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Detection efficiency of a disk shaped detector with a critical detection angle for particles with a finite range emitted by a point-like source

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ABSTRACT

Detection efficiency of a circular detector for particles with a finite range, emitted from a point-like source was investigated, taking a critical detection angle into account. Particles emitted from the source lose some of their energy in the surrounding medium, before entering the detector material. Incident-energy dependence of the critical detection angle was taken into account. The part of the detector exposed to the particles impacting at angles greater than the critical angle (with respect to the detector surface), was determined. Several different cases were investigated, depending on the radius of the detector and the position of the detector with respect to the source. Detection probability expressions were derived for each of the cases. Results obtained using these expressions were compared with Monte Carlo calculations.

1. Introduction

The problem of calculating a solid angle subtended by a circular detector at a point-like source has been treated by many authors (Gardner and Verghese, 1971; Jones, 1996; Prata, 2004; Tryka, 1997; Timus et al., 2007). Other source shapes were also considered using different mathematical methods (Galiano and Rodrigues, 2006; Pagnutti and Galiano, 2008; Pommé, 2004; Pommé, 2007). Calculation of the subtended solid angle enables estimation of the geometrical efficiency of the detector. Detection of particles with a finite range in a surrounding medium was investigated in our previous article (Stajic and Nikezic, 2011) and the present work is a continuation and extension of this work. This problem might be relevant for alpha-particle detection with solid state nuclear track detectors, where the critical angle is one of the most important parameters. It was assumed that the source was monoenergetic and range straggling was neglected so that all particles emitted from the source were considered to have exactly the same range in the surrounding medium. Taking this simplification into account, one can imagine a sphere with a radius equal to the particle range and the center located at the point-like source. Particles cannot leave this sphere and only the detector part lying within the sphere is exposed to them. The problem was previously treated under the simple assumption that all particles reaching the detector were registered i.e. detector characteristics were not taken into account. However, detecting alpha-particles using a SSNT-detector depends on the angle of incidence into the detector surface. A particle that impacts the plastic material of the detector creates damages along its path. Treatment with a suitable etching solution enables formation of tracks that can be visible under an optical microscope (Nikezic and Yu, 2004). If the incident angle is smaller than a certain critical angle (with respect to the detector surface), the particle track will not be visible after etching and the particle will not be detected. This fact must be taken into account while investigating detector efficiency. For given etching conditions, the critical detection angle is considered to be the function of particle incident energy (Barillon et al., 1995; Calamosca et al., 2003; Misdaq et al., 1999). There are several different cases determined by the detector radius and the source position. These cases were analyzed separately and equations for calculating the detection probability were obtained for each of them.

2. Method

Analytical expressions for calculating the probability of hitting a circular detector with particles with a finite range, D, emitted by a point-like source positioned at an arbitrary point A were obtained in our previous work. The coordinate system was chosen in such a way that the detector surface belonged to the xOy-plane and the detector center (O') was located at the x-axis (Fig. 1). The point A' (the projection of point A to xOy-plane) was taken as the coordinate

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origin. In such a system, the coordinates of the detector center were (X_0,0,0) and the position of the source was determined by the coordinates (0, 0, Z_A). The analytical expressions for calculation of hitting probability were obtained by solving the following equation:

$$P=\frac{Z_A}{2\pi}\left[\int_0^{\varphi_{\max}}\frac{d\varphi}{\sqrt{\rho_{\min}^2+Z_A^2}}-\int_0^{\varphi_{\max}}\frac{d\varphi}{\sqrt{\rho_{\max}^2+Z_A^2}}\right] \tag{1}$$

Integration limits ($\rho_{\min}$, $\rho_{\max}$ and $\varphi_{\max}$) were determined by the size of the detector and the position of the source.

The center of sphere S (Fig. 2) is point A and its radius is equal to the particle range, D. Circle K_1 (with radius $R'=\sqrt{D^2-Z_A^2}$) is the circle of intersection of sphere S and the xOy-plane. Circle K_2 represents a detector with radius R. Intersection of circles K_1 and K_2 determines the part of the detector surface exposed to particles emitted from point A. However, not all particles hitting this part of the detector surface will be registered. They can impact the detector at different angles of incidence, β, depending on the direction of emission. Particles hitting the detector at angles smaller than the critical angle, α_C, will not be detected and the detection efficiency will be reduced.

Fig. 3 shows the point-like source that emits particles with initial energy E_0 in all directions. A particle traveling the distance d, loses some of its energy and it hits the xOy-plane at the angle β_d having the incident energy $E_d^{inc}=E^{inc}(d)$. Based on energy loss, the distance d can be defined by the following integral:

$$d=\int_{E_d^{inc}}^{E_0} S^{-1}(E)\,dE \tag{2}$$

where $S(E)$ represents the stopping power function for particles under consideration, in the medium between the source and the detector. On the other hand, according to Fig. 3, the same distance d can also be expressed as

$$d=\frac{Z_A}{\sin\beta_d} \tag{3}$$

The previous two equations could be combined in order to express the relation between the angle of incidence, β, and the

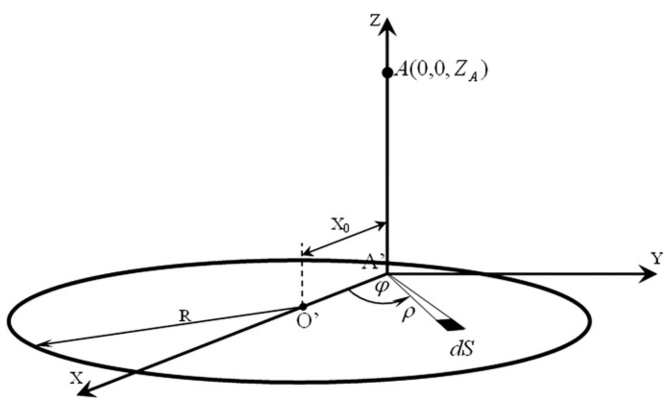

Fig. 1. Most convenient choice of coordinate system: coordinate origin is in point A' (which is a projection of point A onto the xOy plane) and the center of the detector is on the x-axis (point O').

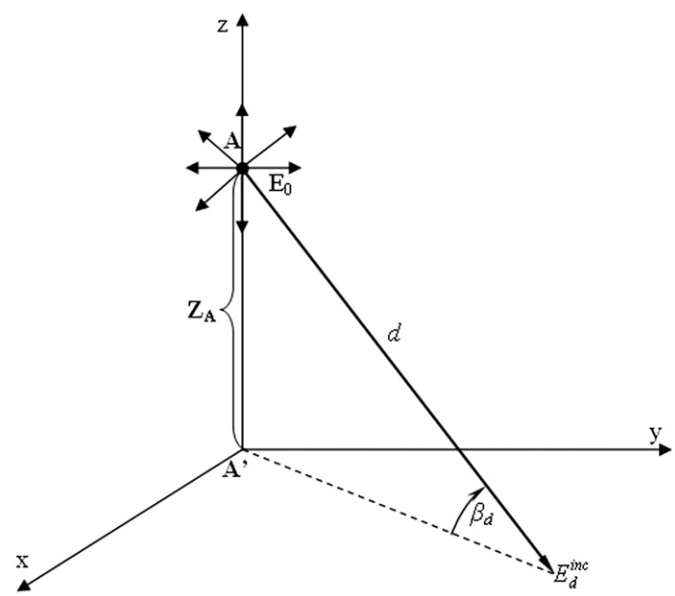

Fig. 3. The source positioned at the point A emits particles with initial energy E_0 in all directions. A particle traveling the distance d hits the xOy-plane at the angle β_d, with incident energy E_d^{inc}.

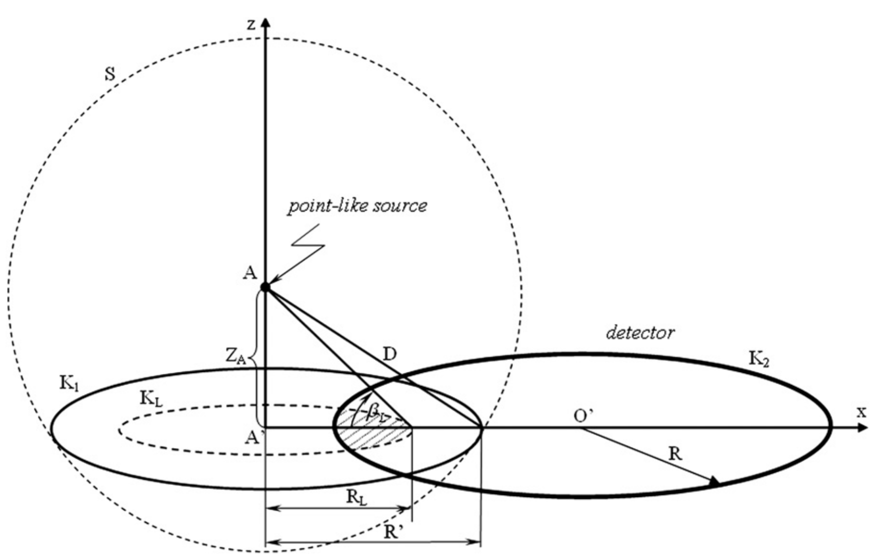

Fig. 2. Circle K_2 is obtained as the intersection of the sphere S and the xOy-plane. The circle K_L is determined by the angle β_L, defined in the text. The shaded area represents the area of integration for this specific case.