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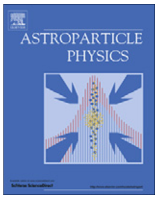

Additional experimental evidence for a solar influence on nuclear decay rates

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ABSTRACT

Additional experimental evidence is presented in support of the recent hypothesis that a possible solar influence could explain fluctuations observed in the measured decay rates of some isotopes. These data were obtained during routine weekly calibrations of an instrument used for radiological safety at The Ohio State University Research Reactor using ^{36}Cl. The detector system used was based on a Geiger–Müller gas detector, which is a robust detector system with very low susceptibility to environmental changes. A clear annual variation is evident in the data, with a maximum relative count rate observed in January/February, and a minimum relative count rate observed in July/August, for seven successive years from July 2005 to June 2011. This annual variation is not likely to have arisen from changes in the detector surroundings, as we show here.

1. Introduction

Evidence for a possible solar influence on nuclear decay rates has recently been presented based on the analysis of decay rate measurements taken at three independent institutions. The first was an apparent change in the measured decay rate of ^{54}Mn during a series of solar flares in December of 2006 [1]. The ^{54}Mn data were being collected as part of a half-life measurement utilizing continuous four-hour measurements. This allowed a time resolution capable of seeing changes that could have been caused by a solar flare, which typically lasts minutes to hours. This work was then followed by two additional papers by our group [2,3], where data were analyzed from half-life measurements taken by two independent groups, one at the Brookhaven National Laboratory (BNL) in Upton, New York, USA, and the other at the Physikalisch-Technische Bundesanstalt (PTB) in Braunschweig, Germany. The BNL group had undertaken a measurement of the half-life of ^{32}Si, and the data from that experiment exhibited a periodic oscillation with an approximate period of 1 year [4]. The measurements taken at the PTB in Germany were of a ^{226}Ra standard used for comparison in the measurements of the half-life of ^{152}Eu [5], and in a longer-term analysis of the stability of detectors used in standards laboratories. The ^{226}Ra data also showed a periodic oscillation, again with a period of approximately 1 year.

In the subsequent analysis of the raw data obtained from the BNL and PTB experiments, both data sets were shown to have not only the same period, but in the two years during which the data sets overlapped they had the same approximate phase and amplitude as well [2,6]. Moreover, it was shown that both data sets were not only in phase with each other, but also appeared to be approximately in phase with the distance of the Earth from the Sun. Taking all of these experiments into account (BNL, PTB and Purdue), a reasonable case could be constructed for the possibility of a solar influence on nuclear decays [3]. This case was subsequently strengthened as a result of an analysis by our group [7,8], where an additional periodicity was identified in the BNL data at 11.25 ± 0.07/yr, and in the PTB data at 11.21 ± 0.13/yr. Both of these peaks may be linked to the rotation (and probable inhomogeneous nature) of the core of the Sun [9–11]. A third periodicity was also identified by our group [12] in both the BNL and PTB data sets, which is analogous to the Rieger periodicity [13] with a period of approximately 173 days. An analysis of the phases of these periodicities was also carried out [14] which determined that the phase characteristics of the annual periodicities could reasonably be attributed to a solar influence on the decay rates.

The suggestion of a solar influence on nuclear decay rates has been met with some criticism, however. An analysis by Norman, et al. [15] of decay data taken for several isotopes in their

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laboratory did not see evidence for an annual effect similar to that reported in Ref. [2]. Silverman and Strange [16] examined data from ^{22}Na decay measurements, and also found no similar fluctuations. Cooper [17] analyzed the heat output data from the radioisotope thermal generators (RTGs) onboard the Cassini spacecraft, and found no evidence for time variation in the decay of ^{238}Pu. Based upon the absence of oscillations similar to those found in the BNL and PTB datasets, both Norman et al. and Cooper concluded that the solar influence suggested in Refs. [1–3] was not present. However, a more recent analysis [18] of the data of Norman et al. [15] does suggest the presence of a solar influence, albeit at a lower level than indicated by the BNL or PTB data. As has been noted previously [19], the very same nuclear physics considerations which are responsible for the fact that beta-decay half-lives vary from fractions of a second to billions of years (i.e., nuclear wavefunctions, selection rules, phase space, etc.) would also apply to the effects of any solar influence. Hence, there should be no expectation that periodic effects would be present in all beta-decays at the same $\sim 3\times 10^{-3}$ level seen in the BNL and PTB data. This observation applies as well to the data in Ref. [16], and especially to the analysis in Ref. [17]. In the latter case, the decay of ^{238}Pu is a pure alpha-decay, and leads to a daughter (^{234}U) which is an alpha decay with a 246,000 year half-life [20]. Therefore, there would have been no significant contributions from beta-decays in the Cassini RTG data, whereas all previous data sets in which periodic effects were seen were measurements of beta-decays or electron capture.

Similar anomalous behaviors and periodicities in nuclear decay data have in fact been observed by other groups. Data from the measurement of ^{60}Co and ^{90}Sr/^{90}Y published by Parkhomov [21–23] also exhibit annual and monthly periodicities when measured on separate Geiger–Müller (G–M) counting systems in a controlled experiment. Interestingly, ^{239}Pu counted by Parkhomov did not show any such periodicities. This demonstrates two important points: first, that the oscillations were likely not of an environmental origin; and second, the oscillations appear to arise primarily in beta-decays, in agreement with the previous remarks. Also, since the counting systems were G–M detectors in the Parkhomov experiments, there would be no environmentally induced gain shifting since there is no amplifier in the system.

Further evidence of annual periodicities in decay data was presented in an earlier publication by Ellis [24]. His data showed an annual oscillation in the measured decay rate of neutron-activated manganese foils used to calibrate a system of plutonium-beryllium neutron sources. Interestingly, the ^{56}Mn counts exhibited an annual periodicity, yet the ^{137}Cs standard used to calibrate his scintillation detection system did not. This indicates that, as an experimental observation, isotopes have different sensitivities to whatever influence is causing the observed effects. Moreover, since the two isotopes were measured on the same counting system, it would also appear to rule out a simple environmental systematic cause. This supports the analysis by Jenkins et al. [19], who examined all of the likely environmental influences on the counting systems utilized in the BNL, PTB and Purdue experiments [2,4,5] and concluded that all of the known suspect effects were too small to have caused the observed oscillatory behavior. Additionally, a recent paper by Steinitz et al. [25] presents extensive evidence for annual and sub-annual periodicities in the measured decay rates of ^{222}Rn (and its progeny), which lends further support to the solar influence hypothesis. Furthermore, we performed additional analyses [26] of the ^{90}Sr/^{90}Y data published in Refs. [21–23], and found that the data which contained annual and monthly periodicities also exhibited striking similarities to the frequency content in the Mount Wilson Solar Observatory's solar diameter measurement data.

Some recent experiments have been performed to test the hypothesis of a neutrino-mediated solar influence on terrestrial nuclear decays by two independent groups, two of them performed by our group and one performed by an independent group in South Africa. The two experiments at the National Institute of Standards and Technology (NIST) performed by our group [27,28] examined a possible variation of the electron anti-neutrino flux ($\bar{\nu}_e$) resulting from the β^--decay of ^{198}Au by utilizing samples with different geometries. The theory behind this experiment is that if the specific activity was high enough from the resulting decay of ^{198}Au in a sphere (compared to a foil as in Ref. [27] or a wire as in Ref. [28]), the $\bar{\nu}_e$ flux could approach the solar electron neutrino (ν_e) flux experienced on Earth, which is $\sim 60\times 10^9\,\nu_e\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$. Although the results of both of these experiments were inconclusive, they did not clearly support the hypothesis that $\bar{\nu}_e$ could affect the ^{198}Au β^--decay. A different experiment was performed by de Meijer, et al. [29], where decay rates of various isotopes were measured in close proximity to a 2 MW$_{th}$ nuclear reactor, which is a well characterized source of $\bar{\nu}_e$. The negative results of this series of experiments led de Meijer, et al. [29] to suggest two possibilities. The first was that the $\bar{\nu}_e$ flux was not high enough from the 2 MW$_{th}$ reactor, and a larger reactor may show better results. The second, which was similar to the conclusions drawn by our group in Refs. [27,28], was that $\bar{\nu}_e$ might not have the same effect as ν_e on β^--decay. Furthermore, the possibility exists that solar ν_e are not primarily responsible for the observed effect, but rather some other component of solar neutrino flux (e.g., ν_μ or ν_τ) or an as yet unknown particle or field [28].

The purpose of this article is to present ^{36}Cl decay data collected at The Ohio State University Research Reactor (OSURR), in Columbus, Ohio, USA, over the course of 7 years, which further strengthen the case for a solar influence on some nuclear decays. The data were taken weekly, as part of the calibration check of an instrument used at the OSURR facility, thus the data were not the result of an experiment per se, but were collected as part of routine operations at the OSURR. It is evident from the data shown in Fig. 1 that there is an oscillation with an approximate annual period that appears to correlate with the inverse-square of the Earth–Sun distance, and possibly additional frequencies that can also be linked to the Sun.

2. Data collection/detector set-up

As noted above, the ^{36}Cl data were collected weekly as part of the efficiency check of the Eberline Beta Counter BC-4 that is used for counting of contamination survey wipes. The detector system incorporates a 1.75 inch (4.4 cm) diameter G-M pancake-style tube contained inside 0.875 inches (2.22 cm) of lead to reduce background [30]. The BC-4 instrument itself sits in the reactor bay at OSURR, which has partial environmental control. Although it is not air-conditioned, space heaters are used to maintain the interior temperature in a comfortable range during colder months. Thus, temperature is controlled to some extent, but relative humidity is not.

The source utilized for the calibration check is a 0.4 μCi ^{36}Cl split check source (manufactured by Nuclear-Chicago, Model SK2–1) with a diameter of 1.0 inch (2.54 cm). The two aluminum half-disk sources which comprise the check source are contained within an aluminum holder with an outer diameter of 1.25 inches (3.2 cm). The active regions of the source are two machined circular depressions, each approximately 0.2 inches in diameter, located near the center of the 1-inch disk on each half disk. The decay of ^{36}Cl is primarily by β^--emission (98.1%, E_o=708.6(3) keV, $T_{1/2} = 3.01(2)\times 10^5$ y [31]) to the ground state of ^{36}Ar, which is stable (there is also a competing K-capture mode to ^{36}S with a 1.90% branching ratio). We note in passing that this is the same isotope used as the standard in the BNL ^{32}Si half-life experiment.