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The neutron, gamma-ray, X-ray spectrometer (NGXS): A compact instrument for making combined measurements of neutrons, gamma-rays, and X-rays

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ABSTRACT

The Neutron, Gamma ray, and X-ray Spectrometer (NGXS) is a compact instrument designed to detect neutrons, gamma-rays, and hard X-rays. The original goal of NGXS was to detect and characterize neutrons, gamma-rays, and X-rays from the Sun as part of the Solar Probe Plus mission in order to provide direct insight into particle acceleration, magnetic reconnection, and cross-field transport processes that take place near the Sun. Based on high-energy neutron detections from prompt solar flares, it is estimated that the NGXS would detect neutrons from 15 to 24 impulsive flares. The NGXS sensitivity to 2.2 MeV gamma rays would enable a detection of ~50–60 impulsive flares. The NGXS is estimated to measure ~120 counts/s for a GOES C1-type flare at 0.1 AU, which allows for a large dynamic range to detect both small and large flares.

1. Introduction

The Neutron, Gamma ray, and X-ray Spectrometer (NGXS) is a compact instrument designed to detect neutrons, gamma-rays, and hard X-rays. The original goal of NGXS was to detect and characterize neutrons, gamma rays, and x-rays from the Sun as part of the Solar Probe Plus (SP+) mission in order to provide direct insight into particle acceleration, magnetic reconnection, and cross-field transport processes that take place near the Sun via energetic solar flare processes [1]. In addition to measuring neutrons and gamma rays from large solar flare events, NGXS measurements could also be used to characterize new types of energetic solar events and understand the seed population of energetic particles [2]. To make the requisite observations on a highly mass-constrained mission, appropriate trades were made between the sensor size and mass versus the types of measurables, their energy ranges, and detection sensitivity. This paper describes the design and implementation of the NGXS as well as its detection sensitivity in an environment rich in energetic particles.

2. NGXS overview

The NGXS instrument is configured as two sensor heads that operate independently while sharing a common electronics box (Fig. 1). The Neutron Spectrometer (NS) and Gamma-Ray Spectrometer (GRS) are combined to enable coincidence techniques that actively reject background charged particles. Effective background rejection is critical because flare-produced neutrons and gamma rays will often be accompanied by large fluxes of energetic ions and electrons. The GRS detector is embedded within the NS detector to achieve almost full 4π active shielding; only those events in anti-coincidence (AC) with the NS detector are accepted. Background

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rejection for the NS is accomplished by identifying neutrons with a time-correlated two-pulse sequence in coincidence with an associated gamma ray detected in the GRS—an effective triple-coincidence measurement. The NS/GRS detector combination is read out with a single photomultiplier tube (PMT) in a phoswich arrangement that maximizes the sensitive detector volume while minimizing the amount of attenuating materials and photodetector mass. 'Phoswich' is a shortened term for phosphor sandwich, and refers to scintillator light readout arrangements where multiple scintillators are read out with a single PMT and signal separation is achieved via pulse time and shape discrimination [3]. A separate CdTe X-ray Spectrometer (XRS) provides high-energy resolution measurements of the hard X-ray region down to the low-energy limit of 20 keV. The estimated total mass of the NGXS is 2.6 kg, and its estimated power is 3 W.

The inner GRS sensor uses a bismuth germanate (BGO) scintillator ($\varnothing 3.8 \times 3.8$ cm long) similar to GRS instruments flown on the Near Earth Asteroid Rendezvous (NEAR), Lunar Prospector (LP), and Dawn missions [4–6]. BGO is well understood and offers the highest photopeak efficiency of any scintillator, which is critical when measuring short-duration bursts of high-energy gamma rays. Its energy resolution of 6% at 2 MeV [7] is more than adequate to resolve the 2.2 MeV H neutron capture line. The GRS covers 0.1–10 MeV with 512 energy channels. Both integral (all events) and AC spectra are reported.

The outer NS sensor uses a $\varnothing 9.7 \times 9.7$ cm long well-shaped boron-loaded scintillator (BC-454) similar to those used successfully on the LP, Mars Odyssey (MO), Dawn, and MESSENGER neutron instruments [5,6,8,9]. Borated plastic scintillators are sensitive to fast neutrons (0.5–20 MeV) and produce a unique two-pulse sequence. An initial prompt pulse caused by energy loss of recoil protons in the scintillator provides a measure of the incident neutron energy with an energy resolution $< 50\%$. A delayed neutron capture pulse unambiguously identifies a neutron event via its energy from the ^{10}B(n,α) reaction along with its 2 μs characteristic time delay from the prompt pulse. Detection of both valid pulse types provides a natural means of rejecting charged particles and locally induced gamma rays. Additional background rejection is achieved by further requiring detection of the coincident 478 keV ^{10}B(n,α) gamma-ray in the GRS, as has been demonstrated with the LP and MESSENGER GRS instruments.

Signals from the NS and GRS sensors are both measured with a single PMT and the risetime difference between the fast BC-454 and slow BGO scintillators allows straightforward digital electronic separation of the signals. Excellent signal separation has been demonstrated in laboratory tests using neutrons and electrons with prototype sensors (Figs. 1 and 2). For incident neutrons below 0.5 MeV, the NS counts the number of capture-only type interactions, which provides a measure of lower energy primary neutrons as well as neutrons that down-scatter in the spacecraft before striking the detector.

The XRS detector, optimized to cover the 20–200 keV energy range, is a pre-packaged assembly similar to the Si-PIN detector flown on NEAR. The $3 \times 3 \times 1$ mm^3 CdTe detector is mounted on a two-stage thermoelectric cooler

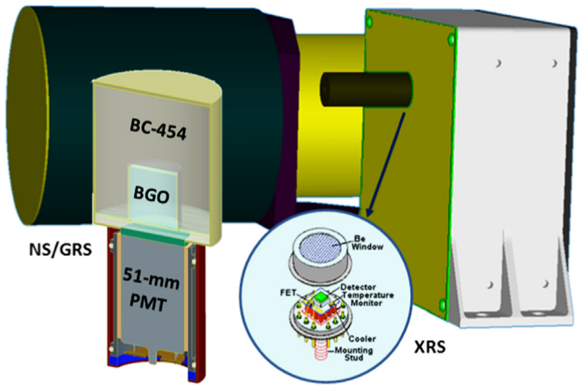

Fig. 1. Views of the combined NS/GRS sensor and the miniature XRS sensor showing active materials. The GRS detector (BGO) is surrounded by the NS detector (BC-454) to achieve almost full 4π shielding against charged particles. The single PMT readout maximizes detector volume and minimizes attenuating materials. A passive collimator that sits atop the XRS excludes background outside the solar disk.

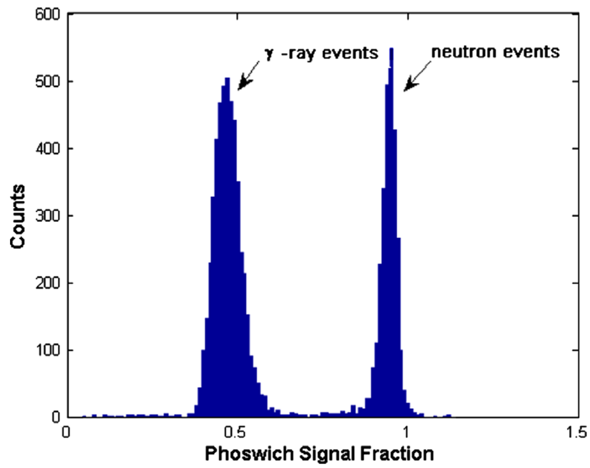

Fig. 2. Laboratory results demonstrate clean separation of gamma ray and neutron signals from prototype sensor using pulse shape discrimination. Phoswich signal fraction is defined as the ratio of a short signal integration to a long signal integration and discriminates between the fast plastic signals that are dominated by neutrons and slow BGO signals that are dominated by gamma-rays.

(TEC) in a sealed vacuum can with a beryllium window. An external collimator made of copper tungsten strongly suppresses the charged-particle background by restricting the field-of-view (FOV) to the solar disk at 9.5 Rs, along with margins for pointing and alignment.

3. Neutron sensitivity calculations

3.1. Neutron fluences

We scale measured neutron count rates to the neutron fluences calculated by Hua and Lingenfelter [10] (hereafter abbreviated H and L) and Murphy et al. [11] (Fig. 3). These studies provide energy dependent fluences in units of (neutrons ster^{-1} MeV^{-1} N_p^{-1}), where N_p indicates the number of flare protons greater than 30 MeV. We note that these fluences assume the neutrons are created in an