DEVELOPMENT OF PORTABLE HPGe SPECTROMETER FOR *IN SITU* MEASUREMENTS

by

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In situ **applications require a very high level of portability of high-resolution spectrometric equipment. Usage of HPGe detectors for radioactivity measurements in the environment or for nuclear safeguard applications, to combat illicit trafficking of nuclear materials or uranium and plutonium monitoring in nuclear wastes, has become a norm in the recent years. Portable HPGe-based radionuclide spectrometer with electrical cooling has lately appeared on the market for *in situ* applications. At the same time deterioration of energy resolution associated with vibrations produced by cryocooler or high weight of the instrument, short time of autonomous operation and high price of these spectrometers are limiting their usage in many cases.**

In this paper we present development results of ultra compact hand held all-in-one spectrometer for *in situ* measurements based on HPGe detector cooled by liquid nitrogen without listing the above disadvantages.

Key words: HPGe spectrometer, in situ radioactivity measurement

INTRODUCTION

Usage of HPGe detectors for radioactivity measurements for environmental and nuclear safeguard applications has become a necessity. Different kinds of solutions are available to fight against illicit trafficking of nuclear materials or uranium and plutonium monitoring in nuclear wastes. HPGe detectors with excellent energy resolution and high intrinsic registration efficiency have identification accuracy advantages over spectrometric scintillation and room temperature compound semiconductor detectors. However, HPGe detectors have to be cooled down to a temperature below 100 K [1].

Ultra compact hand-held HPGe detector cooled by liquid nitrogen has been developed by us earlier for *in situ* applications [2]. The instrument was equipped with planar HPGe detector with sensitive area of 500 mm^2. Its performance was showing excellent energy resolution, better than 580 eV at 122 keV, an extremely short cool down time, less than 1.5 hours, long holding time, more than 20 hours and low weight, less than 2.6 kg.

Hand-held detector was combined with a small multi-channel analyzer [3] powered by battery, a mini-laptop for spectra processing and visualization of the measurement results. Despite a compact design of all the components of the system, application of the solution in the field proved inconvenient due to a necessity of carrying all components separately.

Recently, portable HPGe-based radionuclide identifiers/spectrometers with electrical cooling for *in situ* applications [4, 5] have appeared on the market. Despite many advantages, such solution still have several disadvantages like deterioration of energy resolution associated with vibrations produced by cryocooler, high weight of the instrument, short time of autonomous operation and high price.

Current document presents research and development results of ultra compact hand held all-in-one spectrometer for *in situ* measurements based on HPGe detector cooled by liquid nitrogen. A newly developed system solves all disadvantages mentioned above. Upgraded detection, cooling and spectrometric parts were implemented.

SPECTROMETER DESIGN

Hand-held HPGe spectrometer was designed and developed to meet requirements being placed on radioisotope identifiers [6] and was called Nitro SPEC fig. 1.

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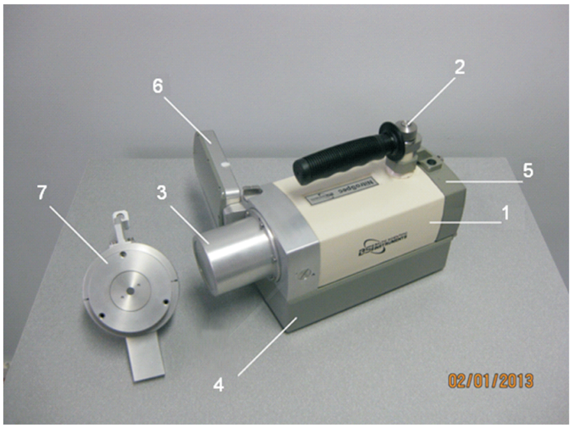


Figure 1. Design of all-in-one hand-held HPGe spectrometer NitroSPEC
1 – Dewar vessel, 2 – liquid nitrogen filling valve, 3 – cryostat with HPGe detector, 4 – electronics section, 5 – power supply section, 6 – touch screen display, 7 – removable shielding cap with collimator

Spectrometer cooling system is based on the Dewar vessel (1) of the same design as in [2], but its volume was enlarged from 0.6 to 0.8 litres to provide a possibility to install HPGe detectors of larger volume. Dewar vessel could be fully filled with liquid nitrogen in less than 10 minutes by means of a filling funnel at normal pressure. To keep dimensions of spectrometer as small as possible Dewar vessel has one valve (2) for liquid nitrogen filling and nitrogen evaporation. Depending on the location of the valve the spectrometer can be used either in a horizontal and upright or in a horizontal and downright orientation.

Dewar vessel volume enlargement allows installing in cryostat (3) coaxial HPGe detectors with efficiency up to 20 % and planar detectors with sensitive area up to 2000 mm^2. Nevertheless, the instrument still has short cooling time of the HPGe detector within 1.5 hours after liquid nitrogen filling and provides more than 20 hours of autonomous non-stop operation time between liquid nitrogen refilling. Refilling of liquid nitrogen once a day is convenient enough for the routine measurements on a day-by-day basis.

All electronic components are hermetically sealed in a separate section (4) under the Dewar vessel. Hermetic section for batteries (5) is located behind the Dewar vessel. Display (6) is made as a folding unit.

Some applications require detector to be shielded from external interference. Initially 10 mm thick lead cap and collimators of different diameters were developed. 7 mm thick tungsten alloy cap having smaller dimensions with removable collimators have been developed and fabricated especially for uranium enrichment measurements. Caps (7) could be easily attached to the Dewar vessel flange through special holes by means of 3 tungsten screws. Collimators have different diameters: 40 mm, 25 mm, 10 mm, and 5 mm, respectfully, and could be screwed into a cap. In order to decrease X-ray fluorescence from tungsten, both cap and collimators have 1 mm thick tin internal lining covered with 1.5 mm thick copper lining.

Dimensions of the spectrometer are only 330 mm 140 mm 210 mm. Total weight of the spectrometer based on 20 % efficiency HPGe detector without liquid nitrogen is 4.950 kg.

ELECTRONICS AND SOFTWARE

Preamplifier with resistive feedback is hermetically sealed in a separate section under the Dewar vessel along with digital signal processing (DSP) electronics (16 k) [7] with integrated high voltage power supply for detector (up to 3.6 kV) and preamplifier power supply (12 V, 60 mA). Linux based minia-ture PC allows the control of all operation modes of the spectrometer, electronic health status diagnostic as well as transfer of the accumulated spectra. The built-in microprocessor has non-volatile memory up to 32 Gb, what allows the storage of practically unlimited acquired spectra and the results of their procession.

All spectrometer settings could be set in the menu. Spectrum acquisition could be made both in live and real time modes as well as without time limitation. Practically unlimited extension of nuclides library base is possible as well as the loading of a new measurement geometries including simulation by a Monte Carlo method.

With a help of the folding built-in display, the user is able to make precise analysis and obtain results in on-line mode with automatic GPS position data indication.

Visualization of measurement results and control of spectrometer parameters is made by means of color built-in touch screen display having resolution of 800 400 pixels and 4" diagonal. Applied Super Amoled display provides high brightness and contrast of image, thus enabling comfort operation even at bright sun light. Complex calculations in real time and results display are provided by high frequency (1 GHz) processor and video accelerator.

The connection to another PC for data exchange could be made by a USB connection or by a wireless WiFi network. Portable spectrometer is fully supported and controlled by expert software of SpectraLine family [8], which provides its application with facilities of precision laboratory spectrometry.

In *easy mode* of spectrometer operation a user can select continuous or preset time of measurement and define desirable time interval in seconds. Continuous measurement of spectrum starts by pushing only a single button. Information is updated every second. For example, fig. 2 shows the part of the spectrum in the energy range of (50 keV-400 keV) for the point source Eu-152, placed on the distance of 10 cm from the cryostat cover.

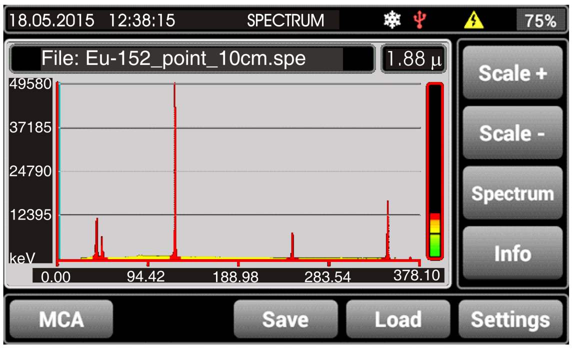
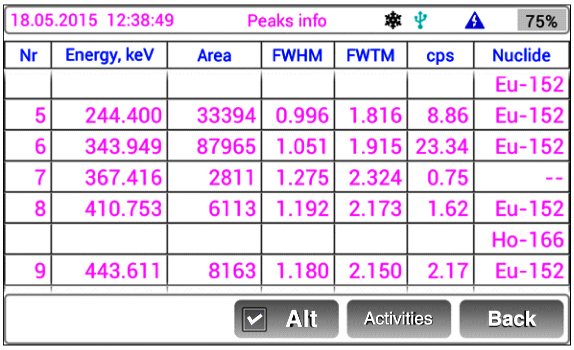


Figure 2. Spectrum of the point source Eu-152, placed on the distance of 10 cm from the cryostat cover


18.05.2015 12:38:49 Peaks info 75%

Nr	Energy, keV	Area	FWHM	FWTM	cps	Nuclide
						Eu-152
5	244.400	33394	0.996	1.816	8.86	Eu-152
6	343.949	87965	1.051	1.915	23.34	Eu-152
7	367.416	2811	1.275	2.324	0.75	--
8	410.753	6113	1.192	2.173	1.62	Eu-152
						Ho-166
9	443.611	8163	1.180	2.150	2.17	Eu-152

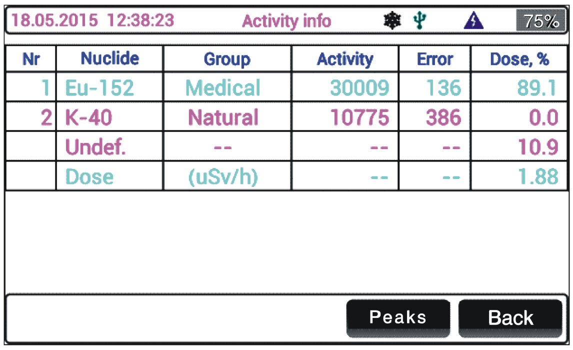
Alt Activities Back

Figure 3. Numerical values of the detected spectrum parameters

Manual energy calibration from touch screen is performed selecting automatically identified spectral lines with count rates above background level and setting corresponding energies using library of radionuclides. The spectrometer screen in table columns shows the energies of the detected peaks, their area, energy resolution on 1/2, 1/10 peak height, count rate and radionuclide name (fig. 3).

In *search mode* of operation a dose rate is calculated from integral spectrum and is visualized on a display in µSv/h. In case of excess of a dose rate over the user defined threshold the instrument produces visual and acoustic alarm. Identification of radionuclides is performed according to library of radionuclides automatically. The calculation for the present spectrum (fig. 2) demonstrates (fig. 4), that the radionuclide Eu-152 from the medical radionuclides group with 30009 Bq activity is detected. The calculation error is 136 Bq. The radionuclide provides the input of 89.1% into the common detected dose. The radionuclide K-40 from the group of Natural radionuclides with activity of 10775 Bq is detected also in the spectrum. The radionuclides, which provide the input of 10.9% into the common dose (1.88 µSv/hour) were not detected.

In *expert mode* of operation the user can select a region of interest or a ratio of regions of interest on the spectrum. This option is convenient for example for U


18.05.2015 12:38:23 Activity info 75%

Nr	Nuclide	Group	Activity	Error	Dose, %
1	Eu-152	Medical	30009	136	89.1
2	K-40	Natural	10775	386	0.0
	Undef.	--	--	--	10.9
	Dose	(uSv/h)	--	--	1.88

Peaks Back

Figure 4. Calculation of the radionuclides activity

enrichment measurements in UF6 cylinders. User could select type of spectra acquisition between real time, live time or integral (the measurement will continue until a certain net area of a peak is reached) as well as select repeated acquisition mode of measurements. Spectrometer can be connected in parallel to laptop via wireless data transfer interface in expert mode of operation. This option is convenient for calculation of activities of radionuclides.

Additionally a spectrometer equipped with two batteries (type Li-Ion) provides power supply of all spectrometer electronic during more than 8 hours without re-charging. Field replacement (hot swapping) of batteries to achieve 16 hours continuous operation time is possible. When accumulators are discharged the software will issue appropriate message. If it is ignored, HV will be shut down automatically when critical low battery charge is achieved to prevent possible damage of the detector.

CONCLUSIONS

Despite that the presented spectrometer requires liquid nitrogen for operation, this instrument is well suited for *in situ* applications such as a border monitoring of illicit trafficking of radioactive materials or nuclear safeguards measurements. Prevention of illicit trafficking of nuclear materials requires reliable and fast radionuclides identification. This is guaranteed by the given spectrometer by means of excellent parameters of energy resolution and high intrinsic registration efficiency of HPGe detector.

Visualisation of the measurement results and identification of radionuclides is realized in the current spectrometer on the basis of automated software algorithms. Control of spectrometer parameters and data evaluation is available for operator from a color built-in touch screen display in immediate vicinity to HPGe detector.

For those nuclear safeguards applications where optimal energy resolution at low energies is of advantage, for example U and Pu monitoring in nuclear wastes, application of liquid nitrogen cooled HPGe detectors is still more effective then those cooled electrically because of the negative impact of microphonic effects on the energy resolution of the latter ones.

In the meantime possibility to avoid both limitations *i. e*., usage of liquid nitrogen as well as avoid vibrations produced by the cryocooler, maintaining compact design of the instruments intended for *in situ* measurements, is still a good perspective for future developments in the field.

Dimensions of developed spectrometer are only 330 mm 140 mm 210 mm, the maximum weight without liquid nitrogen is 4.950 kg (with 20 % efficiency detector) and the time of autonomous operation is at least 8 hours before charging or replacement of batteries.

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AUTHOR CONTRIBUTIONS

Design was developed by A. Sokolov and S. Kim, and electronics by E. Loshevich. Measurements and analysis, photos and figures were made by M. Kaiser and A. Kail, while the manuscript was written by A. Sokolov.

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РАЗВОЈ ПРЕНОСИВОГ HPGe СПЕКТРОМЕТРА ЗА *IN SITU* МЕРЕЊА

Примена *in situ* мерења захтева веома висок ниво преносивости спектрометријске опреме високе резолуције. Употреба HPGe детектора за мерење радиоактивности у животној средини, или примена у нуклеарној безбедности, на пример, борби против незаконитог транспорта нуклеарних материјала или мониторинга уранијума и плутонијума у нуклеарном отпаду, постала је обавезна последњих година. У последње време, на тржишту су се појавили преносиви спектрометри радионуклида за *in situ* мерења заснован на HPGe детектору са електричним хлађењем. Оно што лимитира њихову примену у многим случајевима је погоршање енергетске резолуције услед вибрација криохладиоца, велика тежина инструмената и кратко време аутономног рада.

У овом раду представљен је резултат развоја ултра компактног, ручног целовитог спектрометра за *in situ* мерења заснованог на HPGe детектору са хлађењем течним азотом без раније наведених недостатака.

Кључне речи: HPGe спектрометар, in situ мерење радиоактивности