THE IMPACT OF STRONG SOLAR FLARES ON THORIUM BETA RADIATION COUNT-RATE

by

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This study explores the impact of solar flare events on radioactive materials, focusing in particular on the thorium decay chain. Previous research has indicated that gamma emitters are affected by solar flares, resulting in count-rate dips. In this study, we present, for the first time, concurrent gamma and beta count-rate measurements from a thorium radioactive source, revealing multiple dips in the count rate. Based on a consideration of the temporal relationship between beta and gamma emissions, we propose that the response to solar events originates primarily from beta emissions.
To investigate this phenomenon further, we employ plastic scintillator beta detectors, enabling the examination of various radioactive sources and the study of neutrino interactions and their impact on decay rates. This experimental approach offers an opportunity to expand our knowledge of particle interactions and provides insights into the interplay between solar flares, neutrino flux, and the behavior of radioactive materials.

Key words: radioactive decay, thorium, gamma emission, beta emission, count-rate measurement, plastic scintillator, neutrino interaction

INTRODUCTION

Our recent research has focused on how solar flares affect radioactive decay rates. Fischbach first presented evidence of radiation count-rate fluctuations due to solar flares (SF) in 2006, using a ^{54}Mn radioactive source observing that high-flux X-ray solar flares (classified as class X, above 10^{-4} Wm^{-2}) exhibited a correlation with a decrease in gamma radiation count- rates of ^{54}Mn [1]. This led us to investigate the possibility of solar flare-induced changes in half-life caused by the neutrino flux generated during SF eruptions [2, 3]. In previous publications, using gamma radiation detectors, we provided evidence that solar flares affect the decay rates of various radioisotopes, including ^{241}Am, ^{222}Rn, ^{232}Th, ^{54}Mn, and ^{57}Co [3-6]. Likewise, Parkhomov presented periodic count-rate variations in beta-emission radioactive sources measured using an ion chamber detector. These count-rate changes were observed specifically for ^{60}Co and ^{90}Sr-^{90}Y based on their beta radiation emissions [7].

The current study focuses on a thorium radiation source: a naturally occurring radioactive material found in sands and sediments due to its insolubility [8]. Thorium has a decay chain comprising several radioactive isotopes. The ^{232}Th, with a half-life of 14.5 billion years, and ^{230}Th, with a half-life of 75200 years [9], are of particular interest. We observed that approximately nine days after a SF event, the count rate of ^{232}Th gamma radiation showed a decrease of around 1.1 % [2]. This decrease indicates the potential influence of SF on gamma count rates. For comparison, we also measured beta count rates using a natural thorium specimen, which emits both beta and gamma radiation.

Via this research, we aim to deepen our understanding of the relationship between SF and changes in radioactive decay rates, specifically investigating the effects on both gamma and beta count rates.

METHODS

We collected information concerning the intensity, class magnitude, and duration of daily solar flare events from the Geostationary Operational Environmental Satellites (GOES) operated by the Space Weather Prediction Center of the National Oceanic and Atmospheric Administration, USA. These satellites provide measured solar X-ray flux data, reported in units of Wm^{-2} per minute. We specifically focused on flares of C, M, and X classes, which are known for their high intensity.

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To detect gamma radiation, we utilized a NaI(Tl) gamma radiation detector system, as previously described in our earlier publication [5]. The system is designed to detect gamma radiation using a sodium iodide crystal scintillator. The gamma detector and the beta detector were positioned facing the thorium source, which consisted of 40 grams of $Th(NO_3)_4 \cdot 5H_2O$ in a polyethylene bag (0.05 mm thickness). Total counts were recorded every 15 minutes.

The beta radiation detection was carried out using a plastic scintillator beta radiation detector system. In this study, we employed a plastic scintillator of type BC404, which has a thickness of 25.4 mm and a diameter of 50.8 mm. The scintillator's light output is 68% anthracene, and it has a decay time of 1.8 ns [10]. Plastic scintillators are well-suited to detecting charged particles, such as beta particles, which interact with the active surface area of the plastic. The BC404 beta detector is particularly suitable for fast counting. The plastic scintillator converts the energy of radiation into photons. It is important to consider the energy loss of electrons as they pass through the surface of the plastic scintillator, especially when their energy is relatively low. The energy loss is caused by scattering during the electron's passage through the surface and by bremsstrahlung photons generated as the electron interacts with the medium.

Beta emission activity from progeny of the ^{232}Th decay chain

The following beta decays occur in the ^{232}Th decay chain:
^{228}Ra ^{228}Ac ^{228}Th [4 emission] ^{212}Pb ^{212}Bi Branch [approximately emitted together]: (64 %) ^{212}Bi ^{212}Po, (36 %) [emission] ^{208}Tl ^{208}Pb.

Each beta emission has a unique decay rate. Based on the ^{232}Th initial activity, it is necessary to calculate the balanced activity for each one. Each of the five beta emissions is characterized by a certain spectrum (Probabilities tables are available in Eckerman *et al.* [11]).

We calculate the activity in equilibrium of the beta emitters of the ^{232}Th chain. First, we define,

$$A(^{228}\mathrm{Ra}) \quad A_0 \tag{1}$$

The A_0 – [Th-Nitrate + $5H_2O$] activity (based on 40 g and specific activity), since its half-life is very short compared to the ^{232}Th half-life.

$$A(^{228}\mathrm{Ac}) \quad A_0(1 \quad \mathrm{e}^{\ \lambda(Ac)t}) \quad A_0 \tag{2}$$

The ^{228}Ac half-life is very short, therefore, we can skip its decay and go directly to ^{228}Th.

The activity of ^{228}Th is affected by the equilibrium with ^{228}Ra

$$t_{\max} \quad 1.44\frac{T_{228_{\mathrm{Ra}}}T_{228_{\mathrm{Th}}}}{T_{228_{\mathrm{Ra}}}T_{228_{\mathrm{Th}}}}\ln\frac{T_{228_{\mathrm{Ra}}}}{T_{228_{\mathrm{Th}}}} \tag{3}$$

$$t_{\max} \quad 4.5\ y$$

we can calculate the ratio

$$\frac{A(^{228}\mathrm{Th})}{A(^{228}\mathrm{Ra})} \quad \frac{T_{228_{\mathrm{Ra}}}}{T_{228_{\mathrm{Ra}}} \quad T_{228_{\mathrm{Th}}}} \quad 1.5 \tag{4}$$

Hence,

$$A(^{228}\mathrm{Th}) \quad 1.5A(^{228}\mathrm{Ra}) \quad 1.5A_0 \tag{5}$$

All the next three alpha emitters in this decay chain are short-lived; thus, the activity of ^{212}Pb must remain the same as the activity of ^{228}Th.

$$A(^{212}\mathrm{Pb}) \quad 1.5A_0 \tag{6}$$

Using the following calculation, we obtain

$$\frac{A(^{212}\mathrm{Bi})}{A(^{212}\mathrm{Pb})} \quad \frac{T_{212_{\mathrm{Pb}}}}{T_{212_{\mathrm{Pb}}} \quad T_{212_{\mathrm{Bi}}}} \quad 1.1 \tag{7}$$

Therefore,

$$A(^{212}\mathrm{Bi}) \quad 1.1A(^{212}\mathrm{Pb}) \quad 1.1 \quad 1.5A_0 \quad 1.65A_0 \tag{8}$$

Only 64 % of the ^{212}Bi is beta decay toward ^{212}Po, hence for beta emission

$$A(^{212}\mathrm{Bi})[\mathrm{beta}] \quad 1.056A_0 \tag{9}$$

The other branch led to ^{208}Tl with a probability of 36 %.

$$\frac{A(^{208}\mathrm{Tl})}{A(^{212}\mathrm{Bi})} \quad \frac{T_{212_{\mathrm{Bi}}}}{T_{212_{\mathrm{Bi}}} \quad T_{208_{\mathrm{Tl}}}} \quad 1.053 \tag{10}$$

$$A(^{208}\mathrm{Tl}) \quad 1.053A(^{212}\mathrm{Bi}) \tag{11}$$

$$A(^{208}\mathrm{Tl}) \quad 0.36^{*}1.65A_0 \quad 0.594A_0 \tag{12}$$

To obtain activities numerically, we use the specific activity of thorium as 4.06 MBqkg^{-1} [12]. The Th is 4.07 % by weight in Th-Nitrate + $5H_2O$, so its mass is 1.628 g, providing activity of 66.08 kBq (A_0). Table 1 contains the list of all beta emitters and their activity based on the thorium-specific activity.

Monte Carlo simulations

The BC404 beta detector properties, materials, and dimensions were entered into a set of MCNP Monte Carlo simulation inputs. Each one of the five beta emissions with their specific spectrum probabilities tables

Table 1. Beta emitters radionuclide activity of the thorium decay chain: the numerical values are based on 40 g of $Th(NO_3)_4 \cdot 5H_2O$

Beta source	Relative activity	Activity [kBq]
^{228}Ra	A0	66.08
^{228}Ac	A0	66.08
^{212}Pb	1.5A0	99.12
^{212}Bi	1.65A0	109.03
^{208}Tl	0.594A0	39.25
Total	5.744 A0	379.56

was enclosed in the source cell definition that was isotopically distributed. The MCNP version 5 [13] was utilized to obtain the detector's response to each of the beta radiation radioisotopes with 10^7 histories. The total count rate from the simulations is designed to be compared to the count-rate measurement reading.

RESULTS AND DISCUSSION

Monte Carlo simulations

Each simulation was performed separately, focusing on a specific beta emitter and considering its spectral probability distribution function. The response of the BC404 detector, expressed in units of counts per emission rate, was analyzed concerning the electron energy. The results of these simulations are depicted in fig. 1, which presents the BC404 response for the four beta emitters in the thorium chain. This analysis provides valuable insights into the detection characteristics and spectral properties of these radionuclides, offering important comparisons to the detector measurements.

Based on the simulation response results, the total counts per emission rate were determined as follows: $5.95\ 10^{-4}$ for ^{228}Ac, 0.00568 for ^{212}Bi, and $6.65\ 10^{-4}$ for ^{208}Tl. It should be noted that the counts from ^{212}Pb were found to be negligible, as indicated in fig. 1. By incorporating these emission rates and referring to tab. 1 for the corresponding activities, the overall calculated counts per 15 minutes were determined to be $2.963\ 10^6$ (with an estimated uncertainty of approximately 2 %). These findings provide valuable information regarding the expected count rates based on the simulated responses and the activities associated with each radionuclide.

Measurements results

The detector measured an average count rate of $3.346\ 10^6$ ($2\ 10^3$) counts per 15 minutes, excluding the identified anomalies. Notably, an excess of ~12 %

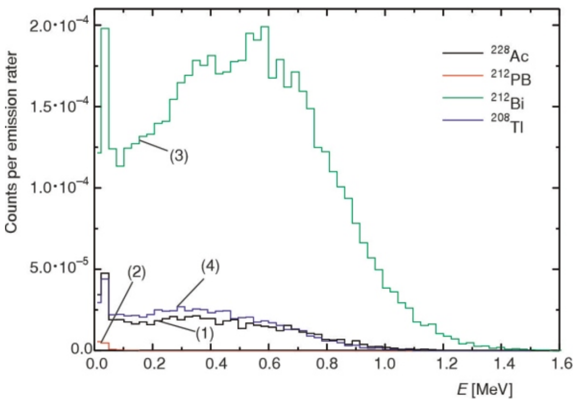

Figure 1. The BC404 Response *vs.* electron energy in counts per emission rate for beta emitters in the thorium chain; (1) ^{228}Ac, (2) ^{212}Pb, (3) ^{212}Bi, and (4) ^{208}Tl

in the count rate per 15 minutes was observed, which could be attributed to additional processes, specifically the emission of secondary electrons (such as photoelectrons and Compton electrons) resulting from the interaction of X-rays with the detector. However, it is important to acknowledge that these secondary electron emissions were not accounted for in the simulations conducted.

Both detection systems, the NaI(Tl) system, and the plastic BC404 system, were located in front of the ^{232}Th source and began operating in parallel in October 2022.

In the study, four distinct dips in the count rates of gamma and beta radiation from thorium were identified and recorded, as outlined in tab. 2. These dips indicate notable changes in the count rates as a direct consequence of SF events. Figure 2 illustrates the impact of a SF class M5.2, which transpired on November 7, 2022. On November 14, 2022, noticeable reductions in both gamma and beta count -rates were observed. The sample numbers in the figure represent a 15-minute increment from each counting period. Similarly, fig. 3 demonstrates the influence of two solar flares (M3.7 and X1.2) that occurred on December 30, 2022, and January 6, 2023, respectively. The count rates for both gamma and beta radiation demonstrated declines starting from January 10, 2023. These findings highlight the relationship between solar flare activity and fluctuations in the count rates of thorium gamma and beta radiation.

Figures 2 and 3 provide evidence of how strong solar flares affect beta emissions from thorium progenies, as well as the effects of solar flares on gamma radiation emissions from the thorium decay chain.

In particular, the beta detector counts obtained on January 23, 2023, exhibited a distinct dip following the occurrence of three consecutive class M solar flares over three-days. This series of strong flares resulted in a prolonged duration of the signal, as illustrated in fig. 4. To assess the significance of the signal dip in the beta count measurements for thorium, the method of *limits-of-detectability* (L_c) described by Knoll was employed [14]. By comparing the count

Table 2. Thorium count-rate responses to SF during Nov 2022-Feb 2023: Left to right: SF occurrence date; SF class (and size in nWm^{-2}); count-rate dip reading date and delay time

SF date	SF type	Count-rate dip date	Delay [d]	Beta counts dip difference
November 7, 2022	M5.2	November 14, 2022	8	–0.14 %
December 30, 2022 January 06, 2023	M3.7 X1.2	January 10, 2023	5-10	–0.15 %
January 14-15, 2023	M4.6, M6, M4.8	January 23, 2023	9-10	–0.24 %
February 17, 2023	X2.2	February 27, 2023	10	–0.13 %

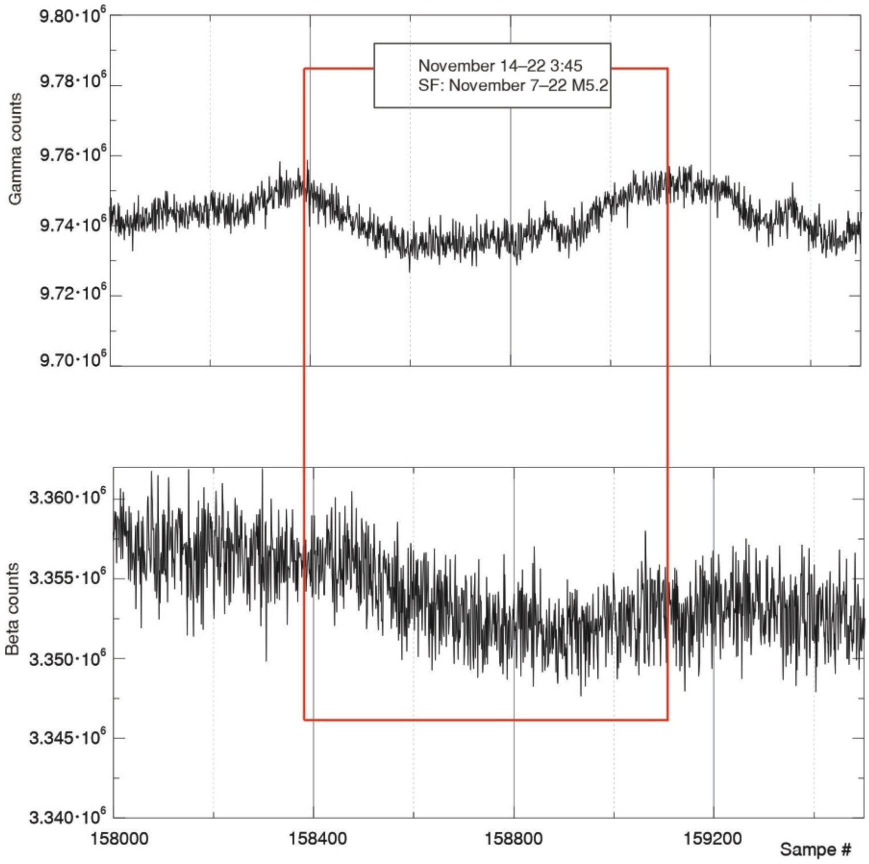

Figure 2. Thorium count-rate dip measured by the gamma detector (up), and the beta detector (down). Information about the relevant SF is provided with the time (UT + 2)

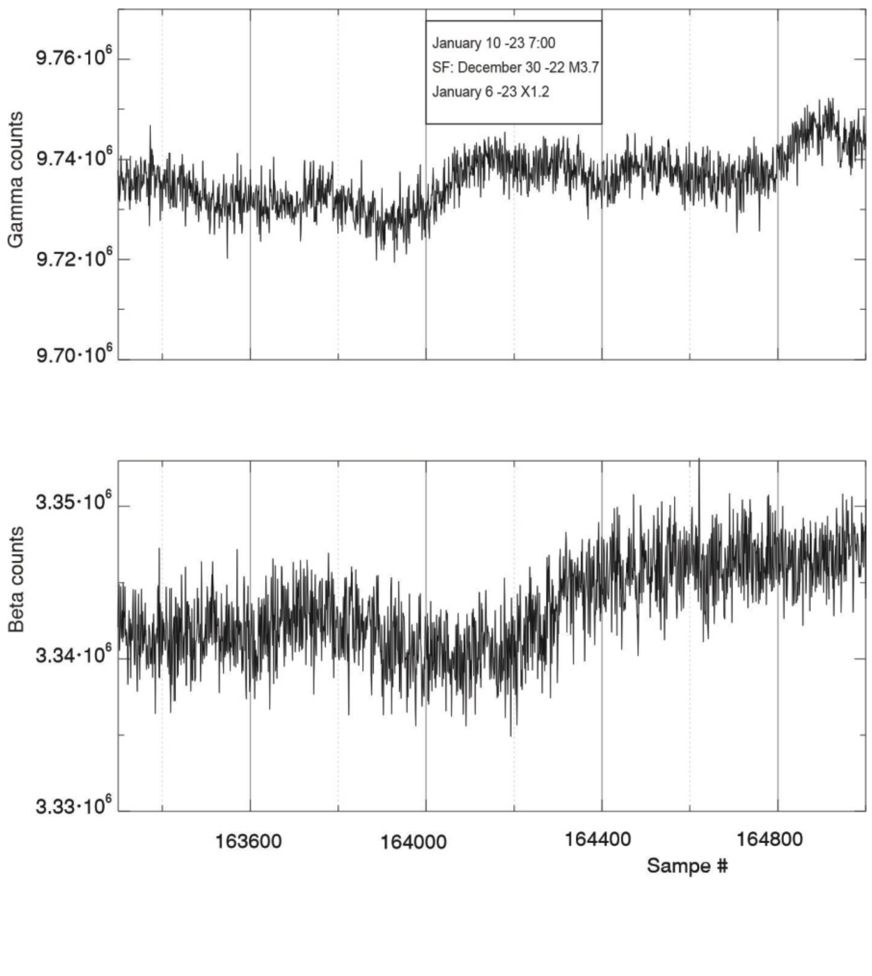

Figure 3. The count rate decreases both in the gamma detector reading (top) and the beta detector reading (bottom), information about the respective SF is provided with the time (UT + 2)

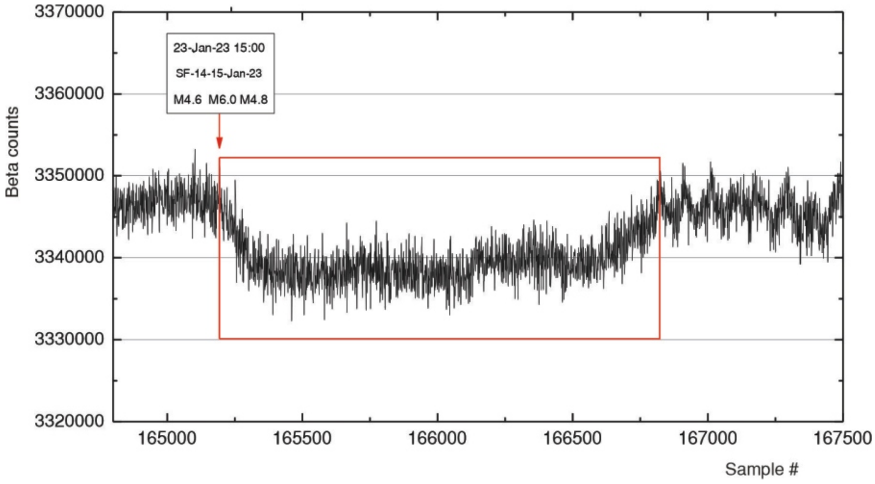

Figure 4. Count-rate decrease occurred in beta counts on January 23, 2023, due to three SF of class M4.6, M6, and M4.8, respectively, on January 14-15, 2023

rate with its mean value, it was possible to determine whether the count rate fell below or above the mean value.

$$\text{Mean} \quad 3.334683E \quad 06$$
$$\sigma \quad 1855.3$$
$$L_c \quad 2.326\,\sigma \quad 2.326\ 1855.3 \quad 4315.4$$
$$\text{Mean} \quad L_c \quad (3.34683E \quad 06) \quad 4315.4 \quad 3342514$$
$$\text{signal} \quad 3338780$$
$$diff\ f \quad |\text{signal} \quad (\text{Mean} \quad L_c)| \quad 3734.6$$

In this dip, 3734.6 counts exceeded the critical level, which is even more than 2.

This approach allowed for a rigorous evaluation of the significance of the observed dip in the beta counts, providing valuable insights into the impact of SF on thorium beta emissions and improving our understanding of the fluctuation patterns in the measured data.

The decrease in beta radiation count rate behaves comparably to the decrease in gamma radiation count rate concerning the delay time following SF events. However, it is worth noting that the beta radiation count rate specifically responds to strong SF of class M or X, whereas the gamma radiation is affected even by lower-intensity flares of class C, as previously documented. This distinction suggests that emissions of gamma rays and beta rays originate from different radioisotopes. The gamma radiation, influenced by a broader range of SF intensities, reflects the impact of various radiation sources within the thorium decay chain.

These findings emphasize the importance of differentiating between the response characteristics of gamma and beta emissions, which originate from distinct radioisotopes and exhibit varying sensitivities to SF events. Such distinctions facilitate a more comprehensive understanding of the complex dynamics between SF and the emissions of different types of radiation.

CONCLUSION

This study offers novel insights into the relationship between solar events and radioactive decay within the thorium decay chain. By concurrently measuring gamma and beta count rates during solar flare events, the research reveals a significant impact on the decay process. Notably, the observed temporal sequence, with beta emissions preceding gamma rays, underscores the primary role of beta emission in responding to solar events. This study's use of plastic scintillator beta detectors opens avenues for investigating the broader implications of solar phenomena on decay rates and neutrino interactions, advancing our understanding of the intricate interplay between these factors. It paves the way for future research to delve into the underlying mechanisms and their implications for various radioactive sources and neutrino-related studies.

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УТИЦАЈ ЈАКИХ СОЛАРНИХ БАКЉИ НА БРЗИНУ БРОЈАЊА БЕТА ЗРАЧЕЊА ТОРИЈУМА

Овај рад истражује утицај соларних бакљи на радиоактивне материјале, посебно се фокусирајући на ланац распада торијума. Претходна истраживања показала су да на гама емитере утичу сунчеве бакље, што доводи до пада брзине бројања. У овој студији, по први пут представљамо истовремена мерења гама и бета брзине бројања из торијумског радиоактивног извора, откривајући вишеструке падове у стопи бројања. На основу разматрања временског односа између бета и гама емисија, предлажемо да одговор на соларне догађаје потиче првенствено од бета емисија.
Да бисмо надаље истражили овај феномен, користимо пластичне сцинтилаторске бета детекторе, који омогућавају испитивање различитих радиоактивних извора и проучавање интеракција неутрона и њиховог утицаја на стопе распада. Овај експериментални приступ нуди прилику да проширимо наше знање о интеракцијама честица и пружа увид у интеракцију између соларних бакљи, флукса неутрона и понашања радиоактивних материјала.

Кључне речи: радиоактивни распад, торијум, гама емисија, бета емисија, мерење брзине бројања, пластични сцинтилатор, интеракција неутрона