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# 2.7 years of beta-decay-rate ratio measurements in a controlled environment

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## HIGHLIGHTS

- A series of publications beginning in 2009 hypothesizes that nuclear decay rates depend on solar activity. If true, this controversial claim points to new physics outside the standard model. Solar-dependent variations would invalidate the purely exponential decay of radioactive nuclei, potentially requiring modifications to radiation standards, with important implications for geo- and astrochronology. If nuclear decay rate variations are related to the solar neutrino flux, for example, measured variations could be used to detect neutrinos or to measure or predict solar flares.
- Since the first papers were published, dozens of published research articles have studied this effect. Some affirm solar-related variations while others refute them. One key commonality in all pro-variation papers is that the detectors are used in an un-controlled ambient environment. The local temperature and pressure change with the weather and seasons. Our work is among the few studies in which the ambient environment is tightly controlled. The sealed, temperature-controlled, low-humidity environment has been nearly un-interrupted and acquiring data for 2.7 years.
- Noisy data, even truly random data, can exhibit small-amplitude periodicities. For example, a Sr/Y data set was published a few years ago. The scientists who generated the data performed a detailed analysis showing that there was no statistically-significant evidence for solar-related variation. This same data set was analyzed by a separate group that claimed to find an indication of Solar-correlated variation. In our present work, we show that such small amplitude "positive" periodicity results can be obtained from pseudo-random noise.
- Finally, we demonstrate how ratio-calibration methods are not as reliable as one might like. Our data illustrates how long-term drifts in both the absolute and relative detection efficiency can masquerade as "interesting" science if systematic effects are not properly considered.
- Our work confirms a null-variability measurement, competitive with the best measurements produced by national standards labs. It illustrates the limits of accuracy and sensitivity for these detector types. We suggest that reducing the limit significantly will require perhaps a new generation of detectors.

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ABSTRACT

We report nearly continuous beta-decay-rate measurements of Na-22, Cl-36, Co-60, Sr-90, and Cs-137 over a period of 2.7 years using four Geiger-Müller tubes. We carefully control the ambient pressure and temperature for the detectors, sources, and electronics in order to minimize environmentally-dependent systematic drifts in the measurement chains. We show that the amplitudes of an annual oscillation in the decay rates are consistent with zero to within 0.004%.

## 1. Introduction

In a series of articles, Pommé et al. argue against the hypothesis that nuclear decay rates depend on the Earth-Sun distance or on solar activity (Pommé et al., 2016, 2017a, 2017b, 2017c, 2018a). These articles analyzed data spanning several decades in time collected by 14 national standards laboratories measuring 20 different radioactive isotopes. Collectively, they set an upper limit of 0.003–0.007% in the amplitude of annual oscillations in the measured beta decay rates (Pommé et al., 2017b) and similar limits for alpha and beta$^+$ decay rates. Many other publications agree with these findings (Bellotti et al., 2018; Borrello et al., 2018; Bergeson et al., 2017a; Cooper, 2009; Kossert and Nähle, 2015, 2014; Meier and Wieler, 2014; Nähle and Kossert, 2014; Norman et al., 2009; Schrader, 2016).

Nuclear radiation detectors are known to be influenced by their operating environment (Bergeson et al., 2017a; Bergeron et al., 2018; Schrader, 2016; Siegert et al., 1998; Stancil et al., 2017; Ware et al., 2015), and these systematic variations can masquerade as interesting

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science. For example, a recent publication observed solar-correlated changes in the measured $^{222}$Rn decay rate (Sturrock et al., 2018). That study used multi-year data from an outdoor monitoring station. When the study was repeated in a laboratory environment, no oscillations were observed (Pommé et al., 2018b). The reported decay-rate-variations appear to be a systematic effect related to the detector temperature (Pommé et al., 2018b). Similarly, solar-correlated variations were previously observed in $^{54}$Mn (Fischbach et al., 2009), $^{36}$Cl (Jenkins et al., 2012), and other elements. However measurements performed by us and many others in carefully controlled ambient environments and using stabilized detectors show no variability at levels well below what was originally reported (Bellotti et al., 2018; Bergeson et al., 2017a; Borrello et al., 2018; Kossert and Nähle, 2015, 2014; Nähle and Kossert, 2014; Norman et al., 2009; Pommé et al., 2016; Schrader, 2016).

The search for new science outside the standard model is a staple of physics research (Safronova et al., 2018). Unresolved questions about dark matter and dark energy (Spergel et al., 2003; Planck Collaboration et al., 2014), the proton size (Udem, 2018), the magnetic moment of the muon (Belyaev et al., 2018; Bauer et al., 2017; Chakraborty et al., 2018), tensor gravity (García-Bellido and Quirós, 1990; Steinwachs and van der Wild, 2018), and temporal variations of the fundamental "constants" (Martins, 2017) inspire studies of axion coupling to normal matter, primordial black holes, sterile neutrinos, and searches for higher-dimensional space, to name a few examples. While these studies are not always successful, they contribute to a growing body of science and remind us that nature sometimes holds surprises.

Even though the link between solar activity and possible variations in nuclear beta decay rates has been disproven at the 0.007% level, the question of the stability of nuclear decay is interesting to consider. In this paper we report an extension of our previous beta-decay-rate measurements to a period of 2.7 years. Our data places an upper limit of 0.004% for the amplitude of an annual oscillation in the decay rate, which appears to be near the limit of accuracy for Geiger-Müller (GM) beta detectors. We show that counting statistics and long-term detector drift pose significant systematic errors below this level of precision.

## 2. Data acquisition

Our experiment is described in previous publications (Bergeson et al., 2017a; Ware et al., 2015). Five 1-$\mu$Ci samples (Na-22, Co-60, Sr-90, Cs-137, and Cl-36) and a blank are mounted in a bismuth-lined sample holder. A closed-loop feedback-controlled rotation stage sequentially rotates the samples into position above four GM tubes, with an accuracy of ± 10 µm. The samples, rotation stage, detectors, and associated electronics are placed in a sealed chamber containing dry nitrogen. The chamber pressure and wall temperature are controlled to be 93.33 kPa (700 Torr) and 32.2 °C (90 °F).

Plastic apertures in front of each sample limit the GM count rate to approximately 400 counts per second (cps) when the experiment was started. Typical background signals are 0.4 cps. Each sample is measured for a period of 4 h each day. We average the count rate over 14 days to get one data point. The statistical uncertainty in each data point is expected to be $\sigma = [(400\ \text{counts/s})(14,400\ \text{s/d})(14\ \text{d})]^{-0.5} = 1.1 \times 10^{-4}$.

The data reported here were acquired between 17 September 2015 and 4 June 2018 (992 days). Because the fractional count rate change with pressure is $10^{-4}\ \text{Torr}^{-1}$, data is discarded when the chamber is opened and the pressure is uncontrolled, Data is also discarded when rotation stage positioning errors are reported. One of the four detectors failed during the experiment, limiting the available data for that detector. Additional information on the detectors and data filtering is presented in the Appendix A.

## 3. Data reduction

Our raw count-rate data is corrected for dead time, using

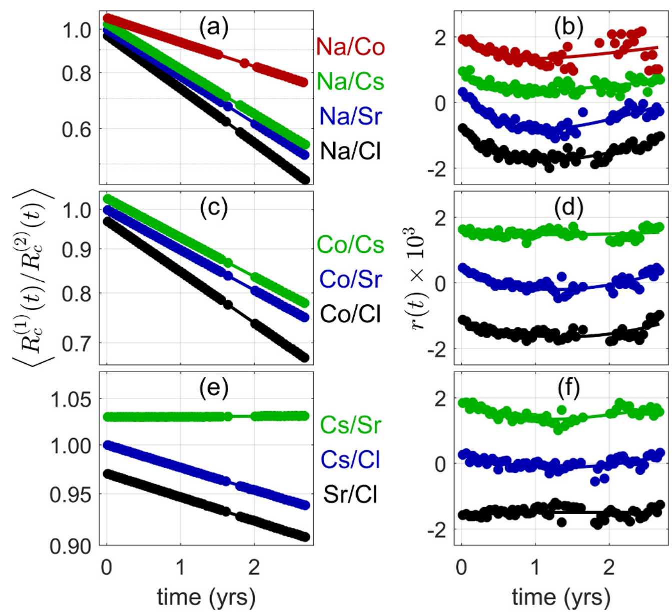


**Fig. 1.** Normalized averaged count rate ratios. The count rate ratios from each detector are averaged together as described in the text. In panels (a), (c), and (e), the circles are the ratio data and the lines represent the exponential best fit to the data. In panels (b), (d), and (f), the points are the residuals $r(t)$ calculated using Eq. (4) and the lines are the detrending function from Eq. (5). The elements used in the count rate ratios are listed to the right of panels (a), (c), and (e) as follows. Panels (a) and (b): Na/Co, red; Na/Cs, green; Na/Sr, blue; Na/Cl, black. Panels (c) and (d): Co/Cs, green; Co/Sr, blue; Co/Cl, black. Panels (e) and (f): Cs/Sr, green; Cs/Cl, blue; Sr/Cl, black. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

$$R_c(t) = \frac{R_m(t)}{1 - R_m(t)\,\tau} - B_m(t), \tag{1}$$

where $R_m$ is the measured count rate, $R_c$ is the dead time-corrected count rate, $\tau$ is the dead time, approximately 200 µs, and $B_m$ is the measured background level for the detector. The corrected count rates for our 5 samples are used to generate 10 unique count rate ratios for each of the 4 detectors. As shown in the Appendix A [Fig. 4(a)], these count rate ratios do not have exactly the same values at time $t = 0$. Furthermore, the count rate ratio data are comprised of different numbers of days on each detector due to the data filtering mentioned previously. We normalize the count rate ratios for each detector using the average of the first 400 days. On a given day, we average the ratio data using all detectors for which the data is valid. These ratio data are plotted in Fig. 1(a), (c), and (e).

In the absence of detector errors and source variability, the count rates should follow simple exponential decay. Although our environmental control eliminates some sources of systematic error related to detector response variability, the detectors themselves age over time. Common-mode drift in the detector response can be minimized by calculating decay rate ratios, although even then artifacts remain (Towers, 2013). Details and an illustration from our data are given in the Appendix A. The ratio data are fit to a single exponential decay. The idealized count rate ratio should be,

$$\frac{R_c^{(1)}(t)}{R_c^{(2)}(t)} = A\exp\left(-\lambda t\right), \tag{2}$$

where the superscripts (1) and (2) refer to the elements in the count rate ratio, $A$ is the count rate ratio at time $t = 0$, and $\lambda$ is the decay rate. We linearize this in the usual way as