COMPUTATION OF RESPONSE FUNCTION OF MULTI-DETECTOR DEVICE FOR GAMMA RADIATION ANGULAR DISTRIBUTION MEASURING

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Simulation model, which represents properly measurement of angular distribution of γ-radiation with the help of a device ShD-1, has been developed. Comparison of response function computations with calibrating measurement results is presented.

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1. INTRODUCTION

External gamma radiation is one of the most important factors of deleterious effect to a staff. It limits appreciably a possibility for operations on radiation-dangerous objects be carried out safely and in elimination of the consequences of radiation accidents, for instance on "Shelter" object of ChNPP. For this reason a staff shielding is one of the most principal factors of radiation safety ensuring.

It was shown [1] that in "Shelter" an optimal shielding could be created only with the help of data of angular distribution of gamma radiation intensity. A corresponding optimization method was suggested [2].

The method and the device – detector orb ShD-1 were developed by ISTC "Shelter" and used in exploratory designs of "Shelter" object engineering structures stabilization [5]. The results of investigations were used for shielding optimization in stabilization project elaboration. At the same time it was shown that this method could be used for other operations on "Shelter" object.

The investigations showed that it was necessary to create more precise and efficient method of experimental data processing that would take into account a distance between a radiation source and a measuring site. To solve this problem it was essential to make a mathematical model of the response function for an individual detector.

This paper presents the simulation model of ShD-1 device and its response function. The comparison of simulations and calibration measurements data on transmission factor of gamma-radiation with energy 662 keV passing through ShD-1 are carried out.

2. ShD-1 DEVICE

Principal scheme of ShD-1 device and its construction are shown on Fig. 1 and Fig. 2 respectively.

The ShD-1 device was developed and created (Fig. 2). It is multi-detector device (Fig. 1), which consists from a lead spherical body 1 with 32 collimating apertures 2, which are uniformly distributed on its surface. An opening angle of conical collimating apertures is 45°. It provides the whole space survey. There is a cylindrical deepening with capsule 3 in the top of the collimating aperture cone. This capsule contains thermoluminescent detectors TLD-500K 4.

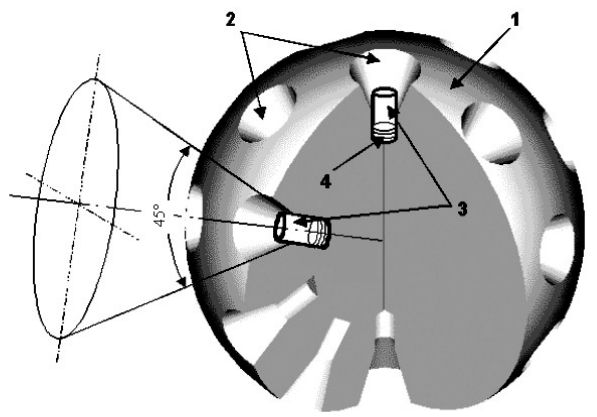

***Fig. 1**. The ShD-1 device scheme: 1 – lead body; 2 – collimating apertures; 3 – capsules with detectors; 4 – thermoluminescent radiation detectors*

For experimental data processing and angular distribution reconstructing special computing algorithms were developed. The main idea was to solve a system of equations:

$$P_i = P_{\exp i} - \sum \alpha_{ij} P_j ,$$

where P_i – sought doze rate created by gamma radiation from i direction (i = 1...32); $P_{\exp i}$ *is* doze rate which was experimentally measured by means of i TLD (this variable includes a sought radiation from the corre-

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sponding direction and a background radiation which needs to be subtracted); α_{ij} is damping factor for gamma radiation from j direction when hitting into i TLD. The damping factors were calculated and then defined more precisely during calibrating measurements; P_j is doze rate that is created by gamma radiation from j direction ($j \neq i$). Summing is over $j = 1...n$ ($j \neq i$).

In this paper the response function of multi-detector device for measuring of angular distribution of gamma radiation is a matrix of damping factors α_{ij}.

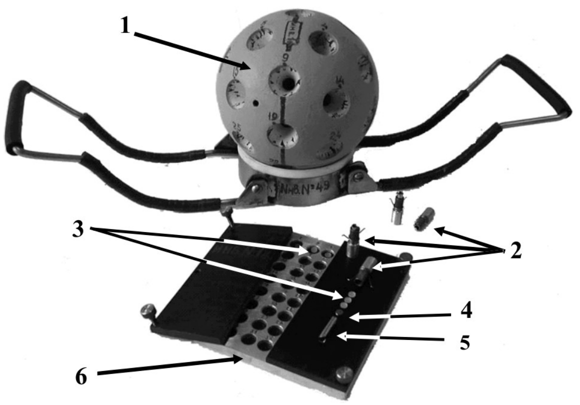

Fig. 2. *Device ShD-1: 1 – a lead body with collimating apertures; 2 – capsules with detectors; 3 – thermoluminescent detectors; 4 – cupper filters; 5 – holders; 6 – table for putting detectors into capsuls*

3. MATHEMATICAL MODEL OF ShD-1 DEVICE

For simulating of photons passing through ShD-1 GEANT 3 libraries were used. They provide definitions of conical and cylindrical surface parts, their centers and allocation in space.

In the model Cartesian coordinates XYZ with the origin in a center of the lead orb was used. Conical surface axe OZ' of the aperture №1 coincides with OZ axe. For each of conical surface there is an azimuthal angle θ formed by OZ' and OZ and horizontal angle φ formed by the axis OX and projection of OZ' onto plane XOY.

A GEANT 3 library package gives possibility to define the conical surface for the aperture №1 ($\theta = 0$, $\varphi = 0$), i.e. conical surface on OZ axe and to describe the rest 31 surfaces like a copies of the conical surface №1. Their coordinates X',Y',Z' were obtained from XYZ by transformation. Transformation matrix is described in GEANT 3 by setting azimuthals and horizontal angles for X',Y',Z' axes in XYZ coordinates. For this purpose there is a function GSROTM. In case of non- orthonormal matrix GEANT 3 corrects it assuming $Y' \perp Z'$ and then setting $Z' = X' \times Y'$. In our case as an input data we have only the azimuthal angle θ3 and horizontal angle φ3 for OZ' axe. Angles for OY', OX' axes can be received by considering OZ' axe as an OX'' axe and using the function GSROTM with θ3 and φ3 as the angles for OX'' axe. It allows to determine angles for $OY'' \perp OX''$ and for $OZ'' = OX'' \times OY''$. So, we get an intermediate coordinate system $X''Y''Z''$, from which system $X'Y'Z'$ can be obtained by cyclic rearrangement and by checking if coordinate system $X'Y'Z'$ is right-hand one.

Obtained angles are used for defining 32 copies of cylinders for detectors and cylindrical surfaces the coordinates of which coincide with coordinates $X'Y'Z'$ of conical surfaces.

In simulation we considered a point source of γ-quantum with energy 662 keV that was allocated on different distances from the orb center and parallel beam of γ- quantum with the same energy. Particles fell on the upper. The source was situated over different points of the orb therefore it was necessary to define coordinates transformation for source moving. Instead of changing the source position (or hade of the parallel beam) the position of ShD-1 was changed so that the point over which the source had set was always on OZ axe.

For instance if the source must be set on OZ' of the aperture № 11 it is necessary to turn ShD-1 so that OZ' coincides with OZ axe i.e. to make an operation which is inverse to the operation which has been applied to turn surfaces of the aperture № 1 ($\varphi = 0$, $\theta = 0$) to get the aperture № 11 surface.

For receiving the surface of aperture № 11 a transformation matrix A11 is used. This matrix is defined by the azimuthals and horizontal angles (θ1, φ1, θ2, φ2, θ 3, φ3). Values of these matrix elements can be received using GSROTM function. Further an inverse matrix is calculated and we get new transformation matrix A111 for ShD-1 turn using special part of the application that transforms the elements of the inverse matrix into angles. In that way the source will be allocated on OZ axe and on the axe of the aperture № 11 and the beam will be parallel to OZ axe and will fall to the upper hemisphere.

The application provides an output of γ- quantum energy and number of detector that has registered γ-quantum or in which γ- quantum has hit.

The aim of this model creating was to check an effect of distance from the ionizing radiation source to the ShD-1 device on possibility to find correctly a direction towards the source. For that dependencies of the response function from the distances were calculated. Also for checking correspondence between the model and real data there were calculated such cases of positional relationship that had been used during test irradiation in September 2001 in Metrology Department of Nuclear Investigations Institute (Kiev). The example of the calibrating measurements is shown on Fig. 3.

Due to spherical shape of ShD-1 device it is natural to represent allocation of detectors in spherical coordinates. Coordinates of any detector look like "latitude" and "longitude". At that the direction to one of the detectors has been defined as (0°, 0°). The direction to one of the adjacent detectors is (37,4°, 0°). Coordinates of the rest of detectors can be found relatively these two reference points.

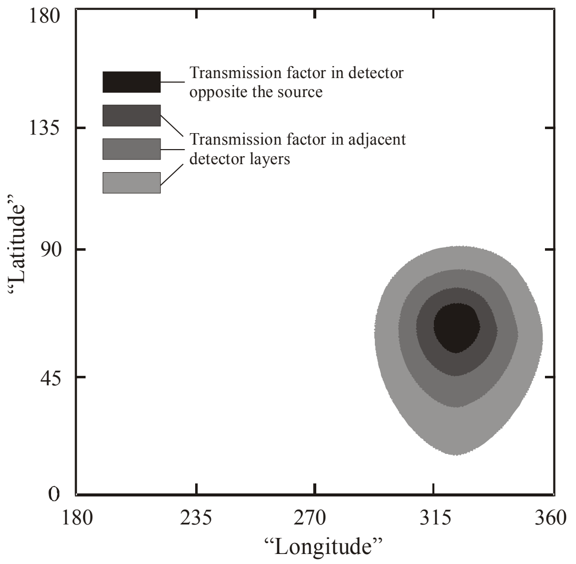

Fig 3. *The results of calibration of ShD-1 for one irradiation direction*

A look at ShD-1 device towards axe of one of the apertures gives possibility to see symmetry of apertures allocation relatively pivot turn. At that a notion of "layer", as group of apertures that are symmetrical relatively given direction is possible to introduce (Fig. 4). All apertures belonging to one layer have the same damping factor for the irradiation from given direction. Therefore it is possible to show the results of irradiation passing in direction of one of the apertures grouped in layers.

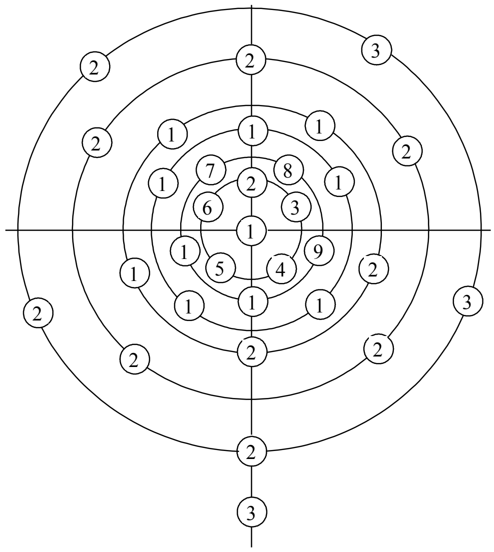

Fig. 4. *Allocation of detectors*

4. SIMULATION RESULTS

The examples of computations are given on Fig. 5-7. To be easier represented these diagrams show not the damping factor but an inverse value – transmission factor.

Fig. 5 shows comparison of experimental (the results of measurement on Fig. 3) and calculated dependences of transmission factor from the layer number. The irradiation source was situated against the aperture (63,4°, 252°) 80 cm away from center of device. As evident the mathematical model is adequate to physical one.

Fig. 6 and Fig. 7 give dependences of transmission factors for different layers from the distance "the irradiation source – the center of the device ShD-1" for two cases of the source allocation. As evident in both cases, starting from 70 cm distance the transmission factors (so and damping factors) changes slightly. Therefore for a point source, device ShD-1 must give identical results when the distance to the source is more then 70 cm.

In future it is planned to perform calculations for an arbitrary allocation of the source (not on the axe of aperture) and to consider parallel beam of γ- quantum.

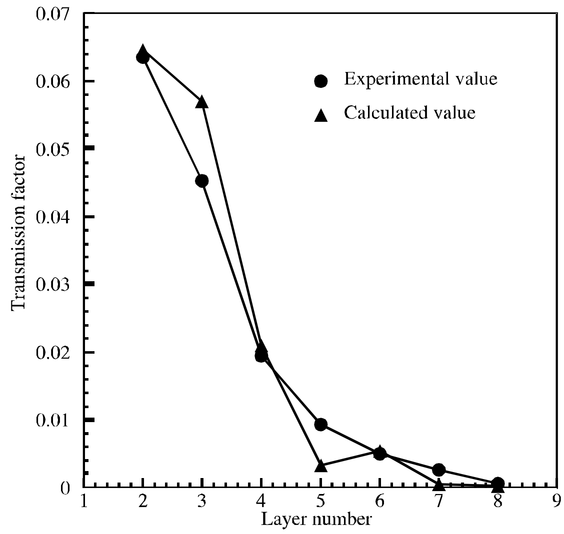

Fig. 5. *Transmission factor versus the layer number. The irradiation source was situated opposite the aperture (63,4°, 252°) 80 cm away from ShD-1 center*

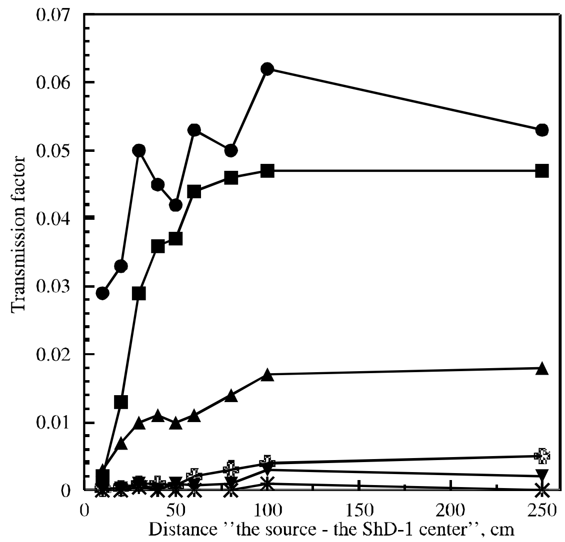

Fig. 6. *Dependence of transmission factor in different layers (● - 2nd, ■ - 3d, ▲ - 4th, ▼ - 5th, ✞ - 6th, ✱ - 7th) from the distance "the irradiation source – the center of the device ShD-1". The source was situated opposite the aperture (63,4°, 252°)*

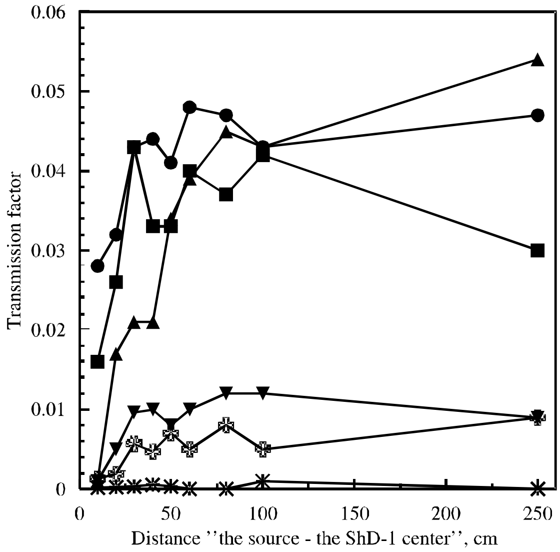

Fig. 7. *Dependence of transmission factor in different layers (● - 2nd, ■ - 3d, ▲ - 4th, ▼ - 5th, ✣ - 6th, ✱ - 7th) from the distance "the irradiation source – the center of the device ShD-1". The source was situated against the aperture (37,4°, 216°)*

5. CONCLUSIONS

The mathematical model that adequately represents angular distribution measuring by means of the device ShD-1 has developed.

The results of computations coincide sufficiently with calibrating measurements. It points out that developed model of real device allows simulating reliably real angular distribution measuring.

The results of simulation give possibility to define the response function more precisely and to raise observation accuracy.

The results show that the response function changes insignificantly at a distance more then 70 cm, therefore this function can be used for reconstructing real angular distributions of gamma radiation from distant sources independently of its remoteness. This fact proofs reliability of the data that have been received during exploratory design.

The findings points out to the possibility to modernize ShD-1 device by means of mathematical modeling. In particular, for its size optimization, for simulating of measurements in case of using different detectors, for developing a device certification method.

In future it is necessary to get the closest approach to real conditions on "Shelter" object, to simulate a real spectrum, a parallel beam (very distant source), to investigate the results sensitivity to different conditions like a device size, detector efficiency, gamma-spectrum.

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РАСЧЕТ ФУНКЦИЙ ОТКЛИКА МНОГОДЕТЕКТОРНОЙ УСТАНОВКИ ДЛЯ ИЗМЕРЕНИЯ УГЛОВЫХ РАСПРЕДЕЛЕНИЙ ГАММА-ИЗЛУЧЕНИЯ

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Разработана имитационная модель, адекватно отображающая процесс измерения угловых распределений гамма-излучения с помощью установки ШД-1. Представлено сравнение расчетов с результатами калибровочных измерений.

РОЗРАХУНОК ФУНКЦІЙ ВІДКЛИКУ БАГАТО ДЕТЕКТОРНОЇ УСТАНОВКИ ДЛЯ ВИМІРЮВАННЯ КУТОВИХ РОЗПОДІЛІВ ГАММА-ВИПРОМІНЕННЯ

В.Г. Батій, Н.О. Кочнев, В.О. Кузьменко, І.М. Прохорець, С.І. Прохорець, М.А. Хажмурадов, В.В. Єгоров

Розроблено імітаційну модель, що адекватно відтворює процес вимірювання кутових розподілів гамма-випромінювання за допомогою установки ШД-1. Надано порівняння розрахунків з результатами каліброваних вимірювань.