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Optimisation of systems to locate discrete gamma-ray sources within a large search area

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Abstract

Most systems used to locate discrete gamma-ray sources involve systematically passing a detector over the search area while seeking a significant increase in the observed count-rate. This paper discusses the ways in which such systems may be designed to maximise the probability of locating a source. It is shown that optimised systems use a collimated, energy-discriminating detector and overlapping counting intervals determined by the scanning geometry and speed.

Keywords: Hot particles; Particle detection; Radioactive particle; Radioactive contamination; Orphan source; Contraband materials; Environmental monitoring

1. Introduction

Over the past 20 years, various organisations have developed systems to locate discrete gamma-ray sources within large search areas (Pradeepkumar et al., 2004; Smolander and Toivonen, 2004; SEPA, 2005). Some of these systems are used to locate 'hot' particles; others are used to locate orphan sources; and some systems are being developed to locate contraband materials. The Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) built such

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a system (Long et al., 2004) to locate radioactive particles at the former nuclear test site at Maralinga in South Australia (MARTAC, 2003; Cooper et al., 1994).

Most of these systems systematically pass a detector over the search area while observing the count-rate. The observed count-rate is due to both the proximity of a discrete source and the ubiquitous presence of radioactive materials. The presence of a discrete source is indicated by a significant increase in the observed count-rate. The random nature of radioactive decay may result in a minimal increase in the observed count-rate due to the presence of a discrete source. Conversely, an observed increase in count-rate may be due to a statistical fluctuation in the background rate. Therefore, it is possible for such systems to fail to detect the radiation source (a false-negative event) and they may also indicate the presence of a source where none exists (a false-positive event).

Scientific consideration of the basic methodology enables one to choose a detector and a counting method that maximises the significance of the signal from the source. Maximising the significance of the source signal will, in turn, minimise the probability of a false-negative event, increase the sensitivity to low-activity sources and minimise the false-positive rate.

2. Detector optimisation

2.1. Detector selection

The signal from the chosen radiation detector need not contain any information about the energy deposited in the detector, such as in the case of Geiger–Müller tubes or scintillators attached to simple counters. These detectors have the advantage of simplicity but suffer the major disadvantage that most of the signals are likely to be due to the presence of naturally occurring radioactive material. The presence of the source for which the system is searching may produce only a moderate increase in count-rate, making the task of source detection vulnerable to statistical fluctuations.

In most cases, the source for which the system is searching primarily comprises a particular radionuclide. An energy-discriminating detector could be calibrated so that a signal is produced only when the radiation deposits energy equivalent to that of the full-energy peak associated with the gamma rays emitted by the source. Such a detector has two advantages: the detector is far less sensitive to other radionuclides due to differences in gamma-ray energies and the increased count-rate due to the source is much more significant due to the reduced background rate in the energy region of interest.

A detector tuned to the energy of the gamma rays emitted by the source is still sensitive to other radioactive materials that emit higher-energy gamma rays. This is due to the production and detection of gamma rays of the energy of interest through Compton scattering of higher-energy gamma rays within the detector or within the environment. A detector with a greater peak-to-Compton ratio will produce a larger signal in the energy region of interest, resulting in a greater relative sensitivity to the source.

The width of the energy region of interest is determined by the energy resolution of the detector for the gamma ray of interest. The background count-rate scales roughly with the width of this region. Using a higher resolution detector enables one to use a smaller region of interest that still includes the full-energy peak of interest but incorporates less of the background due to Compton-scattered events. Thus, the use of a higher resolution detector will increase the signal to background ratio.