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The use of energy windowing to discriminate SNM from NORM in radiation portal monitors

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Abstract

Energy windowing is an algorithmic alarm method that can be applied to plastic scintillator-based radiation portal monitor (RPM) systems to improve operational sensitivity to certain threat sources while reducing the alarm rates from naturally occurring radioactive material. Various implementations of energy windowing have been tested and documented by industry and at Pacific Northwest National Laboratory, and are available in commercial RPMs built by several manufacturers. Moreover, energy windowing is being used in many deployed RPMs to reduce nuisance alarms and improve operational sensitivity during the screening of cargo. This paper describes energy windowing algorithms and demonstrates how these algorithms succeed when applied to "controlled" experimental measurements and "real world" vehicle traffic data.

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1. Introduction

Following the events of September 11, 2001, radiation portal monitors (RPMs) have been, and continue to be, installed at international border crossings (e.g., Fig. 1) as part of various programs to interdict radioactive materials of concern, such as nuclear weapons or special nuclear material (SNM). An overview of radiation detection at borders is provided in references [1–3]. The vast majority of these RPMs use plastic scintillator material for gamma-ray detection [4]. These detectors cannot provide detailed spectroscopic information; rather, they are gross-count detectors. With these gross-count detectors there are often radiation alarms observed arising from non-threatening sources of radiation, primarily from naturally occurring radioactive material (NORM) and persons treated with medical radiopharmaceuticals [5,6]. These alarms are real (not the false-positive alarms from statistical fluctuations or instrument faults) and are referred to as *nuisance*, or *innocent*, alarms.

Because all radiation alarms at a border crossing must be further investigated to determine if threat materials are actually present, the occurrence of nuisance alarms increases the cost and operational impact of radiation screening. Strategies to minimize nuisance alarms have, therefore, been under investigation. This article discusses a software algorithmic method for minimizing the number of NORM-induced nuisance alarms from RPMs in which plastic scintillation materials are used. This algorithmic method is referred to in this document by the term *energy windowing* (EW). Others have also referred to this method as spectral analysis and natural background reduction.

The use of the EW algorithm was first reported in a German patent application in 1997 by Trost and Iwatschenko [7] and later by Iwatschenko-Borho [8], Iwatschenko-Borho et al [9], and Rieck and Iwatschenko

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Fig. 1. A picture of a typical deployed RPM system arrangement for screening truck cargo.

[10]. In these papers, the ability to discriminate NORM from man-made radiation sources in plastic scintillator gamma-ray detectors was reported. The method disclosed in the patent involved taking the ratio of the intensity from the low energy[1] part of the scintillation light spectrum to the intensity in the higher energy part of the spectrum. This ratio turns out to be different for NORM and many man-made radiation sources of interest, particularly SNM, due to the difference in the incident gamma-ray spectrum and the resulting Compton continuum characteristic of plastic scintillator. Because this method required dividing the broad total-energy spectrum from a plastic scintillation material into a few smaller, non-overlapping "windows of energy," it became known as energy windowing.[2]

EW has also been shown to have a mitigating effect on a phenomenon known as shadow shielding. Shadow shielding is the decrease in the gamma-ray detector background level caused by the passing of a vehicle with dense cargo through a RPM. The vehicle and cargo temporarily shield the detector from the main sources of background radiation, which are generally the ground or pavement and any nearby brick or concrete structures. This reduction in background effectively negatively impacts the alarm sensitivity of the RPM. Over the past several years, extensive testing of the EW methods at Pacific Northwest National Laboratory (PNNL) has shown that it, in combination with gross-count thresholds, can reduce the rate of NORM alarms and mitigate the effects of shadow shielding [5]. Other non-cargo applications of RPMs (such as mail screening and personally owned vehicle monitoring) do not typically involve the observation of NORM, and, thus, do not tend to benefit from the use of EW.

The EW method has been implemented in commercial plastic scintillator-based RPMs built by several manufacturers including Ludlum Measurements, SAIC, and Thermo-Electron Corporation. These companies have tested the capability of EW associated with the screening of scrap metal, which was one of the major applications of RPMs before radiation screening at international borders became a significant endeavor. The use of EW for RPM screening of cargo traffic is a new application of the EW methodology, and, therefore, required verification to ensure continued sensitivity to SNM.

The purpose of this paper is to describe in detail various EW algorithms, and to show their success when used in RPM applications. This work is based upon data from hundreds of deployed RPM systems as well as laboratory testing. The material is presented in three sections. Section 2 gives a brief overview on radiation detection in plastic scintillator material and nuisance alarms. Section 3 delineates and compares gross-count and EW algorithmic methods. Section 4 applies EW to measurements taken under controlled experimental circumstances and to data from actual vehicle traffic for systems with two-window, three-window, and five-window implementations of EW.

2. Radiation detection for radiation portal monitors

2.1. Plastic scintillators

Radioactive materials emit various types of radiation, but only energetic gamma and neutron radiation can typically be used to detect these materials at distances appropriate to cargo screening. This paper will consider only the detection of gamma radiation. For this task, plastic scintillator material is used in the majority of RPMs as it is a cost-effective material that provides the large cross-sectional detector area needed for vehicle screening applications, and is physically robust for the challenging environmental conditions encountered at borders. Polyvinyl toluene (PVT) is the most common type of plastic scintillator material used for these applications. Hereafter, the term PVT will be used as a generic reference to plastic scintillators.

For passive screening applications the gamma-ray energy range of interest is from a few kilo-electron volts (keV) up to several million electron volts (MeV). Over this range of energy, Compton scattering overwhelmingly dominates the photo-absorption and pair–production

[1]Energy deposited in plastic scintillator gives rise to light that is collected with a phototube where it is amplified and converted to a pulse height that is recorded as an energy spectrum. Generally, like other scintillators, the relationship between recorded energy and energy deposition is complicated by non-linear factors and loss of collected light that depends on the geometry of the system. The term low energy is used to represent the signal observed from incident low-energy photons in the detector. The observed average count-rate in the detector is a measure of the number of primary photons incident on the detector as well as their energy. At the relevant count rates, individual incident photon events can be resolved.

[2]Note that the application of EW in plastic scintillators is not the same as when used with spectroscopic-capable detector materials like thallium-doped sodium iodide NaI(Tl), for example, in the medical field [11]. The spectra in these applications contain full-energy photopeaks, and partitioning the full spectra into smaller regions in which characteristic photopeaks are located enables rapid determination of the presence of specific radiation sources.