.

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AUTHOR CONTRIBUTIONS

Development of the electronics and software was done by V. Kondratjev and technical realization and control for the development by A. Sokolov. The development of the concept, selection of the cooler type and manuscript writing was realised by V. Gostilo.

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ГАМА СПЕКТРОМЕТРИЈСКИ МОДУЛ ЗАСНОВАН НА HPGe ДЕТЕКТОРУ ЗА ПРЕНОСИВЕ МОНИТОРЕ ЗРАЧЕЊА

Појава на тржишту различитих типова електричних криохладњака довољне снаге и малих димензија, отворила је могућност примене HPGe детектора у преносивим мониторима зрачења. Приказани су први резултати спектрометријског модула са HPGe детектором релативне ефикасности од 45 %, хлађеним Стирлинг системом за хлађење. Спектрометар има енергетску резолуцију мању од 0.95 keV и 1.95 keV, на енергијама од 122 keV и 1332 keV, респективно. Слабљење енергетске резолуције HPGe детектора хлађеног електричним криохладњаком у поређењу са детекторима хлађеним течним азотом је око 8 % на енергији од 1332 keV. Уз употребу активираних филтера за сузбијање импулса произведених механичким вибрацијама, енергетска резолуција спектрометра је 0.8 keV и 1.8 keV, респективно, међутим, релативна ефикасност на енергији од 1332 keV опада на 39 %.

Кључне речи: HPGe спектрометрија, мерење зрачења, преносиви монитор зрачења, електрично криохлађење