The simulation of aerial γ spectrometer of CdZnTe detector

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Abstract

Monte Carlo simulation method based on MCNP5 is applied to simulate CZT detector for detecting aerial γ ray. In particular, the low energy 137Cs, 131I, 152Eu will become particularly important when the nuclear accident occurs, so the intrinsic efficiency of the 137Cs, 131I, 152Eu and other nuclide of releasing low-energy γ ray are simulated to obtain the intrinsic efficiency of nuclide characteristic γ ray, then the paper simulates the incident rate of aerial γ ray by using F5 detector of MCNP to obtain the minimum detection activity (MDA) of the CZT detector.

Keywords

Monto Carlo; Aerial γ Ray; Intrinsic Efficiency; Minimum Detection Activity (MDA).

1. Introduction

Aerial γ measurement plays an important role in finding mineral resources and the nuclear leaks. Because the traditional aerospace γ spectrometer has shortcomings of low energy resolution and large size, with the development of semiconductor materials, CZT detector is also widely used, it has a higher energy resolution and smaller size, which not only can be used as aerial γ spectrometer, but also can be used as hand-held γ spectrometer, and compared to the traditional scintillator, CZT detector for the low-energy γ-ray has a more effective detection efficiency.

For the aerial γ spectrometer, it mainly studies uranium, thorium, 40K and their radioactive decay in the soil, but the general flight distance of aerial γ spectrometer is about 100m ~ 120m, so 222Rn and its radioactive decay daughter in the air can not be ignored. In this paper, aiming at the problem that traditional scintillator detectors have low energy resolution for low energy γ-ray, Monte Carlo method is used to simulate air and soil background, and calculating detection limits for ^{137}Cs, ^{131}I, ^{152}Eu.

2. Theory Basis

2.1 Monte Carlo method

Monte Carlo is a software based on the Monte Carlo method for electronic, photon, and neutron transport invented by the Los Alamos National Laboratory in Los Angeles, and the Monte Carlo method is also called random sampling or statistical experimental methods. Monte Carlo method can truly simulate the actual physical process, so its simulation result can coincide better with the really result.

2.2 The minimum detectable activity

The minimum detectable activity indicates the minimum activity that the detector can detect, and can only be detected by the detector when the radiation source activity is greater than the minimum detectable activity, which is also a very important indicator of evaluation that the detector is good or bad.

3. MCNP Simulation

3.1 Intrinsic Efficiency of CZT detector

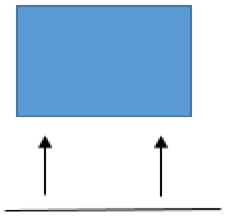

Fig.1 the simulation model for calculating intrinsic Efficiency of CZT detector

In this paper, the simulation use 15cm *15cm square surface source and 15 cm *15 cm *0.1 cm cube CZT detector, and thicknesses of the detector were respectively set to 0.3 cm, 0.5 cm, 1 cm, 1.5 cm, 2 cm. Respectively, characteristic γ-ray energy of 137Cs, 152Eu, 131I is perpendicularly directed to the detector, the space between the detector and the surface source is set to a vacuum. In other words, there is no scattering between the detector and the surface source.

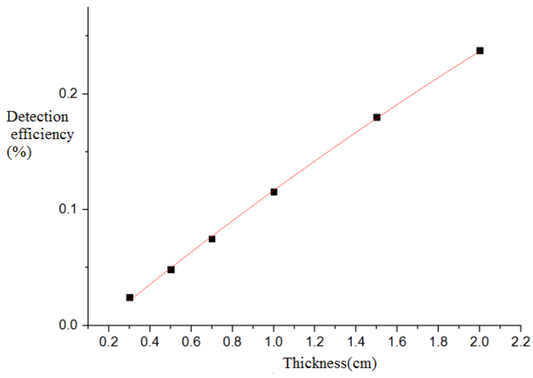

Fig.2 Simulation curve of ^{137}Cs

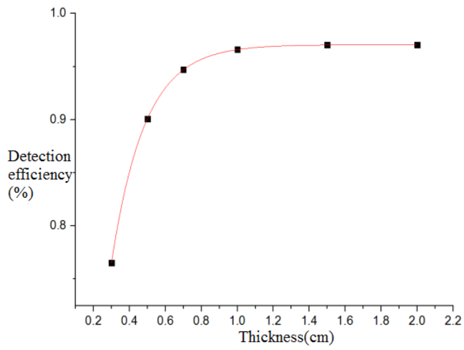

Fig.3 Simulation curve of ^{152}Eu

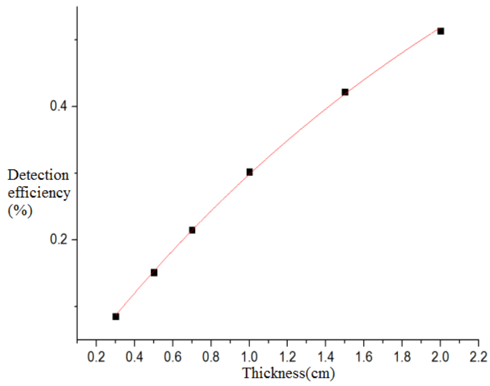

Fig.4 Simulation curve of ^{131}I

3.2 background model

Because the range of aerial γ detection is very large, in the simulation we use a limited source to approximate the infinite source, and the distance between the detector and the ground-to-air interface is calculated by the line attenuation coefficient. The calculated equation is as follows:

$$I_0 = \mathrm{I}e^{-uE} \tag{1}$$

$$\mathrm{I} = 0.001 I_0 \tag{2}$$

Where μ is the line attenuation coefficient; E = 1.33 Mev and it can determine the distance from the detector to the ground-to-air interface.

According to the equation (2), the distance can be derived thatR = 971m. So we take R = 1000 to simulate. As shown below that

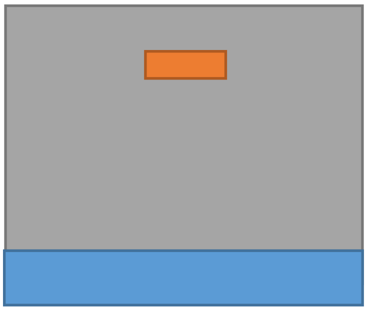

Fig.5 Simulated background model by MCNP

3.3 The minimum detection activity (MDA) of the CZT detector

The MDA is an important index of measuring the detector system, and only when the nuclide activity is greater than the MDA, the nuclide can be detected possibility by the detector.

$$\mathrm{MDA} = \frac{1}{\eta} \times 3 \times \sqrt{\frac{B}{t}} \tag{3}$$

Where η is the sensitivity of the detector; B is the net peak area of the background; t is the detection time of detector and is generally 1 s in the aerial γ detection

Based on the principle of equivalent thickness, and considering factors of MCNP particle sampling efficiency, so F5 detector count card is used to simulate in the paper.So

$$\eta = \frac{A}{\mathrm{A} \times \mathrm{V} \times \varepsilon \times \varphi \times \Phi} \tag{4}$$

Where A represents the activity, the unit (Bq/m^3);V represents the volume, the unit m^3; ε represents the probability that nucleus decays once release γ photon; Φ represents the intrinsic efficiency of the instrument; and φ is the incident rate on the instrument.

The formulation of the background net peak rate (B) is as follows:

$$\mathrm{B} = \varepsilon \times \Phi \times \mathrm{A} \times \varphi \tag{5}$$

Where ε represents the probability that the nucleus decays once release γ photon; Φ represents the intrinsic efficiency of the instrument; A represents the activity, the unit (Bq/m^3), and φ is the incidence on the instrument.

3.4 the simulation result by MCNP and its analyse

Considering the Compton scattering of uranium, thorium and potassium in the air, which the energy spectrum is continuous and has an effect on the low energy segment count. However, it is impossible to calculate the scattering and other factors in the calculation process, we can not calculate the fluency rate of the full spectrum.so in the paper we use the MCNP simulation to calculate it. On the one hand we can simulate the energy response function of detector, the solid angle of detector and other factors, On the other hand we can simulate γ spectrum distribution in the ground and air interface.

Table 1. Detector Sensitivity

Energy/Mev	η/cps/(Bq/m3)
0.662	3104.37
0.365	1153.71
0.12178	70396.63

From table 1, the energy sensitivity of the detector in table 1 can be calculated by using the formula (4), and the general measurement time of the aerial γspectrometer is 1 second or a few seconds. Through the simulation of MCNP, the count (Table 2) of ^{137}Cs, ^{131}I, ^{152}Eu can be calculated by the formula (5), which [1] its emission probability ofγphoton is 85% , its emission probability of γ photon is 82% in the signal ^{131}I decays, its emission probability of γ photon is 0.254% in the signal ^{152}Eu decays.

Table 2. Simulated blank count by MCNP

Energy/Mev	Count
0.661	1.90E-02
0.365	1.98E-01
0.12178	8.39E+00

The detection limit of energy in Table 3 can be obtained by the calculation of Eq. (3). From Table 2, we can see that the contribution of scattering to low energy count.

Table 3. Simulated MDA by MCNP

Energy/Mev	MDA/(Bq/m3)
0.661	1283.29
0.365	1153.71
0.12178	611697.60

4. Conclusion

In this work, the Monte Carlo simulation of the aerial γ spectrometer was carried out, and the air and soil were simulated at the same time, which the MDA of ^{137}Cs, ^{131}I and ^{152}Eu was obtained, it was close to the real situation. Compared to traditional scintillator detectors, CZT detectors have a more excellent detection limit. But development of CZT detectors is not mature now, so we need to make more investment in order to produce the array detector that has the same specifications with this simulation. And because ^{152}Eu γ photon release probability is too low, only 0.254%, the ^{152}Eu of MDA is larger.

In the actual situation, the aerialγspectrometer is not only used to detectγrays of low-energy segment, and but in the event of nuclear leakage and nuclear accidents, a large amount of high-energy γrays are released, which is not involved in this simulation. In the next step, the detection limit of high-energy γrays will be simulated to suit the detection capability of the CZT detector for γ rays in different situations.

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