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SOFTWARE AT MOBILE SPECTROMETER WITH CZT-DETECTOR

Oleh V. Maslov$^{1)}$
ORCID: 0000-0002-0288-0289; maslov@opu.ua
Vadim A. Mokritskiy$^{1)}$
ORCID: 0000-0002-2514-4137; mokrickiy37@gmail.com
$^{1)}$ Odessa National Polytechnic University, 1, Shevchenko Ave., Odessa, 65044, Ukraine

ABSTRACT

The technology is based on a semiconductor CdZnTe-portable (almost the size of a mobile phone) gamma-ray spectrometer with high resolution, which provides high efficiency of rapid identification of radionuclides and assessment of radiation dose from low to moderately high levels. The CdZnTe gamma-ray spectrometer is a highly efficient device based on the use of CdZnTe (CZT) semiconductor detectors operating at room temperature with very low power consumption, a digital multichannel analyzer, and a microcomputer. CdZnTe-portable spectrometer is a self-contained device and consists of three modules - a detector module, a multichannel analyzer, and a microcomputer. The detector module contains a high-quality CdZnTe detector, a preamplifier, and a high voltage power supply for the detector. There are detector modules with different volumes of the CZT detector from 5 mm^3 to 1600 mm^3. It is possible to use a multi-detector system. The analyzer module contains an amplifier, a digital signal processor, a low voltage power supply, and a computer interface. The microcomputer software interacts with the multichannel analyzer, analyzes gamma spectra, and provides the accumulation of time profiles of the dose of gamma radiation, communication with other information systems. Spectrometric measurements in real-time make it possible to use "electronic collimation" technologies to build a map of the radiation field and localize sources of ionizing radiation, with the subsequent certification of identified sources, creation of an effective radiation monitoring system with the functions of certification of ionizing sources radiation. The corresponding software allows you to solve the following tasks – building a three-dimensional map of the fields of ionizing radiation of various degrees of spatial detailing, taking into account the radiation energy, localization, and certification of gamma radiation sources. The special laboratory kit is based on μSPEC microspectrometers. A LattePanda single board computer is used to control the operation of spectrometers, collect and analyze data. LattePanda – A Windows 10 Computer with integrated Arduino. This explains the choice of LattePanda. Windows 10 application allows you to use the WinSPEC software to control the multichannel analyzer operation supplied with the spectrometer. The built-in Arduino allows you to remote control the movement of the radiation source during laboratory experiment. Both the traditional problems of calibrating spectrometers (energy calibration and efficiency curves), including those for various source geometries, processing the measured spectra using standard programs, calculating the activity of sources, and the problem of creating a spectra processing program and a spectrometer control program are considered. The values of the minimum detectable activity are given.

Keywords: Gamma-ray spectroscopy; spectra analyzes software; IoT; mobile radiation spectrometer; CdZnTe-detector; peak searching algorithm

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INTRODUCTION

The development of industrial civilization inevitably leads to the fact that the environment and humans are exposed to new technogenic “pollutants”. This is chemical pollution of the air, electromagnetic fields of industrial and household electrical equipment, communications, and much more. But there is a special class of influencing factors – ionizing radiation. The development of technologies using radiation sources, the use of minerals with increased content of natural radionuclides, including construction, nuclear weapons testing, and accidents at nuclear energy facilities have led to the fact that we are constantly surrounded by radiation fields. Of course, there are also sources of radiation of cosmic origin. But this is the background to which basically the person as a whole has already adapted. Problems arise in cases of unplanned exposure caused by loss of control over the source of radiation, including in connection with undeclared (illegal) trafficking in AI and special nuclear materials (SNM). To identify and assess the impact of radiation sources in order to take compensatory measures, a monitoring (control) network is created.

But the absence of signs “does not mean“ no item. This is because, however comprehensive the inspections, there is a certain degree of uncertainty in any country-wide verification process that makes it necessary to verify that there are no easily concealed objects such as trace amounts of nuclear material or components of nuclear weapons, unknown sources of ionizing radiation The current concept of radiation monitoring devices may not have a positive effect – it is designed for a different version of control and protection. As a result, a new need for measurements with ensuring the identification of isotopes with a wide range of different requirements has arisen. Measurements should be carried out in the field in a short time when the results are needed within tens of seconds. The devices with which the personnel work should be the portable and low background.

Taking into account the rapidly changing world and with the emergence of new “challenges” related to security, all of the above has actually led to an explosive growth of interest in the creation of a new class of devices, which is based on the use of new technologies. This fact is reflected in scientific publications [1] and international normative documents.

In the report “Impact of Novel Technologies on Nuclear Security and Emergency Preparedness” [2], Joint Research Center (JRC), the European Commission's general principles and an overview of new technologies that can be applied in the creation of modern radiation monitoring systems taking into account the tasks to be solved are considered - control of the undeclared movement of radiation sources at the border, emergency preparedness and emergency management in the event of loss of control over a radiation source in the country, radiological crime scene management, nuclear forensics and accident management at nuclear facilities. A more detailed description of new technologies for radiation monitoring is given in the report [3]. In [4], possible options for the implementation of information systems and solutions to practical problems of radiation monitoring based on the use of new technologies are considered.

New technologies have allowed the development of more efficient detection systems [2]. In particular, digitalization and the Internet of Things (IoT) offer great opportunities for collaboration at the technical level. The IoT connectivity layer for detectors and detector networks provides continuous low-level online early warning automation and effective high-level technical and scientific expert support. Big data and its associated data mining, combined with automatic online monitoring, can allow observations to be analyzed over longer periods of time, enabling early warning and early prevention of prevailing illegal activities. For nuclear security, data security is of paramount importance, and mechanisms must be in place to ensure the safe exchange of information at the national and international levels. There is a need to operate large distributed systems based on shared protocols for data structures and data processing, including procedures for how different units should interact with each other to ensure efficient flow of information across borders, in close collaboration with decision-makers and experts.

Possible technical and scientific topics to consider are [4]:

– new detection solutions;

– digitization of information already at the detector in standardized formats;

– using the Internet of Things or another solution to automatically transfer data from the detector to the data server, taking into account the related cybersecurity issues;

– automated analysis of digitized information and dissemination of information to various technical/scientific centers for expert support;

– big data and data mining.

It is important to note that many new technologies are not simply improved replacements for existing systems. Instead, to harness the full potential of new technologies, the concept of work should also be changed [2].

MOBILE GAMMA-RAY SPECTROMETER WITH SEMICONDUCTOR CZT-DETECTOR

In the most general case, when normalizing the exposure to radiation, we are interested in dosimetric quantities such as absorbed dose, kerma, effective equivalent dose. But due to the fact that there are several types of radiation with different energies, the relationship between the measured characteristics of radiation fields and dosimetric quantities is rather complex. For almost all significant types of radiation in the observed energy range, several channels of radiation energy transfer to matter with different ionization mechanisms will be implemented. The use of spectrometric measurements in which the radiation energy is analyzed can reduce the uncertainty. This was reflected in the review [1]. The choice of a specific construction scheme will largely be determined by the specific problem to be solved [2] and the preferences of the developers [4]. This is clearly seen from the proposed prototype of the system in [5] based on the scintillation module [6], which implements the approaches described in [7]. But it is important to note that the continued prototype considers the implementation of support for an open protocol for the exchange of spectrometric data [8].

Another direction in the creation of small-sized but highly efficient gamma-ray spectrometers is the use of wide-gap semiconductors, such as CdZnTe [10]. The solutions we offer are based on the use of CdZnTe [11, 12].

However, one can single out general approaches to the creation of mobile spectrometers using modern technologies [13]. Fig. 1 shows a typical data processing diagram from [3]. It is important to note here that all measured spectra are transmitted and processed to a remote local computer [9].

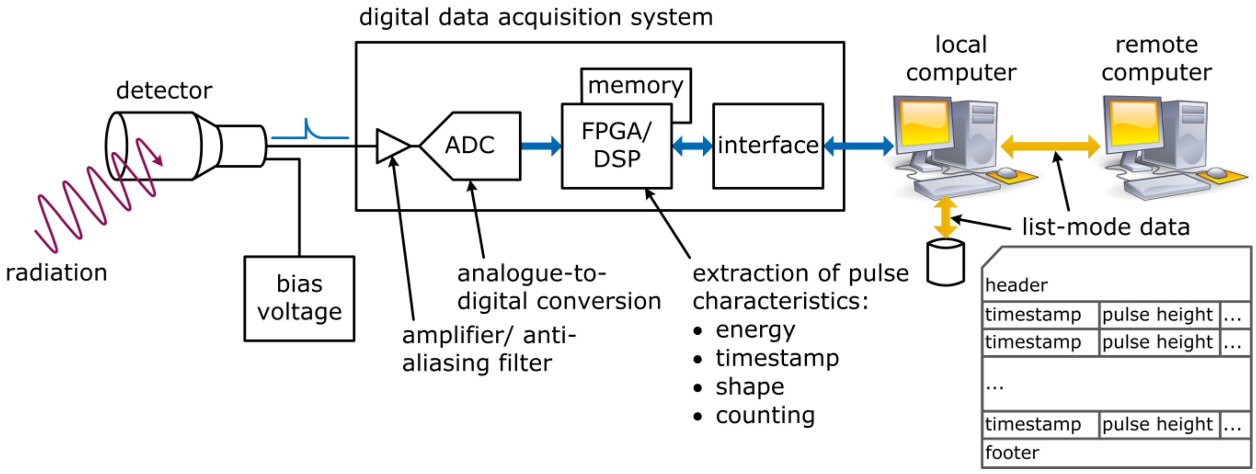

Fig. 1. **Typical data acquisition scheme used with modern radiation detectors [3]**

***Source*: [3]**

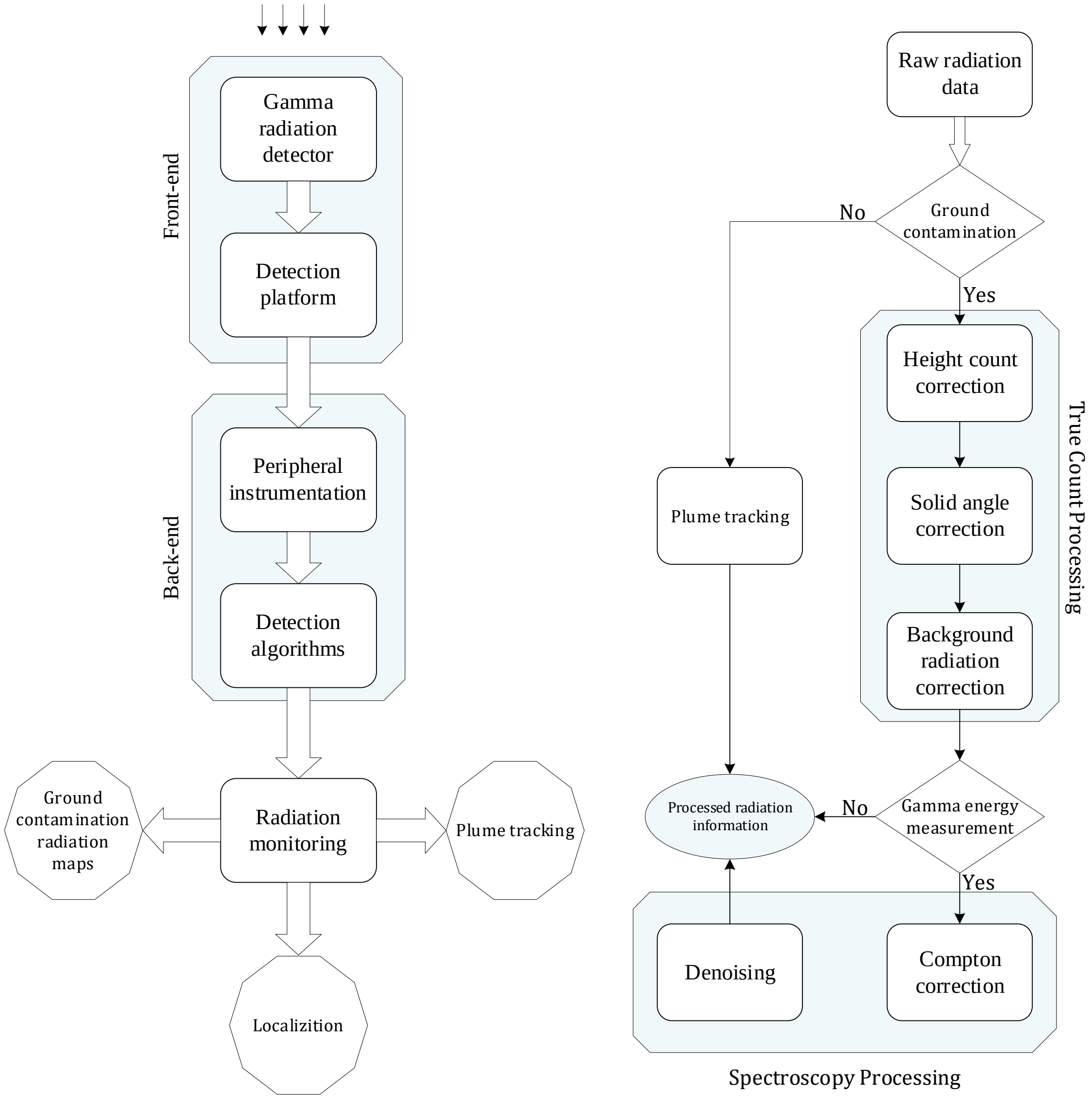

Fig. 2. **Radiation monitoring system [12]**

***Source*: [12]**

In fact, the difference between the solution presented in Fig. 3 [11] and our solution presented in Fig. 4 lies in the openness of the platform, both hardware and software [16]. All components of the microspectrometer are built on a modular basis with the possibility of upgrading and changing the configuration [17]. There are two possibilities for working with the analyzer - direct data exchange and command transmission to the microprocessor of the multichannel analyzer using the data exchange protocol [18], or using a special software interface in the form of a library [19]. In addition, it is possible to work according to the procedure shown in Figure 1 with automatic data transfer in the form of standard protocol files supported by the IAEA [20]. It is important to note that the compatibility of protocols and the analyzer control library is supported, which made it possible to apply solutions and peak search algorithms previously tested for the MCA-166 analyzer [21].

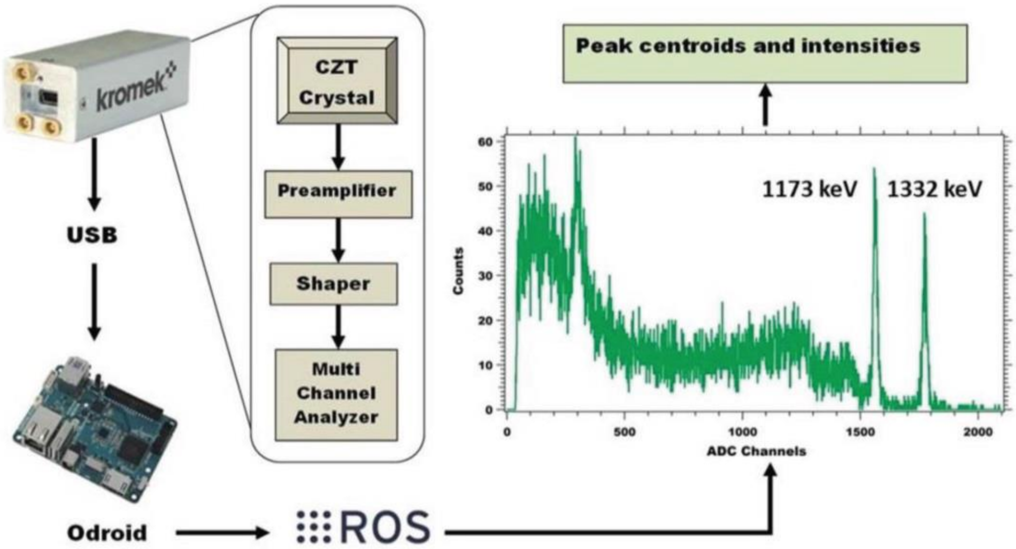

Fig. 3. **Kromek CZT sensor operation [11]**

***Source*: [11]**

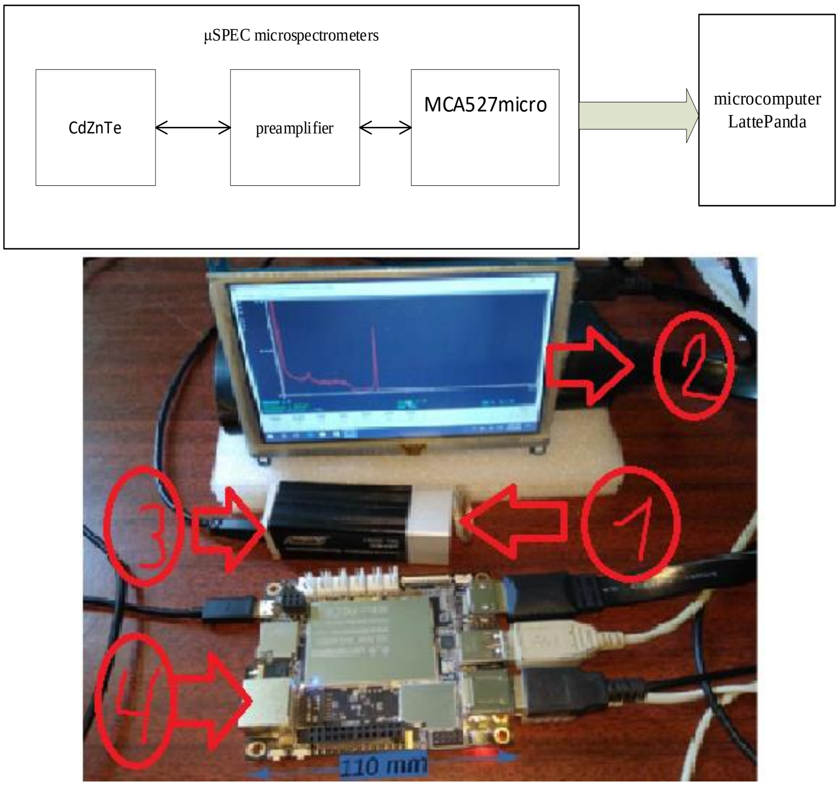

Fig. 4. **CZT sensor operation**

1 – CZT-detector; 2&4 – LattePanda; 3 – MCA527micro

***Source*: compiled by the author**

The basis is a semiconductor CdZnTe-portable (almost the size of a mobile phone) high-resolution gamma-ray spectrometer, which provides high efficiency of rapid identification of radionuclide's and radiation dose estimation from low to moderately high levels [22]. The system is built on the basis of an IoT platform with open hardware to create a suitable mobile network of measuring device modules [23]. Modules can be with functions inherent in ordinary smartphones, but can also be specialized. Construction of a mobile spectrometer within the IoT allows to provide a fairly low cost of the product and the possibility of its mass use and as a result almost complete operational control and construction of a map of gamma radiation fields for the whole country with operational control of their changes [24].

In this context, the digital spectrometer involves the implementation of a digital spectrometric path for the CdZnTe detector, i.e. the signal from the output of a single module "detector preamplifier" is converted into digital form and further processing is carried out by digital signal processors [25].

This allows:

− increase the amount of information received in the measurement process;

− to ensure good scalability of the created measuring systems due to the use of a unified measuring channel (path) “element of the detector matrix – individual preamplifier - ADC – DSP”;

− to implement in the form of a single finished product (module) the following options “array of CdZnTe-detectors pre-amplifiers for each element” or “array of CdZnTe-detectors pre-amplifiers for each ADC element” [26];

− and, as mentioned above, to provide the possibility of deep modification, almost complete processing of the already assembled product by making changes to the firmware [27].

SPECTRA PROCESSING AND DATA ANALYSIS

Search for peaks using the “Generalized second derivative” method [28]. The search for peaks is carried out by the “Generalized second derivative” method according to the formulas [29] :

$$S_i = Y''_{ism} = \sum_{j=-4}^{4} a_j Y_{i+j} \ ,$$

$$a_j = C''_{ism} = \left[\frac{j^2 - 0{,}18 \cdot b^2}{0{,}035 \cdot b^5}\right] \cdot \exp\left(\frac{-j^2}{0{,}36 \cdot b^2}\right),$$

where: *Yi* + *j* is the number of pulses in the unsmoothed spectrum in the *i* + *j* channel; 2k + 1– the number of channels through which the spectrum smoothing is carried out; – b is the width at half maximum of the Gaussian function [30].

The boundaries of the peaks are determined by the maximum of the second derivative [31].

The area of the peaks is as follows:

– the right border of the peak is found, then its left border;

– the full integral of the peak is calculated

$$Integral = \sum_{i=I_l}^{I_r} Spectr_i \ ,$$

where: I_l, I_r - left and right boundaries of the peak; $Spectr_i$ – number of samples in the *i* channel;

– the area under the peak is calculated

$$Background = \frac{(I_r - I_l + 1)}{8} \cdot \left(\sum_{i=I_l-3}^{I_l} Spectr_i + \sum_{i=I_r}^{I_r+3} Spectr_i\right)$$

where *Background* is the area under the peak;

– the area of the peak is calculated, from the total area we subtract the area under the baseline

$$S = Integral - Background$$

Calculation of peak-to-peak ratios for ^{137}Cs. The ratios of the peaks of the found isotopes in the library to the ^{137}Cs peak are calculated using the following formulas [31]:

– detector registration efficiency

$$\varepsilon = a \cdot \exp(b \cdot E)$$

where: – *a*, *b* - coefficients; *E* – energy, keV;

– for each isotope found, the coefficient is calculated

$$I_i = \left(\frac{S_i}{t \cdot Y_i}\right) / \varepsilon \ ,$$

where: – S_i is the area of the *i*-th peak; *t* – live dialing time, sec; – *Y* is the quantum yield of the *i*-th isotope;

– for each isotope found, the ratio of the coefficient to ^{137}Cs is calculated

$$K = \frac{I_i}{I_{Cs-137}} \ .$$

The algorithm implementing the described procedure is shown in Fig. 5.

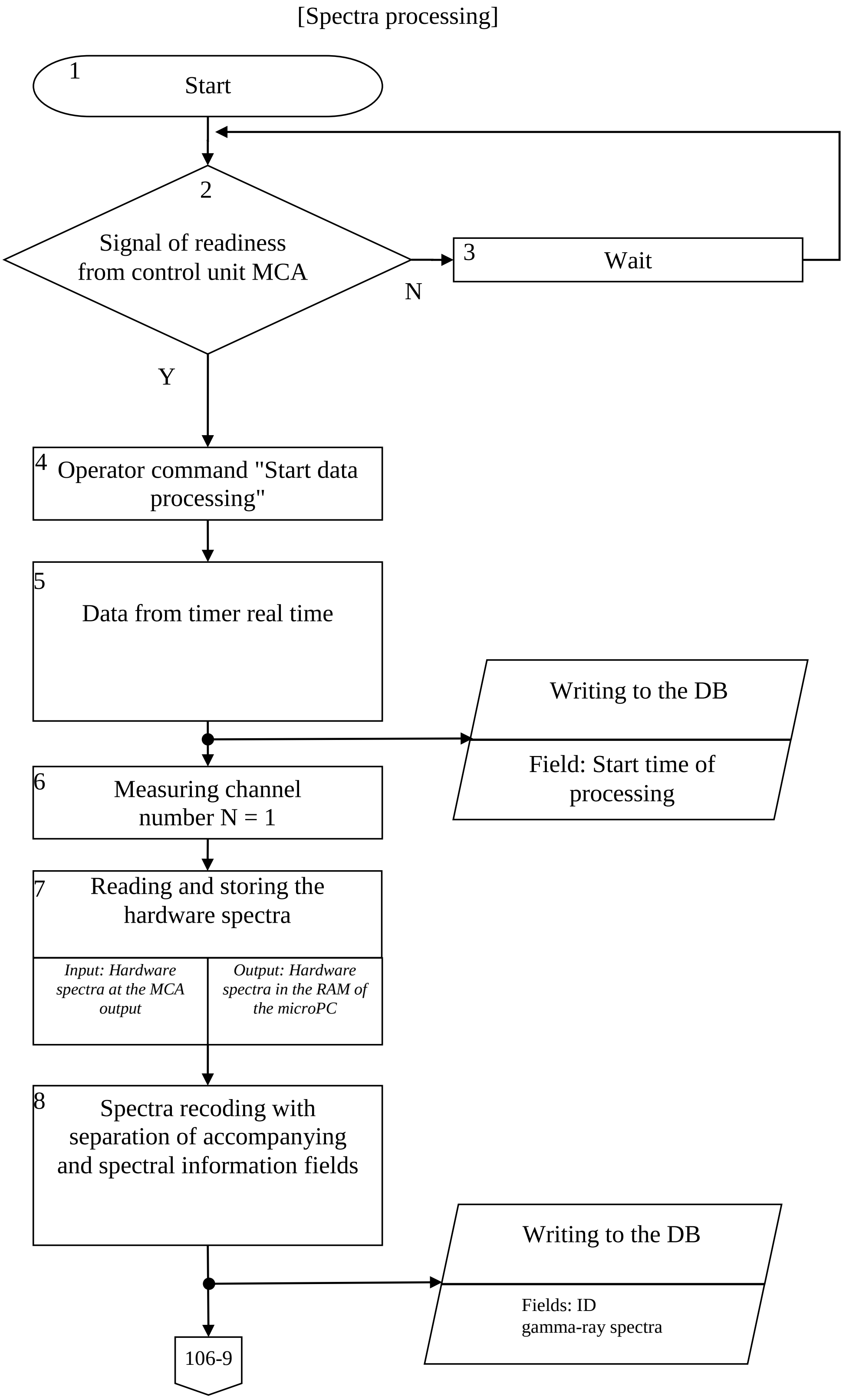

Fig. 5a. **Gamma-ray spectra processing. Part 1**
***Source*: compiled by the author**

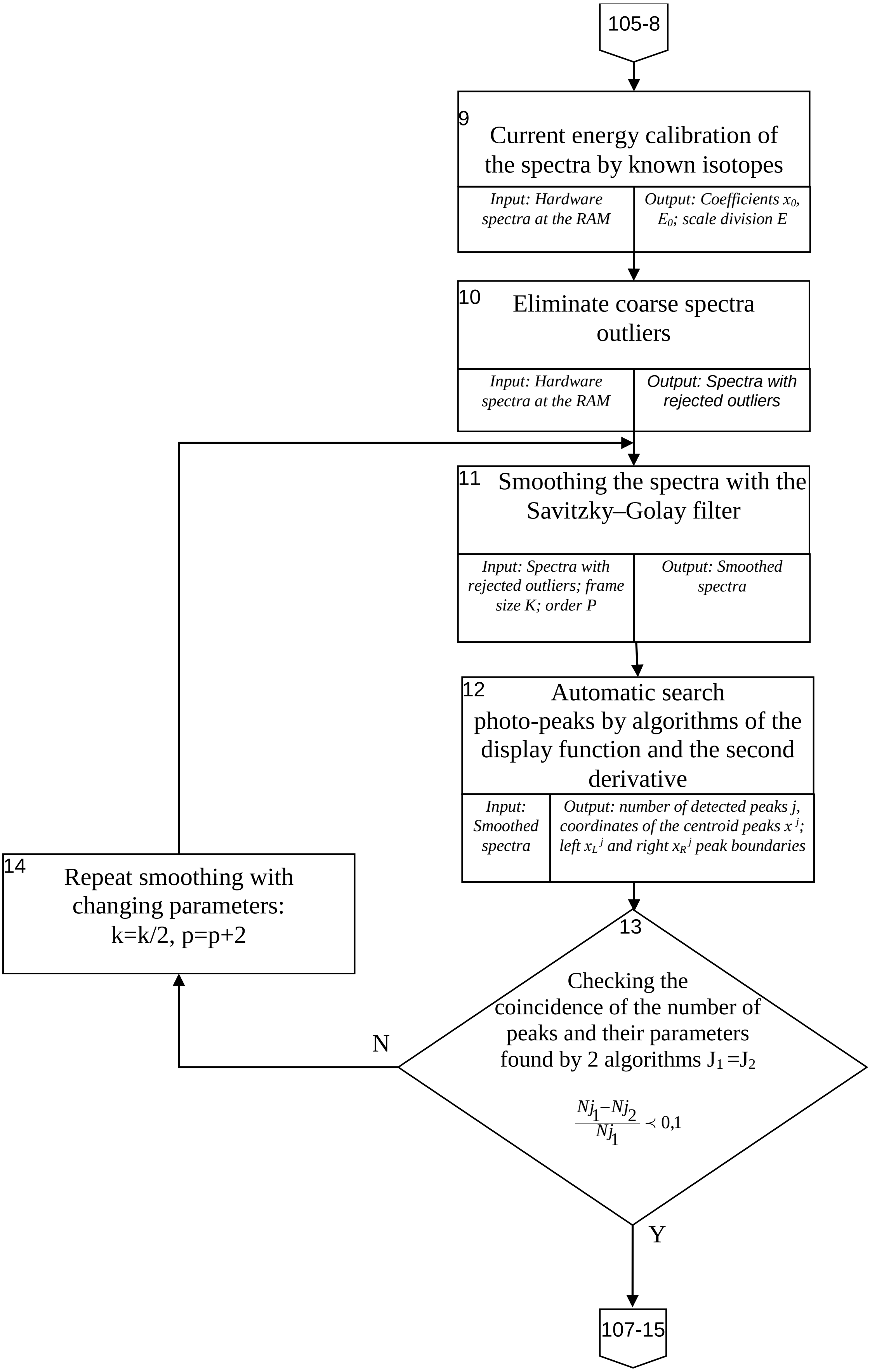

Fig. 5b. **Gamma-ray spectra processing. Part 2**

***Source*: compiled by the author**

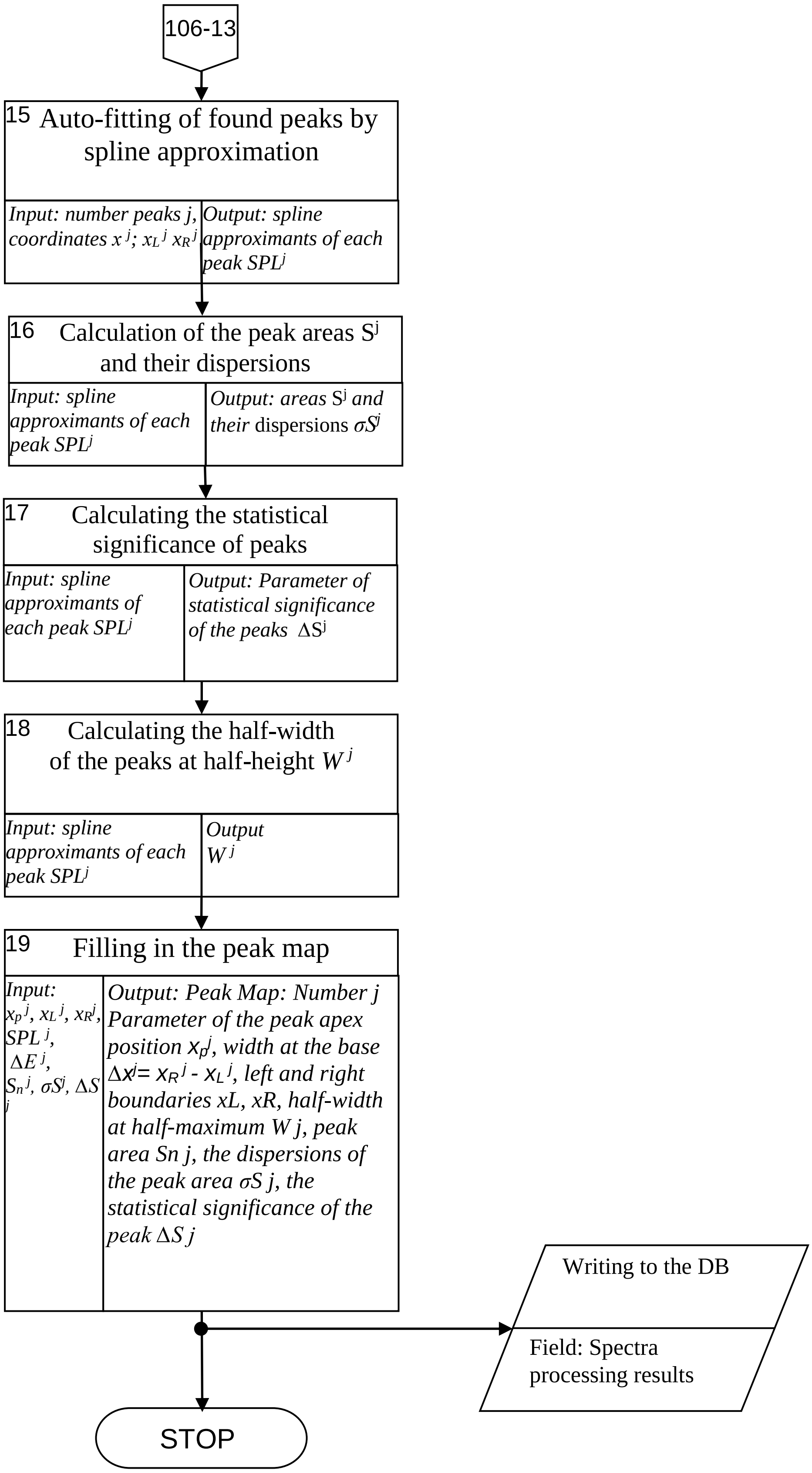

Fig. 5c. **Gamma-ray spectra processing. Part 3**

***Source*: compiled by the author**

CONCLUSION

Minimum Detectable Activity (MDA) is the maximum activity of a radionuclide that could be present in a sample, but as a result of analysis of the spectrum of this sample at given parameters remained unnoticed. The MDA value is determined by the “variable” background pedestal (including the Compton background) in the energy interval or peak zone of the selected radionuclide and by coefficients that establish the confidence probability and statistical uncertainty of the useful signal. The calculation of MDA is performed for spectra from samples where the total activity is any, so this characteristic is used to determine low activities on a weak and strong background. The formula for calculating the MDA [28] is as follows

$$\mathrm{M}DA \approx \frac{4\sqrt{2}}{\varepsilon \cdot \mathrm{Y}}\sqrt{\frac{\mathrm{R_b}}{\mathrm{T}}},$$

R_b – background pedestal; ε – is the absolute registration efficiency for a given radionuclide in the selected measurement geometry; Y – is the output of this type of radiation at each act of decay of the selected radionuclide.

Obtained on the basis of experimental data MDA is:

1) ^{137}Cs - 4.1 kBq.
2) ^{226}Ra - 7.5 kBq.
3) ^{60}Co - 40.8 kBq.
4) ^{133}Ba - 12.6 kBq.

For ^{137}Cs, the value obtained is twice less than the threshold for exemption from state regulation.

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ПРОГРАМНЕ ЗАБЕЗПЕЧЕННЯ МОБІЛЬНОГО СПЕКТРОМЕТРА З CZT-ДЕТЕКТОРОМ

Олег Вікторович Маслов
ORCID: 0000-0002-0288-0289; maslov@opu.ua
Вадим Анатолійович Мокрицький
ORCID: 0000-0002-2514-4137; mokrickiy37@gmail.com
Одеський національний політехнічний університет, проспект Шевченка,1, Одеса, 65044, Україна

АНОТАЦІЯ

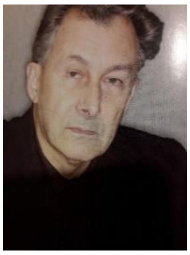
Основу технологій складає напівпровідниковий CdZnTe-портативний (практично розміром з мобільній телефон) спектрометр гамма-випромінювання з високою роздільною здатністю, який забезпечує високу ефективність експрес-ідентифікації радіонуклідів та оцінки дози випромінювання від низьких до помірних високих рівнів. CdZnTe спектрометр гамма-випромінювання - це високоефективний пристрій, заснований на CdZnTe напівпровідниковому детекторі, якій працює при кімнатній температурі з дуже малим енергоспоживанням, цифровому багатоканальному аналізаторі та мікрокомп'ютері. CdZnTe-портативний спектрометр – самодостатній пристрій і складається з трьох модулів - детекторного модуля, багатоканального аналізатора та мікрокомп'ютера. Модуль детектора містить високоякісний детектор CdZnTe, попередній підсилювач і джерело живлення високої напруги детектора. Є детекторні модулі з різними об'ємами CZT детектора від 5 мм^3 до 1600 мм^3. Можливо використання багатодетекторної системи. Модуль аналізатора містить підсилювач, цифровий процесор сигналів, джерело живлення низької напруги та комп'ютерний інтерфейс. Програмне забезпечення мікрокомп'ютера взаємодіє з багатоканальним аналізатором, аналізує гамма-спектри та забезпечує накопичення часових профілів дози гамма-випромінювання, зв'язок з іншими інформаційними системами. Спектрометричні вимірювання в реальному часі дозволяють використовувати технології «електронної колімації» для побудови карти радіаційного забруднення та локалізації ДІВ, з подальшою паспортизацією виявлених джерел, створення дієвої системи радіаційного контролю з функціями паспортизації ДІВ. Відповідне програмне забезпечення дозволяє вирішити наступні завдання – побудова тривимірної карти полів іонізуючого випромінювання різної міри просторової деталізації з врахуванням енергії випромінювання, локалізація і паспортизація джерел гамма-випромінювання. Основою спеціального лабораторного комплекту є мікроспектрометри μSPEC. Для управління роботою спектрометрів, збору і аналізу даних використовується одноплатний комп'ютер LattePanda. LattePanda – A Windows 10 Computer with integrated Arduino. Наявність вбудованого Arduino дозволяє реалізувати управління переміщенням джерела під час лабораторного експерименту. Розглянуто як традиційні завдання проведення калібрування і градирування спектрометрів, в тому числі і для різних геометрій джерел, обробки виміряних спектрів з використанням стандартних програм, розрахунку активності джерел, так і завдання створення програми обробки спектрів і програми управління спектрометром. Наведені значення мінімальної детектируемой активності.

Ключові слова: гамма спектрометрія; програмне забезпечення аналізу спектрів; Інтернет речей; мобільний спектрометр випромінювання; CdZnTe-детектор, алгоритм пошуку піків

ABOUT THE AUTHORS

Oleh V. Maslov – Dr. Sci. (Eng), Head of the Department Physics.Odessa National Polytechnic University. Odessa National Polytechnic University. 1, Shevchenko Ave., Odesa, 65044, Ukraine
ORCID: 0000-0002-0288-0289; maslov@opu.ua
Research field: Cyber-Physical Systems; Data Analysis; Computer Modeling

Олег Вікторович Маслов – доктор технічних наук, завідувач кафедри Фізики. Одеський національний політехнічний університет. Одеський національний політехнічний університет, проспект Шевченка,1, Одеса, 65044, Україна



Vadim A. Mokritskiy – Dr. Sci. (Eng), Professor. Odessa National Polytechnic University. 1, Shevchenko Ave., Odesa, 65044, Ukraine
ORCID: 0000-0002-2514-4137; mokrickiy37@gmail.com
Research field: Cyber-Physical Systems; Data Analysis; Computer Modeling

Вадим Анатолійович Мокрицький – доктор технічних наук, професор. Одеський національний політехнічний університет, проспект Шевченка,1, Одеса, 65044, Україна