



Solar influence on radon decay rates: irradiance or neutrinos?

S. Pommé^a

European Commission, Joint Research Centre (JRC), Geel, Belgium

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Abstract Radon decay rate data from 2007–2011, measured in a closed canister with one gamma counter and two alpha detectors, were made available for analysis by the Geological Survey of Israel (GSI). Sturrock et al. have published several papers in which they claim that decay rate variations in the gamma counter can be associated with solar rotation. They assert influences by solar and cosmic neutrinos on beta decay and draw unsubstantiated conclusions about solar dynamics. This paper offers an alternative explanation by relating the daily and annual patterns in the radon decay rates with environmental conditions. Evidence is provided that the radon measurements were susceptible to solar irradiance and rainfall, whereas there is no indication that radioactive decay is influenced by the solar neutrino flux. Speculations about solar dynamics based on the concept of neutrino-induced beta decay are ill-founded.

1 Introduction

A consortium of national metrology institutes has studied the temporal behaviour of repeated radioactivity measurements in search of a relationship with variations in the solar neutrino flux due to seasonal changes in the Earth–Sun distance and solar dynamics [1–10]. They analysed the most extensive data set of precise activity measurements collected over periods spanning 6 decades and came to the solid conclusion that there is no indication for deviations from the exponential decay law other than instrumental instabilities, amongst which those induced by changes in environmental conditions. All claims raised by Fischbach, Sturrock, and co-workers on ‘neutrino-induced decay’ (see e.g. [11–15]) have been scrutinised and refuted convincingly (see [1–10] and references therein).

The most recent investigation [10] concerned the claim by Sturrock et al. [13–15] that measurements of gamma radiation associated with the emanation and decay of radon in a sealed container at the Geological Survey of Israel (GSI) laboratory [16] performed over a decade show cyclic modulations indicative of the dynamics of the solar interior. From a subset of the gamma data, covering a one-year period from April 2013 to June 2014, Pommé et al. could establish a direct relationship between daily peaks around noon with solar irradiance on the experimental set-up as well as a baseline shift of nocturnal signals due to exposure to rainfall driven by southern wind [10]. Consequently, it was concluded that the radon measurements performed at the GSI [16] are insufficiently stable to investigate the variability of decay constants. Moreover, on physical grounds, the short half-lives of the beta emitters in the radon decay chain rule out neutrino-induced beta decay as the governing process behind the hypothetical monthly fluctuations [10].

Sturrock et al. [17] wrote a “rebuttal” to these conclusions, however their argumentation mostly consisted of ignoring the counterevidence [18]. They admitted that neutrinos do not necessarily induce decay, but repeated the gratuitous assertion that solar influences affect the “directionality” of the subsequent gamma emissions. Shortly after, Sturrock et al. [19] and Steinitz et al. [20] published papers in which they analyse additional data from the GSI radon experiment, dating from Feb 2007 until July 2011. Again, they haphazardly associate count rate instabilities at a monthly time scale with solar rotation, thus disregarding all literature references demonstrating the invalidity of their assumptions. In this work, the GSI 2007–2011 gamma and alpha decay rate data, kindly provided by Steinitz et al., are scrutinised and compared with historical weather records in Israel.

^a e-mail: stefaan.pomme@ec.europa.eu

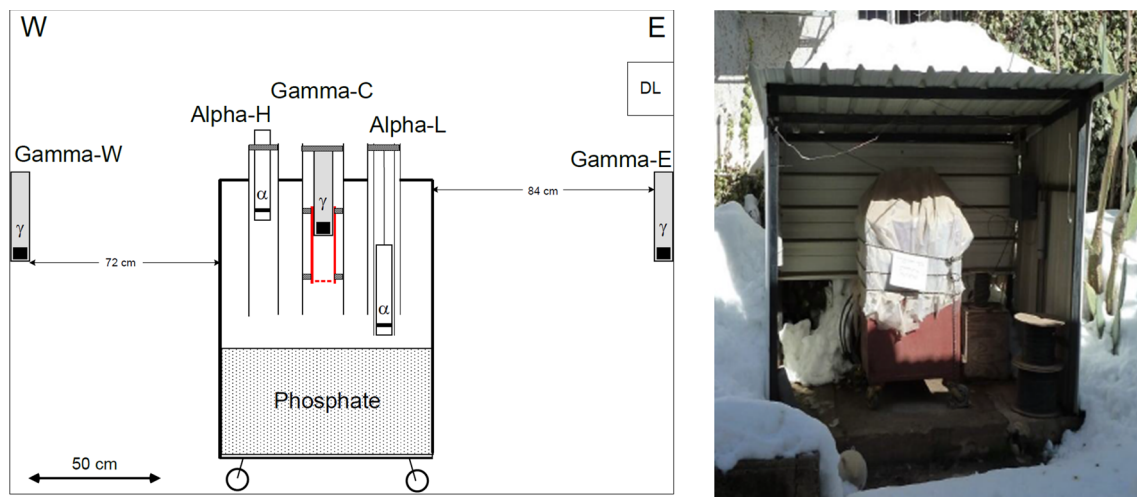


Fig. 1 Schematic representation and frontal picture of the radon experiment at GSI [16,20], with the phosphorite rock at the bottom and the positions of the gamma and alpha sensors. The covering hut is open to the south, such that the instrument is partially exposed to sunlight

and rainfall driven by southern wind. The hut and adjacent building cast a shadow on different parts of the set-up. The external parts of the electronics are covered with large polyethylene sheets for protection

2 Observations

2.1 Daily patterns

The experimental set-up at GSI has been described by Steinitz et al. [16,20] and briefly by Pommé et al. [10]. In Fig. 1, a schematic drawing and a picture are shown. A 2"×2" NaI(Tl) gamma detector and two alpha detectors are suspended in a sealed tank containing phosphorite rock which emanates radon (^{222}Rn) and its progeny. The Alpha-H sensor is positioned at the high left side of the tank, the Gamma-C detector in the centre and the Alpha-L at the bottom right, close to the ground rock. The gamma detector (PM-11, ROTEM Inc., Israel) is inserted into a 5-mm-thick lead pipe with a perforated lead plate at the bottom, which confines its measurand primarily to the activity of the gas inside the pipe. The alpha detectors (Barasol BT45N with 450 mm² Si diode) mostly detect particles emitted within a range of a few cm in front of their sensitive area. The set-up is installed in the garden of the GSI research institute, inside a covering hut which is open to the south. It is partially exposed to sunlight, rainfall and wind. Two additional external gamma detectors were fixed to the hut at the east (Gamma-E) and west (Gamma-W) side, at the height of the air volume in the tank. About half of their count rate is produced by the radon progeny in the gas volume [20].

The integral count rates in the detectors show significant daily and annual variations [13–20]. In Fig. 2, typical count rates in the Gamma-C, Alpha-H and Alpha-L detectors are shown as a function of the time of the day. They are presented as residuals from the mean count rate. Averages were taken

over the years 2008, 2009 and 2010, during January, April, August and October, respectively. In addition, graphs are provided showing the corresponding temporal dependence of the ambient temperature, the atmospheric pressure and the battery voltage recorded at the GSI [16,20]. The battery voltage shows a negative correlation with the ambient temperature. The air pressure shows local maxima before noon and midnight, and is on average anti-correlated with the temperature.

The gamma count rate shows a diurnal pattern which loosely resembles the evolution of the ambient temperature, except for a negative dip in the early evening. The daily peaks show resemblance with the expected intensity of solar irradiance in Jerusalem [10]. The relative intensities of most peaks in the 2013–2014 data could be reproduced with a simple mathematical model of solar irradiance [21] for any time of the day and for any day of the year. The alleged relationship with solar or cosmic neutrinos can be refuted, since there is no matching diurnal variation of the neutrino flux on Earth. The timing of the local dip varies smoothly between 14:30 in winter and 17:30 in summer (expressed in local time, UT+2 h), which is about 1–2 hours before the end of daylight in Jerusalem [22]. It may correspond to a period in which a part of the set-up is in the shadow of the adjacent building.

The alpha-H count rate is fairly stable throughout the night and morning, but shows a marked dip in the evening, between 15:30 in winter and 18:30 in summer (UT+2 h), which is about one hour before sunset [22]. Speculatively, this may correspond to a period in which the top side of the tank receives more sunlight than the bottom side due to the rising shadow of an external object. The dip is more pronounced

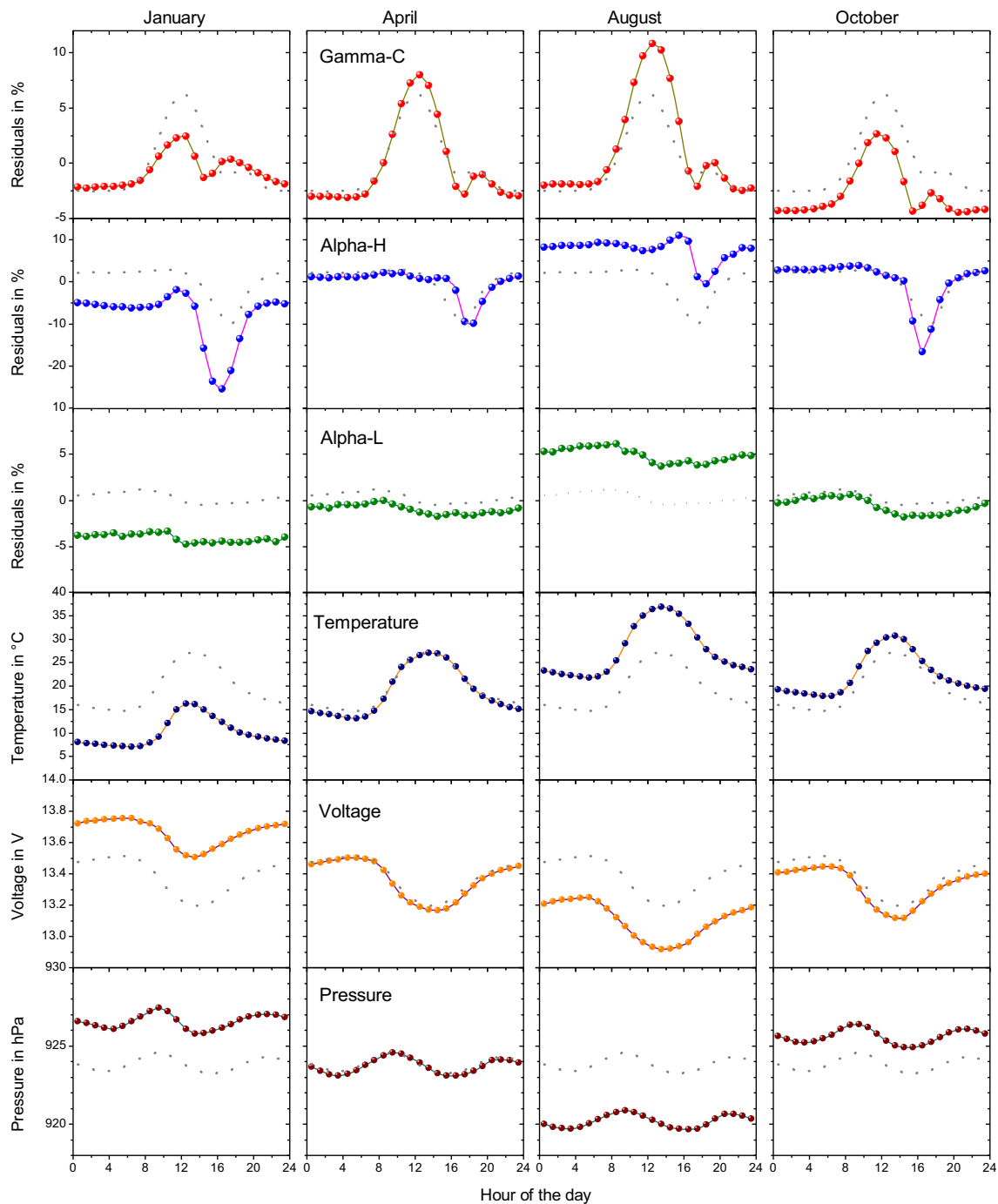


Fig. 2 Temporal dependence of the count rates in the Gamma-C, Alpha-H and Alpha-L detectors in the closed radon tank, together with the ambient temperature, atmospheric pressure in the hut and the battery

voltage of the instrument. Averages were taken over the years 2008–2010 for each day in January, April, August and October, respectively

in winter than in summer. The alpha-L count rate, measured closely to the rock at the bottom of the tank, is comparably stable on a daily timescale. It features a negative slope around noon and a positive slope along the remainder of the day and night. Throughout the year, it shows on average a positive correlation with temperature.

The count rates in the external gamma detectors were not available for analysis in this work, but some characteristics have been published by Steinitz et al. [20]. At a daily timescale, they show a maximum rate at night and a minimum at noon and early afternoon, the shape of the curve resembling the inverse of the temperature variation. In Gamma-W, there is a local peak in the early evening, comparable to Gamma-C.

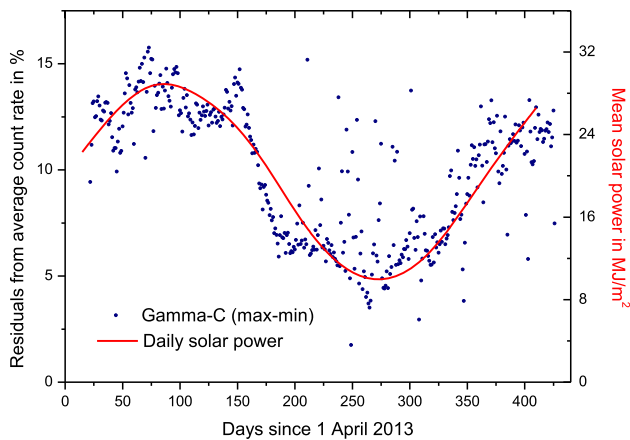


Fig. 3 Relative difference between the daily maximum and minimum count rate measured by the gamma counter in the radon tank at GSI [16,20] as a function of the day (starting from 1 April 2013), compared to the typical daily solar power produced in Mega Joule per m^2 in Jerusalem

2.2 Seasonal trends

The evidence suggests that solar irradiance is the driving force behind the daily peaks in the Gamma-C count rates [10]. This is corroborated by Fig. 3, which shows a comparison between the peak heights in the count rates measured in the radon tank from April 2013 to June 2014 by Steinitz et al. and the typical daily solar power produced in Jerusalem [23]. The peak heights were calculated in a rudimentary manner, as the difference between the maximum (around noon) and minimum count rate (at night) in the gamma counter, and they were plotted as relative differences (in %) from the overall mean count rate value. The solar power values were obtained as monthly averages (in MJ/m^2) and intermediate data were derived from a spline function in the graphical tool. The correlation between both quantities is striking. Some of the local deviations from the smooth trend line can be associated with exceptionally bright or cloudy days. The particularly high variance of the count rate in the winter period appears to be related with the higher frequency of rainfall. The same may apply to the Gamma-E and Gamma-W detectors [20].

A similar pattern was found in the Gamma-C data collected in the period 2007–2011. There was some variation in the height of the peaks from one year to another – possibly because the plastic cover of the set-up was renewed annually – but the seasonal trend was qualitatively the same: smoothly varying large peaks in the summer and small peaks with high variance in the winter. Figure 4 presents a daily mean value of the peak heights averaged over the years 2008–2014, compared to the squared value of the maximum radiance at noon (expressed as a percentage) derived from a mathematical model [21]. The correlation factor between the daily average temperature and the gamma count rate peak at noon (max–

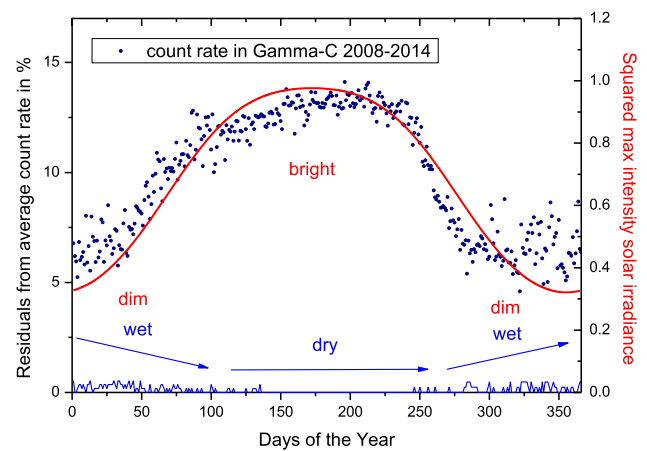


Fig. 4 Average daily peak heights (max-min) in gamma count rates measured at GSI in 2008–2014 as a function of the day of the year, compared to the squared amplitude of the solar irradiance from a mathematical model [21]. At the bottom, an indication of the occurrence of rainfall over the covered period is shown

min) is 0.67. These are some of the many indications that the radon measurements were susceptible to sunlight and environmental conditions outside the tank [10], whereas interactions with cosmic neutrinos offer no plausible explanation.

A similar susceptibility to solar power can be observed in the daily maximum and minimum count rates in the alpha-particle counters, shown in Fig. 5 together with the gamma data over a period from Aug 2008 to May 2011. The seasonal variations in the Alpha-H and Alpha-L count rates largely follow the trend of the ambient temperature. The correlation factor between the daily average temperature and the daily maximum count rate in Alpha-H is 0.75 and for Alpha-L (max or min) it is 0.6. On top of this seasonal trend, local deviations appear in the three counters, presumably influenced by specific weather conditions.

2.3 Extraordinary events

Steinitz et al. [16,20] have monitored atmospheric temperature and pressure in the hut, but did not take account of the solar irradiance and rainfall affecting the exterior of the tank and the protruding electronic components at the top side of the set-up. For additional weather information, use can be made of historical weather data from the Ben Gurion airport in Tel Aviv [24], about 50 km away from GSI in Jerusalem.

In Ref. [10], evidence was provided that unusual amplitudes of the gamma peaks were not only related to exceptionally bright or dim weather, but also occurred in coincidence with rainfall and thunderstorms. In Fig. 6, the peak heights (= max–min) and daily minimum count rates (at night) in the 2013–2014 gamma count rates are plotted together with an indication of rainy days and the amount of precipitation (in Tel Aviv). Even though there is no simple one-to-one relation-

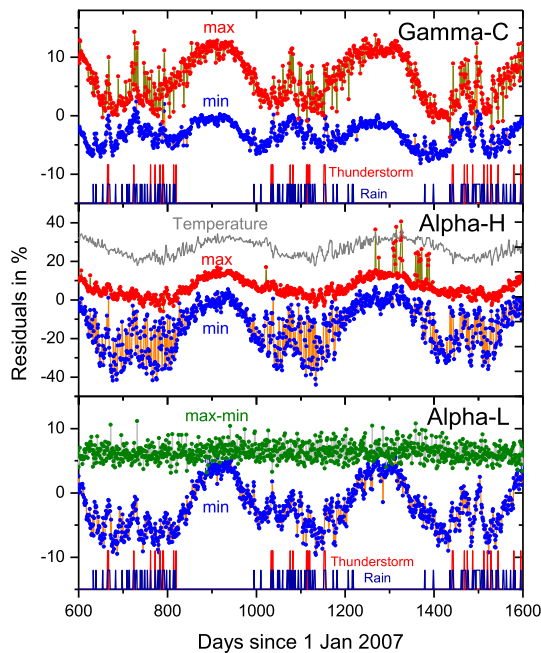


Fig. 5 Daily maximum (or max–min) and minimum count rates in the gamma and alpha counters measured from Aug 2008 to May 2011, together with indications of rainfall and thunderstorms at 50 km distance [24] and the average ambient temperature

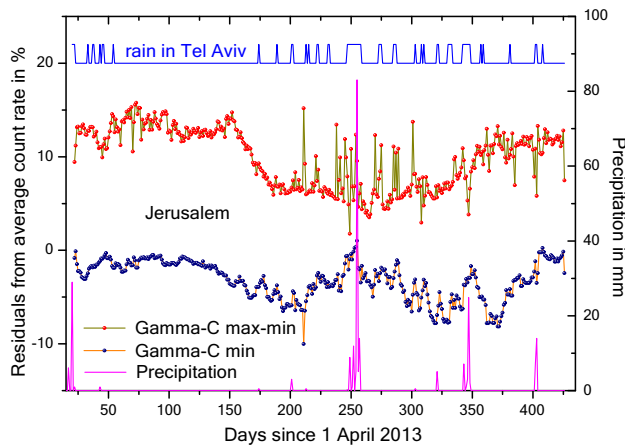


Fig. 6 Diurnal peak heights (max–min) and minimum count rates (at night) measured by the Gamma-C counter in the radon tank [16,20], compared to days with rainfall and amount of precipitation measured at the airport in Tel Aviv [24]. The base count rate rises in rainy periods and gradually decreases afterwards

ship between rainfall (at 50 km distance) and the measured gamma count rate in the radon tank, it is striking that precipitation often coincides with significant variations in peak height during the day and an increase of the count rate at night.

The set-up is particularly exposed to rainfall driven by southern wind, and such events manifest themselves in pronounced peaks in the daily minimum count rates in all three detectors. This is apparent from the 2007–2011 data, which

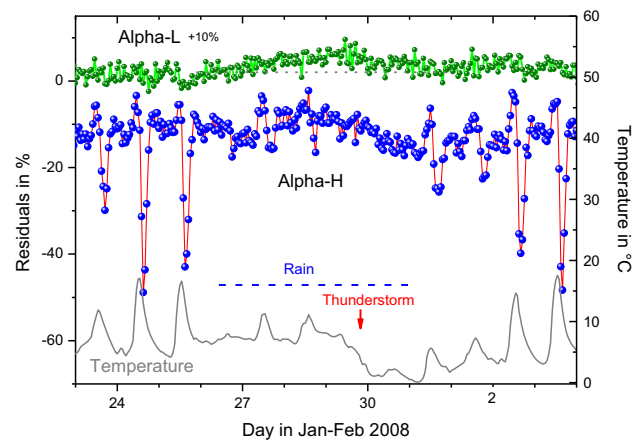


Fig. 7 Influence of rain and a thunderstorm on the local temperature and the count rates in the Alpha-H and Alpha-L detectors. (The alpha-L residuals were shifted upwards for visibility.) They show a positive trend during the thunderstorm. The Alpha-H count rate loses its typical negative dip, probably by lack of a significant temperature gradient

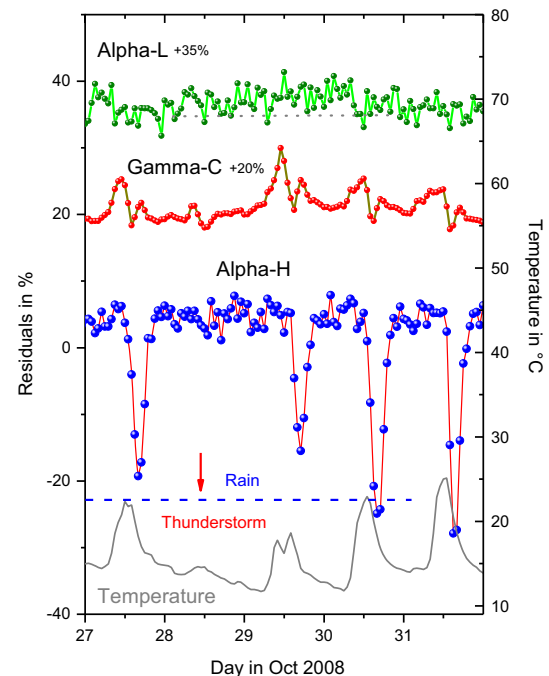


Fig. 8 Influence of rain and a thunderstorm on the local temperature and the count rates in the internal detectors. (The Gamma-C, and Alpha-L data have been shifted upwards for visibility.)

contain numerous coincidences between rainfall and deviations from normal behaviour in the gamma and alpha detectors. In Fig. 5, the count rates follow a smooth seasonal trend in dry periods, i.e. mostly in summer, but exhibit abrupt variations on days with rainfall and thunderstorms. Two examples are highlighted in Fig. 7, showing a close-up of the Alpha-H and Alpha-L count rates in Jan 2008, and in Fig. 8, showing the three counter outputs in Oct 2008. It is evident that the count rates deviate from their regular pattern on rainy days

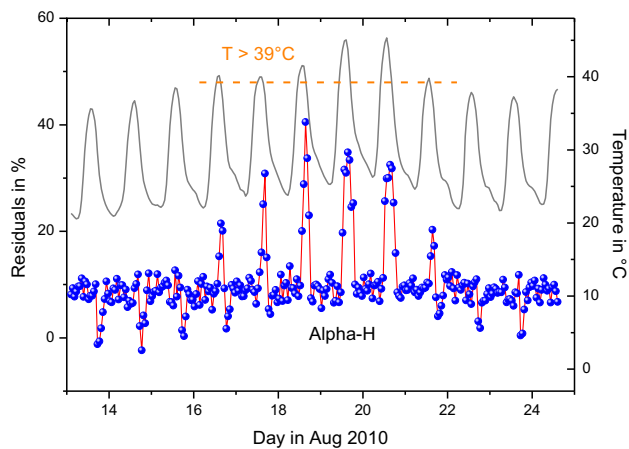


Fig. 9 Occurrence of exceptional peaks in the Alpha-H count rate, appearing about 1 h after the ambient temperature has exceeded 39 °C

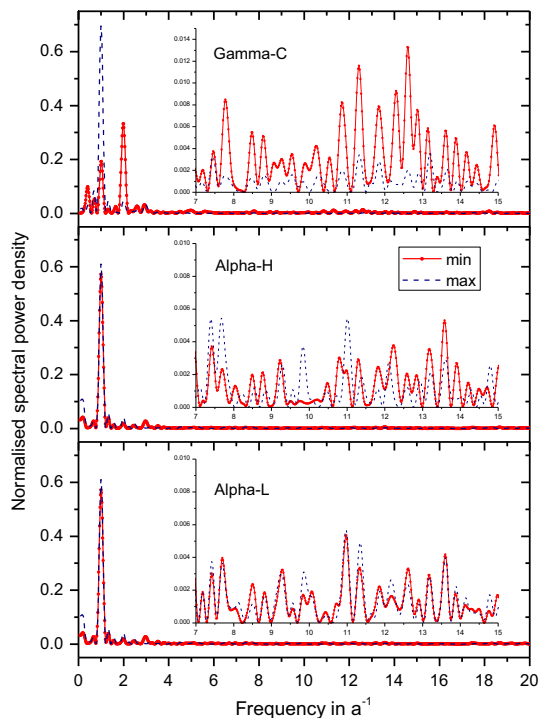


Fig. 10 Lomb-Scargle periodogram [9] of the daily maximum and minimum count rates in the Alpha-L, Gamma-C and Alpha-H sensors. All have an annual cycle due to temperature gradients. The nocturnal gamma count rate has an additional cycle at 2 a⁻¹ caused by its sensitivity to rainfall in the wet season. The small peaks in the mid-frequency band are mainly related to time differences between rain showers

and in particular during the thunderstorms in the night of Jan 29th and the morning of Oct 28th, respectively.

Simple statistical tests on the entire 2007–2011 data set confirm that these coincidences are not fortuitous. The average gradient in the minimum count rates one day before and one day after a day with rainfall is positive by 0.6% (Alpha-L), and 0.8% (Gamma-C, Alpha-H). It is even larger on days

with a thunderstorm: 0.7% (Alpha-L), 1% (Gamma-C), and 4% (Alpha-H), respectively. The minimum count rate drops in the following days, such that on average the slope is negative by roughly -0.1% on dry days.

Another type of anomaly is readily observed from Fig. 5, where the alpha-H maximum count rate exhibits distinct outliers on an otherwise smooth trend line. A more detailed graph in Fig. 9, representing events from mid-August 2010, reveals that these salient peaks only occur at exceptionally hot days. They peak around 15:30 (UT+2 h), typically 1 h after the ambient temperature has exceeded 39°C. On days with lower temperatures, the positive peaks disappear and the characteristic negative dips reappear in the evening.

2.4 Cyclic events

Lomb-Scargle periodograms [9] in Fig. 10 of the daily max and min count rates reveal a large resonance at a frequency of 1 a⁻¹, and minor ones at the nearest harmonic frequencies. This reflects the obvious annual seasonality. In the particular case of the daily minimum count rates in the Gamma-C counter, the largest resonance is at 2 a⁻¹. There are indeed two periods per year in which the nocturnal measurements are relatively high: in summer (associated with high temperatures) and in winter (associated with rainfall), whereas spring and autumn correspond to local dips (intermediate temperatures and low rainfall).

More importantly, no significant cycles can be found in the mid-frequency band (6 – 16 a⁻¹) in which Sturrock et al. [17, 19] locate signs of solar rotation. The normalisation of the periodograms – as defined in Ref. [9] – is such that the spectral power represents the relative reduction of the χ^2 by hypothetically fitting a sinusoidal function at a certain frequency. A power of 100% corresponds to a perfect match. Since the power values for monthly frequencies are generally less than 0.5%, there is neither a pronounced signature of singular cycles, nor of cycle pairs spaced by 1 a⁻¹. A fortiori, the proclaimed [17, 19] solar frequencies at 9.43 a⁻¹, 11.35 a⁻¹, and 12.63 a⁻¹ do not emerge from the data sets. Moreover, the environmental influences have to be filtered out before one can investigate hypothetical violations of the exponential decay law. The small peaks in the 6–16 a⁻¹ frequency range merely reflect time differences between rain showers.

3 Interpretation

3.1 Daily pattern

The daily patterns in the gamma counter are strongly correlated with solar irradiance. The alpha counters follow a different pattern in timing and amplitude, alpha-H showing a

huge local drop about 1 h before sunset and alpha-L slightly dipping at noon. It is difficult to provide a conclusive interpretation of these phenomena without direct access to the experiment. The most likely mechanism behind these daily variations is the free movement of radon gas inside the canister, possibly in combination with sensitivity of the detectors and electronics to humidity, heat and/or scattered light.

The air and radon gas in the tank mix through diffusion and convection. The radon progeny, sometimes electrically charged, attaches to aerosol particles or deposits on surfaces. The tank is a closed system in which the volume and number of gas molecules are quasi constant. The main variables are the temperature and pressure, which are assumed to be linearly correlated and anisotropic inside the tank. Temperature gradients in the tank can be expected when its walls and content adapt to the temperature variations outside. Bellotti et al. [25] have demonstrated that a tiny temperature gradient of 0.01 °C inside a glass sphere suffices for radon to preferentially occupy the colder places in the gas volume. Such effect is used to the extreme in a primary standardisation [26] technique based on the counting of alpha particles at a defined solid angle [27], by condensation [28] of gaseous radon on a cold finger [29,30].

Heavy structures with a large heat capacity need more time to equilibrate. This may be the case for the rock layer and the combination of the lead pipe and the NaI crystal in the centre. The temporal dependence of the alpha-L count rate possibly suggests that the rock heats up due to direct sunlight hitting the bottom of the tank around noon and cools down for the rest of the day and night. The lead pipe may have a relatively stable temperature due to a low thermal contact with the walls of the tank. This may explain why the Gamma-C count rate increases proportionally with the solar power, as the radon follows the temperature gradient from the heated walls to the colder pipe. It is also compatible with the opposite behaviour in the external gamma counters [20], since their detection efficiency decreases quadratically with the distance when the radon activity shifts towards the centre of the tank. The dip in the alpha-H count rate suggests a local heating of the west top area of the set-up two hours before sunset.

3.2 Annual trend

When disregarding peaks associated with rainfall, the nocturnal (midnight) count rates in the three detectors follow a sinusoidal function with a 1-year period. Nocturnal count rates in the alpha-L detector vary smoothly throughout the year, with deviations from the mean ranging between −5% in February and +6% in June (see also Fig. 2). At the same time, alpha-H count rates vary between −6% and +9%, following a temporal dependence intermediate between solar power and average temperature. The Gamma-C pattern is

less pronounced, in part because the negative trend in winter is counteracted by a positive correlation with rainfall.

The nocturnal trends suggest a seasonal variation of the radon gas concentration in the air volume of the tank, possibly due to a temperature dependence of radon emanation from the rock material. Empirical research has shown a positive linear dependency of radon emanation from soil as a function of temperature by about 0.2% per 1 °C (in a range between −20 °C and 45 °C) [31]. This may be due to a reduction in adsorption of radon onto grains when diffusing through porous material [32].

The maximum count rates in the three detectors are correlated with temperature and solar irradiance. The magnitude of the seasonal effect (comparing dry days in winter and summer) is roughly 10% in Gamma-C, 14% in alpha-L and 45% in alpha-H. Heat and humidity appear to be the driving forces. They may affect radon transport and detector response.

3.3 Extraordinary events

On particularly hot days, such as e.g. 21 June 2010 with a maximum temperature of 41 °C, one observes extremely high peaks in the Gamma-C (max–min = 15%), Alpha-L (max–min = 8%) and Alpha-H (max–min = 30%). The inverse is true on days with a thunderstorm, when the sunlight is largely blocked by thick clouds. For example, on 28 Oct 2008 (Fig. 8) the peaks in the count rates in Gamma-C (max–min = 3%), Alpha-L (max–min = 6%) and Alpha-H (max–min = 7%) are comparably low, as is the merely 2 °C temperature difference between night and day. This confirms solar irradiance as the driving force in the diurnal cycles.

The Alpha-H count rate shows towering, positive peaks about 1 h after the ambient temperature exceeds 39 °C, such that the negative dip in the evening disappears (Fig. 9). Without spectral information, it is difficult to assess whether this should be associated to unusual effects in radon transport or in detection efficiency. It is conceivable that thermal noise may surpass the electronic threshold when the detector has reached a critical temperature. It is also striking that the dip in the alpha-H count rate pattern is deeper in winter than in summer, except on rainy days (with low irradiance).

It has been established that the minimum count rate in the counters rises on rainy days and decreases in the subsequent dry periods (Figs. 5, 6). The occasional wetting of the set-up may affect the electronics and the temperature of the tank walls, especially at the south side. Possibly some humidity gets trapped in the tubes hosting the detectors. Without spectral information it is unclear whether the humidity has an effect on the threshold of the detectors. The day after a thunderstorm, the peak in the Gamma-C counter can be higher than expected from the ambient temperature (see e.g. 29 Oct 2008 in Fig. 8). This may point to an enhanced temperature

gradient due to cooling down of the Gamma-C detector and lead collimator during the stormy day.

4 Conclusions

The instabilities in the radon measurements at GSI are obviously related with solar irradiance and rainfall and cannot be ascribed to neutrinos. Besides sensitivity of the electronics, free movement of radon gas inside the tank along temperature gradients is the most likely mechanism behind the diurnal and seasonal decay rate changes in the small gas volumes monitored by the detectors.

The observation of “neutrino-induced decay” appears to be an illusion fed by confirmation bias. The experiment has not been conducted with sufficient care to eliminate environmental influences and counterevidence has been systematically ignored to maintain the claim of new physical discoveries. The evidence does not suggest that radioactive decay is triggered by neutrinos. The subsequently emitted radiation is not aligned with neutrino flux. There are no cyclic deviations from the exponential decay law. Ensuing inference about solar dynamics is unfounded.

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Data Availability Statement This manuscript has no associated data or the data will not be deposited. [Authors’ comment: The data set is property of the Geological Survey of Israel (GSI).]

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