Xenon gamma-ray spectrometer for radioactive waste controlling complex

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Abstract. Xenon detector based gamma-ray spectrometer for a radioactive waste sorting complex and its characteristics are described. It has been shown that the “thin-wall” modification of the detector allows better registration of low-energy gamma rays (tens of keV). The spectrometer is capable of operation in unfavorable field conditions and can identify radionuclides of interest in less than 1 second.

1. Introduction
At present one can observe an intensive development of the nuclear power industry, the so called “nuclear renaissance”, which was significantly held back by after the Chernobyl accident. At the present the new nuclear power units are being launched and new nuclear power plants (NPP) are being built. It becomes clearer each day that further development of humanity is impossible without nuclear energy.

On the other hand, the increasing number of NPP and their units, as well as discontinuation of operation of the old ones, lead to the growth of radioactive waste (RAW) that needs to be sorted according to its composition and concentration of radionuclides to determine their burials’ locations.

These days it is not enough to simply determine a level of radioactivity of the RAW. It is necessary to determine with high accuracy the composition and concentration of particular radionuclides in every RAW sample. To solve this problem highly sensitive gamma-spectrometers with high energy resolution have to be utilized for effective sorting of RAW [1,2].

It needs to be noted that usage of modern gamma-spectrometers in radioactive waste controlling complexes will bring about a great economic effect due to separation of RAW with regards to their activity and composition. As it is known, the cost of burial of the RAW with long half-life and great activity is largely different from the cost of low-activity samples burial [3]. Therefore, it is currently quite important to create new gamma-spectrometric devices that would sort RAW in accordance with their activity and composition that have to have high sensitivity, stability towards external vibro-acoustic influence, are capable of operation in field conditions, meaning that they have to possess necessary impermeability and protection.

In this paper a high-pressure xenon gamma-spectrometer created at NRNU MEPhI that will be employed in a RAW controlling complex is described.
2. Equipment description

The xenon gamma-spectrometer (XGS) contains a xenon gamma-ray detector (XGD) made of a cylindrical pulse ionization chamber with Frisch grid. It has an increased useful sensitive volume of 4 liters and the total mass of the working medium is 1.2 kg.

To widen the energy range of the registered gamma-rays, especially at low energies (30–50 keV), body of the detector is made of 0.5 mm wide stainless steel. Taking into consideration the fact that xenon in the detector is under pressure of 40 atm., it is necessary to assure strength of the thin-wall ionization chamber. This goal is achieved by means of usage of composite material Kevlar or glass fiber [4,5]. The latter option was chosen for this work.

Notably, usage of this composite material decreases the mass of the XGD nearly by factor of 3 in comparison with the thick-wall model, the total mass of such device is 5 kg. XGD main physical and technical characteristics are given in table 1, its image is in figure 1.

| Characteristics                              | Value         |
|----------------------------------------------|---------------|
| Mass, kg                                      | 5.0           |
| Working medium mass, kg                       | 1.2           |
| Working volume, cm³                           | 4000          |
| Dimensions, mm (Diameter)                    | 119           |
|                                               | (Length) 400  |
| Wall thickness, mm                            | 0.5           |
| Operating temperature range, °C              | 0 °C to 100°C |
| Level of acoustic influence, dB              | 0 dB to 100 dB|

Table 1. XGD main physical and technical characteristics.

Besides xenon detector, XGS includes a digital electronics unit (DE) for electric pulse processing and a power supply (PS). DE enables processing of every electric pulse coming from XGD and forms gamma-ray energy spectra [4,6]. The total mass of the equipment is 6 kg.
3. Results of XGS testing

Testing of the XGS was carried out using radiation sources from the standard kit. Processing of the electrical pulses and spectra formation took place in the DE and further processing of the spectrometric information was performed by means of special software enabling gamma-ray spectrum identification.

Figure 2 presents a gamma-ray spectrum of $^{241}$Am source without background subtraction. A 59.6 keV line is clearly visible in the image. This shows that a thin-wall XGD allows reliable registration of gamma rays with energies of several tens of keV, which is extremely important for identification of fissile materials.

![Figure 2. Gamma-ray energy spectrum of $^{241}$Am source.](image)

Figure 5 shows energy spectrum of $^{137}$Cs gamma-ray source with subtracted background. In this case energy resolution for 662 keV line was (2.3±0.3)%.

![Figure 3. Gamma-ray energy spectrum of $^{137}$Cs source.](image)
During trials the possibility to discover and identify various radionuclides with short exposition time was tested. It was shown that $^{137}\text{Cs}$ source with activity of $\sim 9 \text{kBq}$ can be discovered and identified by XGS from a distance of 5 cm from the detector in $(5–10)$ seconds. Discovery and identification were carried out using special software implementing the $3\sigma$ background excess method as well as the documented requirements for minimum activities of individual nuclides. Processing time for each spectrum was less than 1 second. Here the activities of the studied sources were in the range of $(4\div10)$ kBq.

4. Conclusion
A modified high-pressure xenon gamma-ray detector with digital electronics implementing a new method of electric pulse processing that allows utilization of the XGS in various models of radioactive waste control complexes was created. Software for XGS that carries out processing of gamma-ray spectra and identification of various radionuclides in less than 1 second was developed. The described XGS can be installed as part of the radioactive waste control complex.

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