EFFECT OF SOLAR FLARES ON ^{54}Mn AND ^{57}Co RADIOACTIVE DECAY CONSTANTS PERFORMANCE

by

Jonathan WALG [1], ***Yael PELEG*** [1], ***Anatoly RODNIANSKI*** [1], ***Nir HAZENSHPRUNG*** [2], ***and Itzhak ORION*** [1*]

[1]Ben Gurion University of the Negev, Beer Sheva, Israel
[2] Soreq NRC, Yavne, Israel

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Changes in radioactive decay rates due to solar flares have attracted increasing scientific attention in recent decades. In previous studies we demonstrated that solar flares cause changes in the decay rate of ^{241}Am, ^{222}Rn, and ^{232}Th. The change in the count rate of ^{54}Mn due to solar flares, as observed by scholars at Purdue University in 2006, encouraged us to repeat the measurements. In addition, we measured gamma radiation count rates of ^{57}Co that undergoes electron capture, as in ^{54}Mn decay. Our new measurements indicate that there is a delay of about five days between the solar flare occurrence and the decrease in ^{54}Mn count rates. Also, we conclude that in the ^{54}Mn study of 2006 there was a delay between the solar flares and the resulting count rate dips. With regard to the ^{57}Co counting system, we measured about a seven-day delay between the occurrence of solar flares and the count rate dips. We conclude that ^{54}Mn and ^{57}Co interact with neutrinos that originate during solar flares.

Key words: sun, flares, neutrino, decay constant

INTRODUCTION

The radioactive ^{54}Mn isotope is an electron-capture decay nucleus with a 312-day half-life [1]. According to Jenkins and Fischbach, the solar flares that occurred in December 2006 were among the reasons for the change in the decay rate of ^{54}Mn [2]. Indeed, they proposed that the decay rate of ^{54}Mn may decrease during solar flares.

Pommé [3] contradicted these findings, arguing that solar flares cannot affect decay rates. Pommé's work presented measurements for a wide range of radioactive materials, including average count rates gathered over a long period that could obscure the type of results presented by Jenkins and Fischbach [2]. However, we agree with Pommé's use of extensive averaging to study periodical changes in the radiation count rates of radioisotopes because in these cases wide-scale averaging was appropriate [4].

In addition, a study by Parkhomov concerning radioactive decay rates presented further examples similar to Jenkins and Fischbach's work [2]. Parkhomov conducted experiments involving beta sources, claiming that the sources responded to cosmic neutrinos [5].

Papers previously published by our research group [6-8] demonstrated decreases in count rates, supporting the possibility that changes in the neutrino flux during solar flares affect decay rates. The findings were obtained using several radioactive materials. During solar flares, particle emission from the Sun rises by several orders of magnitude and many types of particles are emitted towards the Earth. Most of the radiation stops at the ionosphere, except neutrinos, which can reach the Earth. When solar flares occur, the neutrino flux increases by three to four orders of magnitude due to nuclear reactions [9]. The count rate of ^{241}Am gamma-radiation was affected 14 days after the solar flare occurrence, indicating a decrease in count rates of ~1 % [6]. For ^{222}Rn, we obtained a response in the count rate ~12 hours following the solar flare, with a decrease of around 0.5 % [7]. In the case of thorium (nat.), the count rate decreased 9 days after the solar flare by ~1.1 % [8].

We planned to repeat the experiment with ^{54}Mn to complete the results published by Jenkins and Fischbach [2].

METHODS

We integrated two separate measurement systems, each for a radioactive source. The counting systems are located in a lab that is permanently locked to avoid any external influence and environmentally controlled in terms of temperature and clean air-flow, reducing detector efficiency dependence. The system is shielded by 5 cm thick lead bricks, as shown in fig. 1.

Corresponding author; e-mail: iorion@bgu.ac.il

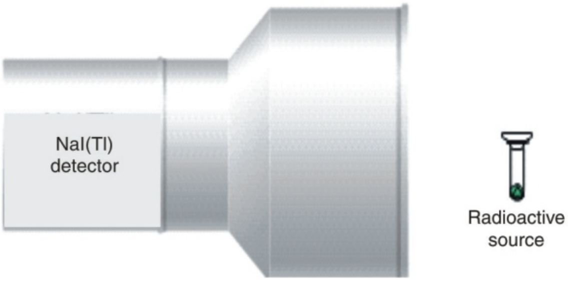

Figure 1. Schematic illustration of the gamma-radiation counting system consisting of an NaI(Tl) detector and a radiation source

For ^{54}Mn we used a spectrometry system containing a 3" 3" NaI(Tl) gamma-radiation detector attached to a multi-channel-analyzer (MCA) scintiSPEC (FLIR Systems, Inc.). The MCA was connected to a computer to control the system, obtaining spectral output every 15 minutes. The detector was placed in front of the ^{54}Mn source (103 kBq activity at on 1-Feb-2021).

For ^{57}Co we used a NaI(Tl) gamma-radiation detector system (PM-11 manufactured by Rotem Inc.) for total counting measurements, as described in our previous publications [6, 7]. The detector was placed in front of the ^{57}Co source (370 MBq activity on 22-Sep-2011).

^{54}Mn decay emits gamma-rays of 835 keV (half-life is 312 days), and ^{57}Co emits gamma-rays of 122 keV (half-life is 272 days). Both radioactive decays begin with electron capture.

The information about the occurrence of the solar flares was obtained from the GOES satellite [10]. Solar flares are classified by labels A, B, C, M, or X according to peak flux magnitude, where class A, the lowest X-ray flux, is less than 10^{-7} W^{m-2}, X is above 10^{-4} Wm^{-2}.

RESULTS AND DISCUSSION

The ^{54}Mn

The NaI(Tl) system in front of an ^{54}Mn source began operating in May 2021. Two decreases in the count rate of ^{54}Mn were observed, as shown in fig. 2, indicating that the count rate decreases corresponding to solar flares that occurred in May 2021. These decreases occurred following two separate solar flare events. The first event, a solar flare class M3.9, took place on May 7, and the second event, a solar flare class C1.5, happened on May 12. When decreases in

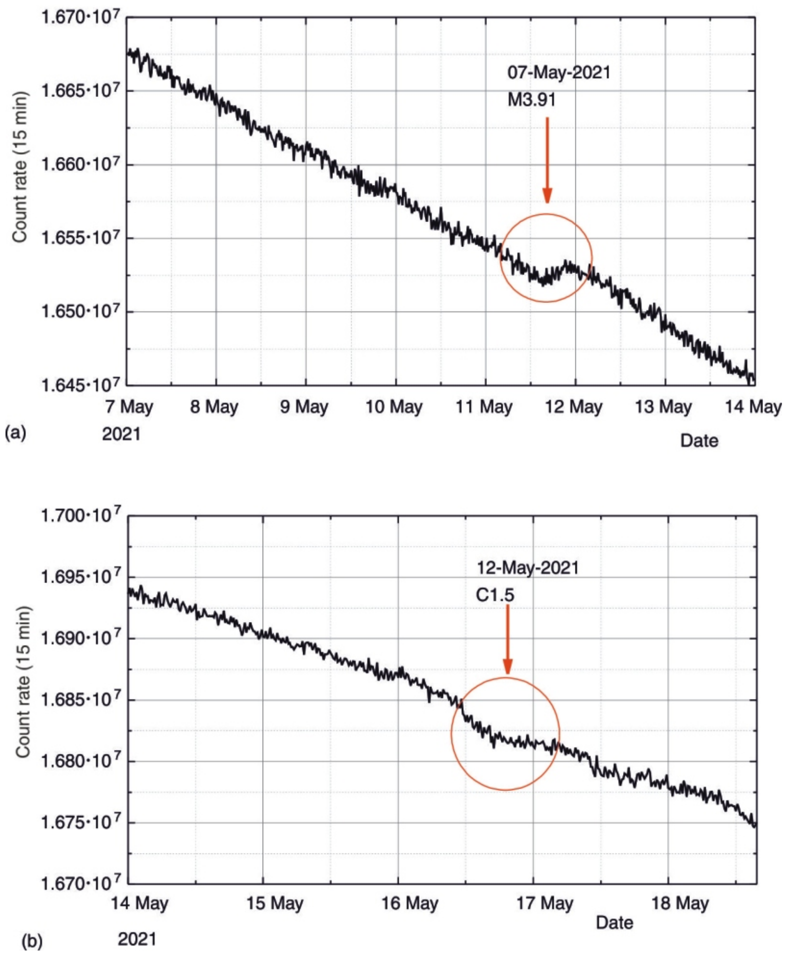

Figure 2. The ^{54}Mn count rate results. Arrows and circles mark observed decreases. Information is provided concerning the time (UT + 2) and type of solar flares

the count rate were measured, the sun was calm, hence the solar activity magnitude was low (A5 and B2, respectively).

In fig. 2(a) the decrease on May 11, 2021 that occurred between 5:30 to 22:30 (UT+2) was about 17 hours long. This decrease occurred after solar flare class M3.91; in addition, the following solar flares events were registered: C1.5 and C8.64 on May 08, 2021, and C1.6 and C4.04 on May 09, 2021. We presume that the response of all those solar flares was accumulated into a single decrease on May 11, 2021. The decrease on May 16, 2021, fig. 2b, occurred in response to a single solar flare.

In order to statistically confirm our results, we performed a trapezoidal area calculation concerning the results from May 16, 2021: six data points were averaged on both sides around the dip. Average performance is calculated to reduce ordinary fluctuations in readings from the detector.

Trapezoidal area calculation

$$S_{\text{trapezoid}} \quad \frac{(16847714+16813128)\ \ 64}{2} \quad 1077146971$$

Measured counts sum at the same region was $S_{\text{count rate}} = 1076482900$.

When deducting the trapezoidal area from the measured counts sum, we obtain the dip area

$$\Delta_{\text{readings}} \quad 1076482900 \quad 1077146971 \quad\quad 664071$$

Decrease of -664071 counts received in the graph in fig. 2(b).

Calculation of the limit of detection (L_c)

$$\sigma \quad 32820$$

$$L_c \quad 2.326\ \sigma \quad 2.326\ \ 32820 \quad 76339$$

There is almost a difference of one order of magnitude between the measured decrease counts and the limit of detection. Therefore, this result was found to be statistically significant [11].

Comparing these results with those published by Jenkins and Fischbach [2] and in light of our previous findings [6-8], delays between the solar flare and the response of ^{54}Mn were observed. In the Jenkins and Fischbach's December 2006 study we can identify delays of about five days ([2] – fig. 1):

- Solar flares that occurred on December 5-6, 2006 affected radiation detection on December 12, 2006.
- A solar flare that occurred on December 12, 2006 affected the count rate on December 17, 2006.
- A solar flare that occurred on December 14, 2006 affected count rates on December 19-22, 2006.

Jenkins and Fischbach's phenomenological results, which were the first to be published, are novel and of great importance for the field of nuclear physics. Their pioneering contribution led other research groups to conduct intensive studies regarding how solar flares affect the radioactive decay constant.

The ^{57}Co

Measurements of radioactive ^{57}Co, which undergoes electron capture radioactive decay similarly to ^{54}Mn, were conducted. Figure 3 presents two results of ^{57}Co count rates. Six decreases in the count rate of ^{57}Co were observed.

The calculation for the changes in the count rate of ^{57}Co was performed using the same method as for ^{54}Mn. The calculation was based on the result from November 18, 2020. A decrease of -2173118 was obtained, with $L_C = 20348$. More than two orders of magnitude of difference between the decrease and the limit of detection were found, which is statistically significant [11]. In a ^{57}Co radioactive source, a delay of about seven days between the solar flare occurrence and the decrease in the count rate was observed.

Table 1 provides a list of six ^{57}Co and two ^{54}Mn events accompanied by the magnitude of the solar flare (type), its occurrence date, the dip date, and the delay. Solar flares with an intensity of less than C1 cannot be revealed by ^{57}Co or ^{54}Mn. At this stage, the relation between solar flare intensities cannot be indicated.

CONCLUSIONS

Solar neutrino detection is known to be a very challenging task due to the minuscule absorption cross-section. This study reveals additional radioactive sources that significantly respond to solar neutrinos.

Following the research presented by Jenkins and Fishbach in 2009 [2], this study demonstrated changes in the count rates for ^{54}Mn and for ^{57}Co. In our previous studies regarding ^{241}Am, ^{222}Rn, and ^{232}Th, we discerned a delay between solar flares and count rate decreases. Our innovative results for electron capture sources supplement our previous studies, which examined alpha emitters, thus strengthening our argument concerning the effect of solar neutrinos on radioactive materials.

With regard to ^{54}Mn, two count rate decreases were observed, resulting from two solar flares that occurred on May 7 and May 12, 2021. We conclude that there is a delay of about five days between the solar flare and the resulting count rate dip for ^{54}Mn, supporting our findings in previous studies. For ^{57}Co, six count rate decreases were observed. We found that there is a delay of about seven days between the solar flare and the decrease in the count rate. For both sets of results, the calculated limit of detection was found to be of statistical significance.

The results of this study support the argument that there is neutrino involvement in the decay processes for several radioactive materials. We can therefore conclude that ^{54}Mn and ^{57}Co interact with neutrinos that originate during solar flares.

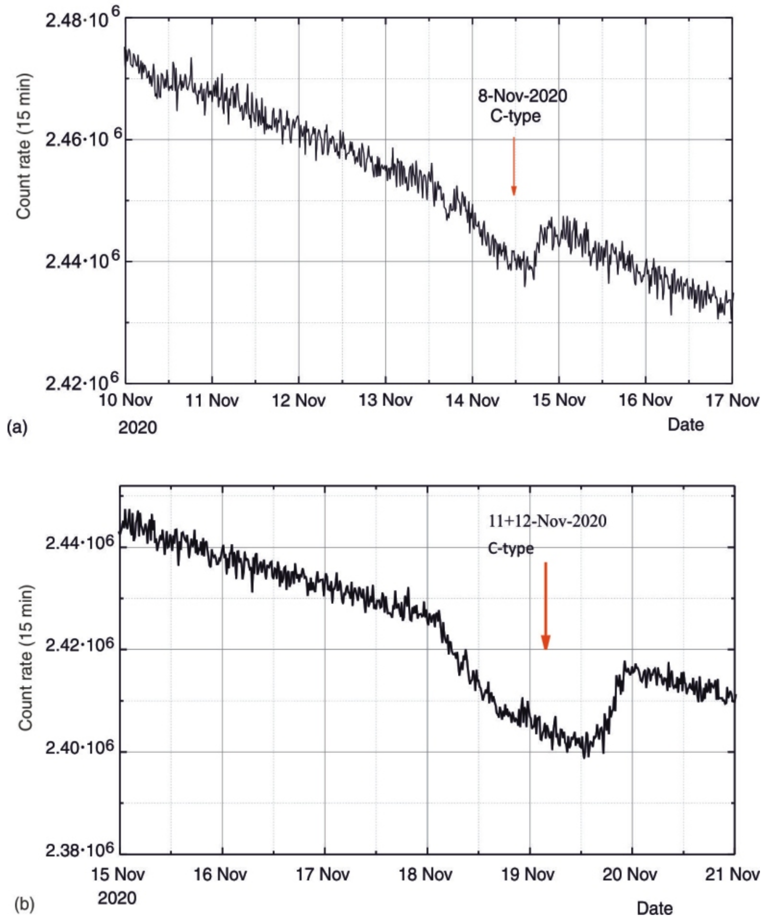

Figure 3. Count rate results for ^{57}Co. Arrows mark the observed dips. Information is provided concerning the time (UT + 3) and type of flares

Table 1. Measured ^{57}Co and ^{54}Mn count rate events, dates, and information on solar flares

Radionuclide	Solar flare date	Solar flare type	Count-rate rate dip date	Delay [d]
^{57}Co	8 Nov 2020	C5.7	14 Nov 2020	7
^{57}Co	11-12 Nov 2020	C2.6	18-19 Nov 2020	7
^{57}Co	20 Nov 2020	C1.9	25 Nov 2020	6
^{57}Co	22 Nov 2020	C3.3	30 Nov 2020	8
^{57}Co	29 Nov 2020	M4.4	8 Dec 2020	10
^{57}Co	7 Dec 2020	C7.4	13 Dec 2020	7
^{54}Mn	7 May 2021	M3.9	11 May 2021	4
^{54}Mn	12 May 2021	C1.5	16 May 2021	5

The results for ^{54}Mn and ^{57}Co indicate that a rise in neutrino flux can alter the decay rates of the electron capture radioactive process, which involves neutrino emission. Thus, we can assume that the presence of a relatively greater amount of surrounding neutrinos reduced the decay.

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Џонатан ВАЛГ, Јел ПЕЛЕГ, Анатолиј РОДНИЈАНСКИ,
Нир ХАЗЕНШПРУНГ, Јицак ОРАЈОН

УТИЦАЈ СОЛАРНИХ БАКЉИ НА ОСОБИНЕ КОНСТАНТИ РАДИОАКТИВНОГ РАСПАДА ^{54}Mn И ^{57}Co

Промене у брзинама радиоактивног распада услед сунчевих бакљи привукле су већу научну пажњу последњих деценија. У претходним радовима показали смо да сунчеве бакље изазивају промене у брзини распада ^{241}Am, ^{222}Rn и ^{232}Th. Промена у брзини одброја ^{54}Mn услед сунчевих бакљи, како су уочили истраживачи са Универзитета Пурдуе 2006. године, подстакла нас је да поновимо мерења. Поред тога, измерили смо брзину одброја гама зрачења ^{57}Co услед захвата електрона, као и у распаду ^{54}Mn.

Наша нова мерења показују да постоји кашњење од око пет дана између појаве сунчеве бакље и смањења брзине одброја ^{54}Mn. Такође, закључујемо да је у проучавању ^{54}Mn из 2006. године постојало кашњење између соларних бакљи и резултујућих падова брзине одброја. Што се тиче структуре бројања ^{57}Co, измерили смо око седам дана кашњења између појаве сунчевих бакљи и пада брзине одброја. Закључујемо да ^{54}Mn и ^{57}Co интерагују са неутринима који настају током сунчевих бакљи.

Кључне речи: Сунце, бакља, неутрино, константа радиоактивног распада