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PHYSICAL INSTRUMENTS FOR ECOLOGY, MEDICINE, AND BIOLOGY

The SPEDOG γ-Ray Spectrometer–Dosimeter

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Abstract—The main characteristics of the SPEDOG portable γ-ray spectrometer–dosimeter are compared to those of its analogs currently available on the Russian market. The use of a KX605A silicon crystal in the instrument as the sensor unit is substantiated. The results from investigating the main physical and performance characteristics of the instrument are presented, particularly the temperature dependence of its energy resolution, the dependence of the spectrum shape on the relative positions of the detector and a radiation source, and the estimated efficiency of the instrument in mixed radiation fields.

INTRODUCTION

In this paper, we describe a small, portable, versatile spectrometer–dosimeter (SPEDOG) designed to measure the following characteristics of γ-ray fields:

(1) The partial energy spectrum in the region of γ-ray peaks, used to identify radionuclides;

(2) The continuous energy spectrum, i.e., the distribution of detected γ rays in 16 groups corresponding to a total range of 0.05–3 MeV;

(3) The radiation flux density;

(4) The equivalent dose.

The following requirements were specified for the instrument:

(1) Ease of operation and the possibility of promptly obtaining all necessary information on γ rays;

(2) The possibility of using the detector without a special cooler;

(3) Low sensitivity to accompanying radiation (neutrons).

The SPEDOG γ-ray spectrometer–dosimeter (Fig. 1) meets all the above requirements owing to the use of the unique measuring technique described in [1–3]. The SPEDOG instrument differs from other portable γspectrometers in the following ways:

(1) The use of a silicon crystal as the detector;

(2) The ability to simultaneously function as a spectrometer, dosimeter, and radiometer;

(3) The possibility of obtaining (with the use of special software), along with a γ-ray spectrum, the range of its measurement error.

CRITERIA FOR CHOOSING A DETECTOR

The SPEDOG measures γ-ray spectra by processing distributions of Compton electrons; hence, it is necessary that the detector have a high energy resolution and that the thickness of its sensitive layer be comparable to the Compton electron path length in silicon. An analysis of commercially produced silicon detectors shows that a KX605A detector is best suited to this application.

A KX605A detector has the following characteristics (averaged over 35 specimens): sensitive layer, 2–3 mm thick and 1.7–2.5 cm^2 in area; operating supply voltage, 100–600 V; detector back current, 8.8 μA; detector capacitance, 32 pF; energy equivalent for noise, 20 keV; energy resolution over the range of 0.05–3 MeV, 30 keV; and detection efficiency (for ^{137}Cs), 8.0%.

At room temperature, the average energy resolution of the KX605A detector is ~30 keV and depends on the γ-ray energy only slightly. The best detector specimens have a resolution of 25 keV. Furthermore, since the path

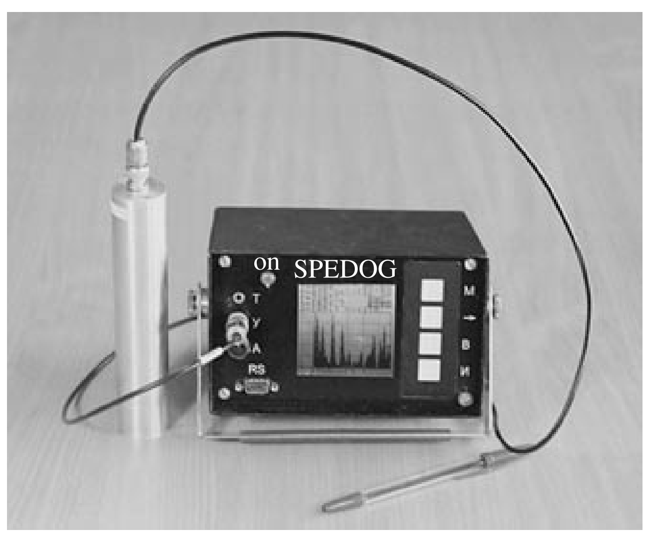

Fig. 1. The SPEDOG γ-ray spectrometer–dosimeter.

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Performance characteristics of the SPEDOG spectrometer–dosimeter

Characteristic	Value
Energy range, MeV	0.05–3
Detector type	KX605A silicon detector
Type of response mechanism	Compton effect
Range of dose rate measurements, μSv/h (mR/h)	0.1–2000 (0.01–200)
Sensitivity to 0.661-MeV γ rays (^{137}Cs), pulse · cm^2/photon	0.12
Relative energy resolution, %:	
for 0.661-MeV γ rays	6
for 1.33-MeV γ rays	3
Absolute energy resolution, keV	No worse than 30–40
Error in determining flux density by the area of a γ-ray peak, %	≤20
ADC channels	256
Number of energy groups over the range 0.05–3 MeV	16
Number of spectra to be archived	99
Error of dose rate measurements, %	10
Data acquisition time, s	1–9999
Maximum counting rate, count/s	10^4
Warmup period, min	1
Supply voltage, V	12
Continuous operating time, h	10
Specified service life, yr	5
Operating temperatures, °C	–10 to +35
Mass of the instrument, kg	≤3 kg
Dimensions of the instrument, cm:	
main unit	18 × 16 × 12
remote detector	d = 3.8; L = 18

length of a 1-MeV electron in silicon is 1.6 mm, detection of 3-MeV electrons requires that the sensitive volume of the silicon detector must be at least ~0.3 cm^3, while the thickness of its sensitive layer must be no less than 0.2 cm. KX605A detectors meet these requirements.

MAIN PERFORMANCE CHARACTERISTICS OF THE INSTRUMENT

Dependence of the Energy Resolution on the Ambient Temperature

To assess the performance of the instrument under different temperature conditions, we measured γ-ray spectra of several radionuclides at temperatures ranging from –16 to +40°C. The results from these experiments were as follows:

(1) Cooling the detector to –16°C improves the resolution of the instrument by a factor of 2 as compared to its resolution at room temperature.

(2) After the detector is heated to temperatures above +35°C, the noise level of the spectrometer exceeds the level of the useful data; hence, this temperature can be defined as the boundary temperature.

As a result, the SPEDOG can efficiently operate at ambient temperature without using a special cooler, and its resolution is ~30–40 keV over the energy range 0.05–3 MeV (see the table).

According to our assessments, when using a thermoelectric cooler with which it is possible to reach a temperature of –40°C, the resolution of the instrument can be brought to a level of 6 keV. This value is by one order of magnitude comparable to the resolution of a spectrometer with a germanium detector cooled to a temperature of –196°C.

Dependence of the Spectrum Shape on the Spatial Orientation of the Detector

The sensitive layer of the KX605A detector varies in thickness, depending on its orientation in space with respect to the radiation source. We investigated how the angle of incidence of γ rays affected the shape of the measured spectrum. To accomplish this, point radionuclide sources (^{60}Co and ^{137}Cs) were placed so that γ rays were incident either on the detector's end face or side surface.

The pulse height distributions recorded for two relative positions of the detector and the source show that the detector's anisotropy is less pronounced for γ rays with an energy of 1.33 MeV or under. This permits the taking of measurements over the given energy range of virtually isotropic fields without resorting to any special technique. The measured spectra are decoded using a matrix of detector responses created for the normal incidence of radiation on the detector's end face.

The anisotropy of experimental results increases slightly with increasing γ-ray energy. In this case, the detector should be oriented so that its smaller surface (the end face) is perpendicular to the predominant direction of γ-ray incidence.

Measuring γ-Ray Spectra in Mixed Radiation Fields

The main problem encountered when measuring γ-ray spectra in neutron fields is the distortion of the measured spectrum through the superposition of secondary γ rays, due to interaction between neutrons and nuclei of the detector material. In the case of germanium detectors, this problem is also complicated by the neutrons damaging the lattice and thereby impairing the characteristics of an expensive crystal.

One feature of the SPEDOG, owing to which it compares favorably to other γ spectrometers, is the ability to effectively operate under neutron irradiation. Using the SPEDOG, it is possible to obtain photon spectra that largely cover the energy range of γ rays emitted by nuclear power units and fissile materials [4]. In addition, according to the results of our experiments [5], the instrument can act as a fissile material indicator when determining isotopic composition and assessing the quantity of isotopes in a sample under investigation (if their content in it is >1 g).

Below, we present the data on the interaction between neutrons and nuclei of materials used in γ spectrometers as the detectors:

Substance	Thermal neutron absorption cross section, b	Resonance integral
Si	0.17	0.08
Ge	2.11	5.79
Na	0.53	0.31
I	6.27	157

It is evident from the above data that a silicon detector is much less susceptible to the effect of neutron irradiation than germanium spectrometers or scintillators.

The reliable operation of the SPEDOG has been corroborated more than once in practice. Below we present the values of the neutron-to-γ-intensity ratio observed during measurements of γ-ray spectra above the surface of the experimental research setup, performed using the SEPDOG at the Institute of Physics and Power Engineering (Obninsk, Russia) and the Institute of Nuclear Research (Rez near Prague, Czech Republic) for different types of sources enclosed in the setup [4, 5]:

Source type	Neutrons/γ rays
^{252}Cf	1/3
^{239}Pu + Be	1/1.3
^{252}Cf + ^{40}Fe	10/1
^{252}Cf + ^{40}Pb	20/1

From the results obtained, it may be concluded that neutrons have virtually no effect on the measured γ-ray spectra. According to the estimates for a ^{252}Cf nuclide that emits neutrons and γ rays in a ratio of 100 : 1 (in practice, such numbers never reach these values), the distortion of the γ-ray spectrum recorded using the SPEDOG is no greater than 10%.

OPERATING PRINCIPLE OF THE INSTRUMENT

The current pulses induced in the detector under the action of γ rays are converted into counts and stored into the instrument's memory. The SPEDOG can simultaneously store as many as 99 measured spectra. These spectra can be subsequently transmitted to a computer and processed using special software that is supplied along with the instrument (the program interface is shown in Fig. 2). The software is based on the method of experimental data processing that was described in [2].

The main function of the instrument is to identify radionuclides by their γ-ray spectra. Identification is performed by comparing the measured spectra (after their processing) to the reference spectra stored in the software library. Thus, with a portable computer, radionuclides can be identified directly on site, allowing the operator to quickly make appropriate decisions. The library of γ-ray spectra currently contains information on the following radionuclides: ^{60}Co, ^{137}Cs, ^{22}Na, ^{54}Mn, ^{226}Ra, ^{65}Zn, ^{88}Y, ^{152}Eu, ^{134}Cs, ^{133}Ba, ^{95}Nb, ^{95}Zr, ^{40}K, ^{182}Ta, ^{125}Sb, etc. The γ-ray spectrum of a mixture of radionuclides, measured with the SPEDOG instrument, is shown in Fig. 3 as an illustration.

Research and development work aimed at creating the SPEDOG instrument has been under way for ten years. The instrument has passed tests under field and plant conditions at the following establishments: the Leningrad Nuclear Power Plant, the Radon Research and Production Association, the OKB Vympel Federal State Unitary Enterprise, the Institute of Physics and Power Engineering (Obninsk, Russia), the Institute of Nuclear Research (Rez near Prague, Czech Republic), and the Zvezdochka Federal State Unitary Enterprise (Severodvinsk, Russia).

The SPEDOG instrument has been used effectively to solve various problems at the facilities of the Radon Research and Production Association and the OKB Vympel Federal State Unitary Enterprise.

The SPEDOG was certified in August 2002. The instrument was registered in the State Catalog of Instrumentation as a γ-ray spectrometer–dosimeter and approved for use in the Russian Federation.

At exhibitions held during the Week of High Technologies in St. Petersburg in June 2004, the SPEDOG spectrometer–dosimeter was awarded a gold medal in a competition for innovative developments and projects. In addition, it was placed first in the competition for the best applied project of 2004, "From a High Level of Basic Research to High Technologies," held by the Foundation for the Support of Applied Research (estab-

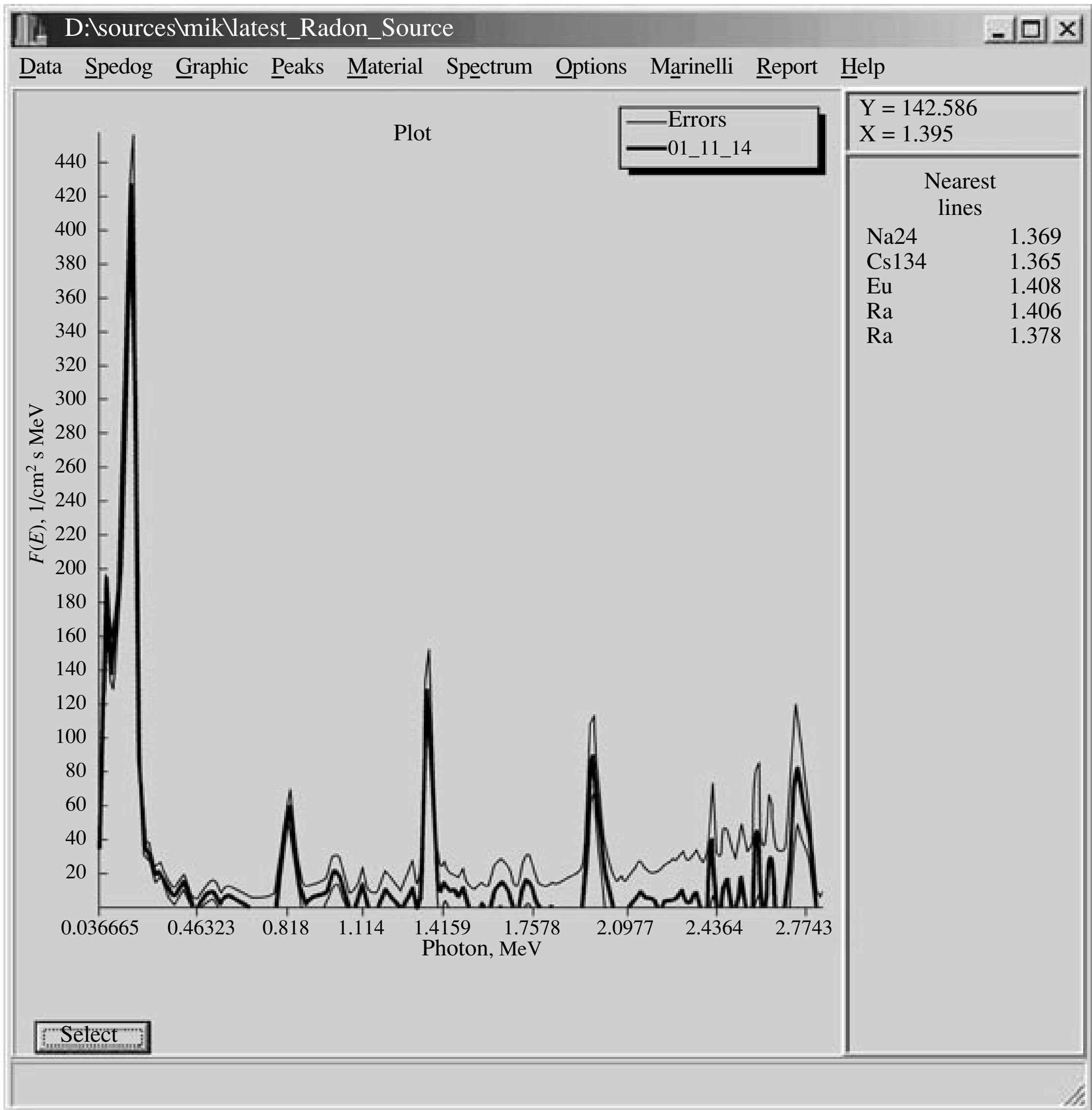

Fig. 2. User interface of the SPEDOG software.

lished by the Russian Academy of Sciences' Scientific Council for Applied Nuclear Physics).

CONCLUSIONS

Owing to the engineering solutions used in it, the SPEDOG has a number of advantages over other instruments that perform similar functions. For example, in contrast to germanium γ spectrometers, the SPEDOG detector requires no liquid nitrogen cooler and is hence more suitable for measurements under field conditions or in hard-to-reach places. The cross section of neutron scattering by silicon nuclei is considerably smaller than that of germanium; the SPEDOG can therefore be used in mixed radiation fields. This has always been a problem for germanium γ spectrometers because of the degradation, caused by the interaction with neutrons, in the characteristics of an expensive crystal. In addition, silicon crystals are less expensive than germanium crystals.

When comparing the SPEDOG to scintillation spectrometers, one must consider the characteristic high sensitivity of the latter, which is governed by the detector size. Though the SPEDOG sensitivity is high enough to measure even the natural radiation background, the instrument is nevertheless inferior in this regard to scintillators. On the other hand, the SPEDOG has the following advantages:

(1) A higher energy resolution that permits a finer spectrometric analysis to be performed: the SPEDOG provides a resolution of 30–40 keV (see the table), while the resolution of scintillators for 1-MeV γ rays is usually 60–80 keV;

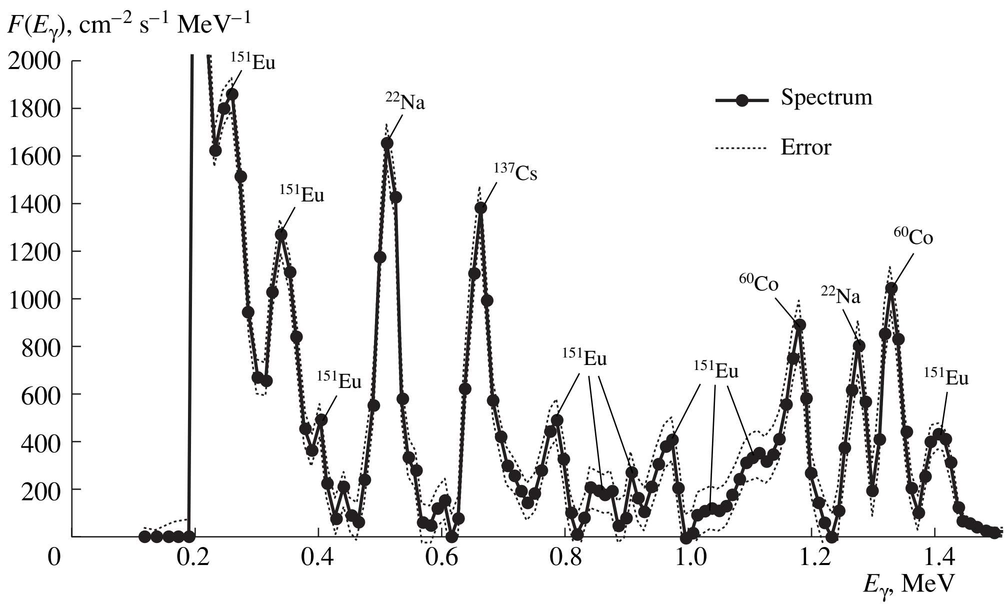

Fig. 3. Spectrum of γ-ray sources ^{151}Eu + ^{60}Co + ^{137}Cs + ^{22}Na.

(2) Aweaker interaction between neutrons and Si nuclei as compared to Na and I, owing to which a spectrum obtained using the SPEDOG contains virtually no overlapping peaks (these result from the detection of secondary γ rays produced during interactions between neutrons and the nuclei of the detector's material and substantially complicate any spectrometric analysis);

(3) The absence of a photomultiplier tube in the SPEDOG, which allows the power consumption to be reduced and the consistency of experimental results to be improved: the operating voltage of the scintillation detector is as high as 1000 V, while that of the SPEDOG is only 200 V. The experience gained in using the SPEDOG shows that it is able to provide consistent experimental results without frequent recalibration of the instrument (which cannot be avoided when using scintillators).

Hence, in cases of a very low radiation intensity (when measurements are performed, e.g., from an airplane or during customs inspection, when the radionuclide location is not known in advance), it is advantageous to use scintillation spectrometers, while the SPEDOG is more effective as a radionuclide identifier in higher γ-ray fields (the situation that most frequently occurs in the nuclear power industry).

This instrument would be most useful in the comprehensive engineering and radiation surveys performed for nuclear power plant units and transport nuclear power units as they are being withdrawn from service, since nuclear safety regulations often require that measurements of the γ-ray parameters be made in hard-to-reach places and in the presence of the accompanying neutron radiation.

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