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Alpha-, beta-, gamma-radiometric measurements using semiconductor detectors

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Referring to shortcomings of modern radiation detection and monitoring devices, an operable prototype of the device for determination of the gamma radiation exposure dose rate within the range from 10 μR/h to 1000 R/h, with the energy γ-radiation sensitivity range from 50 keV to 3 MeV, has been offered. The prototype is able to register the α-radiation and β-radiation flux density. The device operates using two detection units and a two-channel counting unit. Registration of the exposure dose rate is provided by using CdTe detector, and registration of the α-radiation and β-radiation flux density is provided by using Si detector.

Предложен действующий макет прибора для определения мощности экспозиционной дозы гамма-излучения в диапазоне 10 мкР/час до 1000 Р/час с энергетическим спектром чувствительности по γ-излучению от 50 кэВ до 3 МэВ, способный регистрировать плотность потока α-, β-излучения. Прибор работает с применением двух блоков детектирования и двух канального счетного устройства. Регистрация мощности експозиционной дозы обеспечивается использованием CdTe детектора, а плотность потока α, β-излучения — Si детектором.

Альфа-, бета-, гамма-радіометріія з використанням напівпровідникових детекторів. *А.М.Григорьєв, О.В.Сакун, В.В.Марущенко, З.В.Білик, Ю.В.Литвинов, О.Ю.Чернявський, Є.Ф.Воронкін.*

Запропоновано діючий макет приладу для визначення потужності експозиційної дози гамма-випромінювання у діапазоні 10 мкР/год до 1000 Р/год з енергетичним спектром чутливості з γ-випромінювання від 50 кеВ до 3 МеВ, здатний фіксувати щільність потоку α-,’ β-випромінювання. Прилад працює з застосуванням двох блоків детектування та двоканального лігільного пристрою. Реєстрація потужності експозиційної дози забезпечується використанням CdTe та Si детекторів, а щільність потоку α-, β-випромінювання — Si детектором.

1. Introduction

Currently, some special requirements [1] are applied to devices for the measurement of radioactive contamination represented by the wide range of radiation detection and monitoring devices (DP-5V, IMD-1, IMD-12, IMD-21, MKS-U, MKS-0,5, etc.). In particular, radiation detection devices must provide any function from the listed below or any part of such function following from the tasks set:

— measurement of the exposure dose rate (EDR) within the range from 10 mR/h to 10^3 R/h:

— registration of gamma quanta within the energy range from 10 keV to 3 MeV;

— measurement of α-radiation and β-radiation flux density;

— automatic transfer of data obtained to stations of collection and processing of information (IMD-31).

Analysis of use of the existing dose monitoring devices [1] proves that there is no universal device able to provide functions listed above simultaneously at the disposal of military radiation reconnaissance services.

The latest results of research and design work prove that use of semiconductor detectors (SCD) of gamma radiation based on CdTe, CdZnTe [2, 3] and ultra-pure Si [4] give the best results. The advantages of CdTe include the following:

— width of the band gap is close enough to the optimal one (1.42 eV), this enables to get the resistivity value up to 10^9 Ohm/cm at the room temperature;

— high gamma radiation sensitivity due to large atomic numbers of its components Cd and Te (48:52) and due to its high density (6,06 g/cm^3);

— quite large values of mobility and lifetime of main carriers, that enables to get satisfactory signal-to-noise ratios at the energy value exceeding 50 keV.

— possibility to vary the band gap by adding a third component (e.g., Zn) in order to increase the operating temperature;

— detectors made of CdTe can operate long enough (at least 24 hours) at 90°C and are able to pass the cycle many times: from the room temperature to 90°C [5, 6].

To measure the α-radiation flux density, an ultra pure Si detector covered with 1 μm aluminium layer for protection from the external light is used.

To measure the β-radiation flux density, an absorber covered with the 30 μm aluminium layer has been placed before the detector; it has absorbed the flux of α-particles and it has been transparent for β-particles with the energy value exceeding 100 keV.

As it was shown in [4], surface-barrier light emitting Si-diodes FD 337 A can be used for alpha-spectrometric measurements. The energy distribution for the line of plutonium-238 may not exceed 10–12 keV. Specifications of silicon photodiodes FD 337 A are promising for the purpose of α-radiation and β-radiation measurements because they have the following useful features:

— open surface of the p–n junction with area 1 cm^2;

— technology of production of the p–n junction uses the boron and phosphorus diffusion, that enables to rely on the increased radiation and mechanical stability;

— thickness of the p–n junction may reach 0.3 mm, that enables to measure energies of β-particles up to 300 keV and energies of α-particles up to 10 MeV.

Disadvantages of the SCD of nuclear radiation (NR) include:

— limited radiation stability (~ 10^7 rad for gamma radiation) in comparison with 10^8 rad for gas filled counters;

— necessity to use an amplifier of signals with a large amplification factor that requires use of additional measures for screening the detection unit;

— large difference between the dependence of sensitivity on energy of gamma radiation and the dependence of biological effect on energy of gamma radiation.

Therefore, there is a necessity in the design of the new field gamma radiation measuring device with the range of measurement of the exposure dose rate from 10 mR/h to 1000 R/h, with the energy of gamma quanta of 50 keV and more, and with the possibility to measure alpha-radiation and beta-radiation. Such device does not require switching measurement sub-bands and replacement of the detection units.

Purpose of the article: the determination of the possibility to use γ-radiation detectors within the EDR range up to 1000 R/h for manufacturing wide-range multifunction radiation detection devices and determination of the possibility to use silicon photodiodes for the registration of alpha- and beta-radiation.

2. Presentation of the main material

Taking into account all specifications of radiation detection devices mentioned in the preamble, the universal operable prototype of the device for simultaneous determination of values of γ- and α-radiation or β-radiation by its detection units has been manufactured.

Structure of the device includes detection units with semiconductor detectors' screened communication cable and two-channel counting unit for registration of pulses coming from the detection unit.

Table. Results of the check of DUs by means of the ionizing radiation field generated by reference SIRs (channel 1)

SIR type	R, cm	X	Readings of the device					Average value
			1	2	3	4	5	
A_3	232.2	100 μR/h	47	68	71	84	65	67
A_3	73.4	1 μR/h	426	459	437	478	421	444.2
A_2	137.8	10 μR/h	3816	4002	4069	3817	3994	3939.6
A_2	43.6	100 μR/h	28600	29523	28891	29076	28351	28888
A_1	103.8	1 R/h	260449	261783	258373	256093	252455	257830
A_1	32.8	10 R/h	936414	894996	948263	884139	930654	918893
A_1	10.3	100 R/h	1334167	1427855	1325662	1274652	1357871	1344041
A_1	3.2	1000 R/h	1564333	1527831	1603729	1504479	1492375	1538549

The detection unit has appearance of the aluminium cylinder that is 45 mm in diameter and 195 mm in length.

One frame of the detection unit contains sockets for amplifiers' and the other frame is a movable cover with two openings that can be rotated around the axis of the cylinder in order to open the silicon detector for measuring the α- and β-radiation flux density. The detectors consist of semiconductor crystals placed inside casings of the detection units: Si crystal (10×10 mm^2 in area) and CdTe crystal ($6\times6\times3$ mm in area). In this respect, the detector made of silicon (Si) is placed on the front part of the cylinder (near the cover with opening), and the second detector made of cadmium telluride (CdTe) is placed in the geometric center of the aluminium cylinder near its axis. The amplifier of electrical signals is provided for each detector. The principle of functioning of the detection unit is the following: when the opening covered with foil, that prevents α-particles from passing through, is located against the Si-detector, the β-radiation flux density is measured, and in the case of use of the opening not covered with foil, the α-radiation and β-radiation flux density is measured. If the Si-detector is closed in such a way that the openings are not located against it (material of the cover), it can measure the flux density of fast neutrons if the polyethylene film is placed under the cover [7]; to measure the exposure dose rate (EDR) within the range from 10 μR/h to 1000 R/h, the CdTe detector is used.

The operation principle of the device is based on property of semiconductor crystals to transform the energy of α-, β- and γ-radiation into electric signals. The electrical signal coming from the detectors is amplified to the level of detection of signals by the counting unit. The counting unit receives pulses of the electrical signals from the detectors using the appropriate channels, then the unit registers these pulses and shows the number of counts, equal to the quantity of particles of nuclear radiation trapped by the detectors, on the electronic display.

To determine specifications of the designed universal operable prototype of the device, the method based on registration of the number of counts received from the reference sources is used. When checking the accuracy of measurement of γ-radiation EDR, the reference sources of ionizing radiation (SIR) were installed in check points and measurements were provided, which results are shown in Table, where R is distance from a source of ionizing radiation to the detection units (DU), and X is an exposure dose rate.

The reference point sources of γ-radiation:

— Cs^{137} — $A_0 = 2.4\cdot10^{11}$ Bq (denoted in the Table by A_1);

— Cs^{137} — $A_0 = 4.2\cdot10^{9}$ Bq (denoted in the Table by A_2);

— Cs^{137} — $A_0 = 1.2\cdot10^{8}$ Bq (denoted in the Table by A_3).

Measurement time range: from 1 to 60 seconds.

Diagram of the dependence of readings of the device on EDR of the reference sources of radiation (see Fig.) has been plotted in accordance with the measurement results. The scale included into the equipment of the field repair chemical workshop PRXM-D, used for the check, gives a possibility to calibrate the device within the EDR measurement range from 100 μR/h to 100 R/h, and the next range from 100 R/h to 1000 R/h has been estimated indicatively. The analysis

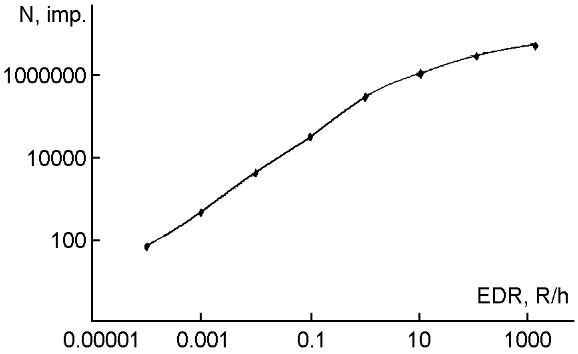

Fig. Diagram of the dependence of the number of counts N on the radiation EDR of the reference source for the channel of the CdTe detector.

of the dependence of the number of counts *N* on the radiation EDR of the reference source proves that the device shows the linear dependence within the range from 10 μR/h to 10 R/h. Basing on this dependence, it is possible to associate numbers of γ-quanta with *R/h* measurement units, i.e. to develop the table for the recalculation of the number of measured γ-quanta into *R/h* values. Registration of the flux of α- and β-particles has been provided in the following way.

To measure the surface density of the flux of β-particles, the source of radioactive nuclides strontium-90 + yttrium-90 with the activity $4.7 \cdot 10^4$ Bq has been used.

The area of the operating surface of the source was 1 cm^2.

During the experiment, the DU has been brought to the source, and the counter has shown the changed number of pulses that proves registration of beta-particles by the device.

To register alpha-particles, the source of radioactive nuclides plutonium-239 with the activity $1.09 \cdot 10^4$ Bq has been used.

The area of the operating surface of the source was 1 cm^2.

During the experiment, the distance from DU to the source of alpha-radiation was changed within the range 1–5 cm, and the counter has shown the changed number of pulses that proves the registration of alpha-particles by the device.

Thus, the results of the experimental research of the operable prototype of the wide-range EDR measuring device prove that the manufactured device:

— measures the radiation EDR within the range from 10 μR/h to 100 R/h quite accurately;

— has the energy spectrum of sensitivity to γ-radiation ≥50 keV;

— is able to register the α-radiation and β-radiation flux density;

— is efficient for the measurement of EDR values exceeding 100 R/h but specifications of the CdTe detector are to be studied additionally.

Disadvantages of the device are the following:

— the operable prototype of the device within the range from 10 R/h shows nonlinearity of measurements for the channel of the cadmium telluride detector.

4. Conclusions

It is urgent matter to design of the field gamma radiation measuring device with the range of measurement of the exposure dose rate from 10 μR/h to 1000 R/h, with the energy of gamma quanta of 50 keV and more, and with the possibility to measure α- and β-radiation, providing that such device does not require switching of measurement sub-bands and replacement of the detection units during radiation detection.

The following experiments have been made during the operation determination of the operation range of the CdTe detector for measurement of the γ-radiation EDR; registration of the surface density of the flux of α-particles and β-particles.

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