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Improved localization of a "hot spot" in the lungs for an array of four HPGe detectors—the simultaneous use of two gamma energies

O. Pelled[a,*], S. Tsroya[a], U. German[a], A. Abraham[a], Z.B. Alfassi[b]

[a] *NRC-Negev, P.O.B. 9001, Beer-Sheva 84190, Israel*
[b] *Ben-Gurion University of the Negev, Beer-Sheva 84105, Israel*

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Abstract

Significant errors in the determination of radioactivity in lungs are caused by the usual assumption of homogeneous distribution, while actually the radioactive contamination can be in the form of a "hot spot". Modern Lung Counter systems use several HPGe detectors, and the ratio of the different count rates of the detectors can be used to locate the "hot spot" and apply correction algorithms for activity calculation.

An average error of only 9.5%, can be obtained when using this information for detection of a natural uranium point source in the lungs, when the analysis is based on either the 186 or the 92 keV peaks. In the present paper it is shown that the uncertainty can be further reduced to about 3.8%, if the two gamma energy peaks (186 and 92 keV) are analyzed simultaneously for the localization of the uranium point source.

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Keywords: Point source; Lungs; Lung Counter; Location; Test of similarity; Uranium

1. Introduction

The basic assumption generally made when calibrating a Lung Counter is that the deposition of the radioactive aerosols in lungs is homogeneous, but it has been reported that the distribution is a function of the aerosol size and breathing rate, and changes with time [1]. In some cases, the contamination can be present in the form of a single "hot" particle. The count rate of an external detector will be strongly dependent on the position of the "hot particle" because of the geometrical factor (determined by the distance) and the absorption factor (which depends on the path

*Corresponding author. Tel.: +972 8 6567583; fax: +972 8 6567210.
E-mail address: opelled@bezeqint.net (O. Pelled).

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length and absorbing material). In other studies, the possible errors in activity determination due to deviations from homogeneity were evaluated to be factors of 26, 3 and 1.8 for photon energies of 17, 60 and 1000 keV, respectively [2], and factors of up to 20 for natural uranium [3].

A modern Lung Counter system is based on four HPGe detectors [4–6] and such a system is operated also at NRC-Negev. In a previous study by us [7], it was found that the ratio of the count rates of the four detectors measuring the gamma radiation emitted from the human body can be used to determine the location of a "hot spot" in the lungs with a reasonable degree of accuracy, greatly reducing the error of the activity determination. The average error in the activity determination for natural uranium was found to be about 10% when the analysis was based on either the 186 or the 92 keV peaks.

The present work presents the improvement achieved in the accuracy of localization of a natural uranium point source, by simultaneously analyzing the two gamma energy peaks of 186 and 92 keV, instead of using only one energy. It should be emphasized that these energies are due to different isotopes of uranium, and hence the isotopic composition must be known.

2. The method and experimental system

The subject of source location identification (i.e. localization) by multi-detector measurement is a special case of multi-parameter identification. This problem was discussed in detail for the identification of an unknown molecule from its electron impact mass spectrum in comparison with the mass spectra of many known molecules kept in a library of mass spectra.

Stein and Scott [8] suggested to look at the ion intensities of each mass in the mass spectrum as the components of a vector and to normalize the vectors to unit length. Each individual normalized vector can be described as a single point on a sphere with unit radius in a hyperspace of n dimensions, where n is the number of components of the vector (the number of the peaks in the mass spectrum). If two vectors are identical in all their components, they will be a perfect "match" and will lead to the same point in the hyperspace. However, because of instrumental instability and the statistical nature of the measurements, very rarely the unknown point will coincide with one of the points of the library of standards. Stein and Scott [8] suggested three criteria for a matching factor (MF). Two of the criteria are based on the inverse of various distances (suggested earlier by Rasmussen and Isenhour [9]) between the point of the unknown compound and the points of the library compounds, looking for the library compound with the minimal distance from the point of the unknown. Following a technical report of Finnigan Corporation [10], Stein and Scott [8] suggested another test for similarity of the vectors. This method is based on the calculation of the cosine of the angle between the two vectors, through the use of their scalar product:

$$\vec{x} \cdot \vec{y} = |\vec{x}| \cdot |\vec{y}| \cdot \cos\theta$$

where $|\vec{x}|$ and $|\vec{y}|$ are the length of the vectors, and θ is the angle between them. Both the scalar product and the lengths can be calculated from the components of the vectors

$$\vec{x} \cdot \vec{y} = \sum x_i \cdot y_i, \quad |\vec{x}| = \sqrt{\sum x_i^2} \quad \text{and} \quad |\vec{y}| = \sqrt{\sum y_i^2}$$

where the summation is done over all components of the two vectors. Hence

$$\cos\theta = \frac{\sum x_i \cdot y_i}{\sqrt{\sum x_i^2 \cdot \sum y_i^2}}.$$

The matching factor was defined by Stein and Scott [8] as $\mathrm{MF}_\theta = \cos^2\theta$

In a previous work by us [7], we checked various criteria for the determination of the correct location of the radioactive point source ("hot particle") in the lungs, and estimated the associated errors in the activity determination. The different criteria are summarized in Table 1.

Measurements were performed with a natural uranium point source located at 56 points in the lungs of a phantom. These data were used to build a reference matrix of 56 rows, each row consisting of four values that represent the average counts of each detector. Each average was calculated from four experimental values. Each row was