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ScienceDirect
Applied Radiation and Isotopes 66 (2008) 1250–1261
Applied Radiation and Isotopes
www.elsevier.com/locate/apradiso

Signatures for several types of naturally occurring radioactive materials

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Received 27 July 2007; received in revised form 5 February 2008; accepted 5 February 2008

Abstract

Detectors to scan for illicit nuclear material began to be installed at various screening locations in 2002. On the sites considered, each vehicle drives slowly by radiation detectors that scan for neutron and gamma radiation, resulting in a time series profile. One performance limitation is that naturally occurring radioactive materials (NORM), such as cat litter, are routinely shipped across borders, leading to nuisance alarms. One strategy for nuisance alarms is to define and recognize "signatures" of certain types of NORM so that many nuisance alarms can be quickly resolved as being innocent. Here, we consider candidate profile features, such as the peak width and the maximum energy ratio, and use pattern recognition methods to illustrate the extent to which several common types of NORM can be distinguished.

Keywords: Passive gamma counting; Feature selection; Pattern recognition; Naturally occurring radioactive materials; Signatures; Multi-dimensional scaling

1. Introduction

Data from passive radiation portal monitors (RPMs) have been collected at various screening locations since 2002 (Geelhood et al., 2004). The purpose is to detect potentially harmful radioactive cargo (such as special nuclear material, SNM) that emits gamma rays and/or neutrons.

Current systems use polyvinyl-toluene-based plastic scintillation gamma-ray detectors coupled to photo-multiplier tubes. These can provide only very coarse energy resolution into a few energy bands, such as a low-energy and a high-energy band. Alarm rules for the simplest systems are based on the net counts above background for either the low-energy or the high-energy gamma counts, or for the neutron counts.

Because a non-negligible fraction of non-threat cargo contains naturally occurring radioactive material (NORM), such as the potassium in cat litter, the majority of alarms are not due to statistical fluctuations, but instead are true (nuisance) alarms due to NORM (Kouzes et al., 2004, 2006). Also, because a simple count criterion leads to many nuisance alarms arising from NORM, and because background suppression (see the next section) by the vehicle is smaller for ratios of gamma counts than for counts alone, some systems are including both gamma count and gamma count ratio alarm criteria (Ely et al., 2005; Burr et al., 2007).

Following current convention, we define the gamma ratio as the ratio of low-energy gamma counts to total-energy gamma counts, where the total-energy count is the sum of low-energy and high-energy counts. We refer to low-energy gamma counts as "low gammas" and to high-energy gamma counts as "high gammas."

One strategy for nuisance alarms is to define and recognize "signatures" of certain types of NORM so that many alarms can be quickly resolved as being innocent. Our purpose here is to consider candidate profile features, such as the peak width and the maximum energy ratio, and to use pattern recognition methods from the machine and statistical learning communities to illustrate the extent to which several common types of NORM can be distinguished.

Following sections include additional problem description; a description of available data; features for pattern

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doi:10.1016/j.apradiso.2008.02.080

recognition; pattern recognition methods, and pattern recognition results. We conclude that some types of NORM have a signature that is sufficiently consistent to be of potential benefit.

2. Distinguishing NORM types using available measurements

The data are collected as each vehicle slowly passes by a set of fixed radiation sensors, resulting in a profile time series measurement from each sensor. The most common sensor configuration is a bottom detector on both the driver's and passenger's sides (Panels 1 and 2, respectively) and a top detector also on both the driver's and passenger's sides (Panels 3 and 4, respectively), each recording a neutron count in addition to a low-energy and high-energy gamma counts every 0.1 s during the vehicle profile. This gives a total of 12 counts (three counts from each of four detectors) every 0.1 s. Because vehicle speeds and lengths vary, the lengths of vehicle profiles vary, with most lengths being in the range of approximately 20–600 samples, representing 2–60 s.

Detection of illicit SNM using passive detectors is complicated by several issues. One such issue is vehicle self-shielding, which leads to suppression of the background radiation. Background suppression occurs because vehicles with or without radioactive material suppress the natural background radiation that typically arises mainly from the asphalt, concrete, and rock near the RPM. Because profile lengths and vehicle characteristics (size, shape, density, etc.) vary, the shape of the suppression effect varies among vehicles, thus making it difficult to define an effective suppression adjustment (Burr et al., 2007; LoPresti et al., 2006). This implies that the detection probability for threat items is reduced by background suppression. For our purposes here, we will ignore background suppression because we consider alarming profiles that have a much higher average count rate than the background and the suppression effect. However, if we attempt to adjust each profile for background suppression, then the feature values considered below could change. Therefore, a separate study would be required if alarming profiles are adjusted for background suppression.

From knowledge of the key gamma emitters in the constituents of common NORM types, the ratio of low-energy to total-energy gamma counts is anticipated to be approximately the same for NORM as for the background, while, for most threats, this ratio is anticipated to increase. For example, see Fig. 1, which shows two example NORM-carrying (cat litter) vehicle profiles. The left plots

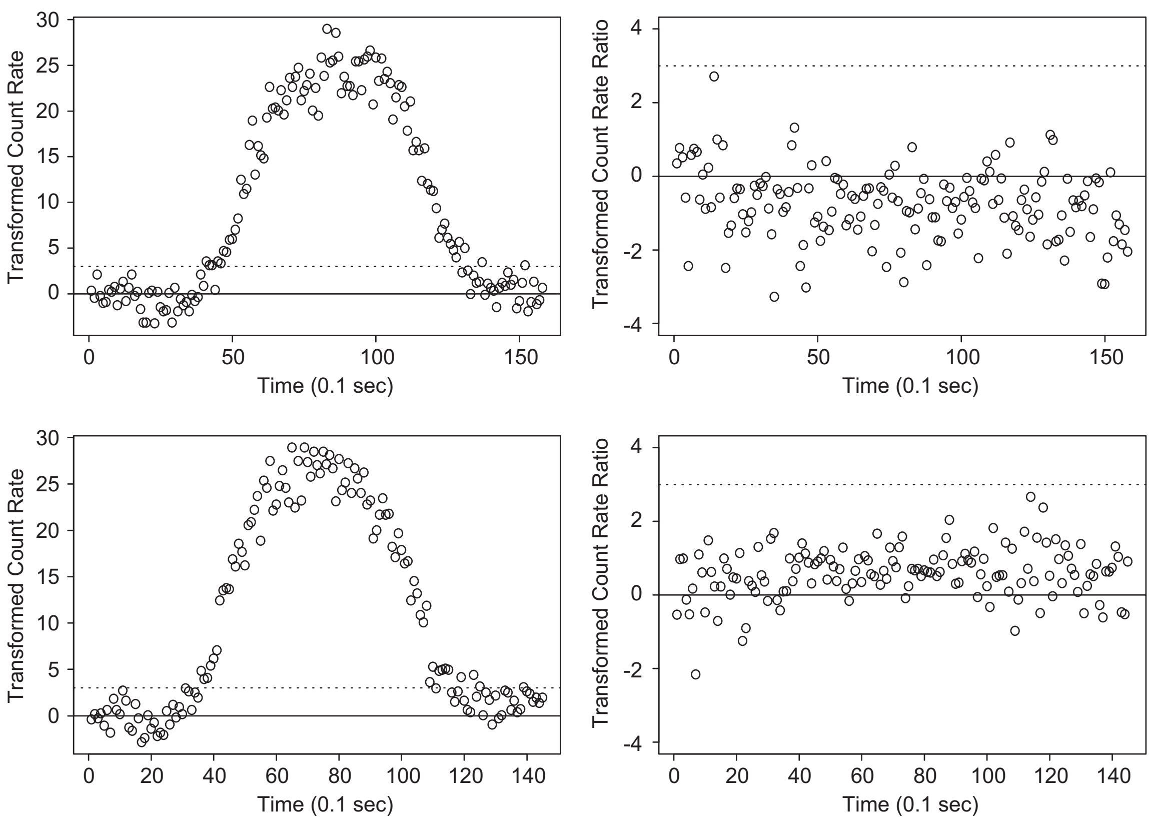

Fig. 1. Two example NORM-carrying (cat litter) vehicles that alarmed using the currently implemented low-energy gamma count criterion. Left plots: The transformed maximum low-energy gamma count $(P_L - B_L)/\sqrt{B_L}$. Right plots: The transformed $(P_L/(P_L + P_H) - \text{avg}[B_L/(B_L + B_H)])/\text{S.D.}[B_L/(B_L + B_H)]$ count ratio. Notice that the count ratio remains low throughout the profile, indicating that it would not have alarmed. The solid line at zero aids the eye in checking how the transformed counts vary around zero. The dotted line is at three transformed units above zero, which would be a typical alarm limit.