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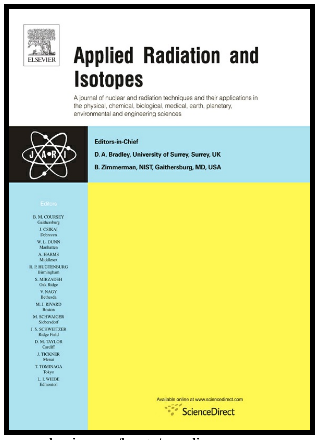

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An algorithm for filtering detector instabilities in search of novel non-exponential decay and in conventional half-life determinations

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Abstract

Recent reports of Solar modulation of beta-decay have reignited interest in whether or not radioactive half-lives are constants. A numerical approach for filtering instrumental effects on residuals is developed, using correlations with atmospheric conditions recorded while counting ^{204}Tl emissions with a Geiger-Müller counter. Half-life oscillations and detection efficiency oscillations can be separated provided their periods are substantially different. A partial uncertainty budget for the ^{204}Tl half-life shows significant decreases to medium-frequency instabilities correlated with pressure and temperature, which suggests that further development may aid general improvements in half-life determinations.

Keywords: radioactivity, Geiger-Müller tube, total efficiency correction, half-life, ^{204}Tl, beta decay, decay rate fluctuations, Earth-Sun distance
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1. Introduction

Radioactive decay is classically considered a Poisson random process, such that when registered by a single, distinguishable emission, the count of emissions from a source of n atoms with decay parameter λ over a duration Δt is a Poisson random variable $C = \mathrm{Poi}(\mu)$ with mean value $\mu = n\lambda\Delta t$. The familiar time-exponential decay law $C(t) = C_\circ e^{-\lambda t}$ emerges when successive counts of duration Δt are collected, each count C_i resulting from the depletion of emitters $n_i = n_{i-1} - C_{i-1}$ during the previous collection. The earliest investigations [1] of radioactivity failed to find significant non-exponential behavior or correlations with external factors, such as temperature, pressure, humidity, electric and magnetic fields, or chemical state[3][2]. Quantum mechanics does however predict a few very special counting conditions where non-exponential decay is expected, though they may be experimentally inaccessible [3]. A small group of reports (some early, independent examples include [4, 5, 6, 7]) over the past 20 years have claimed experimental evidence that at least some radioisotopes, particularly beta emitters, do not decay exclusively according to an exponential decay law, but rather, at the level of a few per mil, periodically alternate between faster and slower-than-expected decay rates.

Starting in 2009 [8, 9, 10, 11], Jenkins, Fischbach *et al.* reported to have measured such phenomena, found evidence of the same in existing decay data sets and even hypothesized that novel solar neutrino-nucleus interactions or interactions with beyond-Standard Model particles are the culprit [10]. In this hypothesis, the Earth's orbital eccentricity and the rotation of Sun about its own axis are taken as proxies for the flux of the affecting particle(s), explaining evidence that decay data residuals contain periodic signals of 1 year [8] and 27 days [11], respectively. This has renewed interest in the question of whether or not radioactive decay rates are exclusively exponential, particularly since confirmation of such a hypothesis would have a broad impact across nuclear engineering and astrophysics fields.

Experimental searches for non-exponential decay requires similar considerations as for half-life determinations. Important sources of uncertainty are periodic changes to ambient conditions which can alter the efficiency for registering decay events in a detection system. Periodic fluctuations, comparable or shorter than the experiment duration, in decay data residuals are included under "medium-frequency instabilities" for uncertainty analysis [12]. For just a few examples: annual changes in temperature, pressure and humidity can (1) modulate detector intrinsic efficiency, (2) attenuate emissions over the source-detector transit, or (3) alter the natural background radiation, all creating periodic fluctuations in residuals. At the part per mil level, it is possible to imagine many such mechanisms affecting

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[3]A notable exception are electron-capture decays, which can in some cases be modulated through chemical state or prohibited by total ionization and isolation of the parent atom, such as the case of ^{7}Be [2].