Calculation of the Effective Energy Release Center's Position of Inorganic Scintillation Detectors for Calibration at Small "Source–Detector" Distances

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Abstract

Inorganic scintillation detectors are widely used to measure of dose rate in the environment due to their high sensitivity to photon radiation. A distinctive feature when using such detectors is the need to take into account of the position of the effective energy release center. This peculiarity is actual when using measuring instruments with inorganic scintillation detectors as working standards during calibration at short "source–detector" distances in conditions of low-background shield or using a facility with protection from external gamma radiation background in the dose rate range from 0.03 to 0.3 μSv/h (μGy/h). The purpose of this work was to calculate the position of the effective energy release center of NaI(Tl) scintillation detectors and to take it into account when working at short "source–detector" distances.

An original method of determining the position of the effective energy release center when irradiating the side and end surfaces of inorganic scintillation detector with parallel gamma radiation flux and point gamma radiation sources at small "source–detector" distances using Monte Carlo methods is proposed. The results of calculations of the position of the effective energy release center of NaI(Tl) based detectors of "popular" sizes for the cases of parallel gamma radiation flux and point sources of gamma radiation at small "source–detector" distances are presented. The functional dependences of the position of the effective energy release center of NaI(Tl) based detectors on the distance to the point gamma radiation sources and the energy of gamma radiation sources are presented.

As a result of the study it was found that for scintillation NaI(Tl) detectors of medium size (for example, Ø25×40 mm or Ø40×40 mm) the point gamma radiation source located at a distance of 1 m or more, creates a radiation field which does not differ in characteristics from the radiation field created by a parallel flux of gamma radiation. It is shown that approaching the point gamma radiation source to the surface of scintillation detector leads to displacement of the position of the effective energy release center to the surface of the detector.

Keywords: effective energy release center, inorganic scintillation detector, near background radiation, Monte Carlo method.

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Расчёт положения эффективного центра энерговыделения сцинтилляционных детекторов для задач калибровки при малых расстояниях «источник–детектор»

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Неорганические сцинтилляционные детекторы широко используются для измерения мощности дозы в окружающей среде благодаря их высокой чувствительности к фотонному излучению. Отличительной особенностью при использовании таких детекторов является необходимость учёта положения эффективного центра энерговыделения. Эта особенность актуальна при использовании средств измерений с неорганическими сцинтилляционными детекторами в качестве рабочих эталонов при калибровке на малых расстояниях «источник–детектор» в условиях низкофоновой камеры или установки с защитой от внешнего фона гамма-излучения в диапазоне мощностей доз от 0,03 до 0,3 мкЗв/ч (мкГр/ч). Целью данной работы являлся расчёт положения эффективного центра энерговыделения сцинтилляционных NaI(Tl) детекторов и его учёт при работе на малых расстояниях «источник–детектор».

Предложен оригинальный метод определения положения эффективного центра энерговыделения при облучении боковых и торцевых поверхностей неорганического сцинтилляционного детектора параллельным потоком гамма-излучения и точечными источниками гамма-излучения на малых расстояниях «источник–детектор» с использованием методов Монте-Карло. Представлены результаты расчёта положения эффективного центра энерговыделения детекторов на основе NaI(Tl) «популярных» размеров для случаев параллельного потока гамма-излучения и точечных источников гамма-излучения на малых расстояниях «источник–детектор». Приведены функциональные зависимости положения эффективного центра энерговыделения детекторов на основе NaI(Tl) кристаллов от расстояния до точечных источников гамма-излучения и энергии источников гамма-излучения.

В результате исследования установлено, что для сцинтилляционных NaI(Tl) детекторов небольших размеров (например, Ø25×40 мм или Ø40×40 мм) точечный источник гамма-излучения, находящийся на расстоянии 1 м и более, создаёт поле излучения, не отличающееся по характеристикам от поля излучения, которое создаёт параллельный поток гамма-излучения. Показано, что приближение точечного источника гамма-излучения к поверхности сцинтилляционного детектора приводит к смещению положения эффективного центра энерговыделения к поверхности детектора.

Ключевые слова: эффективный центр энерговыделения, неорганический сцинтилляционный детектор, околофоновое гамма-излучение, метод Монте-Карло.

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Introduction

An important task in radiation monitoring is the correct measurement of dose rate at the level of natural radiation background. For this purpose it is necessary to use measuring instruments with high sensitivity, low level of own background and high temporal stability. In this case, an important problem to be solved during calibration of dosimetric measuring instruments is to provide the lower limit of measuring range at the level of the background radiation of the environment. According to the recommendations of the International Electrotechnical Commission (IEC) [1–3] and technical requirements for ARMS of nuclear power plants[1], the lower limit of the measurement range of dose rate of radiation protection instruments when controlling the radiation situation in the environment should be at 0.03 μSv/h (μGy/h). The use of highly sensitive dosimetry devices based on scintillation spectrometric detection units becomes possible to measure dose rates below 0.1 μSv/h (μGy/h), and the ability of such devices to measure dose rates below 0.1 μSv/h (μGy/h) should be confirmed by special studies[2]. In addition, in the calibration scheme[3] requirements to working standards having protection from external gamma radiation background for metrological support of photon radiation fields of near background levels for dose rate (0.03–0.3 μGy/h (μSv/h)) are given. This dose rate range is easily achievable for inorganic scintillation detector units with NaI(Tl) crystals, even of medium size.

A significant contribution to the dose rate for measurements below 0.3 μSv/h (μGy/h) is the natural background radiation. In this case the calibration or verification of measuring instruments under normal laboratory conditions is practically impossible, because the radiation background in the laboratory can change during the measurements due to many factors, which can significantly affect the measurement results of gamma radiation fields of the near background level on the dose rate.

To create the reference near background photon radiation fields it is necessary metrologically to provide the dose rate values at the level of 0.03–0.3 μSv/h (μGy/h), i. e. to creation of reference near-background photon radiation fields with minimal influence of natural radiation background, e. g. in a low-background shield or on a facility with protection from external gamma radiation background by a reference measuring instruments. For this purpose it is necessary to use highly sensitive measuring instruments and ensure their calibration in similar reference photon radiation fields with dose rate of 0.03–0.3 μSv/h (μGy/h).

Dose rate calibrations and measurements in near-background photon radiation fields in low-background laboratories are limited by the location of such laboratories (e. g. UDO II in Germany or IFIN-HH in Romania) [4–5], which implies certain difficulties for periodic calibrations and verifications of measuring instruments. To solve this problem it is optimal to use low-background shield and facility which are smaller in physical size than installations in low-background laboratories. The limitation of the size of low-background shield and facility is related to the compromise between the cost of protective materials for such a unit and sufficient source-detector distance to provide the necessary characteristics of the radiation field. The use of a low-background shield or facility with a small range of distances for calibration of measuring instruments also requires ensuring the accuracy of positioning of the measuring instrument relative to the radiation source. This is especially relevant when using measuring instruments based on inorganic scintillation detectors as reference instruments for transmitting dose rate units. Since we apply the method of substitution when calibrating measuring instruments, it is necessary to ensure with good accuracy the same distance from the radiation source to the center of the detectors of measuring instruments.

The purpose of this work was to calculate the position of centers of inorganic scintillation detectors from the energy of radiation and to take it into account when working at short "source-

[1]STO 1.1.1.01.001.0875–2017. Automated system for monitoring the radiation environment of a nuclear power plant. Technical requirements. – Introduced 10.12.2018. – Rosenergoatom Concern OJSC, 2018.

[2]MU 2.6.5.008–2016. Nuclear power and industry. Control of radiation situation. General requirements. Methodical instructions. – Introduced 22.04.16; with amendments 05.05.17. – M., 2016. – P. 82.

[3]State calibration scheme for measuring instruments of kerma in the air, kerma power in the air, exposure dose, exposure dose rate, ambient, directed and individual dose equivalents, powers of ambient, directed and individual dose equivalents and energy flow of X–ray and gamma radiation. – Introduced on 31.12.20 by the Federal Agency for Technical Regulation and Metrology. – Rosstandart, Moscow, 2020. – P. 13.

detector" distances within the project on creation of a facility with protection from external gamma radiation background for calibration and verification of dosimetric measuring instruments.

Calibration method

Calibration of an instrument for environmental radiation monitoring is accomplished by placing its detectors in a radiation field with a known dose rate and comparing the instrument readings to this dose rate. The dose rate can be determined in two ways: either by using an instrument whose calibration is traceable to national standards or by using a radioactive source whose activity is known and using the kerma constant to calculate the kerma rate in the air in the point of measurement, taking into account attenuation in air and the influence of scattered radiation. The second approach causes some difficulties because of the necessity to take into account the attenuation of radiation in the air and the influence of scattered radiation, therefore at the calculated distances dose rates are usually measured with a reference measuring instrument, which are taken as values of dose rate in the point of measurement. After that the calibration or dose characteristic of dosimetric measuring instruments at these points is carried out by the method of substitution.

The advantage of the first approach is that both measurements are made under the same conditions, so the method of substitution eliminates systematic measurement errors caused by errors of the reference measuring instrument serving for comparison of the measured quantity with the investigated or calibrated measuring instrument. In addition, the response of the instrument being calibrated and the reference instrument to scattered radiation can be corrected. To do this, dose rate measurements with and without an individually shaped lead shield for the reference and calibrated instruments should be performed. Using this approach, the distance from the source to the detector must be large enough to provide an almost parallel and homogeneous gamma radiation flux over the entire volume of the detector. This requirement is readily achievable on dosimetric facilities in laboratories.

But the main disadvantage of making measurements in a low–background shield or on a facility with protection from external gamma radiation background lies in the limited space of the shield or facility itself, which imposes restrictions on the application of this approach. In addition, the short distances between the radiation source and the measuring instrument in a low–background shield or on a facility with protection from external gamma radiation background require accurate positioning of the measuring instrument relative to the radiation source, taking into account the effective or geometric center of the detector.

If we consider measuring instruments based on Geiger-Mueller counters, semiconductor detectors or organic scintillators, it is sufficient to use the geometric center of the detector for positioning. In inorganic scintillation detectors, the position of the energy release center depends on the energy of the radiation, so it is necessary to speak of the effective energy release center as the averaged center of energy loss of charged secondary particles as they pass through the scintillator substance. Therefore, the effective center corresponds to a conditional point of the detector's sensitive volume, in relation to which the absolute efficiency of registration when moving the radiation source changes according to the law of inverse squares [6].

To determine the metrological characteristics of the gamma radiation field of near-background levels at the facility having protection from external gamma radiation background, using point gamma radiation sources and reference measuring instruments based on inorganic scintillation detectors, it is necessary to evaluate the influence of the geometry of irradiation of the measuring instrument on the position of the effective energy release center in the detector.

The problem of the effective energy release center

Failure to take into account the distance from the surface of the detection unit to the position of the effective center may affect the accuracy of determining the distance between the radiation source and the detector and, consequently, the determination of the dose rate, especially when measurements are made at short distances from the radiation source, as in the case we are considering in the conditions of a low-background shield or on a facility with protection from external gamma radiation background.

In case of point sources the dose rate changes proportionally to the inverse square of the distance R. Displacement of the dosimeter reference point in the beam by ΔR in the beam direction leads to a relative error in the calibration coefficient of $2\Delta R/R$ at distance R [7].

In [8–9] you can find several formulas to calculate the effective energy release center of scintillation detectors:

$$d(E)=\frac{1}{\mu(E)}\ln\frac{1+e^{-\mu(E)l}}{2};\ [8] \quad (1)$$

$$d(E)=\frac{1}{\mu(E)}\ln\frac{\mu(E)l}{1-e^{-\mu(E)l}},\ [9] \quad (2)$$

where $\mu(E)$ is the linear attenuation coefficient of gamma radiation with energy E for the NaI(Tl) detector, cm^{-1}; l is the thickness of the NaI(Tl) detector, cm.

It is important to note that there are no reservations in the publications [8, 9] about the location of scintillation detector (radiation falls on the face or side surface of the detector), so, based on these formulas, we can assume that the position of effective detector center depends only on detector length and gamma radiation energy. Table 1 presents the results of calculating the position of the effective center of the detector based on NaI(Tl) using the formulas from [8, 9] and the Monte Carlo method. The SNEGMONT software package, which was developed and successfully used at ATOMTEX enterprise, was used for the calculations [10].

Table 1

Comparison of the results of calculation of the effective center of the NaI(Tl) detector Ø40×40 mm when the radiation falls on the end surface using formulas from various sources and the Monte Carlo method

Gamma radiation energy, keV	Results of calculations of the effective center of the NaI(Tl) detector Ø40×40 mm, mm		
	Monte Carlo method	according to the formula from [8]	according to the formula from [9]
20	0.09	0.07	0.09
59.5	0.32	1.92	0.30
100	1.19	5.40	1.20
165.9	4.60	11.5	4.21
391.7	14.1	17.3	12.6
661.6	16.2	18.2	14.8
1250	17.3	18.8	16.4
2614	17.9	19.1	17.3
5000	17.9	19.2	17.5
10000	18.7	19.2	19.1

As can be seen from Table 1, calculations of the position of the effective center of the NaI(Tl) Ø40×40 mm detector using the Monte Carlo method and the formula from [9] give comparable results. The calculated values of the detector effective center position using the formula from [8] in the 60 keV–3 MeV range are larger than those obtained by the Monte Carlo method and the formula from [9], while in the 60–200 keV range they are significantly overestimated (up to 600 %) relative to the values obtained by the Monte Carlo method and the formula from [9].

However, there is no information about the position of the effective center when the source is located at a short distance from the detector, because in this case, the smaller the distance between the radiation source and the detector, the more heterogeneous the dose profile.

Since point sources are used for calibration, and the distance between the radiation source and the detector in a low–background shield or on a facility with protection from external gamma radiation background is small, the dose profile is determined according to the law of squares of distance. In such a case, the location of the effective center of the detector will be significantly affected by the distance between the radiation source and the detector itself – the smaller the distance, the steeper the dose profile in the detector.

Thus, errors in determining the distance from the center of a point gamma radiation source to the effective energy release center of the detector can lead to incorrect determination of the dose rate, which in turn will lead to errors in the calibration of dosimetric measuring instruments by the method of substitution.

Results and discussion

To account for the position of the effective center of the detector depending on the detector irradiation geometry and on the distance to the radiation source, calculations were performed for NaI(Tl) based scintillation detectors of “popular” sizes using the Monte Carlo method. The distances between the radiation source and detector were chosen based on the operating distances that could be achieved in a low–background shield or on a facility with protection from external gamma radiation background. In addition, we compared the position of the effective energy release center for scintillation detectors based on NaI(Tl) “popular”

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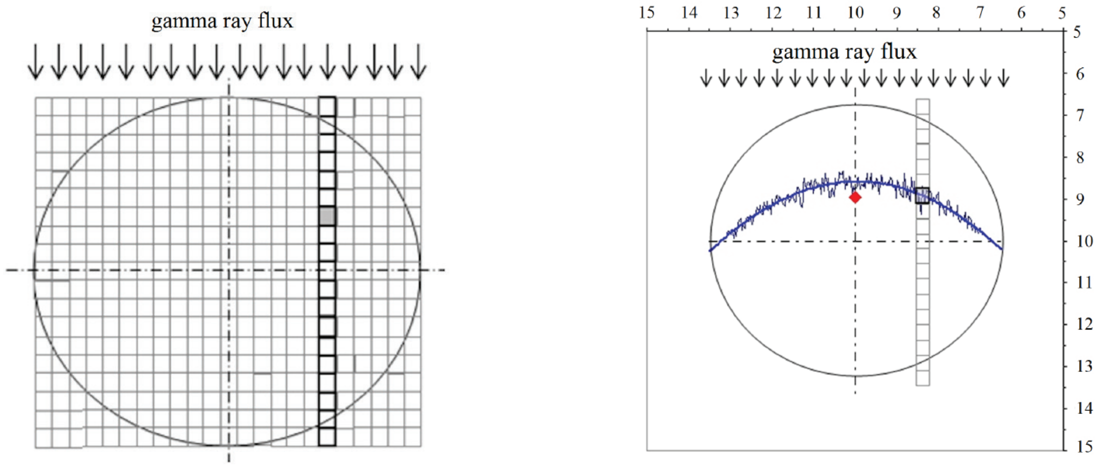
sizes for the case with a point source and a parallel flux of gamma radiation.

To solve this problem, an original method was applied, which we will consider using the examples when the uniform gamma radiation flux is normal to the side surface of the detector and when a point source of radiation is applied to the end face of a cylindrical detector.

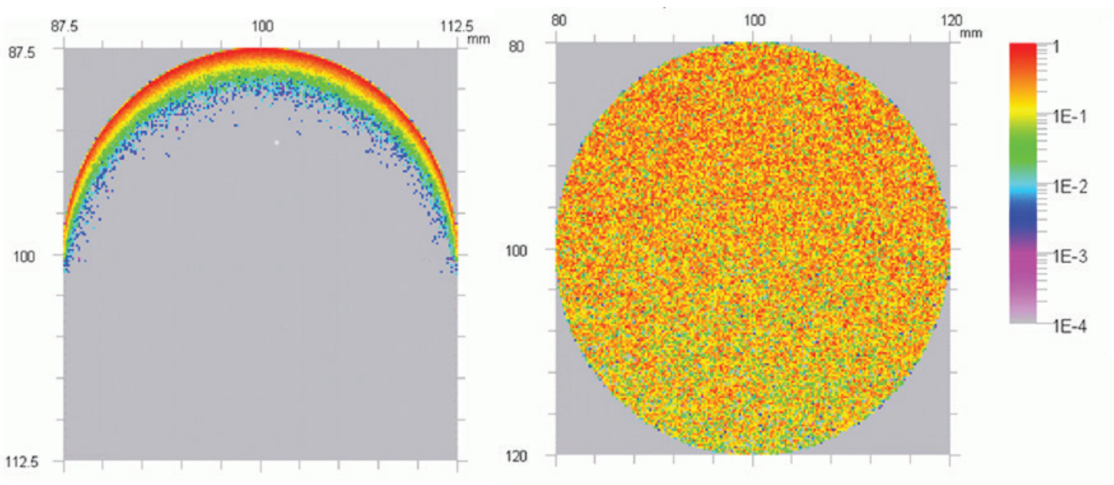
When calculating the position of the effective energy release center for a uniform gamma ray flux, we imposed on the cylinder a virtual grid consisting of tightly spaced cells. The virtual grid itself as a whole is a parallelepiped with a height equal to the height *H* of the cylindrical detector. The cross section of this parallelepiped is a square with a side equal to the diameter of the detector *D*. This parallelepiped is sliced along the height into narrow extended cells. The length of each cell is equal to the height of the cylinder *H*. The cross section is square with side *D*/*N*, where *N* is the number of cells.

In the process of modeling the impact of gamma ray flux on the detector, we accumulate the energy release in each cell separately. As a result we obtain for each cell some value averaged over its volume. I. e. at the output we have a two–dimensional table of energy release. And then we find the position of the effective center for this detector by a certain technique (Figures 1 and 2).



a *b*

Figure 1 – Visual representation of the effective center calculation: the process of overlaying the grid on the detector side projection (*a*) and energy accumulation in each grid cell (*b*)



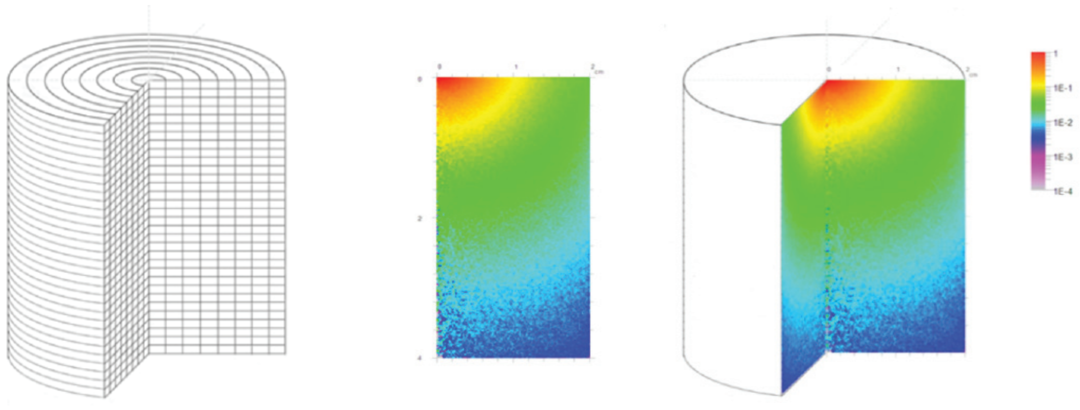
a *b*

Figure 2 – Energy distribution of gamma radiation flux with energy 59.5 keV (*a*) in NaI(Tl) scintillation detector Ø25×40 mm and 662 keV (*b*) in NaI(Tl) scintillation detector Ø40×40 mm. In the palette on the right, one represents the maximum, and the other numbers represent its fractions

In the case of a point source, it was above the detector on its symmetry axis, so the problem was solved in the axial symmetry approximation.

The elementary cell of the virtual grid of accumulation of allocated energy was a ring with a rectangular cross section. The figure is simplified, because in reality the partitions are not 8 in radius and not 32 in height, but an order of magnitude more. For example, for NaI(Tl) Ø40×40 mm, 662 keV point source on the surface of the entrance window (i. e., 50 mm from the crystal), 50 radial partitions and 100 in height were made. Thus, 5.000 ring-shaped elementary cells were set (although the cells "strung" on the symmetry axis are not rings, but disks, conditionally they can be called rings with zero internal radius).

At the end of the simulation, the energy accumulated in each ring was divided by its volume (or mass, depending on the desired units). The result was a two-dimensional distribution of the specific energy allocated in the detector crystal. The grid of partitioning the cylindrical crystal into energy release cells in the simulation had the form shown in Figure 3.



a *b* *c*

Figure 3 – Simplified example of dividing the crystal volume into 8 elementary rings by radius and 32 layers by height (*a*); example of a two–dimensional energy release pattern (*b*); example of a three–dimensional energy release pattern (*c*). In the palette on the right, one represents the maximum, and the other numbers represent its fractions

Next, the extracted energy was summed over the radial cells for each layer. As a result, a one–dimensional depth distribution of the extracted energy was obtained. The effective center was found provided that the areas under the curve to the right and left of it were equal.

Tables 2, 3 present the results of Monte Carlo calculations of the position of the effective energy release center of NaI(Tl) Ø40×40 mm and NaI(Tl) Ø25×40 mm detectors for a point gamma radiation source at different distances from the detector and for a parallel flux of gamma radiation in the case when the radiation falls on the end and on the side surface of the detector, respectively.

As can be seen from tables 2, 3: as the distance between the detector and the point gamma radiation source increases, the effective center shifts deep into the detector and for a distance of 1 meter practically coincides with the case when the radiation field is created by a parallel flux of gamma radiation. This suggests that at distances of more than 1 meter between the source and the detector, the dose profile in the detector is similar to the dose profile when the radiation falls on the detector as a parallel flux. So, for distances less than 1 m between the source and the detector, the displacement of the position of the effective energy release center must be taken into account.

Consider the NaI(Tl) detector Ø40×40 mm. For the 12.5 cm "point source–detector" distance, the displacement of the position of the effective energy release center of the detector in the example of the source with the radionuclide ^{137}Cs is 2.2 mm for the end-exposed geometry and 2.3 mm for the side-exposed geometry relative to the parallel gamma radiation flux. This offset will lead to relative errors in dose rate determination of 3.5 % and 3.7 % for the detector end and side irradiation geometries, respectively. When using a source with radionuclide ^{241}Am, the displacement of the position of the effective energy release center for the end geometry at any distance according to our calculations is not observed, and in the lateral irradiation geometry the displacement will be 1.04 mm at 12.5 cm "point source–detector" relative to the parallel flux of gamma radiation.

Table 2

Results of calculating the position of the effective energy release of the NaI(Tl) Ø40×40 mm detector for a point gamma radiation source at different distances from the end and side surfaces of the detector, for a parallel flux of gamma radiation

Distance from source to end surface, mm	Distance from the end surface of NaI(Tl) scintillator to the effective center, mm					
	59.5 keV	100 keV	200 keV	392 keV	662 keV	2.614 keV
50	0.29	1.10	5.13	10.4	12.1	13.0
125	0.32	1.15	5.90	12.2	14.1	15.5
250	0.32	1.19	6.30	13.0	15.1	16.6
500	0.32	1.21	6.51	13.5	15.7	17.3
1000	0.32	1.22	6.61	13.8	15.9	17.6
Parallel flux	0.32	1.23	6.65	14.1	16.3	18.2
Distance from the source to the side surface, mm	Distance from side surface of NaI(Tl) scintillator to the effective center, mm					
	59.5 keV	100 keV	200 keV	392 keV	662 keV	2.614 keV
50	1.95	2.80	6.75	11.12	12.4	13.1
125	3.25	4.16	8.56	13.7	15.2	16.2
250	3.76	4.72	9.29	14.7	16.2	17.2
500	4.02	4.99	9.64	15.1	16.7	17.8
1000	4.17	5.14	9.83	15.4	17.0	18.1
Parallel flux	4.29	5.19	9.97	15.7	17.5	19.9

Table 3

Results of calculating the position of the effective energy release of the NaI(Tl) detector Ø25×40 mm for a point gamma radiation source at different distances from the end and side surfaces of the detector, for a parallel flux of gamma radiation

Distance from source to end surface, mm	Distance from the end surface of NaI(Tl) scintillator to the effective center, mm					
	59.5 keV	100 keV	200 keV	392 keV	662 keV	2.614 keV
50	0.28	1.10	5.12	10.1	11.6	12.8
125	0.29	1.19	6.00	11.9	13.7	15.3
250	0.30	1.23	6.34	12.8	14.7	16.4
500	0.30	1.25	6.52	13.2	15.3	17.1
1000	0.30	1.26	6.63	13.5	15.6	17.5
Parallel flux	0.30	1.27	6.67	13.6	15.8	18.1
Distance from the source to the side surface, mm	Distance from side surface of NaI(Tl) scintillator to the effective center, mm					
	59.5 keV	100 keV	200 keV	392 keV	662 keV	2.614 keV
50	1.77	2.61	6.08	8.78	9.30	9.57
125	2.34	3.23	6.99	9.86	10.5	10.8
250	2.55	3.44	7.34	10.3	10.9	11.3
500	2.66	3.56	7.52	10.5	11.1	11.5
1000	2.71	3.62	7.60	10.6	11.2	11.6
Parallel flux	2.80	3.70	7.80	10.7	11.4	12.0

In this case, the relative error in determining the dose rate for the lateral geometry will be 1.7 %. Obviously, when the distance "point source–detector" increases, the relative error in measuring the dose rate will decrease. In addition, it should be noted that using the geometric center of the detector instead of the effective energy release center of the detector, will lead to an even larger relative error in determining the dose rate.

When making measurements or calibrations under conditions of small distances between the point radiation source and scintillation inorganic detector of NaI(Tl) type for working distance "source–detector" from 10 to 50 cm it is necessary to calculate the position of effective energy release center of during calibration of measuring instruments on dose rate taking into account the distance between gamma radiation source and detector. This is relevant when working on calibration under conditions of the facility that has protection from external gamma-radiation background, using point gamma-radiation sources. For working "source-detector" distances greater than 50 cm, it is possible to use calculations of the position of the effective detector energy release center for parallel uniform gamma radiation flux without taking into account the influence of the distance between the radiation source and the detector. In this case, the relative error in determining the dose rate will not exceed 0.3 %.

Since the issue of taking into account the displacement of position of the effective energy release center when working at short distances using point gamma radiation sources has been resolved, it was decided to find functional dependences to determine the position of the effective center of energy release for calibration in conditions of low-background shield or at a facility with protection from external gamma radiation background when using sources with radionuclides ^{241}Am and ^{137}Cs. The choice of these sources is justified by their application during calibration and verification of measuring instruments, including in accordance with the verification scheme for facilities with protection against external gamma radiation background. The range from 10 to 100 cm was chosen as the working distance "source–detector" based on practical considerations.

Table 4 presents the calculated functional dependences of the position of the effective energy release center for two types of NaI(Tl) detector sizes Ø40×40 mm and Ø25×40 mm as a function of the distance from the point source of radiation to the detector.

Table 4

Functional dependences of the position of the effective energy release center depending on the distance to the point radiation source in the range of operating distances from 10 to 100 cm

Type of detector size	Gamma radiation source	Geometry of detector irradiation	Function $f(x)$, mm
Ø25×40 mm	^{241}Am	End	$8.387\times10^{-5}\cdot x-6.056\times10^{-8}\cdot x^2+0.277$
		Side	$1.409\times10^{-3}\cdot x-9.086\times10^{-7}\cdot x^2+2.202$
	^{137}Cs	End	$6.819\times10^{-3}\cdot x-4.301\times10^{-6}\cdot x^2+13.074$
		Side	$2.718\times10^{-3}\cdot x-1.734\times10^{-6}\cdot x^2+10.209$
Ø40×40 mm	^{241}Am	End	$9.527\times10^{-5}\cdot x-7.084\times10^{-8}\cdot x^2+0.295$
		Side	$3.377\times10^{-3}\cdot x-2.15\times10^{-6}\cdot x^2+2.932$
	^{137}Cs	End	$6.706\times10^{-3}\cdot x-4.249\times10^{-6}\cdot x^2+13.461$
		Side	$6.745\times10^{-3}\cdot x-4.334\times10^{-6}\cdot x^2+14.542$

The above functional dependences allow us to calculate the distance of the detector surface to the effective center, taking into account the detector's packing and reflector. Detectors with MgO reflectors with a density of 0.6 g/cm^2 and aluminum packaging with a thickness of 1.5 mm were used in the calculations. For detectors within detector units, the distance from the surface of the detector unit to the surface of the detector must also be taken into account.

Conclusion

An original method of determining the position of the effective energy release center of scintillation detector when irradiated by a point source of radiation on the side and end surface of the crystal using Monte Carlo methods is proposed. Calculations are made and functional dependences of the position of the effective energy release center of the NaI(Tl) scintillation detector of "popular" sizes are obtained.

The study confirmed that for inorganic scintillation detectors of medium sizes (e. g., Ø25×40 mm or Ø40×40 mm) the point source of gamma radiation, located at a distance of 1 m or more, produces a radiation field, which does not differ in characteristics from the field of radiation produced by parallel flux of gamma radiation.

It is shown that approaching the point source of gamma radiation to the surface of inorganic scintillation detector leads to displacement of the effective energy release center to the surface of the detector. This is most likely due to large photon dispersion due to close location of the point gamma radiation source to the detector surface, as a result most of the photons after one or more interactions leave the detector working volume, and it is also related to the dose profile according to the inverse law of distance squares.

Based on the calculated data obtained, the functional dependences of the position of the effective energy release center of NaI(Tl) crystal-based detector units on the distance to the point gamma radiation sources and the energy of gamma radiation sources for calibration problems in conditions of small "source–detector" distances were constructed. For example, under conditions of calibrating the dosimeter on a low-background shield or on a facility with protection from external gamma radiation background.

The results of the study will also be relevant for detectors of larger sizes, for example, Ø63×63 mm or larger. For such cases, the displacement of the position of the detector's effective energy release center relative to the parallel gamma radiation flux will be larger than for the detectors given in the article. Accordingly, the relative error in determining the dose rate from point sources at small source–detector distances for such detectors will depend on the linear dimensions of the detector.

The obtained data and functional dependences of the position of the effective energy release center of scintillation detectors are planned to be used on the facility with protection against external gamma radiation background for calibration and verification of dosimetric measuring instruments at the "ATOMTEX" enterprise.

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