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MONTE CARLO SIMULATION OF γ SCATTERING FOR DENSITY VARIATION MEASUREMENT

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This paper studies the possibility of using backscattered γ radiation for checking the density fluctuations of concrete layer of newly constructed highways by means of the Monte Carlo simulation. A computer program named NUCLGAUGE has been written in Visual Basic language. It should be useful for designing a device for density variation measurement of concrete layer of newly constructed highways using backscattered γ radiation.

В работе изучается возможность использования гамма-излучения с обратным рассеянием для проверки флуктуаций плотности определенного слоя сконструированных каналов с помощью моделирования методом Монте-Карло. На языке Visual Basic написана компьютерная программа NUCLGAUGE, необходимая для моделирования прибора по измерению вариаций плотности определенного слоя сконструированного канала с использованием гамма-излучения с обратным рассеянием.

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INTRODUCTION

In Vietnam, the testing techniques for asphalt density covered on the surface of newly constructed highways are based on that founded hundreds of years ago. It involves extracting a core sample and using Archimede's principle of water displacement to measure pavement density. This test is destructive, very time-consuming and is becoming obsolete. We are now planning to build an apparatus using backscattering γ-ray technique for density testing in Vietnam. As a first stage of the project, it is necessary to study feasibility of the method by simulation. The Monte Carlo method has been used for simulation. A software has been written in Visual Basic language and is being used for designing a density gauge at our Institute of Physics.

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1. SIMULATION METHOD

Schematic representation of the geometry configuration used in simulation is shown in Fig. 1, which involves a radioactive γ source and a detector. The employed geometry involves a radioactive source with γ-ray energy usually less than 1200 keV and a detector system placed on the surface of the layer to be tested. The source separates from the detector by lead shielding. The shielding prevents the γ rays coming directly from the source to the detector. In these circumstances, the γ rays from the source pass down into the layer under test, suffer interactions with matter and are backscattered onto the detector placed at a distance d from the source. In addition, because of further interactions, the beam is continuously attenuated in both the forward and the backward passages through the layer. In general, the relevant absorption coefficient is made up of the absorption due to the photoelectric effect, the scattering due to the Compton effect and the absorption due to the pair production. However, since energy of primary γ ray is less than 1200 keV, the contribution of pair production can be neglected.

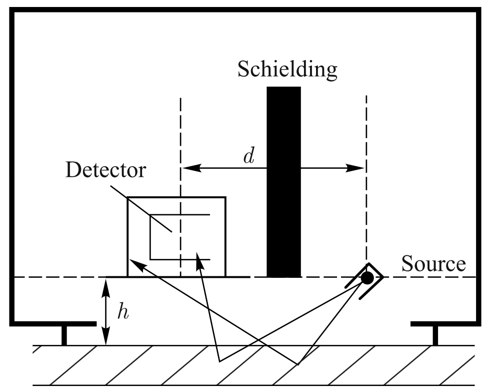

Fig. 1. Schematic representation of the geometric configuration used in the simulation

The Monte Carlo method used in our calculation is similar to the one previously described in [3]. The program NUCLGAUGE has been written in Visual Basic language. The following parameters will be needed for simulation: thickness of asphalt layer, its effective mass and charged numbers, its density in g/cm^3; thickness of concrete pavement, its effective mass and charged numbers, its density in g/cm^3; diameter of gamma source, its energies, its activity, the inclined angle to the vertical direction, distance from the source to the upper front layer of asphalt; diameter of detector, distance between the source and detector, distance to the upper front layer of asphalt, efficiency of the detector. The program allows one to simulate the intensity of backscattered γ ray as a function of several changing parameters including the thickness of asphalt layer, the density of asphalt layer, the distance between the source and detector, the declination angle relative to the vertical direction, etc. By using the program, we are able to investigate the dependence of the backscattered γ-ray intensity as a function of various parameters needed to be optimized.

2. RESULTS OF SIMULATION

The γ-ray source is assumed to be ^{137}Cs and NaI detector is used for registration of the backscattered γ rays. A typical result of the dependence of γ-ray intensity on the material densities is presented in Fig. 2, *a*. In this simulation, we assumed that the intensity of the source is 1 mCi. The diameter of the source collimator is 2 cm and the inclined angle to the vertical direction is $45°$. The diameter of NaI crystal is 6 cm with 6% of efficiency. Separation between detector and source is 5 cm and the distance from detector to the surface of

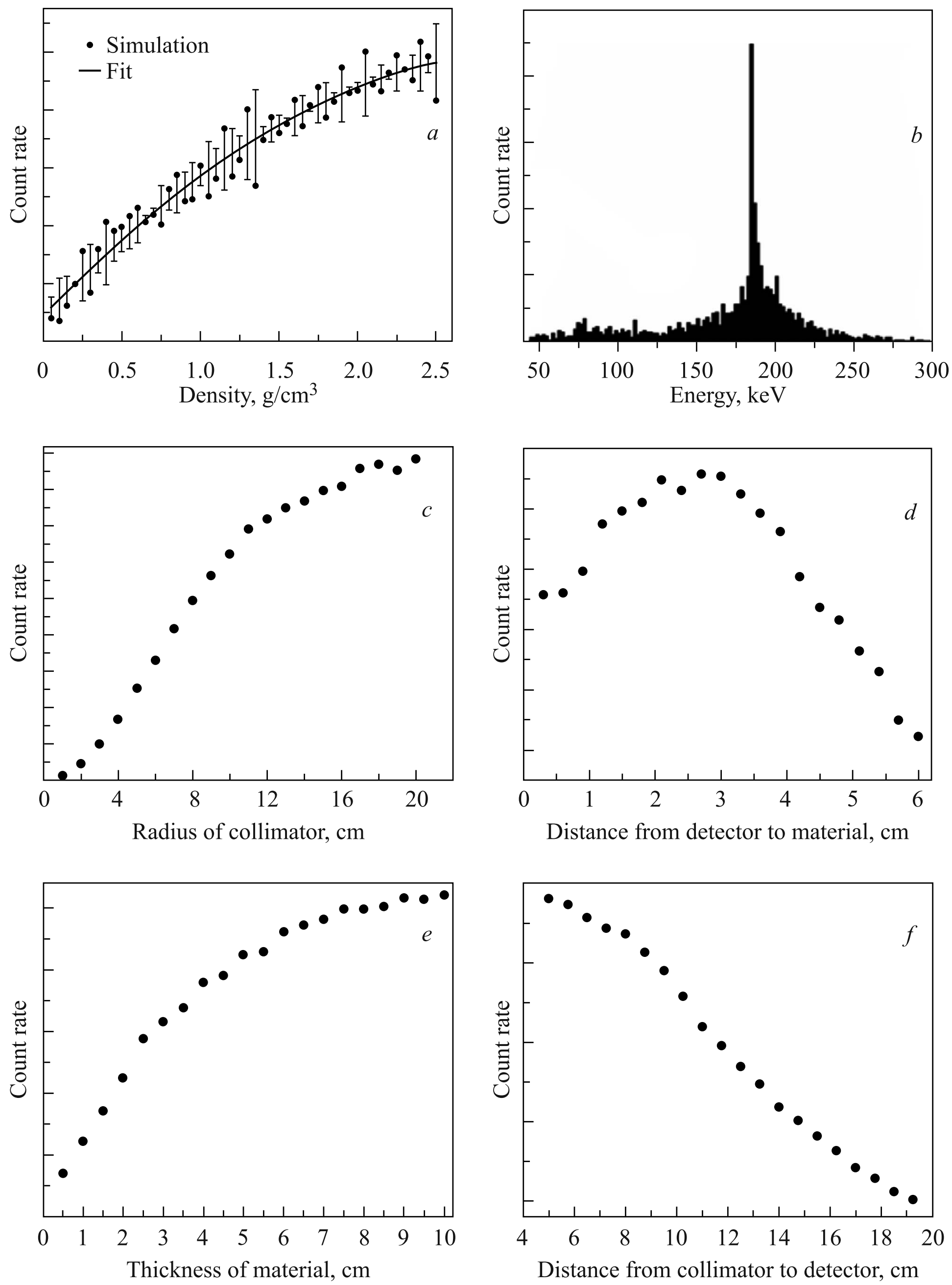

Fig. 2. Dependence of γ-ray intensity on: *a*) density of material; *b*) energy of backscattered γ ray; *c*) radius of source collimator; *d*) source surface of layer distance; *e*) thickness of layer; *f*) detector-surface layer distance

material layer is 5 cm. The investigated material is soil with an effective charge number of 10 and effective mass number of 21. It is clearly seen from Fig. 2 that the backscattered γ-ray intensity linearly depends on the material density up to 2 g/cm^3. Therefore, it is possible to measure the variation of material density by measuring the backscattered γ rays. The energy distribution of the backscattered γ rays is presented in Fig. 2, *b*. Most of the γ rays have an energy around 175 keV and are in agreement with the Klein–Nishina formula. From the figure, we can easily choose an optimal energy window in order to eliminate the background γ rays coming from other sources. The dependence of detected γ-ray intensity on radius of source collimator is shown in Fig. 2, *c*. In this simulation, the size 5×5 cm of the detector is fixed. A disk source, whose radius is 80% of the inner radius of the collimator, is used. It can be seen that the wider the collimator is, the higher intensity can be obtained. From this dependence, it is easy to choose an optimal radius of the collimator. For optimizing the distance from detector to investigated material, the simulations using different distances have been done. The dimension of the detector is fixed for these simulations. The optimal diameter of the collimator is assumed to be 0.7 cm. The results are shown in Fig. 2, *d*.

The dependence of γ-ray intensity on the thickness of material layer is shown in Fig.2, *e*. It is seen that the total number of counts measured by the detector increases as the thickness increases in the range from 0 to 6 cm. Over this range, it is not able to use this technique. The dependence of γ-ray intensity on detector-source distance is shown in Fig.2, *f*. It is clearly seen from the figure that the γ-ray intensity decreases as the detector-source distance increases. However, if this distance is too short, then the background due to primary γ ray from the source will increase. Therefore, in designing we have to optimize these two parameters in order to maximize the efficiency of the apparatus.

CONCLUSIONS

We have studied the dependence of the backscattered γ-ray intensity on various parameters of the proposed apparatus for density measurement based on the Compton scattering by the Monte Carlo method. The NUCLGAUGE computer program has been developed by our group for optimization of the design.

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