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SIMULATION OF INSTRUMENTAL SPECTRA CDZNTE-DETECTORS FOR MEASURING THE INTRINSIC GAMMA-RADIATION OF SPENT NUCLEAR FUEL

As a result of passage gamma-radiation through detector and the subsequent processing of received signal, it is possible to obtain an instrumental spectrum, which is a direct reflection of the interactions gamma-rays with the detecting medium. It provides primary information used for further analysis of gamma radiation.

The instrumental spectrum is complex because of the peculiarities gamma-radiation detection by proportional detectors. In addition, there are both natural and technological limitations on how accurately the detection system can register the energy of gamma-radiation. The natural limitation arises mainly due to statistical fluctuations associated with charge formation processes in the detector. The positions of the total absorption peaks can also be distorted by such electronic effects as noise, imposition of pulses, incorrect installation of the «pole-zero» scheme, etc.

In addition, real gamma-ray spectrum of a sample may differ significantly from the spectra obtained under laboratory conditions.

When developing the methodology, the statement was used that linear irreversible transformations of the space of instrumental spectra correspond to changes in measurement conditions, and the spectrum of the i-th component under arbitrary measurement conditions can be represented as:

$$\varphi(a) = \sum_{i=0}^{L} a_i \varphi_i(a), \quad \sum a_i = 1, \tag{1}$$

where $\varphi_i(a)$ – are linearly independent spectra obtained during preliminary measurements, and the coefficients are the same for all components.

The technique for modeling the instrumental spectra is based on the following procedures:

1. The spectrum of isotopes with a large number of lines is represented as a linear combination of monoenergetic spectra taking into account the quantum yield in the «narrow beam» geometry; self-absorption in fuel assemblies is not taken into account for each isotope.

2. Simulates the change in the monoenergetic spectrum due to the interaction with the material of the technological environment and the fuel matrix.

3. The first and second procedures are used to form the instrumental spectra of a mixture of isotopes.

To represent the Compton distribution $\mu(E,E_i)$, we used method of statistical tests (Monte Carlo method), which is most effective when considering the transfer of radiation in a substance due to the statistical nature of this process. This is explained by the fact that elementary scattering events take place on a free electron and, therefore, the properties of crystal are not significant. In addition, the scattering has a continuous spectrum of secondary particles and need more statistics for its correct representation. Therefore, it is optimal to use Monte Carlo method, in which the random motion of a particle is considered as a certain trajectory, and its state at each focal point is played using random numbers from the corresponding distributions. It is shown that modern algorithms for the implementation of this method allow to achieve simulation accuracy up to 1-2% [1; 2].

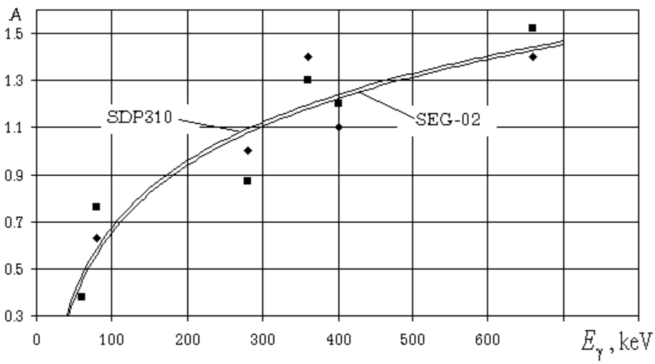

Figure 1. The dependence of the parameter *A*, which determines the amplitude of function F_t, on energy of detected radiation: 1 – prototype crystal with quasispherical contact design; 2 – prototype crystal with planar contact design.

On the basis of the developed methodology and experimentally determined spectrometer characteristics, hardware spectra were simulated under various measurement conditions with subsequent processing of the obtained model spectra.

To verify correctness of implementation, spectrum of a ^{137}Cs point source was simulated with the superposition of random noise (Figure 2). For comparison, figure 3 shows the measured ^{137}Cs spectrum from a set of gamma-ray spectra. A characteristic feature of the model is a more pronounced peak in region of the maximum energy of Compton electrons.

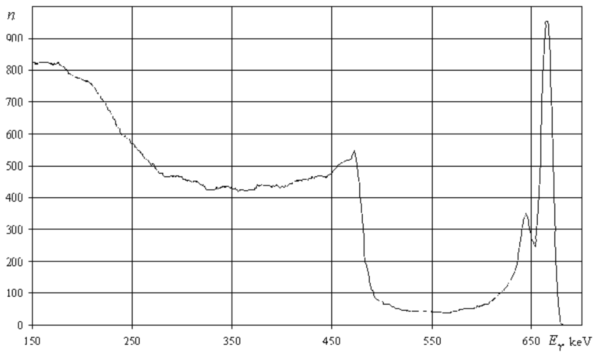

Figure 2. Model of the instrumental spectrum when measuring a ^{137}Cs point source

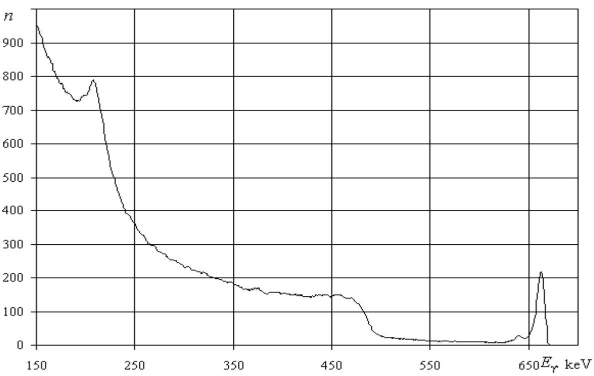

Figure 3. Instrumental spectrum when measuring a point source ^{137}Cs

A technique has been developed for modeling the instrumental spectra obtained by measuring the intrinsic gamma radiation of spent nuclear fuel with different burnup depths and the degree leaks of the fuel cladding. The spectrum model of the analyzed fuel assembly allowed us to determine sensitivity of the measurements and select optimal algorithm for processing the spectra. Due to this, the cost of developing the hardware and software components of the nuclear fuel condition monitoring system has been reduced.

This method differs from the known ones in that it did not use the simulation of distribution of electric field strength in the crystal volume of the sensor and did not use the Monte Carlo method to simulate electric charge induced during the primary interaction of gamma-radiation with the crystal.

Experimental verification of the methodology using example of modeling spectrum of the ^{137}Cs source confirmed the effectiveness uses of the spectrometer based on the CdZnTe-detector created in this work: compliance with requirements of monitoring the state of nuclear fuel in real time; identification of fuel assemblies containing fuel elements with a non-hermetic casing; determining fuel burnout based on fission product activity.

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