Adjusting of the detection efficiency of Geiger-Muller counters in the energy range of gamma radiation from 50 to 3000 keV

A.Yu. Ivasheva\textsuperscript{1,2,*}, V.S. Borisov\textsuperscript{1}, P.V. Semenikhin\textsuperscript{2,3}

\textsuperscript{1}Peter the Great SPb Polytechnical University, Saint Petersburg, 195251, Russia
\textsuperscript{2}RTC, Saint Petersburg, 194064, Russia
\textsuperscript{3}Ioffe Institute, Saint Petersburg, 194021, Russia
\*nastena9688@mail.ru

Abstract. Possibilities of adjusting detection efficiency of Geiger-Muller counters in the energy range of gamma radiation from 50 to 3000 keV have been investigated. Various metal foils were used as filters. Applying filters led to increase in the counting rate of the Geiger-Muller counters. Such increase can be explained by photoelectric effect.

1. Introduction
Nuclear accidents which occurred in the last decade with different sources of gamma radiation: the Fukushima Daiichi nuclear disaster (Japan, 2011), pollution by Co-60 of the metal scrap market near Mayapuri (Delhi, India, 2010) \cite{1} and other accidents caused interest in the issue of radiation safety. The increasing of passengers traffic and new flight routes makes the question about the radiation safety at civil flights also relevant in the presents time. For example, the radiation level at height of flight across the North Pole can exceed land level radiation by 100 times \cite{2}. Small-sized devices are needed for control local of radiation situation \cite{3}.

Usually in radiation detection devices use Geiger-Muller counters \cite{4,5}. Counters of this type are compact and allow using relatively simple circuit technology for processing recorded pulses, based on them can be developed means of visualization of gamma radiation sources \cite{6}.

The principle of operation of Geiger counters based on the effect of impact ionization. Gamma quanta getting into the outer wall of the counter (cathode) knock electrons out of it. Inside the counter is gas-filled, and a high voltage is applied between the cathode and the anode of the meter, which accelerates the electrons knocked out of the counter's wall, which causes the formation of an ion avalanche, a current pulse occurs, which is interpreted as an act of gamma quantum registration. The probability of gamma quantum registration by a meter depends on the material and thickness of the outer wall (cathode). Increasing the wall thickness increases the effective volume in which the gamma-quantum interacts with the substance, but with a large wall thickness, the ejected electrons will be absorbed on the cathode. Dose rate of gamma radiation is calculated according to indications of the counter by means of sensitivity coefficient:

\[ P = \frac{1}{\eta} \cdot \frac{n}{1 - n \cdot \tau} \]

where, \( P \) is the desired absorbed dose rate in (mkR/h), \( \eta \) is the counter sensitivity in
(imp/c) / (mkR/h), \( n \) is the counter count rate in (imp/sec), \( \tau \) is the dead time in seconds.

Sensitivity factor calibrated on Cs-137 gamma ray source (the spectrum of its radiation has sharp radiation peak with energy \( \sim 661 \) keV and this radionuclide is frequent source of radioactive pollution [7]). However, efficiency of registration of counters strongly depends on a radiation energy. There is an additional error which depends on the radiation energy in case of measurement of dose rate of gamma radiation of source with a energy of radiation different from Cs-137 (for example, a range of a natural radiation background or some other radionuclides emerging in case of radiation accidents or nuclear explosions).

The most common task in civilian application of small-sized radiation monitoring devices is to account for the doses received by medical workers in x-ray offices, and the range of x-ray tubes for medical diagnostics lies in the range from 10 to 60 keV [8]. Also, dosimetric control of customs officers working with X-ray installations for inspection of luggage and goods. According to the established rules, these installations incorporate an intensive source of x-ray radiation with a maximum energy up to 160 keV. [9].

The discrepancy between the radiation energy, which is used for calibration of Geiger-Muller counters by the manufacturer [10] and the radiation range faced by the user of the dosimetric monitoring device, caused the relevance of the correction of the counter registration efficiency.

Table 1 shows the discrepancy between the measured dose rate and the actual one for the SBM-21 counter. The measurements were carried out at the VNIIM named after Mendeleev on the stand of the state primary etalon of air kerma units, exposure dose, their power and X-ray and gamma-radiation energy flux GET 8-2011 [11] on the model of the detecting unit; Counter supply scheme complied with TU.

| Source | \( P_{\text{real, mkR/h}} \) | \( P_{\text{measured, mkR/h}} \) |
|--------|-----------------|-----------------|
| Cs-137 | 100             | 108.6           |
| Co-60  | 100             | 105.4           |
| N-80*  | 37.1            | 356.9           |
| N-100  | 19.8            | 137.5           |
| N-120  | 21.9            | 110.7           |
| N-150  | 167.4           | 621.4           |
| N-200  | 83              | 153.3           |
| N-250  | 29.8            | 352.6           |

* N - radiation lines comply with ISO-4037 [12].

To adjust the dependence of the registration efficiency of Geiger-Muller counters on energy, the filters [13], which are metal plates or foils, are used to partially absorb low-energy radiation. Carried out research devoted to define of optimum filter parameters, for equalizing detection efficiency of Geiger-Muller counters in range 50 to 3000 keV.
2. The object and methods of research
The development of a correction filter was carried out for the Geiger-Muller SBM-21 counter [10]. The choice of this counter as an object of research is proved by its high prevalence in small-sized dosimetric equipment.

Measurements of the attenuation of gamma radiation were carried out using reference (exemplary) closed radionuclide photon radiation sources, the parameters of which are presented in Table 2.

| Radionuclide | Radiation energy, keV (Quantum yield, %) |
|--------------|------------------------------------------|
| Ti-44        | 68.9 (94.4)                              |
|              | 78.3 (96.2)                              |
|              | 1157.0 (99.9)                            |
| Cs-137       | 661.7 (85.1)                             |
| Co-60        | 1173.2 (99.9)                            |
|              | 1332.5 (100)                             |
| Am-241       | 26.3 (2.4)                               |
|              | 59.5 (35.8)                              |

To estimate the attenuation of gamma radiation by various materials from OSGI sources, a scintillation spectrometer with NaI crystal SDN 31.150.50 was used.

3. Results
Primarily low-energy gamma ray radiation absorption by different filters were investigated with scintillation counter.

Theoretical estimates of the absorption of gamma radiation in the filters in a variety of materials have been carried out [9]. Spectra of absorption by different filters were obtained with scintillation counter (NaI, model SDN 31.150.50). Uses a set of exemplary gamma spectrometric sources.

For a scintillation spectrometer, the data on the attenuation of gamma radiation were closed to the calculated theoretical ones. For example, Fig. 1 shows the obtained graph of the attenuation of gamma radiation for a layer of 0.12 mm tungsten foil.
Figure 1. Energy spectrum for set of radionuclides without and with 0.12 mm thick tungsten filter.

At the second stage, a series of filters was checked to adjust the registration efficiency of Geiger-Muller counters.

Table 3. Filter effect on counting rate

| Filters      | Cs-137 | Ti-44 | Co-60 | Am-241 |
|--------------|--------|-------|-------|--------|
| No filter    | 1,00   | 1,00  | 1,00  | 1,00   |
| 3CuZn        | 0,84   | 0,71  | 0,75  | 0,34   |
| 2CuZn+4Pb    | 0,90   | 0,64  | 0,85  | 0,09   |
| 1CuZn+4Pb    | 0,87   | 0,67  | 0,89  | 0,11   |
| 1CuZn+5Pb    | 0,87   | 0,67  | 0,86  | 0,08   |
| 4Pb          | 1,09   | 0,76  | 0,93  | 0,12   |
| 5Pb          | 1,08   | 0,74  | 0,93  | 0,11   |
| 6Pb          | 1,15   | 0,74  | 0,92  | 0,08   |

The results are presented in table 3. are different from the observed on the scintillator. Adding a filter led to a slight increase in the counting rate on the counter at a radiation energy of 660 keV (Cs-137), and the attenuation of low-energy radiation was much lower.

4. Discussion

The discrepancy is explained by the contribution to the scattering of gamma radiation by the substance of the photoelectric effect. The electrons knocked out of the foil by gamma radiation fell into the working volume of the counter and were recorded, which led to an increase in the count if the distance from the filter to the counter was less than the free path of the electron. This is consistent with the measurements presented in [15].
5. Conclusions
As showed there, when choosing a filter to adjust the registration efficiency of Geiger-Muller counters, it is necessary to take into account electron knockout from the filter by gamma radiation.

6. Acknowledgments
Work was carried out in the laboratory of Physical and mathematical modelling of radiation monitoring systems, RTC.

References
[1] S. Mohanan, D. Damodaran, M. Soneja, N. Jain, A. Mohan, N.K. Vikram, R. Sood, Radiation accident at Mayapuri scrap market, Radiat Prot Dosimetry, 151 (4) pp. 645-51, 2012.
[2] M.A. Morozov, V.B. Lapshin, S.V. Dorensky, A.V. Syroeshkin, Dosimetry for air travel, Heliophysical studies (10), pp. 45-92, 2014.
[3] E. Bekker, A. Farsoni, Wireless fiscal compact gamma-ray spectrometer on field programmable gate array, Photonics, 4 (46), pp. 62-77, 2014.
[4] N.N. Ghuge, Sapna Jasrotia, Anamika, Chilsea Sadhu, Geiger-Muller: A thin end window tube radiation detector, International Journal of Research in Engineering and Technology, 4 (5), pp. 190-196, 2015.
[5] K. Stankovic, P. Osmokrovic, The model for calculating the type A measurement uncertainty of GM counters from the aspect of device miniaturization, IEEE Transactions on Nuclear Science, 61 (3), pp. 1316-1326, 2014.
[6] O. E. Lapin, A. N. Vlasenko, V. P. Demchenko, A. F. Pervishko, Small-sized device for imaging gamma-ray sources // Russian Patent No. 2426151. 2011. Bull. No 22.
[7] I. Y. Vasilenko, Radioactive Cesium-137, Priroda, 3, pp. 70-76, 1999.
[8] A.S. Gogolev, Yu.M. Cherepennikov, Determination of the optimal parameters of an x-ray source based on a compact electron accelerator, News of Tomsk Polytechnic University. 320. № 2, 2012
[9] Order of 27.04.1998 N 255 “On the organization of work on the conduct of individual dosimetric monitoring.
[10] TU 95-93 OD 0.339.544TU
[11] A. V. Oborin A. Yu. VillevaldeS. G. Trofimchuk, National primary standard for the unit of air kerma, air kerma rate, exposure, exposure rate, and x- and gamma-ray energy flux, Measurement Techniques 55 (8), pp 849–857,2012
[12] X and gamma reference radiation for calibrating dosimeters and doserate meters and for determining their response as a function of photon energy ISO 4037 1:1996 (1996)
[13] J. V. Sivintsev, How dangerous radiation, Moscow, Knowledge, 1988.
[14] E. Storm, H. Israel "Sections of interaction of gamma radiation" Handbook, Moscow, Atomizdat, 1973.
[15] H. Zhu; S. Kane ; S. Croft ; R. Venkataraman ; F. Bronson, Optimization of the Canberra UltraRadiac GM Tube Wrapping, IEEE Nuclear Science Symposium Conference Record. (2006)