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Rain-induced increase in background radiation detected by Radiation Portal Monitors☆

R.J. Livesay [a,*], C.S. Blessinger [b], T.F. Guzzardo [b], P.A. Hausladen [b]

[a] Mason Livesay Scientific, LLC, 1519 Fremont Place, Knoxville, TN 37917, United States
[b] Oak Ridge National Laboratory, 1 Bethel Valley Road, Oak Ridge, TN 37831, United States

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ABSTRACT

A complete understanding of both the steady state and transient background measured by Radiation Portal Monitors (RPMs) is essential to predictable system performance, as well as maximization of detection sensitivity. To facilitate this understanding, a test bed for the study of natural background in RPMs has been established at the Oak Ridge National Laboratory. This work was performed in support of the Second Line of Defense Program's mission to enhance partner country capability to deter, detect, and interdict the illicit movement of special nuclear material.

In the present work, transient increases in gamma-ray counting rates in RPMs due to rain are investigated. The increase in background activity associated with rain, which has been well documented in the field of environmental radioactivity, originates primarily from the wet-deposition of two radioactive daughters of ^{222}Rn, namely, ^{214}Pb and ^{214}Bi. In this study, rainfall rates recorded by a co-located weather station are compared with RPM count rates and high-purity germanium spectra. The data verify that these radionuclides are responsible for the largest environmental background fluctuations in RPMs. Analytical expressions for the detector response function in Poly-Vinyl Toluene have been derived. Effects on system performance and potential mitigation strategies are discussed.

1. Introduction

The effect of radioactive precipitation has been observed at hundreds of sites around the world and extensively studied for several decades (Mercier & et al., 2009). The subject is of interest to numerous subfields that depend on environmental radiation measurements, including monitoring for environmental contamination at nuclear facilities and using radon progeny as natural tracers to study atmospheric processes (Greenfield & et al., 2008). The most ubiquitous and prominent sources of naturally occurring radioactivity in precipitation are the ^{222}Rn progeny ^{214}Pb and ^{214}Bi that are scavenged within clouds and deposited on the ground during rain (Fujinami, 1996). ^{222}Rn is a product of the very long lived (half-life of 4.468^*10^9 years) and globally ubiquitous ^{238}U.

While there are many additional background contributors, they are shown to have negligible effects on the data in Fig. 5, especially when compared to the abundance of radiation from the prominent radon daughter activities. For instance, the expected 477 keV gamma ray from ^{7}Be does not show any difference between rain and non-rain events, and is therefore not further considered in this work (Radon Transport, 1981). It is recognized by the authors that geography will play a role in the distribution and prevalence of various contributions to the background radiation spectrum. The results of this work are specific to the deposition of radon daughters based on the magnitude and frequency of their effect on the collection of detectors under analysis.

The present work is focused on characterizing the response of Radiation Portal Monitors (RPMs) to rain-induced increases in background gamma-ray radiation to ultimately maximize system performance. RPMs typically consist of two gamma-ray detectors, each consisting of a slab of polyvinyl toluene (PVT) scintillator, and two neutron detector modules, consisting of ^{3}He proportional counters moderated by polyethylene, mounted in an upright rectangular pillar. The RPMs target passive detection of the low-energy

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* Corresponding author. Tel.: +1 865 771 8132.
E-mail address: jake@masonlivesay.com (R.J. Livesay).

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gamma-ray emissions of special nuclear material (SNM) in the PVT and neutrons of a broad energy in the ^{3}He proportional counters. Typically, two pillars are arranged to face each other, one on either side of a lane of commercial traffic at a port or border crossing.

The RPMs in this work record gross counts which correspond to gamma rays with energies between a single upper and lower level discriminator. The values of these discriminators are determined programmatically to target specific threat materials. The data are displayed as the counts that fall in this window as a function of time. The background is generally expected to be constant, but as can be seen from Fig. 1, there are ongoing deviations from the average, some of which are significant. The study of these deviations gives information about the health of the systems as well as information about the environment surrounding it.

The Office of the Second Line of Defense has deployed an extensive array of RPMs to detect and deter the transport of illicit nuclear material, as part of a larger nuclear nonproliferation effort. RPMs are currently operating in hundreds of sites around the world. Some are used indoors to monitor pedestrian traffic, while others monitor the passage of cargo containers through seaports and border crossings.

During decay by means of their most probable branches, ^{214}Pb and ^{214}Bi emit gamma rays of 351.99 keV and 609.32 keV, respectively. This emission of radiation and the subsequent increase in background counting rate is easily observed using conventional radiation detectors. In addition to the energy of gamma rays, the characteristic decay time can be used for isotope identification: ^{222}Rn decays with a half-life of 3.8 days, while ^{214}Pb and ^{214}Bi decay with much shorter half-lives of 27 min and 20 min, respectively. This study utilizes these physical properties of radon progeny to isolate the source of the background increases observed in RPMs.

In this work, “background” will be used to refer to the signal measured by an RPM, while not occupied. The rain deposition of radioactive nuclei provides a transient source term to the background, yielding the measured background. In the case of RPMs, the dominant source of background is typically due to construction materials, soil, and bedrock, which contain ^{40}K, ^{232}Th, and ^{238}U and their progeny (Vecchi and Valli, 1997).

Radioactive sources travel near and through RPMs for a variety of reasons. Naturally occurring radioactive material (NORM), medical treatments, orphaned industrial sources, and weather all contribute to the signal measured by RPMs. Arguably the most common deviation from the natural radioactive background is due to the deposition of radioactive ^{214}Bi and ^{214}Pb from precipitation. This effect is seen in varying degrees in most outdoor RPMs, with some sites experiencing background fluctuations of more than 100% of their average background values. The effect appears as positive spikes in the data, since the decay time is very short (hours) compared to the scale over which data are generally analyzed (months) (Fig. 1). When the scale is expanded for more detailed analysis of the spikes, the structure of the effect becomes visible. The spikes have a variety of shapes and durations, but all have a characteristic final decay half-life of approximately 30 min. Short rains are the easiest to identify because they possess a short rise time and relatively long decay time, without multiple spikes to complicate the analysis. For short rains, the background will be elevated above the nominal background for several half-lives, which often amounts to approximately 4 h. The decay shape is a consequence of the quick deposition of radionuclides (often minutes) and their decay (hours). More complex shapes are due to multiple rains occurring within the decay time, increasing the activity with each deposition, causing a rough saw-tooth pattern.

Although the effect of rain dissipates in a few hours, RPMs underperform until the additional background radiation decays away and the background returns to the expected background value used to calculate system performance. The rain-induced increase in background affects the statistical precision of measurements and should be addressed alongside other challenges present in the deployment and operation of RPMs. Any additional source of background is detrimental to RPM performance since increasing background always decreases sensitivity.

2. Material and methods

In order to characterize and ultimately mitigate the effects of rain-induced background increases observed in RPMs, the Portal Monitor Test Bed was constructed at Oak Ridge National Laboratory. The experimental test bed features an ORION 510 Weather Station mounted on a small instrument trailer, a TSA Systems VM-250AGN RPM, and an Ortec Detective high-purity germanium (HPGe) detector. Data streams from the detection devices are combined and analyzed with an in-house code specifically designed for the measurement of radioactive decay (Guzzardo and Livesay, 2011). Time stamps from the acquisition computers provide the necessary correlation between meteorological and radiological events. A detailed study of approximately 50 rain events supports the basic model of radon transport, which relies on the deposition of radon progeny through precipitation. Establishing the basic mechanism for the rain-increased background in RPMs is a first step in determining suitable remediation solutions.

Gamma rays with energies on the order of a few hundred keV are most likely to interact in PVT detectors through Compton scattering (the photoelectric effect is essentially non-existent in materials with such low densities) – this process only transfers a fraction of a gamma ray's energy into scintillated light, resulting in a mostly featureless spectrum (Fig. 2). Therefore, it is difficult to

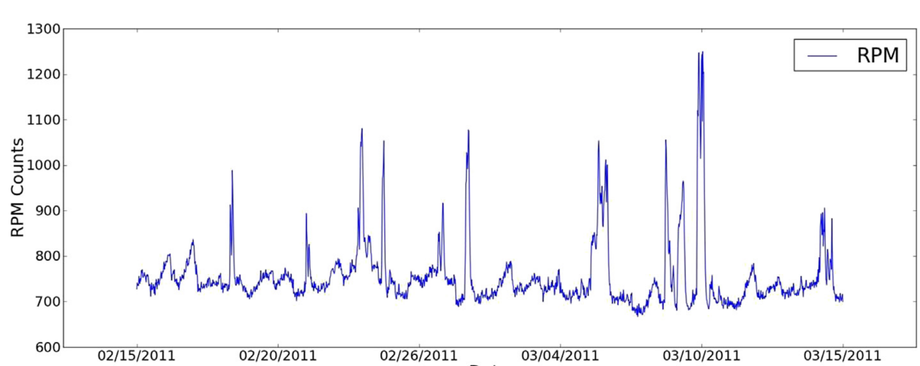

Fig. 1. One-month window of background data from one RPM (sum of individual count rates of four gamma-ray detectors). The spikes in the data are clear deviations from the static background (well outside the statistical variance).