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ELEMENTARY PARTICLES AND FIELDS
Experiment

The Possibility of Using $C3$–$C4$ Calorimeter Leak Detectors for Neutron Registration in the GAMMA-400 Complex

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Abstract—The article describes the method for modifying the scintillation calorimeter detectors $C3$ ($S3$) and $C4$ ($S4$) of the GAMMA-400 space complex in order to obtain the possibility of detecting neutrons produced in the process of passing electrons (positrons) and high-energy protons through detector matter. The presented method will allow to increase the rejection factor of background radiation without degrading the basic capabilities of the detectors $S3$ and $S4$.

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1. INTRODUCTION

The GAMMA-400 complex (Fig. 1) is a project for a space gamma observatory capable of detecting gamma radiation, as well as electron and positron fluxes of high energies [1]. The main research directions of GAMMA-400 are: the search for dark matter particles (WIMPs), the study of the nature and properties of variable activity in the gamma range of astrophysical objects, and the study of the propagation and interaction of cosmic rays in the intergalactic medium. For this, the complex should have the ability to register gamma radiation in a wide energy range (20 MeV–3 TeV) [2]. High-energy gamma radiation entering the converter tracker complex is converted into electron–positron pairs, therefore the important task of the complex is to separate such electron (positron) events from cascades, formed by high-energy background particle flows, for example, protons. In the GAMMA-400 complex it is planned to apply several methods of background rejection by particle track projection analysis [3]. The $S3$ and $S4$ calorimeter detectors use an amplitude threshold to separate proton and electron (positron) cascades. Simulations have shown that the hadronic background can also be rejected by the number of neutrons produced in the cascades, which is different for different types of primary particles [4]. The efficiency of the neutron detector (ND) in solving such types of problems was confirmed in practice in the PAMELA space experiment [5]. Some of the existing projects of neutron detectors for the rejection of cosmic ray background include, inter alia, the use of plastic scintillators for neutron detection [6].

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2. CHARACTERISTICS OF THE NEUTRON PRODUCTION IN THE GAMMA-400 EXPERIMENT

The main contribution to the total rejection factor for protons in the GAMMA-400 telescope is based on the registration of significantly different number of neutrons generated in the electromagnetic and hadron cascades. In cascades induced by protons, the generation of neutrons is more intensive than in the electromagnetic showers. The main mechanisms of neutron production from high-energy gamma radiation are giant resonance reactions: $X(\gamma, n)$, $X(\gamma, 2n)$, and others. The cross sections of these reactions, as a rule, do not exceed 10^{-2} barn for heavy nuclei and 10^{-4} barn for light particles and reaches a maximum at sufficiently high energies ($E >$ 10 MeV). Since protons make the main contribution to the background of charged particles in outer space, reactions with the participation of protons, which result in the production of neutrons, i.e. various fragmentation reactions, are the main contribution to the neutron background. For high-energy protons, the cross sections for these reactions can be as large as 1 barn or higher. Thus, the number of neutrons produced in reactions involving high-energy protons should be more than an order of magnitude more than in reactions involving gamma rays with the same energy release in the calorimeter of the GAMMA-400 complex.

3. DESCRIPTION OF THE $S3$–$S4$ DETECTORS

Currently, the GAMMA-400 project is in the process of upgrading the calorimeter system, in particular, the preliminary decision is made to keep the

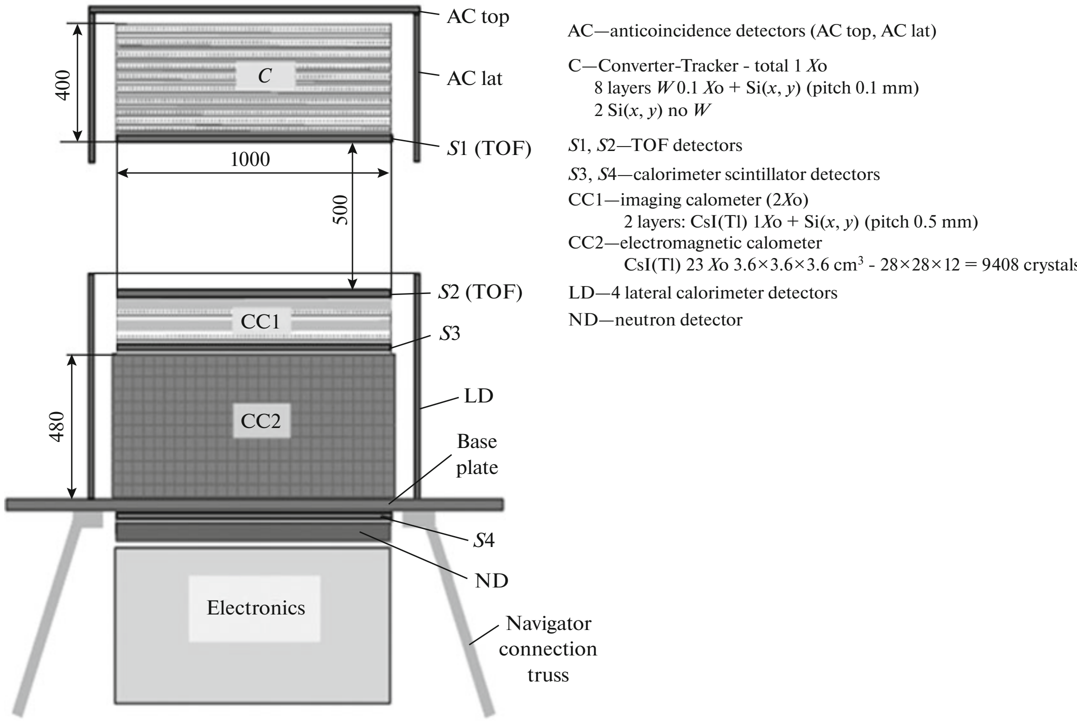

Fig. 1. Detectors layout in the GAMMA-400 complex before modernization.

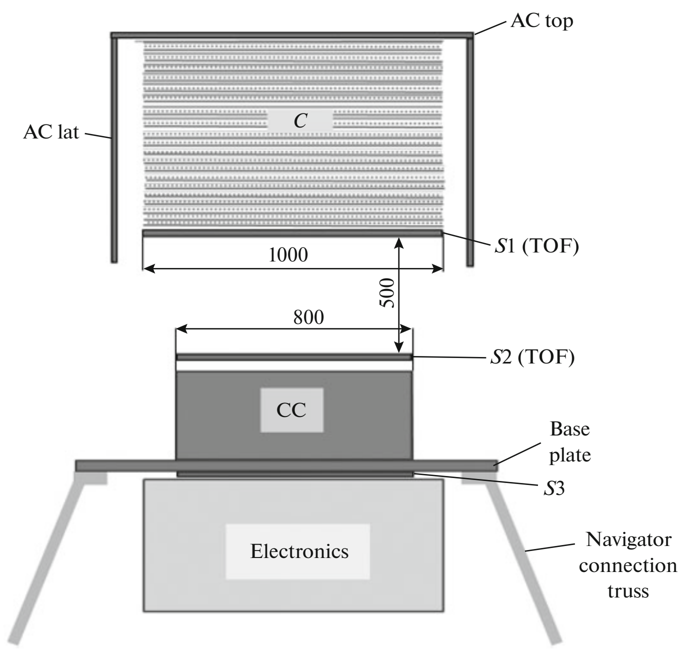

Fig. 2. Diagram of the detector system location in the modernized GAMMA-400 complex.

$S3$ and, may be, $S4$ detector, but to remove the ND (Fig. 2). Detectors $S3$ and $S4$ are a plane with an area of 80×80 cm^2, recruited from eight light-insulated strips of plastic scintillator of increased transparency of Saint-Gobain BC-408 type [7]. The scintillator, in addition to its main functions, serves as a light guide. The total dimension of each detector strip is $80 \times 10 \times 1.2$ cm^3. Light collection is carried out from the ends of the strip bands using matrices of silicon SiPM photomultipliers. Thus, each detector band is an independent radiation detector.

Due to the different nature of the attenuation of

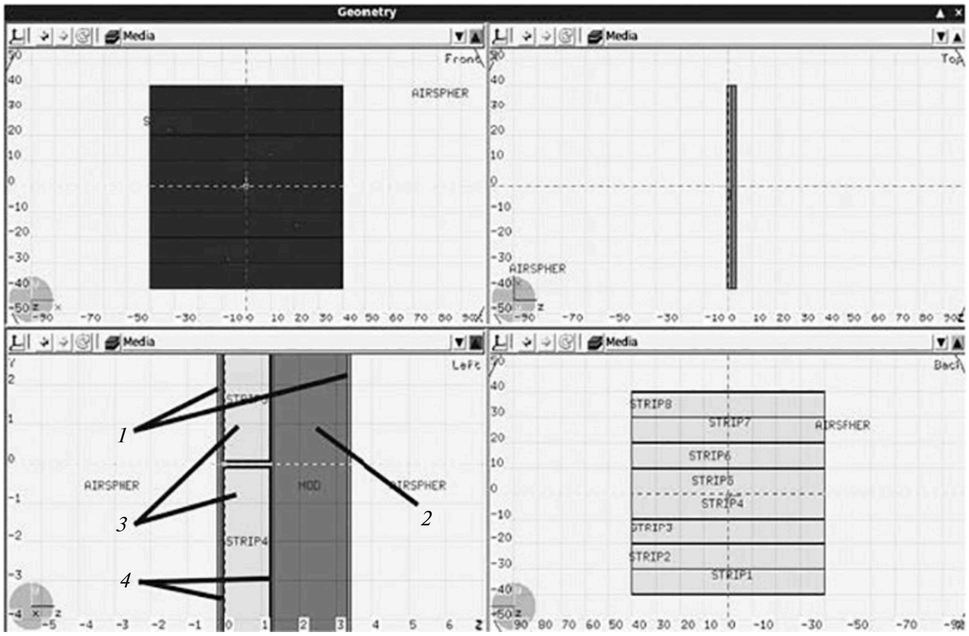

Fig. 3. Computational model of the neutron detector based on the scintillation detector $S3$. 1—aluminium case; 2—additional layer of moderator; 3—strips of plastic scintillator; 4—scintillation screens.

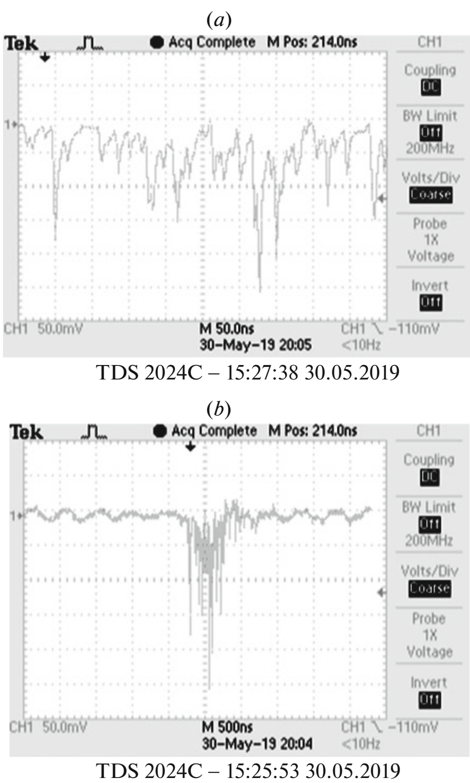

Fig. 4. Oscillograms for the detection of responses from a detector containing plastic scintillators without additives, when registering pulse from the test neutron generator with a pulse duration of about 0.5 μs: (a) small scintillator (cross section is about 10×10 mm); (b) large scintillator (about 100×10 mm).

the electromagnetic and proton cascade inside the GAMMA-400 calorimeter, protons are rejected in the $S3$ and $S4$ detectors by means of a set amplitude threshold of the recorded signal.

4. DRAFT FOR MODERNIZATION OF $S3$ AND $S4$ AS NEUTRON DETECTORS

The plastic scintillators used in the $S3$ and $S4$ detectors can itself be used to register fast neutrons with the help of recoil protons, since they have a relatively high concentration of hydrogen atoms (H: C ~ 1.1) [7]. However, there are several factors that prevent the direct use of plastic scintillator as a neutron detector. The thickness of the detectors $S3$ and $S4$ is 12 mm, which will only lead to an insignificant energy release when registering recoil nuclei. Considering that the light output of plastic scintillators is of the order of N_0/E_e, where $N_0 = 10000$ photons and $E_e = 1$ MeV, it will be quite difficult to detect a light flash from fast neutrons from a detector as short as $S3$ or $S4$. In addition, the signal from the recoil nuclei approximately coincides in time with the transit time of the rest of the shower particles, therefore, it will most likely be impossible to isolate it against the background of the multitude of particles produced in the cascade. To solve this problem, it is possible to use the registration not of fast, but of slow neutrons using nuclear reactions, such as $^{10}\mathrm{B}(n,a)$ and $^{6}\mathrm{Li}(n,t)$. A computational model of a neutron detector based on the scintillation detector $S3$ is shown in Fig. 3. Since the time of neutron thermalization in a plastic

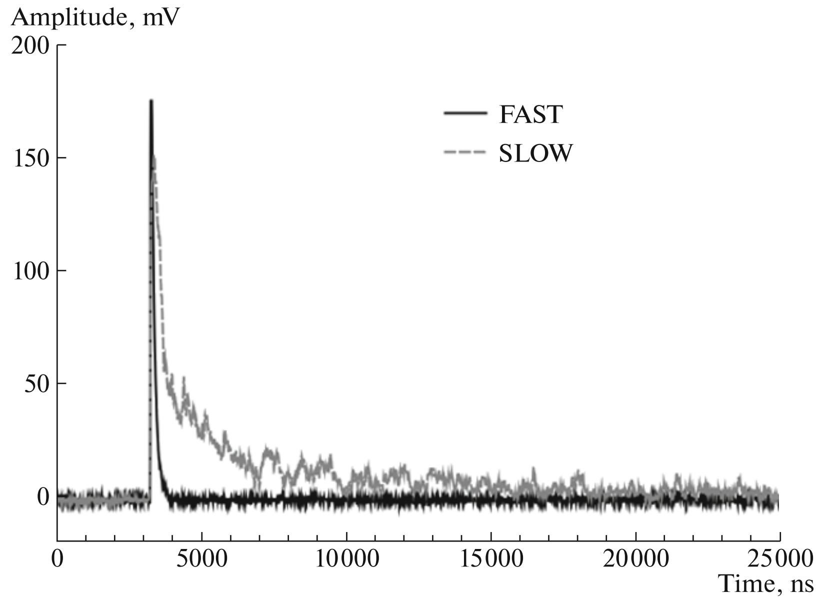

Fig. 5. Oscillograms for the registration of responses from a detector containing plastic scintillators with polyethylene screens and activated by ^{252}Cf. The slow and fast signals (corresponding to slowed and immediate neutrons) are clearly seen.

scintillator is of the order of several microseconds, one can expect a time delay between the system trigger (from particles of the shower) and the neutron registration process, thereby effectively separating neutron events from useful shower events. Neutrons slowed down in the detector environment were recorded by process of the capture of slow neutrons by hydrogen and carbon nuclei in plastic scintillator. We used the neutron generator pulse (about 0.5 μs) for the time delay testing. Figure 4*a* shows a registration of practically fast protons only (recoil protons) in a small scintillator during the pulse, and Figure 4*b* shows that some of the slowed neutrons can be recorded up to 2 μs after the start of the test neutron generator in a large scintillator.

To register neutrons in modernized $S3$ and $S4$ prototype detectors, it is proposed to use the plastic scintillator with the addition of two layers of ZnS(Ag) + LiF scintillation screens of the Scintacor NG or Eljen EJ-426 type (lithium is enriched to 6% in the ^{6}Li isotope) each 0.45 mm thick. Using a scintillation screen will allows the selection of events from slowed neutrons according to the shape of the signal (Fig. 5), since the ZnS(Ag) + LiF screen has a fundamentally different flashing characteristic relative to the plastic scintillator (the flashing time is about 100–150 ns against 2.5 ns for BC-408) and low detection efficiency of fast charged particles due to its small thickness and relatively low density. The maximum of the emission spectrum for ZnS(Ag) falls at 450 nm, which makes it possible to use it in conjunction with the main SiPM models. The maximum estimated efficiency of such detector for the ^{252}Cf spectrum (approximately corresponds to the neutron energy spectrum expected in the experiment) is about 8%. To improve the efficiency of neutron registration, using of polyethylene as a neutron moderator can be considered.

5. CONCLUSION

This paper presents the project for the modernization of the calorimeter scintillation detectors for the GAMMA-400 scientific equipment complex, in particular, the $S3$ or $S4$ detector, as closest to the base of the space station supporting structure. Currently, the GAMMA-400 project is also in the process of upgrading the calorimeter system due to the hard mass restriction of the complex, in particular, the neutron detector ND is planned to be removed and the preliminary decision is made to keep the $S3$ detector only (Fig. 2) with the $S4$ tasks assigned to it. This modernization has almost no effect on the basic characteristics of the scintillation detector $S3$, while allowing you to improve the possibilities for rejection of background radiation by analyzing neutron fluxes from various types of particle cascades. It is important also, this project can be implemented on any scintillation detector designed to solve similar problems.

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