

PERFORMANCE STABILIZATION OF SCINTILLATION SPECTROMETERS FOR AEROSOL MONITORING

by

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The article presents the results of the development of the scintillation gamma spectrometers, based on NaI(Tl), LaBr₃ or SrI₂(Eu) scintillators, intended for aerosol monitoring over a wide temperature range. The stabilization of the characteristics is provided by applying various stabilization methods of the spectrometric chain. The estimation of the impact of those methods on the stability of the characteristics of the developed radiation spectrometer is provided.

Key words: aerosol monitor; scintillation detector; performance stabilization

INTRODUCTION

Scintillating materials (organic, inorganic, plastic, *etc.*) are the basis of a wide range of detectors used to detect gamma and X-ray radiation, neutrons and charged particles. With a diverse variety of characteristics (atomic number, light output, luminescence time, *etc.*), scintillating materials can provide suitable solutions for numerous tasks in scientific studies and medicine, atomic energy and environmental monitoring, inspection control and many other applications in radiochemistry, radiobiology, safety systems, and geology [1-3].

In comparison to other types of detectors, scintillation detectors provide better efficiency and sensitivity for detecting ionizing radiation. In addition, many scintillation detectors for nuclear radiation operate in the proportional regime with acceptable energy resolution. As a result, they are broadly used not only in radiometry but in the spectrometry of nuclear radiation.

However, in addition to their many positive characteristics, scintillators may suffer from temperature-dependent variations of light output, luminescence time, or other parameters [1-4]. The gain of photomultipliers, which register light flashes from the scintillator, also may change with temperature. The result is that the conversion coefficient of these devices is susceptible to temperature instabilities. The photomultiplier gain, which enters into the conversion coefficient, also may change as a result of other factors, such as the ambient magnetic field and the count rate. All these potential causes of variability call for stabilisation of the spectrometric chain, espe-

cially if the device is intended for the solution of a precisely defined spectrometric task.

Aerosol and iodine monitors are designed to detect and measure the radioactive contamination (gamma, alpha, and beta emitters) in the air, and at times they must work continuously in harsh outdoor conditions [5-7]. Though the standard [8] does not define strictly the operating temperature range for these devices, the real application conditions for aerosol monitors require that they should function reliably over a wide temperature range between -20 °C and +50 °C. Of course, without taking special measures, it is not possible to ensure the stability of the most critical instrument parameters over such a wide range. Furthermore, as previously mentioned, other factors besides temperature could lead to instability of the conversion coefficient.

The purpose of the present work is the development of the scintillation gamma radiation spectrometers based on NaI(Tl), LaBr₃ or SrI₂(Eu) scintillators and intended to operate in harsh environments, including a wide range of temperatures. In order to achieve the necessary stability, it was necessary to analyse and implement various stabilization methods in the spectrometric chain [9], evaluating their impact on the stability of the relevant instrument parameters.

For the first prototype we used gamma spectrometer based on NaI(Tl) crystal with a size of Ø76 mm 76 mm, which is able to detect gamma quanta in the energy range of 50-3000 keV [10]. The design permits installing any of the scintillation crystals listed above in the spectrometer case. Besides the detector, the case of the spectrometer contains a preamplifier board, a

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high-voltage (HV) supply board, a multi-channel analyser (MCA) board, and a microcomputer, which could transfer by LAN cable not only the acquired spectrum, but also the results of the calculation of the radionuclide activity in accordance with the built-in calibration and applied calculation method.

THE DEVELOPMENT OF THE THERMOSTABILIZING HOUSING

The overall stabilization of the spectrometric chain could be achieved by implementing a thermally stabilised housing. To provide a stable operation of the spectrometer, the thermostabilizing housing TSH-L with automated temperature control in the ambient temperature range from $-20\text{ }^{\circ}\text{C}$ to $+50\text{ }^{\circ}\text{C}$ was developed. The design of the spectrometer in the thermostabilizing housing is presented in fig. 1.

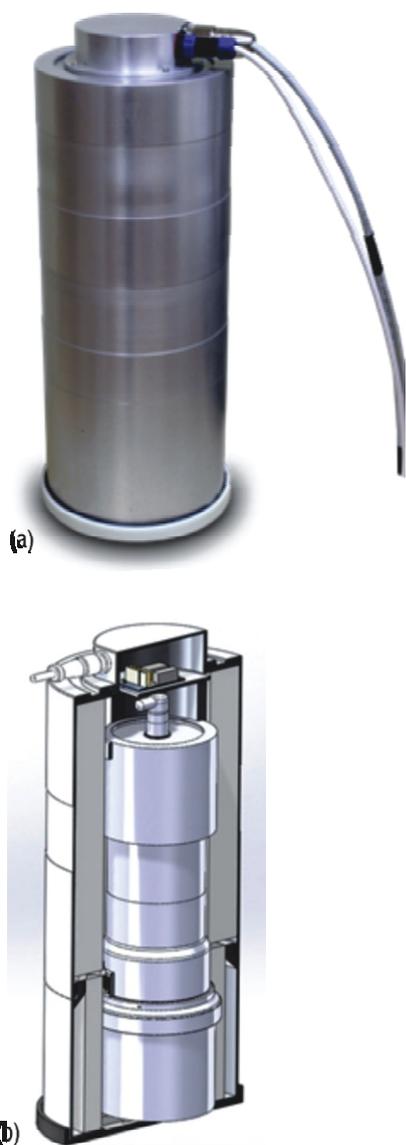


Figure 1. Photo (a) and cross-section (b) of the spectrometer in thermostabilizing housing TSH-L

The spectrometer case itself is located inside the thermostabilizing housing, which provides protection against dust and humidity as well as thermal isolation against abrupt ambient temperature changes. In addition, the thermostabilizing housing TSH-L is equipped with an automated heating system that maintains the temperature of the crystal in the approximate range of $(17-20)\text{ }^{\circ}\text{C}$, also in the case of ambient temperatures below freezing. The maximum overall dimensions of the insulating housing are $\text{Ø}170\text{ mm} \times 440\text{ mm}$.

The thermostabilizing housing TSH-L has the bottom part on which the entire device can be assembled see fig. 1(b). The inner part of the housing is made from the thermally insulating material enclosed by a light aluminium case. On the side of the scintillation crystal, the aluminium case has a carbon window to allow detecting low-energy gamma radiation. Two cables penetrate the housing through feed-through connectors in the upper part of the case: the power supply cable ($+12\text{ V}$) and the data transfer cable. The spectrometer can be controlled via LAN and RS-485 interfaces.

The spectrometer can be heated using three resistors that are installed on the heat exchange ring. The same ring has a temperature sensor, which provides feedback according to which the heating system can be activated and deactivated. One additional temperature sensor is installed on the case of the scintillation crystal for additional temperature control. The thermal housing's automated heating system was tested both in refrigerating ($T_{\text{amb}} = +5\text{ }^{\circ}\text{C}$) and in freezing chambers ($T_{\text{amb}} = -20\text{ }^{\circ}\text{C}$). The set-point below which the heater is turned on was adjusted at different times. Tables 1 and 2 show the temperatures of the crystal, T_{det} , as a function of time along with the set-point value of the heating system ($T_{\text{on/off}}$).

Tables 1 and 2 show that the heating automatically started when the temperature of the heat exchange ring reached $+14\text{ }^{\circ}\text{C}$ and stopped when its temperature reached $+19\text{ }^{\circ}\text{C}$. In this way, the temperature of the crystal remained within the range $+(17-19)\text{ }^{\circ}\text{C}$. Thus, the heating system reacted appropriately to the low ambient temperature, maintaining the temperature of the scintillation crystal at a constant level.

STABILIZATION USING THE ^{241}Am ALPHA PEAK AS A REFERENCE

As another method for stabilization of the spectrometric chain, we implemented a stabilisation scheme based on a ^{241}Am source [11-13]. The 59 keV gamma peak was used at the lower end of the energy range, whereas the peak corresponding to the energy deposit of the alpha particle was used at the upper end of the range. The alpha peak has the advantage of falling near the upper end of the energy range and of not having an energy distribution due to Compton scatter-

Table 1. Test results of the thermal stabilization of the detector in the refrigerating chamber
($T_{\text{amb}} = +5\text{ }^{\circ}\text{C}$; heating phase ; cooling phase)

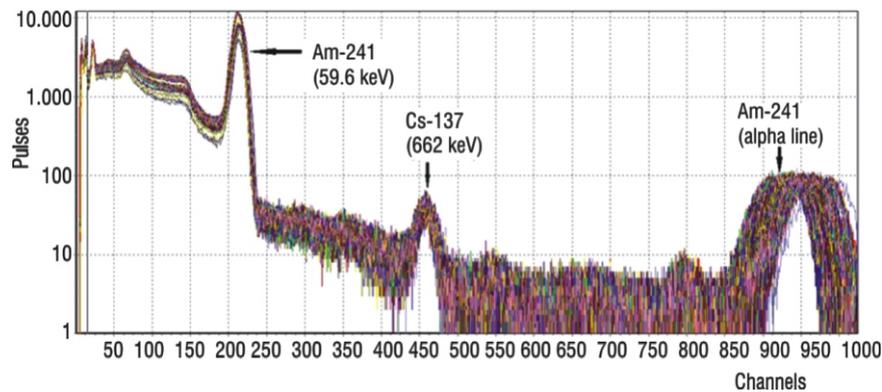
Heating time [min]	13.08	13.10	13.11	13.13	13.13	13.14	13.14	13.15	13.16
T_{dets} [$^{\circ}\text{C}$]	18.2	18.2	17.5	17.4	17.6	17.8	18	18.2	18.2
$T_{\text{on/off}}$ [$^{\circ}\text{C}$]	17	15	14	15	16	17	18	19	18

Heating time [min]	13.08	13.19	13.20	13.22	13.23	13.24	13.24	13.25	13.26
T_{dets} [$^{\circ}\text{C}$]	18.0	17.7	17.4	17.4	17.8	18.1	18.2	18.2	18.0
$T_{\text{on/off}}$ [$^{\circ}\text{C}$]	16	15	14	15	17	18	19	18	17

Table 2. Test results of the thermal stabilization of the detector in the freezing chamber
($T_{\text{amb}} = -20\text{ }^{\circ}\text{C}$; heating phase ; cooling phase)

Heating time [min]	13.50	13.52	13.53	13.54	13.55	13.55	13.56	13.56	13.57
T_{dets} [$^{\circ}\text{C}$]	18.2	17.2	17.0	17.0	17.1	17.5	17.7	17.8	18.0
$T_{\text{on/off}}$ [$^{\circ}\text{C}$]	18	16	15	16	17	18	19	20	20

Heating time [min]	13.57	13.158	13.59	14.00	14.01	14.01			
T_{dets} [$^{\circ}\text{C}$]	17.9	17.8	17.6	17.3	17.0	16.9			
$T_{\text{on/off}}$ [$^{\circ}\text{C}$]	19	18	17	16	15	16			

**Figure 2. All measured spectra obtained during the tests displayed on one plot**

ing. The amplification coefficient of the MCA could be adjusted with a pre-set periodicity, say once per minute, with the aim of locating the centroid of the reference peak in a given channel. In this way, the stability of the spectrometric chain can be assured with confidence.

The following tests were performed to evaluate the implemented solution. The spectrometer's internal instrument program is already capable of stabilising the spectrometric chain based on the 662 keV peak of ^{137}Cs and maintaining it in its initial channel for the energy range up to 3 MeV. For the test, the crystal temperature was lowered from $+18\text{ }^{\circ}\text{C}$ to $+14\text{ }^{\circ}\text{C}$, then raised to $+28\text{ }^{\circ}\text{C}$, and finally lowered again to $+18\text{ }^{\circ}\text{C}$. For the purpose of the experiment, the reference peak dynamics of the ^{241}Am alpha peak for the case when ^{137}Cs peak is fixed (*i. e.*, the internal instrument program corrects the amplification and holds the position of the ^{137}Cs peak in the fixed channel) should be cleared up. Knowing the variation of the ^{241}Am centroid as a function of temperature for the fixed ^{137}Cs peak position [Centroid

(^{241}Am , $^{137}\text{Cs} \Rightarrow \text{const.}) = f(T)$] and solving the inverse problem, we could determine the amount by which the position of the ^{241}Am peak should be shifted (by modifying the amplification coefficient) for the given temperature so that the ^{137}Cs peak is saved in the computer memory in the same fixed channel. With the specified periodicity, the spectrum was saved in the computer memory and after the tests, all dependence diagrams of reference peak position on temperature were assembled into one figure (see fig. 2).

Figure 2 shows that the ^{241}Am alpha reference peak changes its position from channel 920 to channel 970 while the ^{137}Cs position is stable to within 1 channel. A small instability of the detected intensity of the ^{137}Cs peak is connected with the fact that the measurement configuration has changed slightly due to the spectrometer being removed from the cooling chamber and later replaced. Based on the obtained results the desired rectilinear dependence has been determined, and it is shown in fig. 3.

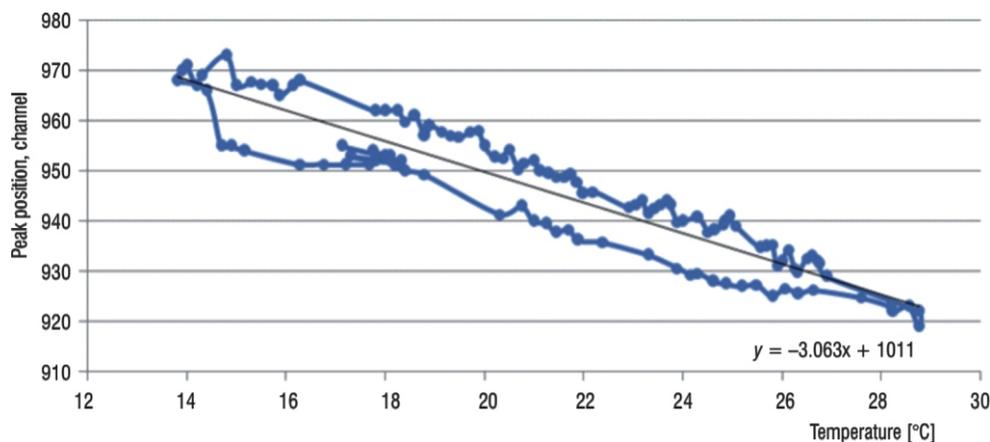


Figure 3. Plot of the reference peak position as a function of temperature

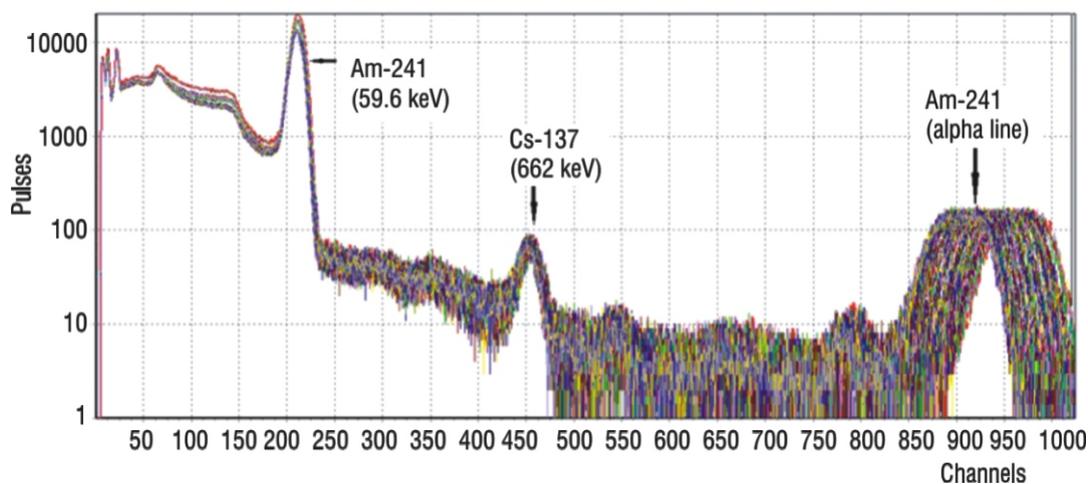


Figure 4. The drawing of all measured spectra during the tests

The hysteresis visible in fig. 3 is caused by the thermal inertia of the large-volume crystal (76 mm 76 mm) during heating and cooling. The test was repeated after the correction function obtained from fig. 3. was included in the spectrometer's internal software (SW). However, this time, the program was instructed to maintain the alpha reference peak in a specific channel in such a way that the ^{137}Cs peak also remains in a fixed channel. Thus, the program determines the temperature, T , for the normal operating conditions, then, based on fig. 3, it defines the channel number in which the alpha peak reference should be set up for the temperature, T , to maintain the ^{137}Cs peak in its fixed channel. Finally, it corrects the amplification coefficient so that the alpha peak reference appears in that channel. As a result, the whole energy range is corrected appropriately. Figure 4 shows the typical plot of a spectrum in which again the dynamics of the reference peak position are seen, but the reference peak position nevertheless is stable.

Figure 5 shows the position of the ^{137}Cs peak as the crystal temperature is changed from +14 °C to +32 °C. The peak position instability was only 0.36 %, which shows the high stability of the implemented solution [14].

STABILIZATION SYSTEM WITH APPLICATION OF LIGHT DIODE

To exclude implementation of radionuclide source for stabilization of spectrometers where it is not desirable, we designed an alternative online stabilization method based on a light-emitting diode (LED) [15-18]. Figure 6 shows a schematic diagram of the LED stabilisation system.

Between the scintillation crystal and photomultiplier, there is a glass insert that contains an Optocoupler (LED + photo diode). The optical parameters of the optocoupler have been selected to provide an optimal match with the flashes of the scintillator and LED in the range of operation of the photomultiplier. The optocoupler is placed in a black, lightproof case with an aperture of 0.8 mm diameter. The aperture's location and orientation are optimised to provide the most uniform exposure of the glass insert. Thus, the flashes of the scintillator and LED together reach the cathode of the photomultiplier for further amplification and processing by the spectrometric device.

The LED pulses are stabilised by means of a proportional regulator with feedback. The LED flashes are

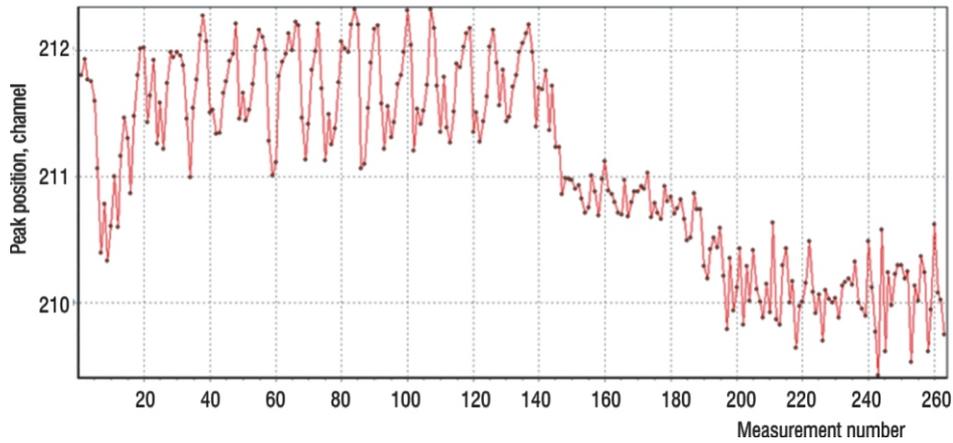


Figure 5. Position stability of peak 662 keV of radionuclide ^{137}Cs

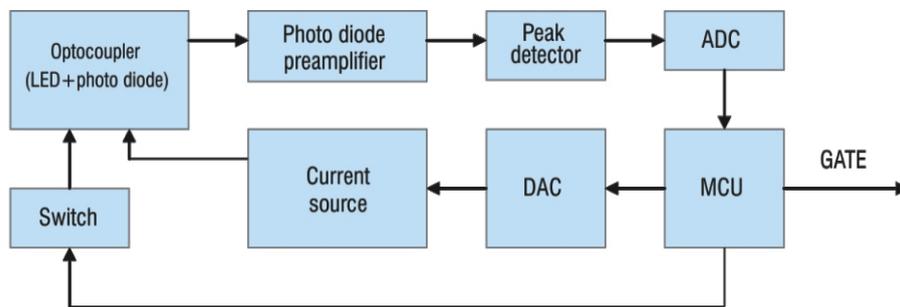


Figure 6. Block diagram of the stabiliser of the spectrometric chain with the application of LED

registered by a photo diode, the signals of which are amplified by the photo diode preamplifier. The amplified pulse's amplitude is fixed by a peak detector and digitized by an analog-to-digital converter (ADC). The microcontroller (MCU) then regulates the LED current to stabilise the brightness of the light pulses.

The microcontroller controls the whole stabilization process. It shapes the pulses that drive the LED with the switch. The brightness of the flashes is defined by the current that passes through the LED. The current value is regulated by the precision current source and is specified by the microcontroller through a digital-to-analog converter (DAC). The LED flashes pass through the aperture to the photomultiplier and are converted into a signal spectrum after the amplifiers in the spectrometric chain. Simultaneously with the LED pulse, the MCU shapes the strobe signal GATE, which allows LED flashes to be distinguished from scintillation light produced by radiation prior to further processing in the MCA. By adjusting the LED current, one can shift the position of the LED reference in the spectrum.

Because the MCA can discriminate the incoming pulses through coincidence with the GATE pulse there are two spectra: the real radiation spectrum and the reference spectrum. Prior to the measurement, the position of the stabilised LED reference peak can be adjusted so to be in the centre of the spectrum and fixed in the memory. During the measurements, the instrument

SW controls the reference peak position and once a minute compensates the centroid drift by adjusting the amplification coefficient in the MCA. Our experiments demonstrated that the drift of the 662 keV ^{137}Cs peak position was less than 2% over the entire range of ambient temperatures from -20 to $+50$ °C.

SOFTWARE

Aerosol monitors are the hardware-software complexes which provide the radionuclides detection and their activity measurement in the air. They enable the measurement results in real time mode what is the best solution for the ambient monitoring of uncontrollable radioactive emissions in the environment. Usually such monitors are united in the systems distributed over the vast territories. The Comprehensive Nuclear-Test-Ban Treaty (CTBT) Organization has the largest monitoring global system [19]. In that system, the separate aerosol monitors should provide not only the measurements at a considerable distance from each other but also the interaction among them and secure the distance control, test and service, possible adjustment, regulations, *etc.* To organize the operation and modifications in the system various SW products are required for its proper operation.

During the development and testing of the stabilised spectrometer – radiometer, three types of SW have been developed:

- the instrument SW *Airsoft* programmed in C++ for Linux;
- the user checkout demo SW *AirSpec-control*, programmed in Delphi for Windows;
- the multifunctional spectrometric SW *GammaPro* for Windows [20].

The SW *Airsoft* allows for remote control of the spectrometer via Ethernet or an RS-485 interface. It can start a measurement, control the adjustments of the built-in micro MCA, read spectra, and transfer the data via the selected interface. Furthermore, the SW *Airsoft* stabilises the spectrometric section and calculates the activities (specific or volumetric) based on the implemented calibration. Finally, the SW *Airsoft* can obtain data via an RS-232 interface from the pressure sensors, flow meters, and other sensors that are implemented in the specific aerosol monitor.

The user checkout demo SW *AirSpec-control* executes the interface functions of the spectrometer control panel. Launched on the user's PC, it allows remote control of all functions of the spectrometer (start, stop, reading of the spectra, and calculation of the activity results, *etc.*), sending and receiving the commands over the Internet.

The spectrometric SW *GammaPro* provides not only control and basic adjustment functions for the developed stabilized radiation spectrometer but also carries out all of the principal spectrometric tasks, including the measurement of the volumetric activity of the radionuclides in the air and aerosols.

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AUTHORS' CONTRIBUTIONS

The stabilisation method development applying the built-in source was made by F. V. Finkel while the development of the thermostabilising housing was made by I. A. Krainukovs. V. S. Litvinsky executed the development of the stabilisation method with LED and V. V. Gostilo provided the development of the software and the test of the method.

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**СТАБИЛИЗАЦИЈА ПЕРФОРМАНСИ СЦИНТИЛАЦИОНИХ
СПЕКТРОМЕТАРА ЗА МОНИТОРИНГ АЕРОСОЛА**

У овом раду приказани су резултати развоја сцинтилационих гама спектрометара заснованих на NaI(Tl), LaBr₃ или SrI₂(Eu) сцинтилационим материјалима намењеним мониторингу аеросола у широком температурном опсегу. Стабилизација карактеристика је обезбеђена применом различитих стабилизационих метода спектрометријског ланца. Такође, процењен је утицај ових метода на стабилност карактеристика развијеног спектрометра.

Кључне речи: мониторинг аеросола, сцинтилациони детектор, стабилизација перформансе
