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Anomalous effects of radioactive decay rates and capacitance values measured inside a modified Faraday cage: Correlations with space weather

F. Scholkmann[1], V. Milián-Sánchez[2], A. Mocholí-Salcedo[3], C. Milián[4], V. A. Kolombet[5] and G. Verdú[2,6]

[1] *Research Office for Complex Physical and Biological Systems - 8038 Zurich, Switzerland*
[2] *Institute for Industrial, Radiophysical and Environmental Safety, Universitat Politècnica de València Camino de Vera, s/n, València, Spain*
[3] *Traffic Control Systems Group, ITACA Institute, Universitat Politècnica de València Camino de Vera, s/n, València, Spain*
[4] *Centre de Physique Théorique, CNRS, École Polytechnique - F-91128 Palaiseau, France*
[5] *Institute of Theoretical and Experimental Biophysics, Russian Academy of Science - Moscow Region, Pushchino 142290, Russia*
[6] *Chemical and Nuclear Engineering Department, Universitat Politécnica de València Camino de Vera, s/n, València, Spain*

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Abstract – Recently we reported (Milián-Sánchez V. *et al.*, *Nucl. Instrum. Methods A*, **828** (2016) 210) our experimental results involving ^{226}Ra decay rate and capacitance measurements inside a modified Faraday cage. Our measurements exhibited anomalous effects of unknown origin. In this letter we report new results regarding our investigation into the origins of the observed effects. We report preliminary findings of a correlation analysis between the radioactive decay rates and capacitance time series and space weather related variables (geomagnetic field disturbances and cosmic-ray neutron counts). A significant correlation was observed for specific data sets. The results are presented and possible implications for future work discussed.

Introduction. – In a recently published paper [1] we reported measurements of ^{226}Ra decay rates and capacitance changes inside a modified Faraday cage (MFC). The measurements exhibited anomalous effects of unknown origin. In particular, it was shown not only that the mean (or the median) values of the measurements performed outside and inside the box were different, but also that other statistics (particularly the variance) were significantly different. Regarding the anomalous variations (increase or decrease) in radiation counts, we concluded that this finding could be explained, but only partially, by changes in the electronic circuit capacitance; at the same time, these capacitance changes could not be explained. It was also shown that those anomalies were not caused by environmental factors like air temperature, pressure and humidity (for example, see figs. 2a and 2b in [1]). It has also been possible to exclude that the process of positioning the radioactive source inside the counter system caused the effect, and it was ruled out that the connecting cables inside the box were involved producing the effect [1].

One could think that those anomalous variations (ascending and descending ramps and peaks), as in fig. 3 of [1] (see also fig. 1 below), could have been caused by some other trivial unnoticed factor in the measuring chain. In what follows it will be seen that, in principle, it seems that there was no such factor to which those effects could be ascribed. Rather, they can be correlated with other unexpected environmental factors.

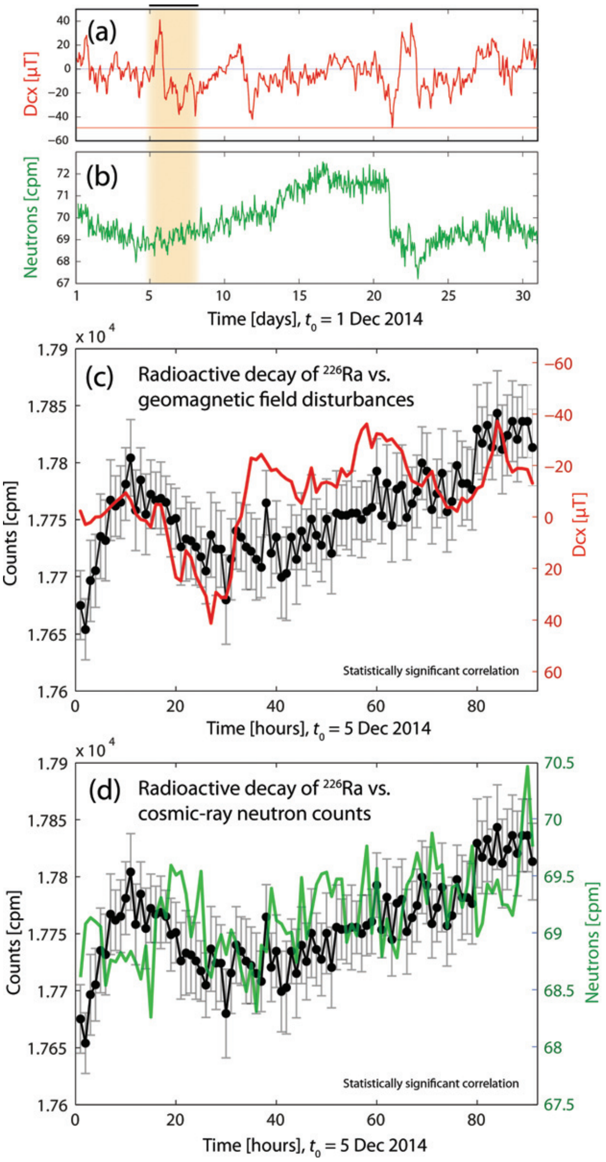

Fig. 1: (Colour online) Correlations between decay rates of ^{226}Ra inside the MFC (black) and Dcx and N time series. (a)–(b) Time-series of Dcx index and N during December 2014 1st till 31st. The time when the experiment was performed is marked with an orange area. (c) Changes of the decay rate and Dcx index (red), (d) changes of the decay rate and N (green). In (c) the scaling of the y-axis is reversed for the Dcx values to make it easier to see the correlation. The radioactive decay data shown correspond to the data depicted in fig. 3a in [1].

Correlations between space weather and measured radioactive decay rates and capacitance time series. – In a new analysis of our data, we recognized that, on the one hand, the anomalous measurements of decay rates sometimes showed peaks coincidentally close to solar noon and solar midday (see figs. 1c, 1d, 3a, 4a, and 5 in [1]). On the other hand, a closer inspection of the peak in fig. 5 in [1] showed that it coincided with a peak in geomagnetic activity [2].

Before continuing with this discussion, it should be highlighted that in the previous paper [1] the possible influence of mundane environmental effects was ruled out. For example, see fig. 1 and (sect. 2.2.2.1 a) of [1]: at the beginning of the experiments (outdoors), the temperature was 17.9 °C and it dropped about 8 °C at the point where the first maximum was reached (located 0.8% higher than the first measurements in the graph). But on the base of the linear regression line that can be drawn between ambient temperature and the count rate of the detector, the maximum would have been up to 0.36% higher. Beside this, it has been also shown that the wet air density increased by 0.035 kg m^{-3} between the two aforementioned time points, and, therefore, without such increase true readings would have been even higher.

Having discarded all the referred environmental factors, and based on the aforementioned coincidence observed (*i.e.*, count rates *vs.* geomagnetic activity), one of the authors (FS) performed a new analysis of the data given in [1] to check for possible correlations between those data and certain astrophysical/geophysical indices, namely, the geomagnetic activity and the cosmic-ray neutron counts.

According to the premises explained in ref. [3], the geomagnetic activity index (Dcx) was chosen in this new analysis as the relevant parameter to quantify the geomagnetic field disturbances (the larger the amplitude of the index, the stronger the disturbances; a geomagnetic storm causes a sharp positive elongation of Dcx followed by a large negative spike). On the other hand, measuring neutron counts (N) gives information about the cosmic-ray activity and the solar-terrestrial environment. To conduct our study, hourly data of the Dcx index and of the N values were obtained from `http://dcx.oulu.fi` and `http://www.nmdb.eu/nest/search.php`, respectively. The Dcx index correlates with the intensity of the geomagnetic field disturbances (*i.e.*, low: Dcx $= [-50\,\text{nT}, 0\,\text{nT}]$; moderate: Dcx $= [-100\,\text{nT}, -50\,\text{nT}]$; high: Dcx $= [-250\,\text{nT}, -100\,\text{nT}]$).

As a result of the data analysis, we obtained statistically significant correlations between the mentioned indices and i) decay rates and ii) capacitance measurements. This finding constitutes the main result presented in this letter.

For the correlation analysis the Spearman correlation coefficient (r) and the statistical significance of the correlation were determined using a robust correlation analysis considering bivariate outliers in the data and conducting a null hypothesis statistical significance testing based on a percentile bootstrap test (95% bootstrap confidence intervals (CI), corresponding to $\alpha = 5\%$) [4]. The statistical test based on the percentile bootstrap CIs has the advantage over the traditional t-test that it is less sensitive to heteroscedasticity.

Data presented in the figures in [1] were analyzed to look for correlations with the two aforementioned indices (Dcx and N). In particular, data presented in figs. 1d, 3a, 4b, 4d, 5, 6b, 6c, 6d, 9a, 9b, and 10 were analyzed since these data sets provided a large enough data corpus to perform a statistically meaningful analysis. Of those analyses, twelve out of eighteen (*i.e.*, 66.6%) showed statistically significant correlations. In this letter, only two of those correlations are presented in fig. 1. In a subsequent paper we will present all the analyzed figures and the results (*i.e.*, the values of the correlation coefficients, p-values and the 95% CIs) obtained, along with a detailed description of the circumstances under which those correlations occurred.

In fig. 1(b)–(d), the measurement of a decay rate is plotted against both Dcx (fig. 1(c)), and cosmic-ray neutron counts (fig. 1(d)). The correlations are clearly visible and statistically significant: $r(^{226}\mathrm{Ra}, \mathrm{Dcx}) = -0.300$, 95% CI $[-0.479, -0.101]$; $r(^{226}\mathrm{Ra}, N) = 0.303$, 95% CI $[0.112, 0.471]$.

Discussion. – These observed correlations indicate that the geomagnetic field disturbances and the cosmic-ray activity are not directly accountable for the variations observed inside the MFC (fig. 1) since the magnetic field variations are too small to induce the anomalous effects reported in [1]. Furthermore, the described environmental neutron activity variations, to the best of our knowledge, have not been reported as a factor inducing such changes in passive components (*i.e.*, class-I capacitors) and Geiger-Müller counters. However, there does appear to be some link between the geomagnetic field state and the cosmic-ray activity (and thus the space weather) and the observed effects inside the MFC. The physical phenomena represented by these two indices (Dcx and N) seem to be primary factors which act indirectly upon the systems measuring the decay rates and the capacitance (as described in [1]).

Surprisingly, these correlations cannot be observed in the absence of the MFC, which, in turn, seems to act as an additional intermediary element between the first primary physical phenomena and the final results. One question that arises is whether another design of the MFC (*e.g.*, an increased or decreased number of metal layers) would yield different correlation values.

Interestingly, a correlation of decay rate properties (characteristics of the fluctuations) and space weather indices has also been observed by other investigations. A correlation was reported in the study by Zenchenko *et al.* [5], for example, and various publications pointed to a possible link between decay rate fluctuations and solar activity (*e.g.*, [6,7]).

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